SAN JOAQUIN RIVER RESTORATION STUDY
BACKGROUND REPORT

DECEMBER 2002

PREPARED FOR:

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Lindsay, CA 93247
and
Natural Resources Defense Council
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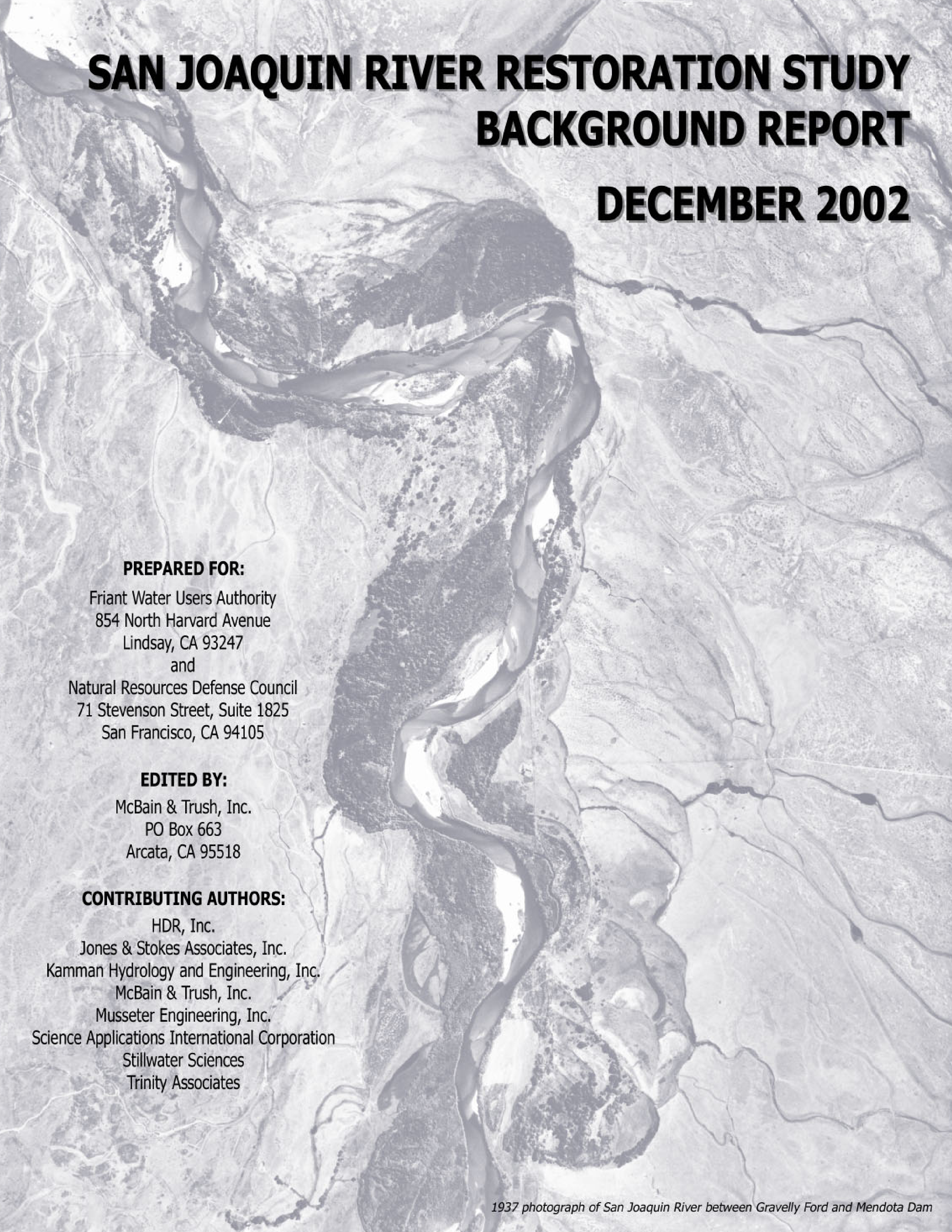

1937 photograph of San Joaquin River between Gravelly Ford and Mendota Dam

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PREFACE

The transformation of the San Joaquin River ecosystem from the mid 1800's to present is perhaps the most dramatic alteration of all the large Central Valley Rivers. This transformation imposes daunting challenges to rehabilitation and restoration. However severe these challenges, restoration opportunities that improve the health of the river, restore the fishery, and increase riparian habitat are great, and beginning this ambitious effort now will benefit future generations for years to come.

This report provides historical and contemporary background information, and builds a foundation for developing a scientifically sound restoration plan. The transformation of the San Joaquin River to the present-day condition was virtually complete several generations ago, such that the present generation does not have the institutional memory of what the San Joaquin River used to be. The same can be said from a scientific standpoint. Building a strong restoration plan requires a strong underpinning of historical facts and understanding; hence, the river's background information is important. This historical information is not an indictment of basin development, nor will historical conditions be set as absolute goals for the restoration program. Rather, the historical story of the San Joaquin River is meant to provide an understanding of how the river ecosystem functioned historically, and how human-induced changes impacted the physical and biological components of the ecosystem. With this understanding, we can better prioritize restoration actions that achieve restoration objectives.

ACKNOWLEDGEMENTS

Much of this report's material was compiled by Jones & Stokes Associates and Mussetter Engineering, and we acknowledge their important contribution to this effort. They provided draft text for all chapters of this Background Report. Subsequently, HDR, Kamman Hydrology and Engineering, McBain & Trush, Science Applications International Corporation (SAIC), Stillwater Sciences, and Trinity Associates collected and synthesized additional information on behalf of the Restoration Oversight Team (ROST) to complete this Background Report. The collective authors of this report would also like to acknowledge the important assistance from Marcia Wolfe and Associates, Monty Schmitt of NRDC, Valerie Curley and Siran Erysian of the Bureau of Reclamation, Amanda Kochanek of GreenInfo, Chris White of CCID, and others who have contributed data and ideas for this report.

Revisions to all chapters were overseen by McBain & Trush, with specific revisions assigned to assisting consultants. The technical leads and contributors for each chapter revision are listed below:

Chapter	Topic	Technical Leads
1	Introduction	McBain & Trush
2	Surface Water Hydrology	McBain & Trush
3	Fluvial Processes and Channel Form	McBain & Trush, Stillwater Sciences
4	Shallow Groundwater Hydrology	Kamman Hydrology, McBain & Trush
5	Water Related Infrastructure and Human Channel Modification	HDR, McBain & Trush
6	Water Quality	Stillwater Sciences, SAIC, McBain & Trush
7	Fish Resources	Stillwater Sciences, McBain & Trush
8	Vegetation	SAIC, McBain & Trush, Stillwater Sciences
9	Special Status Plants and Wildlife	Stillwater Sciences
10	Land Use and Ownership	Trinity Associates, SAIC
11	Social and Cultural Factors	Trinity Associates
12	Other Programs, Downstream Opportunities and Constraints	McBain & Trush, HDR

Appendix	Topic	Technical Leads
A	Annual Hydrographs	McBain & Trush
B	Fish Life History Summary	Stillwater Sciences
C	Chinook Salmon Distribution	Yoshiyama et al. (1996)
D	Fish Life History Timing Tables	Stillwater Sciences

ACRONYMS USED IN THE BACKGROUND REPORT

ACRONYM	DEFINITION
ac-ft	acre-feet
ACOE	[U.S.] Army Corps of Engineers
AEAM	Adaptive Environmental Assessment and Management
AFRP	Anadromous Fish Restoration Project
BLM	[U.S.] Bureau of Land Management
CalEPA	California Environmental Protection Agency
CALFED	CALFED Bay-Delta Program
Caltrans	California Department of Transportation
CCR	California Code Regulations
CDEC	California Data Exchange Center
CDFG	California Department of Fish and Game
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
cfs	cubic feet per second
Chl-a	Chlorophyll-a
CIMIS	California Irrigation Meteorologic Information System
CNPS	California Native Plant Society
CRWQCB	California Regional Water Quality Control Board
CSSC	California Species of Special Concern
CSU	California State University
CVHJV	Central Valley Habitat Joint Venture
CVP	Central Valley Project
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWA	Clean Water Act
DDT	Dichlorodiphenyltrichloroethane
Delta	Saramento-San Joaquin River Delta
DMC	Delta-Mendota Canal
DO	dissolved oxygen
DOI	[U.S.] Department of the Interior
DPR	[California] Department of Pesticide Regulation
DWR	[California] Department of Water Resources
EC	Electrical Conductivity
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EPA	[U.S.] Environmental Protection Agency
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
ET	Evapotranspiration
FERC	Federal Energy Regulatory Comission
FONSI	Finding of No Significant Impact
GIS	geographic information System
HEC	Hydraulic Engineering Center model (U.S. Army Corps of Engineers)
IEP	Interagency Ecological Program
IFIM	Instream Flow Incremental Methodology
JSA	Jones and Stokes and Associates

LWD	Large Woody Debris
MCL	maximumum contaminant level
mg/l	milligrams per liter
MOU	memorandum of understanding
mS/cm	milisiemens per centimeter
msl	mean sea level
NAWQA	[USGS] National Water Quality Assessment Program
NDDB	Natural Diversity Database
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDWR	National Primary Drinking Water Regulations
NRCS	U.S. Department of Agriculture Natural Resources Conservation Service
NTU	nephelometric turbidity units
NWR	National Wildlife Refuge
NWS	National Weather Service
OCAP	Operating Criteria and Procedures
ºF	degrees Fahrenheit
PCBs	polychlorinated biphenyls
PEIS	Programmatic Environmental Impact Statement
PFMC	Pacific Fishery Management Council
PHABSIM	Physical Habitat Simulation
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion; parts per thousand
PRBO	Point Reyes Bird Observatory
PROSIM	Project Simulation Model
psi	pounds per square inch
RM	River Mile
ROD	Record of Decision
SJRRP	San Joaqin River Restoration Plan
SR	State Road
SWP	State Water Project
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TNC	The Nature Conservancy
TSS	total suspended solids
USBR	[U.S. Bureau of] Reclamation
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
µS/cm	microsiemens per centimeter
VAMP	Vernalis Adaptive Management Plan
VELB	valley elderberry longhorn beetle
WQO	water quality objective
WUA	weighted usable area
WY	water year

CONVERSION FACTORS

While the authors prefer to use Metric units, most historical and contemporary information is available only in English units. Therefore, this report uses English in most cases rather than Metric units of measure. The table below is provided to enable English to Metric conversion of most measures used in this report.

Quantity	**English Unit**	**Metric Unit**	**To Convert English Unit Metric Unit Unit Multiply English Unit by**	**To Convert Metric Unit English Unit Unit Multiply Metric Unit by**
Length	inches (in)	millimeters (mm)	25.4	0.03937
	Inches (cm)	centimeters (cm)	2.54	0.3937
	feet (ft)	meters (m)	0.3048	3.2808
	yards (yd)	meters (m)	0.9144	1.094
	miles (mi)	kilometers (km)	1.6093	0.62139
Area	square feet (ft^2)	square meters (m^2)	0.092903	10.764
	square miles (mi^2)	square kilometers (km^2)	2.59	0.3861
Volume	cubic feet (ft^3)	cubic meters (m^3)	0.028317	35.315
	cubic yards (yd^3)	cubic meters (m^3)	0.76455	1.308
	acre-feet (ac-ft)	cubic decameters (dam^3)	1.2335	0.8107
Flow	cubic feet per second (cfs)	cubic meters per second (cms)	0.028317	35.315
Velocity	feet per second (ft/s)	meters per second (m/s)	0.3048	3.2808
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)	(°F-32)/1.8	(1.8x°C)+32

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND OF RESTORATION STUDY REPORT

Over a century of water development in the San Joaquin River basin has contributed to the economic growth of the region, state, and nation through many industries, most notably agriculture. Water development has regulated flows; confined the river system with levees; constructed flood bypass structures; drained and cleared riparian floodplains and wetlands for agricultural, gravel mining and urban uses; and lowered the water table through groundwater pumping. These changes to the river ecosystem have decreased the quantity, diversity, and connectivity of native floodplain habitats along the lower San Joaquin River. These habitat changes have caused a general reduction in wildlife populations and impairment of wildlife movement, and specifically resulted in the extirpation of all anadromous salmonids on the San Joaquin River.

As a result of the cumulative habitat changes resulting from the diversion of natural streamflows in the upper San Joaquin River, a coalition of environmental organizations led by the Natural Resources Defense Council (NRDC) filed suit against the U.S. Bureau of Reclamation. The Friant Water Users Authority (Friant), a joint powers authority under the Central Valley Project (CVP) of the U.S. Bureau of Reclamation, intervened in the suit. After several court proceedings, the NRDC and Friant obtained a stay and entered into settlement agreement negotiations. One component of this settlement agreement process is to develop a San Joaquin River Restoration Study Report (Restoration Study). The parties also developed a Mutual Goals Statement, as follows:

> *"The mutual goals of the parties is to expeditiously evaluate and implement, on a mutually acceptable basis, instream and related measures that will restore natural ecological functions and hydrologic and geomorphologic processes of the San Joaquin River below Friant Dam to a level that restores and maintains fish populations in good condition, including but not limited to naturally reproducing, self-sustaining populations of Chinook salmon. It is further the mutual goal of the parties to accomplish these restoration goals while not adversely impacting the overall sufficiency, reliability and cost of water supplies to Central Valley Project Friant Division water users.*

The intent of the Restoration Study is to develop up to three strategies that will achieve the objectives set forth in the Mutual Goals Statement. Parallel to the Restoration Study development is a corresponding Water Supply Study, which investigates various water supply strategies that will enable implementation of the Restoration Study strategies and minimize adverse impacts to water supply. Once both studies are completed, they will be integrated into a single plan (Figure 1-1). The integrated plan will be part of the underpinnings of the settlement agreement.

1.2. RESTORATION STUDY SCOPE OF WORK

The April 2000 Scope of Work for the San Joaquin River Restoration Study organizes the Study as follows:

- Task 1. Summarize Historical and Existing Conditions. Summarize historical conditions and processes along the San Joaquin River for various geomorphic, vegetative, and biotic indicators; summarize how these conditions have changed over time; and summarize available information to develop the Restoration Study Report.
- Task 2. Analyze Opportunities and Constraints. Analyze opportunities and constraints on restoration activities imposed by human infrastructure, land use, and other programs affecting the San Joaquin River.

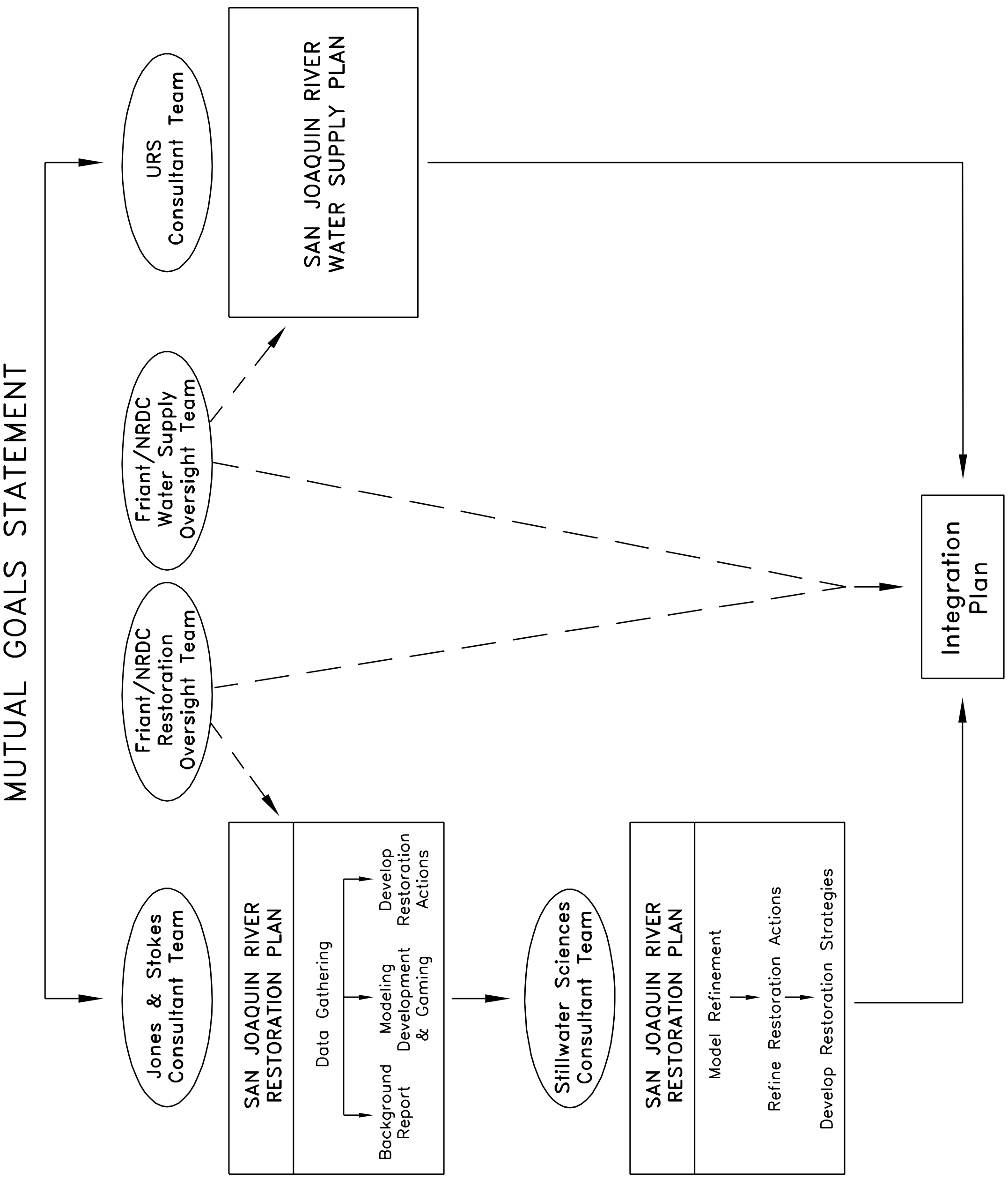


Figure 1-1. The general governing process outlined for development of the Restoration Plan, as defined by the NRDC v. Patterson settlement.

- Task 3. Detailed Description of the Restoration Goal. Evaluate historical and existing conditions in Task 1 and the opportunities and constraints in Task 2, then refine the quantitative objectives for the Restoration Study.
- Task 4. Develop Conceptual Models and Hypotheses. Based on historical and existing conditions and review of recent scientific literature, develop conceptual models of ecological and physical processes for the San Joaquin River, and develop hypotheses which support restoration objectives developed in Task 3.
- Task 5. Quantify Ecosystem Linkages. Identify and quantify linkages between desired environmental conditions and the modifications in flow or habitat necessary to produce these conditions.
- Task 6. Develop List of Potential Restoration Actions. Develop a wide list of possible restoration actions, based on quantitative linkages between desired effects and corresponding modification. Then for each potential restoration action, document the benefit of the action towards achieving the restoration objectives; the anticipated time of achievement; the geographic location, scale, or magnitude of the action; the approximate cost of the action; and water volume required.
- Task 7. Prioritize Restoration Actions. Develop criteria that prioritize actions or groups of actions that best achieve restoration objectives, and evaluate the actions or groups of actions based on the prioritization criteria.
- Task 8. Develop Wide Range of Restoration Strategies: Bundle individual restoration actions into 3 to 5 restoration strategies that achieve the common restoration goal, but encompass a diversity of approaches to achieve that goal.
- Task 9. Refine Restoration Strategies. Based on input from the Restoration Study Oversight Team, refine Task 8 strategies into 2 to 3 final restoration strategies that include details on cost, benefits, constraints, timeline, water and land requirements, and non-flow restoration actions.

The Task 9 restoration strategies will be integrated with the Water Supply Study to develop a final restoration strategy for the Settlement Agreement. Several modifications to this scope of work have occurred since April 2000; however, changes to the scope of work related to this Background Study have been minimal, and can be found in Contract Modification #3 (August 31, 2001).

1.3. OBJECTIVES OF BACKGROUND STUDY

This Background Report is intended to be a stand-alone document that summarizes information generated in Tasks 1, 2, and 4, which will provide a foundation for Restoration Strategy development as part of the Restoration Study effort. In this Background Report, we expend a significant amount of effort on 1) describing the historical conditions and processes of the San Joaquin River, and 2) describing the evolution of these historical conditions and processes to the present. A question commonly asked in similar restoration planning efforts is “Why spend time evaluating the past, when restoration should really focus on the future?” The answer is that by knowing how a river used to function in a healthy condition, we can develop and evaluate restoration measures that best achieve future restoration objectives. In other words, knowing how the river is “broken” gives us tremendous insight on how to fix it. To this end, we focus our analysis on the following:

- How the San Joaquin River used to function as a backdrop to evaluating how contemporary physical and ecological factors limit populations of the fish species and other populations of concern identified in Tasks 1, 2, 3, and 4;

- Hypotheses on the physical and ecological processes and conditions necessary to restore the restoration subcomponents listed above (or identified in Task 3);
- Key linkages between potential management interventions and ecosystem responses that need to be quantified to efficiently scale the management intervention and expert recommendations on the best methods for quantifying those linkages;
- Additional information needs, competing hypotheses, and important uncertainties and disagreements on the hypothetical restoration intervention necessary and recommendations for testing these hypotheses to reduced uncertainty.

1.4. PHYSIOGRAPHIC AND ECOLOGICAL SETTING

The San Joaquin basin setting is briefly described to provide context for the evaluations and analyses in this Background Report. Additional detail can be found in subsequent chapters.

1.4.1. Ecological Functions

We now recognize that ecological systems (ecosystems) are composed of more that just a collection of biological communities. Ecosystems manifest relationships of interdependence and competition among organisms, are driven by variable inputs of energy and nutrients, and are manipulated by humans, all of which result in a high level of complexity and internal structure. Contemporary river ecology has embraced this realization, and restoration efforts are now increasingly adopting a broader, more holistic ecosystem-based approach to conservation and restoration efforts that attempt to improve geomorphic and hydrologic functions of the river (Ligon et al. 1995; Stanford et al. 1996). According to this approach, by restoring the physical structure and processes within the river corridor, we can initiate biotic responses that will eventually support a diverse, resilient assemblage of native plants and animals.

Restoring natural physical processes to the river channel and floodplain offers the basis for successful ecological function within the ecosystem. Ecological process such as floodplain inundation, sediment supply and transport dynamics, and variability in streamflow patterns determine the physical and chemical habitat quality, quantity, structure, and connectivity in river-riparian-floodplain ecosystems. Species abundance, distribution, composition, and trophic structure are directly related to these attributes (Figure 1-2).

Aquatic food webs depend on physical processes within the river channel. Primary (algal) production within the river channel often requires scouring flows to provide surfaces for colonization. Algal mats provide nutrients and habitat for macroinvertebrates and have been shown to be important for macroinvertebrate species diversity (Power 1990). Invertebrate production within the channel and along the floodplain provides food sources for salmonids, as well as other native fishes, and emerging insects provide prey for birds and bats foraging along the river corridor. The nutrient cycle is completed during salmon spawning when carcasses decay and return nutrients to the river, where they can be taken up by primary producers.

A healthy riparian ecosystem also depends on hydrologic and fluvial geomorphic processes, such as inundation regimes and sediment deposition patterns within the river corridor. Supporting a diverse riparian corridor is important because riparian zones provide the interface between terrestrial and aquatic habitats and food webs and are widely recognized as centers of biodiversity and corridors of dispersal for plants and animals within the landscape (e.g., Gregory et al. 1991; Stanford et al. 1996). Riparian forests filter nutrients and agricultural chemicals from runoff; stabilize channel banks; and provide leaf litter for aquatic food webs, large woody debris and overhead cover for fish, and nesting

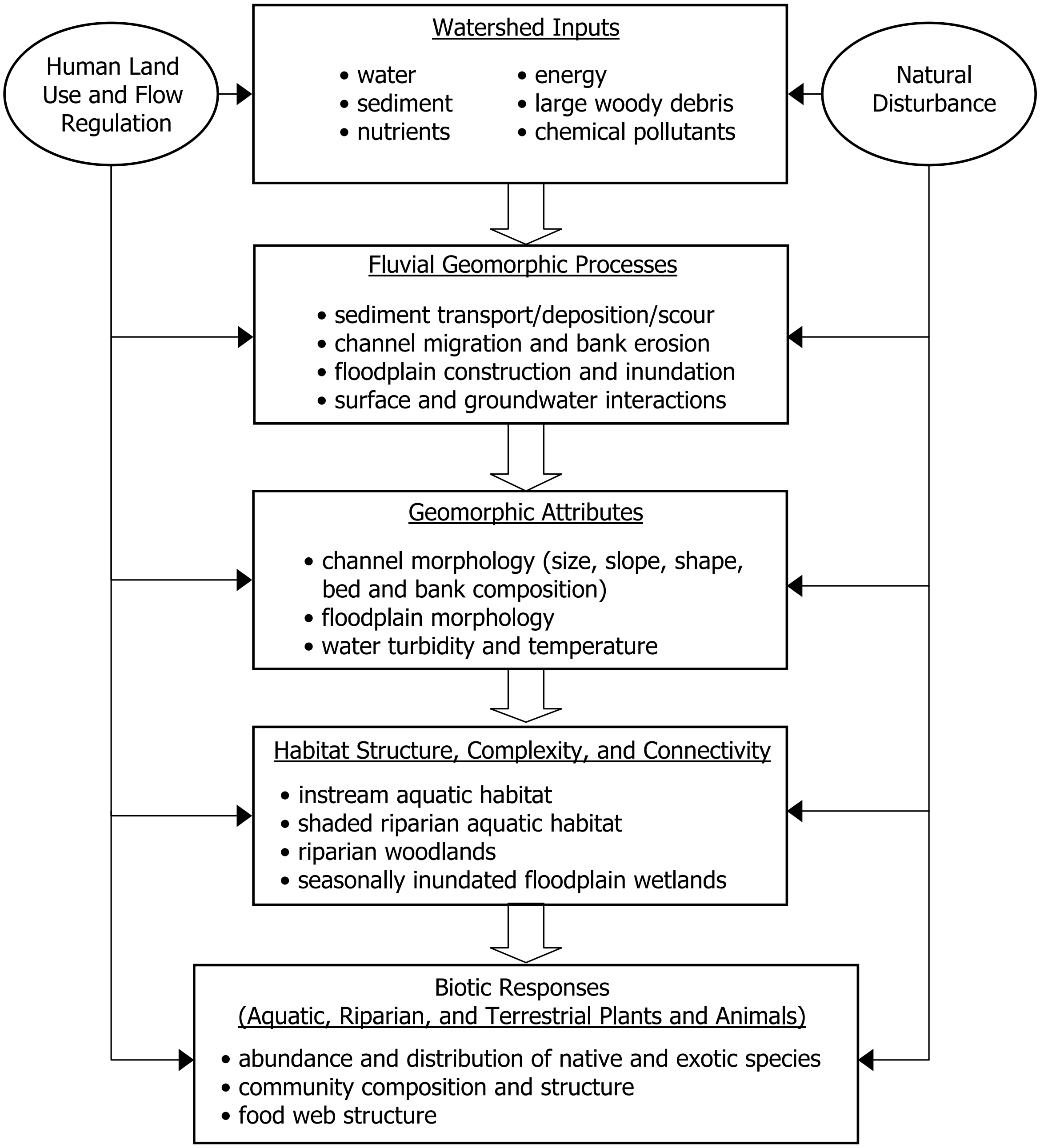


Figure 1-2. A simplified conceptual model of the physical and ecological linkages in alluvial river-floodplain systems.

and roosting habitat and migratory corridors for birds and mammals. Some birds and bats in particular forage over the river corridor and require specific habitat elements along the channel. In addition, over time, successional processes along the floodplain can alter the vegetation composition, and leaf litter from pioneer species can provide nutrients to the floodplain soils, creating suitable habitats for a greater diversity of species.

Non-native species are usually beneficiaries of disturbed ecosystems, and the San Joaquin River is no exception. Restoring more natural hydrologic and fluvial geomorphic conditions often has the added benefit of supporting a shift from non-native species back to healthy ecosystems and food webs dominated by native species.

1.4.2. Watershed Characteristics and Hydrology

The San Joaquin River and Sacramento River are the two largest rivers in the Central Valley; the Sacramento River drains the northern portion of the valley and the San Joaquin River drains the south (Figure 1-2). The San Joaquin River originates in the highest peaks in the Sierra Nevada Mountains above 11,000 ft, and flows down to sea level at the delta. Where the San Joaquin River leaves the Sierra Nevada foothills at Friant, the watershed area is 1,676 mi^2, and the watershed area near the delta at Vernalis is 13,536 mi^2. Precipitation in the watershed is variable and depends on watershed elevation, ranging from as little as 6 inches/year on the valley floor, to as much as 70 inches/year at higher elevations of the Sierra Nevada. Precipitation above the 4,000 ft to 5,000 ft elevation is primarily snowfall, and its melting dominates the unimpaired streamflow hydrology on the river.

Snowmelt runoff generates a majority of the flow volume from the watershed. Unimpaired snowmelt peak flows at Friant ranged from 3,500 cubic feet per second (cfs) to over 30,000 cfs, with typical values in the 10,000 cfs to 15,000 cfs range. Winter rain-on-snow events contributed much larger floods than the snowmelt peak flows, sometimes exceeding 95,000 cfs (e.g., 1997 flood inflows, 1862 flood). While the snowmelt peaks likely played a less important channel-forming role than the winter rain-on-snow events, the snowmelt runoff period was probably the most important biological hydrograph component. The spring snowmelt hydrograph caused prolonged periods of overbank inundation, creating vast floodplain and wetland habitat that supported large populations of fish and wildlife.

A unique aspect of the San Joaquin River's hydrology was the interaction between the San Joaquin River and the Tulare Basin during flood flows. Historically, flood flows likely drained from the San Joaquin River into Tulare Basin when Tulare Lake was at a moderate to low elevation, and when Tulare Lake was higher and/or the Kings River was at high flow, flood flows from the Tulare Basin drained into the San Joaquin River at Mendota. This flood flow contribution from the Kings River still occurs, but the contribution of flood flows from the San Joaquin River to Tulare Lake is rare. For baseflows, historical accounts suggest that the shallow groundwater and artesian springs substantially augmented summer and fall baseflows to the lower San Joaquin River (Grunskey 1929). These historical accounts also describe the San Joaquin River as susceptible to floods and droughts, with droughts being more severe than those experienced in the Sacramento River basin. San Joaquin basin droughts were most likely more severe because the San Joaquin River groundwater contribution was less than the comparable contribution of springs and shallow groundwater in the Sacramento River and its tributaries.

Contemporary hydrology is dominated by irrigation storage, irrigation delivery, and flood control releases. Irrigation and flood control has virtually eliminated all traces of the natural flow regime, with the periodic exception of flood control releases. Reach 1 has a constant baseflow to provide for riparian water rights (50 cfs to 300 cfs), Reach 3 has releases for downstream diversion at Sack Dam (200 to 500 cfs), and lower Reach 4B and Reach 5 receive varying amounts of agricultural return flows. Reach 2 and 4 are usually perennially dry. Even though the Friant Dam outlet works can release up to 16,000 cfs, contemporary flood control restrictions limit releases to less than 8,000 cfs. Larger releases can still occur during very large storm events that encroach into the flood control space behind Friant Dam, as occurred in 1997 when 60,300 cfs was released (ACOE 1999). Further impacting this loss of surface water to the river is the groundwater pumping in downstream reaches of the river. Groundwater pumping has eliminated most of the historic groundwater contribution to the river, and in most reaches, shifted the river from gaining flows from groundwater contribution to losing flows due to infiltration into the depressed shallow groundwater table.

1.4.3. Geology and Geomorphology

The geomorphology of the San Joaquin River is strongly influenced by the underlying geology of the Sierra Nevada Mountains, the Coast Range, and the San Joaquin Valley. Because aquatic and terrestrial habitats are created and maintained by geomorphic and geologic processes, the geologic and geomorphic context is an important consideration in restoration efforts (Figure 1-2). The upper San Joaquin River watershed originates in the Sierra Nevada, and the underlying geology is dominated by crystalline igneous rocks (granite and quartzites). The young age and rapid uplift of the Sierra Nevada, combined with repeated periods of glaciation, resulted in steep, deeply incised river canyons. Sediment yield is low, and combined with the high sediment transport capacity in the canyon, the channel morphology is dominated by bedrock with very little sediment storage.

Tectonic uplift of the Sierra Nevada range, subsidence of the San Joaquin Valley, and surface erosion of the watershed are the dominant natural forces that control the San Joaquin River’s morphology between the foothills and the delta. As the river exits the Sierra Nevada foothills, gradient and confinement decrease, and alluvial sediment storage increases. The river quickly transforms to an alluvial channel, with a meandering alternate bar morphology in most reaches. The Coast Range bounds the lower San Joaquin River from the west, and alluvial fans from the Coast Range tend to keep the San Joaquin River in the central axis of the Central Valley. Tectonically driven subsidence rates are approximately 0.25 mm/yr, and this subsidence is partially counterbalanced by sediment deposition of alluvial fans from the San Joaquin River and tributaries draining from the Sierra Nevada and Coast Range (Janda 1965). Recent groundwater pumping has rapidly increased this natural subsidence rate (Bull and Miller 1975), with the elevations of some areas west of Mendota decreasing by over 25 feet. Stream gradient is very low in all reaches, with steeper reaches in the foothills less than 0.1 percent, and remaining reaches less than 0.05 percent. This low slope results in a relatively short 35-mile gravel bedded reach downstream of Friant Dam, while the remaining 230 miles are sand-bedded.

1.4.4. Biota

The Central Valley is a unique place; its high degree of productivity and habitat diversity is rarely found anywhere else in the world. This productivity and diversity resulted in large numbers and a diversity of plants and animals. Before land and water development, riparian vegetation between Friant and Gravelly Ford was dominated by sycamore, cottonwood, willow and alder, and was confined between bluffs and terraces. Once the river left the confinement of the foothills and terraces at Gravelly Ford, riparian vegetation and wetlands extended laterally downstream to Mendota. Vegetation within the San Joaquin River floodway downstream of Mendota was historically dominated by tule marsh, which thrived under periods of prolonged inundation from snowmelt runoff, flow contribution from the Tulare Basin, artesian springs, and shallow groundwater contribution. Tule marsh was fringed with riparian vegetation along the river margins, and by grasslands, desert saltbush, and Frankenia in alkaline upland areas (summarized in Preston 1981).

The San Joaquin River corridor and adjoining grasslands once supported large herds of elk and pronghorn antelope, grizzly bear, and other terrestrial species (summarized in Preston 1981). Floodplains and seasonal wetlands supported large numbers of waterfowl, beaver and the river supported salmon populations numbering in the tens of thousands to hundreds of thousands (summarized in Yoshiyama 1999). While the river corridor still supports large numbers of wildlife relative to today's numbers, several species are now extinct or have been extirpated from the San Joaquin River corridor. Populations of remaining species are much smaller than those occurring before land and water development.

1.4.5. Anthropology

The San Joaquin River has been a focal point for human use for thousands of years prior to European immigration. The Yokut people historically inhabited the Tulare Basin and southern San Joaquin River basin, congregating along the riverbanks to take advantage of the river's extraordinary resources. Salmon were an important dietary staple, as were other plants and animals found along the river. With the coming of the Spanish in the late 1700s, and of the Americans in during the gold rush after 1849, the Yokuts and other Native Americans were displaced from their ancestral lands, and land use along the river quickly changed from hunting and gathering to more intensive uses. Navigation, livestock grazing, and seasonal grain crops were the primary land and river uses through the late 1800s. With the increasing irrigation came a rapid agricultural expansion along the river corridor, with the agricultural economy dominating the regional economy. The agricultural economy continues to dominate, although urban and suburban areas along the river are expanding.

1.5. STUDY AREA

The San Joaquin River is bounded by the Sierra Nevada on the east and Coast Ranges on the west; its southern boundary is on divide between the Tulare Lake basin, and its northern boundary is the Delta near Stockton (Figure 1-3). The San Joaquin River Restoration Study area includes approximately 150 miles of the San Joaquin River from Friant Dam at the upstream end near the town of Friant, to the confluence with the Merced River at the downstream end (Figure 1-3). The river flows to the north of the metropolitan area of Fresno, then passes near the communities of Biola, Mendota, Firebaugh, Dos Palos, and Los Banos, within the counties of Fresno, Madera, and Merced (Figure 1-4). As defined in the April 2000 Scope of Work, the study area's width was to correspond with the pre-Friant Dam 100-year floodway. However, this definition of study area width is not explicitly delineated in this report because the inundation area of the pre-Friant Dam 100-year floodway has not been conducted. Instead, we have defined the study area's width based on estimates of unimpaired riparian and wetland areas, derived from other studies that assessed historical sources, soils, and vegetation conditions (Figure 1-5). Certain information downstream of the Merced River confluence is presented and discussed in this Background Report due to its relevance restoration efforts (e.g., delta pumps, water quality); however, this downstream reach is generally considered outside the study area of the Restoration Study and Background Report.

Within this 148-mile section of the San Joaquin River from Friant Dam to the Merced River confluence, the river passes through several reaches differentiated by their geomorphology and resulting channel morphology, and by their human-imposed infrastructure along the river. Therefore, the river has been subdivided into five primary reaches that exhibit similar flows, geomorphology, and channel morphology (Figure 1-3). Reach boundaries, infrastructure, and landmarks are listed in Table 1-1, and each of the five reaches is briefly described below.

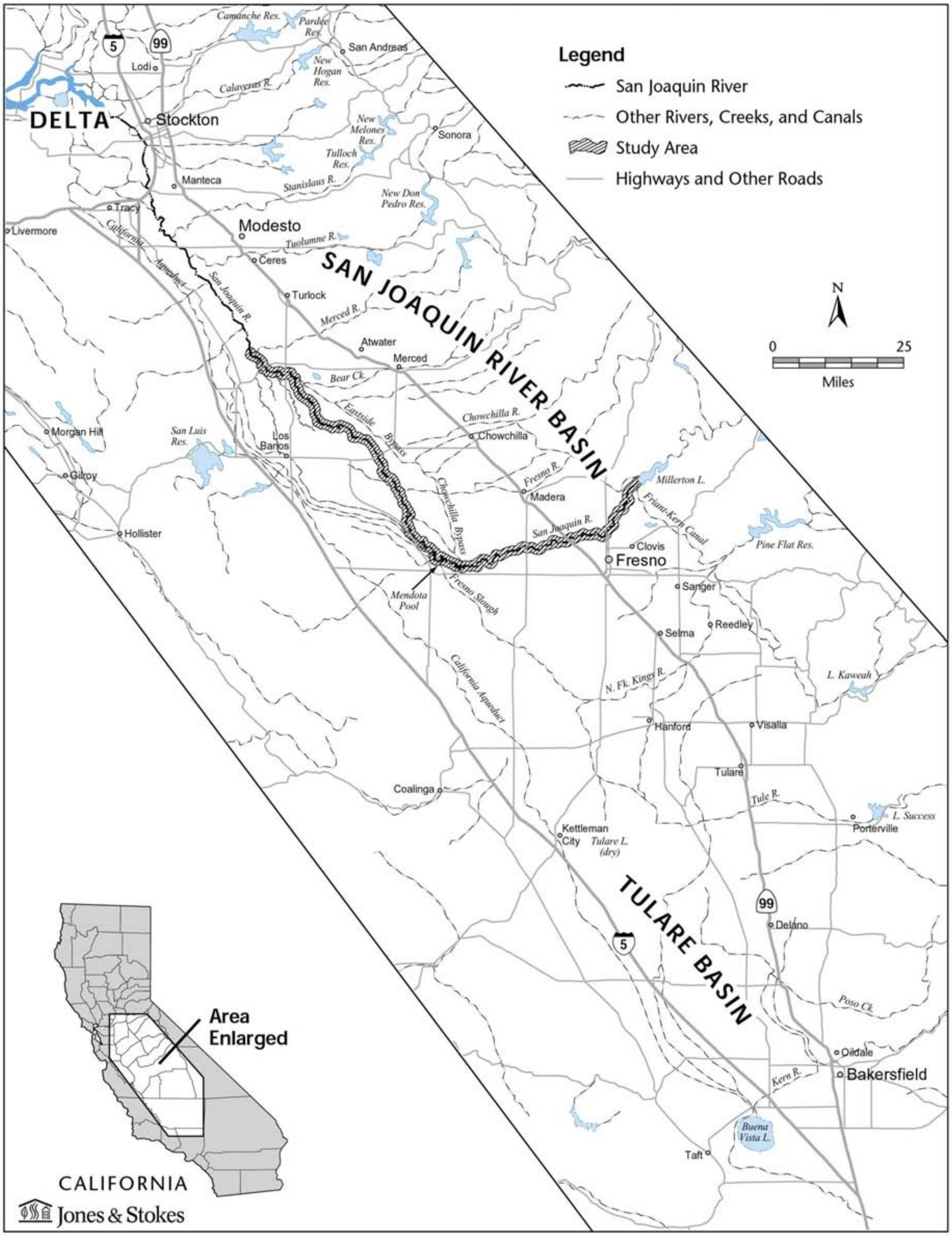


Figure 1-3. Location of the study area for the San Joaquin River Restoration Plan.

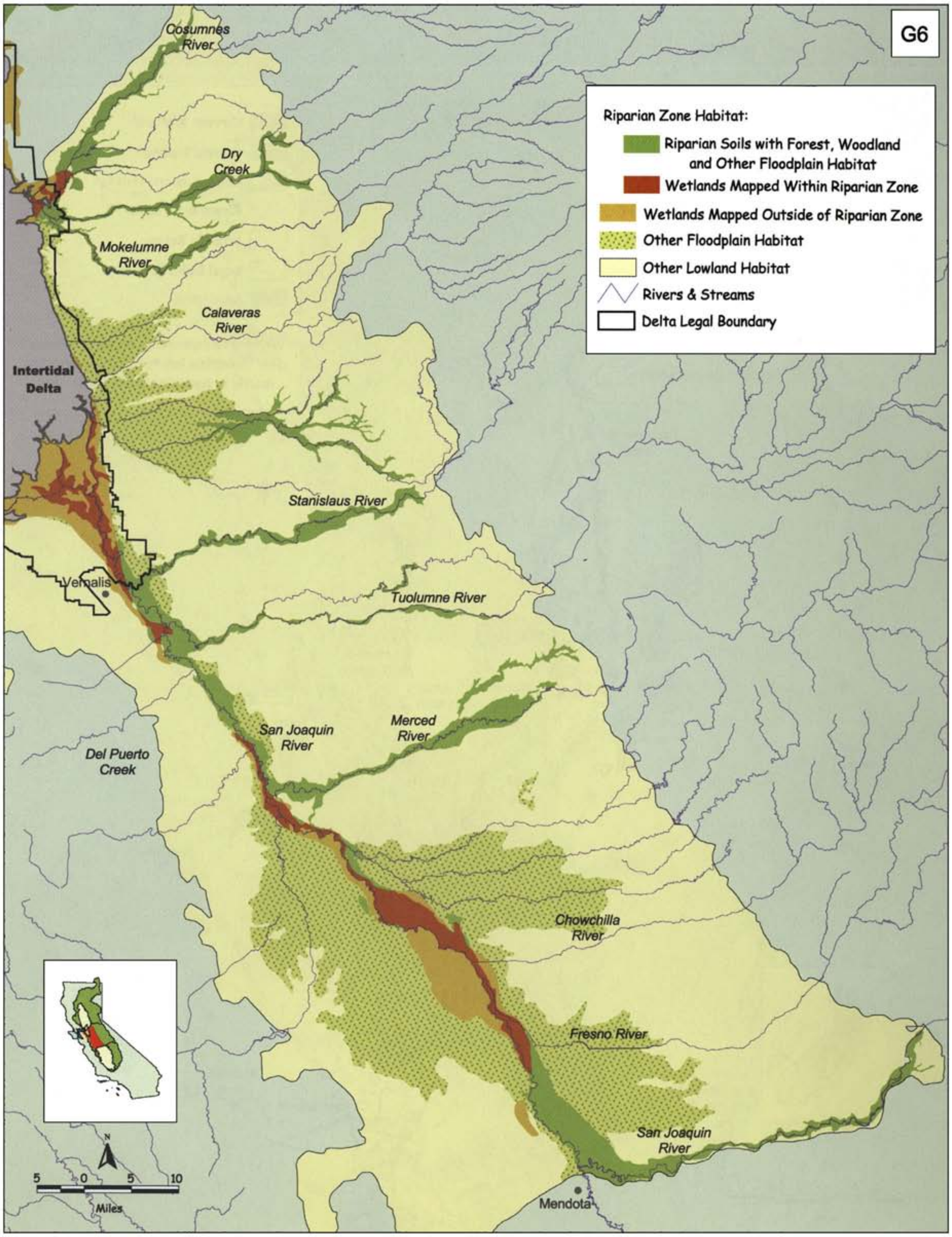
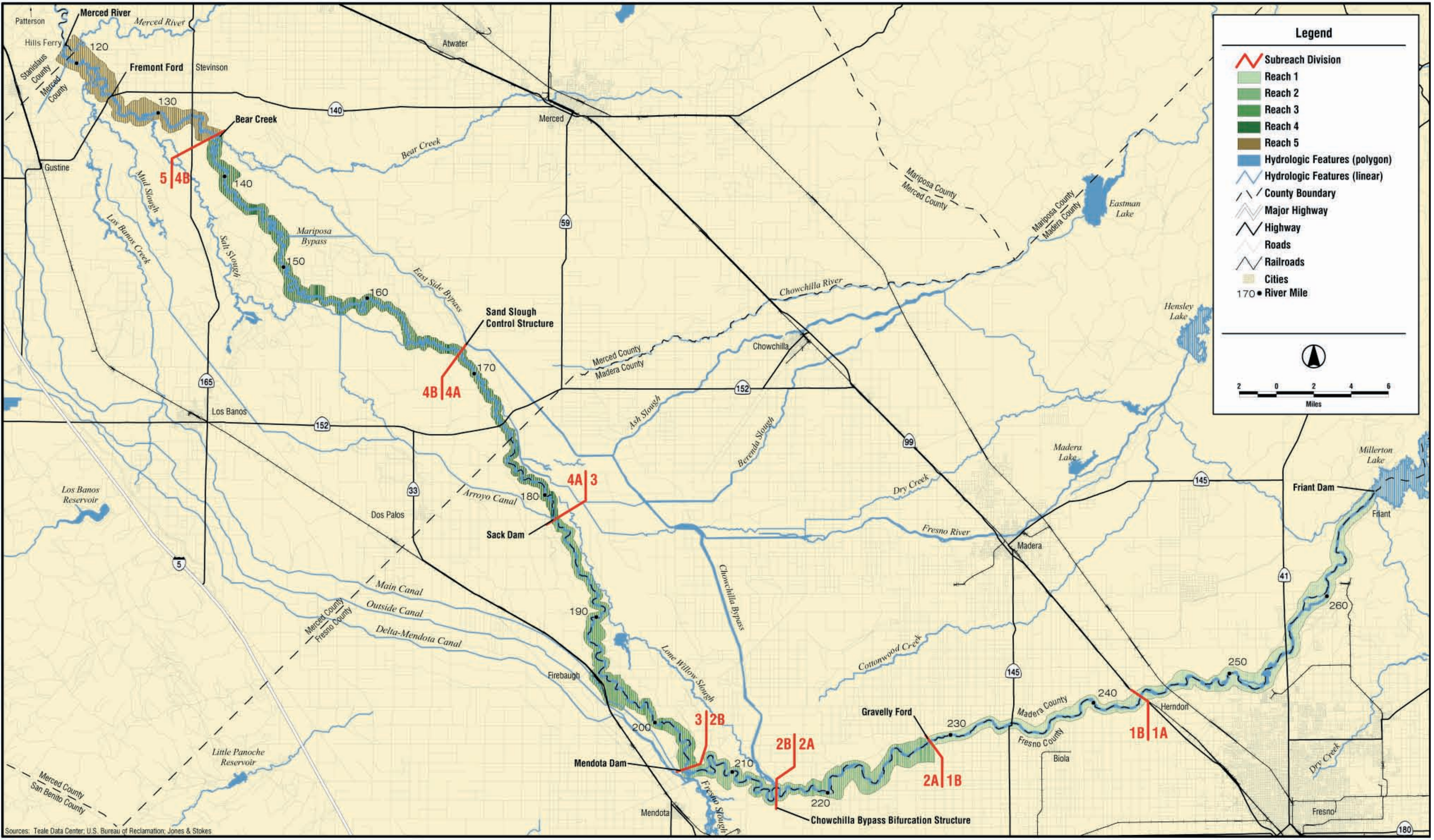


Figure 1-4. Estimated historical extent of the San Joaquin River and floodplain ecosystem, based on evaluation of soil characteristics (from The Bay Institute, 1998).



Sources: Teale Data Center; U.S. Bureau of Reclamation; Jones & Stokes

Jones & Stokes

Figure 1-5. Study area for the San Joaquin River Restoration Plan, showing the reach and sub-reach boundaries.

Table 1-1. River mile boundaries of five reaches, infrastructure, and selected landmarks within the study reach.

	Landmark	**River Mile**
REACH 1		*267.5 to 229.0*
	Friant Dam	267.5
	North Fork Road Bridge	266.8
	Cobb Island Bridge	259.0
	State Route 41 (Lanes Bridge)	255.2
	Scout Island Bend	250.0
	ATSF Railroad Bridge	245.0
	State Route 99	243.2
	Southern Pacific Railroad	243.2
	State Route 145 Bridge (Skaggs Bridge)	234.1
	Gravelly Ford	229.0
REACH 2		*229.0 to 204.8*
	Gravelly Ford	229.0
	Upstream Limit of Right Bank Levee	227.0
	Upstream Limit of Left Bank Levee	225.0
	Chowchilla Bypass Control Structure	216.1
	Mendota Dam	204.8
REACH 3		*204.8 to 182.0*
	Mendota Dam	204.8
	Avenue 7.5 Bridge (Firebaugh)	195.2
	Sack Dam	182.0
REACH 4		*182.0 to 135.8*
	Sack Dam	182.0
	State Route 152 Bridge	173.9
	Sand Slough Control Structure	168.5
	Mariposa Slough Control Structure	168.4
	Turner Island Road Bridge	157.2
	Mariposa Bypass confluence	147.2
	Bear Creek/Eastside Bypass confluence	135.8
REACH 5		*135.8 to 118.0*
	Bear Creek/Eastside Bypass confluence	135.8
	State Route 165 Bridge (Lander Avenue)	132.9
	Salt Slough confluence	127.7
	State Route 140 Bridge (Fremont Ford)	125.1
	Mud Slough confluence	121.2
	Merced River confluence (Hills Ferry Bridge)	118.0

1.5.1. Reach 1—River Mile 267.5 to River Mile 229.0

Reach 1 begins at Friant Dam, where the San Joaquin River exits the Sierra Nevada foothills and enters the Central Valley floor. The downstream end is defined at Gravelly Ford because this point defines the historical transition between gravel and sand bedded reaches. Reach 1 is gravel bedded, of moderate slope, and is confined by bluffs and terraces. Reach 1 is divided into two subreaches; Subreach 1A extends from Friant Dam to State Route 99, is the steepest portion of Reach 1, and is confined by bluffs. Subreach 1B begins at State Route 99 and extends downstream to Gravelly Ford, and this reach's gradient is much lower, is confined by terraces, and contains the contemporary transition from gravel bedded to sand bedded. Gravel mining and agriculture is the primary land use in this reach.

1.5.2. Reach 2—RM 229.0 to RM 204.8

Reach 2 is entirely sand bedded, and meanders across the Pleistocene alluvial fan of the San Joaquin River between Gravelly Ford and Mendota Dam. The confining terraces end at Gravelly Ford, and mark the beginning of the San Joaquin River alluvial fan. The downstream boundary at Mendota Dam also marks the location where the river intersects the north-south axis of the valley, and where slope decreases. Reach 2 is divided into two subreaches. Subreach 2A begins at Gravelly Ford and extends downstream to the Chowchilla Bypass Bifurcation Structure. Subreach 2B extends from the bifurcation structure downstream to Mendota Dam. Both subreaches have confining levees protecting agriculture land uses in the reach.

1.5.3. Reach 3—RM 204.8 to RM 182.0

Reach 3 is sand bedded and meandering, and is different from other reaches because it contains perennial flows of up to 600 cfs, due to water deliveries from the Delta Mendota Canal, through the San Joaquin River channel, and to the Sack Dam diversion into Arroyo Canal. No unique subreaches are delineated within Reach 3. Agriculture is the primary land use in this reach, and the river is confined by local dikes and canals on both banks.

1.5.4. Reach 4—RM 182.0 to RM 135.8

Reach 4 is sand bedded and meandering, and is usually dewatered due to the diversion at Sack Dam. Reach 4 is divided into two subreaches. Subreach 4A extends from Sack Dam downstream to the Sand Slough Control Structure. The flows in this subreach are usually negligible due to the Sack Dam diversion, but periodically flood control flows are conveyed such that a channel is defined through the reach. Subreach 4B begins at the Sand Slough Control Structure and extends downstream to the confluence with Bear Creek and the Eastside Bypass, The upstream portion of Subreach 4B no longer conveys flows because the Sand Slough Control Structure diverts all flows into the bypass system. As a result, the channel in the upstream portion of Subreach 4B is poorly defined, filled with dense vegetation, and in some cases, Subreach 4B is plugged with fill material. Agriculture is the primary land use in the entire reach. In Subreach 4A, the left bank (west side) of the river is bounded by the Poso and Riverside canals, and the right bank (east side) is confined by local dikes. In Subreach 4B, the river is no longer bounded by canals, but is confined by small local dikes downstream to the confluence with the Mariposa Bypass at the San Luis National Wildlife Refuge. Project levees begin at the Mariposa Bypass and continue downstream on both banks.

1.5.5. Reach 5—RM 135.8 to RM 118.0

Reach 5 is sand bedded and meandering, and flows continuously due to agricultural return flows. No subreaches were delineated within Reach 5. Reach 5 is bounded on the left bank by Project levees downstream to the Salt Slough confluence and on the right bank to the Merced River confluence.

1.6. REPORT ORGANIZATION AND AUDIENCE

1.6.1. Report Organization Principles

The Background Report is organized into chapters based on an interpretation of subtasks in the Scope of Work. To communicate the information required to support the development of the Restoration Study, the Background Report chapters are organized to discuss: 1) the physical and chemical underpinnings of the San Joaquin River ecosystem (Chapters 2-6), 2) the biota that inhabit the San Joaquin River corridor (Chapters 7-9), then 3) the human aspects of the San Joaquin River (Chapters 10-12). The chapters following the introductory Chapter 1 are as follows:

- Chapter 2: Surface Water Hydrology
- Chapter 3: Channel Processes and Form
- Chapter 4: Groundwater Hydrology
- Chapter 5: Water-Related Infrastructure, Flood Control, and Diversions
- Chapter 6: Water Quality and Temperature
- Chapter 7: Fish Resources
- Chapter 8: Vegetation Communities
- Chapter 9: Special-Status Species;
- Chapter 10: Land Use and Ownership
- Chapter 11: Social and Cultural Factors
- Chapter 12: Other Programs, and Downstream Opportunities and Constraints

1.6.2. Audience

The San Joaquin River Restoration Study process contains considerable participation from stakeholders with technical understanding of the issues. Therefore, this Background Report is written as a technical document, but also attempts to simplify and summarize concepts for a non-technical audience within reasonable constraints. The chapters contain technical terminology that reflect the level of science and expertise applied in the course of this study, but attempts have been made to present the analysis in lay terms to inform decision-makers and persons with a general environmental background. Finally, to ensure appropriate context, a comprehensive glossary is not included; but important terms are defined in the body of the text where applicable.

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CHAPTER 2. SURFACE WATER HYDROLOGY

2.1. INTRODUCTION

Surface water hydrology is one of the key driving variables in river ecosystems. The natural characteristics of a river ecosystem are (1) influenced by the underlying geology and tectonics; (2) created and maintained by geomorphic and hydrologic processes that result from energy and material interactions between flowing water and sediment supply; and in some cases (3) influenced by riparian vegetation. The complexity of river ecosystems can be simplified somewhat by a hierarchical conceptual model of how the interaction of water and sediment (the basic independent variables that influence shorter-term channel processes and form) cascade down to the biota (Figure 2-1). This conceptual model illustrates how water and sediment interact to cause fluvial geomorphic processes that are responsible for creating and maintaining channel form (morphology). Correspondingly, the channel morphology provides aquatic and terrestrial habitat within the river corridor, and thus influences the abundance and distribution of riverine biota. Each tier of the hierarchical model can be described as having the following components:

- SUPPLY: Primary natural components of supply are water and sediment, with some influence by logs delivered from eroding banks and the upstream watershed. Changes to water and sediment in this conceptual system cascade down to the biota, but this cascading perspective is often not adequately considered before the management change is imposed on the system.
- PROCESS: The primary natural components of the processes tier are sediment transport, sediment deposition, channel migration, channel avulsion, nutrient exchange, and surface water-groundwater exchange. Sediment transport and deposition form alluvial features, including alternate bars and floodplain surfaces. These processes typically occur during high flow events, which occur over a relatively small percentage of the year.
- FORM: In turn, processes create the channel and floodplain features that define aquatic and terrestrial habitat along the river corridor. Form provides the physical location and suitable conditions that define habitat for aquatic organisms, including native fish species. Channel morphology is thus a critical linkage between fluvial processes and the native biota that use the river corridor.
- BIOTA: Typically the management target, the biota responds to changes cascading from Supply, Process, and Form. Changes to water and sediment in this conceptual system cascade down to the biota, but this cascading perspective is often not adequately considered before the management change is imposed on the system.

Humans are also part of river ecosystems. Within this natural hierarchical framework, there are human components that influence each hierarchy (Figure 2-1). Management of supply, such as dams changing the flow and sediment regime of a river, causes changes to processes and form that influence biota. Additionally, there are constraints within human management infrastructure or policy, such as dam outlet works or property damage avoidance that influence this hierarchy.

This chapter provides background on the Water component of the SUPPLY tier and discusses how changes in water routing and inundation have changed as a result of human management in the San Joaquin River. Chapter 3 provides background on the Sediment component of the SUPPLY tier and addresses how changes in Water and Sediment have caused cumulative changes to PROCESS and FORM. These two chapters are intended to provide the physical foundation for better understanding changes to the biota of interest, and provide insights that may improve the success of the Restoration Study.

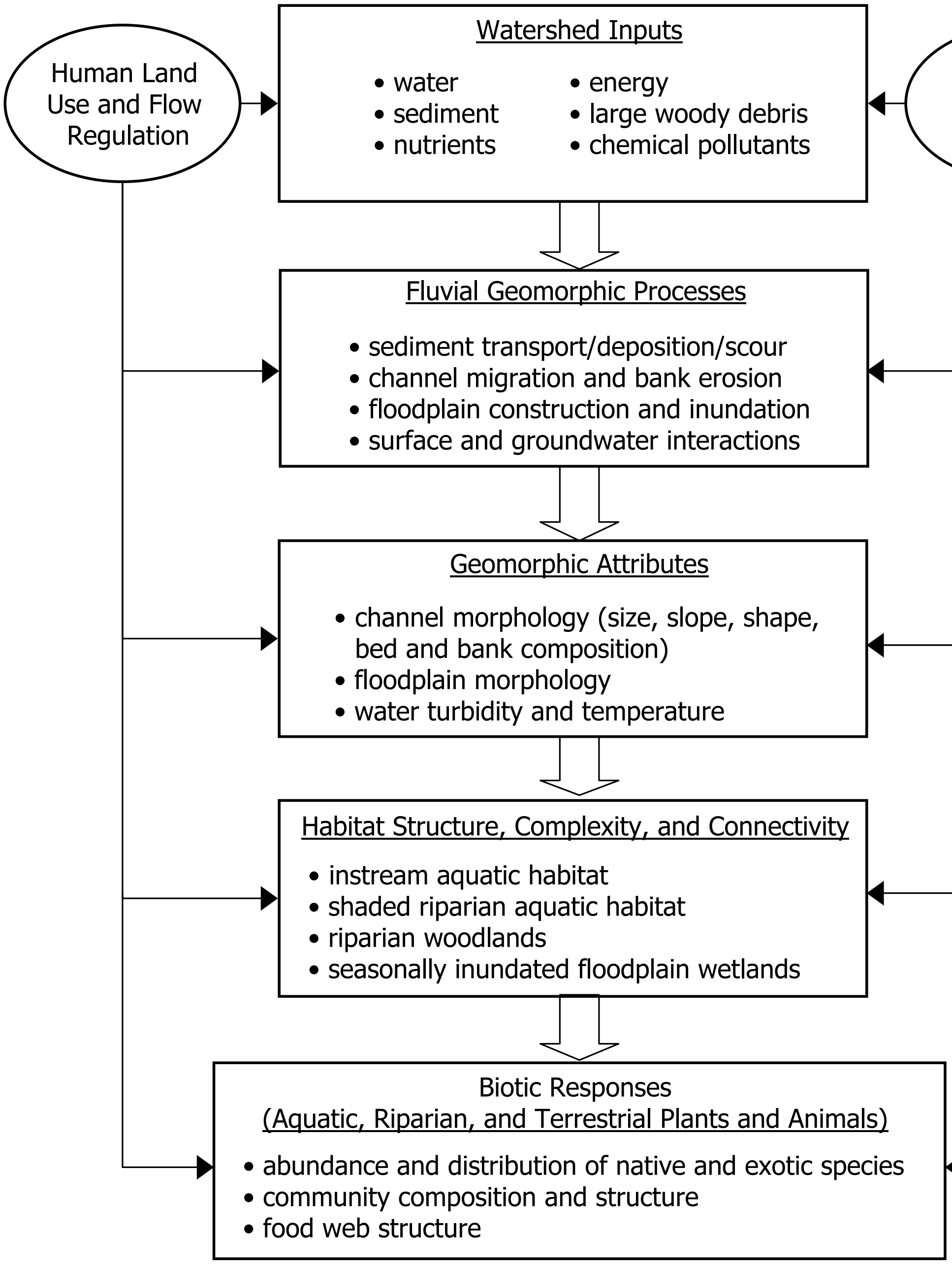


Figure 2-1. Conceptual physical framework of alluvial river ecosystems, showing how natural fluvial geomorphic components and human components cascade to changes in biota.

2.2. OBJECTIVES

The goal of this chapter is to describe the historical flow regime, explain how the flow regime has changed, and provide information that will enable us to hypothesize how these changes to the flow regime have led to changes in biota. The objective IS NOT to provide an argument to returning to the historical flow regime but will establish a framework upon which linkages to the health and productivity of priority biota can be made. It will enable the following questions to be posed (among many others):

- How did spring-run Chinook salmon evolve and adapt their life history to the natural hydrograph?
- How have changes to the natural hydrograph interfered with the spring-run Chinook salmon life history?
- How important are certain hydrograph components to the health, productivity, and survival of spring-run Chinook salmon?
- What geomorphic processes occurred during wetter years and what processes occurred during drier years?

This evaluation of surface flow hydrology will provide insight on certain portions of the flow regime that were more important than others for several species (discussed in subsequent chapters), and may help prioritize portions of the flow regime to improve as part of the Restoration Study. The chapter also gives an overview of historical and present-day flow routing through the system, as well as examples of how infrastructure has changed flood flow magnitude, duration, and inundation areas. Objectives below are summarized from the scope of work:

- Compile and evaluate historical and existing surface water data on the San Joaquin River and tributaries pertinent to the Restoration Study planning process.
- Describe historical and existing longitudinal surface water flow trends from Friant Dam to the Merced River by developing a reach-by-reach water budget of seasonal inflows and outflows along the San Joaquin River using gaging stations, diversion rates, other quantitative data, and qualitative estimates where no quantitative data is available. Describe how longitudinal differences in gaining and losing reaches may have influenced salmonid production.
- Prepare a hydrograph component analysis that describes pre-Friant and post-Friant seasonal flows at mainstem San Joaquin River gaging stations that can be used in other chapters to link life history.
- Assess impact of levees, bypasses, and other infrastructure on flood peak attenuation compared to pre-development conditions.
- Analysis and description of changes in the area and inter-annual variability in areas flooded by the pre-dam events shown on the 1914 CDC maps, and comparable post-dam events of similar flood frequency using the post-dam flood frequency distribution. The purpose of this analysis is to characterize the frequency, duration, and reclining limb of over-bank flows and the areas frequently inundated during both the pre- and post-Friant Dam period, and the pre- and post- flood control period.

2.3. STUDY AREA

The study area for this chapter is defined by the watershed boundary of the San Joaquin River. Under historical conditions, this study area would have included the Tulare Lake basin because during periods of high lake elevations and/or high flows from the Kings River, flows periodically spilled from the Tulare Lake basin through Fresno Slough into the San Joaquin River. Under present conditions, Tulare Lake no longer exists (except during very wet years), but flows still periodically enter the San Joaquin River from the Fresno River via James Bypass and Fresno Slough. Therefore, for discussion purposes, the study area will extend into the Tulare Lake basin. For quantitative purposes, the study area is the San Joaquin River from Friant Dam downstream to the confluence with the Merced River, including selected tributaries to the San Joaquin River (Figure 2-2 and Figure 2-3).

2.4. DATA SOURCES

All of the data discussed in this technical memorandum were obtained from the various agencies that collect data within the project reach. These agencies include the following:

- U.S. Geological Survey (USGS);
- U.S. Bureau of Reclamation (Bureau);
- California Department of Water Resources (DWR);
- San Joaquin River Exchange Contractors;
- Statistical Analysis of Kings River flows to estimate unimpaired San Joaquin River flows (Madeheim, 1999).

Table 2-1 summarizes the gaging stations available in the San Joaquin Valley, although not all were used in the discussion or analysis in Chapter 2. Several individuals conducted the analyses done for this chapter, and the period of record used for the analyses varies to some degree. The date of the most recent data used in an analysis depends on when the analysis was done, and varies from an end date of 1997 at the earliest, with some analyses using data through 2001. The date chosen for defining the pre-Friant Dam to post-Friant Dam transition varies by analysis. Some analyses begin the post-Friant Dam period as 1950 to accommodate completion of the Friant-Kern and Friant-Madera canals, while other analyses begin the post-Friant Dam period as 1944 with the beginning of regulation. The period of record used in each analysis is delineated.

Table 2-1. Summary of flow records available for the project reach of the San Joaquin River from Friant Dam to the confluence with the Merced River.

Gage # (see Fig. 2-2)	Gage Name, Drainage Area	Gage Stn # or CDEC ID	Agency	Data Type	Data Used in Water Budget Analysis[1]	Period of Record[2]
1A	San Joaquin River release from Friant Dam (DA=1,640 sq mi)	MIL	USBR	mean daily	X	1944 - present
1B	San Joaquin River below Friant Dam (DA= 1,676 sq mi)	11251000	USGS	mean daily	X	1908 - present
				annual peaks		
2	Cottonwood Creek near Friant (DA= 35.6 sq mi)[1]	11250500	USGS	mean daily annual peaks		1942 – 1951[3]
		CTK	USBR	mean daily		1951- present
3A	Little Dry Creek near Friant (DA= 57.9 sq mi)	11251500	USGS	mean daily annual peaks		1942 - 1956
		LDC	USBR	mean daily		1951- present
3B	Little Dry Creek near mouth (DA= 77.4 sq mi)[2]	11251600	USGS	mean daily annual peaks		1957 – 1961[4]

Table 2-1. cont.

Gage # (see Fig. 2-2)	Gage Name, Drainage Area	Gage Stn # or CDEC ID	Agency	Data Type	Data Used in Water Budget Analysis[1]	Period of Record[2]
4	San Joaquin River @ Donny Bridge (DA= not published)		USBR	mean daily		1984-1999
5	San Joaquin River @ Skaggs Bridge (DA= not published)		USBR	mean daily		1984-1999
6	San Joaquin River at Gravelly Ford (DA= not published)	GRF	USBR	mean daily	X	1987[5] - present
	San Joaquin River near Biola (DA= 1,811 sq mi)	11253000	USGS	mean daily annual peaks		1953-1961
7	San Joaquin River below Bifurcation (DA= not published)	SJB	USBR	mean daily		1986 - present
8	Chowchilla Bypass at Head (DA= not published)	CBP	DWR	mean daily	X	1980 - 1991
			USBR	mean daily	X	1986 - present
9	James Bypass (Fresno Slough) near San Joaquin (DA= not published)	11253500	USGS	mean daily	X	1948 - present
10	San Joaquin River near Mendota (DA= 3,940 sq mi)	11254000	USGS	mean daily		1940 - 1954
				annual peaks		1940 - 1954
			USBR	mean daily	X	1986 - present
11	Arroyo Canal (DA= not applicable)		Exchange Contractors	mean daily	X	1990 - present
12	San Joaquin River near Dos Palos (DA=4,669 sq mi)	11256000	USGS	mean daily		1941 - 1954
				annual peaks		1941 - 1954
			USBR	mean daily	X	1986, 1987, 1995
13	San Joaquin River near El Nido (DA=6,443 sq mi)	11260000	USGS	mean daily		1940 - 1949
				annual peaks		1940 - 1949
14	Eastside Bypass near El Nido (DA= not applicable)	ELN	DWR	mean daily	X	1980 - present
15	Mariposa Bypass near Crane Ranch (DA= not applicable)		DWR	mean daily	X	1980 - 1994
16	Eastside Bypass below Mariposa Bypass (DA = not applicable)		DWR	mean daily	X	1980 - present
17	Bear Creek below Eastside Canal (DA= not published)		DWR	mean daily	X	1980 - present
18	San Joaquin River near Stevinson (DA= not published)	SJS	DWR	mean daily	X	1980 - present
19	Salt Slough at HW 165 near Stevinson (DA = not applicable)	11261100	USGS	mean daily	X	1986 - 1994, 1996- present
				annual peaks		1986 - present
			DWR	mean daily	X	1980 - present
20	San Joaquin River at Fremont Ford Bridge (DA= 7,619 sq mi)	11261500	USGS	mean daily	X	1937 - 1989
				annual peaks		1937 - 1989
21	Mud Slough near Gustine (DA = not applicable)	11262900	USGS	mean daily	X	1986 - present
				annual peaks		1986 - present

Table 2-1. cont.

Gage # (see Fig. 2-2)	Gage Name, Drainage Area	Gage Stn # or CDEC ID	Agency	Data Type	Data Used in Water Budget Analysis[1]	Period of Record[2]
22	Merced River near Stevinson (DA= 1,273 sq mi)	11272500	USGS	mean daily	X	1941 - 1995
				annual peaks		1924, 1941 - 1995
23	Merced River Slough near Newman (DA = not applicable)	11273000	USGS	mean daily		1942 - 1972
				annual peaks		1951 - 1972
24	San Joaquin River near Newman (DA= 9,520 sq mi)	11274000	USGS	mean daily	X	1912 - present
				annual peaks		1914 - present

[1] Water budget analyses used data through WY 1999.

[2] Water years - may contain missing periods

[3] USBR/DWR re-started station (CDEC code CTK), period of record: 2/98-present; electronic data from USBR 1986- present

[4] USBR/DWR re-started station (CDEC code LDC), period of record: 2/98-present; electronic data from USBR 1986- present

[5] Earlier records may be available from USBR

2.5. BACKGROUND

The San Joaquin River and tributaries drain approximately 13,500 mi^2 (measured at the USGS gaging station at Vernalis) along the western flank of the Sierra Nevada and eastern flank of the Coast Range, and flow northward into the Sacramento-San Joaquin delta, (where it is joined by the Calaveras and Mokelumne River before combining with the Sacramento River). Typical of Mediterranean climate catchments, flows vary widely seasonally and from year to year. Three major tributaries join the San Joaquin from the east: the Merced, Tuolumne, and Stanislaus rivers. Smaller tributaries include the Fresno River, Chowchilla River, Bear Creek, and Fresno Slough (from the Kings River). Precipitation is predominantly snow above about 5,500 to 6,000 feet in the Sierra Nevada, with rain in the middle and lower elevations of the Sierra foothills and in the Coast Range. As a result, the natural hydrology reflected a mixed runoff regime, dominated by winter-spring rainfall runoff and spring-summer snowmelt runoff. Most flow is derived from snowmelt from the Sierra Nevada, with relatively little runoff contributed from the western side of the drainage basin in the rain shadow of the Coast Range. Watershed elevation ranges from sea level near Vernalis to over 14,000 ft at the crest of the Sierra Nevada. Precipitation averages from 5 to 15 inches/year in the floor of the San Joaquin Valley, up to 80 inches/year at higher elevations of the Sierra Nevada (USGS 1998). The unimpaired average annual water yield (WY 1906-2002) of the San Joaquin River as measured immediately above Millerton Reservoir is 1,801,000 acre-ft (USBR 2002); the post-Friant Dam average annual water yield (WY 1950-2000) to the lower San Joaquin River is 695,500 acre-ft (USGS, 2000). As average precipitation decreases from north to south, the San Joaquin River basin (including the Stanislaus, Tuolumne, and Merced rivers) contributes only about 22% of the total runoff to the Delta (DWR 1998).

The following sections describe components of the natural flow regime, tributaries, and water management infrastructure within the study reach. Additional information on water management infrastructure can be found in Chapter 5.

2.5.1. The Natural Flow Regime

The flow regime of a river or stream describes the temporal variability of runoff at two scales: that within a single hydrologic year (*intra-annual*, e.g., an annual hydrograph depicting winter floods,

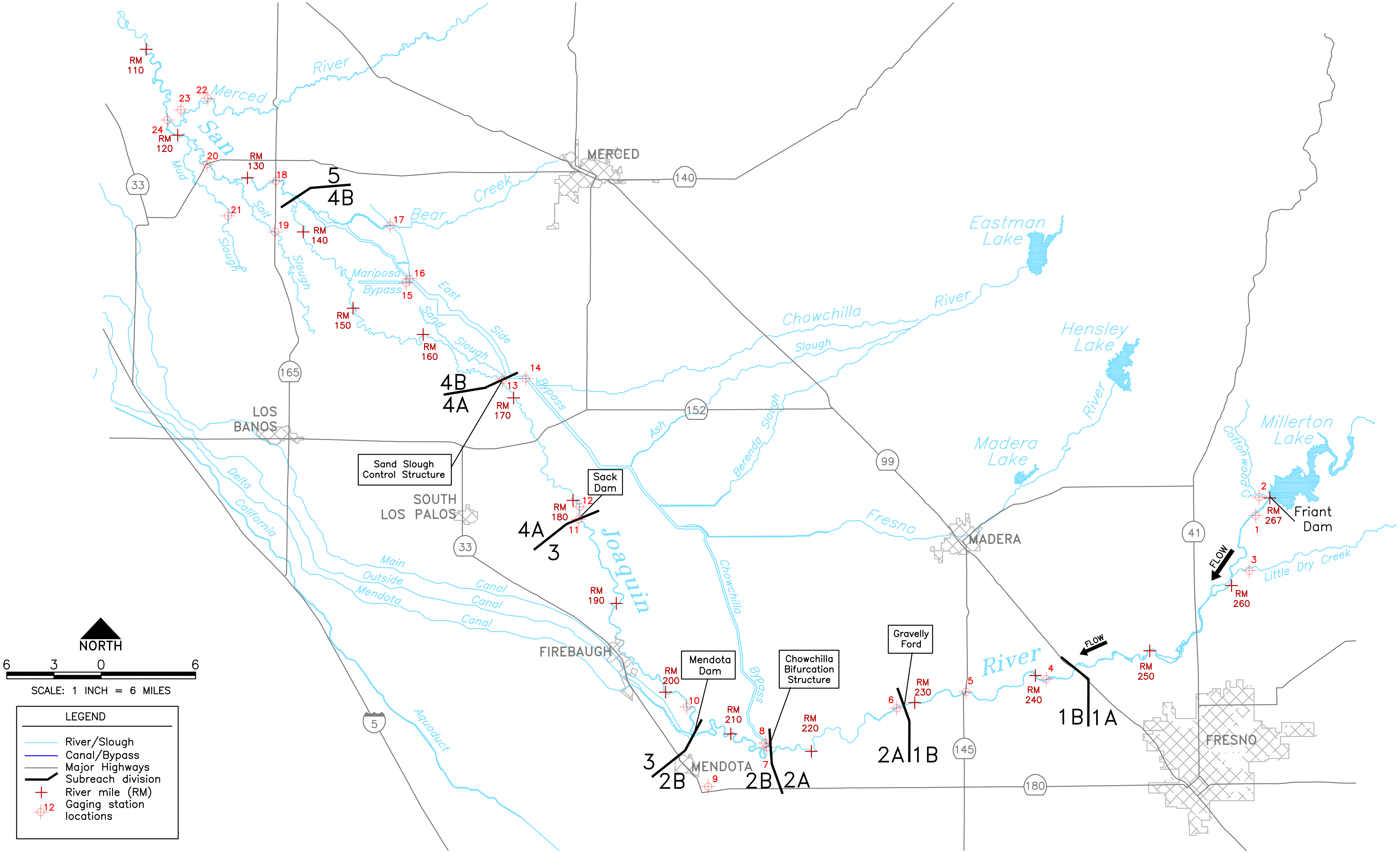


Figure 2-2. Project area of the San Joaquin River Restoration Plan showing Reach and Subreach Boundaries, and gaging stations.

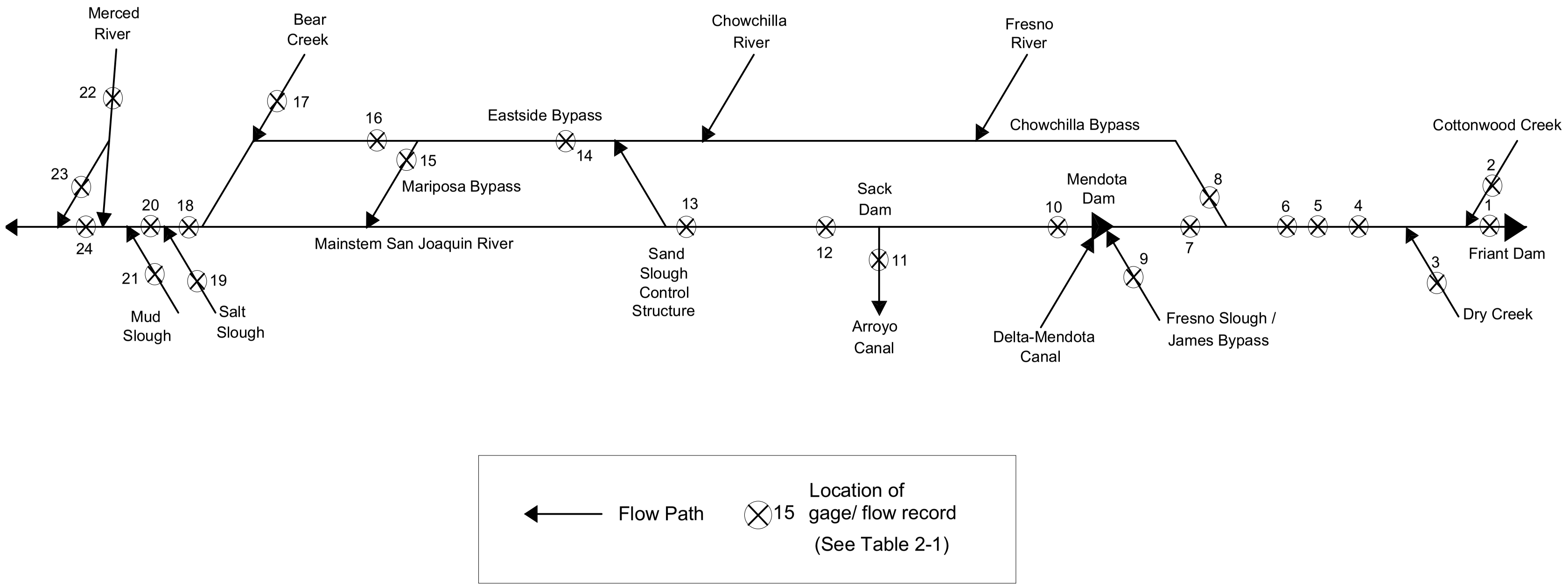


Figure 2-3: Schematic of San Joaquin River showing location of gaging stations presented in Table 2-1 and Table 2-3.

spring snowmelt runoff, recession, and baseflow) and that from year-to-year (*inter-annual*, e.g., dry years, wet years, and multi-year cycles of alternating drought and high water yield). Both temporal scales are important to fluvial processes, channel morphology, and ecosystem functions. The natural (unimpaired) flow regime of any given stream is unique to that stream, and is a primary determinant of the size, shape, and character of the stream. It is a function of a variety of factors, including the magnitude, duration, frequency, and timing of precipitation; the form of precipitation (rain versus snow); and the properties of the watershed that control how precipitation translates into streamflow (geology, soils, vegetative cover, elevation, aspect, gradient, development, etc.).

The concepts of *magnitude, duration, frequency,* and *timing* are useful for describing hydrological phenomena, for comparing flow regimes of different streams, and for comparing unimpaired with impaired flow regimes for a single stream before and after flow regulation.

- *Magnitude* refers to the rate of discharge of either high flows or low flows of geomorphic or biological significance, such as peak discharges and dry season low flows.
- *Duration* refers to the length of time a river carries a specific flow rate, or the percent of time over a specific period that a specific discharge is equaled or exceeded (information that can be derived from a flow-duration curve).
- *Frequency* describes the rate of occurrence of a particular flow, for example, the 100-year flood occurs, on average, once every 100 years (information that can be derived from a flood frequency curve).
- *Timing* of low and high flows is also important for supporting riparian and aquatic ecosystem processes. Species are adapted to natural cycles of high and low flows that provide hydrologic conditions necessary for key life history stages.

The natural or “unimpaired” flow regime historically provided large variation in the magnitude, timing, duration, and frequency of streamflows, both inter-annually and seasonally. Variability in streamflows was essential in sustaining ecosystem *integrity* (long-term maintenance of biodiversity and productivity) and *resiliency* (capacity to endure natural and human disturbances) (Stanford, et al. 1996). Restoring the natural flow variability of a river is now recognized as a fundamentally sound approach to initiating river ecosystem restoration (Poff, et al. 1997). Historic river restoration efforts have not tended to restore flow variability due to a variety of reasons, primarily due to poor understanding of the ecological links to a variable flow regime. One of the goals of this chapter is to provide the hydrology foundation to be able to establish these ecological links in the Restoration Study.

2.5.2. Definition of Hydrologic Records

Various terms are used to describe periods of the hydrologic record that can lead to confusion for the readers. Water storage development in the San Joaquin River watershed began in the 1850’s with the gold rush, and has increased in scale to the present day (Table 2-2). The following terms are defined to provide consistency in hydrology descriptor, and to explain what information is being used.

2.5.2.1. Unimpaired runoff

Unimpaired runoff represents the flow that would occur absent any diversions or reservoir regulation, and is directly derived from the measured flows. Although it is sometimes referred to as the full natural runoff or full natural flow, the unimpaired runoff does not reflect fully natural conditions since it does not account for changes in natural watershed runoff characteristics that have occurred in the past 200 years due to land use alterations and vegetation conversion. It is assumed, however, that the

Table 2-2. Cumulative water storage facilities in the upper San Joaquin River watershed.

Year Completed	Dam Name	Stream	Storage capacity (acre-ft)[1]	Storage as % of annual unimpaired runoff	Cumulative storage (acre-ft)	Cumulative storage as % of annual unimpaired runoff [2]
1896	No. 1 Forebay	Tributary of North Fork San Joaquin River	69	0.004%	69	0.004%
1906	No. 3 Forebay	Tributary of North Fork Willow Creek	20	0.001%	89	0.005%
1910	Crane Valley (Bass Lake)	North Fork Willow Creek	45,410	2.5%	45,499	2.5%
1912	No. 2 reservoir	North Fork Willow Creek	103	0.0%	45,602	2.5%
1913	Dam 4	Big Creek	60	0.0%	45,662	2.5%
1918	Huntington Lake	Big Creek	88,834	4.9%	134,496	7.5%
1920	Kerckhoff Diversion	Mainstem San Joaquin River	4,200	0.2%	138,696	7.7%
1921	Dam 5	Big Creek	49	0.0%	138,745	7.7%
1923	Big Creek #6	Mainstem San Joaquin River	993	0.1%	139,738	7.8%
1926	Florence Lake	South Fork San Joaquin River	64,406	3.6%	204,144	11.3%
1927	Shaver Lake	Stevenson Creek	135,283	7.5%	339,427	18.8%
1927	Bear Creek Diversion	Bear Creek	103	0.0%	339,530	18.9%
1942	Friant/Millerton	Mainstem San Joaquin River	520,500	28.9%	860,030	47.8%
1951	Big Creek #7 Redinger	Mainstem San Joaquin River	26,000	1.4%	886,030	49.2%
1954	Vermillion Valley Thomas Edison	Mono Creek	125,000	6.9%	1,011,030	56.1%
1955	Portal Powerhouse Forebay	Tributary of South Fork San Joaquin River	325	0.0%	1,011,355	56.2%
1960	Mammoth Pool	Mainstem San Joaquin River	123,000	6.8%	1,134,355	63.0%
1986	Balsam Meadow Forebay	West Fork Balsam Creek	2,872	0.2%	1,137,227	63.1%

[1] Division of Safety of Dams, Bulletin 17-00, July 2000; USBR Millerton Lake Operations Report (for Big Creek #7)

[2] Unimpaired runoff = 1,801,000 acre-ft, from USBR computed full natural flows 1906-2002.

cumulative effect of those alterations on the seasonal runoff is relatively minor and the unimpaired runoff is a satisfactory representation of natural runoff. This report estimates unimpaired runoff using data developed by Madeheim (1999) from extrapolating the Kings River data to the San Joaquin River. This report also uses full natural runoff or full natural flow estimates provided by USBR. These estimates are computed from upstream gaging stations and inflow into Millerton Reservoir, and consider reservoir evaporation and upstream storage.

2.5.2.2. Pre-Friant Dam flows

Construction of Friant Dam began in 1939, and flows were moderately regulated by Friant Dam between 1942 and 1951 when the Friant-Kern and Friant-Madera canals were completed. Pre-Friant Dam flows are measured at the San Joaquin River at Friant gaging station (STN #11-251000), and the 1908-1942 period of record was used. As shown in Table 2-2, there was increasing flow regulation in the upper watershed prior to completion of Friant Dam that would affect flows measured at the Friant gaging station; therefore, these flows are not considered unimpaired. While the flows were impaired by upstream dams prior to the completion of Friant Dam, the degree of impairment was small compared to the flow regime after completion of Friant Dam.

2.5.2.3. Post-Friant Dam flows

Friant Dam was completed in 1942; however, because the Friant-Kern canal and Friant-Madera canal was not fully completed until 1951, the degree of flow regulation downstream of Friant Dam differed as the canals were constructed. Therefore, to use a consistent time period where operations, diversions, and downstream releases were consistent, the 1950-present period of record is used to represent post-Friant Dam flows for most analyses. The flood frequency analysis uses 1944-present for Post-Friant Dam flows because the reservoir was used for flood control purposes immediately after the dam was completed. Flows are measured at the San Joaquin River at Friant gaging station (STN #11-251000).

2.5.3. Hydrologic Features

The hydrologic network of the approximately 150 miles of the San Joaquin River between Friant Dam and the Merced River is formed and influenced by confluences, diversions, and flood control features. This infrastructure is discussed in more detail in Chapter 5; a shorter summary is provided below.

Instream flows in the San Joaquin River are controlled by releases from Friant Dam. Two small intermittent tributaries join the river immediately downstream from Friant Dam: Cottonwood Creek and Little Dry Creek. Numerous gravel pits are present in the river and floodplain along the approximately 35-mile gravel-bedded reach of the mainstem downstream from Friant Dam. Because of the effects of channel percolation losses and diversions, flow varies significantly along the reach between Friant Dam (RM 270) and Gravelly Ford (RM 230). A bifurcation structure at RM 216 controls a flow split between the mainstem San Joaquin River and the Chowchilla Bypass. Mendota Dam at RM 204.5 provides the headworks for distributing water that is brought into the system through the Delta-Mendota Canal. A portion of the imported water is distributed into several canals that connect to Mendota Pool upstream from the dam, and a portion is passed into the river for downstream delivery to the Arroyo Canal. Flows are diverted from the San Joaquin River into the Arroyo Canal at Sack Dam (RM 182.1). The Sand Slough Control Structure at RM 168.5 controls the flow split between the mainstem San Joaquin River and the Eastside Bypass. The Mariposa Bypass delivers flow back into the river from the Eastside Bypass near RM 148. The remaining flows in the Eastside Bypass downstream from the Mariposa Bypass and inflows from Bear Creek enter the river near RM 136. A schematic of the flood control system is shown on Figure 5-5. Salt Slough and Mud Slough enter the San Joaquin River from the west near RM 129.5 and RM 121.3, respectively. The Merced River enters the San Joaquin River near RM 119. A line diagram of the main features of the hydrologic network of the San Joaquin River between Friant Dam and the Merced River is presented in Figure 2-3 and a summary of the available gage records is presented in Table 2-1. The following sections describe each of the major components of the network.

2.5.3.1. Friant Dam Releases

Instream flows are released to the San Joaquin River from Friant Dam. Both the Bureau of Reclamation and USGS maintain a record of flows downstream from Friant Dam. The Bureau of Reclamation records represent calculated flow releases from the dam outlet works (including flows to the Friant Hatchery), while the USGS flows are obtained from a continuously monitored gaging station that is located downstream from the dam and hatchery release. A summary of inflows, typical diversions, and typical instream releases is shown on Figure 5-2.

2.5.3.2. Tributaries: Cottonwood Creek and Little Dry Creek

Two intermittent tributaries join the San Joaquin River downstream from Friant Dam. Cottonwood Creek enters from the north immediately downstream from Friant Dam, and has a drainage area of 35.6 mi^2 at the former USGS gaging station. Little Dry Creek enters from the south approximately 6 miles downstream from the dam, and has a drainage area of 57.9 mi^2 at the former USGS gaging station. These tributaries are very small and contribute very little to the overall runoff volume in the San Joaquin River. However, during periods of low flow releases from Friant Dam in the winter months, these tributaries can contribute significantly to the flow during storm events. The ACOE recommended San Joaquin River flow limit of 8,000 cfs includes these tributaries, so high flows from these tributaries reduce the flood release from Friant Dam. Flows in Little Dry Creek are augmented by flows from Big Dry Creek through a secondary spillway from the Big Dry Creek flood control reservoir. Cottonwood Creek and Little Dry Creek have been gaged by USGS and USBR, and are described further in Section 2.6.2.4 and 2.6.2.5.

2.5.3.3. Gravel Pits

Numerous gravel pits are present in the river and floodplain along the approximately 35-mile gravel bedded reach of the San Joaquin River downstream from Friant Dam. Based on the 1997 aerial photography, the total surface area of the pits is approximately 1,360 acres, of which the San Joaquin River is directly connected to approximately 190 acres of gravel mining pits. The remainder of the pits are located in the floodplain adjacent to the river. These pits are hydrologically connected to the river (separated by permeable gravel berms), and create significant ponding and associated evaporation losses. Gravel pits directly connected to the main channel can significantly attenuate flow release changes from Friant Dam.

2.5.3.4. Diversions and Losses

There are two primary sources of water loss in the study reach (Friant Dam to the Merced River confluence): riparian water diversions, and infiltration losses. Riparian diversions vary considerably, from small individual pumps or diversion canals, to large volume water delivery canals (e.g., Arroyo Canal). These riparian diversions are discussed further in Section 2.7.2.3 and Chapter 5, and a list of diversions mapped by CDFG in 2001 is shown in Table 5-2. Larger diversions are shown on Figure 2-2. Under historical conditions, the San Joaquin River gained flows from the shallow groundwater table in most reaches (see Chapter 4). Groundwater pumping over the last 150 years has reduced the shallow groundwater table in most reaches, such that instream flows infiltrate into the shallow groundwater table and instream flows decrease with distance downstream. Because of the effects of infiltration losses and riparian diversions, flow in the San Joaquin River varies significantly along the reach between Friant Dam and Gravelly Ford, particularly when the flow release from Friant Dam is less than about 500 cfs. Significant flow losses also occur between Gravelly Ford and the Chowchilla Bifurcation Structure, primarily because of percolation losses (Figure 2-4). The measured flow loss for the Friant Dam to Gravelly Ford reach indicates that flow does not reach Gravelly Ford when the discharge at the “below-Friant-Dam” gage is less than about 100 cfs, and that about 150 cfs or more is lost when Friant Dam releases are greater than about 200 cfs. Similarly, no flow reaches the Chowchilla Bifurcation Structure when the discharge at Gravelly Ford is less than about 75 cfs, and the amount of flow loss between Gravelly Ford and Chowchilla Bifurcation Structure increases to about 200 cfs at higher flows (Figure 2-2). These flow losses assume steady-state condition (i.e., losses computed during prolonged periods of steady flows); flow losses can be greater during the initial days of a new flow release or an increasing flow release as the shallow groundwater is recharged by infiltration from the San Joaquin River flows. Seasonal loss estimates are described in Section 2.7.2.6. During normal conditions, the San Joaquin River is dry from just downstream of Gravelly Ford to Mendota Pool, and from Sack Dam to the Mariposa Bypass.

2.5.3.5. Operation of the Chowchilla Bifurcation Structure

A Bifurcation Structure is located at RM 216 that controls a flow split between the mainstem San Joaquin River and the Chowchilla Bypass. Operation of the structure is based on 1 of 2 conditions: (1) Initial flow to the San Joaquin River and (2) initial flow to the Chowchilla Bypass (The Reclamation Board 1969). Review of daily average flows of actual operations during the 1986 and 1995 high flow event suggests that a modified version of condition 1 is usually followed (see Figure 5-13). The actual operations of the bifurcation structures during a flood event depend greatly on three primary factors:

- Flood flows from the Kings River system through Fresno Slough.
- Water Demands from Mendota Pool (thus determining whether check boards are in place at Mendota Dam).
- Seasonality (will seepage/flooding problems affect agricultural practices on adjacent lands).

In all cases, water from the Kings River system (via Fresno Slough) has priority to available capacity on the San Joaquin River below Mendota Pool. When flood flows are below channel capacities, the Lower San Joaquin Levee District is provided the latitude to best utilize the design capacities of the Lower San Joaquin River Flood Control Project.

The first 1,500 cfs at the Chowchilla Bifurcation Structure should be routed to Mendota Pool, as long as flood flows from the Fresno Slough to the Mendota Pool are below 3,000 cfs. Since the rated channel capacity of the San Joaquin River is 4,500 cfs downstream of Mendota Dam, incremental flow from the Kings River above 3,000 cfs should be equally reduced at the Chowchilla Bifurcation Structure and routed to the Chowchilla Bypass. If flows from Fresno Slough are substantially below 3,000 cfs, the check boards at Mendota Pool can remain in place and the pool elevation targeted for 14.2 feet. The bifurcation structures are typically operated to route as steady a flow as possible to Mendota Pool (minimize flow variation).

Based on the assumption of 1,500 cfs being routed to the San Joaquin River at the Chowchilla Bifurcation Structure, the next increment of flood flows on the San Joaquin River from 1,500 cfs to 7,000 cfs (i.e., the next 5,500 cfs) should be routed to the Chowchilla Bypass. The next 1,000 cfs,

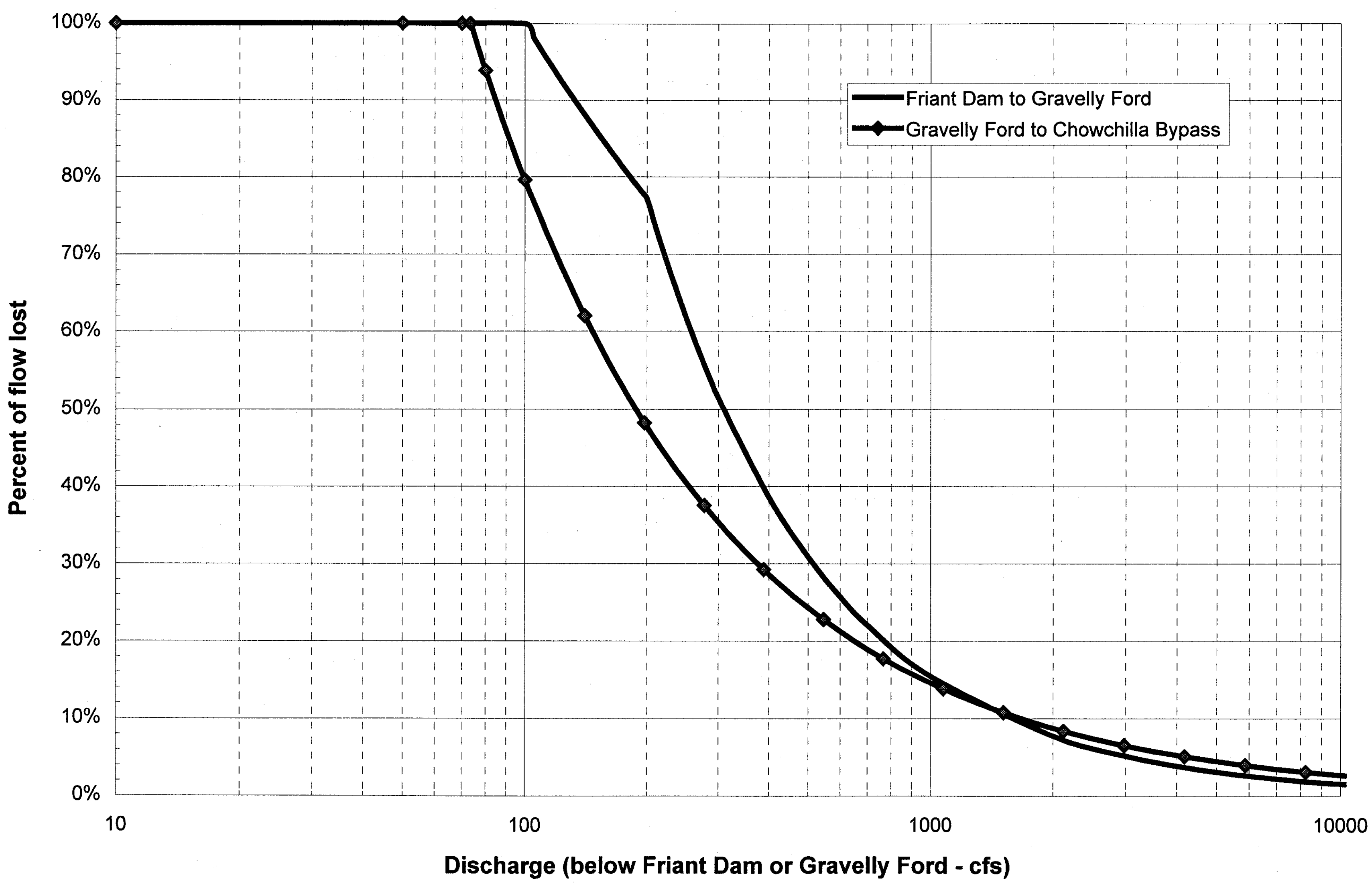


Figure 2-4. Estimated flow loss curves for the San Joaquin River between Friant Dam and Gravelly Ford, and between Gravelly Ford and the Chowchilla Bifurcation Structure.

or flood flows at the Chowchilla Bifurcation Structure of 7,000 cfs to 8,000 cfs, should be routed to the Mendota Pool. At this point, all check boards at Mendota Dam have typically been removed. A total of 2,500 cfs would be routed to Mendota Pool as long as flows from Fresno Slough are 2,000 cfs or lower. If the Fresno Slough contribution is greater than 2,000 cfs, then the channel below Mendota Pool could be subjected to flows greater than the maximum capacity of 4,500 cfs unless flows from the Chowchilla Bifurcation Structure are reduced. Should the flows exceed 8,000 cfs at the Chowchilla Bifurcation Structure or 10,000 cfs total between the San Joaquin River and Fresno Slough, the Lower San Joaquin Levee District is to operate the bifurcation structures at their own discretion with the objective of minimizing damage to the flood control project and protected area.

2.5.3.6. Mendota Dam

Mendota Dam is located at RM 204.5 and provides the headworks for distributing water that is brought into the system through the Delta-Mendota Canal. A portion of the imported water is distributed into several canals that connect to Mendota Pool upstream from the dam, and a portion is passed into the river for downstream delivery to the Arroyo Canal. Figure 5-4 illustrates typical seasonal operation of the Mendota Pool. In addition, during flood periods, flows enter Mendota Pool from the Kings River North via the James Bypass and Fresno Slough. Flows in the Kings River North are controlled by the operation of Pine Flat Dam, where a weir directs flows to the north up to the channel capacity, and then directs any additional flows into the south channel. Although early studies indicated that the capacity of the Kings River North was about 4,500 cfs, flows up to 6,000 cfs have passed through the reach (ACOE 1993).

2.5.3.7. Sack Dam and Arroyo Canal

Flows are diverted from the San Joaquin River into the Arroyo Canal at Sack Dam (RM 182.1), which is a low head earth and concrete structure with wooden flap gates. Flow is provided to Arroyo Canal by releases of Delta Mendota Canal water from Mendota Dam. The Exchange Contractors recorded daily diversions into the Arroyo Canal for the period 1990 to 1999. Typically, all flows less than 600 cfs is diverted from the San Joaquin River at this point, such that the downstream reaches are either dry or supplied by agricultural return flows.

2.5.3.8. Sand Slough Control Structure

The Sand Slough Control Structure, located at RM 168.5, controls the flow split between the San Joaquin River and the Eastside Bypass. There are no known operating rules for the structure during low flows, but the rules limit downstream flows in the San Joaquin River downstream of the structure to the flood control design discharge of 1,500 cfs. Because the present capacity of the San Joaquin River channel is severely limited, current operations limit downstream flows to 300 to 400 cfs. However, it appears that actual operations no longer open the gates to allow flows into the San Joaquin River, including during the 1997 flood. The San Joaquin River downstream of the Sand Slough Control Structure is dry until agricultural return water begins to allow positive flow to occur again.

2.5.3.9. Eastside Bypass

The Eastside Bypass begins at the confluence of the Chowchilla Bypass and the Fresno River, and extends downstream approximately 36 miles to the confluence with the San Joaquin River at the downstream end of Reach 4B. The Mariposa Bypass splits from the Eastside Bypass approximately 26 miles downstream from the confluence of the Fresno River and Chowchilla Bypass.

2.5.3.10. Mariposa Bypass

The Mariposa Bypass delivers flow back into the San Joaquin River from the Eastside Bypass near RM 148. The official operating rules for the Mariposa Bifurcation Structure require all flow to be diverted back into the San Joaquin River at discharges in the Eastside Bypass up to 8,500 cfs, with any higher flows to remain in the Eastside Bypass (San Luis Canal Company 1969). Review of flow data in the Mariposa Bypass indicates that actual operations released less flow into the river through the Mariposa Bypass than would be required by the operating rules (see Figure 5-14).

2.5.3.11. Bear Creek

The remaining flows in the Eastside Bypass and tributary inflows from Bear Creek re-enter the San Joaquin River near RM 136. The Department of Water Resources (DWR) has operated stream gages on Bear Creek just upstream from its confluence with the Eastside Bypass, and on the Eastside Bypass just downstream from the Mariposa Bypass since 1980.

2.5.3.12. Tributaries: Salt Slough and Mud Slough

Salt Slough and Mud Slough enter the San Joaquin River from the west side of the San Joaquin Valley near RM 129.5 and RM 121.3, respectively. Gage records are available from the USGS on both Salt Slough (at the Highway 165 Bridge) and Mud Slough since 1986. The DWR has also operated a gage on Salt Slough since 1980.

2.5.3.13. Merced River

The Merced River enters the San Joaquin River near RM 119. The USGS gage records are available for the Merced River from 1941 through 1995, and for Merced Slough, which is a bypass channel that carries a portion of the Merced River flows to the San Joaquin River at high flow, from 1942 through 1972.

2.5.3.14. Eastside Tributaries

The Eastside Bypass presently intercepts several significant tributaries that historically connected to the San Joaquin River. These tributaries include the Fresno River, Ash Slough, Berinda Slough, the Chowchilla River, Owens Creek, and Bear Creek. These tributaries historically entered the flood basin in Reach 3-5 rather than the mainstem San Joaquin River itself, and contributed to the prolonged inundation of the flood basins, particularly during winter storm events and spring snowmelt floods.

The Fresno River, with an average annual unimpaired discharge of 76,800 acre-ft (USGS, 1975), is now controlled by Hidden Dam located approximately 38 miles upstream from the San Joaquin River. Based on review of USGS gaging records, flow is released during the summer months for agricultural used downstream. There are no gaging stations near the confluence of the San Joaquin River, but field review suggests that little to no flow reaches the San Joaquin River under normal conditions. The Fresno River connects to the Chowchilla Bypass approximately 15 miles downstream from the Chowchilla Bifurcation Structure, and flows can be directed back into the old Fresno River channel downstream of the bypass through a headgate known as the Road 9 Structure. However, only the amount of flow necessary to satisfy riparian water rights on properties between the Chowchilla Bypass and the San Joaquin River are directed into the river; so little or no Fresno River flows reach the mainstem under the present operating system.

The Chowchilla River, with an unimpaired average annual flow of approximately 71,000 acre-ft (USGS 1975), is controlled by Buchanan Dam, located about 32 miles upstream from the San Joaquin

River. Flood control releases from the Chowchilla River enter the Eastside Bypass. As with the Fresno River, flow is released during the summer months for agricultural used downstream. Again, there are no gaging stations near the confluence of the San Joaquin River (Eastside Bypass), but field review suggests that little to no flow reaches the San Joaquin River under normal conditions. Flood control releases from the Chowchilla River enter the Eastside Bypass system and are routed to the San Joaquin River through either the Mariposa Bypass or Eastside Bypass (Figure 2-2).

In addition to these tributaries, Lone Willow Slough served as a distributary channel of the San Joaquin River between the present location of the Chowchilla Bifurcation Structure and approximately the confluence of the Fresno River. The historical slough intercepted several minor tributaries that drain from the east. Lone Willow Slough was also used as a diversion for the Columbia Canal Company, and the headgates are still in place at the head of the slough. At present, the channel of Lone Willow Slough remains somewhat intact but does not completely connect any longer, and the headgates are no longer opened because irrigation water is supplied to the Columbia Canal Company through a diversion from Mendota Pool. The Chowchilla Bypass and Eastside Bypass presently intercept the tributaries (Fresno River, Chowchilla River).

2.6. HISTORIC AND EXISTING HYDROLOGY

A variety of gaging stations are used to illustrate historic and existing surface water hydrology. For example, changes in surface water hydrology due to cumulative flow regulation dams is best illustrated using the USGS gaging station at Friant immediately downstream of Friant Dam (Figure 2-2). The USGS gaging station near Newman is also used to illustrate changes from upstream dams, including those on those on the Merced River, since the gage is downstream of the Merced River confluence. Key tributaries immediately below Friant Dam are also used to illustrate potential importance of these tributaries to restoration efforts (e.g., possibly supporting steelhead or providing geomorphic flows). The gaging stations listed in Table 2-1 are only a partial list of gages within the study area; however, those stations are the most important to the Restoration Study.

There are many tools to analyze surface water hydrology (e.g., flood frequency analysis, flow duration analysis). Rather than doing a blanket analysis using all the available and/or standard analysis tools, a few specific analyses are carefully applied that are most useful for illustrating linkages to the biological and geomorphological components that are integral to the San Joaquin River Restoration Study. This section presents the following analyses: (1) water year analysis at the Friant gaging station, (2) flood frequency computations of important gaging stations within the study area, (3) hydrograph component analysis at the Friant and Newman gaging stations to illustrate hydrograph trends at the upstream and downstream ends of the study reach, and (4) present example hydrographs of several key upstream tributaries.

2.6.1. Water Year Analysis

Streamflow is often described in terms of the average annual water yield (e.g., acre-feet per year) over a number of years, or an average flow duration curve over a number of years. While this may describe a long-term average water yield from a stream, this averaging masks inter-annual variability that strongly influences river ecosystem processes. By classifying the distribution of water years, the inter-annual flow variability can be better illustrated. Water managers use water year classifications for water delivery forecasting and management. A water year classification is also useful to describe correlations between river ecosystem processes and wetter and drier years.

There are many water year classifications in use on the different Central Valley watersheds. Other classifications (e.g. DWR/SWRCB) are for water supply purposes and also include precipitation and previous year's runoff. To guide some of the analyses in this section, we use a simple classification to describe inter-annual flow variability. This classification system is not meant to replace other systems, but simply to illustrate some important aspects of the inter-annual variability in runoff. The measuring point used is the computed unimpaired water year yield at Friant, which has been computed for the period 1896 to 1999 by Madeheim (1999). The annual water yield volumes are plotted cumulatively from wettest to driest against exceedence probabilities, with water year classes divided symmetrically into five equally weighted classes separated by annual exceedence probabilities (p) of 0.20, 0.40, 0.60, and 0.80. Thus, the five classes can be named "Extremely Wet" (p = 0 to 0.20), "Wet" (p = 0.20 to 0.40), "Normal" (p = 0.40 to 0.60), "Dry" (p = 0.60 to 0.80), and "Critically Dry" (p = 0.80 to 1.00). The boundaries of the classes do not necessarily have to be in 0.20 increments; it is important that they are symmetrical around the median value (p=0.50) to ensure that wetter and drier years are weighted equally. This classification system helps depict the range of variability in the annual water yield and provides an equal probability for each class that a given water year will fall into that category (equally distributed around the mean), which in turn allows simpler interpretation of comparisons between water year types. The result of this analysis at Friant is illustrated in Figure 2-5.

While this analysis is useful for comparing years, other specific ecological objectives (e.g., flows for fish migration) require focusing on a specific portion of the year. Differences among and within water year classes have meaningful geomorphic and biological consequences, and will be discussed later in this section with examples.

2.6.2. Flood Frequency

A flood frequency analysis predicts frequency that a given flood magnitude would occur, and a certain flood magnitude (e.g., 50,000 cfs) is labeled an "X-year flood" (e.g., 100-year flood, which has a 1% chance of occurrence any given year). These relationships were developed for selected San Joaquin River gaging stations based on their location and on their available peak flow record. Flood frequency analyses provide a useful tool to hydrologists and geomorphologists because they describe the flows responsible for geomorphic work. A probability distribution is fitted to the record of instantaneous annual maximum floods at a given station, and the estimated parameters of the distribution are then used to predict the average recurrence interval of floods of a given magnitude (Dunne and Leopold 1978). In this section, flood frequency computations performed by the ACOE (1999) for available gages in the study area are presented, as well as additional computations performed by the authors for certain stations important to describing the San Joaquin River hydrology that were either not computed by the ACOE, or the ACOE used only rainfall data in their computations. For these latter stations chosen for additional analyses, they were selected because they contribute high flows to the San Joaquin River that may influence restoration efforts. Cottonwood Creek and Little Dry Creek were chosen because they are in Reach 1, which will be important for salmonid spawning and rearing. James Bypass was included because it measures the amount of flow actually delivered to the San Joaquin River from the Fresno River. The San Joaquin River near Newman gage was included because it provides a pre-and post-Friant Dam comparison at the downstream end of the Study Reach. With the exception of the James Bypass gaging station, the raw data for the annual maximum series is plotted. Annual maximum data is not available for the James Bypass gaging station, so annual maximum daily average values were used. A log-Pearson Type III distribution is then fitted to the raw data. Flood frequency curves and flood magnitudes with recurrence intervals of 1.5, 5, 10, 25, and 50 years are summarized for both the unimpaired and regulated periods of record. The log-Pearson curve fitting was performed using standard procedures (USGS 1982); however, the curve fitting to measured data for several of the gaging stations is poor, and predicted flood magnitudes for floods greater than the 10-year flood should be viewed with caution.

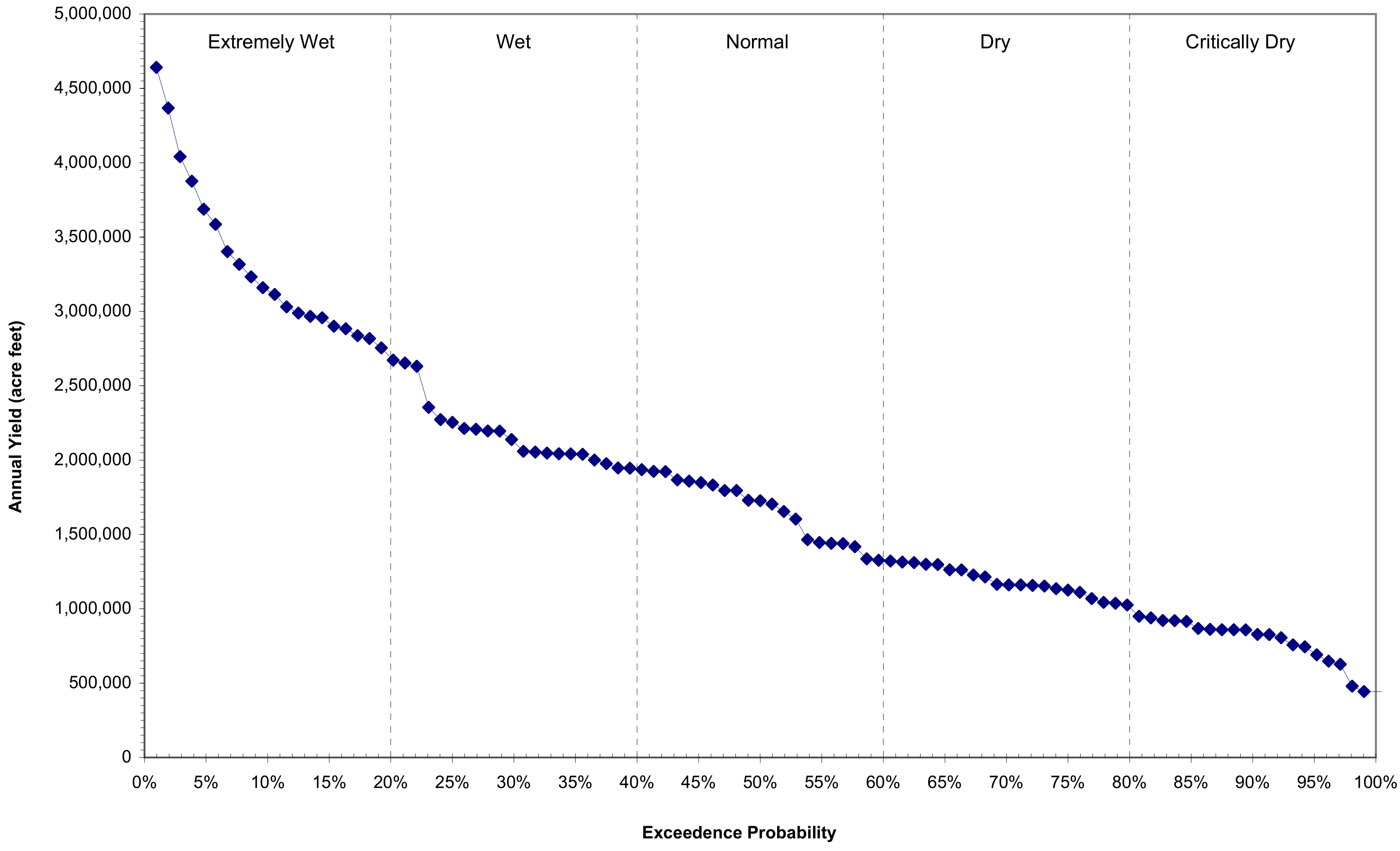


Figure 2-5. Water year classification at Friant Dam using computed unimpaired flow data from Madeheim (1999). This water year classification is used only for describing the hydrograph component analysis. ``

The ACOE performed flood frequency analyses at the San Joaquin River near Friant gaging station and San Joaquin River at Gravelly Ford gaging station (ACOE 1999). The ACOE analysis was performed as part of a post-flood assessment in response to the widespread regional flooding of 1997, and the emphasis of their analysis is placed on generating representative probabilistic flooding relationships as they pertain to the contemporary regulated flow regime. The ACOE flood frequency was developed using a combination of actual and hypothetical data to create a “regulated flood flow frequency curve.” The actual and hypothetical data are based on rainfall generated flood events rather than all potential floods (e.g., snowmelt floods); thus results are different from those generated by a standard flood frequency analysis of post-Friant Dam data (as done in Section 2.6.2.1). The actual data include only post-dam (regulated) annual peak streamflow series from 1949 to 1997, and the hypothetical data include modeled large flood events. The modeled hypothetical data were added to the actual peak flow data set to offset the “minimal amount of historical data,” thereby allowing for larger-scale, less-frequent flood events to be included in the analysis.

The results of the flood frequency analyses are summarized in Table 2-3, and are discussed in more detail below. The gaging stations used for the flood frequency analyses are shown on Figure 2-2 and Figure 2-3.

Table 2-3. Summary of frequency analysis results for selected streamflow gaging stations within the project reach.

Gaging station name and USGS or CDEC I.D. (from Table 2.1)	***Period of Record***	***Drainage Area (mi^2)***	***1.5-Year Recurrence Interval Flow (cfs)***	***10-Year Recurrence Interval Flow (cfs)***	***100-Year Recurrence Interval Flow (cfs)***
Background Report analysis					
San Joaquin River below Friant. USGS: 11-251000	1908-1943 (pre-Friant)	1,676	11,400 [a]	34,400 [a]	80,700 [a]
San Joaquin River below Friant. USGS: 11-251000	1944-2000 (post-Friant)		400 [a]	8,950 [a]	64,400 [a]
San Joaquin River nr Newman. USGS: 11-274000 [c]	1914-1943 (pre-Friant)	9,520	9,150 [a]	20,400 [a]	52,200 [a]
San Joaquin River nr Newman. USGS: 11-274000 [c]	1944-2001 (post-Friant)		2,160 [a]	25,000 [a]	86,500 [a]
Cottonwood Creek nr Friant. USGS: 11-250500	1941-1951	35.6	40 [a]	520 [a]	N/A [b]
Little Dry Creek nr Friant. USGS:11-251500	1942-1956	57.9	190 [a]	1,770 [a]	N/A [b]
James Bypass (Fresno Slough) near San Joaquin, USGS: 11-253500	1948-2001	N/A			
ACOE analysis					
San Joaquin River below Friant. USGS: 11-251000	1949-1997 (post-Friant)	1,676	220	8,000	70,000
San Joaquin River at Gravelly Ford. CDEC: GRF	1949-1997 (post-Friant)	1,805	110	9,000	65,000

Table 2-3. cont.

Gaging station name and USGS or CDEC I.D. (from Table 2.1)	***Period of Record***	***Drainage Area (mi^2)***	***1.5-Year Recurrence Interval Flow (cfs)***	***10-Year Recurrence Interval Flow (cfs)***	***100-Year Recurrence Interval Flow (cfs)***
Fresno River below Hidden Valley Dam. USGS: 11-258000	1976-1998	234	250	3,700	5,000
Chowchilla River below Buchanan Dam. USGS: 11-2590	1976-1998	235	470	3,700	7,000
Ash Slough below Chowchilla River (no gage given)	1976-1998	268	340	2,600	5,000
Berenda Slough below Chowchilla River (no gage given)	1976-1998	268	135	1,050	2,000
Eastside Bypass near El Nido. CDEC: ELN	1965-1998	5,630	230	17,000	21,000

[a] Estimated from Log-Pearson III fit of raw data, flood recurrences greater than 10-yr should be viewed with caution due to poor curve fitting.

[b] Insufficient raw data to extrapolate flow estimate.

[c] Includes flow from the Merced River (see Section 2.6.2.3).

[d] Flood frequency computed from maximum daily average flow, no instantaneous peaks available

2.6.2.1. San Joaquin River near Friant

The “San Joaquin River near Friant” gaging station (USGS station # 11-251000) is located at RM 265.5 and records streamflow data from the 1,676 mi^2 watershed above the gaging station. Until Friant Dam was completed, the gage recorded partially regulated streamflow from 1908 to 1943. Following completion of Friant Dam in 1944 and associated diversion canals in 1948, the gaging record after 1943 reflected much more regulated streamflow conditions. Because of the change in degree of streamflow regulation, the streamflow gaging record can be divided into separate pre- and post-dam series. The change in streamflow hydrology occurred over a 5-year period (1944-1948) as the dam and diversion became operational; therefore, the ACOE used 1948 as the end of the pre-Friant Dam period, while others use 1943 as the end of the pre-Friant Dam period.

The flood frequency analysis done in this report computes flood frequency for the gaging station using all historical gaging data at the USGS gage near Friant (pre- and post-dam). Flood magnitudes for recurrence intervals of 1.5, 5, 10, 25, and 50 years are summarized for both the pre-Friant Dam (moderately regulated) and post-Friant (regulated) periods of record. This analysis allowed a comparison of changes in flood frequency following the completion of Friant Dam (which can be linked to changes in fluvial process and channel form, as discussed in Chapter 3). The pre-Friant Dam analysis used data from 1908-1943, and the post-Friant Dam analysis used data from 1944-2000. Flood frequency analyses typically use annual instantaneous peak flow values in the computations; however, some of the early pre-Friant Dam data provided by the USGS is maximum daily average values rather than annual instantaneous peak values. No explanation was provided by USGS for not publishing annual instantaneous peak values. The maximum daily average values were nonetheless used in the flood frequency analysis, and using these values would slightly underestimate the pre-Friant Dam flood magnitude because the daily average flow values are slightly smaller than the annual instantaneous peak values.

The results of this analysis show a dramatic reduction in the flood flow regime as a result of the construction of Friant Dam and associated diversions. For example, the 1.5-year flood was reduced from 11,400 cfs to 400 cfs, and the 10-year flood was reduced from 32,400 cfs to 8,950 cfs (Figure 2-6). The smaller magnitude, higher frequency floods were much more severely impacted than were the large magnitude, less frequent floods, likely due to a relatively small storage capacity of Millerton Lake (Table 2-2). Additionally, when comparing the pre- and post-dam data, the pre-Friant Dam data is moderately regulated by small upstream dams, so the pre-Friant Dam data is a conservatively low flood magnitude estimate (i.e., actual unimpaired magnitude is probably larger). Lastly, the reduction in flood magnitude during the post-Friant Dam period is not necessarily entirely caused by reduced flow volume to the river downstream of Friant Dam. High flow releases tend to be 8,000 cfs or less due to channel capacity constraints downstream of Friant Dam (particularly in Reach 2) and ACOE flood control release limitations, and this constraint on flood management is observable on the larger number of flows in the 8,000 cfs range on Figure 2-6, Figure 2-7, and Figure 2-8.

The timing of annual instantaneous maximum floods on the San Joaquin River near Friant varied under both pre- and post-Friant Dam periods, although the patterns of magnitude and timing was different between the two periods (Figure 2-7). Prior to Friant Dam, annual instantaneous maximum floods occurred between mid-December and mid-June, indicating that early-winter rainstorms generated these peak flows some years, and by peak snowmelt runoff flows in other years. Figure 2-7 also illustrates that the earlier floods were larger magnitude than the later snowmelt flood peaks. These larger floods were generated from rainfall events, with the largest events generated from rain-on-snow events. The largest peak flood of record was 77,200 cfs (December 1937), although the 1862 flood was probably larger. The smallest annual peak flow was 3,380 cfs, most annual peak flows were greater than 5,000 cfs, and snowmelt peaks typically did not exceed 16,000 cfs (Figure 2-7).

The post-dam period has much lower flood magnitudes and the timing of these floods was spread out over a wider period of the water year. With the exception of the 1997 flood, which was estimated as an 80-year flood event (ACOE 1999), all post-dam peak flows were less than 16,000 cfs. Annual peak flows in the post-Friant Dam period occurred throughout the year because the natural periods of high flow (winter floods and spring snowmelt) are now completely captured by upstream dams and diversions, such that many of the peak flows occur during the summer when Friant Dam releases 200 cfs to 400 cfs for downstream riparian water rights holders.

The ACOE flood frequency curve for the Friant gaging station is presented in Figure 2-8. Although the ACOE did not perform a comparative analysis for the pre- and post-Friant Dam flood flow regime, their analysis shows that for the post-Friant Dam flow regime (based on a slightly shorter period of record than that used for Figure 2-6, from 1949-1997), the 1.5-year flood is approximately 220 cfs, and the 10-year flood flow is approximately 8,000 cfs (Figure 2-8) The ACOE prescribed controlled flood release limit at Friant is 8,000 cfs.

2.6.2.2. San Joaquin River at Gravelly Ford

The San Joaquin River near Gravelly Ford gaging station (CDEC station # “GRF”) is located at RM 229 and records streamflow data draining the 1,805 mi^2 watershed above the gaging station. The gaging period of record is 1987-present (Table 2-1); however, the ACOE analyzed flood frequency using data from 1949-1997. The ACOE does not describe their methods for expanding the measured data set back to 1949. Regardless, as with the San Joaquin River near Friant analysis, the flood frequency analysis at Gravelly Ford was performed as part of a post-flood assessment in response to the widespread flooding of 1997. The ACOE flood frequency curve is presented in Figure 2-9.

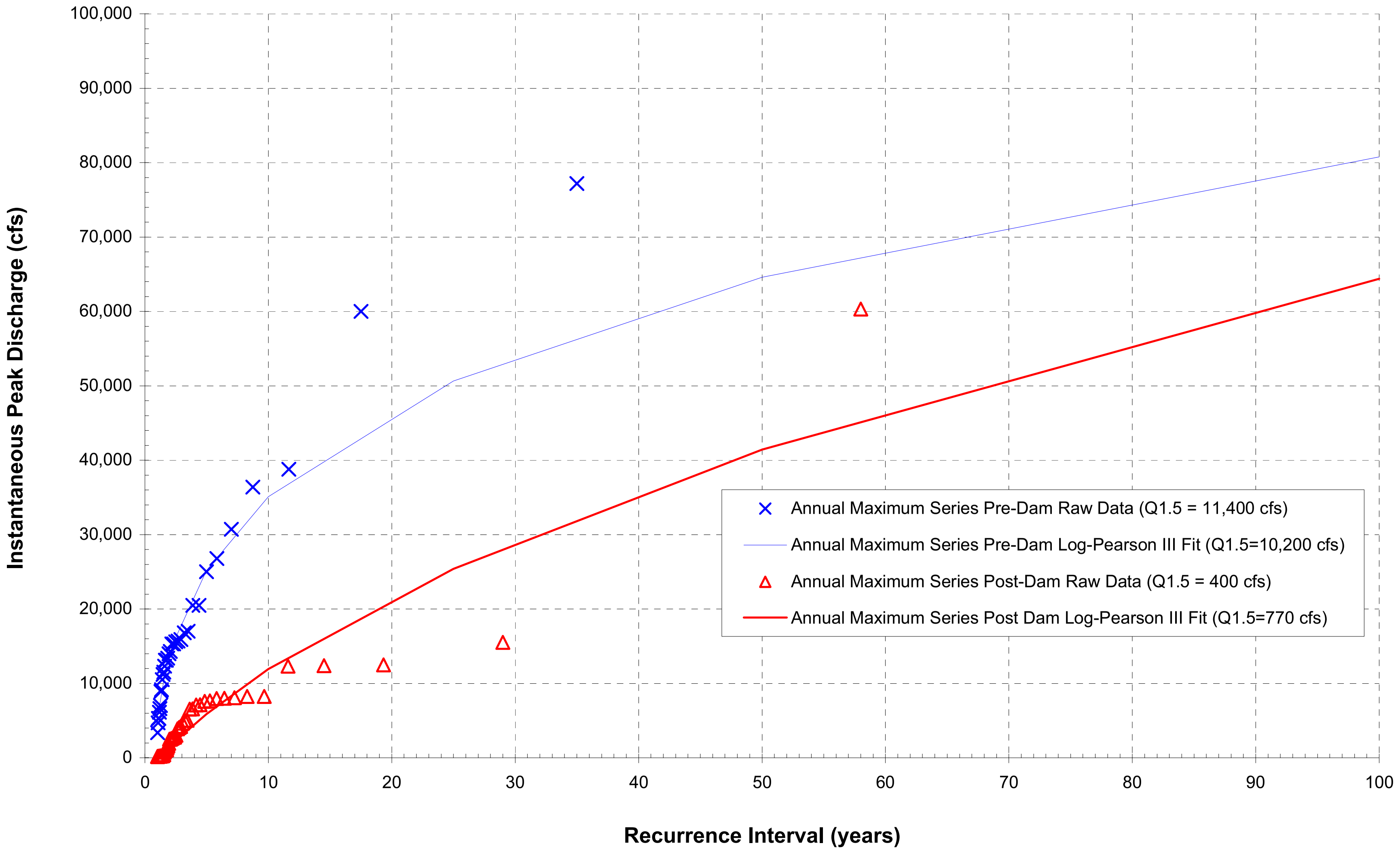


Figure 2-6. Flood frequency at the San Joaquin River below Friant Dam gaging station (# 11-251000) for pre- and post-Friant Dam (pre-dam 1908 – 1943; post-dam 1944 – 2000). Drainage area = 1,676 mi^2.

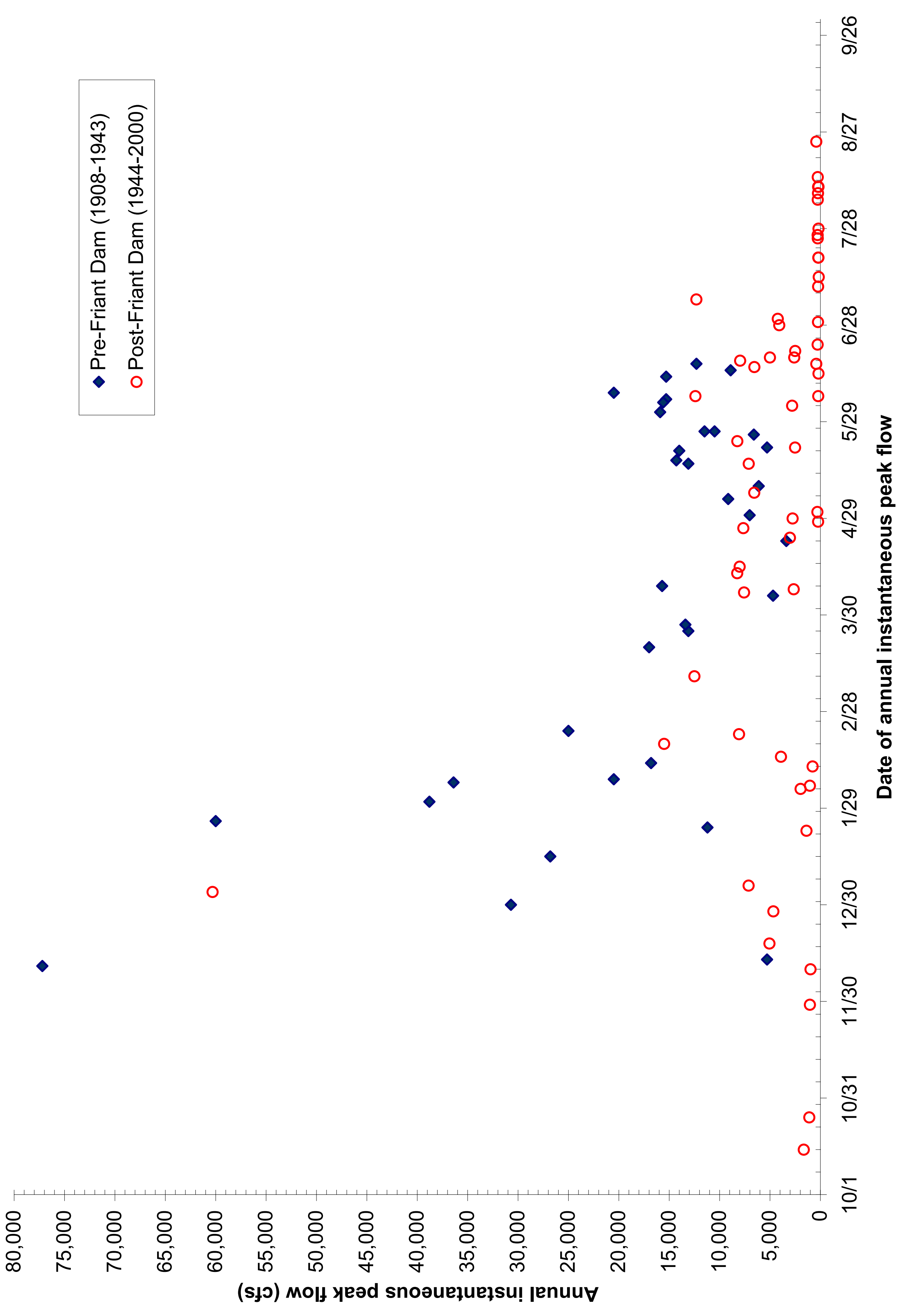
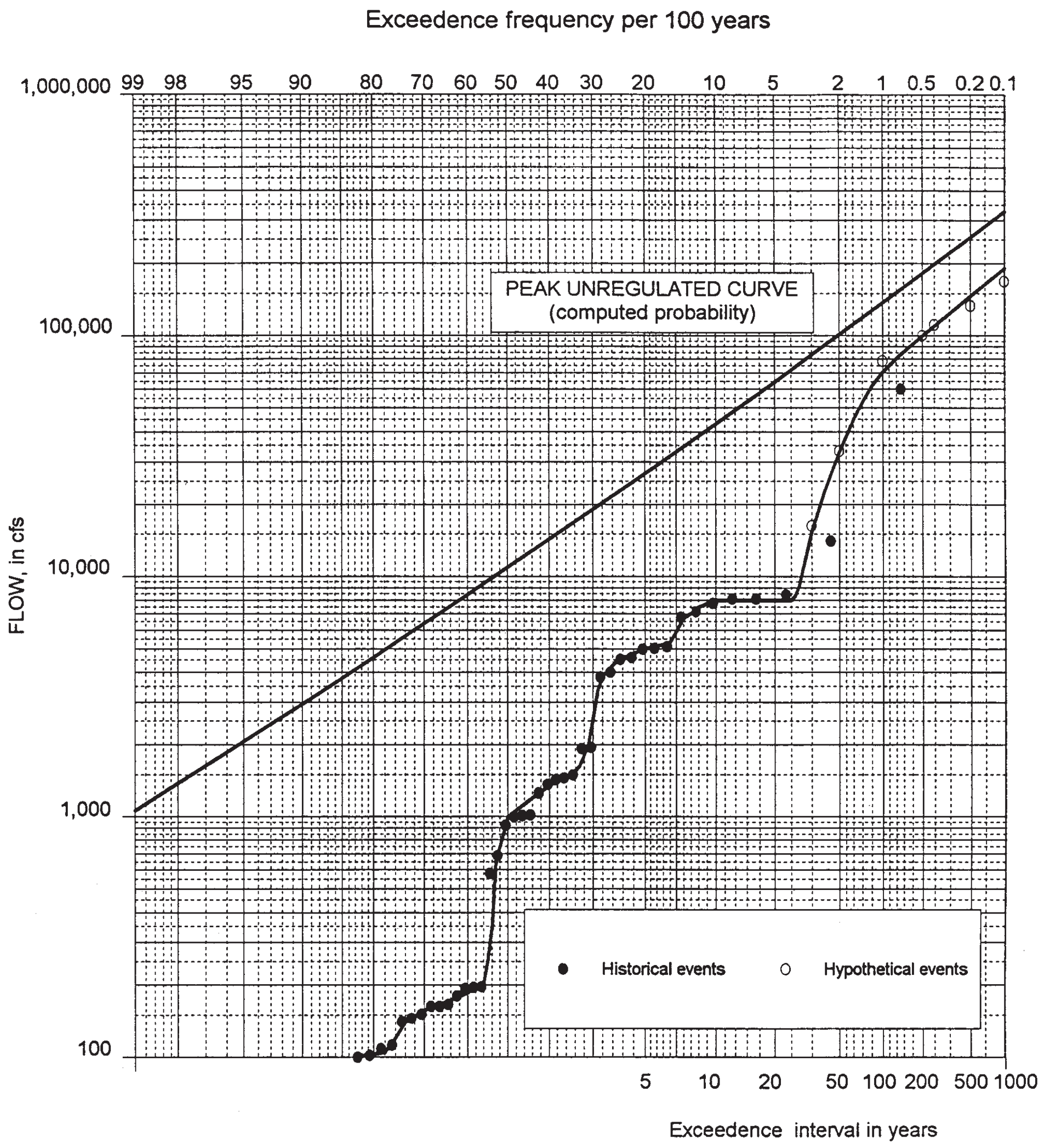


Figure 2-7.Temporal distribution of annual peak flows at the USGS gaging station near Friant (USGS # 11-251000) for pre- and post-Friant Dam records.



NOTES:
1. Median Plotting Positions
2. Drainage Area: 1,676 sq. mi.
3. 49 years of record (1949 to 1997)
4. 1997 event plotted as maximum in 94 years.

Prepared by TKP

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
REGULATED CONDITION

SAN JOAQUIN RIVER AT FRIANT DAM

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

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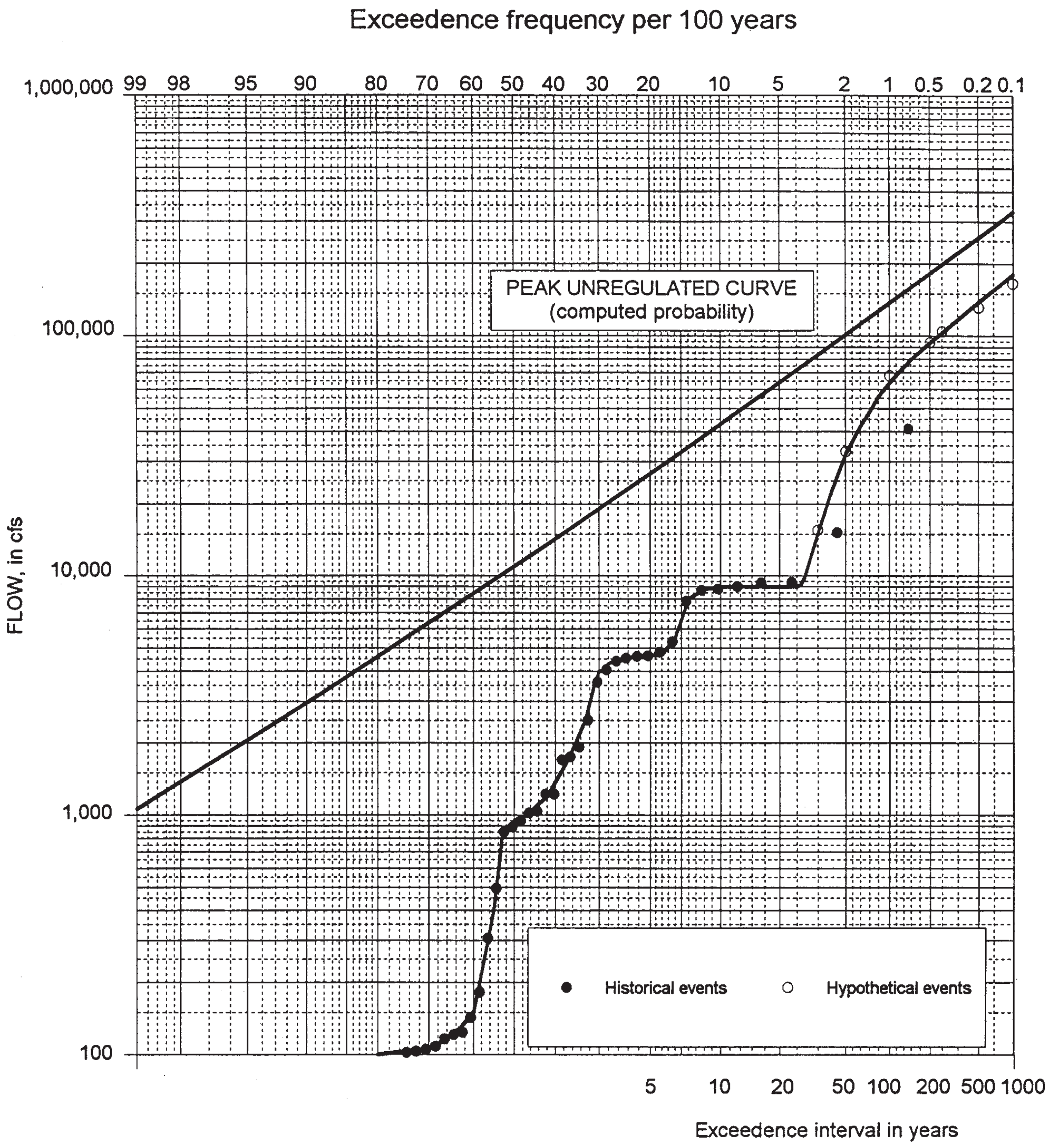
Figure 2-8. ACOE analysis of flood frequency at the San Joaquin River below Friant Dam gaging station (USGS # 11-251000), post-Friant Dam (1949 – 1997). Drainage area = 1,676 mi^2



NOTES:

1. Median Plotting Positions
2. Drainage Area: 1,805 sq. mi.
3. 49 years of record (1949 to 1997)
4. 1997 event plotted as maximum in 94 years.

Prepared by TKP

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
REGULATED CONDITION

SAN JOAQUIN RIVER AT GRAVELLY FORD

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SACRAMENTO DISTRICT

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Figure 2-9: ACOE analysis of flood frequency at the San Joaquin River at Gravelly Ford gaging station (CDEC # GRF), post-Friant Dam (1949 – 1997). Drainage area = 1,805 mi^2

2.6.2.3. San Joaquin River near Newman

The San Joaquin River near Newman gaging station (USGS station # 11-274000) is located at RM 118 and records streamflow data draining the 9,520 mi^2 watershed above the gaging station. At its location on the San Joaquin River, the gaging station is located just downstream of the confluence of the Merced River; therefore, streamflow records include considerable flow contribution by the Merced River, but loses some flow through the Merced River Slough. No attempt was made to subtract the Merced River flow data from the peak flood flow record.

The USGS gaging station near Newman recorded moderately regulated streamflow from 1914 to 1943. Following completion of Friant Dam and associated diversions, streamflow conditions changed. An additional change in hydrology measured at this station may have occurred in 1966 with the completion of New Exchequer Dam on the Merced River. The flood frequency curves for pre- and post-New Exchequer Dam were examined, and there were no significant differences between the two curves. Therefore, flood frequency was computed for the Newman gage by separating the annual peak flow record into two components (Figure 2-10): pre-Friant Dam (1914-1943) and post-Friant Dam (1944-2001). The ACOE analysis produced a rainfall flood frequency curve (Figure 2-11).

Because the computed flood frequency from the Newman gaging record does not solely capture San Joaquin River peak flood flow, the reduction in flood magnitude and frequency at the downstream project boundary is only partially due to Friant Dam and associated diversions. However, by examining the flood frequency curves, a reduction in flood magnitude and frequency is apparent. The post-Friant Dam curve shows a decrease in flood magnitude and frequency for the 1.5- and 2.3-year floods, but then shows a slight increase in flood magnitude and frequency for flood flows between a 5-year and 25-year recurrence, after which the pre-dam and post-dam data appear to converge. Based on this comparison, the flood frequency analysis at the Newman gaging station does not show a definitive trend in reduced magnitude and frequency of larger magnitude flood flows at the downstream end of the study area.

2.6.2.4. Cottonwood Creek near Friant

Cottonwood Creek is a tributary to the San Joaquin River, and joins the San Joaquin River at RM 265, just downstream of Friant Dam. The Cottonwood Creek gaging station was located approximately 0.5 miles upstream of the confluence with the San Joaquin River, and recorded streamflow data from the 35.6 mi^2 watershed above the gaging station. The short period of record (10 years) of USGS data limits the number of peak floods usable for conducting the flood frequency analysis; therefore, the flood frequency analysis for Cottonwood Creek did not extrapolate flood magnitudes for floods larger than the 10-year flood (Figure 2-12). Subsequent data collected by USBR was not used in the analysis.

2.6.2.5. Little Dry Creek near Friant

Similar to Cottonwood Creek, Little Dry Creek is a tributary to the San Joaquin River and joins the River at RM 260.4, approximately 5 miles downstream of Friant Dam. There were two gaging stations on Little Dry Creek, and the downstream-most gaging station was used in this analysis. The downstream-most gaging station was located approximately 4 miles upstream of the confluence with the San Joaquin River, and recorded streamflow data from the 57.9 mi^2 watershed above the gaging station. The period of record of USGS data for this gaging station was short (15 years), so the flood frequency analysis for Little Dry Creek did not extrapolate flood magnitudes for floods larger than the 10-year flood (Figure 2-13). Subsequent data collected by USBR was not used in the analysis.

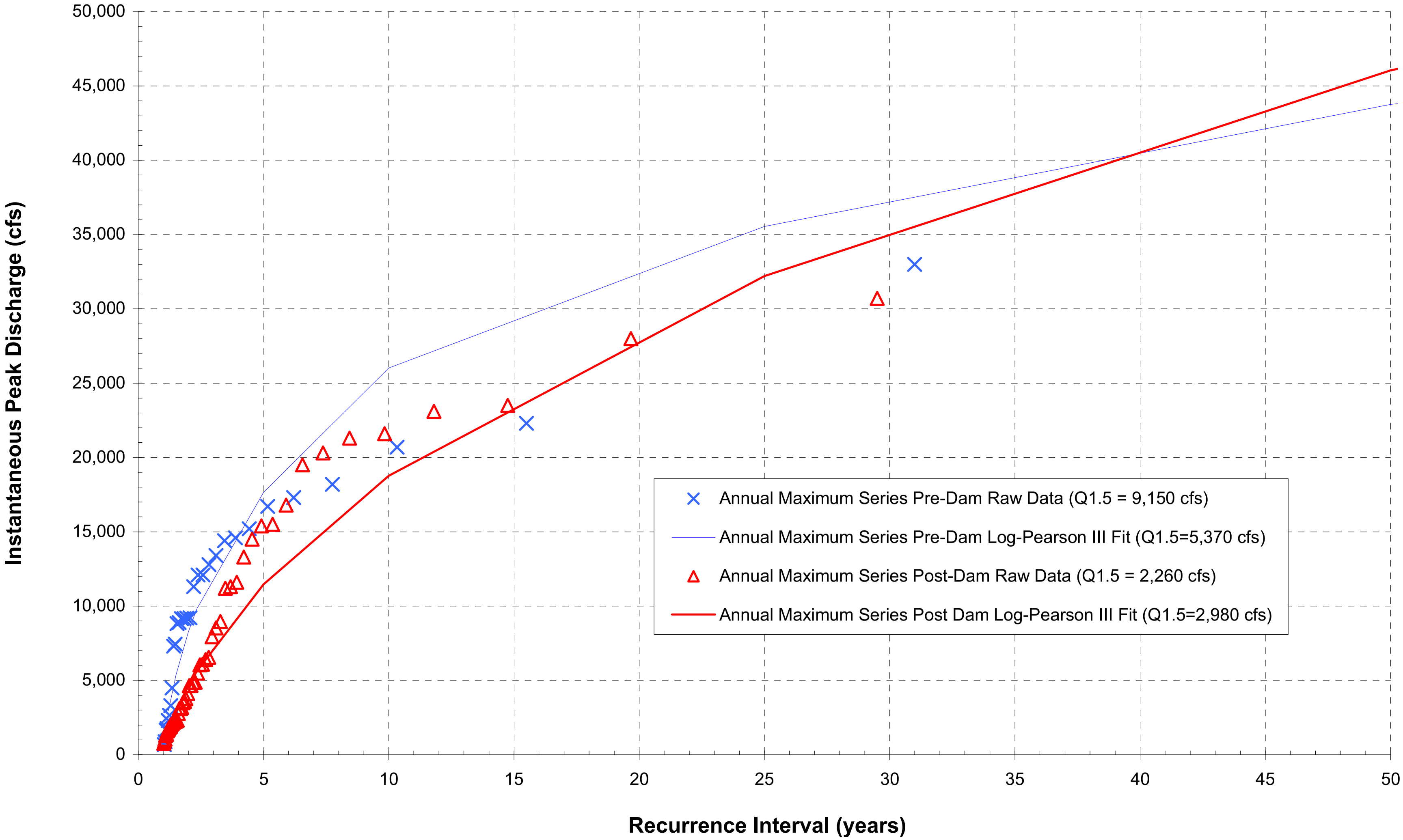
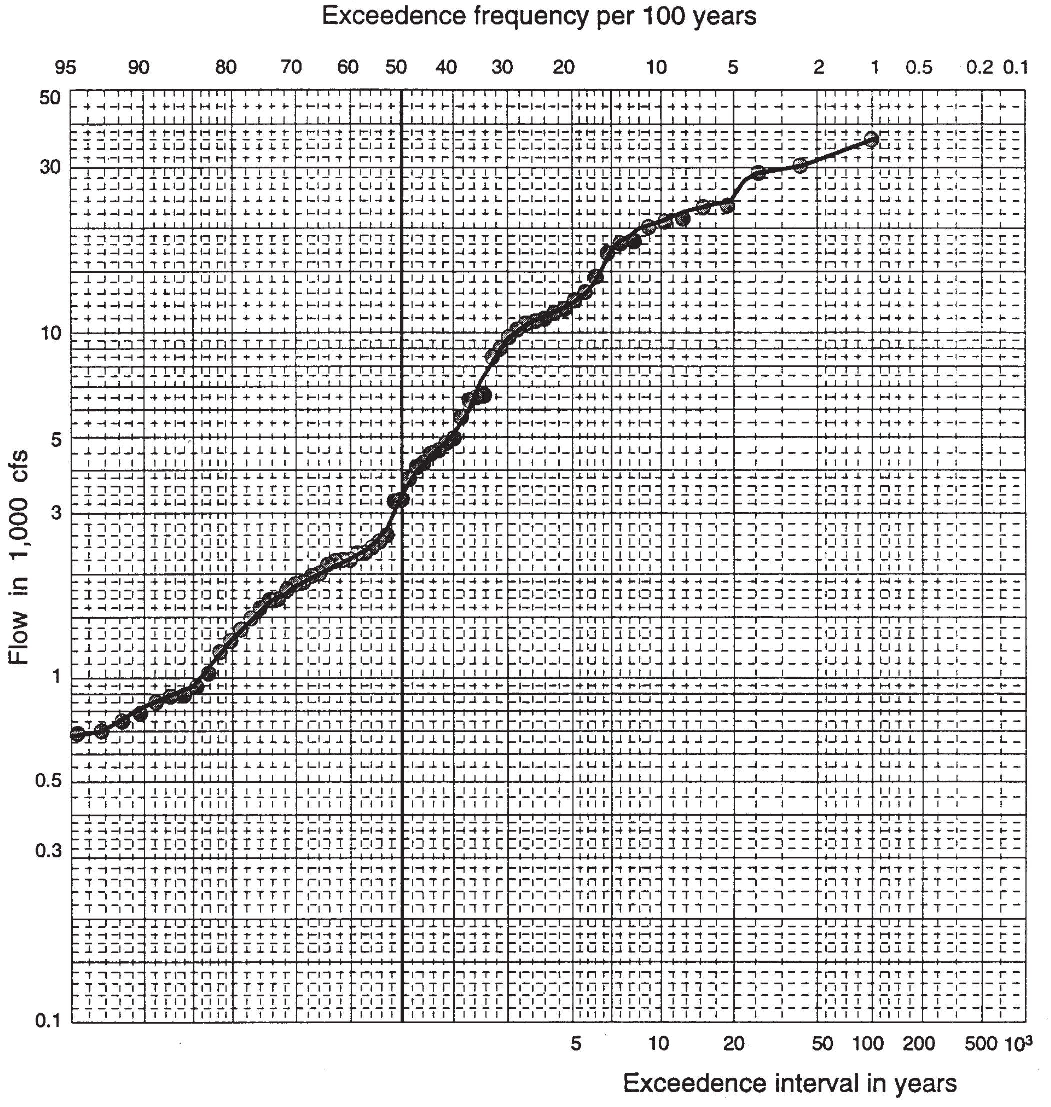


Figure 2-10. Flood frequency at the San Joaquin River near Newman gaging station (USGS # 11-274000) for pre- and post-Friant Dam (pre-dam 1914 – 1943; post-dam 1944 – 2001). Drainage area = 9,520 mi^2.



NOTES:

1. Drainage area is 9,520 sq. mi.
2. Median plotting positions based on 69 years of record (1930-1998)
3. Curve is graphically drawn.
4. Flows before 1975 are simulated.
5. Flows considered at latitude and may include flow out of channel.

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

1-DAY RAIN FLOOD FLOW FREQUENCY CURVE
REGULATED CONDITION
SAN JOAQUIN RIVER NEAR NEWMAN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by JAL

Dec 98

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Figure 2-11. ACOE analysis of flood frequency at the San Joaquin River near Newman gaging station (USGS # 11-274000), post-Friant Dam (1949 – 1997). Drainage area = 9,520 mi^2.

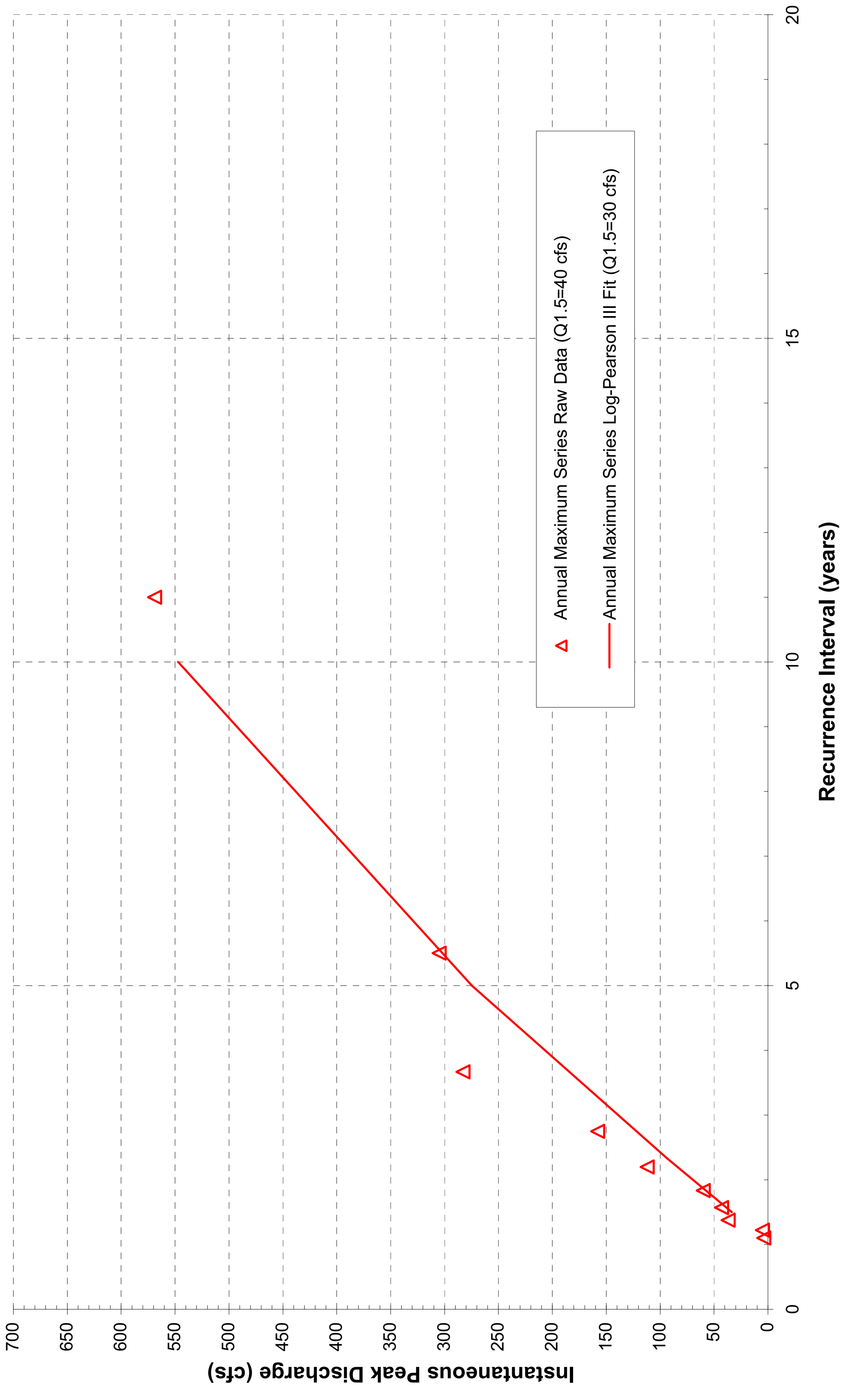


Figure 2-12. Flood frequency at the Cottonwood Creek near Friant gaging station (USGS # 11-250500), 1942 – 1951. Drainage area = 35.6 mi^2.

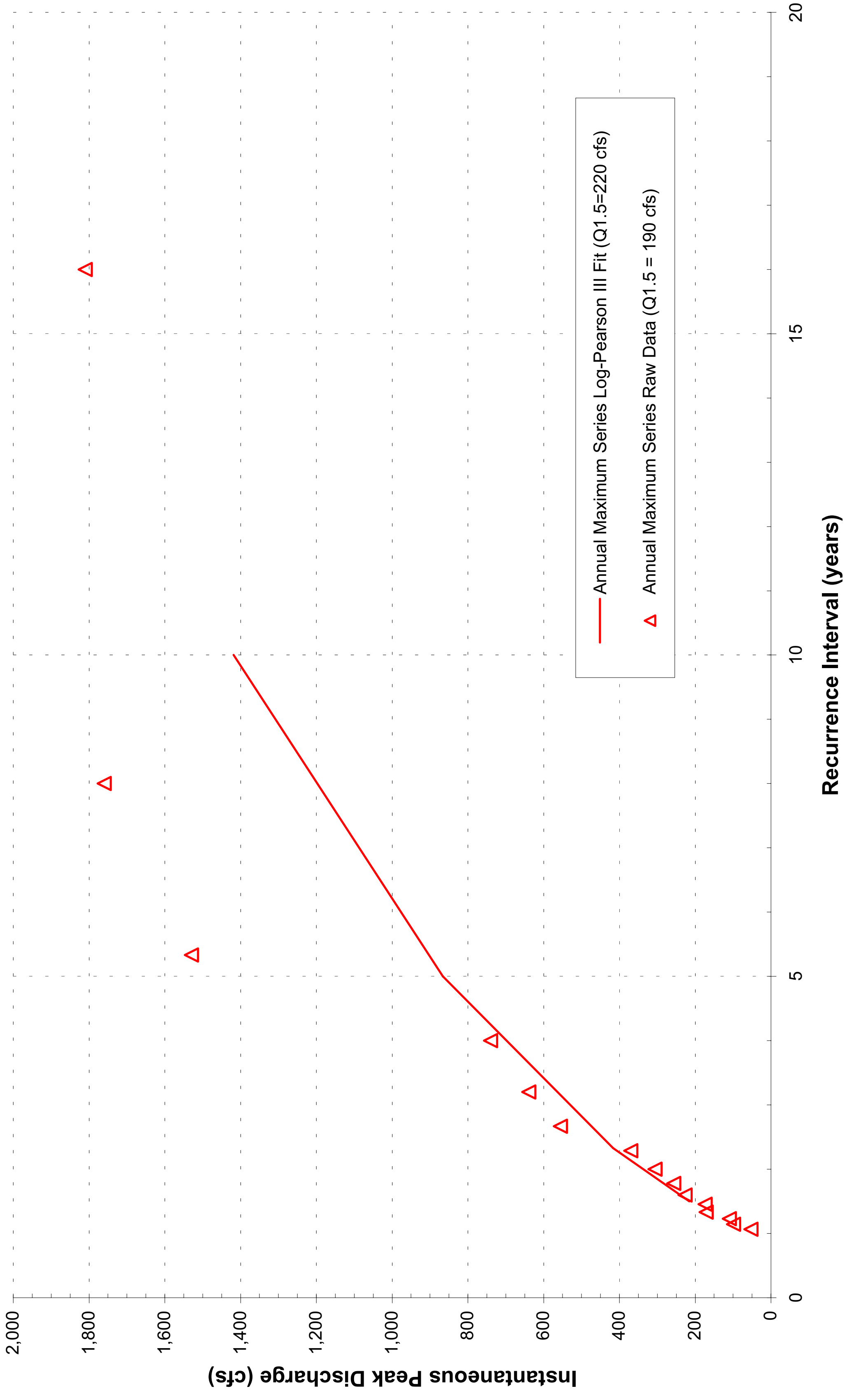


Figure 2-13. Flood frequency at the Little Dry Creek near Friant gaging station (USGS # 11-251500), 1942 – 1956. Drainage area = 57.9 mi^2.

2.6.2.6. James Bypass (Fresno Slough)

The James Bypass diverts flood flows from the Kings River (drains into the Tulare Lake basin south of the San Joaquin River) into the San Joaquin River at Mendota Pool (RM 205). During wetter water years, a considerable volume of flood flows are delivered to the San Joaquin River from the Kings River, where it is diverted at Mendota Pool or Sack Dam, and/or routed through the San Joaquin River flood management system. There are no records for annual instantaneous maximum flows for the period of record (the typical flow measure used in flood frequency analysis); therefore, annual maximum daily average values were used (Figure 2-14). Historical data is not available to quantify or estimate unimpaired flow contribution or seasonality to the San Joaquin River from the Kings River via Fresno Slough, but flow regulation on the Kings River must have significantly decreased the annual volume of flow contributed to the San Joaquin River. Review of recent flow data (1948-present) shows that flows are zero most of the year, with positive flows to the San Joaquin River primarily occurring during flood control releases on the Kings River. It is unknown how much (if any) unimpaired summer baseflows were contributed to the San Joaquin River from the Kings River, but historical accounts (e.g., Derby 1852) discuss Fresno Slough flow contributions over significant portions of the year (winter through the end of the snowmelt runoff season in August).

2.6.2.7. Rivers entering Eastside Bypass

The larger streams entering the San Joaquin River from the Sierra Nevada within the study area include the Fresno River, Chowchilla River, and Bear Creek. The ACOE (1999) developed flood frequency curves for the Fresno River below Hidden Dam (Figure 2-15), Chowchilla River below Buchanan Dam (Figure 2-16), Ash Slough below Chowchilla River (Figure 2-17), Berenda Slough below Chowchilla River (Figure 2-18), and the Eastside Bypass near El Nido (Figure 2-19). All these streams enter the Eastside Bypass system, and do not re-join the San Joaquin River until the Mariposa Bypass outlet (RM 148) or the outlet of the Eastside Bypass (RM 136).

2.6.3. Hydrograph Components

Larger rivers draining the Sierra Nevada have similar unimpaired runoff characteristics over the water years. While the specific timing and magnitude of these runoff events is variable, there are general trends that are broadly predictable in timing and magnitude. These “hydrograph components” include summer baseflows, fall baseflows, fall floods, winter floods, winter baseflows, spring snowmelt peak, and spring/summer snowmelt recession.

The high flow regime of the San Joaquin River is typical of other large Sierra Nevada rivers. There are two distinct periods of high flows: one in the fall/winter from rainfall and rain-on-snow storm events, and one in the spring and early summer during the snowmelt runoff period. The largest flows typically occurred during winter storms; the highest peak flows are produced when warm rains fall on a large snowpack, such as occurred in December-January 1997. The seasonal low flows typically occurred in late summer and fall, after snowmelt had been exhausted and before the onset of winter rains. There is considerable variation in precipitation (and therefore river flows) from year to year, but snowmelt reliably produced moderately high flows most years because of the San Joaquin River drains some of the highest elevation terrain in the Sierra Nevada. These unique unimpaired runoff characteristics of the San Joaquin River had significant implications to channel form and processes, as well as the life history and ecological connections among the biota that resided in the San Joaquin River corridor (see Section 2.6.4).

Typical unimpaired hydrograph components are described below, illustrated with a pre-Friant Dam hydrograph from the San Joaquin River at Friant (Figure 2-20).

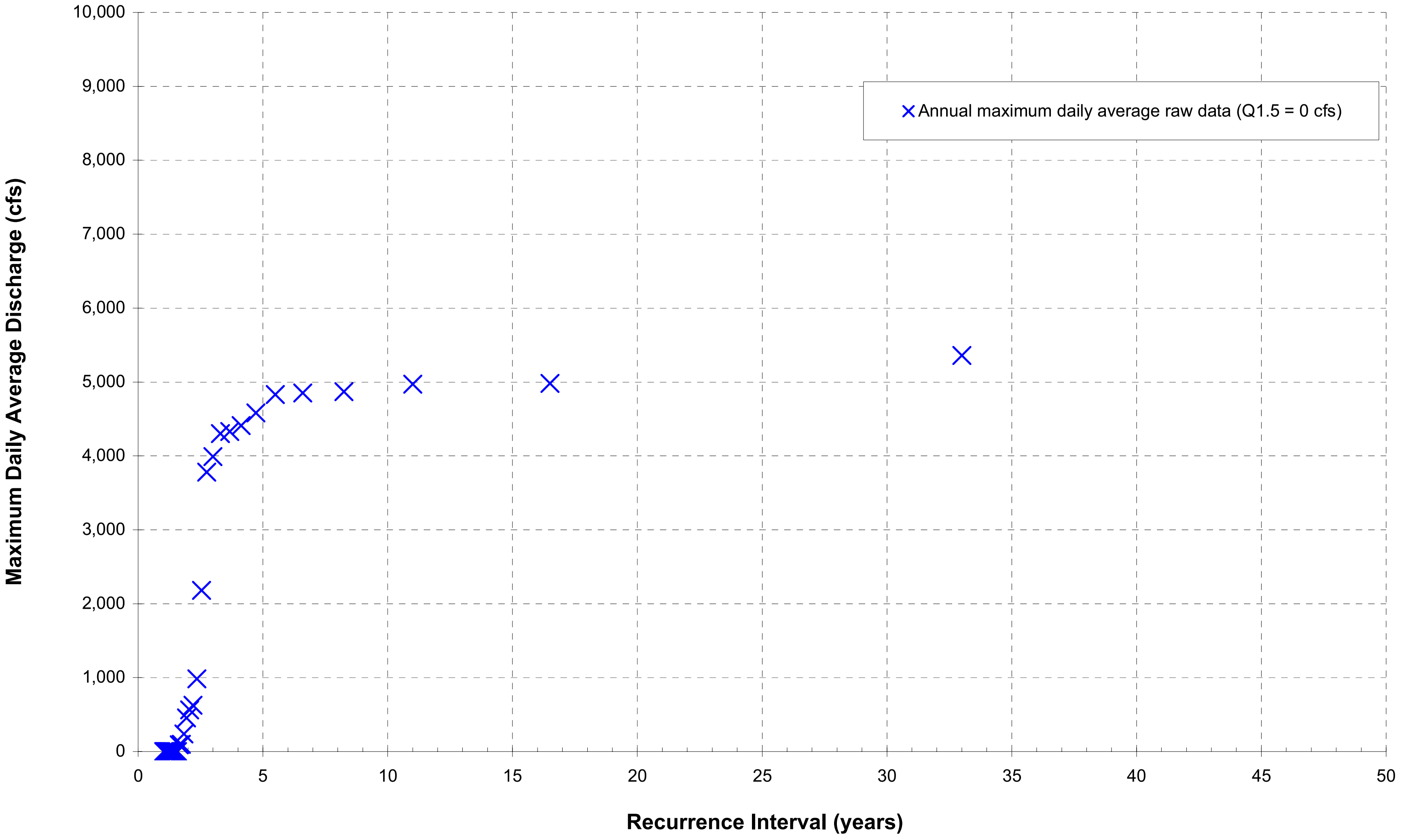
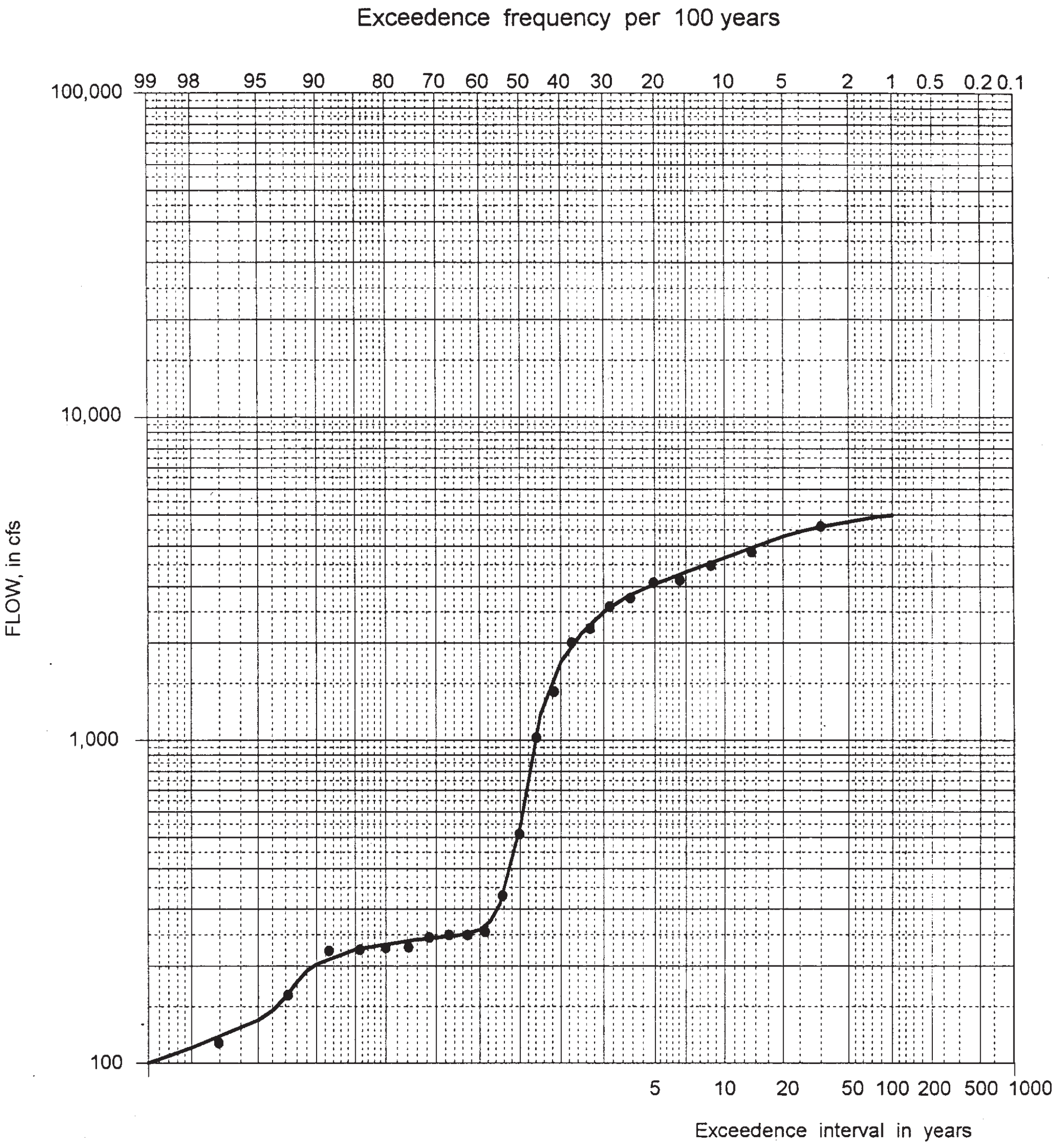


Figure 2-14. Flood frequency at the James Bypass (Fresno Slough) near San Joaquin CA gaging station (USGS # 11-253500), 1948-1954, 1974-2001. No annual instantaneous peak flows published, so flood frequency based on raw data of maximum daily average flows.



NOTES:

1. Median Plotting Positions
2. Drainage Area: 234 sq. mi.
3. 23 years of record (1976 to 1998)

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
REGULATED CONDITION
FRESNO RIVER BELOW HIDDEN DAM

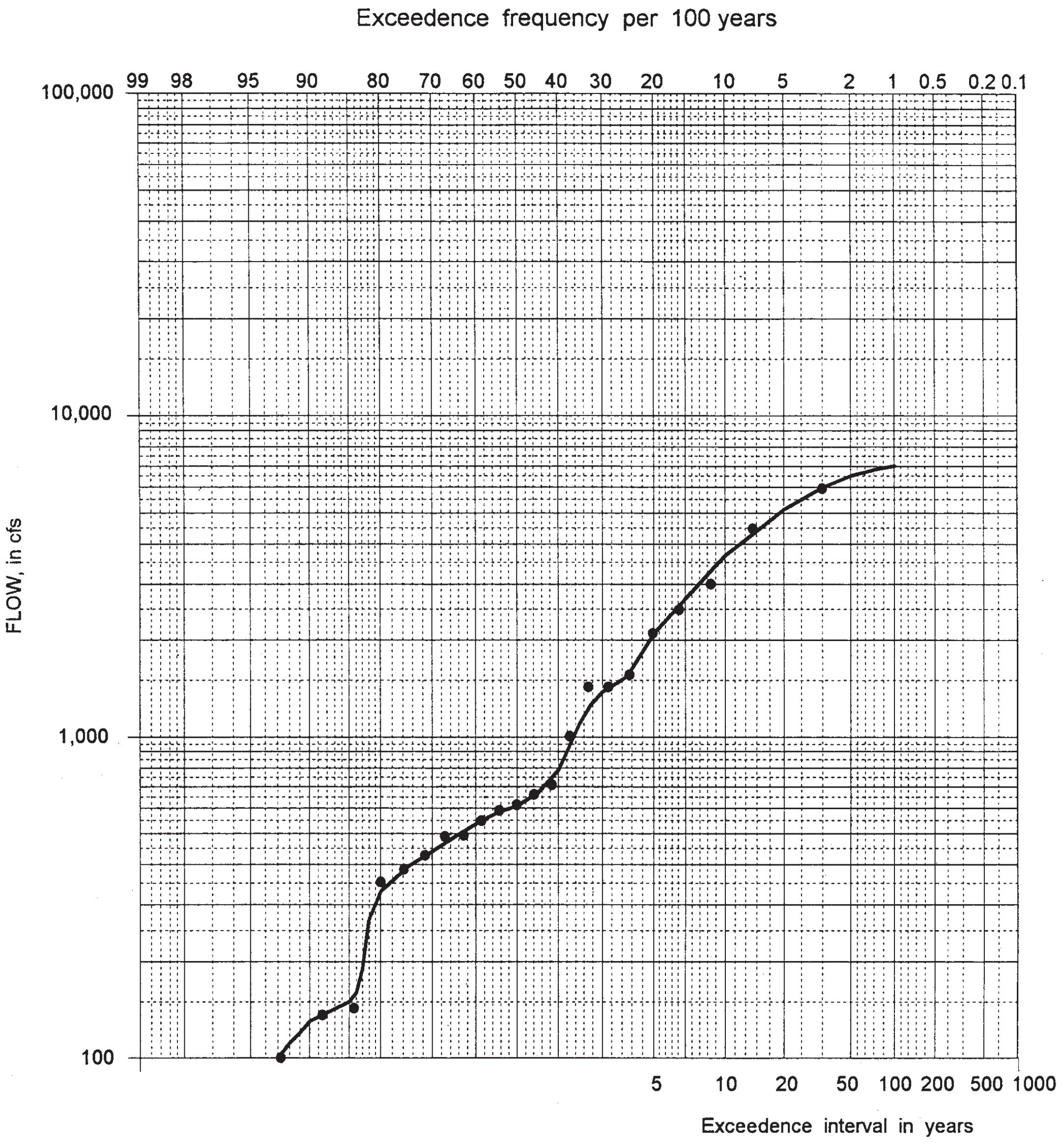
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by JTH

Nov 98

PLATE 20

Figure 2-15. ACOE analysis of peak rain flood frequency at the Fresno River below Hidden Dam gaging station (USGS # 11-258000), post-dam (1976 – 1998). Drainage area = 234 mi^2.



NOTES:

1. Median Plotting Positions
2. Drainage Area: 235 sq. mi.
3. 23 years of record (1976 to 1998)

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
REGULATED CONDITION
CHOWCHILLA RIVER BELOW BUCHANAN DAM

Prepared by JTH

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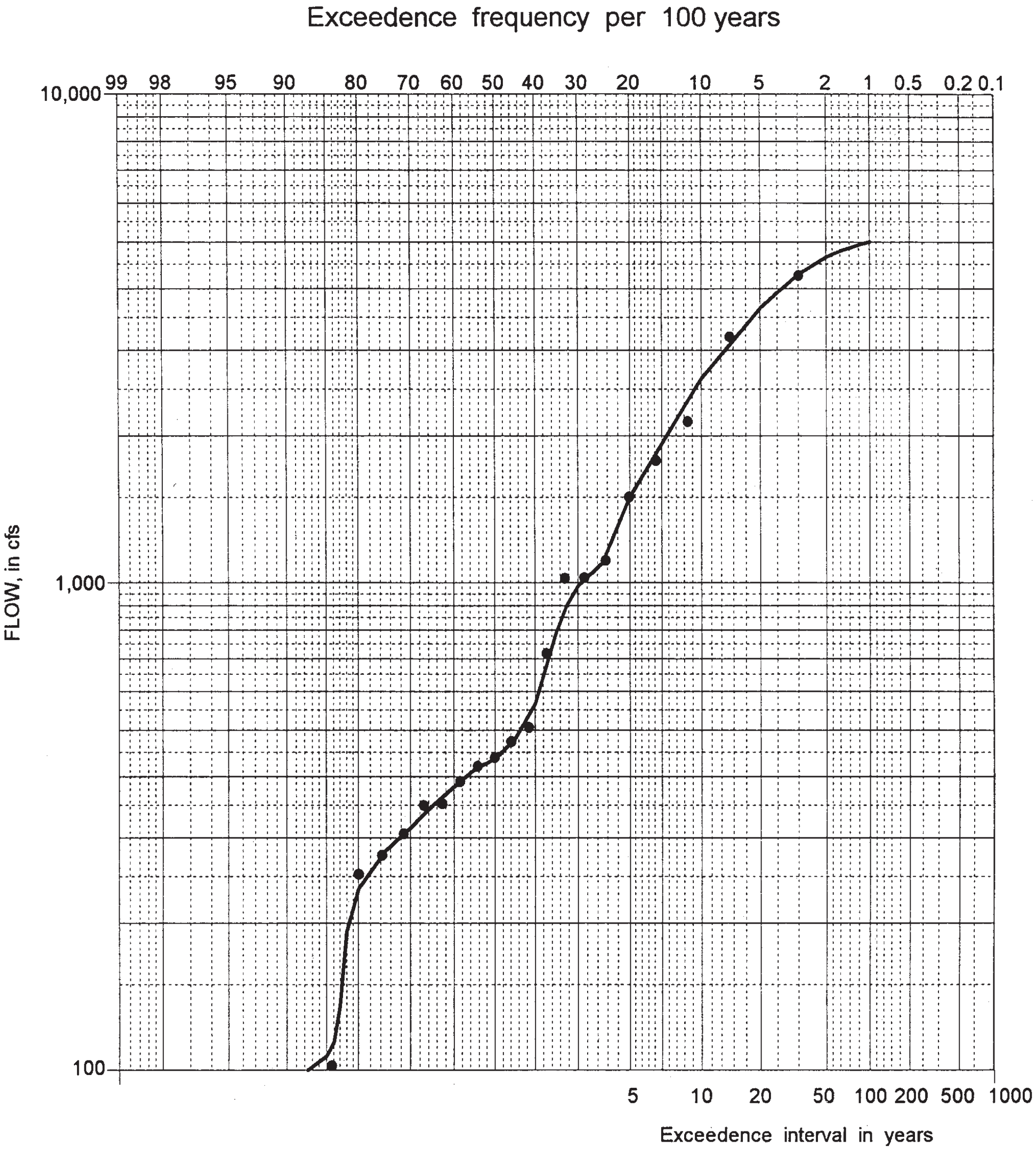
Figure 2-16. ACOE analysis of peak rain flood frequency at the Chowchilla River below Buchanan Dam gaging station (USGS # 11-259000), post-dam (1976 – 1998). Drainage area = 235 mi^2.



NOTES:
1. Median Plotting Positions
2. Drainage Area: 268 sq. mi.
3. 23 years of record (1976 to 1998)
4. Ash Slough is assumed to transport 71 percent of Chowchilla River peak flows.

Prepared by JTH

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
REGULATED CONDITION
ASH SLOUGH
BELOW CHOWCHILLA RIVER

U.S. ARMY CORPS OF ENGINEERS
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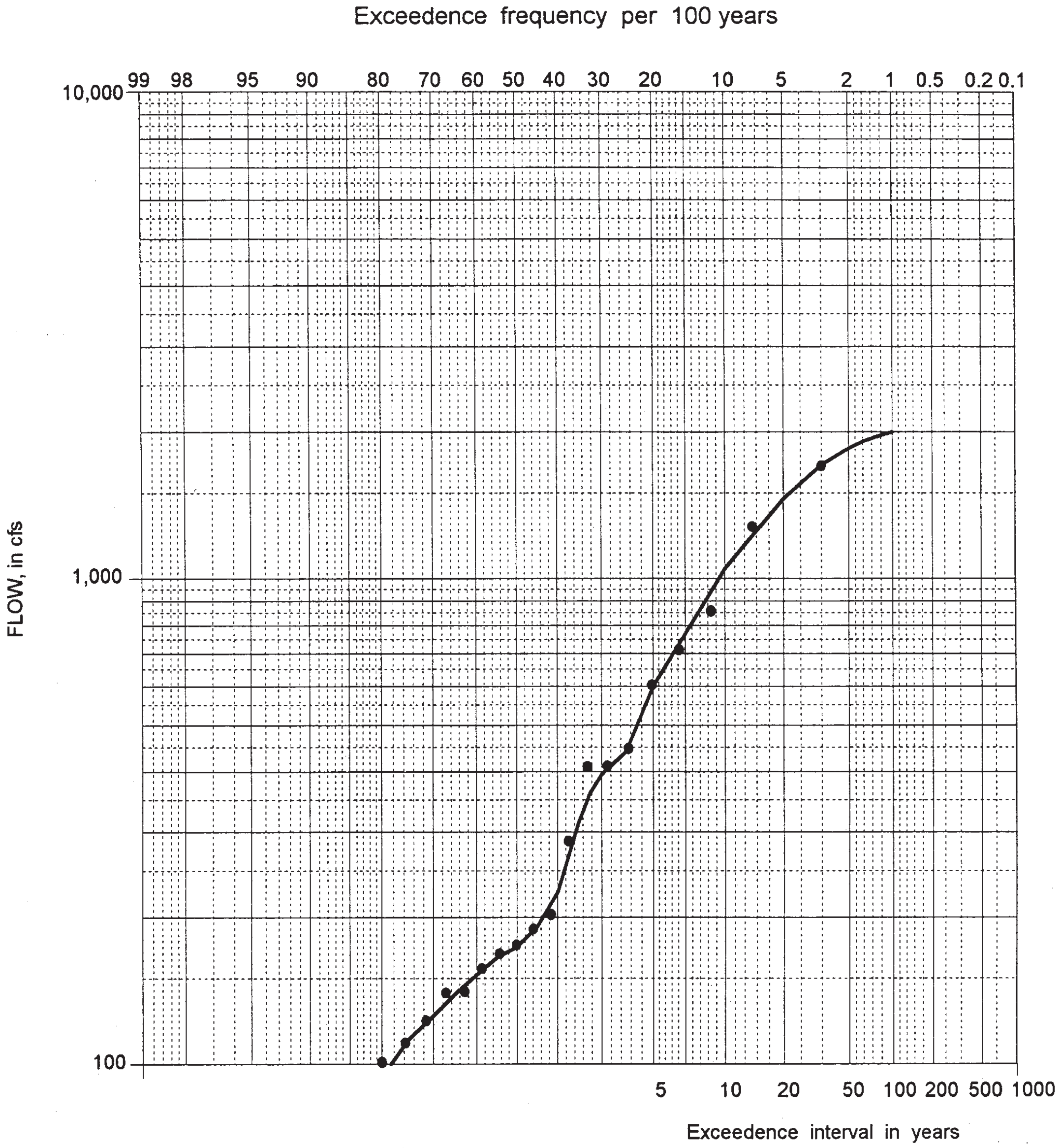
PLATE 22

Figure 2-17. ACOE analysis of peak rain flood frequency at the Ash Slough below Chowchilla River, post-dam (1976 – 1998). Drainage area = 268 mi^2.



NOTES:

1. Median Plotting Positions
2. Drainage Area: 268 sq. mi.
3. 23 years of record (1976 to 1998)
4. Berenda Slough is assumed to transport 29 percent of Chowcilla River peak flows.

Prepared by JTH

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
REGULATED CONDITION
BERENDA SLOUGH
BELOW CHOWCHILLA RIVER

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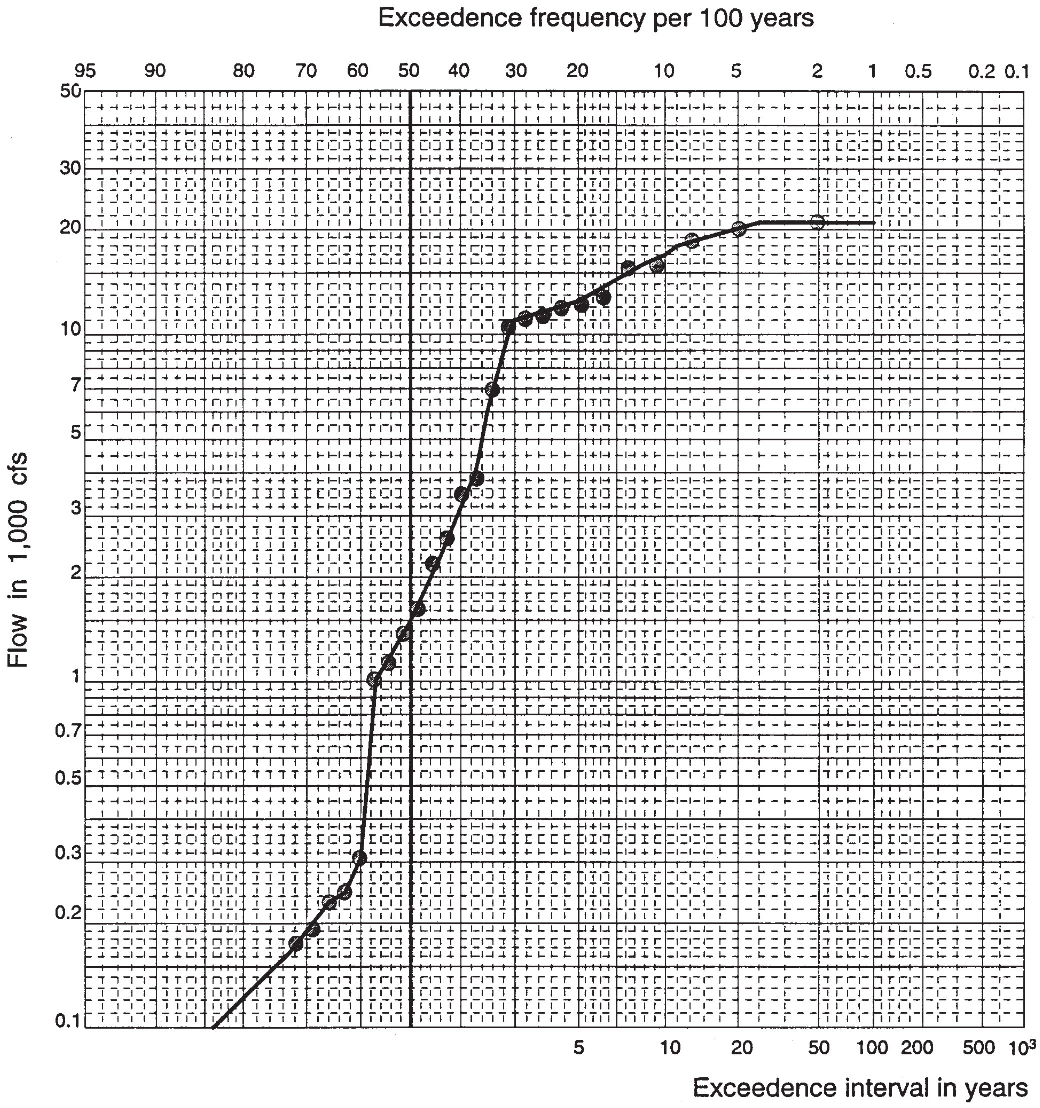
PLATE 23

Figure 2-18. ACOE analysis of peak rain flood frequency at the Berenda Slough below Chowchilla River, post-dam (1976 – 1998). Drainage area = 268 mi^2.



NOTES:

1. Drainage Area is 5,630 sq. mi.
2. Median plotting positions based on 34 years of record (1965-1998).
3. Curve is graphically drawn.
4. Flows before 1976 are simulated.
5. Does not include flow in San Joaquin River.

Prepared by JAL

SACRAMENTO-SAN JOAQUIN BASIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

1-DAY RAIN FLOOD FLOW FREQUENCY CURVE
REGULATED CONDITION
EASTSIDE BYPASS NR EL NIDO

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

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PLATE 24

Figure 2-19. ACOE analysis of peak rain flood frequency at the Eastside Bypass near El Nido gaging station (CDEC # "ELN"), post-dam (1965 – 1998). Drainage area = 5,630 mi^2.

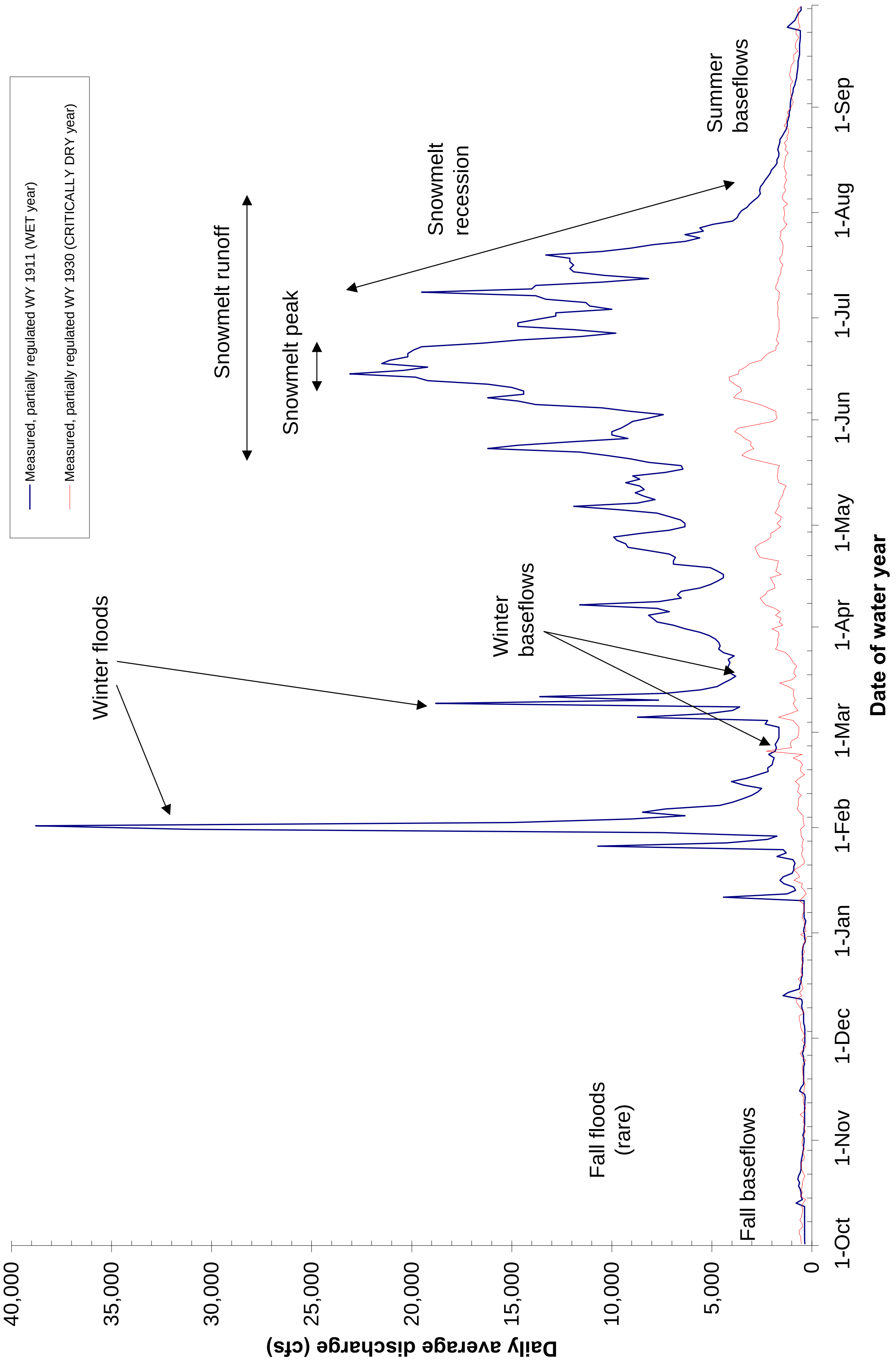

Figure 2-20. Illustration of hydrograph components of the San Joaquin River at Friant for an Extremely Wet water year (1911) and a Critically Dry water year (1930).

2.6.3.1. Summer-Fall Baseflow

Annual low flows occur after the snowmelt recession limb, and occur during the summer-fall baseflow hydrograph component (Figure 2-20). Summer-fall baseflows are derived from the slow drainage of water remaining in hillslopes, stored in riverbanks and floodplains along alluvial reaches (having been recharged by high winter floods), by springs in the Sierra Nevada mountains, and possibly also by artesian springs in the San Joaquin Valley (see Chapter 4). Summer-fall baseflows are neither the same throughout the summer-fall period, nor the same year after year. Summer-fall baseflows decline slowly such that changes in stage would typically not be noticeable to the casual observer on a daily basis, but may be noticeable on a weekly basis (e.g., Figure 2-20). Streams with substantial springs had much larger and more stable summer-fall baseflows, and the lower reaches of the San Joaquin River may have had substantial baseflow contributions from artesian springs and contribution from the shallow groundwater aquifer. Summer-fall baseflows occur from at least August through October (or until the first significant runoff-producing storm of the wet season). In wetter years such as 1911, the seasonal recession limb may continue well into the summer, while on a dry year (such as 1930), the spring snowmelt runoff may end by late-spring (Figure 2-20).

2.6.3.2. Winter Season Floods

Higher flood flows are produced by direct runoff from rainfall, especially when tropical storms drop rain at higher elevations in the watershed on a pre-existing snowpack (‘rain-on-snow’ floods). Peak flows from rainfall and rain-on-snow floods are typically sharply peaked, with rapid rising limbs and slightly slower but still rapidly falling recessional limbs (Figure 2-20). The ‘rain-on-snow’ events have been responsible for the largest historical floods, such as the 1862 flood and the recent flood of January 1997. Winter-spring peak flows tend to be larger for wetter years and smaller for drier years (Figure 2-20).

2.6.3.3. Winter Baseflows

Between winter-spring peak storm events, flow will tend to drop back to a baseflow level, but to a baseflow that is considerably higher than the summer-fall baseflow, and more variable in magnitude through the winter baseflow period (Figure 2-20). The degree to which baseflow recedes between winter storm runoff events depends on the time between storms, the magnitude of those storms, antecedent moisture conditions in the watershed, and watershed runoff characteristics. Wetter water years tend to have more winter storms, such that the baseflow periods between storm events are shorter than drier years (Figure 2-20).

2.6.3.4. Snowmelt Peak Flows

These were high flows occurring during spring and early summer as temperatures increased and the snowpack melted. With the potential exception of extreme drought years, the San Joaquin River had snowmelt peak flows. The USGS gaging station at Friant shows that peak flows for at least half of the years were generated by spring snowmelt runoff, as illustrated by the plot of annual peak discharge against day of the year prior to construction of Friant Dam (Figure 2-7). These were years that lacked a large, warm, runoff-producing winter storms that typically exceed snowmelt peak flows, especially when rain-on-snow events occurred.

Snowmelt runoff can be viewed as a seasonal high flow, driven by heating and melting of snow, with smaller peaks (reflecting warm periods) superimposed on a seasonal rise and fall, as illustrated by the example pre-Friant Dam hydrograph (Figure 2-20). The peaks typically have a moderate rise (over a few days) and less abrupt decline. Dates and length of peak snowmelt runoff would vary among years as a function of precipitation patterns, precipitation volumes, and runoff patterns, but also from year-to-year variation in that particular year's snowpack and the weather in the spring and early summer. In dry years, the (small) snowmelt peaks occurred earlier (typically May) and were shorter, in wet years the peaks were later (typically June) and longer. The snowmelt peak period often had multiple peaks fairly close in magnitude.

2.6.3.5. Snowmelt Recession Limb

The snowmelt recession limb in snowmelt stream is caused by a gradual depletion of melting snowpack. Under unimpaired conditions, this hydrograph component was typified by a gradual decline in flow in years without early summer rains or other abrupt changes in ambient air temperature. Snowmelt was important for slowing the recession of flows into the summer low flow season. In snowmelt-dominated streams (Figure 2-20), the snowmelt recession limb is not a constant decline, but contains frequent but small rises and falls due to changes in ambient air temperature and/or late-spring thunderstorms.

2.6.4. Geomorphic, Riparian, and Fishery Linkages to Hydrograph Components

As discussed earlier, hydrologists often describe the intra-annual flow regime using average values, such as mean monthly flows. However, most geomorphic and ecological processes are dependent upon flows on a much smaller time scale, such as days or hours. Plotting daily average flows for each water year generates the average annual hydrograph, and this daily time-step usually provides enough flow detail to relate to geomorphic and ecological processes (Appendix A). A hydrograph component analysis of the unimpaired annual hydrographs is very useful to describe intra-annual flow variability, and when overlain with the life-history of key biota, provides the foundation for hypotheses and conceptual models for (1) how these species evolved and adapted to best survive under the unimpaired flow regime, and (2) how changes to the unimpaired flow regime through watershed development (e.g., flow regulation, river engineering) have impacted these species.

2.6.4.1. Summer-Fall Baseflows

Although summer baseflows are not large enough to exceed geomorphic process thresholds, they are important for riparian and fishery purposes. Historically, summer baseflows provided year-round habitat for native fish assemblages in the watershed upstream of Friant Dam (Table 2-4). Historic water temperatures downstream of Friant Dam were likely too high to support year-round rearing of juvenile salmonids or adult spring-run Chinook salmon (see Chapter 6), with the exception of the potential occurrence of artesian springs that may have provided local cold-water refugia. However, during fall baseflows beginning mid to late October, historic ambient air temperatures and corresponding water temperatures cooled, allowing fall-run Chinook salmon to migrate upstream during these low flows. Unimpaired fall baseflows ranged between 200 cfs and 400 cfs, providing sufficient flows to allow adult migration. The unimpaired shallow groundwater table was assumed to be increasing flows in the San Joaquin River in most reaches (see Chapter 4), such that established riparian vegetation was supported by both baseflows in the river and the shallow groundwater table. Under current conditions, the overdrafted groundwater table makes future summer baseflows very important for maintaining the shallow groundwater table and associated riparian vegetation.

2.6.4.2. Fall and Winter Floods

Fall and winter floods are nearly all rainfall or rain-on-snow generated events. While fall baseflows likely provided adequate passage flows for upstream adult Chinook salmon migration, the first fall storms may have improved passage by increasing water depths, lowering water temperatures, and providing a physiological queue for adult salmon to begin their upstream migration (Table 2-4). Perhaps the most important function of the fall and winter flood events was geomorphic work along the floodway. These floods were larger magnitude and thus initiated larger scale geomorphic processes (channel migration, channel avulsion, bar creation, bed scour, floodplain creation) than other hydrograph components (Table 2-4). Habitat was created and maintained by these floods. Riparian vegetation benefited by these floods as geomorphic surfaces and seedbeds were created (fine sediment deposited on floodplains, scour channels created on floodplains, meander cutoff, and oxbow creation).

2.6.4.3. Winter Baseflows

Between winter storms, flow tends to recede back to a baseflow level, but one that is considerably higher than the late summer-fall baseflow, and one that varies more day-to-day compared to summer-fall baseflows. Slow draining of the shallow groundwater table largely supports this baseflow, and because it is always higher magnitude than summer baseflows, it is important for allowing upstream migration of winter-run steelhead and juvenile rearing for all salmonid species (Table 2-4). Because of the low magnitude of winter baseflows, sand transport would have been the only geomorphic processes potentially provided by winter baseflows.

2.6.4.4. Snowmelt Runoff Peak

The timing of the snowmelt runoff peak coincided with important life history stages of several key species, and the longer duration of these flows compared to fall and winter floods provided important functions to several species. Spring-run and fall-run Chinook salmon smolts tended to outmigrate during this time; the increasing flows likely provided a behavioral queue for smolt outmigration, and the large magnitude of cold snowmelt runoff likely provided adequate water temperatures for successful outmigration in most years. The snowmelt peak in wetter years provided long-duration periods of overbank flow, which provided high quality rearing habitat for juvenile salmonids and other native species within the “deep-bodied fishes assemblage” (e.g., delta smelt, splittail per Moyle 2002) that inhabit aquatic habitats along the valley floor. The snowmelt runoff peak was often large enough to initiate some larger scale geomorphic processes (e.g., bed mobility, channel migration), while in drier years, the smaller snowmelt peak may only have transported sand (Table 2-4). The timing of the snowmelt runoff peak often corresponded to the peak of key riparian species seed distribution (e.g., Fremont cottonwood, black willow), such that the snowmelt runoff peak facilitated seed germination and seedling growth. During wetter years with larger peak flows, riparian vegetation also benefited by overbank flows, fine sediment deposition on floodplains, weed removal on floodplains, and seedbed creation.

Table 2-4. General hypothesized relationships between hydrograph components and ecosystem processes for the San Joaquin River.

Hydrograph component	**Geomorphic-hydrologic processes**	**Riparian processes**	**Salmonid life-history processes**
Summer-fall baseflows		Encourages late seeding riparian vegetation initiation and establishment within bankfull channel	Water temperature for over-summering salmonid juveniles and spring-run Chinook salmon adults, immigration for fall-run Chinook salmon adults
Fall and winter floods	Wetter years: channel avulsion, significant channel migration, bed scour and deposition, bed mobility, floodplain scour, floodplain inundation, fine sediment deposition on floodplains, large woody debris recruitment Normal years: Some channel migration, minor bed scour, bed mobility, floodplain inundation and fine sediment deposition	Wetter years: mature riparian removal within bankfull channel and portions of floodplain, scour of seedlings within bankfull channel, seedbed creation on floodplains for new cohort initiation, microtopography from floodplain scour and fine sediment deposition Normal years: scour of seedlings within bankfull channel, some fine sediment deposition on floodplains	Wetter years: partial loss of salmon cohort due to redd scour or entombment from deposition, improve spawning gravel quality by scouring/redepositing bed and transporting fine sediment, mortality by flushing fry and juveniles, mortality by stranding fry and juveniles on floodplains, reduce growth during periods of high turbidity, reduce predation during periods of high turbidity, creation and maintenance of high quality aquatic habitat Normal years: improve spawning gravel quality by mobilizing bed and transporting fine sediment, low mortality by flushing fry and juveniles, low mortality by stranding fry and juveniles on floodplains, reduce growth during periods of high turbidity, reduce predation during periods of high turbidity, maintenance of high quality aquatic habitat
Winter baseflows	Fine sediment transport		Increase habitat area in natural channel morphology, migration flows for winter-run steelhead
Snowmelt peak	Wetter years: bed mobility, long duration floodplain inundation, moderate channel migration, groundwater recharge Normal years: bed mobility, short duration floodplain inundation	Wetter years: riparian seedling scour within bankfull channel, riparian seedling initiation on floodplains, discourages riparian seedling initiation within bankfull channel Normal years: periodic riparian seedling initiation on floodplains	Wetter years: Increase juvenile salmonid growth rates by long-term floodplain inundation, increase stranding by inundating floodplains, stimulate smolt outmigration, reduce predation mortality by reducing smolt density and increasing turbidity Normal years: Increase juvenile growth rates by short-term floodplain inundation, increase stranding by short-term floodplain inundation, stimulate outmigration, reduce predation mortality by reducing smolt density and increasing turbidity Drier years: Increase smolt outmigration predation mortality by increasing density and reducing turbidity
Snowmelt recession	Gradual decrease in water stage, maintain floodplain soil moisture	Wetter years: Allow riparian seedling establishment on floodplains Normal and drier years: Discourages riparian seedling establishment on floodplains by desiccating them, encourage seedling establishment within bankfull channel	Wetter years: Increase smolt outmigration success by reducing water temperatures and extending outmigration period Normal years: Increase smolt outmigration success by reducing water temperatures and extending outmigration period Drier years: Increase smolt outmigration mortality by increasing water temperatures and shortening outmigration period

2.6.4.5. Snowmelt Recession Limb

As the water stage falls during the recession limb, it leaves behind moist, bare, mineral surfaces on point bars and other channel and floodplain surfaces on which seedlings of riparian plants can potentially establish (depending on timing of the recession limb relative to timing and mode of seed dispersal for different species). The rate of stage decline during this recession limb is also an important hydrologic variable, because if the water table in the gravel bar drops faster than the seedlings can extend their roots downward, they will not survive the summer and fall. This effect has been documented for cottonwoods in the Rocky Mountain region (e.g., Mahoney and Rood 1998). Presumably, similar controls exist along the San Joaquin River. Fall-run Chinook salmon smolts outmigrate during this period, while adult spring-run Chinook immigrate during this period.

2.6.5. Significance of Inter-Annual Flow Variations

The volume and pattern of runoff from the San Joaquin River varies widely between years (Figure 2-5); segregating annual hydrographs by water year classes is a useful tool to identify trends between years. Assessing this inter-annual variability can develop initial hypotheses for important ecosystem processes. For example, comparing annual water yield with recruitment success of Fremont cottonwood and narrow-leaf willow may illustrate that the cottonwood is more successful during wet years, and the narrow-leaf willow is more successful during drought years. From this casual observation, we can then change temporal scales by developing more focused hypotheses on what parts of wet or dry years cause this to occur. This example is expanded a bit below, discussing the role of wetter and drier water years to geomorphic processes, cottonwood regeneration and survival, and Chinook salmon life-history (Table 2-5).

2.6.5.1. Wetter Water Years

Wetter water years tend to have larger floods, larger snowmelt runoff peaks, later snowmelt peaks, longer snowmelt recession, and higher baseflows. Because of these higher flood flows, the larger scales of geomorphic work (channel avulsion, large sediment fluxes, etc.) tend to occur during wetter years. Cottonwood recruitment may also tend to occur during wetter water years because (1) high flood flows clear a space on floodplains for seeds to land and germinate, and (2) the long duration snowmelt hydrograph keeps the substrate wet where the seeds germinate and grow, thus enabling establishment and maturation. By overlaying cottonwood seed phenology over annual hydrographs, we find that cottonwoods tend to disperse their seeds during the snowmelt recession limb, and because wetter years have larger snowmelt runoff flows, the cottonwood seedlings tend to initiate on floodplains rather than in the low flow channel (because the low flow channel is underwater during seed dispersal, germination cannot occur there). Lastly, wetter water years may also tend to provide longer and colder flows during the Chinook salmon smolt outmigration period, increasing their outmigration success and overall productivity.

2.6.5.2. Drier Water Years

Drier water years tend to have smaller floods, smaller snowmelt runoff peaks, earlier snowmelt runoff peaks, shorter snowmelt recession, and smaller baseflows. Typically, the drier the water year, the less geomorphic work is accomplished by flows during that year. Flows during some dry years are insufficient to accomplish any significant geomorphic work. Riparian seedlings (particularly narrow-leaf willow) may tend to initiate along the summer baseflow channel margins because flows are lower during their seed dispersal period. These seedlings would normally be scoured away by the first high flows of a wetter year. However, sequences of drier water years may allow these seedlings and those

Table 2-5. Hypothesized relationships between water year classes and ecosystem processes for gravel-bed streams. Only three water year classes chosen to better illustrate the differences between water years.

Water year	**Hydrologic processes**	**Geomorphic processes**	**Ecological processes**
Extremely Wet	Large winter floods (much larger than bankfull), large snowmelt runoff peak (larger than bankfull), long duration snowmelt runoff that occurs later in season (June), higher summer and winter baseflows, lower water temperatures	Channel avulsion, channel migration, high bedload transport rates, bed scour, floodplain scour, prolonged floodplain inundation, large amount of fine sediment deposition on floodplains, new alluvial deposits formed	Scours seedlings along low flow channel margin, mature riparian vegetation removal, woody debris recruitment, recruit successful cottonwood cohort, greater migrational access to upstream habitat, salmonid redd scour/burial, high juvenile salmonid growth rates on floodplains, low salmonid outmigration mortality
Normal	Moderate winter floods (near or exceeds bankfull), moderate snowmelt runoff peak (smaller than bankfull), moderate summer and winter baseflows	Initiate channel migration, initiate bedload transport, short-term floodplain inundation, small amount of fine sediment deposition, alluvial deposits mobilized	Scours seedlings along low flow channel margin, minor woody debris recruitment, moderate salmonid migrational access to upstream habitat, low salmonid outmigration mortality
Critically Dry	Small winter floods (much below bankfull), minor snowmelt runoff peak, short duration snowmelt runoff that occurs early in season (April), higher water temperatures	No channel migration, some sand transported as bedload, no gravel transport, alluvial deposits not mobilized	Riparian vegetation initiates lower in channel, no riparian scour along channel margin, low salmonid migrational access to upstream habitat, moderate water temperature induced stress and mortality to salmonids, moderate salmonid outmigration mortality

of other more invasive species to mature, leading to riparian encroachment if a large flood does not soon follow to remove the encroaching vegetation.

In dry years, the (small) snowmelt peaks occurred earlier (typically May) and were shorter; in wet years the peaks were later (typically June) and longer. Many young salmon smolts would migrate seaward during these snowmelt flows, taking advantage of the strong downstream currents, cold temperatures, and turbidity (which made them less visible to predators). Similarly, spring-run Chinook salmon and other species migrated upstream as adults during this time period, taking advantage of predictable high flows to navigate shallow sections and otherwise difficult passage conditions. The impact of drier water years on Chinook salmon production may be variable; lower flood flows during egg incubation periods would reduce mortality caused by bed scour; however, lower flows during smolt outmigration increase temperature stress and predation as the smolts migrate down the San Joaquin River to the delta.

2.6.6. Hydrograph Component Analysis

The hydrograph component analysis focused on two USGS gages along the San Joaquin River corridor with lengthy periods of record available prior to, and after, construction of Friant Dam – the San Joaquin River below Friant (USGS 11-251000), and the San Joaquin River near Newman (USGS 11-274000) (Table 2-6). The Friant gage is ideally located at the upstream end of the study reach. Unimpaired daily average flows for the Friant gage is estimated (computed unimpaired) for the 1896-1951period from a model developed by former ACOE hydrologist Huxley Madeheim, using flow data from the Kings River at Piedra (USGS 11-222000); from water years 1952 to 1999 the unimpaired flows are computed by the USBR using actual flow data from the San Joaquin River and adjusting it for upstream storage changes and diversions. It is important to note that reservoir storage began upstream of Friant Dam in 1910, such that flow data measured prior to Friant Dam at the San Joaquin River at Friant gaging station does not represent unimpaired conditions, but rather minor impairment conditions (Table 2-2). This is one of several reasons why the hydrograph component analysis uses computed unimpaired flow data at Friant rather than USGS gaging data. Post-dam flow data for the San Joaquin River at Friant used actual flow data from the USGS gage for the period 1950 to 2000.

The San Joaquin River near Newman gage is located below the confluence with the Merced River, and includes a portion of the runoff from the Merced River, as well as contributions from the Fresno River, Chowchilla River, and other small streams that join the San Joaquin River between Friant and Newman. Computed unimpaired flow data were not available at the Newman gage, so the actual flow data from 1914-1942 were used (a period which is about 8% drier than the long term (1910-2000) average runoff at Friant). Selection of this data assumes that significant regulation by Friant Dam (and associated diversion canals) began in 1950, whereas minor impairments prior to completion Friant Dam in 1942 were not considered as significant. Flow regulation by prior to Friant Dam was most significant during the summer baseflow period, when riparian diversions into canals caused the most proportional reduction in flows in the San Joaquin River. The regulated period of record used data from the Newman gage for 1967-2001, which included regulation by both Friant Dam and New Exchequer Dam on the Merced River.

The San Joaquin River at Fremont Ford gaging station would have been a more ideal location at the downstream end of the study reach (above the Merced River confluence), but the period of record (1938-1989) was inadequate for the pre- and post-Friant Dam comparison. Additional USGS data were available for the San Joaquin River at Dos Palos (1941-1954), El Nido (1940-1949), and Mendota (1940-1954), but these data were not extensive enough for analysis of hydrograph components.

Table 2-6. Summary of selected streamflow gaging stations used for Hydrograph Component Analysis.

Gaging station name and USGS or CDEC I.D. (from Table 2-1)	***Period of record***	***Drainage Area (mi^2)***	***Average annual water yield (AF)***
San Joaquin River below Friant, CA. USGS: 11-251000	1896-1999 (modeled unimpaired)	1,676	1,828,000
San Joaquin River below Friant, CA. USGS: 11-251000	1950-2000 (post-Friant Dam)		538,000
San Joaquin River near Newman, CA. USGS: 11-274000	1914-1942 (pre-Friant Dam)	9,520	1,866,000
San Joaquin River near Newman, CA. USGS: 11-274000	1967-2001 (post-Friant Dam, post-New Exchequer Dam)		1,537,000

2.6.6.1. Methods

Our hydrograph component analysis for the two gaging stations listed in Table 2-6 used the following procedure:

- The unimpaired annual water yield (runoff volume in acre-feet) was computed for each water year between 1896 and 1999, then plotted as a cumulative distribution curve by ranking the annual yield (Figure 2-5).
- The cumulative distribution curve was then divided symmetrically into five equally weighted classes separated by annual exceedance probabilities (p) of 0.80, 0.60, 0.40, and 0.20, and the five water year classes were named “Extremely Wet,” “Wet,” “Normal,” “Dry,” and “Critically Dry,” respectively. This classification system addresses the range of variability in the annual water yield and provides an equal probability for each class that a given water year will fall into that category (equally distributed around the mean), which in turn allows for simpler interpretation of comparisons between water year types.
- Based on the computed unimpaired water yield at the Friant gage, the annual water yields for both pre-and post-Friant Dam periods were grouped into the five water year classes. For example, if water year 1965 computed unimpaired runoff at Friant was classified as a “Wet” year, then the regulated runoff was also classified as a “Wet” water year. Then, to highlight the true annual flow variability, a single representative annual hydrograph for that water year class was overlaid on the average annual hydrograph for that water year class.
- Based on the patterns exhibited by the annual hydrographs and the range of their occurrence, the following hydrograph components were delineated (Figure 2-20):
- Fall Baseflows, October 1 – December 20
- Fall Floods, October 1 – December 20
- Winter Baseflows, December 21 – March 20
- Winter Floods, December 21 – March 20
- Snowmelt Floods, March 21 – June 21
- Snowmelt Recession, variable based on peak snowmelt flood
- Summer Baseflows, July 15 – September 30

After each hydrograph component was assigned a period of occurrence, all water years for each water year type were grouped, and statistical parameters (e.g., median, maxima, minima) were computed for each hydrograph component. This analysis was performed for the unimpaired and regulated periods of record for the two gaging stations listed in Table 2-6, to allow for a comparison of how each hydrograph component was affected as a result of streamflow regulation. The dates for each component were chosen to provide a discrete period for analyses that are comparable for each gaging record and water year, but do not necessarily capture all the variability in the duration of the component.

The results of the Hydrograph Component Analysis for the San Joaquin River at Friant gage are summarized in Table 2-7 (computed unimpaired) and Table 2-8 (Post-Friant Dam), and for the San Joaquin River near Newman gage in Table 2-9 (Pre-Friant Dam) and Table 2-10 (Post-Friant Dam and Post New Exchequer Dam). Following the summary tables, we include all the hydrologic information we used for the Hydrograph Component Analysis at each gage, including (1) table of annual water yields, exceedance probability, and water year classification, (2) bar chart of annual water yield, and (3) frequency distribution of annual water yield, (4) average and representative hydrographs, and (5) annual hydrograph for each year of record used in the analyses. The following sections discuss the results of our Hydrograph Component Analysis for each gaging record. The summary is not meant to report all the hydrograph components for each of the periods of record analyzed, nor to provide comparisons among the different rivers, but is instead intended to summarize the salient components and the major changes that have occurred at each location.

2.6.6.2. San Joaquin River below Friant

The San Joaquin River below Friant gaging record was analyzed for the period 1896-1999, and separated into an unimpaired record (1896-1999) and a post-dam regulated period (1950–2000). Based on analyzing water yield between the two data sets, the average annual water yield was reduced from 1,812,000 acre-ft to 528,000 acre-ft, a 71% reduction in yield. More than half the regulated runoff years analyzed had annual yield less than 125,000 acre-ft, which is approximately 7% of the average unimpaired water yield. The following discussion highlights several key differences between the modeled unimpaired hydrograph components and the regulated post-Friant Dam components. In addition to the hydrograph component summary in Tables 2-7 and 2-8, Figures 2-21 through 2-25 illustrate (1) the average annual hydrograph for a given water year class, (2) an example representative unimpaired hydrograph for that given water year class, and (3) the corresponding representative regulated hydrograph for that given water year class.

2.6.6.2.1. Summer, Fall, and Winter Baseflows

- Unimpaired summer baseflows generally varied as a function of the duration of the snowmelt recession and the water year type (i.e., the wetter the year and consequently the longer the snowmelt recession, the higher were the subsequent summer baseflows). Median summer baseflows ranged from approximately 200 cfs in Critically Dry years, to above 1,000 cfs during Extremely Wet years. During Extremely Wet years the snowmelt hydrograph descending limb extended nearly to the end of August, and remained above 1,000 cfs in August for nearly all Extremely Wet years. The September baseflows during Extremely Wet years typically remained above 500 cfs. Under regulated conditions, summer/fall baseflows have been reduced to the minimum flow releases required to meet downstream water deliveries. Median summer baseflows ranged from 135-245 cfs. Minimum summer baseflows generally remained above 75 cfs, during dryer water year types; maximum summer baseflows approached flows typical of unimpaired conditions, suggesting Friant dam has less effect on summer flow releases during wetter water year types because of its relatively smaller storage capacity.

Table 2-7. Summary of Hydrograph Components for the San Joaquin River near Friant for unimpaired conditions (USBR and modeled unimpaired flows from Hux Madeheim) for water years 1896-1999.

	WATER YEAR TYPE					
Hydrograph Component	***Extremely Wet***	***Wet***	***Normal***	***Dry***	***Critically Dry***	***All Water Years***
Probabilty of Exceedence	*20%*	*40%*	*60%*	*80%*	*100%*	
Number of Water Years	20	21	21	21	21	104
Average Daily Flow (cfs)	4,597 cfs	3,022 cfs	2,307 cfs	1,635 cfs	1,063 cfs	2,505 cfs
Average Annual Yield (af)	3,328,190 ac-ft	2,187,744 ac-ft	1,670,032 ac-ft	1,183,424 ac-ft	769,731 ac-ft	1,812,000 ac-ft
Maximum Annual Yield (af)	4,641,537 ac-ft	2,672,303 ac-ft	1,936,172 ac-ft	1,321,069 ac-ft	949,591 ac-ft	2,304,134 ac-ft
Minimum Annual Yield (af)	2,755,032 ac-ft	1,945,119 ac-ft	1,326,827 ac-ft	1,026,184 ac-ft	361,178 ac-ft	1,482,868 ac-ft
Fall Baseflows (Oct 1 - Dec 20)						
Median	380 cfs	318 cfs	432 cfs	295 cfs	274 cfs	340 cfs
Minimum	115 cfs	114 cfs	194 cfs	97 cfs	100 cfs	124 cfs
Maximum	1,705 cfs	1,547 cfs	895 cfs	666 cfs	610 cfs	1,085 cfs
Fall Floods (Oct 1 - Dec 20)						
Median Peak Magnitude	2,118 cfs	2,368 cfs	2,066 cfs	1,315 cfs	909 cfs	2,066 cfs
Maximum	45,728 cfs	19,677 cfs	42,352 cfs	11,734 cfs	8,294 cfs	45,728 cfs
Winter Baseflows (Dec 21 - Mar 20)						
Median	1,712 cfs	875 cfs	564 cfs	450 cfs	310 cfs	782 cfs
Minimum	989 cfs	160 cfs	200 cfs	250 cfs	154 cfs	350 cfs
Maximum	3,202 cfs	1,975 cfs	1,512 cfs	867 cfs	627 cfs	1,637 cfs
Winter Floods (Dec 21 - Mar 20)						
Average Peak Magnitude	31,256 cfs	15,560 cfs	9,719 cfs	6,655 cfs	3,797 cfs	13,397 cfs
Median Peak Magnitude	28,345 cfs	12,822 cfs	8,489 cfs	5,734 cfs	3,735 cfs	11,825 cfs
Minimum	11,248 cfs	6,407 cfs	3,548 cfs	2,078 cfs	1,486 cfs	4,953 cfs
Maximum	77,467 cfs	40,982 cfs	23,908 cfs	27,292 cfs	7,928 cfs	35,515 cfs
Snowmelt Floods (Mar 21 - June 21)						
Average Peak Magnitude	18,925 cfs	15,361 cfs	12,162 cfs	9,640 cfs	5,942 cfs	12,406 cfs
Median Peak Magnitude	19,275 cfs	14,467 cfs	11,740 cfs	9,641 cfs	5,742 cfs	12,173 cfs
Minimum	11,645 cfs	10,512 cfs	8,583 cfs	6,635 cfs	3,549 cfs	8,185 cfs
Maximum	25,316 cfs	32,217 cfs	16,941 cfs	13,986 cfs	10,092 cfs	19,711 cfs
Snowmelt Recession						
Median Date of Peak	31-May	23-May	27-May	19-May	12-May	22-May
Earliest Peak	28-Apr	26-Apr	6-May	25-Apr	22-Apr	27-Apr
Latest Peak	21-Jun	30-Jun	13-Jun	15-Jun	16-Jun	19-Jun
Summer Baseflows (July 15 - Sep 30)						
Baseflow Median	1,013 cfs	583 cfs	389 cfs	284 cfs	212 cfs	496 cfs
Minimum	453 cfs	302 cfs	200 cfs	133 cfs	114 cfs	241 cfs
Maximum	2,105 cfs	1,049 cfs	582 cfs	664 cfs	584 cfs	997 cfs

Daily Average Discharge = 2,505 cfs
Total Annual Runoff = 1,812,000 ac-ft

Annual Maximum Flood Frequency		***Unimpaired***	***Regulated***
$Q_{1.5}$	=	10,227 cfs	850 cfs
Q_{5}	=	26,195 cfs	6,749 cfs
Q_{10}	=	36,758 cfs	13,644 cfs
Q_{25}	=	53,000 cfs	28,727 cfs

Table 2-8. Summary of Hydrograph Components for the San Joaquin River near Friant for post-Friant regulated conditions (USGS data) for water years 1950-2000.

	WATER YEAR TYPE					
Hydrograph Component	***Extremely Wet***	***Wet***	***Normal***	***Dry***	***Critically Dry***	***All Water Years***
Probabilty of Exceedence	*20%*	*40%*	*60%*	*80%*	*100%*	
Number of Water Years	10	10	10	10	11	51
Average Daily Flow (cfs)	2,345 cfs	950 cfs	208 cfs	121 cfs	88 cfs	730 cfs
Average Annual Yield (af)	1,697,624 ac-ft	687,662 ac-ft	150,839 ac-ft	87,888 ac-ft	63,570 ac-ft	528,224 ac-ft
Maximum Annual Yield (af)	3,174,569 ac-ft	1,180,140 ac-ft	262,264 ac-ft	99,816 ac-ft	75,116 ac-ft	3,174,569 ac-ft
Minimum Annual Yield (af)	1,187,252 ac-ft	285,118 ac-ft	104,426 ac-ft	79,474 ac-ft	48,424 ac-ft	48,424 ac-ft
Fall Baseflows (Oct 1 - Dec 20)						
Median	117 cfs	105 cfs	127 cfs	81 cfs	62 cfs	105 cfs
Minimum	52 cfs	71 cfs	54 cfs	44 cfs	36 cfs	36 cfs
Maximum	480 cfs	1,050 cfs	495 cfs	125 cfs	87 cfs	1,050 cfs
Fall Floods (Oct 1 - Dec 20)						
Median Peak Magnitude	299 cfs	196 cfs	194 cfs	126 cfs	93 cfs	194 cfs
Maximum	5,020 cfs	3,130 cfs	1,020 cfs	693 cfs	120 cfs	5,020 cfs
Winter Baseflows (Dec 21 - Mar 20)						
Median	1,095 cfs	65 cfs	86 cfs	54 cfs	36 cfs	65 cfs
Minimum	49 cfs	52 cfs	56 cfs	26 cfs	24 cfs	24 cfs
Maximum	5,720 cfs	110 cfs	173 cfs	71 cfs	61 cfs	5,720 cfs
Winter Floods (Dec 21 - Mar 20)						
Average Peak Magnitude	10,313 cfs	5,777 cfs	684 cfs	361 cfs	165 cfs	3,460 cfs
Median Peak Magnitude	7,985 cfs	4,900 cfs	711 cfs	172 cfs	117 cfs	711 cfs
Minimum	4,030 cfs	936 cfs	146 cfs	106 cfs	66 cfs	66 cfs
Maximum	36,800 cfs	14,900 cfs	1,380 cfs	1,950 cfs	580 cfs	36,800 cfs
Snowmelt Floods (Mar 21 - June 21)						
Average Peak Magnitude	7,320 cfs	4,212 cfs	888 cfs	418 cfs	183 cfs	2,604 cfs
Median Peak Magnitude	7,960 cfs	3,890 cfs	583 cfs	229 cfs	171 cfs	583 cfs
Minimum	291 cfs	168 cfs	198 cfs	121 cfs	136 cfs	121 cfs
Maximum	12,400 cfs	8,080 cfs	2,370 cfs	2,110 cfs	217 cfs	12,400 cfs
Snowmelt Recession						
Median Date of Peak	8-Jun	8-May	18-Jun	5-Jul	10-Jul	15-Jun
Earliest Peak	26-Apr	21-Apr	20-May	1-May	25-Apr	30-Apr
Latest Peak	12-Jul	4-Jul	15-Aug	11-Aug	17-Aug	30-Jul
Summer Baseflows (July 15 - Sep 30)						
Baseflow Median	245 cfs	148 cfs	175 cfs	162 cfs	135 cfs	162 cfs
Minimum	76 cfs	86 cfs	107 cfs	82 cfs	90 cfs	76 cfs
Maximum	2,090 cfs	1,750 cfs	267 cfs	201 cfs	144 cfs	2,090 cfs

Daily Average Discharge = 730 cfs
Total Annual Runoff = 528,224 ac-ft

Annual Maximum Flood Frequency		***Unimpaired***	***Regulated***
$Q_{1.5}$	=	10,187 cfs	771 cfs
Q_{5}	=	25,177 cfs	5,885 cfs
Q_{10}	=	35,111 cfs	11,922 cfs
Q_{25}	=	50,650 cfs	25,379 cfs

Table 2-9. Summary of Hydrograph Components for the San Joaquin River near Newman for unimpaired conditions (USGS data) for water years 1912-1942.

			WATER YEAR TYPE			
Hydrograph Component	***Extremely Wet***	***Wet***	***Normal***	***Dry***	***Critically Dry***	***All Water Years***
Probabilty of Exceedence	*20%*	*40%*	*60%*	*80%*	*100%*	
Number of Water Years	6	6	6	6	6	
Average Daily Flow (cfs)	5,920	3,243	2,233	1,114	377	2,577
Average Annual Yield (af)	4,285,758	2,347,746	1,616,433	806,555	273,157	1,868,153
Maximum Annual Yield (af)	6,257,161	2,759,183	1,780,792	1,108,268	390,522	
Minimum Annual Yield (af)	2,929,807	1,959,896	1,361,260	453,271	141,808	
Fall Baseflows (Oct 1 - Dec 20)						
Median	204	275	143	300	187	222
Minimum	86	120	81	103	60	90
Maximum	450	484	1,030	955	458	675
Fall Floods (Oct 1 - Dec 20)						
Median Peak Magnitude	940	1,155	966	1,275	300	927
Maximum	4,840	6,000	3,700	1,910	870	3,464
Winter Baseflows (Dec 21 - Mar 20)						
Median	2,850	1,325	1,480	713	421	1,358
Minimum	735	540	222	305	231	407
Maximum	3,970	1,910	3,120	1,180	970	2,230
Winter Floods (Dec 21 - Mar 20)						
Average Peak Magnitude	19,577	11,740	7,837	4,125	1,138	8,883
Median Peak Magnitude	19,450	12,000	8,050	3,505	838	8,769
Minimum	8,260	7,140	3,660	2,240	560	4,372
Maximum	33,000	14,600	13,400	6,520	2,240	13,952
Snowmelt Floods (Mar 21 - June 21)						
Average Peak Magnitude	16,583	12,133	9,190	5,252	1,328	8,897
Median Peak Magnitude	15,600	11,750	8,985	5,540	675	8,510
Minimum	12,000	8,600	7,200	1,570	227	5,919
Maximum	25,200	15,200	12,600	8,900	4,280	13,236
Snowmelt Recession						
Median Date of Peak	5-Jun	29-May	24-May	8-May	6-May	20-May
Earliest Peak	21-Mar	4-Apr	21-Mar	31-Mar	22-Mar	26-Mar
Latest Peak	17-Jun	21-Jun	13-Jun	21-Jun	3-Jun	15-Jun
Summer Baseflows (July 15 - Sep 30)						
Baseflow Median	720	352	251	214	105	328
Minimum	353	260	84	92	23	162
Maximum	1,045	450	467	315	200	495

Daily Average Discharge	2,577
Total Annual Runoff	1,868,153

Table 2-10 Summary of Hydrograph Components for the San Joaquin River near Newman for post-Friant and post-New Exchequer regulated conditions (USGS data) for water years 1967-2001.

	WATER YEAR TYPE					
Hydrograph Component	**Extremely Wet**	**Wet**	**Normal**	**Dry**	**Critically Dry**	**Average**
Probabilty of Exceedence	*20%*	*40%*	*60%*	*80%*	*100%*	
Number of Water Years	7	7	7	7	7	
Average Daily Flow (cfs)	5,898	2,504	1,144	656	415	2,124
Average Annual Yield (af)	4,270,314	1,813,004	827,999	474,705	300,744	1,537,365
Maximum Annual Yield (af)	8,413,250	2,390,894	925,537	568,721	395,665	
Minimum Annual Yield (af)	2,470,020	955,928	577,676	413,343	182,221	
Fall Baseflows (Oct 1 - Dec 20)						
Median	630	1,110	901	767	414	764
Minimum	83	266	308	523	270	290
Maximum	2,930	5,700	1,370	875	574	2,290
Fall Floods (Oct 1 - Dec 20)						
Median Peak Magnitude	1,050	2,370	1,510	1,550	691	1,434
Maximum	11,600	10,100	2,360	2,130	996	5,437
Winter Baseflows (Dec 21 - Mar 20)						
Median	570	984	887	791	520	750
Minimum	293	438	532	626	208	419
Maximum	9,050	2,040	1,190	864	683	2,765
Winter Floods (Dec 21 - Mar 20)						
Average Peak Magnitude	24,300	9,793	5,221	1,821	1,189	8,465
Median Peak Magnitude	23,300	6,570	4,630	1,840	1,010	7,470
Minimum	13,100	3,650	1,380	850	661	3,928
Maximum	36,000	23,000	10,900	2,740	2,310	14,990
Snowmelt Floods (Mar 21 - June 21)						
Average Peak Magnitude	15,016	9,534	2,950	1,236	946	5,936
Median Peak Magnitude	15,500	6,190	3,280	1,070	875	5,383
Minimum	2,210	1,180	1,330	747	299	1,153
Maximum	24,900	20,200	3,720	2,180	2,010	10,602
Snowmelt Recession						
Median Date of Peak	28-Mar	23-Mar	29-Mar	12-Apr	28-Mar	30-Mar
Earliest Peak	21-Mar	21-Mar	21-Mar	21-Mar	21-Mar	21-Mar
Latest Peak	11-Jun	27-Apr	25-Apr	9-May	30-May	14-May
Summer Baseflows (July 15 - Sep 30)						
Baseflow Median	1,165	657	508	365	264	592
Minimum	410	360	415	251	50	297
Maximum	3,440	1,160	908	517	415	1,288

Daily Average Discharge	2,124
Total Annual Runoff	1,537,365

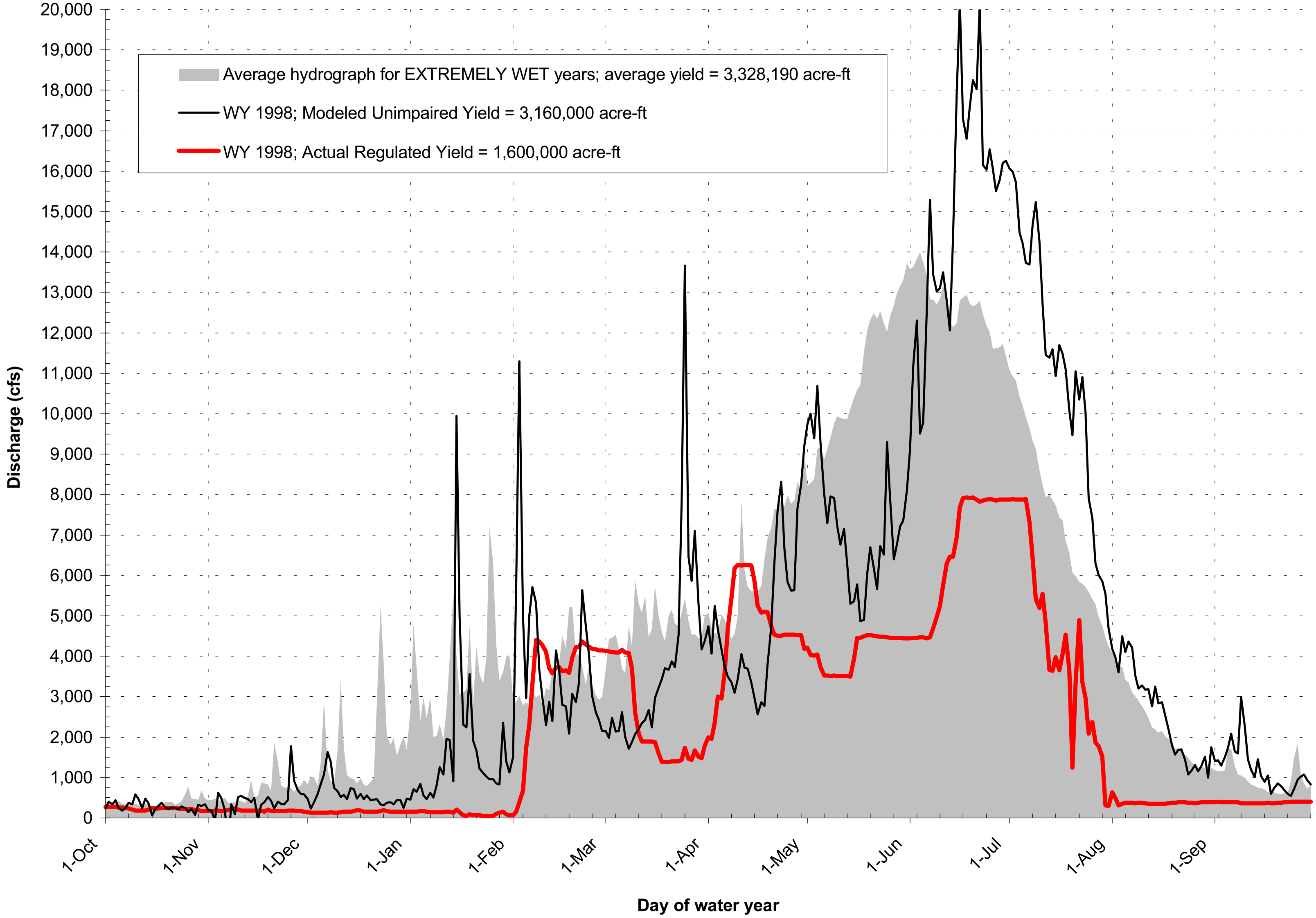

Figure 2-21. Average annual unimpaired hydrograph for an Extremely Wet water year at the San Joaquin River at Friant gaging station. A representative Extremely Wet water year hydrograph (1998) for unimpaired and post-Friant Dam conditions is included.

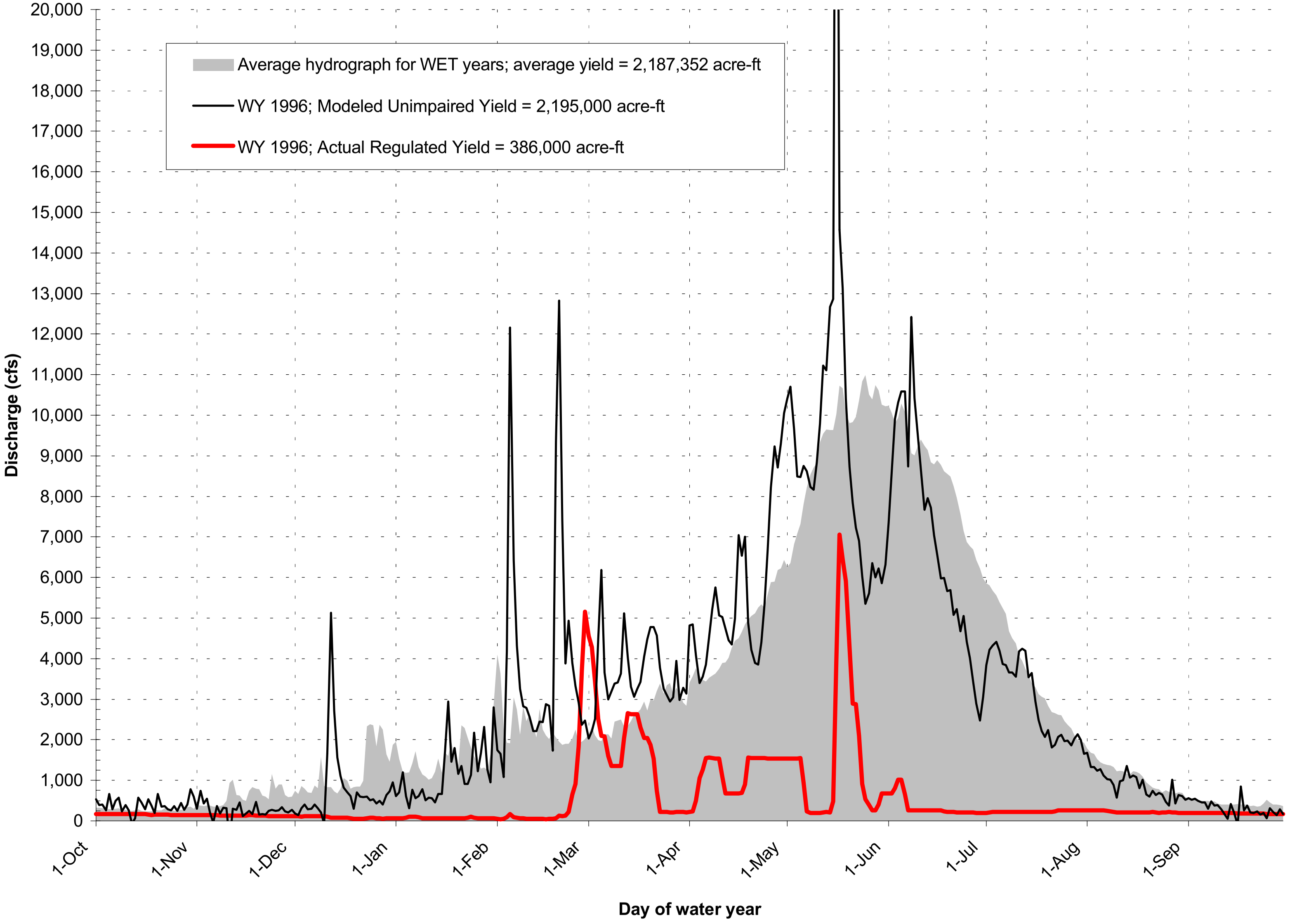

Figure 2-22. Average annual unimpaired hydrograph for a Wet water year at the San Joaquin River at Friant gaging station. A representative Wet water year hydrograph (1996) for unimpaired and post-Friant Dam conditions is included.

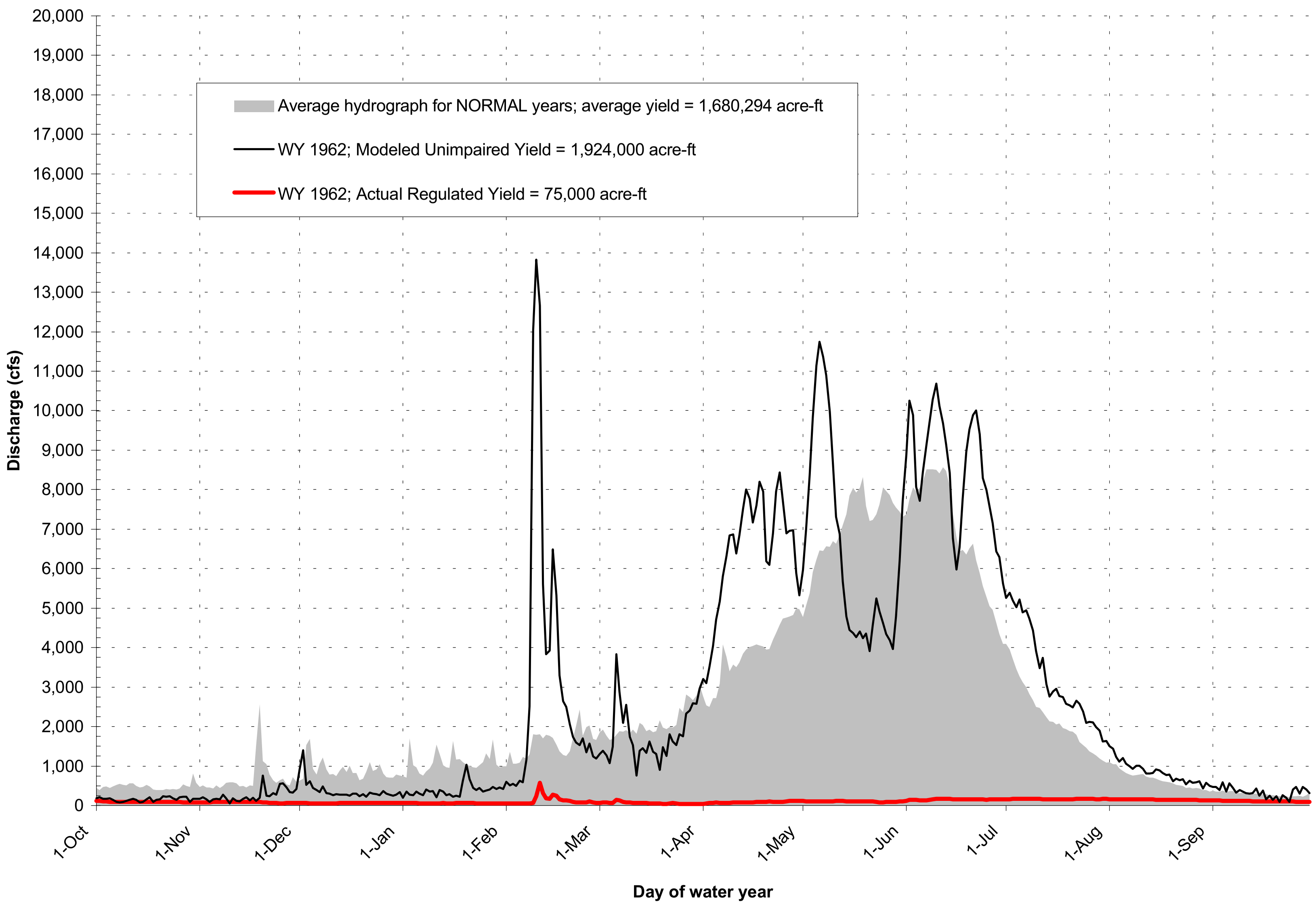

Figure 2-23. Average annual unimpaired hydrograph for a Normal water year at the San Joaquin River at Friant gaging station. A representative Normal water year hydrograph (1962) for unimpaired and post-Friant Dam conditions is included.

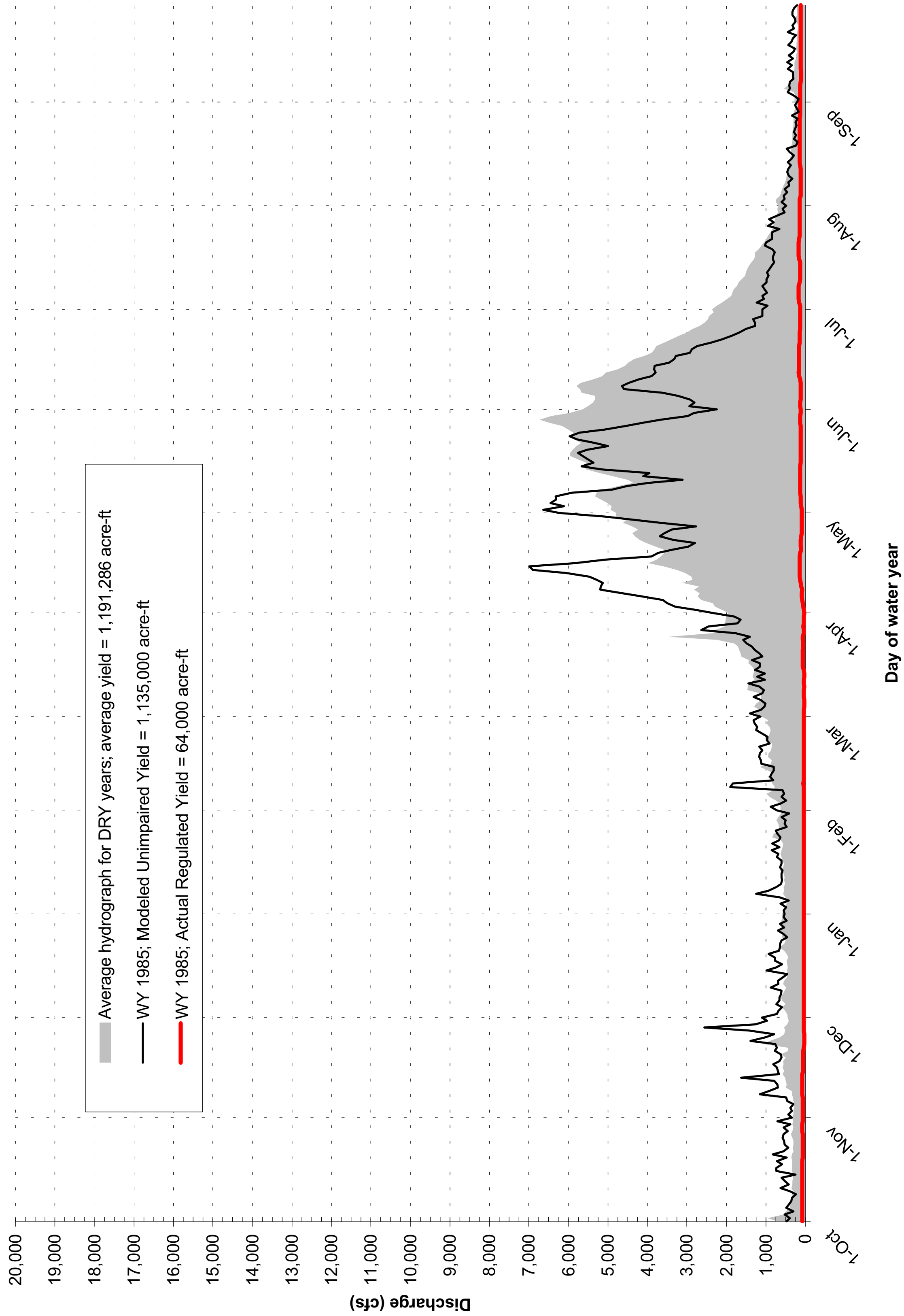

Figure 2-24. Average annual unimpaired hydrograph for a Dry water year at the San Joaquin River at Friant gaging station. A representative Dry water year hydrograph (1985) for unimpaired and post-Friant Dam conditions is included.

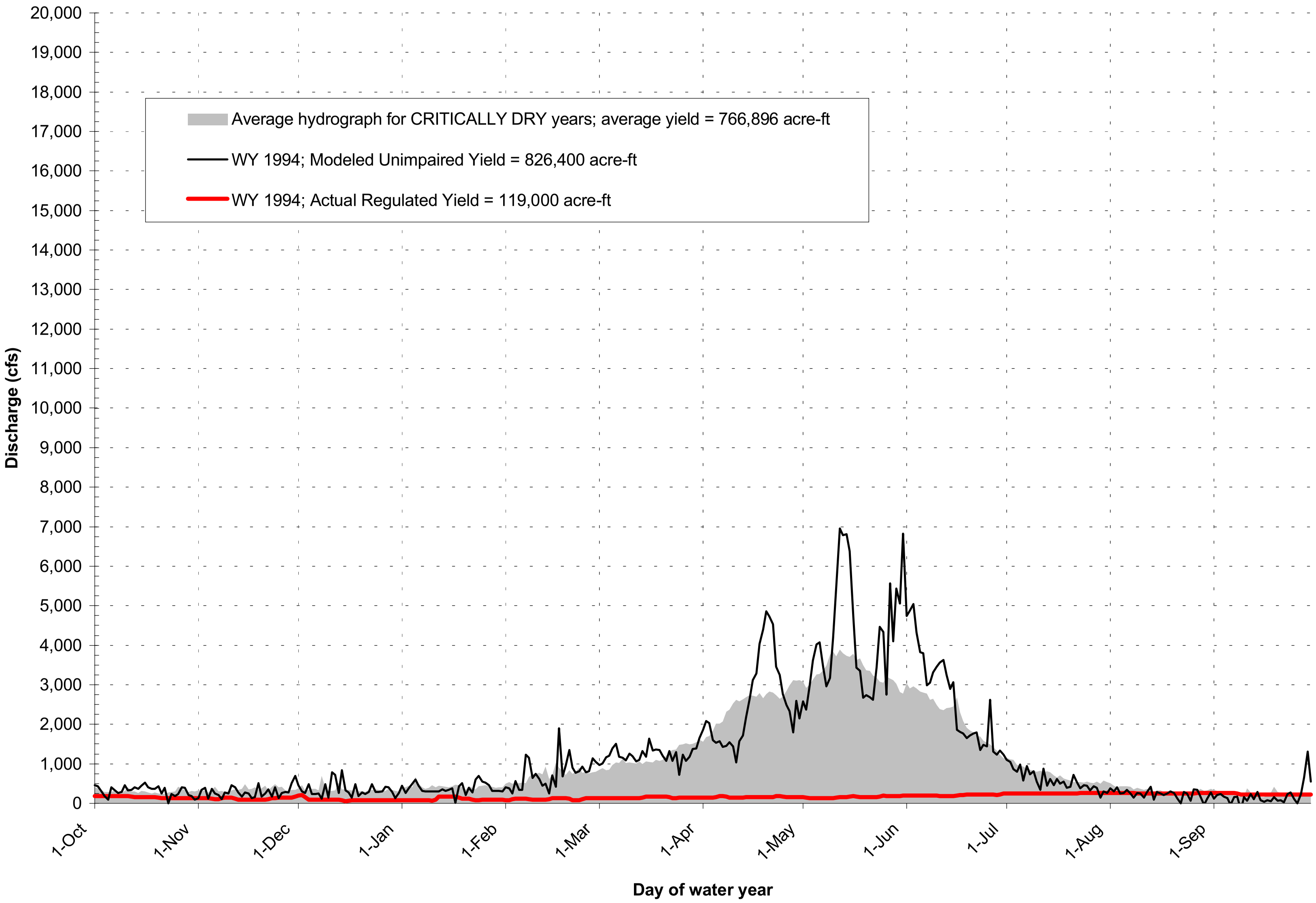

Figure 2-25. Average annual unimpaired hydrograph for a Critically Dry water year at the San Joaquin River at Friant gaging station. A representative Critically Dry water year hydrograph (1994) for unimpaired and post-Friant Dam conditions is included.

- Unimpaired fall baseflows also varied as a function of the water year type, and ranged from 274-380 cfs in Critically Dry and Extremely Wet years, respectively. Wet and Extremely Wet year fall baseflows occasionally exceeded 1,000 cfs, whereas minimum fall baseflows were often as low as 100 cfs. Under regulated conditions, fall baseflows have been reduced to the minimum flow releases required to meet downstream water deliveries, until the irrigation season ended and fall baseflow releases were reduced to increase reservoir storage. Median summer/fall baseflows ranged from 36-71 cfs during Critically Dry and Wet years, respectively. The flow release requirements for irrigation water delivery appear to have sustained higher summer baseflows than fall baseflows. Occasionally, Wet and Extremely Wet fall baseflow maxima exceeded 4,000 cfs, which likely resulted from flow releases to vacate flood storage space in Millerton Reservoir during wet water year conditions.
- Median winter baseflows ranged from 310-1,700 cfs under unimpaired conditions, and were reduced significantly more than summer/fall baseflows by regulation from Friant Dam. Median winter baseflows under regulated conditions were less than 300 cfs more than 80% of the days, but were conversely extremely high during Extremely Wet water years, with median flows exceeding 5,000 cfs. Critically Dry year minima frequently reached as low as 33 cfs. The larger winter flow releases were also likely due to the small flood storage space available in Millerton Reservoir and the consequent need to spill large volumes of water during wet winters.
- Two distinct periods of record – from April 1974 to November 1978 (1,332 days), and from April 1986 to October 1993 (2,350 days) – were particularly dry. Compared to the unimpaired winter baseflow daily average flow of approximately 2,500 cfs, these two periods reported daily average flows of 100 cfs and 125 cfs, respectively, with maximum flows for these entire periods of only 236 and 313 cfs, respectively.

2.6.6.2.2. Fall and Winter Floods

- Fall rainstorms and the consequent floods they caused were generally the first floods of the runoff season, and were thus generally smaller in magnitude than floods occurring between December and March. Median unimpaired fall floods ranged from 900-2,300 cfs during Critically Dry and Wet years respectively. These early-season fall storms were essentially eliminated in Critically Dry, Dry, and Normal water year types, and appear to have been largely unaffected in Wet and Extremely Wet years. The largest floods of record generally occurred earlier in December to March when early cold snowstorms were followed by warm tropical rains that resulted in a rain-on-snow flood event. This scenario occurred most recently during the January 1997 flood (ACOE 1999). In the unimpaired period of record, the flood of record occurred on December 11, 1937, and was thus categorized as a Fall Storm. The maximum daily average discharge of this flood was 45,000 cfs, with an instantaneous peak discharge of 77,200 cfs and recurrence interval of 32 years.
- Most other flood events were categorized as winter floods. The hydrograph component analysis evaluates the daily average maxima, whereas the flood frequency analysis (Section 2.6.2) evaluates the annual instantaneous maxima. Median daily average unimpaired winter storms ranged from 3,700-28,000 cfs during Critically Dry and Extremely Wet years, respectively. Under regulated conditions, winter floods were eliminated during Critically Dry, Dry, and Normal water year types, and were reduced to 4,000-10,000 cfs during Wet and Extremely Wet water year types. Several winter floods during the unimpaired period of record exceeded 30,000 cfs, but only one winter flood exceeded 15,000 cfs since construction of Friant Dam: the flood of January 1997 with measured instantaneous peak discharge below Friant of 60,300 cfs. The unimpaired peak magnitude of this flood, measured as peak hourly inflow into Millerton Lake, was 95,000 cfs (ACOE 1999).

2.6.6.2.3. Snowmelt Peak and Recession Limb

- The snowmelt hydrograph component contains the largest portion of the total annual runoff, and is consequently affected most severely by regulation. Under unimpaired conditions, the median snowmelt floods ranged from 5,700-19,000 cfs, during Critically Dry and Extremely Wet water years, respectively. These snowmelt peaks had a duration lasting up to several weeks, and corresponding recession limbs lasted several months. The recession limb lasted through August in most years, and lasted into September in wetter years. Several unimpaired snowmelt flood peaks exceeded 20,000 cfs as a daily average maximum. The minimum unimpaired snowmelt flood magnitude during Critically Dry years still exceeded 3,500 cfs.
- The snowmelt hydrograph component was virtually eliminated in all water year types. Computation of the median spring peak runoff showed that the peak flow for Normal, Dry, and Critically Dry water year types did not exceed 800 cfs, which is not truly a flood peak, but is merely a sustained baseflow throughout the snowmelt period. Wet and Extremely Wet years had substantially reduced snowmelt floods ranging from 1,700-5,000 cfs, respectively.

2.6.6.3. San Joaquin River near Newman

The gaging station on the San Joaquin River near Newman records the volume of flow from the San Joaquin River, a portion of the Merced River, and other tributary inflows such as Cottonwood Creek, the Fresno River, Fresno Slough, the Kings River, and the Chowchilla River. Prior to construction of Friant Dam, streamflow regulation occurred on many of these tributaries, and as such, flows recorded near Newman for the period of record prior to Friant Dam are considered “partially regulated.” In addition, natural hydrologic processes, such as groundwater accretion, storage of floodwaters on floodplains, contributions of shallow groundwater to surface flow, and anthropogenic processes resulting from irrigation diversion and return flows, all cumulatively affect flows measured at the Newman gage. Therefore, comparison of hydrograph components between the Friant and Newman gaging stations are somewhat obscured. Based on analyzing water yield at the Newman gage before and after Friant Dam was constructed, the average annual water yield was reduced from 1,868,153 acre-ft to 1,537,365 acre-ft, an 18% reduction in yield. This reduction includes effects of New Exchequer Dam on the Merced River, Friant Dam, and other diversions, as well as irrigation water imported to the basin from the Delta-Mendota canal. In addition to the hydrograph component summary in Table 2-8 and Table 2-9, Figure 2-26 through Figure 2-30 illustrate (1) the average annual hydrograph for a given water year class, (2) an example representative unimpaired hydrograph for that given water year class, and (3) the corresponding representative regulated hydrograph for that given water year class. The following section summarizes the important hydrograph components as measured at the Newman gage.

2.6.6.3.1. Summer, Fall, and Winter Baseflows

- Median summer baseflows near Newman ranged from 105-720 cfs during the pre-Friant period, with minimum summer baseflows occasionally falling below 100 cfs. The highest summer baseflows at Newman (pre-Friant) infrequently exceeded 1,000 cfs. During the post-Friant period, median summer baseflows have actually increased, and now range from 264-1,165 cfs. The maximum baseflows during this period are also higher, ranging as high as 4,000 cfs during Extremely Wet years, and up to 1,600 cfs during Critically Dry years.

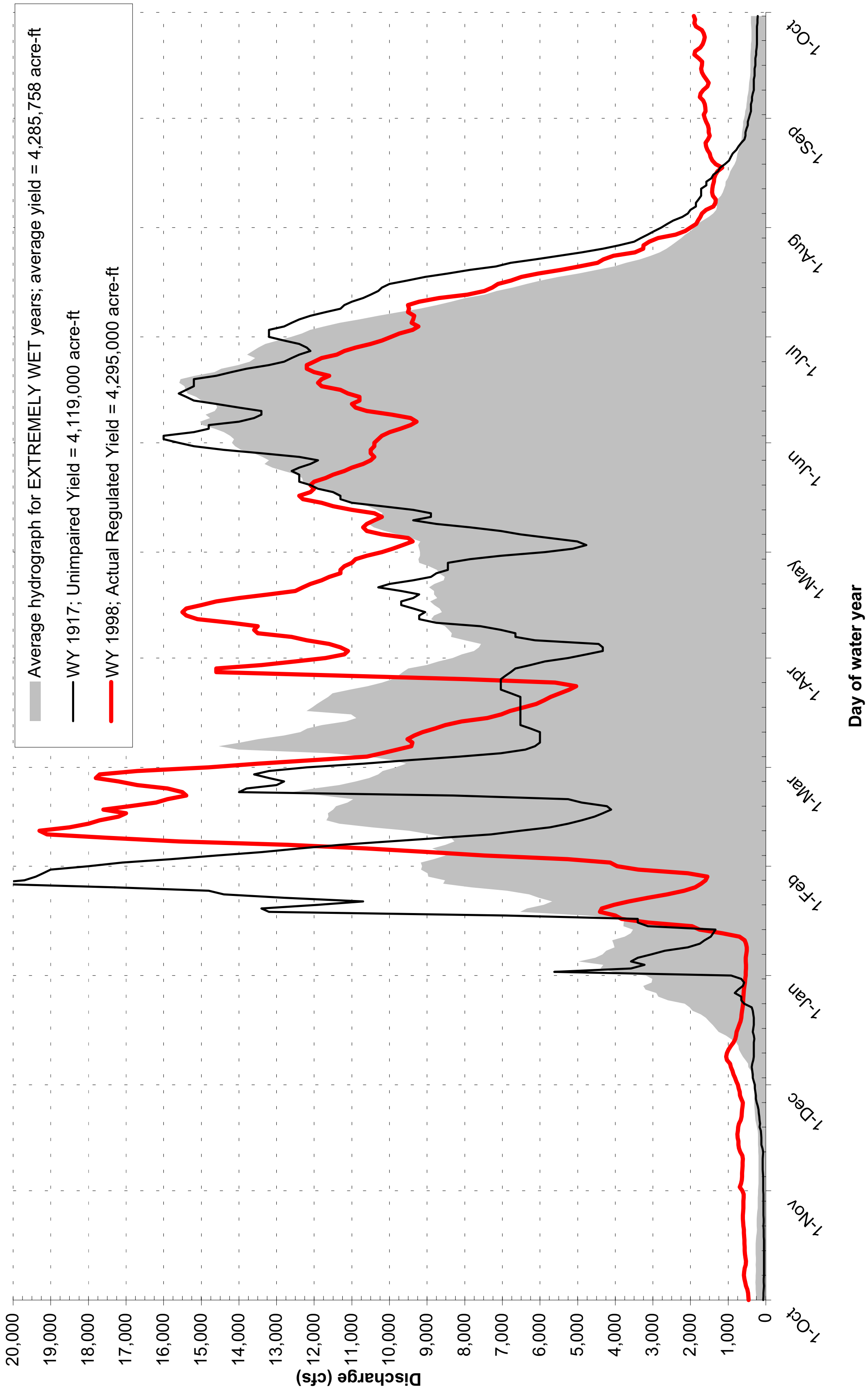

Figure 2-26. Average annual unimpaired hydrograph for an Extremely Wet water year at the San Joaquin River at Newman gaging station. Representative Extremely Wet water year hydrographs for Pre-Friant Dam (1917) and post-Friant Dam (1998) conditions are included.

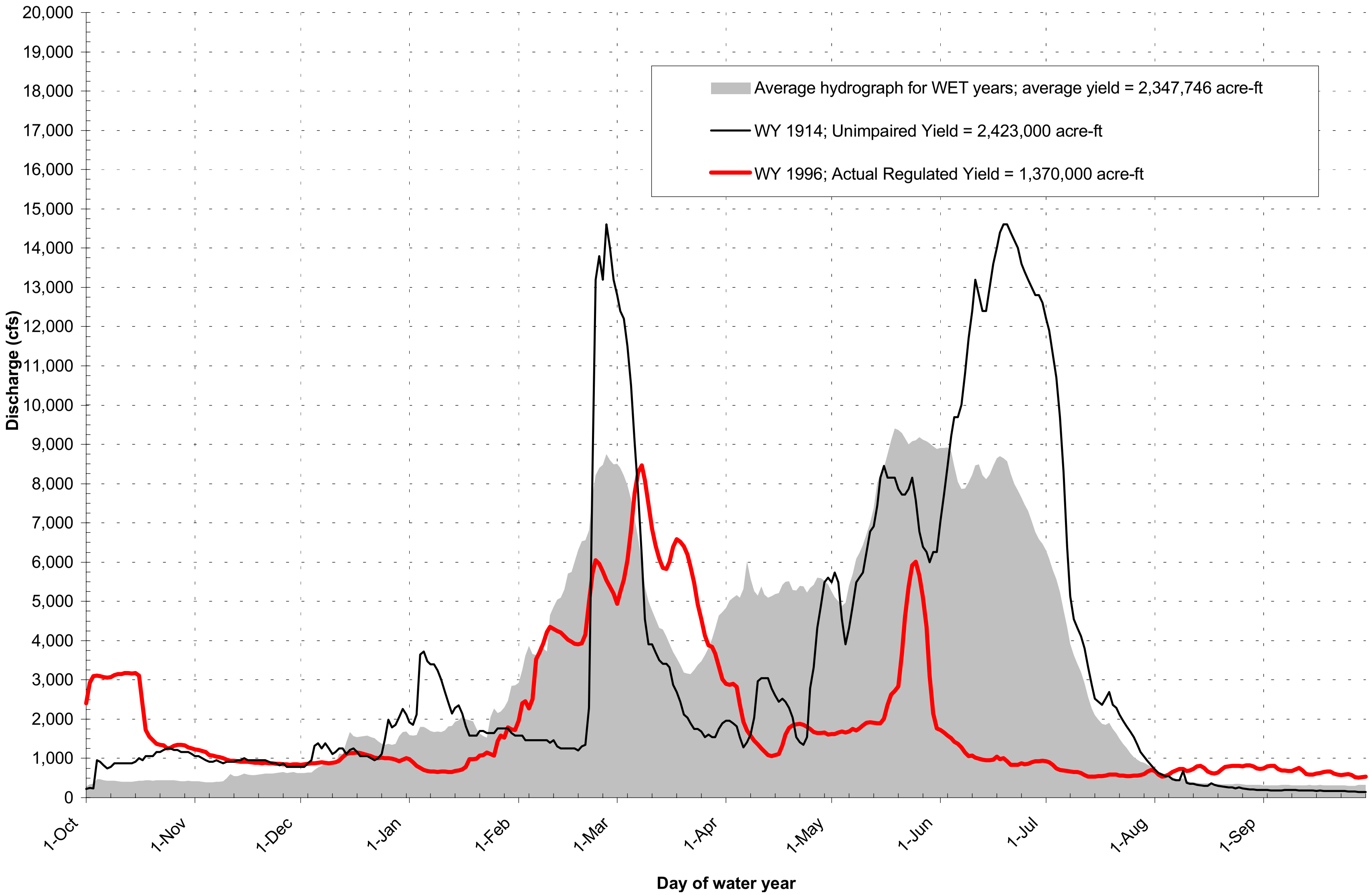

Figure 2-27. Average annual unimpaired hydrograph for a Wet water year at the San Joaquin River at Newman gaging station. Representative Wet water year hydrographs for Pre-Friant Dam (1914) and post-Friant Dam (1996) conditions are included.

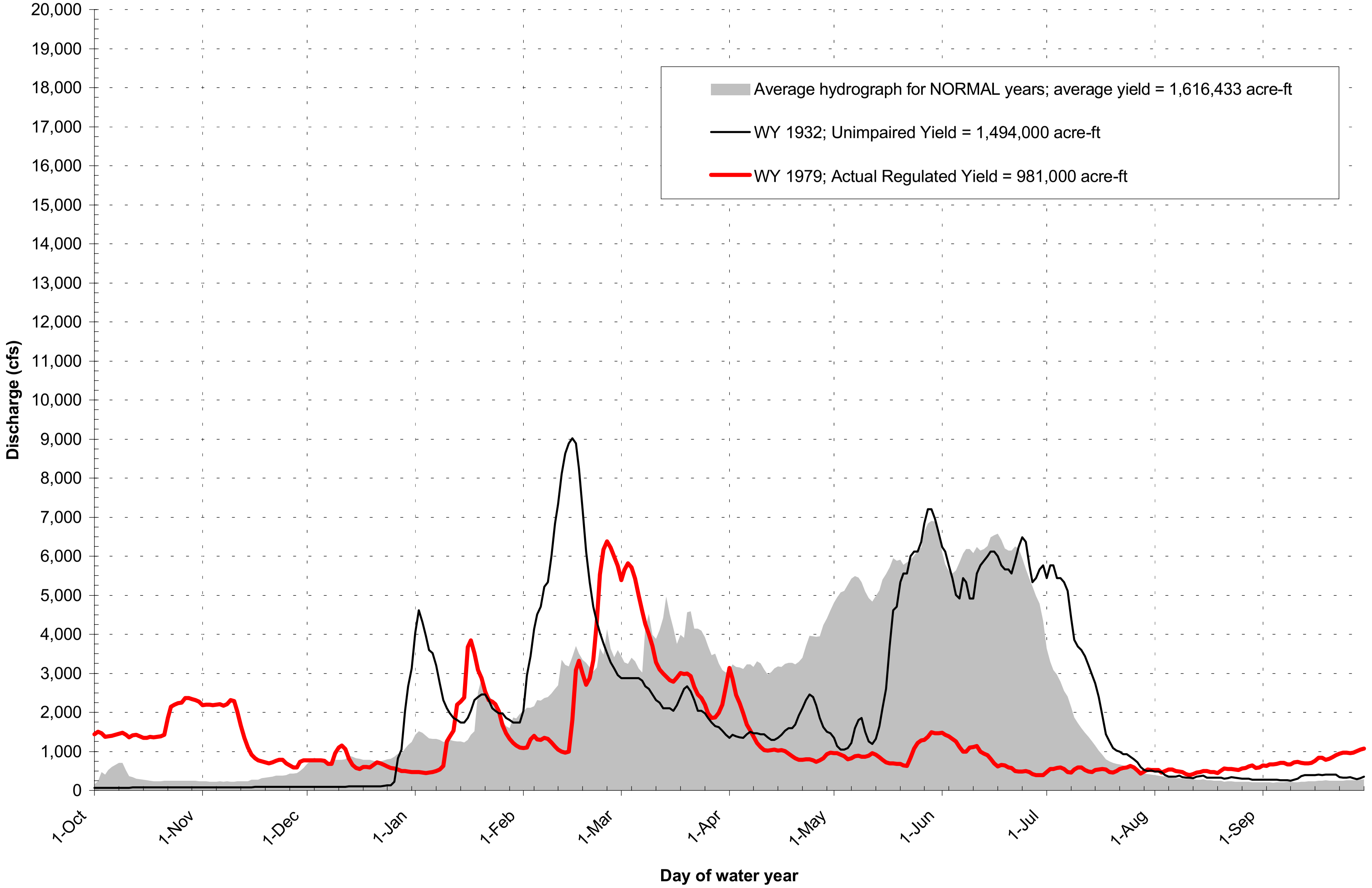

Figure 2-28. Average annual unimpaired hydrograph for a Normal water year at the San Joaquin River at Newman gaging station. Representative Normal water year hydrographs for Pre-Friant Dam (1932) and post-Friant Dam (1979) conditions are included.

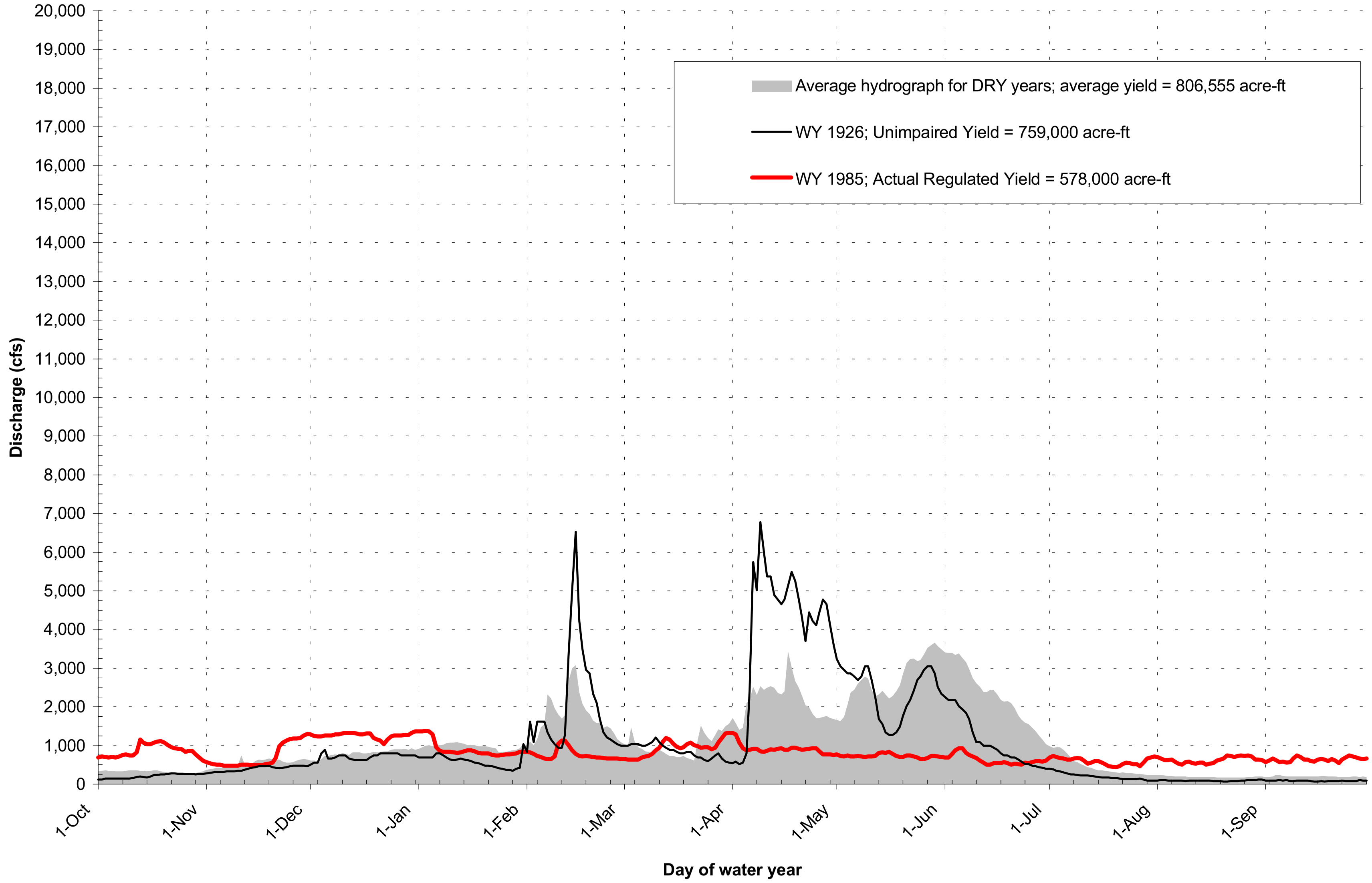

Figure 2-29. Average annual unimpaired hydrograph for a Dry water year at the San Joaquin River at Newman gaging station. Representative Dry water year hydrographs for Pre-Friant Dam (1926) and post-Friant Dam (1985) conditions are included.

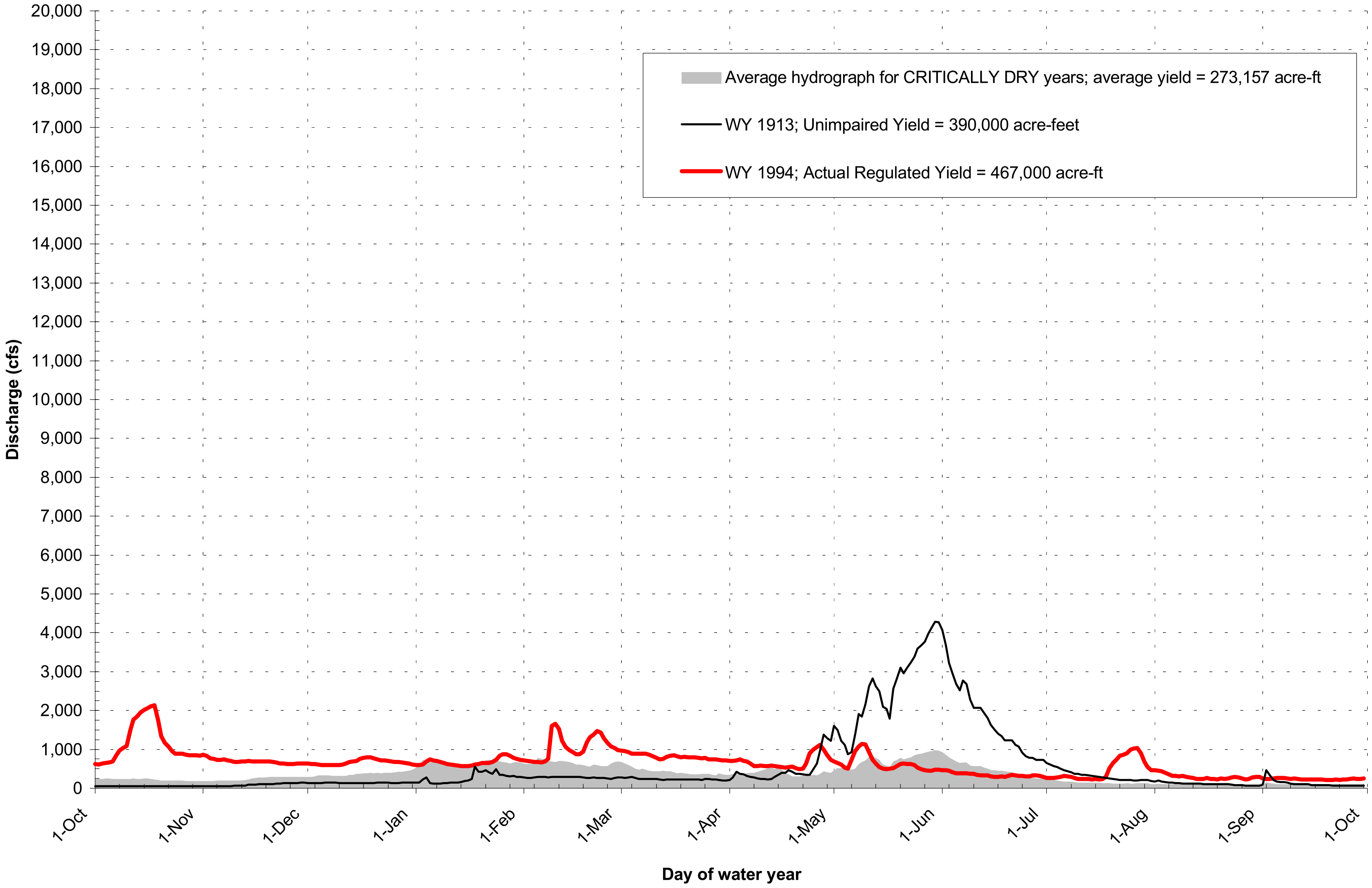

Figure 2-30. Average annual unimpaired hydrograph for a Critically Dry water year at the San Joaquin River at Newman gaging station. Representative Critically Dry water year hydrographs for Pre-Friant Dam (1913) and post-Friant Dam (1994) conditions are included.

- Median (pre-Friant) fall baseflows near Newman generally had a very narrow range during the pre-Friant period, ranging between 143-300 cfs. The maximum fall baseflows occasionally ranged as high as 1,000 cfs. Under regulated conditions, median fall baseflows also increased and ranged from 414-1,110 cfs. This increase is likely attributed to irrigation return flows from water imported via the Delta-Mendota Canal.
- Pre-Friant median winter baseflows were an order of magnitude larger than the summer/fall baseflows. The median winter baseflow for Extremely Wet years was 2,850 cfs, with a maximum baseflow of 3,970 cfs. Critically Dry and Dry median pre-Friant winter baseflows were 421 cfs and 713 cfs, respectively. Under regulated conditions (post-Friant Dam and post-New Exchequer Dam), both the magnitude and the range of winter baseflows were reduced, and ranged from 520-980 cfs during Critically Dry and Wet years, respectively. The primary cause of this reduction in winter baseflows was Friant Dam operation; however, a large but unknown cause was also likely the reduced flow contribution from the Kings River via Fresno Slough.

2.6.6.3.2. Fall and Winter Floods

- The fall flood hydrograph component appears to have been much less significant at the Newman gage than at Friant due to the vast flood storage in Reaches 2-5 attenuating peak flows moving downstream along the San Joaquin River. Pre-Friant streamflow regulation could also have reduced the magnitude of fall floods. The pre-Friant fall floods (peak daily average flow magnitude) ranged from 300-1,200 cfs, but did not appear to increase with wetter water years. Pre-Friant fall peak magnitudes increased slightly, ranging from 690-2,300 cfs, and again not increasing with wetter water years.
- Considering the location of the Newman gage below the Merced River confluence, winter storms were much smaller in magnitude than might be expected, compared to unimpaired peak magnitudes recorded at the Friant gage. Again, this factor is likely attributable to flood peak attenuation as floodwaters inundated floodplains and filled wetlands along the valley bottom, then were slowly released back into the channel. This effect reduced the overall magnitude of flood events, but increased the duration of winter floods. Daily average unimpaired winter floods ranged from 1,100-19,000 cfs during Critically Dry and Extremely Wet years, respectively, with the maximum daily average peak reaching 33,000 cfs in water year 1938.
- Regulation by Friant Dam and New Exchequer Dam appears to have had little effect in reducing winter flood magnitudes at the Newman gaging station. Median winter floods near Newman ranged from 1,100-24,000 cfs under regulated conditions. The flood of January 1997 reached 38,000 cfs near Newman, which is estimated to be approximately the 100-year flood (ACOE 1999). Flood flow contribution from the Kings River via Fresno Slough still occurs for winter storm events under present-day conditions (although probably reduced in magnitude by Pine Flat Dam), as opposed to the winter baseflow hydrograph component where significant flow reductions were likely significantly caused by reductions in Kings River contribution.
- A comparison of annual hydrographs for Friant and Newman indicates that antecedent conditions were an important factor determining the magnitude and duration of floods near Newman. Early winter floods appear to have been more readily absorbed by low-land floodplains and wetlands, and these early flood peaks near Newman were strongly dampened. Later in winter, however, relatively smaller peak magnitudes at Friant produced sustained-duration and higher peak floods near Newman as the downstream flood storage capacity of floodplains and wetlands was more readily exceeded.

2.6.6.3.3. Snowmelt Hydrograph

- Snowmelt floods near Newman varied widely under pre-Friant conditions, ranging from small floods of 1,300 cfs during Critically Dry years up to 16,500 cfs under Extremely Wet conditions. The maximum flood under unimpaired conditions was 25,000 cfs (WY 1938). The drought years of 1929-31 and 1934 did not have measurable snowmelt floods, and may have been more significantly influenced by instream diversions.
- Under regulated conditions, median snowmelt floods did not change appreciably during Extremely Wet and Wet water years (15,000-9,000 cfs, respectively), but were reduced considerably more during Normal to Critically Dry water years (3,000-900 cfs, respectively). The water year 1983 snowmelt flood of 24,900 cfs (daily average flow) was the largest snowmelt flood during the post-Friant Dam and post-New Exchequer Dam period.

2.6.7. Representative Annual Hydrographs

Tributary streams downstream of Friant Dam play an important role in delivering water to the mainstem San Joaquin River channel, particularly during storm runoff periods when flow releases from Friant Dam are minimal. Two tributaries, Cottonwood Creek and Little Dry Creek, are located in the immediate downstream reach below Friant Dam (see Figure 2-2 and Figure 2-3). These two tributaries are unregulated (with the exception of small watering ponds for livestock), so their natural flow pattern is more variable than the regulated release from Friant Dam. As such, the flow contribution from these tributaries can contribute peak flows during winter rainfall generated storms. The following discussion focuses on (1) Cottonwood Creek and Little Dry Creek, highlighting their relationships to mainstem San Joaquin River flows in the upper portion of the project reach; and (2) mainstem San Joaquin River gages to illustrate longitudinal gradient in hydrographs for the mainstem San Joaquin River. Representative hydrographs for the Friant gaging station (RM 266) and the Newman gaging station (RM 119) are not discussed in this section because they were discussed in the hydrograph component section, and all hydrographs for these two gaging stations over the entire period of record are included in Appendix A. Representative hydrographs for the Friant gaging station and Fremont Ford gaging station (RM 125) are provided to assess flood pulse lag time and potential changes in flood routing due to levees and other floodway manipulations.

2.6.7.1. Cottonwood Creek near Friant

Streamflow on Cottonwood Creek (drainage area = 35.6 mi^2) was recorded by the USGS from water year 1942 to water year 1951; the USBR has monitored the station since 1951. Although the USGS period of record does not provide enough pre-Friant information to perform a comprehensive hydrograph component analysis, the variability of water year types that can be classified as ranging from Extremely Wet to Critically Dry within this time provides an example of Cottonwood Creek's hydrology. For the measured period of record, we plotted all annual hydrographs (see Appendix A) and selected three that represent Extremely Wet, Normal, and Critically Dry water year types (1942, 1947, and 1948, respectively). These hydrographs illustrate the variability of streamflow hydrology in Cottonwood Creek, such as the timing and magnitude of flows delivered to the mainstem San Joaquin River during each of these water year types (Figure 2-31). Cottonwood Creek is dry most of the year, such that fish species that require year-round flow (e.g., steelhead) could not survive in most years without supplemental flows. Cottonwood Creek is extremely flashy in response to rainfall events, increasing from low flow to over 100 cfs in a short period of time (hours to a few days), with receding flows decreasing more gradually, but still dropping down to low baseflows in a matter of days. This pattern is characteristic of all rainfall dominated small streams draining the Sierra Nevada foothills.

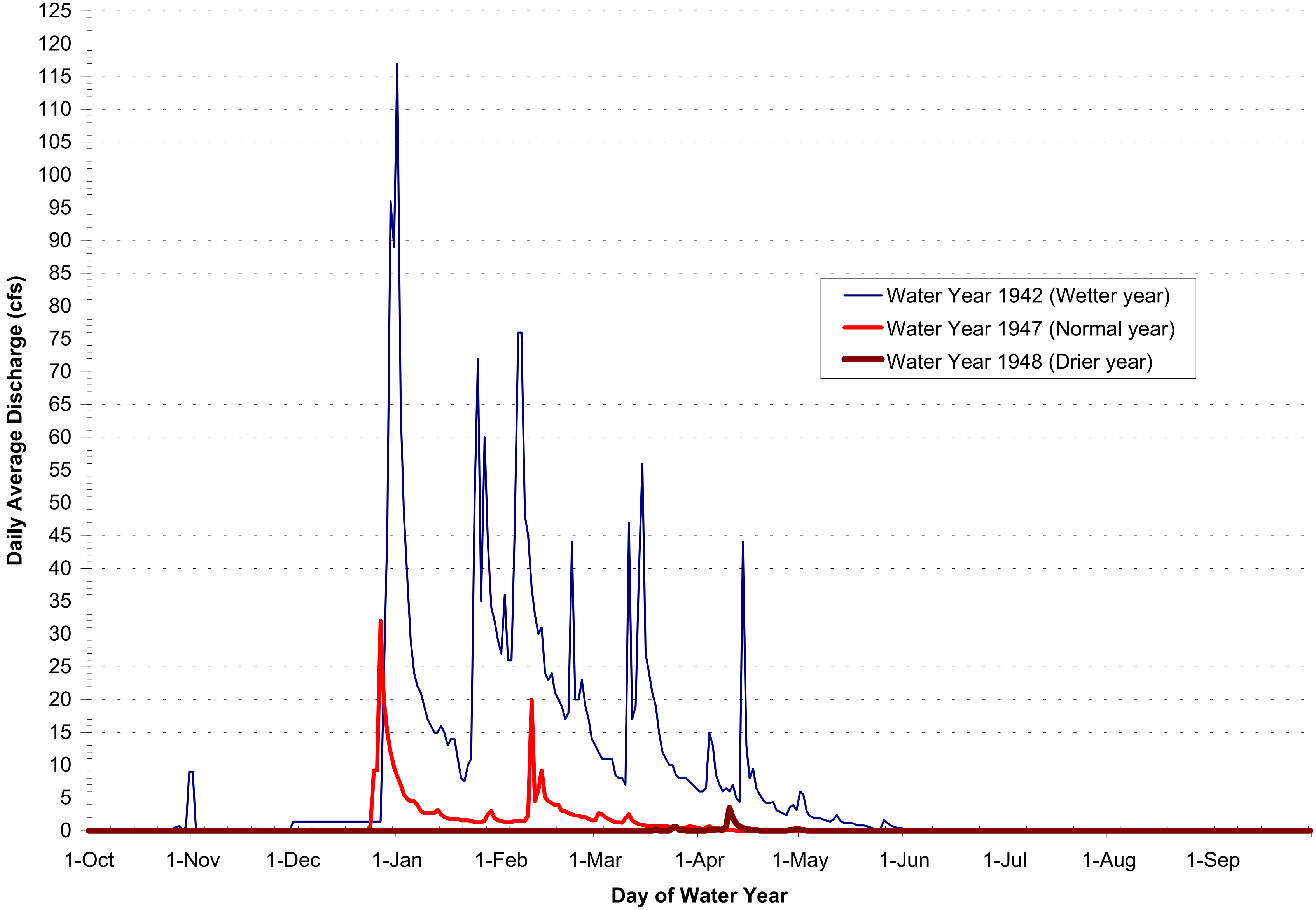

Figure 2-31. Cottonwood Creek near Friant, CA, annual hydrographs for Extremely Wet (1942), Normal (1947), and Critically Dry (1948) water year types.

2.6.7.2. Little Dry Creek near Friant

Streamflow on Little Dry Creek (drainage area = 57.9 mi^2) was recorded by the USGS from water year 1942 to water year 1956; the USBR has monitored the station since 1956. Similar to Cottonwood Creek, the USGS streamflow record is relatively short and does not provide enough information to perform a comprehensive hydrograph component analysis. However, the variability of water year types that can be classified as ranging from Extremely Wet to Critically Dry within this time provides an example of Little Dry Creek's hydrology. As with Cottonwood Creek, we plotted all annual hydrographs for the 1942-1956 period of record, and then selected three that represent Extremely Wet, Normal, and Critically Dry water year types (1942, 1944, and 1948, respectively). These hydrographs illustrate the variability of streamflow hydrology in Little Dry Creek, such as the timing and magnitude of flows delivered to the mainstem San Joaquin River during each of these water year types (Figure 2-32).

Because of its proximity to the Cottonwood Creek gage, we would expect the Little Dry Creek water year classifications that span the same time period (1942-1951) to match those for Cottonwood Creek. These gages are located so close to each other that they experience the same climatic events responsible for their runoff; therefore, the water year classifications should be similar. However, only three years classify as the same water year type for both records. The primary cause for this difference is likely that the short period of record for both gages captures less variability in flows than would otherwise be captured with a longer record. More specifically, the Cottonwood Creek record is 10 years, and the Little Dry Creek record is 15 years. The longer record for Little Dry Creek captures greater variability (thereby biasing its comparison with Cottonwood Creek) but is too short to accurately portray actual runoff conditions in the watershed. Other factors that may account for the difference between the gage can be attributed to the physical (geomorphic) differences between watersheds, such as drainage area size and aspect.

The larger drainage area of Little Dry Creek result in larger peak flows (up to 1,250 cfs in 1956) compared to Cottonwood Creek, but the pattern of long periods of low to zero flow still occurs. The lower portions of Little Dry Creek would be inhospitable to fish species requiring a year-round flow without supplemental flows, but the basin is large enough that upstream reaches have perennial flow based on field observations in August 2002 (B. Trush, pers. comm.).

2.6.7.3. Friant to Fremont Ford Hydrographs

Two methods were used to examine high flow routing relationships between Friant and downstream locations (1) empirical method comparing daily average hydrographs between the San Joaquin River at Friant gaging station (RM 266) and the San Joaquin River at Fremont Ford (RM 125) gaging station, and (2) high flow routing modeling. The flow magnitude and travel time of peak flows at Friant Dam and Fremont Ford was analyzed to determine the changes in flow peak attenuation and travel time caused by Friant Dam and the flood control system downstream of Friant Dam. The periods of record for the two gages that overlapped (water years 1938-43; 1950-71) were used, and each annual hydrograph was examined for discrete high flow events at Friant Dam that produced a subsequent high flow peak at Fremont Ford. The dates and magnitudes of these peaks were compiled for each of the gages, then plotted to determine the relationship between upstream and downstream peak flow magnitudes and timing. Because the travel distance between the two gages was so large (140 miles), daily average hydrographs provided adequate resolution to assess changes in flow magnitude and travel time, thus hourly flow data was not necessary. For the pre-Friant Dam period with moderately-regulated hydrographs, paired high flow peaks between the two gaging stations were more common, and 20 data points were identified. During the post-Friant record, the effects of regulation severely altered the shape of almost all peak hydrographs, and only six discrete peak

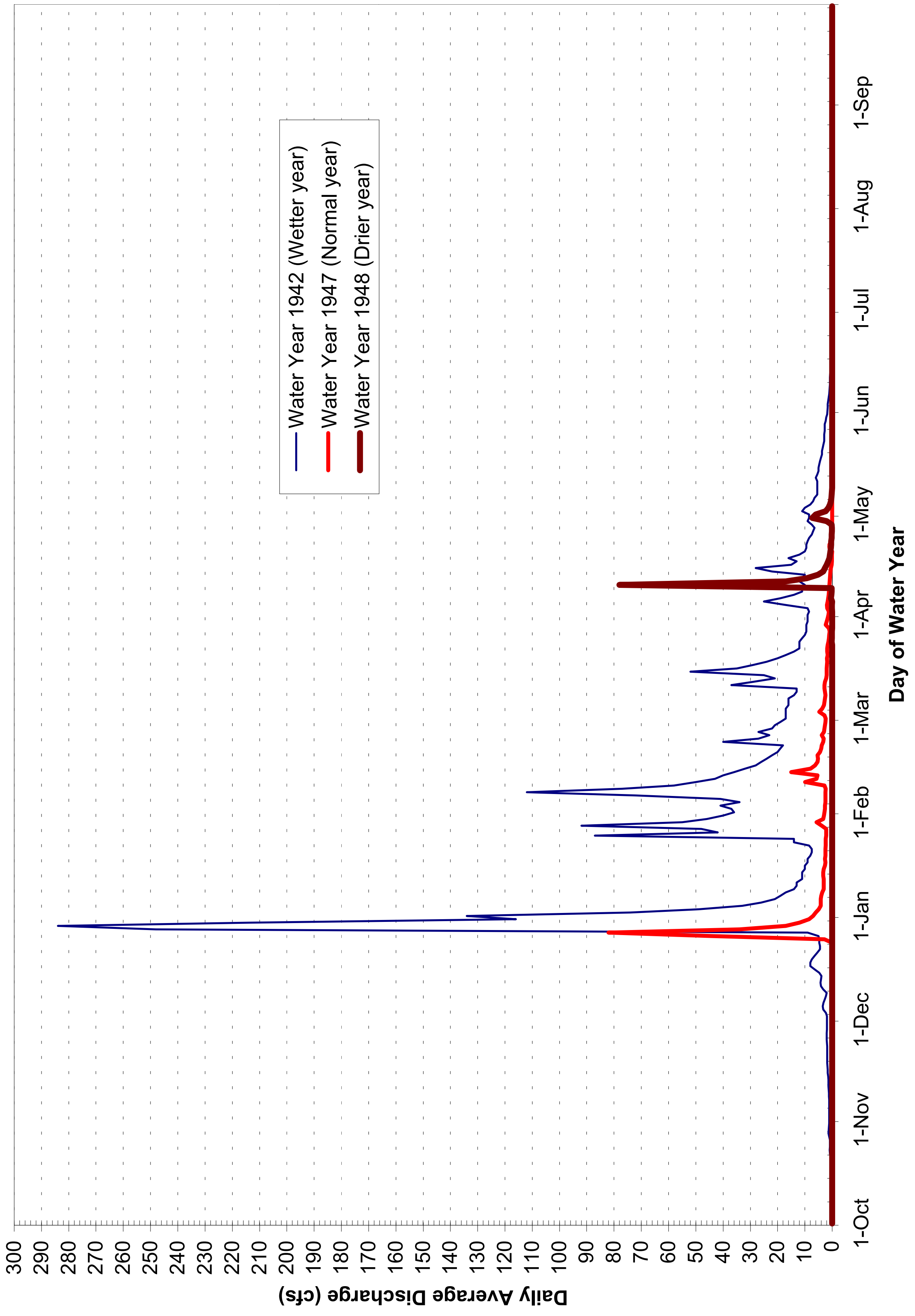

Figure 2-32. Little Dry Creek near Friant, CA, annual hydrographs for Extremely Wet (1942), Normal (1947), and Critically Dry (1948) water year types.

events from 26 water years contained a distinct connection upon which magnitude and travel time differences could be compared. Both the Pre-Friant Dam hydrographs are shown on Figure 2-33 and post-Friant hydrographs shown in Figure 2-34.

During unregulated conditions, there appears to have been an upper limit in peak discharge at the San Joaquin River at Fremont Ford gaging station, relatively independent of discharge from Friant Dam (Figure 2-35). Peak discharges ranging from 5,000 cfs to 20,000 cfs at Friant consistently produced peak flows up to, but rarely exceeding 5,500 cfs at Fremont Ford. The ratio of Friant to Fremont Ford discharge was 2.8. The range of flood peak magnitudes occurring in the post-Friant Dam period was much lower than the pre-dam period, ranging up to only a 7,980 cfs peak at the Friant gage. During the post-dam period, the peak discharge data points were clustered within the pre-Friant Dam data (Figure 2-35), but the ratio of Friant to Fremont Ford discharge was closer to one (1.4). The USGS water resources records state that for the Fremont Ford gaging station, “during periods of high flow, water bypasses this station through Mud Slough.” This undefined high flow bypass is likely a leading cause of the approximate 5,500 cfs cap at the Fremont Ford gage, but because Mud Slough was not gaged during this period, the degree of flow bypass (and flow threshold for beginning to bypass) cannot be determined.

The travel time for floods from Friant Dam to Fremont Ford was relatively consistent under the pre-Friant Dam period, ranging from 6-10 days, with a median (and mean) of 7 days. One outlier was identified from water year 1938, in which a December 11, 1937 flood peak of 45,700 cfs at Friant Dam caused only a 3,500 cfs peak at Fremont Ford (Figure 2-36). Overlaying more recent travel times under the post-Friant Dam period suggest that the travel time is slightly less, ranging from 1-8 days, with a median of 5 days. This slight decrease is not conclusive due to the small number (8) of high flow peaks compared.

The hypothesis being evaluated in this travel time assessment is that the increased confinement along the lower San Joaquin River between the two gaging stations has reduced travel time of flood peaks and reduced the amount of flood peak attenuation provided by the large-scale flood basins that were historically flooded. Unfortunately, the small number of data points available for the post-Friant Dam evaluation is too small (eight high flow peaks) to make any definitive conclusions about changes in travel time or flood magnitude. Other sources of variability that hampered this comparison include the following:

- in the pre-Friant Dam period, there may have been several other tributaries (e.g., Fresno River) that contributed to flood peaks at Fremont Ford, increasing the difference in magnitude and travel time between Friant and Fremont Ford (i.e., making the data more random, and less dependent upon overbank flood storage).
- in the post-Friant Dam period, most or all of these other tributaries are now regulated by a large storage dam, so there is a better relationship between the Friant and Fremont Ford peak magnitudes (and shorter travel time).

2.7. FLOW ROUTING

This section provides broad flow routing processes under historical and existing conditions between Friant Dam and the Merced River confluence. There are two primary components of flow routing: baseflows and flood flows. The descriptions of baseflow routing are based on historical accounts and maps from early explorers, aerial photographs, and gaging stations. The descriptions of flood flow routing are based on historical accounts and maps from early explorers, aerial photographs, gaging stations, and modeling.

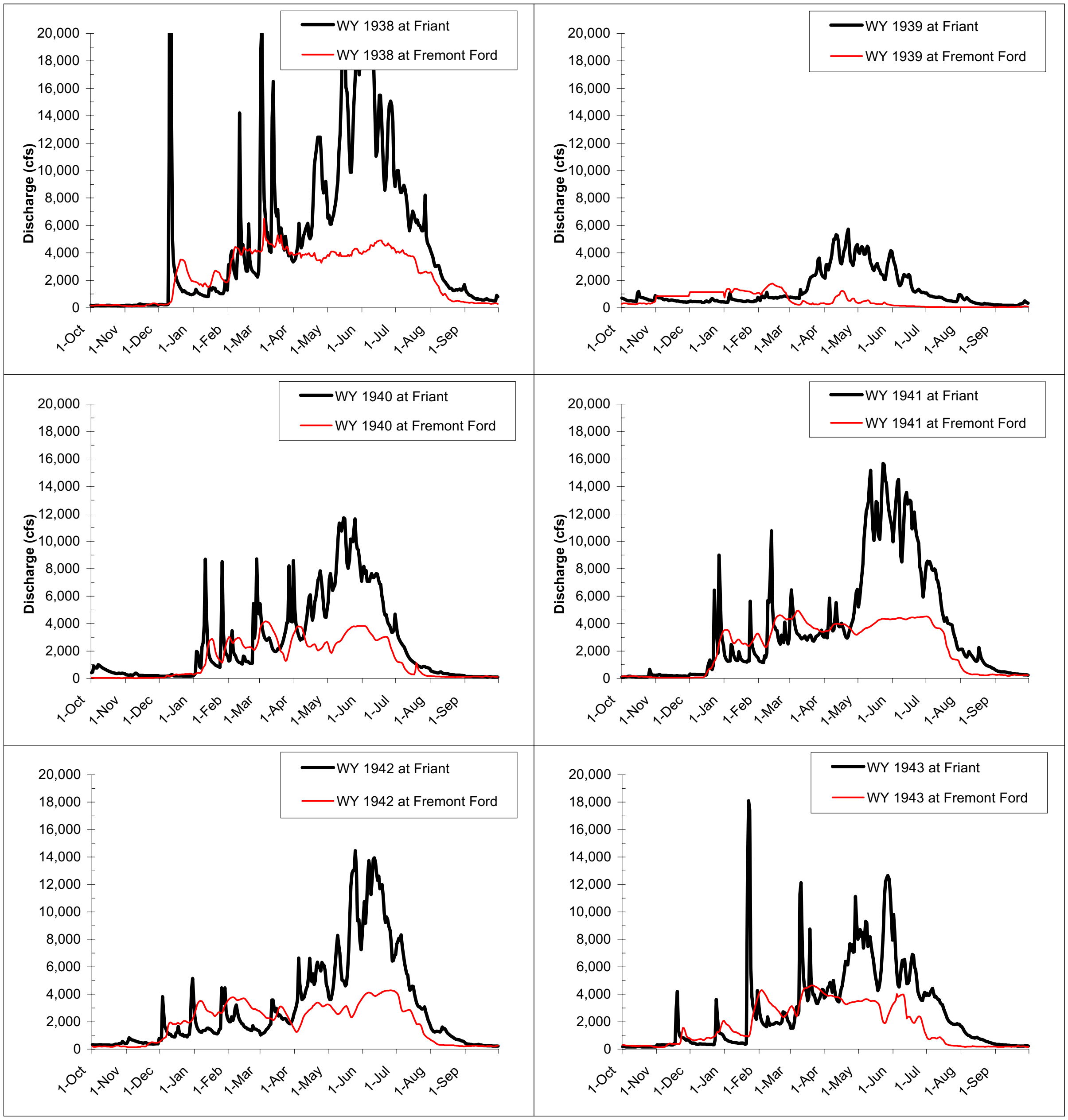

Figure 2-33. Overlay of annual hydrographs at the San Joaquin River at Friant gaging station and San Joaquin River at Fremont Ford gaging station (1938-1943), showing pre-Friant Dam peak flow magnitude and travel time for specific high flow events.

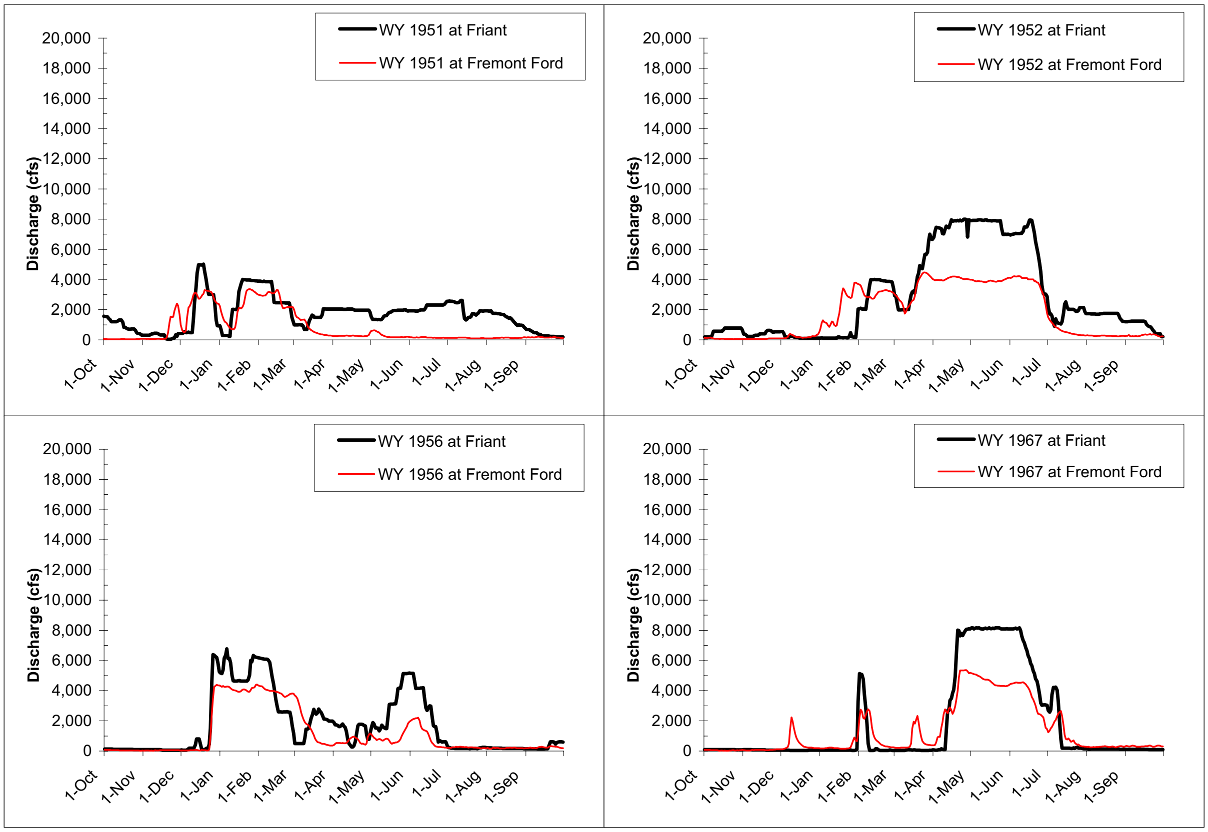

Figure 2-34. Overlay of annual hydrographs at the San Joaquin River at Friant gaging station and San Joaquin River at Fremont Ford gaging station (1951, 1952, 1956, 1967), showing post-Friant Dam peak flow magnitude and travel time for specific high flow events.

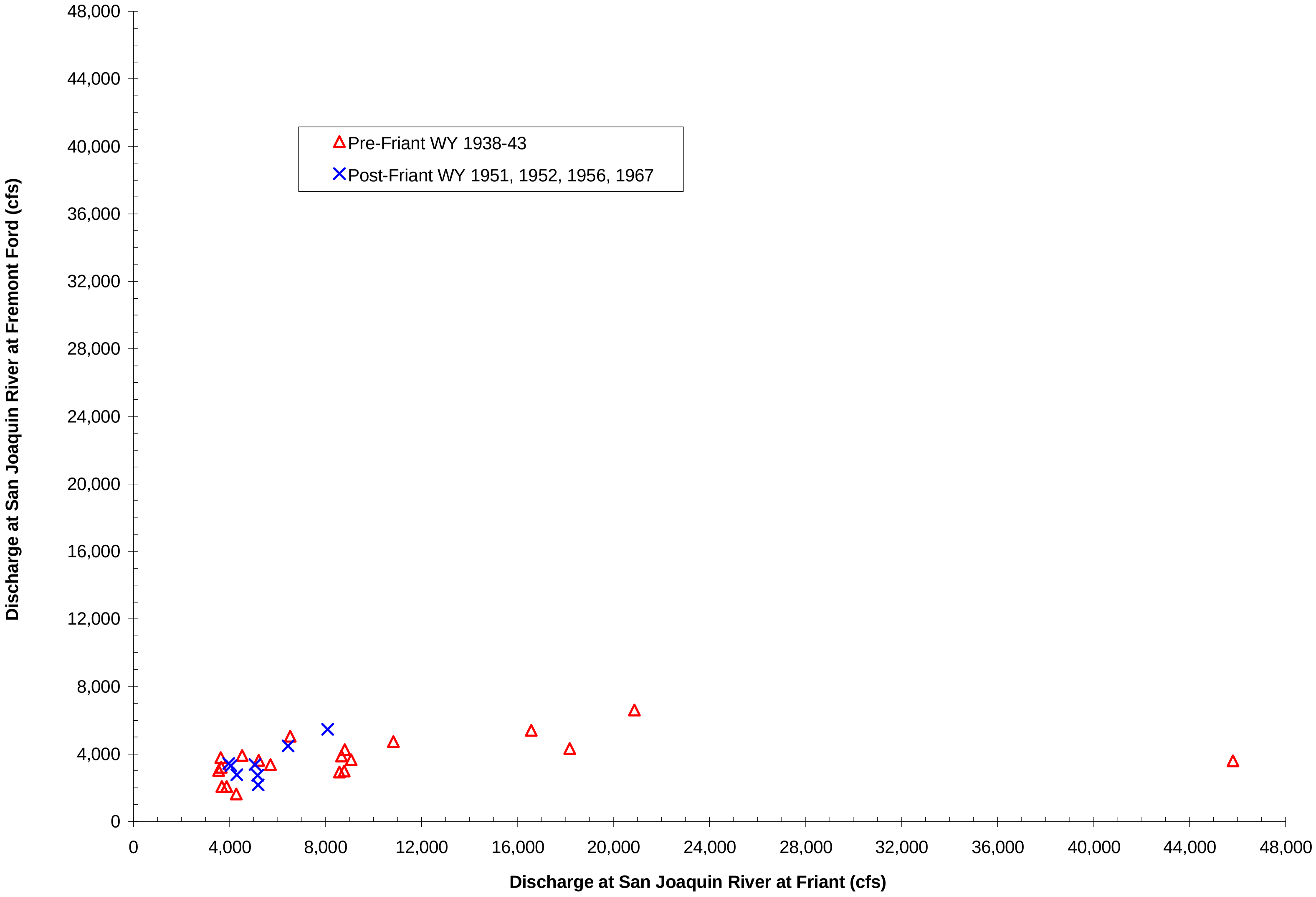

Figure 2-35. Comparison of flood magnitude between the San Joaquin River at Friant gaging station and San Joaquin River at Fremont Ford gaging station under pre-and post-Friant Dam periods. Hydrographs in Figures 2-33 and 2-34 are used.

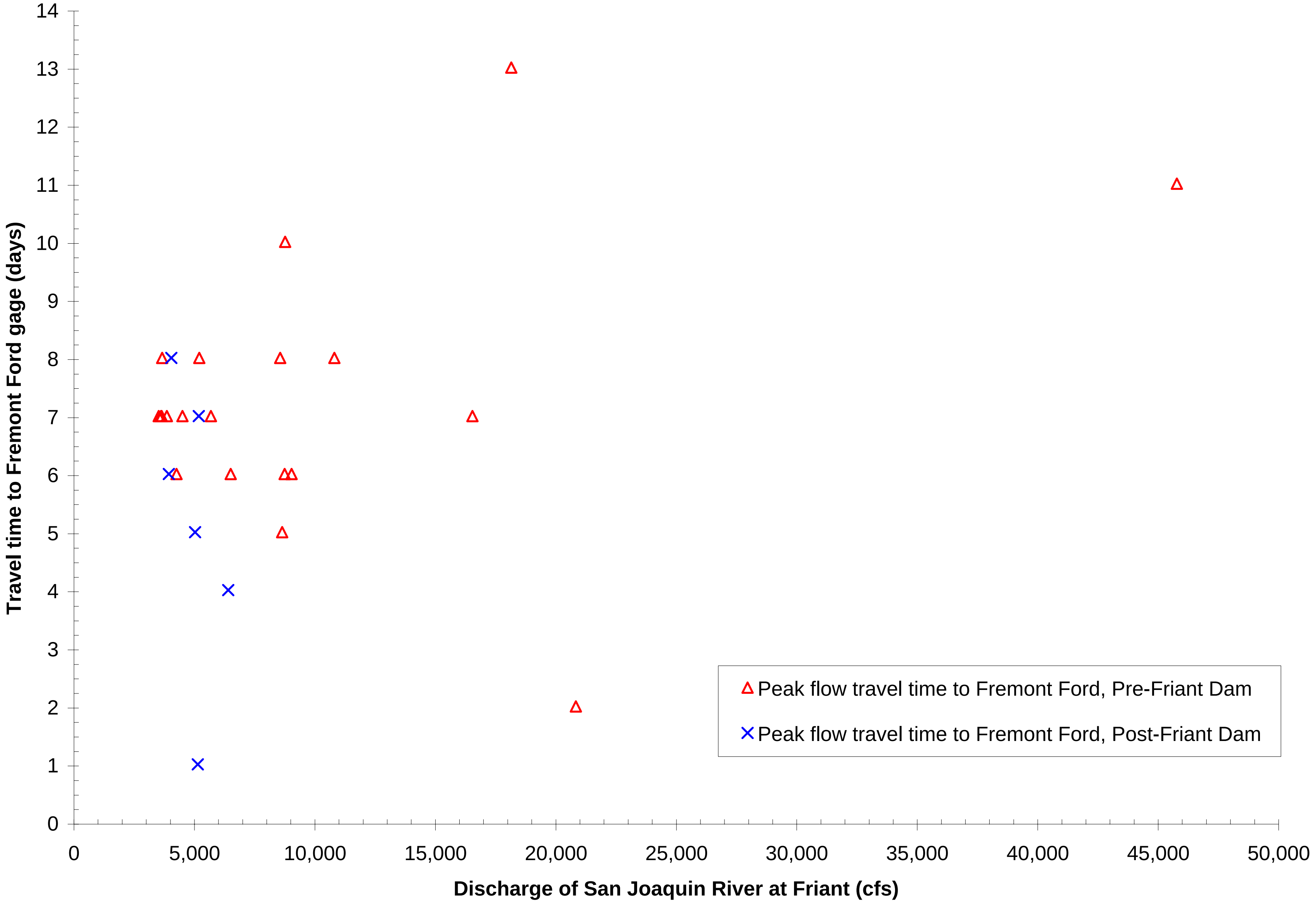

Figure 2-36. Comparison of travel time between the San Joaquin River at Friant gaging station and San Joaquin River at Fremont Ford gaging station under pre-and post-Friant Dam periods. Hydrographs in Figures 2-33 and 2-34 are used.

2.7.1. Historical and Existing Baseflow Routing

Historical baseflows were most likely contained within the San Joaquin River channel(s) between Friant and the Merced River confluence. Most early maps clearly show that baseflows were contained within a single channel of the San Joaquin River, or in two or more secondary channels (e.g., Lone Willow Slough in Reach 2 and 3, Santa Rita Slough in Reach 3, Salt Slough in Reach 3 and 5) as shown on Government Land Office plat maps, Hall (1878) maps, and Derby (1952) maps. Derby's 1852 map shows channels passing from the San Joaquin River to the Fresno Slough; however, review of historical aerial photographs shows that these channels did not convey baseflows as observed in the 1937 aerial photographs, and thus these channels are likely high flow sloughs (see Figure 2-37). There has been some inference that there was baseflow contribution from the Tulare Lake basin groundwater from an anonymous reference in 1873 (as cited in Fox 1987a):

> *the San Joaquin River receives an important accession of volume from underground drainage-probably from the Tulare Lake drainage*

Review of the Hall (1878) and ACOE (1917) maps, combined with descriptions of the artesian springs along the San Joaquin River in Reaches 2-5, suggests that baseflow contribution from groundwater sources was likely dominated by artesian springs along the river corridor rather than underground drainage from the Tulare Lake basin. This baseflow contribution, as well as gaining and losing reaches under historical and existing conditions, is discussed further in Chapter 4.

Under existing conditions, baseflow magnitude and routing has changed considerably as a result of infrastructure development in the San Joaquin Valley (see Chapter 5). Baseflows are still conveyed by the San Joaquin River, but several differences have occurred:

- The magnitude of baseflows has changed, with baseflows decreased in Reach 1, 2, 4, and 5, and baseflows increased in Reach 3 due to Delta-Mendota Canal water deliveries to Arroyo Canal.
- The number of secondary channels conveying baseflows have decreased as they have been converted to agricultural return channels or reclaimed (filled) for agriculture.
- The routing of baseflows has changed drastically as a result of the irrigation flow distribution system.

Current baseflows along the San Joaquin River are summarized in Table 2-11. Estimated unimpaired baseflows at the San Joaquin River at Friant gaging station are also provided in Table 10. Pre-Friant Dam flows were examined at the downstream end of the study reach (at Fremont Ford from 1938-1943), but those baseflows were lower than those at Friant due to agricultural diversions; therefore, unimpaired discharges downstream of Friant were simply listed as "greater than Friant". Current typical seasonal flow distribution is provided for Friant Dam in Figure 2-38, and at Mendota Pool in Figure 2-39.

2.7.2. Water Budget and San Joaquin River Model

In order to model existing and future flow routing through the study area, a water budget analysis was conducted for subreaches between Friant Dam and the Merced River confluence. This information was also used in the development of the San Joaquin River Model. The San Joaquin River Model was constructed to model the daily or monthly flow patterns (hydrographs) that are required to achieve some of the specified quantitative restoration objectives of the Restoration Study. The daily flow and water budget model components provide the basis for calculations of streamflow and associated riparian conditions that depend on the flow or hydraulic parameters along the San Joaquin River channel.

Table 2-11. Typical seasonal flows in different reaches of the San Joaquin River based on trends observed in USGS gaging station data and from descriptions of flow by local irrigation district staff.

UNIMPAIRED TYPICAL BASEFLOWS			EXISTING TYPICAL BASEFLOWS		Comments on existing typical baseflows
Reach	Unimpaired summer/fall baseflows (cfs)	Unimpaired winter baseflows (cfs)	Summer flows during the irrigation season (cfs)	Winter flows during the non-irrigation season (cfs)	
1A	340[1]	780[1]	200-300	50-100	Riparian diversions and infiltration losses
1B	340	780	5-200	5-50	Riparian diversions and infiltration losses
2A	>340	>780	0-20	0-20	0-20 cfs flow at Gravelly Ford (upstream end of Reach 2A)
2B	>340	>780	0	0	Downstream of Chowchilla Bifurcation Structure
3	>340	>780	500	200	Delta Mendota Canal water delivered to Arroyo Canal
4A	>340	>780	0	0	Some seepage and flow accretion occurs, but is pumped from river at many locations through reach
4B	>340	>780	0-10	0-10	Control structure at entrance prevents any flows from entering from upstream reach, agricultural return flows re-water channel downstream of Mariposa Bypass
5	>340	>780	0-60	0-60	Agricultural return flows

[1] From median values of hydrograph component analysis at San Joaquin River at Friant gaging station

2.7.2.1. Water Budget Methods

An annual water budget analysis was prepared using the available gage data and results of previous analyses by MEI (2000a, 2000b). The analysis was based on the period of record between 1986 and 1999. The estimated natural flow at Friant Dam was derived from a synthetic record that was provided by the USBR and Mr. Huxley Madeheim. This record represents the best available estimate of the amount of flow that would have occurred at that location in the absence of the upstream storage and flow regulation projects. This is the only location for which an estimate of the unimpaired flows is available. The 1986-1999 period includes a severe six-year drought (in addition to some of the wettest years in the mid to late 1990's), so this period should cover the range of climatic conditions experienced over the long term on the San Joaquin River. The average unimpaired runoff in the 1986-99 period was about 98% of the 1901-2000 average; this period had more winter runoff than the longer term average, and had a greater number of dry and wet years (5 Extremely Wet, 1 Wet, 1 Normal, 1 Dry, 6 Critically Dry). The existing conditions (i.e., 1986-1999) flows in each subreach were estimated as follows:

- **Friant Dam**—from the USGS record of mean daily flows at the Friant gage.
- **Gravelly Ford**—Friant Dam flows modified by the flow loss curves for the Friant Dam to Gravelly Ford reach (Figure 2-4).
- **San Joaquin River upstream from the Chowchilla Bifurcation Structure**—Gravelly Ford flows modified by the flow loss curve for the Gravelly Ford to Chowchilla Bifurcation Structure reach (Figure 2-4).

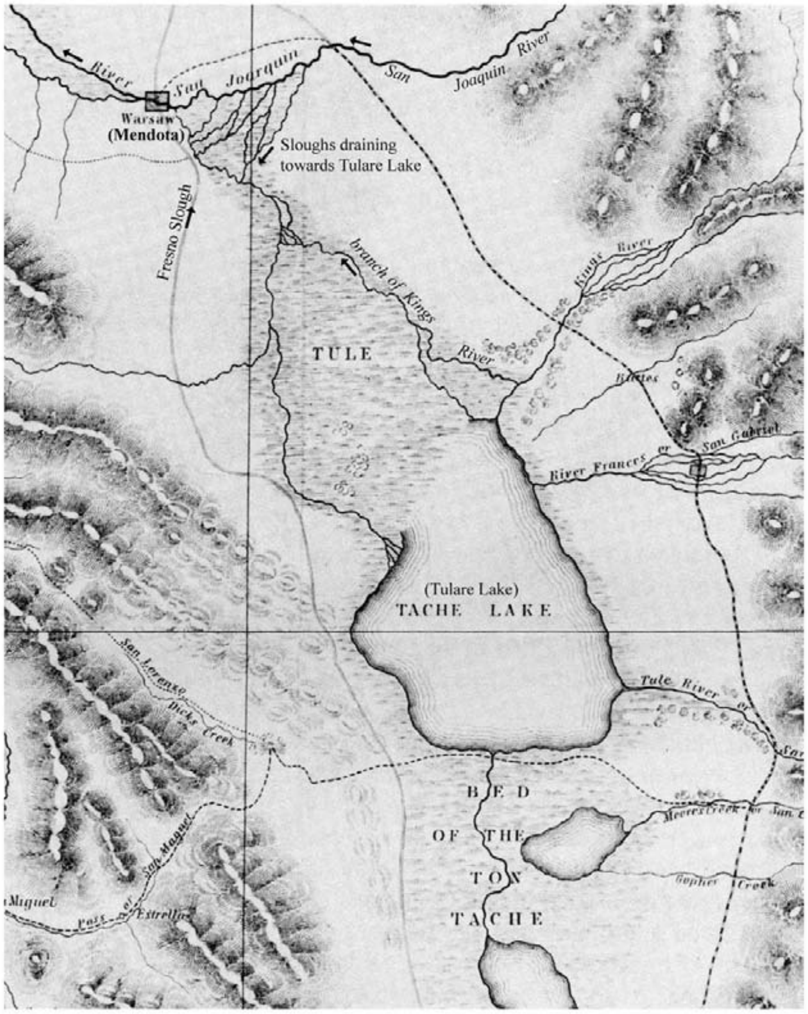

Figure 2-37. 1852 map of the San Joaquin River between present-day Friant and Firebaugh, showing sloughs draining towards Tulare Lake, and Fresno Slough draining towards the San Joaquin River from the Kings River.

- **Chowchilla Bifurcation Structure to head of Mendota Pool**—Estimated flows in the river upstream from Chowchilla Bifurcation Structure, less measured flows in the Chowchilla Bypass where data were available. Where data were not available, flows in the river downstream from the Chowchilla Bifurcation Structure were estimated based on the “initial flow to the river” operating rule.
- **Mendota Dam to Sack Dam**—The San Joaquin River near Mendota gage was used to represent the flows in this subreach. Missing data were estimated by interpolation.
- **Sack Dam to Sand Slough Control Structure (Node 5-6)**—Where available, the flows in this subreach were estimated using the recorded flows at the San Joaquin River near Dos Palos gage. Flows during other periods were estimated using the assumption that all flow in the upstream river would be diverted into the Arroyo Canal up to the approximate canal capacity of 600 cfs.

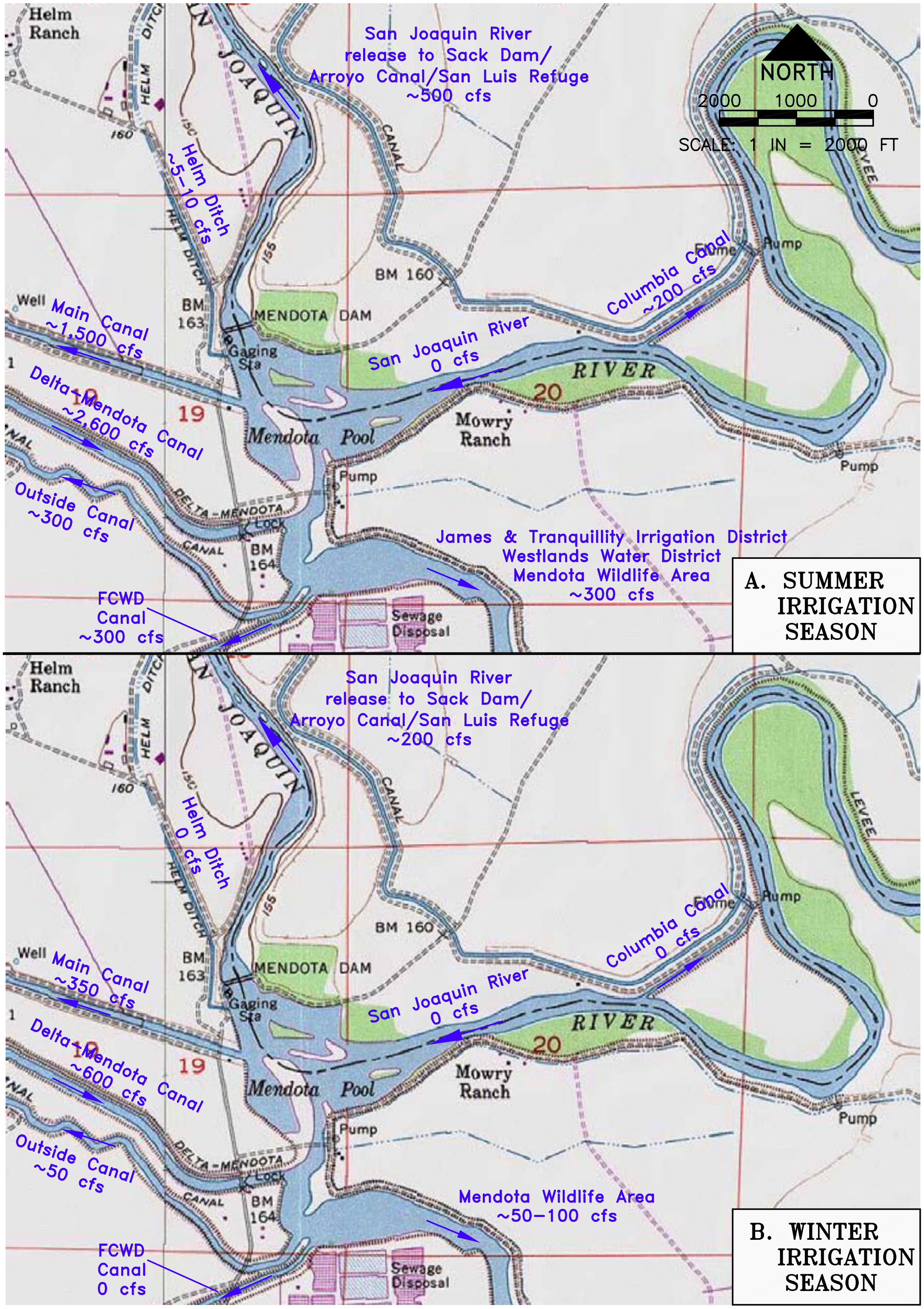

Figure 2-38. Diagrammatic of typical river releases and diversions from Friant Dam during summer irrigation season and winter non-irrigation season.

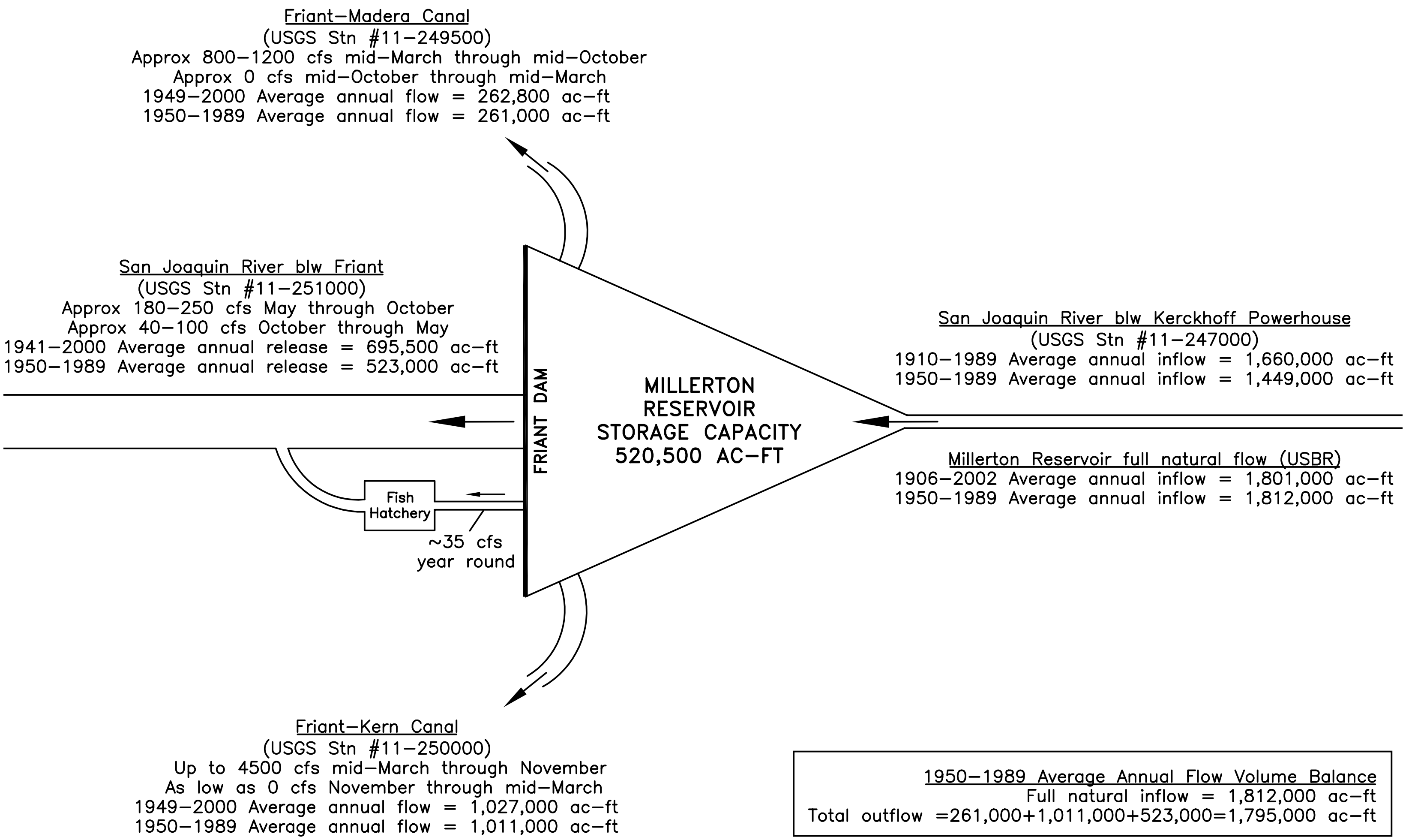

Figure 2-39. Schematic diagram of typical river releases and diversions from Mendota Dam during summer irrigation season and winter season. Winter diversions and releases are largely for wildlife refuges.

- **Sand Slough Control Structure to Mariposa Bypass**—No direct flow records are available for this reach. Consequently, the flow estimates were made by subtracting the flow in the Mariposa Bypass from the estimated flows in the Mariposa Bypass to Bear Creek Reach (see below), with the flows shifted by 1 day to account for the travel time.
- **Mariposa Bypass to Bear Creek**—Flows in this subreach were estimated by subtracting the total flow in Bear Creek at the mouth from the recorded flows at the San Joaquin River near Stevinson gage.
- **Bear Creek to Salt Slough**—The recorded flows at the San Joaquin River near Stevinson were used for this subreach.
- **Salt Slough to Mud Slough**—Flows in this subreach for water years 1986 through 1989 were derived from the San Joaquin River at Fremont Ford Bridge gage record or from the recorded flows in Salt Slough and the recorded flows at the San Joaquin River near Stevinson gage.
- **Mud Slough to Merced River confluence**—Flows in this subreach for water years 1986 through 1995 were estimated by subtracting the recorded flows at the Merced River near Stevinson gage from the recorded flows at the San Joaquin River near Newman.
- **Downstream from Merced River**—Flows downstream from the Merced River were derived from the San Joaquin River near Newman gage record.

The accuracy of the restoration simulations depend on the flow and hydraulic geometry calculations because all other simulated river variables are dependent on these hydraulic parameters (i.e., depth and velocity). The daily flow and water budget model consists of the following elements:

- managed (i.e., controlled) release of water from Friant Dam, Chowchilla Bifurcation Structure (both into the San Joaquin River and into the Chowchilla Bypass), Mendota Pool, Sack Dam, and the Sand Slough gate;
- tributary inflows from Cottonwood, Little Dry, and Bear Creeks; Salt and Mud Sloughs; the Merced River; other local runoff or irrigation returns; and Eastside Bypass return flows during high-flow events, as well as Delta-Mendota Canal inflow to Mendota Pool (considered a tributary inflow that must be specified);
- agricultural diversions (i.e., pumps) along the San Joaquin River, canals that divert from Mendota Pool and Sack Dam (Arroyo Canal), and the flood control diversions into the Chowchilla and Eastside Bypasses (during high-flow events);
- evapotranspiration losses from the water and riparian vegetation along the San Joaquin River channel;
- seepage along the San Joaquin River channel caused by infiltration to groundwater or discharge from the shallow groundwater to the stream channel;
- measured streamflow losses; and
- temporary storage of water in the alluvial deposits along the riparian corridor as streamflow (i.e., stage) increases and subsequently declines during a storm event or pulse flow period. This alluvial storage may occur in ponds along the stream or within the gravel beds of the river alluvium.

The methods and assumptions for estimating these daily water budget terms are described in the remainder of this section.

2.7.2.2. Managed Releases of Water Assumptions

Managed releases of water from Friant Dam, Chowchilla Bifurcation Structure, Mendota Pool, Sack Dam, and the Sand Slough gate can be specified in San Joaquin River Model. Appropriate values for these flows were estimated using measured data. The San Joaquin River flow changes downstream from these release points were estimated in the water budget calculations.

Releases from Friant Dam supply riparian diversions along the San Joaquin River downstream to Gravelly Ford, the downstream end of Reach 1. There is a flow gage below Friant Dam and another flow gage at Gravelly Ford, with a nominal flow target of 5 cfs year-round. The flow through the California Department of Fish and Game Friant Fish Hatchery (currently 35 cfs) is discharged into the San Joaquin River approximately one mile downstream from Friant Dam. The hatchery flow is measured at the Friant Dam flow gage and is included in the USBR records of Friant Dam releases. During dry years, the seasonal pattern of releases can be used to estimate the net effects of diversions, evapotranspiration, and seepage along this 40-mile river segment (i.e., Reach 1). Separating diversions from seepage and evapotranspiration is more difficult.

Higher releases than those necessary for supplying riparian diversion are made from Friant Dam only when large rainfall events and anticipated snowmelt conditions force flood control releases. During high-flow events, the Chowchilla Bifurcation gates are used to divert water from the San Joaquin River into the Chowchilla Bypass and subsequently into the Eastside Bypass floodways. The Eastside Bypass flows return to the San Joaquin River at the Mariposa Slough confluence and at the Bear Creek confluence in Reach 5 (MEI 2000a, MEI 2000b).

The Delta-Mendota Canal delivers water from the Tracy Pumping Plant to the water districts that are collectively known as the exchange contractors. The Delta-Mendota Canal supplies water to the river at Mendota Pool, where a majority of the irrigation canals divert water. Some water is released from Mendota Pool and flows downstream in Reach 3 to Sack Dam and into the Arroyo Canal. Releases from Sack Dam at RM 182 are generally very small (leakage). Normally, most of the flow is diverted into the Arroyo Canal. However, during flood events, the flow past Sack Dam is recorded at the Dos Palos gage. Flood flows are generally diverted into the Eastside Bypass at the Sand Slough Control Structure at RM 168. Releases of water into the San Joaquin River channel downstream of the Sand Slough Control Structure are controlled by a gate; local landowners indicate that these gates have not been opened since at least before the 1997 flood. Flood flows from the Eastside Bypass return to the San Joaquin River in the Mariposa Bypass at RM 147 and the downstream end of the Eastside Bypass (Bear Creek confluence) at RM 136.

Historical daily flow records are available from below Friant Dam, at Gravelly Ford, at the Chowchilla Bifurcation, below Mendota Pool, below Sack Dam at Dos Palos (during high-flow periods), and at the Stevinson gage (downstream of the Eastside Bypass) in Reach 5. The historical flow records can be used to characterize the net flows along the San Joaquin River, but several reaches do not have sufficient concurrent flow data to adequately estimate flow losses (e.g., Reach 4 and Reach 5).

2.7.2.3. Agricultural Diversions Assumptions

Monthly estimates of agricultural diversions from the San Joaquin River are included in the San Joaquin River Model. DFG staff has provided a listing of diversion pumps and canals, based on comprehensive river surveys, but with only limited estimates of the capacity for diversion at each structure. Agricultural diversions are generally operated to satisfy a seasonal demand that follows the evapotranspiration pattern for the riparian vegetation. It is therefore difficult to distinguish between diversions and riparian evapotranspiration.

Table 2-12 gives the locations and sizes of the pumps identified by DFG along the San Joaquin River between Friant Dam and Gravelly Ford. If the diversion pipe size was measured, an assumed velocity of 5 feet per second (ft/sec) was used to calculate the diversion capacity. The actual water velocity in the pump will depend on the pump horsepower and the head (elevation difference) between the river and the discharge. If the horsepower of the pump was recorded (nameplate value), an assumed head of 20 feet was used to estimate the capacity of the diversion.

When aggregated by river mile, the potential diversion capacity between Friant Dam and Gravelly Ford was estimated to be 520 cfs (RM 229), much more than the maximum actual summer diversion rate of up to 200 cfs. The potential diversion capacity is larger than the actual net diversion because not all diversions are continuously operating at full capacity, and agricultural return flows allow re-use. The identified locations of the pumps were used to estimate the location of the main diversions along the San Joaquin River. As indicated in Table 2-12, the simulated diversions were assumed to be located at eight discrete river mile segments where the largest diversions were identified in the DFG survey. The percent of Reach 1 flow loss estimated in the model was longitudinally distributed by the concentration of pumps and their respective proportion of total pumping capacity (last column in Table 2-12).

The Delta-Mendota Canal deliveries and canal diversions from the Mendota Pool were not simulated. The release from the Mendota Dam to the Arroyo Canal, located at Sack Dam (Reach 3) was specified, based on the historical flows measured below Mendota Pool. Almost all of the San Joaquin River flow is diverted into the Arroyo Canal at Sack Dam, except during flood events. For restoration simulations, flow releases from Sack Dam and from the Sand Slough gate are specified. Agricultural diversions downstream of Sack Dam are limited because there is usually little dependable flow downstream of Sack Dam in the summer.

2.7.2.4. Evapotranspiration Loss Assumptions

Evaporation from the water surface of the river and adjacent ponds is a seasonal pattern that can be estimated from the surface area of the water and the measured seasonal evaporation rate (in inches per day [in/day]). Evaporation depends slightly on the water temperature, and the temperature model could calculate the rate of evaporation. However, a regional estimate, based on evaporation pan or meteorological measurements, is used in the model. Table 2-13 shows the average evaporation rates for the San Joaquin River region, calculated from the meteorological data (including effects of air temperature, solar radiation, wind, and humidity). The maximum monthly value in July is about 9 inches (0.30 in/day). The minimum value in December and January is approximately 1.0 inch (0.03 in/day). Evaporation is therefore expected to be about 10 times greater in the summer than in the winter. Transpiration from vegetation along the riparian corridor follows a similar seasonal pattern, although the riparian area and the rate of transpiration are more difficult to estimate. For restoration simulations, the San Joaquin River Model assumes that a fixed additional river width (or acres per mile) with a transpiration rate equal to the specified evaporation rate contributes to the evapotranspiration losses along the San Joaquin River. For the 40 river miles between Friant Dam and Gravelly Ford, which have an estimated river width of 200 feet (i.e., 969 acres), the maximum evapotranspiration loss is approximately 10 cfs.

Table 2-12. Estimates of diversions in Reach 1 from 2001 DFG surveys.

River Mile	Intake Size (Inches)	Horsepower (Hp)	A Estimated Flow From Intake Size (cfs)	B Estimated Flow From Horsepower (cfs)	Maximum of Columns A & B (cfs)	Sum by River Mile (cfs)	Cumulative Percent of Total Diversions	Percent Used in the Model
266.57 L	8		1.74		1.74	1.74	0.31%	
265.73 L	12		3.93		3.93			
265.20 L	7	15	1.34	5.25	5.25			
265.19 R	15	123	6.13	43.05	43.05			
265.13 R	12		3.93		3.93			
265.13 R	12		3.93		3.93			
265.13 R	12		3.93		3.93	64.00	11.51%	
264.75 L	7		1.34		1.34	1.34	11.75%	
263.45 R	12		3.93		3.93			
263.45 R	12		3.93		3.93			
263.06 L	12		3.93		3.93	11.78	13.81%	
262.72 R	6		0.98		0.98			
262.46 L	6		0.98		0.98			
262.46 L	10		2.73		2.73			
262.31 L	10		2.73		2.73			
262.16 R	36	10	35.33	3.50	35.33	42.74	21.30%	20%
261.65 L	8	10	1.74	3.50	3.50			
261.25 L	3		0.25		0.25			
261.21 R	12	25	3.93	8.75	8.75			
261.05 R	24	75	15.70	26.25	26.25			
261.00 L	8		1.74		1.74			
261.00 L	8		1.74		1.74	42.23	28.69%	
260.25 R	7	75	1.34	26.25	26.25			
260.25 R	7	75	1.34	26.25	26.25	52.50	37.89%	
259.95 L	3		0.25		0.25			
259.77 L	9	10	2.21	3.50	3.50			
259.67 L	10		2.73		2.73			
259.48 L	6	7.5	0.98	2.63	2.63			
259.48 L	10	7.5	2.73	2.63	2.73			
259.48 R	6	75	0.98	26.25	26.25			
259.47 L	10	60	2.73	21.00	21.00			
259.20 R	4	5	0.44	1.75	1.75			
259.00 L	7	20	1.34	7.00	7.00			
259.00 R	4	15	0.44	5.25	5.25	73.07	50.69%	30%
258.70 L	12	15	3.93	5.25	5.25	5.25	51.61%	
257.49 R	30	50	24.53	17.50	24.53	24.53	55.90%	5%
256.77 L	8		1.74		1.74			
256.33 R	7		1.34		1.34			
256.32 R	10		2.73		2.73			
256.31 L	3		0.25		0.25	6.05	56.96%	
254.90 R	7	10	1.34	3.50	3.50			
254.90 R	7	10	1.34	3.50	3.50	7.00	58.19%	
253.95 L	13		4.61		4.61			
253.40 L	16	30	6.98	10.50	10.50	15.11	60.83%	5%
252.28 R	8		1.74		1.74	1.74	61.14%	
251.60 R	7		1.34		1.34			
251.57 R	15		6.13		6.13			
251.16 R	7		1.34		1.34	8.80	62.68%	
249.66 R	7		1.34		1.34	1.34	62.92%	
248.00 R	36		35.33		35.33	35.33	69.10%	10%
246.88 R	48	100	62.80	35.00	62.80	62.80	80.10%	10%
245.41 R	36	75	35.33	26.25	35.33	35.33	86.29%	
240.56 L	12		3.93		3.93	3.93	86.98%	5%
230.89 L	5		0.68		0.68			
230.13 R	5		0.68		0.68			
230.06 R	10		2.73		2.73			
230.06 R	10		2.73		2.73	6.81	88.17%	
229.85 R	10		2.73		2.73			
229.56 R	4	10	0.44	3.50	3.50			
229.35 L	8	20	1.74	7.00	7.00			
229.35 L	8		1.74		1.74	14.97	90.79%	
228.89 R	12		3.93		3.93			
228.78 R	24	60	15.70	21.00	21.00			
228.78 R	24	60	15.70	21.00	21.00	45.93	98.84%	15%
227.72 R	10		2.73		2.73	2.73	99.31%	
222.75 R	12		3.93		3.93	3.93	100.00%	
					570.96	570.96		100%

Table 2-13. Average monthly evapotranspiration estimates from California Irrigation Management Information Systems meteorological stations.

Normal Year ETO's from CIMIS webpage
http://wwwdpla.water.ca.gov/cimis/cimis/hq/sjdnorm.htm

CIMIS ID	**80**			**145**	**56**	**148**
	Fresno	**Friant**	**Kerman**	**Madera**	**Los Banos**	**Merced**
Jan	0.9	1.2	0.9	0.9	1	1
Feb	1.6	1.5	1.5	1.4	1.5	1.5
Mar	3.3	3.1	3.2	3.2	3.2	3.2
Apr	4.8	4.7	4.8	4.8	4.7	4.7
May	6.7	6.4	6.6	6.6	6.1	6.6
Jun	7.8	7.7	7.7	7.8	7.4	7.9
Jul	8.4	8.5	8.4	8.5	8.2	8.5
Aug	7.1	7.3	7.2	7.3	7	7.2
Sep	5.2	5.3	5.3	5.3	5.3	5.3
Oct	3.2	3.4	3.4	3.4	3.4	3.4
Nov	1.4	1.4	1.4	1.4	1.4	1.4
Dec	0.6	0.7	0.7	0.7	0.7	0.7
Total	51	51.2	51.1	51.3	49.9	51.4

Evapotranspiration loss rates are expected to be comparable in the other reaches because the meteorological conditions are similar; however, the varying degrees of riparian vegetation along the channel will result in some reach-by-reach variation. The riparian width estimates that are specified in the model for each 1-mile segment will determine the total evapotranspiration losses in these reaches.

2.7.2.5. Seepage Losses Assumptions

Seepage loss along the San Joaquin River is difficult to estimate because the physical properties of the riverbed and alluvial channel below the river are generally unknown. The San Joaquin River Model assumes that the seepage is controlled by the width of the alluvial channel below the river that is saturated with water at low flow. The model specifies a characteristic seepage rate (i.e., infiltration) for each reach. This rate may depend on the soil properties and the head difference thought to control the groundwater flows below the river.

Because the alluvial width and the seepage rate are unknown, the combined seepage loss in cubic feet per second per mile can be used to guide these estimates. The alluvial width can be roughly estimated from the basic geologic description of the river. The model allows the alluvial width to be specified for each mile and the seepage rate to be specified for each reach. For example, a steady-state (“filling” rate is higher when flow changes first occur) seepage rate of 2 in/day has been estimated for Reach 2 between Gravelly Ford and the Mendota Pool, and the alluvial width is assumed to be approximately 500 feet. This alluvial width and seepage rate give a seepage loss of approximately 8.5 cfs per mile, for a total loss of 100 cfs for the 12 miles between Gravelly Ford and the Chowchilla Bifurcation Structure. This magnitude of loss is generally confirmed by the periods of flow data at the Chowchilla Bifurcation Structure (Figure 2-4) and by measurements during the Riparian Restoration Pilot Project in 1999 and 2000. A similar approach of estimating seasonal seepage losses was taken for the reach between Friant Dam and Gravelly Ford, with seasonal values shown in Table 2-14.

Seepage losses in the Mendota Pool and Reach 3 between Mendota and Sack Dam are unknown. Seepage may actually be into the river channel from surrounding agricultural lands (shallow groundwater) in Reaches 4 and 5. The model allows the seepage widths to be estimated for each mile and the seepage rates (positive losses only) to be specified for each reach.

2.7.2.6. Measured Streamflow Losses Assumptions

Measured data were used to estimate streamflow losses used by the San Joaquin River Model. In Reach 2A, the USBR has measured daily streamflow at Gravelly Ford and at the Chowchilla Bifurcation Structure for several years. During periods of no rainfall, the difference between the Friant Dam releases and the flows at downstream locations is a direct measure of the total losses to diversions, evapotranspiration, and seepage. The records from 1987 to 2001 have been graphically evaluated to provide monthly estimates of these flow losses. Because there are no diversions between Gravelly Ford and the Chowchilla Bifurcation Structure, and vegetation density is low resulting in low evapotranspiration rates, the losses along Reach 2A are driven by seepage and are expected to be fairly constant.

Daily streamflow measurements and loss estimates were made for 1987-1999 by subtracting flows measured at Friant with flows measured at Gravelly Ford and at the Chowchilla Bifurcation Structure. This evaluation provided additional details to the flow loss curves presented in Figure 2-4, but this evaluation also illustrated significant variability.

Between the Friant gaging station and Gravelly Ford (approximately 38 river miles), a minimum flow of 105 cfs is needed at the Friant gage to get a measurable flow at the Gravelly Ford gage, suggesting that the minimum seepage loss outside the irrigation season is 105 cfs (2.8 cfs/mile). This correlates well with Figure 2-4. Some years have larger losses (up to 154 cfs) during the winter (non-irrigation) season, perhaps due to some diversion for gravel mining operations in Reach 1. Flow losses increase during the irrigation season as riparian diversions are utilized. Flow losses increase to approximately 130 cfs to 250 cfs during the summer and fall irrigation season.

Between the Gravelly Ford gaging station and Above Chowchilla Bifurcation Structure gaging station (approximately 13 river miles), a minimum of 75 cfs is needed at the Gravelly Ford gage to get a measurable flow at the Above Chowchilla Bifurcation Structure gage, suggesting that the minimum seepage loss outside the irrigation season is 75 cfs (5.8 cfs/mile). This reach has had the greatest depletion in shallow groundwater aquifer due to overdraft, which is likely reflected in the larger unit-length seepage loss rate. This minimum seepage rate also correlates well with Figure 2-4. There do not appear to be as significant seasonal pattern to flow losses between the irrigation season and winter season (as occurred between Friant and Gravelly Ford). Maximum flow losses are approximately 250 cfs, with several years having intermediate “plateaus” of flow loss. These intermediate values of flow losses are likely due to varying degrees of riparian withdrawals in the reach during those times when there are flows in the river.

Losses in 1998 and 1999 are also review specifically, although these two single years do not necessarily reflect normal flow losses due to varying degrees of diversion and groundwater pumping on a year-to-year basis. Based on 1998 pilot project results in 1998, high flows occurred through July. Through July 1998, the combination of large variable local inflows from tributaries and releases from Friant Dam makes flow loss estimates difficult. During August and September 1998, the losses between Friant Dam and Gravelly Ford were about 100–150 cfs, and less for most of the rest of the year. For August through mid-November 1998, the losses between Gravelly Ford and the Chowchilla Bifurcation Structure were relatively constant at about 100 cfs. In 1999, the first year of Friant Dam releases were provided for the riparian vegetation pilot project. A seed dispersal flow of approximately 600 cfs in early July 1999 was followed by an establishment period that had a controlled flow recession through October. Losses from Friant Dam to Gravelly Ford declined from about 150 cfs in July to about 50 cfs in December. Losses between Gravelly Ford and the Chowchilla Bifurcation Structure were about 100 cfs in July, then approximately 80 cfs in August; when Gravelly Ford flows declined to less than 75 cfs, no flow was measured at the Chowchilla Bifurcation Structure.

Lastly, flow losses between the Chowchilla Bifurcation Structure and Mendota Pool (Reach 2B) are considered negligible due to the backwater of Mendota Pool and shallow groundwater recharge by the Mendota Pool backwater.

Table 2-14 provides a monthly summary of the loss estimates from the 1987-2001 daily flow records. For simulation of future San Joaquin River restoration conditions, a monthly value that exceeds most of the measured loss rates was used. The separation of these total losses into the evapotranspiration, diversion, and seepage variables was accomplished with some comparative simulations of the San Joaquin River Model. The seepage rate was set to provide a constant loss that matches the lowest monthly values measured in the November–January periods. The estimated seepage loss from Reach 1 (Friant to Gravelly Ford) is approximately 60 cfs. For the estimated alluvial width of 500 feet along the 40 miles of river, this loss corresponds to a seepage rate of 0.5 in/day. For Reach 2 (Gravelly Ford to Mendota Dam) the seepage loss is estimated to be 120 cfs (20% more than the Gravelly Ford to the Chowchilla Bifurcation Structure loss estimate of 100 cfs). This somewhat contradicts earlier assumptions that flow loss between the Chowchilla Bifurcation Structure and Mendota Dam is negligible; however, this assumption was nonetheless used in the model. This assumed 120 cfs loss corresponds to a seepage rate of 2 in/day for the assumed alluvial width of 500 feet along this 20-mile river reach.

2.7.2.7. Water Budget Results

The water budget analysis indicates that baseflows generally decrease in the downstream direction to Mendota Dam, where flows increase due to contribution of water imported from the Delta-Mendota Canal. Flows are steady downstream to Sack Dam, where all flow is removed from the river. Flows remain at near zero discharge downstream to the Mariposa Bypass, where the annual flow volume increases in the downstream direction as a result of tributary inflows and delivery of flow from the Chowchilla Bypass/Eastside Bypass system back into the mainstem San Joaquin River. Figures 2-40 through 2-42 graphically illustrate the longitudinal variation in average discharge along the reach for the winter baseflow period, spring snowmelt period, and summer baseflow period; however, this figure is based on average computations described below and these “average” conditions do not accurately represent typical flows in this reach. For example, Reach 4B is perennially dry, yet Figures 2-40 through 2-42 suggest that there is a small amount of flow in the reach. The magnitudes of the annual and seasonal average flows are summarized in Table 2-15. The more general flows illustrated in Table 2-10 are typical values based on a more generalized review of USGS gaging records and typical operation of Friant Dam, Mendota Dam, and Sack Dam. The trend of decreasing baseflows in the downstream direction was most likely much different than unimpaired conditions, where artesian springs and downstream tributaries draining the Sierra Nevada augmented baseflows. Examination of flows at the San Joaquin River at Fremont Ford gage between 1938-1943 show a decrease in baseflow, likely due to agricultural diversions (e.g., Mendota Dam was diverting flows in the late 1800’s).

Table 2-14. Monthly Loss Estimates for Reach 1 and Reach 2 based on USGS daily flow records at Friant, and USBR Daily Flow Records at Gravelly Ford and the Chowchilla Bifurcation Structure, all rounded to the nearest 25 cfs.

A. Friant to Gravelly Ford Losses (cfs)

Year	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
January	40	50	50	75	100	100	100	75		75		75	75	75	75
February	50	75	75	100	125	100		100					75		75
March	50	100	125	125		125		125							
April	100	100	125	150	125	175		150							125
May	125	150	175	175	175	200		175			150		100	100	150
June	150	175	200	200	200	225		225		175	175				
July	175	200	200	225	225	250	200	250		200	200		175	150	
August	150	175	175	200	200	250	175	225		175	150	150	150	150	
September	100	150	150	175	175	225	150	200	75	175	150	150	125	150	
October	100	125	125	150	150	200	125	125	75	150	125	125	100	125	
November	50	100	100	125	125	125	100	100	100	100	100		75	100	
December	50	75	100	100	100	100	75	100	50	75	75		75	100	

B. Gravelly Ford to Bifurcation Losses (cfs)

Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
January						100	75		
February							75		
March							50		
April							75		
May	>75				50		75		
June				100	>150				
July	>100				>100		100		
August	>125		150		75	100	100		
September	>100		100		75	100	75		
October			50		75	100	>50		
November					>100	100			
December					>100				

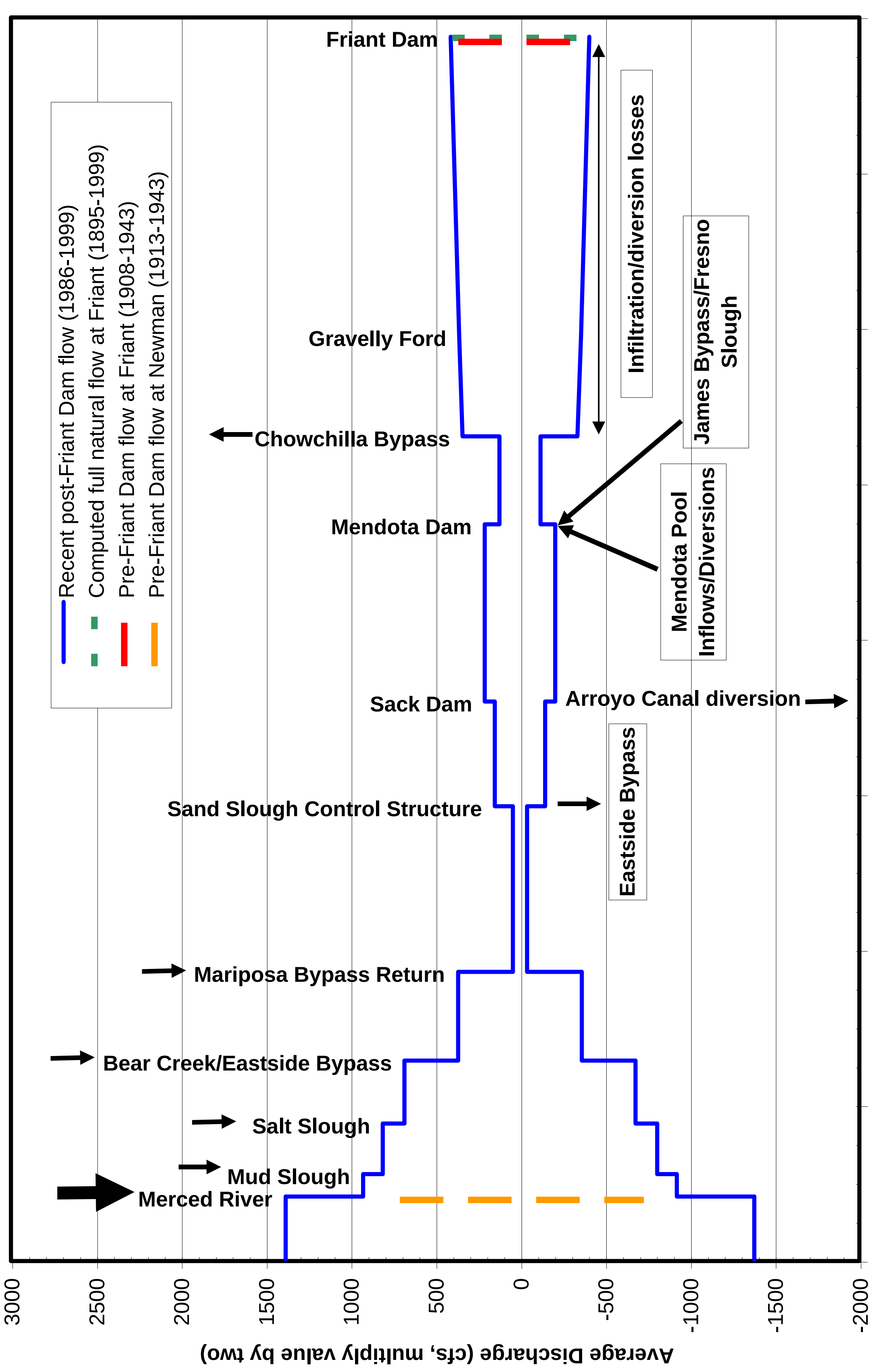

Figure 2-40. Longitudinal variation in average discharge by subreach between Friant Dam and the Merced River for winter baseflow period (December 1-March 31).

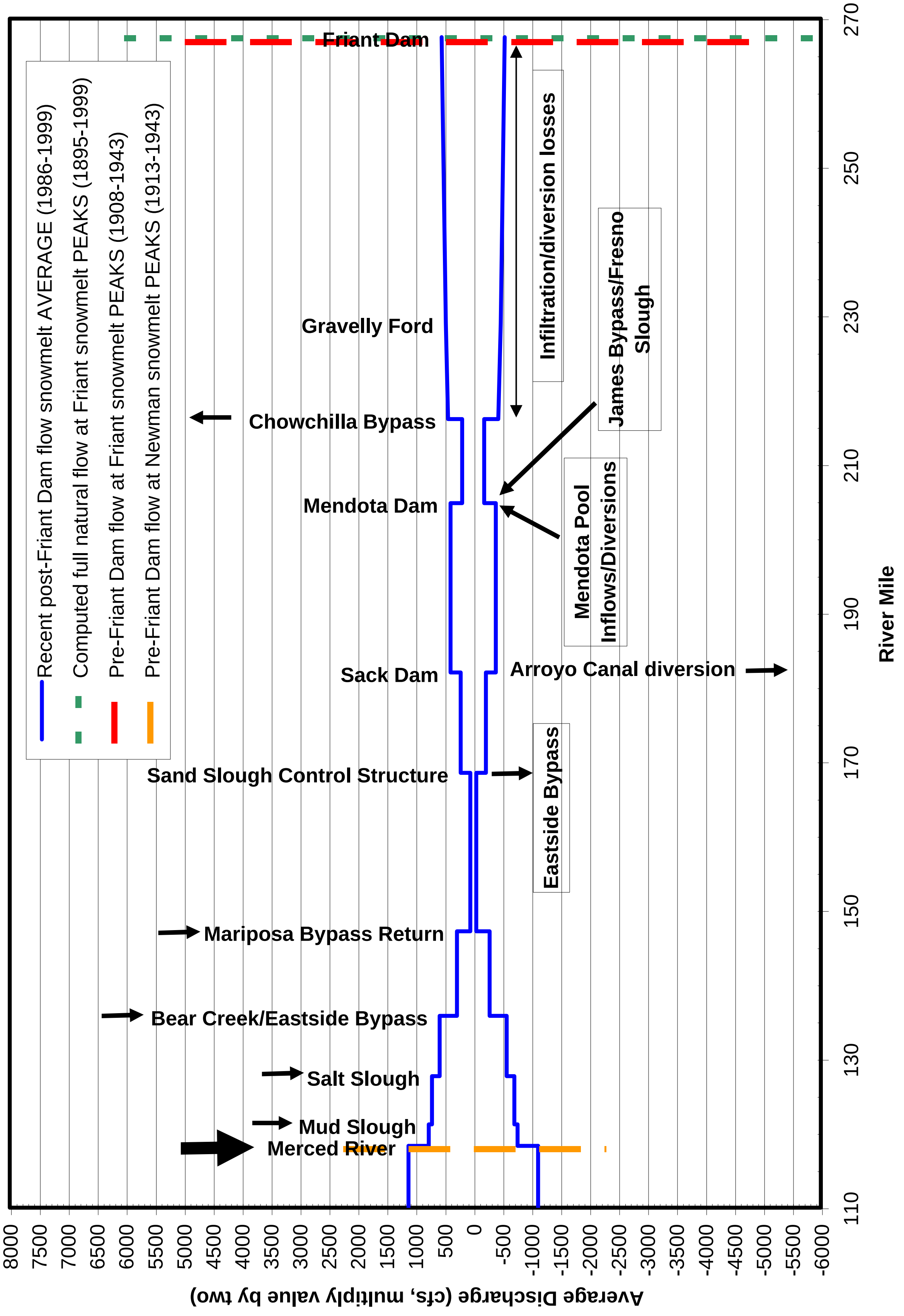

Figure 2-41. Longitudinal variation in average discharge by subreach between Friant Dam and the Merced River for spring snowmelt period (April 1-July 31).

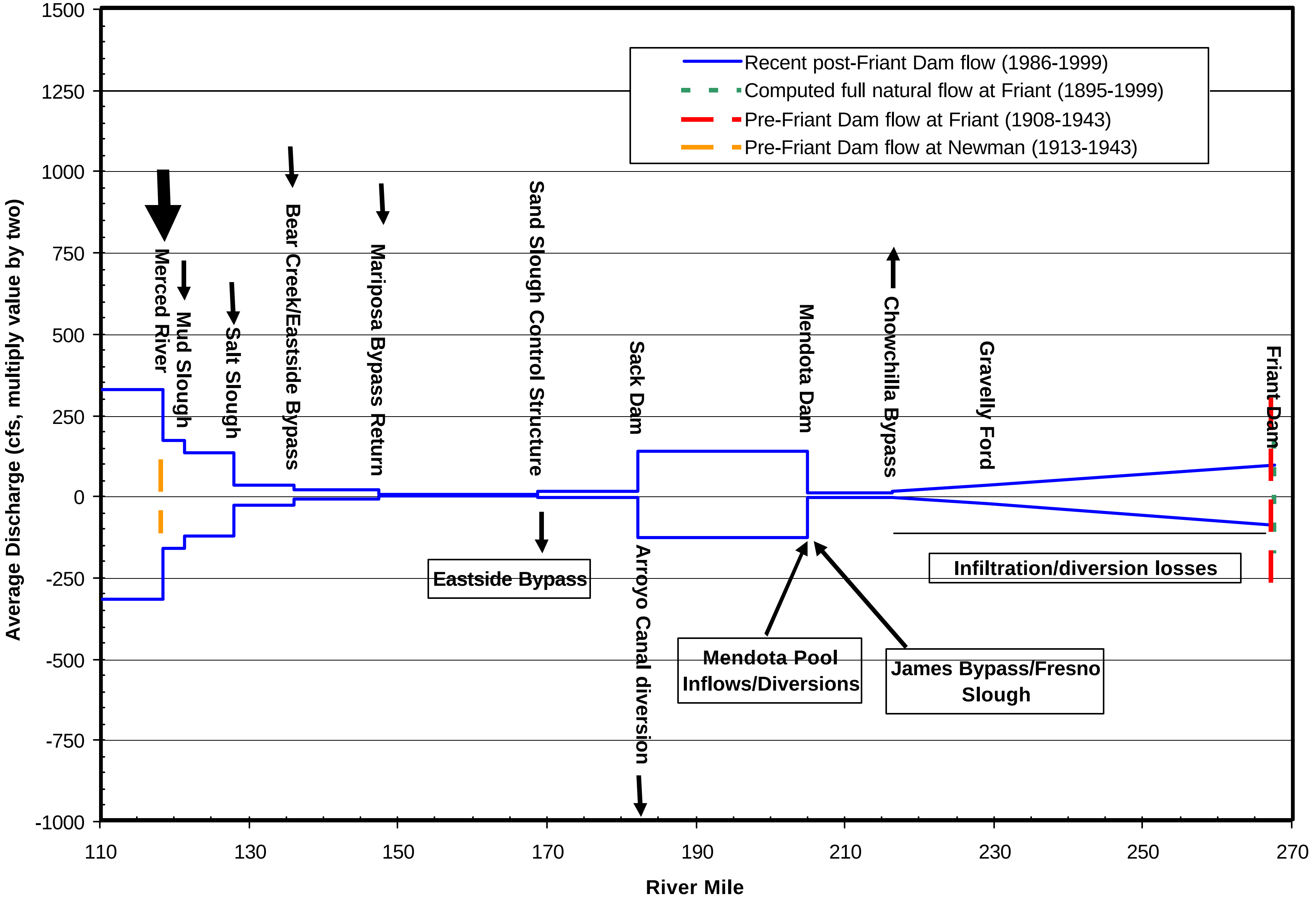

Figure 2-42. Longitudinal variation in average discharge by subreach between Friant Dam and the Merced River for summer baseflow period (August 1-November 31).

Table 2-15. Annual runoff and average annual seasonal discharge by subreach in the San Joaquin River between Friant Dam and the Merced River. "Node" refers to nodes used in the San Joaquin River Model. Note that 1986-1999 data are computed averages, and do not necessarily reflect typical flow conditions for a given reach.

Node	Description	Average Annual Runoff (acre-ft)	Seasonal Discharge		
			Summer Baseflows (cfs)	Winter baseflows (cfs)	Spring Snowmelt (cfs)
Pre-Friant Dam from USGS					
1	Friant Dam (1908-1943)	1,727,000	600[2]	711[2]	9,900[3]
11	downstream from Merced River (1913-1943)	1,866,000	220[2]	1,400[2]	4,437[3]
	Full Natural Flow from Madeheim (1999)				
1	Friant Dam (1895-1999)	1,812,000	340[2]	780[2]	12,000[3]
1986-1999					
San Joaquin River					
1	Friant Dam	504,000	185	816	1,088
2	Gravelly Ford	415,000	55	718	947
3	upstream from Bifurcation Structure	384,000	20	677	869
3-4	Bifucation Structure to Mendota Pool	153,000	15	242	379
4-5	Mendota Dam to Sack Dam	353,000	266	415	782
5-6	Sack Dam to Sand Slough Control Structure	181,000	20	296	435
6-7	Sand Slough Control Structure to Mariposa Bypass	46,000	6	84	101
7-8	Mariposa Bypass to Bear Creek	318,000	31	729	562
8-9	Bear Creek to Salt Slough	621,000	60	1,363	1,155
9-10	Salt Slough to Mud Slough	794,000	255	1,618	1,421
10-11	Mud Slough to Merced River	896,000	332	1,848	1,535
11	downstream from Merced River	1,360,000	645	2,762	2,237
Inflows/outflows					
1-2	Losses between Friant Dam and Gravelly Ford	-89,000	-129	-97.5	-140.1
2-3	Losses between Gravelly Ford and Bifurcation Structure	-31,000	-35	-41.3	-78
3	Chowchilla Bypass	-231,000	-5	-442	-511
4	James Bypass (Fresno Slough)	136,000	1	223	341
4	Gains and losses in Mendota Pool[1]	64,000	250	-50	62
5	Arroyo Canal	-172,000	-246	-119	-347
6	Eastside Bypass	-135,000	-15	-212	-334
7	Mariposa Bypass	272,000	25	645	461
8	Bear Creek	39,000	21	120	21
8	Eastside Bypass	264,000	8	514	572
9	Salt Slough	173,000	195	255	266
10	Mud Slough	102,000	77	230	115
11	Merced River	465,000	312	914	702

Table 2-15. Cont.

[1] The indicated flows represent the combination of imported flows from the Delta-Mendota Canal and other gains and losses associated with flow bypasses and groundwater interaction

[2] Median values, obtained from hydrograph component analysis

[3] Median values of snowmelt PEAK from hydrograph component analysis

This information was used to help develop the San Joaquin River Model. Application of the model to a hydrograph is shown in Figure 2-43, where measured and simulated daily baseflow patterns between Friant Dam and Gravelly Ford are compared for June 2001. The total diversions simulated were 100 cfs, with about 60 cfs of seepage and 10 cfs of evapotranspiration losses. The total depletions between Friant Dam and Gravelly Ford were similar to the data for the first 15 days of June. During the pulse flow event, there was a distinct lag of approximately three days in the flows at Gravelly Ford. In addition, the losses between Friant Dam and Gravelly Ford apparently increased slightly during the pulse flow of 400 cfs. The simulated losses remained the same throughout June. Subsequently, as the flow pulse ended, the flows at Gravelly Ford decreased approximately four days after the drop in flow at Friant Dam. This example suggests that the model reasonably predicts lower flows at downstream gages, but over-predicts higher baseflows at downstream gages. The model also does a reasonable job in predicting the flow attenuation and travel times (Figure 2-43). Further refinements have been made to the model to improve hydrograph predictions.

2.8. FLOOD FLOW ROUTING

This section discusses historic flood flow routing based on historical accounts and maps, then describes existing flood flow routing within the San Joaquin River Flood Control Project. Chapter 5 describes the flood control project in more detail. Existing flood flow routing is described in this report by comparison of discrete hydrographs from several gaging stations between Friant Dam and the Merced River. Finally, a flood routing model has been developed for the study reach in which existing and future high flow hydrographs can be predicted longitudinally. This flood routing model is then used to evaluate historic and existing flood inundation areas.

2.8.1. Historical and Existing Flood Flow Routing

Historic flood routing is fairly straightforward: much of the valley floor along the river corridor was under water, with most San Joaquin River flow routing north to the Delta. There were times, however, when high flows from the San Joaquin River flowed into the Fresno Slough and times when high flows from the Kings River flowed into the San Joaquin River via Fresno Slough. Derby’s 1852 map illustrates how this two-way flood flow routing occurred; San Joaquin River flows sometimes exited from the San Joaquin River channel in Reach 2B via high flow sloughs, and connected with Fresno Slough. In our review of the historic literature, primarily Derby’s first-hand accounts and map (Derby 1850, 1852) (Figure 2-37) of the Fresno Slough-San Joaquin River confluence during the snowmelt runoff period of 1850, it appears that high water flowed from the San Joaquin River through sloughs to the Fresno Slough, which then carried these flows north back to the San Joaquin River. In traversing west along the divide between Tulare Lake and the San Joaquin River, Derby (1850) states:

> *“We…crossed no less than eight distinct sloughs, one of which we were obliged to raft over, before arriving at the Sanjon [Fresno Slough]. In all of these sloughs a strong current was running southwest, or from the San Joaquin River to the [Tulare] lake. The Sanjon is a large and deep slough about forty miles*

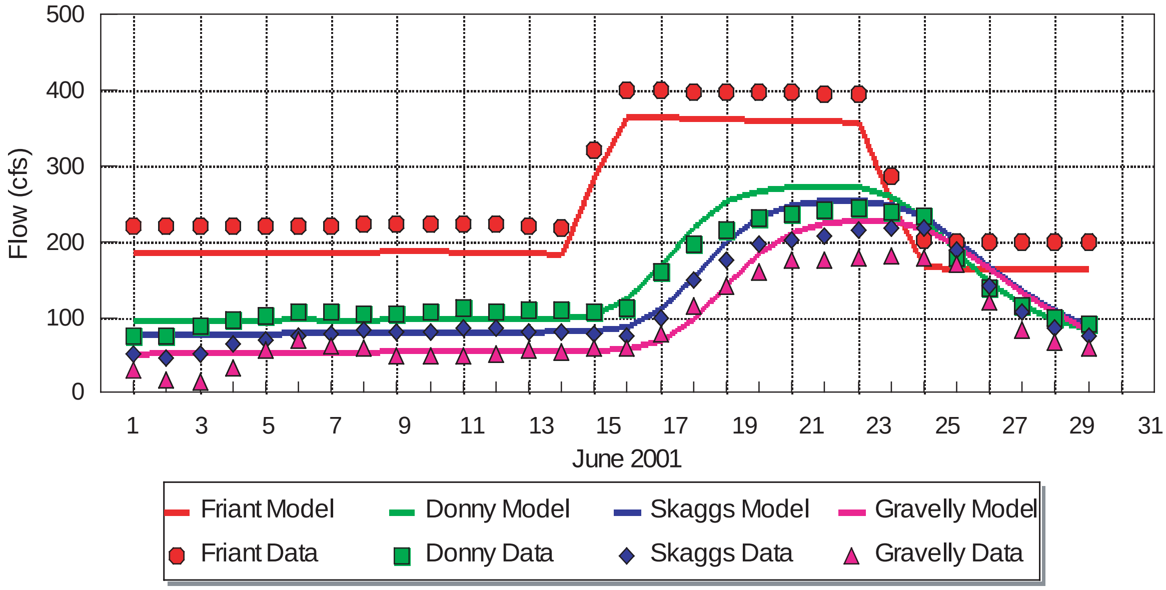

Figure 2-43. June 2001 baseflow pulse on the San Joaquin River to compare flow routing model results with measured flows.

> *in length, connecting the waters of the lake with the San Joaquin River, with which it unites at its great southern bend [at the present location of Mendota]. At this time [May 23, 1850] it was about two hundred and forty feet in width, and with an extremely slow current setting towards the river. I do not think it possible to communicate directly with the lake through this slough. An attempt has been made a week or two previous to our arrival by a party of men in a whaleboat, who examined it for twenty or thirty miles, and found it branching off into innumerable smaller sloughs, which intersected the tule swamp in every direction."*

A portion of high flows from the Kings River certainly flowed through Fresno Slough to the San Joaquin River under historical conditions, and still does occasionally under existing conditions (see Figure 2-37). There was also speculation in the literature on whether the Tulare Lake would rise to the point where it would overflow into the Fresno Slough into the San Joaquin River (as implied on Figure 2-37); however, the elevation of the Tulare Lake surface would have to have risen 30 to 35 feet for this to occur (CDPW, 1931). If this lake overflow did in fact occur, the frequency is not known. Flood flows from streams draining the east side of the valley would empty into the extensive flood basin in Reaches 4 through 5, such that the flood basin was a buffer between the tributary stream and the mainstem San Joaquin River.

The substantial storage capacity of this flood basin had a substantial influence on flood routing through the San Joaquin River valley. Comparing flood peaks for pre-Friant Dam floods between the San Joaquin River at Friant gaging station and the San Joaquin River at Fremont Ford gaging station shows flood peaks were reduced substantially by the large storage capacity of the flood basin even though there was already a substantial number of levees constructed by 1943 (Figure 2-33).

The most significant changes to flood routing under existing conditions are caused by the San Joaquin River Flood Control Project. This project bypasses flood flows from the San Joaquin River at the

Chowchilla Bifurcation Structure and Sand Slough Control Structure, and routes these high flows through the Chowchilla Bypass, the Mariposa Bypass, and the East Side Bypass (Figure 2-44). In addition, the East Side Bypass captures any flood flows from the Fresno River, Chowchilla River, and Bear Creek. The floodway width is much narrower due to confining levees of the flood control project along the river and in the bypasses, and this likely decreases travel time and reduces flood peak attenuation. High flows can still occasionally spill from the San Joaquin River in Reach 2B into Fresno Slough, as happened in 1997 (ACOE 1999), but the reduction in flood magnitude from Friant Dam and levees constructed along Reach 2 greatly reduces the frequency of this occurring. High flows on the Kings River frequently route through James Bypass and Fresno Slough into the San Joaquin River, as illustrated in the James Bypass flood frequency data (Figure 2-14). While flood peak attenuation under existing conditions is likely much less than prior to construction of the San Joaquin River Flood Control Project, flood peak attenuation under existing conditions is still substantial. The following sections evaluate several recent flood hydrographs using gaging stations along the length of the study reach.

The following two sections evaluate 1986 and 1995 flood hydrographs using gaging stations along the length of the study reach. These two years were chosen because they had discrete high flow events that could be easily tracked on gaging records, and these two flood years occurred during a period where there was a larger number of gaging stations through the San Joaquin River and flood control bypasses to provide more calibration points for the flood routing model.

2.8.1.1. Empirical Results of 1986 High Flow Event

During the 1986 high flow event, the peak release from Friant Dam was 7,950 cfs, which occurred on March 11 (Figure 2-45). The recorded peak flow at the Gravelly Ford gage of 7,975 cfs occurred on March 17, 1986. However, the primary component of the rising limb of the Gravelly Ford hydrograph began to level off at about 7,650 cfs on March 12. Comparison of the rising limbs of the Friant and Gravelly Ford hydrographs indicates an approximate 1-day time lag in the flows between the two locations (in contrast to low flow period when it takes 4 to 5 days for flow change at Friant Dam to fully show up at Gravelly Ford). A similar pattern occurred between the Gravelly Ford gage and the measured flows into the head of the Chowchilla Bypass, with an approximately 1-day time lag between Gravelly Ford and the Chowchilla Bifurcation Structure. Inflows to the Chowchilla Bypass peaked at 7,380 cfs on March 22, but the primary part of the rising limb of the hydrograph began to level off at about 6,910 cfs on March 11. The data are based on mean daily flows; thus, the timing of peak and other components of the hydrographs indicated by the data may be up to one day off from the actual timing that occurred in the river.

Measured flows at the Dos Palos gage peaked at 5,030 cfs on March 19. These flows are affected by diversions into the Chowchilla Bypass, inflows and outflows at Mendota Dam associated with the various canals and the James Bypass/Fresno Slough, and diversions into the Arroyo Canal.

The peak discharge at the Stevinson gage near the downstream end of the reach of 17,300 cfs occurred on March 17. At the Fremont Ford gage, which is approximately 8 miles downstream, the peak discharge of 18,100 cfs occurred on March 18, 1986. Comparison of the rising limbs of the hydrographs indicates an approximately 1.7-day time lag.

The rising limb of the Gravelly Ford hydrograph and the early part of the Stevinson hydrographs overlap. Because of the significant distance between the two gage locations, a several-day time lag is expected, which indicates that tributary inflows were responsible for the early part of the rising limb at the Stevinson gage.

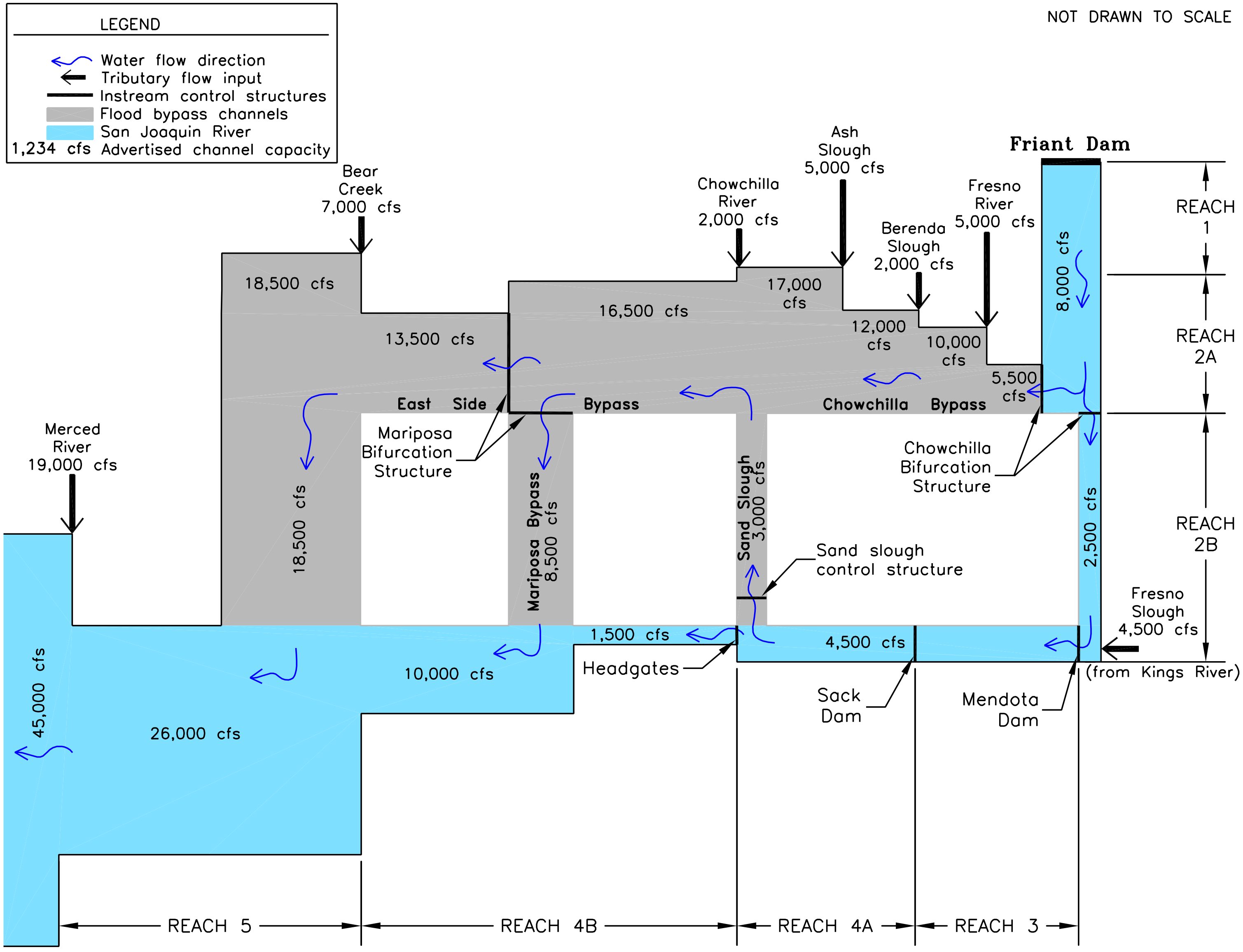

Figure 2-44. Schematic map of structures, flood routing, and reach hydraulic capacity of the San Joaquin River Flood Control Project.

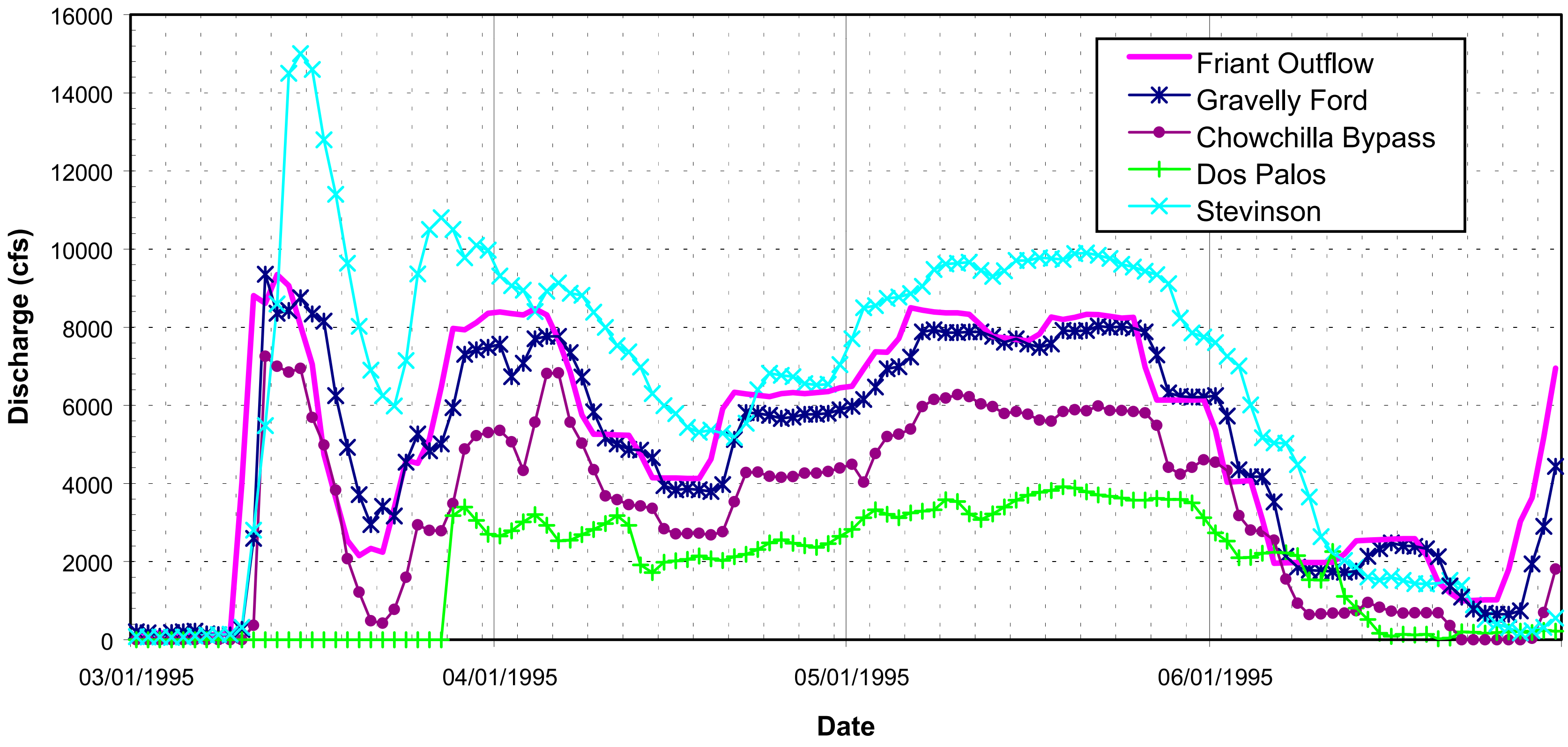

Figure 2-45. Measured mean daily flow hydrographs for the 1986 high flow event at five mainstem San Joaquin River gages.

2.8.1.2. Empirical Results of 1995 High-Flow Event

During the 1995 event, the primary part of the Friant release hydrograph began to level off at about 8,810 cfs on March 11, and the peak of the hydrograph of 9,350 cfs occurred on March 13 (Figure 2-46). At Gravelly Ford, the hydrograph peaked at 9,359 cfs on March 12. Comparison of the rising limbs of the hydrographs indicates an approximately 1-day time lag, which is very similar to the time lag that occurred in the 1986 event. The peak discharge into the Chowchilla Bypass of 7,255 cfs occurred on March 12, and the rising limbs of the hydrograph indicate less than 1 day of time lag between Gravelly Ford and the Chowchilla Bifurcation Structure.

According to the measured flow records, the rising limb of the hydrograph at the Dos Palos gage occurred over a 1-day period from March 27 to 28, and the initial peak of the hydrograph of 3,400 cfs occurred on March 29. The gage records indicate that there was no flow in the river until March 28, which leaves one to suspect that the gage may have been inoperable during the period prior to March 17; thus, the above statement regarding the timing of the rising limb at this location should be treated with caution.

At the Stevinson gage, the peak discharge of 15,000 cfs occurred on March 15, and the early part of the rising limb of the hydrograph exhibits approximately the same timing as occurred at the Gravelly Ford gage. This again indicates that inflows from tributaries closer to the Stevinson gage were responsible for the early rise in flows at that location.

2.8.2. Flood Routing Model

Because the measured hydrographs include inflows from tributaries for which data are not available and the hydrographs do not represent all of the locations of interest, flow routing models were developed and calibrated for each event. These models are not to be confused with the water budget model described in Section 2.7.2. The flow routing models were developed using a combination of the HEC-1 Flood Hydrographs Package and the HEC-2 Water-Surface Profile computer programs (ACOE 1990a and 1990b). The procedures for using these programs to perform river routings are described in Corps Training Document No 30 (ACOE 1990c), and details of the application for this specific project are described in MEI (2000a and 2000b). In general, the procedure involves use of the Modified Pulse storage routing method (Chow 1959), which consists of repetitive solution of the continuity equation assuming that the outflow is a unique function of storage.

When applying this method to rivers, the overall routing reach is subdivided into several subreaches, a storage-outflow relationship is developed for each subreach, and the inflow hydrograph is routed through the overall reach by assuming that the subreaches represent a series of reservoirs, with the inflow to each successive reservoir being the computed outflow from the next upstream reservoir. The storage-outflow relationship for each subreach is developed from the HEC-2 model, based on the total volume of water in the subreach computed from the cross sectional areas and distances between cross sections for each modeled discharge. Calibration of the model is achieved by adjusting the number of reaches and the length of the routing time step until modeled results match, to within a reasonable tolerance, observed hydrographs. Data used in the water-surface profile analysis (HEC-2) were derived from surveys performed by Ayres Associates in 1997 for the ACOE and the USBR, supplemented with additional field survey data collected in 1999, information obtained from plans for various structures along the reach, and where appropriate, from the modern and historical USGS 7½-minute quadrangle maps. Discharge data used in the analysis were taken from available stream gage records along the reach.

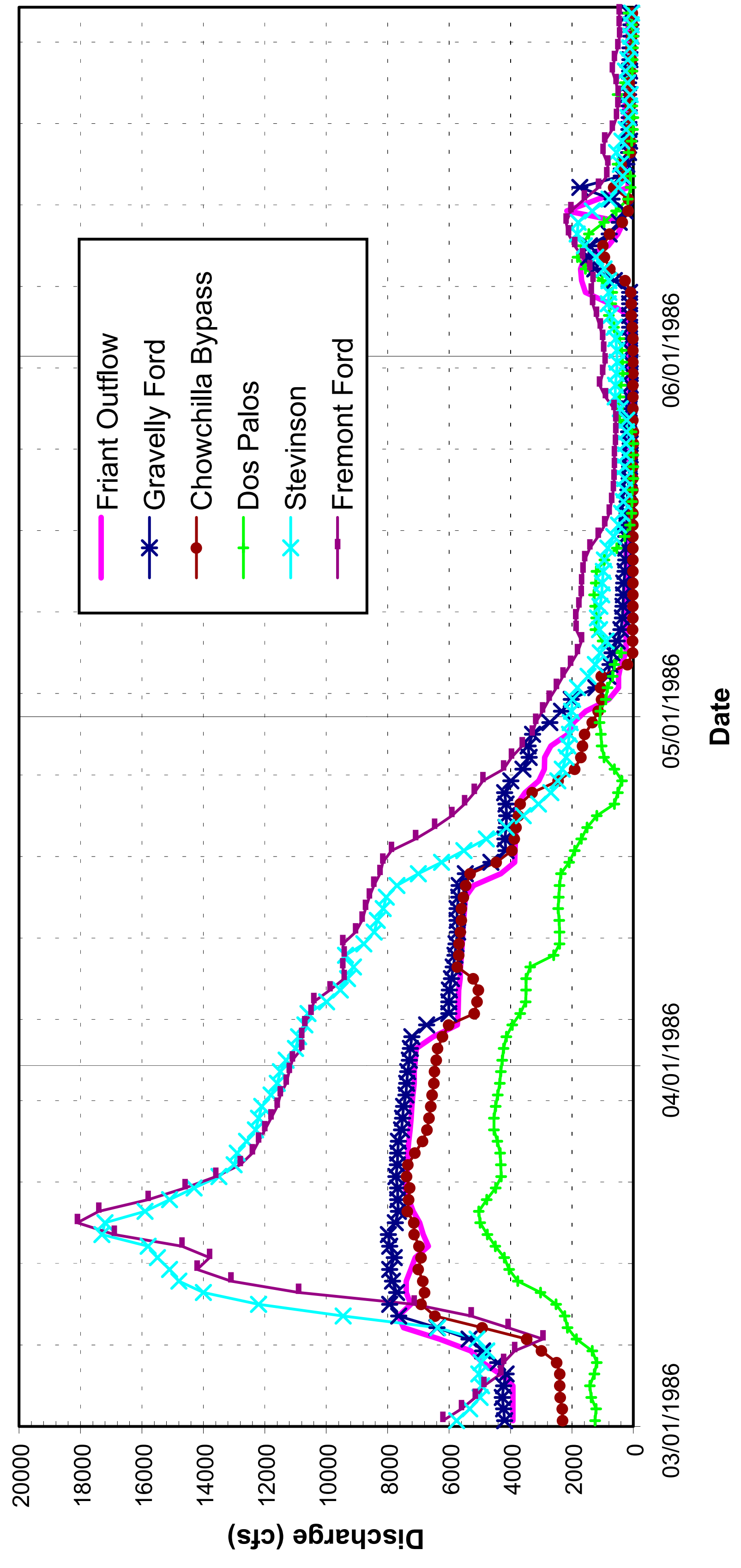

Figure 2-46. Measured mean daily flow hydrographs for the 1995 high flow event at five mainstem San Joaquin River gages.

2.8.2.1. Model Calibration from Friant Dam to Mendota Dam

The flow-routing models were developed and calibrated for the 1986, 1995, and 1999 high flow events to provide a means of evaluating storage and attenuation effects along the study reach. These two high flow events were chosen for calibration because they occurred during a period when many gaging stations were in operation on the mainstem San Joaquin River and Eastside Bypass, which improved calibration. The model for the portion of the reach between Friant Dam and Mendota Dam was initially calibrated using the experimental releases that were made from Friant Dam during June, July, and August 1999. Inflows to the upstream end of the reach were taken from the USGS real-time data at the San Joaquin River below Friant Dam gage, and the flows at Gravelly Ford that were used as a basis for the calibration were taken from real-time flows published on the California Data Exchange web site. The HEC-2 model for the reach includes numerous locations where portions of the overbanks and in-channel gravel pits were blocked from the computations to account for ineffective flow areas to improve the reasonableness of the model results for evaluating the in-channel hydraulics. These ineffective flow areas are important to the flow routing, however, because they store significant amounts of water that can affect hydrograph attenuation and translation through the reach. In addition, the available 2-foot contour mapping on which the cross sections in the HEC-2 model were based covers only a limited amount of the floodplain, and in some cases does not include all of the gravel pits that may affect storage along the reach. For this reason, it was necessary to adjust the storage-outflow relationships that were developed from the calibrated HEC-2 model results to more accurately reflect the flood storage along the reach. The initial adjustment was made by preparing a special version of the HEC-2 model with the encroachments removed so that all of the area below a given water-surface elevation that is represented in the ground profile data in the model would contribute to the computed storage volume. The limits of the storage areas were further adjusted by comparing the extent of flooded areas observed on aerial photographs taken during the period May 23 through May 10, 1993, when releases from Friant Dam ranged from 1,010 to 1,950 cfs, and an aerial videotape taken on May 2, 1995, when the release from Friant Dam was 7,930 cfs. The water-surface elevations in this version of the model were set equal to the computed water-surface elevations from the original version of the model. Because of the uncertainty of the depth in flooded areas along the reach that are beyond the limits of the mapping, additional adjustments to the storage volumes were made to improve overall calibration of the model.

Flow losses to channel percolation and diversion along the reach can be significant, particularly at low flows. The loss relationships between Friant Dam and the Chowchilla Bifurcation Structure (Figure 2-4) were incorporated into the routing model to improve model performance.

The best calibration of the routing model for the 1999 flows was achieved using 18 subreaches between Friant Dam and Gravelly Ford (Table 2-16), and a routing time-step of 1 hour (Figure 2-47). The subreach boundaries were selected based on the volume of storage present in the overbanks, on similarity of hydraulic characteristics and on the location of significant hydraulic structures and controls.

Table 2-16. Subreach boundaries used in the flow-routing models for the San Joaquin River between Friant Dam and Mendota Dam

Flow-routing Subreach	Hydraulic and channel stability Subreach	Downstream boundary stationing (feet upstream of Mendota Dam)	Landmark at downstream portion of Subreach
		399,920	Friant Dam
1	1	309,480	
2	1	302,816	
3	1	295,442	
4	1	283,990	
5	1	274,631	
6	1	266,524	Highway 41 Bridge
7	2	262,344	
8	2	254,139	
9	2	250,742	
10	2	237,280	
11	2	227,429	
12	2	217,109	
13	2	204,174	Highway 99 Bridge
14	3	191,772	
15	3	170,887	
16	3	153,064	
17	3	146,331	
18	4	126,279	Gravelly Ford
19	4	110,187	
20	5	94,987	
21	5	79,986	
22	5	59,770	Chowchilla Bypass Structure
23	6	43,940	
24	6	29,019	
25	6	14,622	
26	6	745	Mendota Pool

After calibration of the model to low flow conditions, the Friant Dam to Gravelly Ford model was expanded to include the reach between Gravelly Ford and Mendota Dam. The modified model used a total of 26 subreaches, including the original 18 subreaches between Friant Dam and Gravelly Ford, and eight additional subreaches between Gravelly Ford and Mendota Dam (Table 2-16). Because only daily flow data were available for the historical flows on which alternative flood release scenarios were based, the routing time-step was increased to 8 hours in this version of the routing model, and the daily flow records were treated as instantaneous flow values. The HEC-1 model internally computes the interpolated discharge values that correspond to each of the 8-hour increments from the daily input values. Trial runs of the model using interpolated values of the inflows that would more closely represent the instantaneous values, and using different time step lengths, indicated that the model results are insensitive to these refinements.

The measured flow record at the San Joaquin River below Friant Dam and at Gravelly Ford for the period March 15 through May 31, 1995, was used to validate the extended model. The validation results indicated that the timing of the computed hydrographs at Gravelly Ford was reasonable, but that the computed discharges were about 5% higher than the measured values (Figure 2-48). Comparison of the measured hydrograph volumes for this period revealed that the flow losses along the reach were about 5% higher than would be indicated by the loss curves in Figure 2-4. This

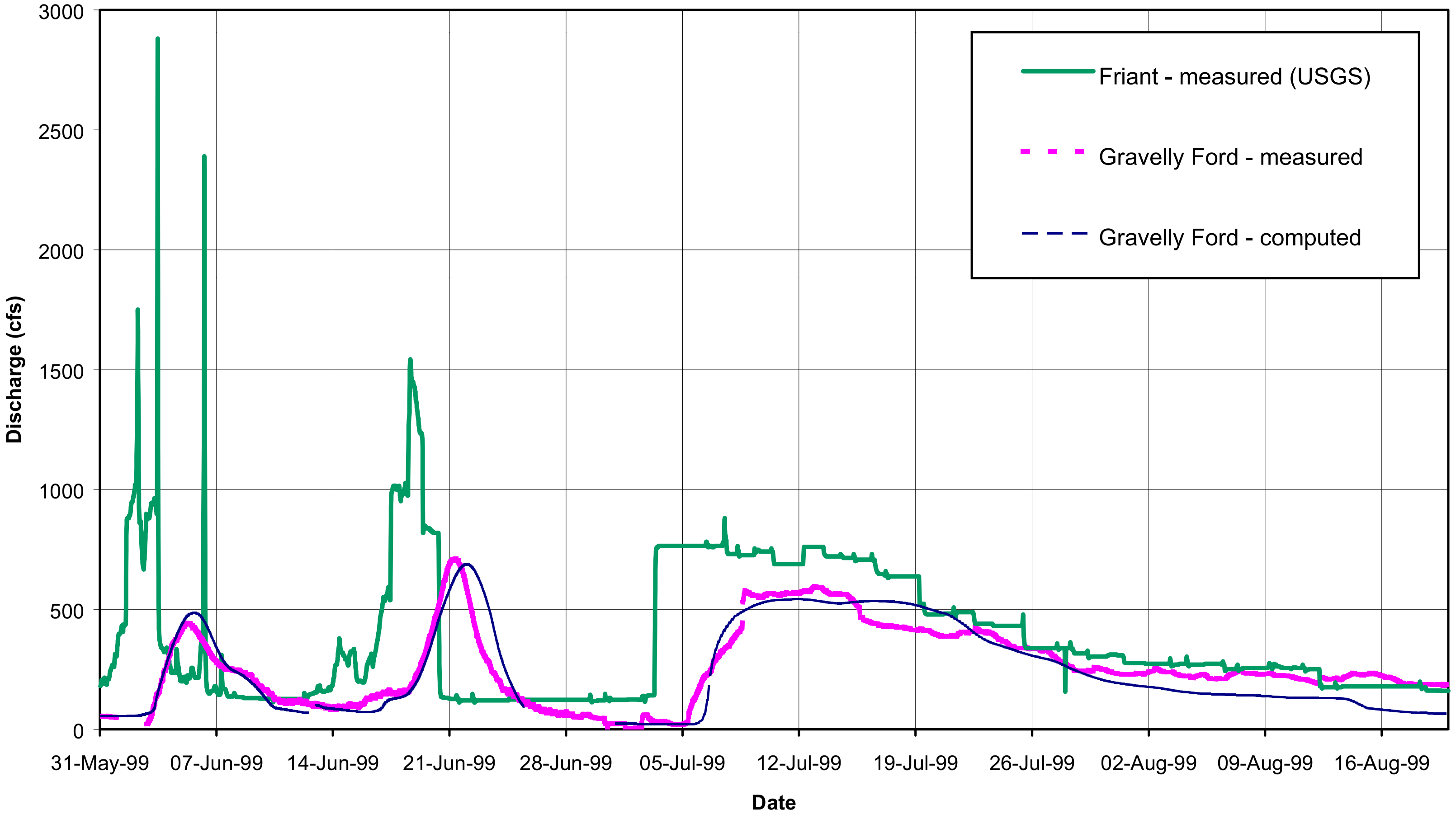

Figure 2-47. Measured and computed mean daily flow hydrographs in the San Joaquin River below Friant Dam and at Gravelly Ford for June 1-August 27, 1999.

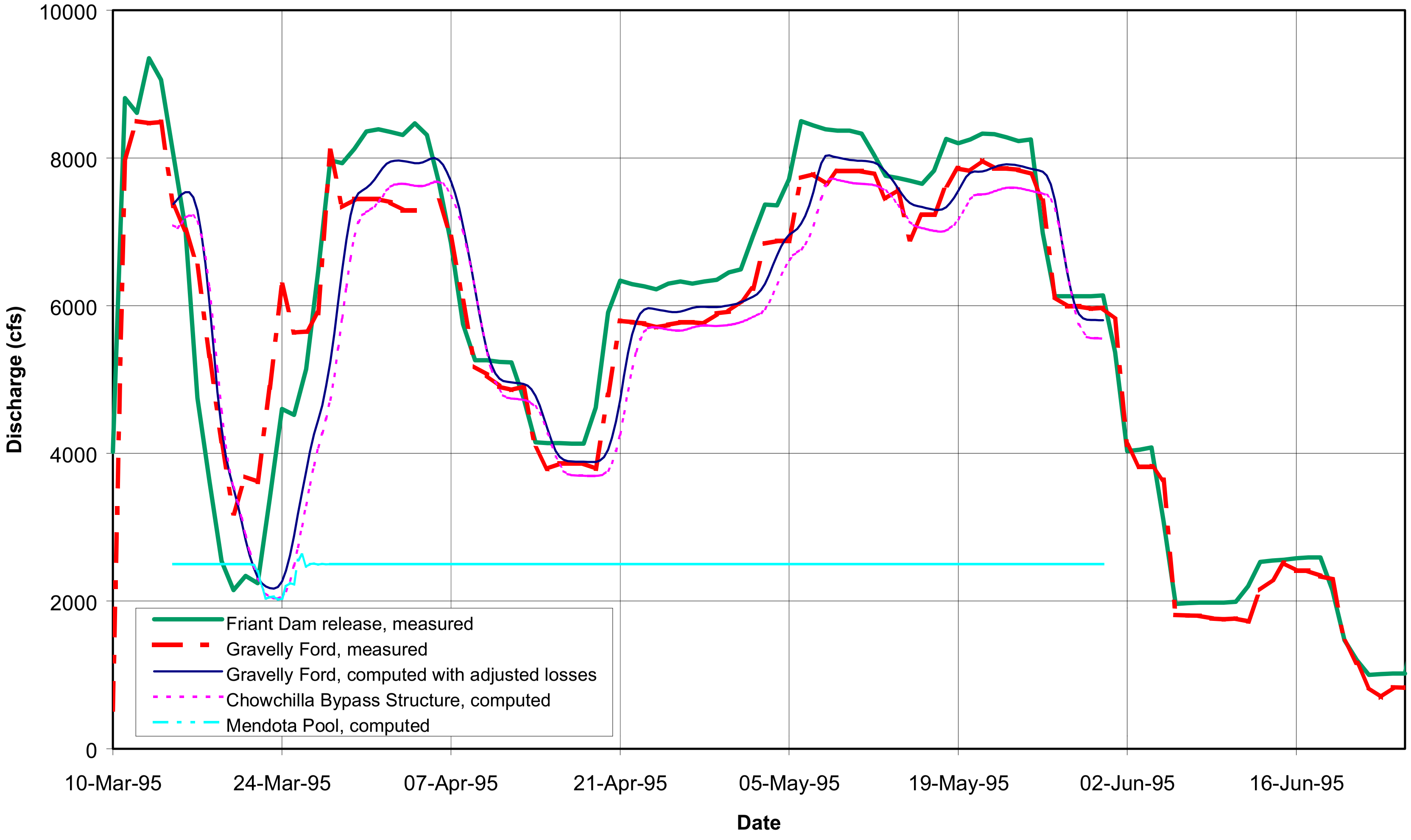

Figure 2-48. Measured and computed mean daily flow hydrographs in the San Joaquin River below Friant Dam and at Gravelly Ford for March 15-May 31, 1995.

apparent discrepancy may be attributable to a variety of factors, including error in the measured flows at Gravelly Ford, the possibility that additional flow loss occurred in the reach associated with levee breaches that are not accounted for in the storage-outflow relationships, and uncertainty in the percolation loss relationships at higher flow. Figure 2-49 shows the results of applying the routing model to the 1986 Friant Dam release hydrograph. Based on the available data, the results obtained from the modified model are believed to provide a reasonable basis for estimating changes in the flood release hydrographs as they move downstream along the reach, assuming that major levee breaches that increase the flood attenuation do not occur. Given the history of this reach, such breaches are likely; thus the routed results provide discharges at each point along the reach that represent the upper limit of the discharge that is likely actually to occur under existing conditions.

2.8.2.2. Model Calibration between Mendota Dam and the Merced River

Procedures similar to those described above were used to develop the flow routing model for the reach between Mendota Dam and the Merced River. Details of the model development can be found in MEI (2000b). This model covers the mainstem of the San Joaquin River and the entire Chowchilla Bypass/Eastside Bypass flood control system (Figure 2-2 and Figure 2-44). The reach between the Chowchilla Bifurcation Structure and Mendota Dam was included in the extended model because MEI obtained additional data after completion of the initial Friant Dam to Mendota Dam study to assist in calibration and definition of the measured flow split at the Chowchilla Bifurcation Structure.

Table 2-17 summarizes the routing subreaches used in the overall routing model and includes the number of subreaches used for each subreach. Where a hydraulic analysis was available (all the mainstem reaches plus Bear Creek), the storage-outflow relationship for each subreach was developed from the HEC-2 model output, based on the total volume of water in the subreach computed from the cross-sectional areas and distances between cross sections for each modeled discharge. At other locations such as the Eastside Bypass system, a typical cross section representing the subreach was input to the model, with the storage-outflow relationships developed internally based on normal-depth calculations.

Table 2-17. Summary of Reaches used in the HEC-1 Flow-Routing Model of the San Joaquin from the Chowchilla Bifurcation Structure to the Merced River

Routing	**Description**	**Length (miles)**	**Number of Routing Subreach**	**Method ***
SJ1	Mainstem, Chowchilla Bifurcation Structure to Mendota Dam	11.2	4	Hydraulic Analysis
SJ2	Mainstem, Mendota Dam to Sack Dam	22.4	6	Hydraulic Analysis
SJ3	Mainstem, Sack Dam to Sand Slough Control Structure	13.6	6	Hydraulic Analysis
SJ4	Mainstem, Sand Slough Control Structure to Mariposa Bypass	21.1	10	Hydraulic Analysis
SJ5	Mainstem, Mariposa Bypass to Bear Creek	11.6	5	Hydraulic Analysis
SJ6	Mainstem, Bear Creek to Salt Slough	6.9	4	Hydraulic Analysis
SJ7	Mainstem, Salt Slough to Mud Slough	7.8	3	Hydraulic Analysis

Table 2-17. cont.

Routing	Description	Length (miles)	Number of Routing Subreach	Method *
SJ8	Mainstem, Salt Slough to the Merced River	3.1	1	Hydraulic Analysis
CB1	Chowchilla/Eastside Bypass, Chowchilla Bifurcation Structure to the Diversion from Mainstem at the San Slough Control Structure	31.9	14	Normal Depth
EB1	Eastside Bypass, Diversion from Mainstem at the Sand Slough Control Structure to Mariposa Bypass	9.1	4	Normal Depth
EB2	Eastside Bypass, Mariposa Bypass to Bear Creek	6.6	3	Normal Depth
MB1	Mariposa Bypass	4.4	2	Normal Depth
BC1	Bear Creek	4.1	2	Hydraulic Analysis

* Method used to develop storage curves: Hydraulic Analysis from HEC-2 modeling; Normal Depth - from typical cross section

Initial routing parameters (number of routing subreaches and time-step length) were specified for each routing subreach based on the routing performed for the Friant Dam to Mendota Dam reach (MEI 2000). The time-step length was set to 12 hours with subreach lengths varying from 6,100 to 16,100 feet. Because of unknown flow splits at diversion points and unknown tributary inflows and flow losses, verification of the routing parameters could not be carried out for all of the individual routing reaches. Therefore, verification was carried out only for reaches without significant unknown tributary or diversion flows and where measured flows existed at each end of the reach. Figure 2-50 shows the results for the reach from the Mendota gage to the Dos Palos gage for the 1995 runoff period (March through May). Diversions into the Arroyo Canal were based on recorded values. The timing and basic shape of the routed hydrograph matches the measured hydrograph at the downstream end reasonably well. Differences in the magnitudes of the flows, particularly during the latter portion of the simulation, may reflect inaccuracies in the gage records and reported diversions into the Arroyo Canal. These differences could not be minimized through adjustments to the model and the routing parameters as originally specified were taken as reasonable for the section of the river between the Mendota gage and the Dos Palos gage.

Figure 2-51 and Figure 2-52 shows the routed versus computed 1986 and 1995 hydrographs, respectively, for the Stevinson gage. The computed flows are based on the recorded flows at the Chowchilla Bifurcation Structure (Chowchilla Bypass at the head and San Joaquin River below the bifurcation) routed through the system with the estimated losses at Mendota and estimated tributary inflows to the Eastside Bypass above the El Nido gage accounted for. The figure shows that recorded flows are consistently greater than the routed flows in the early portion of each hydrograph, indicating ungaged tributary inflow below the El Nido gage. A 5-day moving average of the computed flow differences was used to develop the estimated inflow hydrographs for the eastside tributaries between the El Nido gage and Bear Creek. The inflows were assumed to end on April 14 in 1986 and April 4 in 1995.

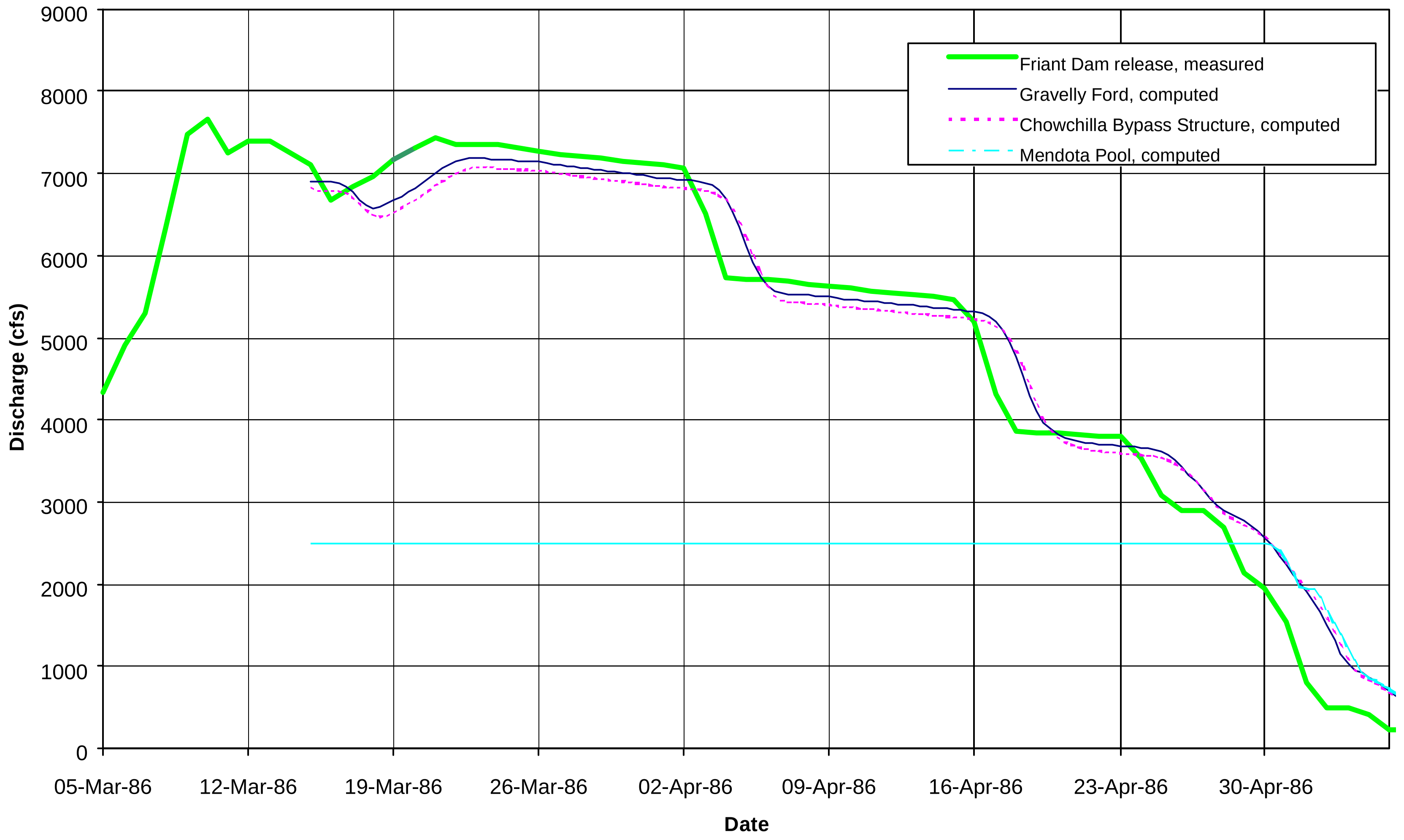

Figure 2-49. Measured and computed mean daily flow hydrographs in the San Joaquin River below Friant Dam and at Gravelly Ford for March 15-May 7, 1986.

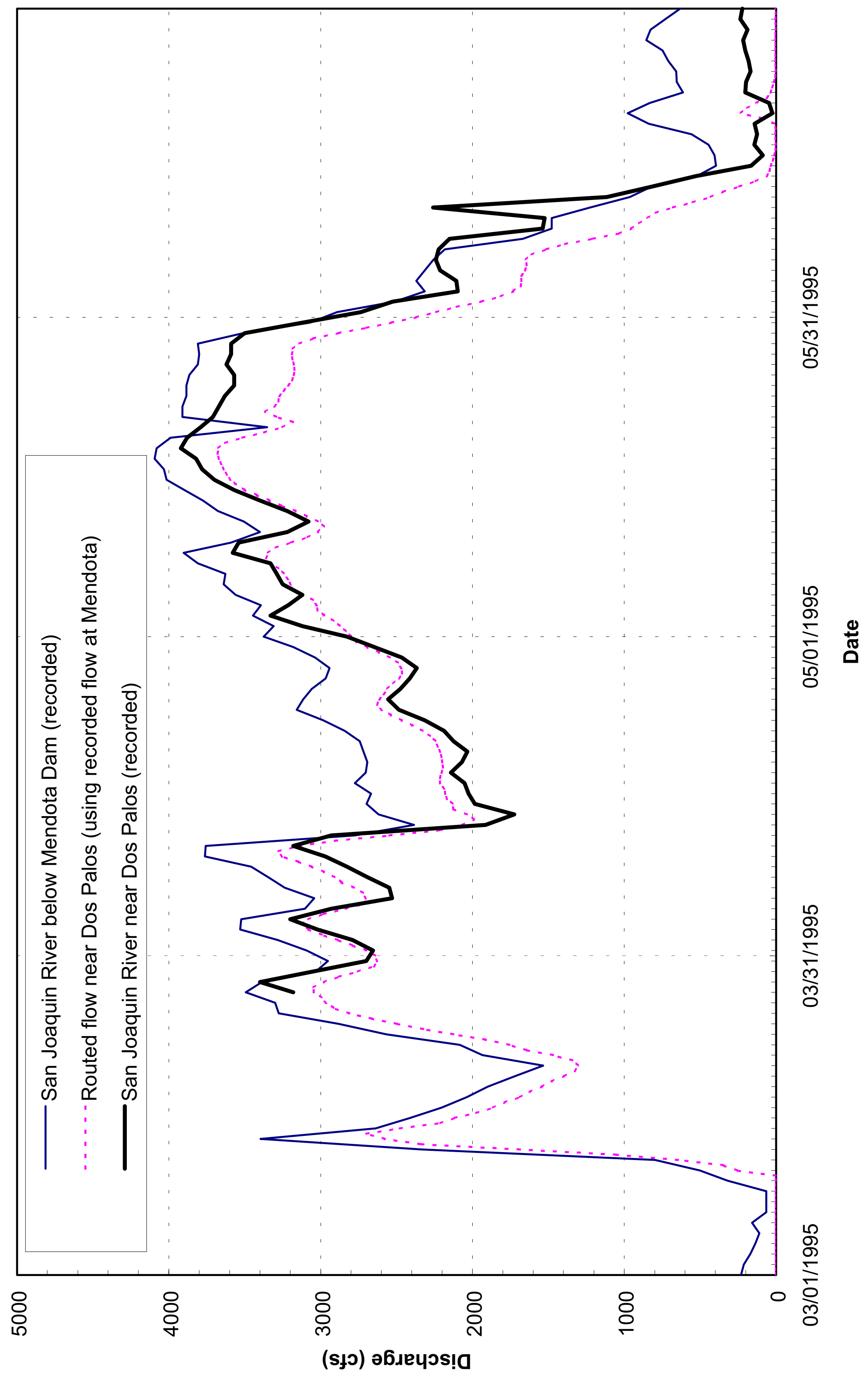

Figure 2-50. Measured and computed mean daily flow hydrographs in the San Joaquin River below Mendota Dam and at the Dos Palos gaging station for March 1-May 31, 1995.

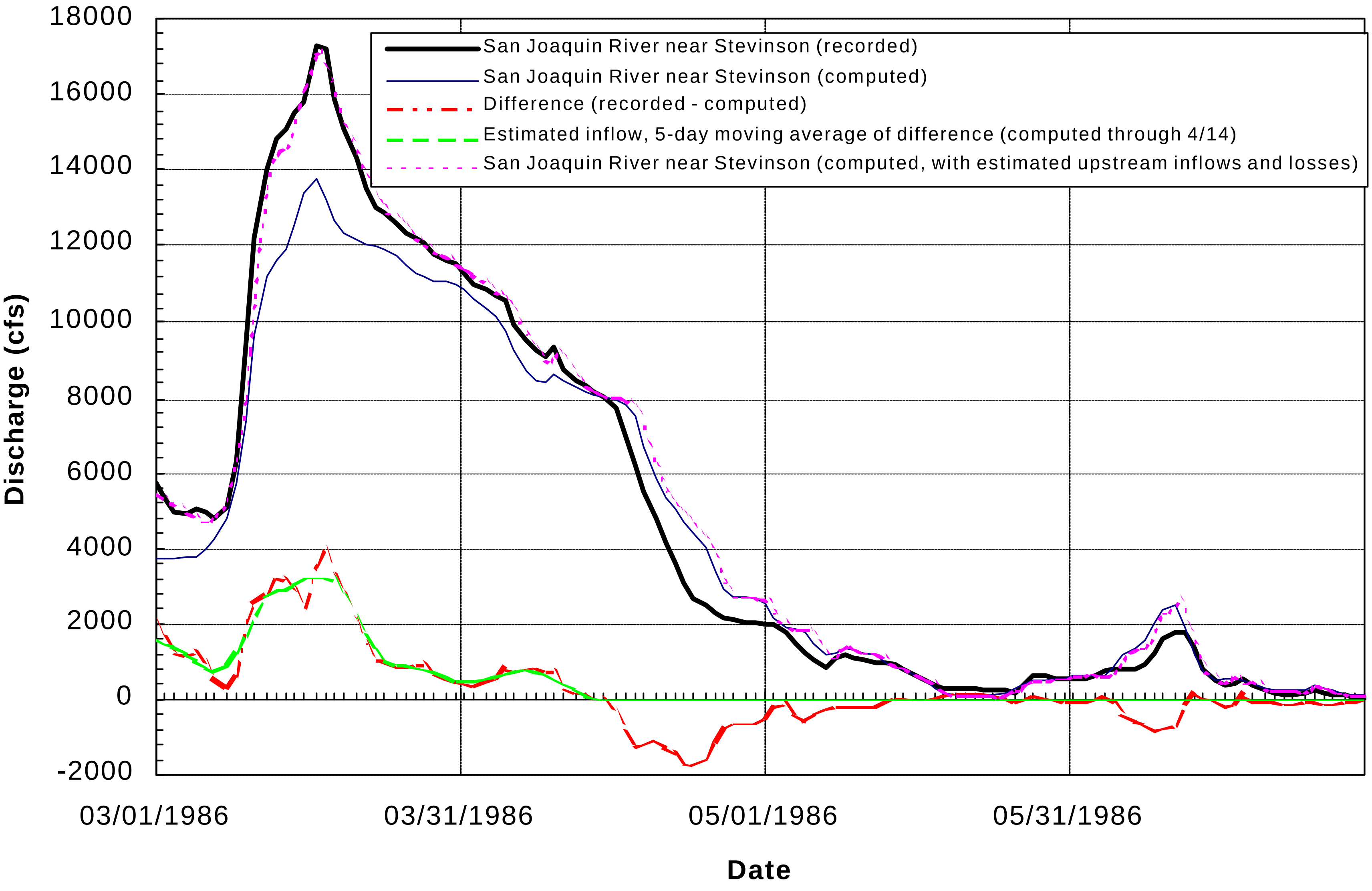

Figure 2-51. Measured and computed mean daily flow hydrographs in the San Joaquin River below Mendota Dam and at the Stevinson gaging station for March 1-May 31, 1986.

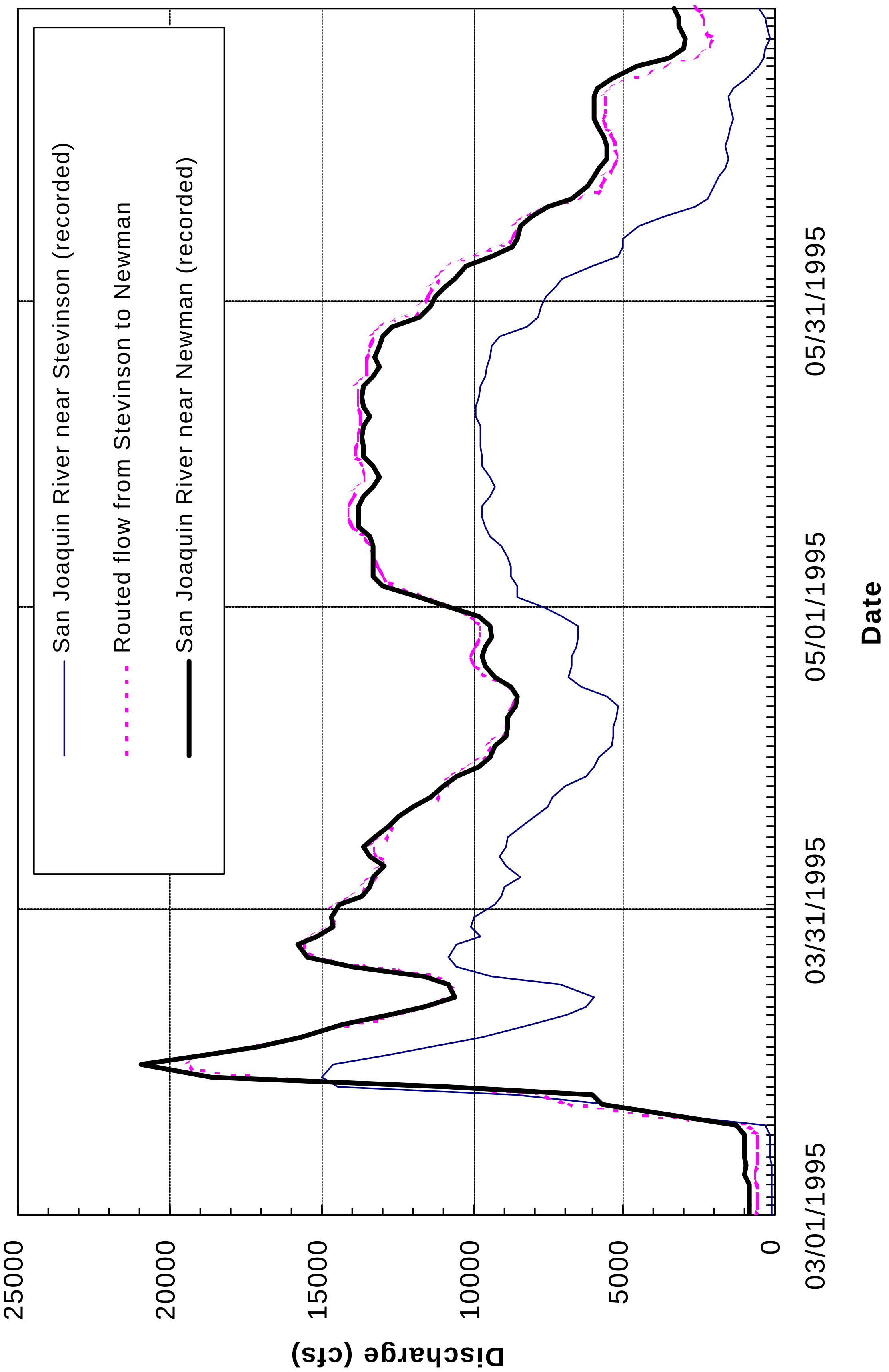

Figure 2-52. Measured and computed mean daily flow hydrographs in the San Joaquin River below Mendota Dam and at the Stevinson gaging station for March 1-May 31, 1995.

Figure 2-53 and 2-54 show the routed versus computed 1986 and 1995 hydrographs, respectively, for the Newman gage. Inflows for Salt Slough, Mud Slough, and the Merced River are known for each event. The plot shows that the computed hydrographs match the measured hydrographs at the downstream end reasonably well, verifying the routing parameters for the section of the river from the Stevinson gage to the Newman gage. Based on these results, it was assumed that the routing parameters developed in a similar manner for the other sections of the river and bypass system are reasonable.

Ungaged inflows into the Eastside Bypass system occur at various locations, and an apparent flow loss occurs near Mendota Dam during high flows. These inflows and losses were concentrated at three locations in the routing model: (1) Overflow losses at Mendota Dam, which represent the apparent losses near the dam during high flows; (2) Eastside tributaries 1, which represent ungaged inflows to the bypass system between the Chowchilla Bifurcation Structure and the El Nido gage; and (3) Eastside tributaries 2, which represent ungaged inflows to the bypass system between the El Nido gage and the mouth of Bear Creek. The unknown flows at each of these locations were estimated for both the 1986 and 1995 runoff periods by comparing computed flows (routed flows from known points upstream) with recorded flows.

The model was also calibrated at the gaging station below Mendota Dam using 1986 and 1995 flows. The computed flows are based on recorded flows in the river below the Chowchilla Bifurcation Structure routed to Mendota Dam and added to the recorded inflows from the James Bypass/Fresno Slough. For each time period, measured flows at the Mendota gage are in general much lower than the computed flows, indicating significant flow losses. Assuming accuracy in the gage records, these losses are likely a result of outflows into the various irrigation canals that connect to the river at Mendota Pool. The losses were estimated as the difference between the computed and measured hydrographs, with the computed hydrographs lagged by 1 day for each time period to more accurately align with the recorded hydrographs. A 5-day moving average of the computed differences was used to smooth out the estimated loss hydrograph. Computed negative values represent net irrigation inflows.

Figure 2-55 and Figure 2-56 show 1986 and 1995 computed versus recorded flows at the El Nido gage on the Eastside Bypass, respectively. The computed flows are based on recorded flows at the head of the Chowchilla Bypass, the routed flows at Mendota with the losses accounted for, recorded (1995) or estimated (1986) diversions into the Arroyo Canal, and the estimated flow split at the Sand Slough Control Structure (see below). For the 1986 time period, the hydrographs match reasonably well, indicating minimal tributary inflow. The inflow was assumed to be zero for this time period. For 1995, the computed hydrograph is in general lower than the recorded hydrograph prior to about April 6, but shows a less consistent variation after this, which is attributable largely to the timing of the hydrographs. The computed difference for the period March 1 to April 6, smoothed using a 5-day moving average, was used to develop the estimated inflow hydrograph for 1995 for the eastside tributaries between the Chowchilla Bifurcation Structure and the El Nido gage.

2.8.2.3. Flow Routing Results: Attenuation and Storage Effects under Existing Conditions

Results obtained from the calibrated flow routing model for the 1995 event were used to evaluate the attenuation and storage effects along the reach under existing river conditions. Figure 2-57 shows the measured flows at the Friant gage and the routed hydrographs at eight points along the reach for the period between March 1 and April 1, 1995. The routed hydrographs show an approximately 2-day time lag in flows between Friant Dam and Gravelly Ford and a ½-day time lag between Gravelly Ford and the Chowchilla Bifurcation Structure. The peak discharge among these three locations attenuates

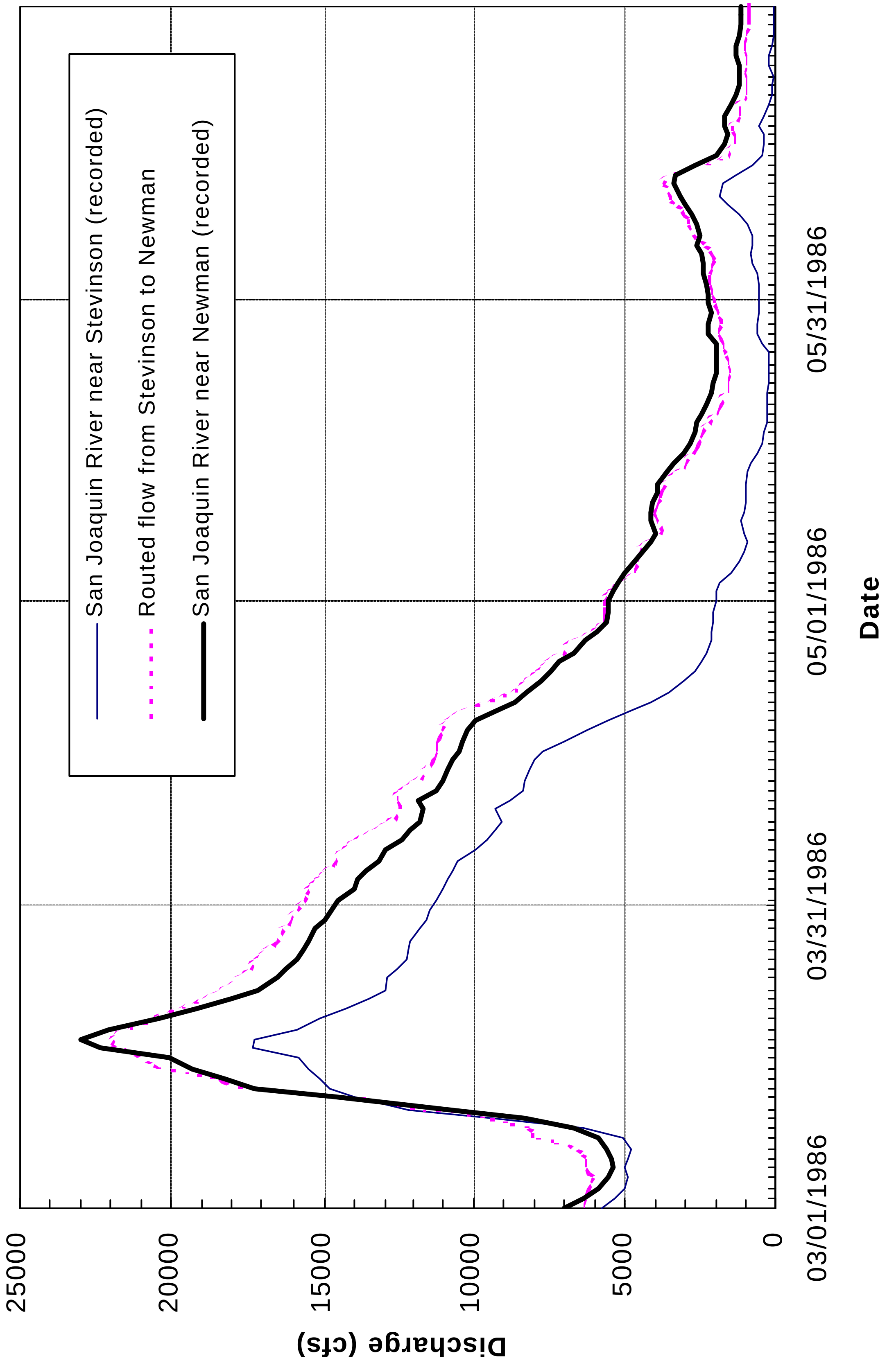

Figure 2-53. Comparison of measured and computed mean daily flow hydrographs at the San Joaquin River near Newman gaging station for March 1-May 31, 1986.

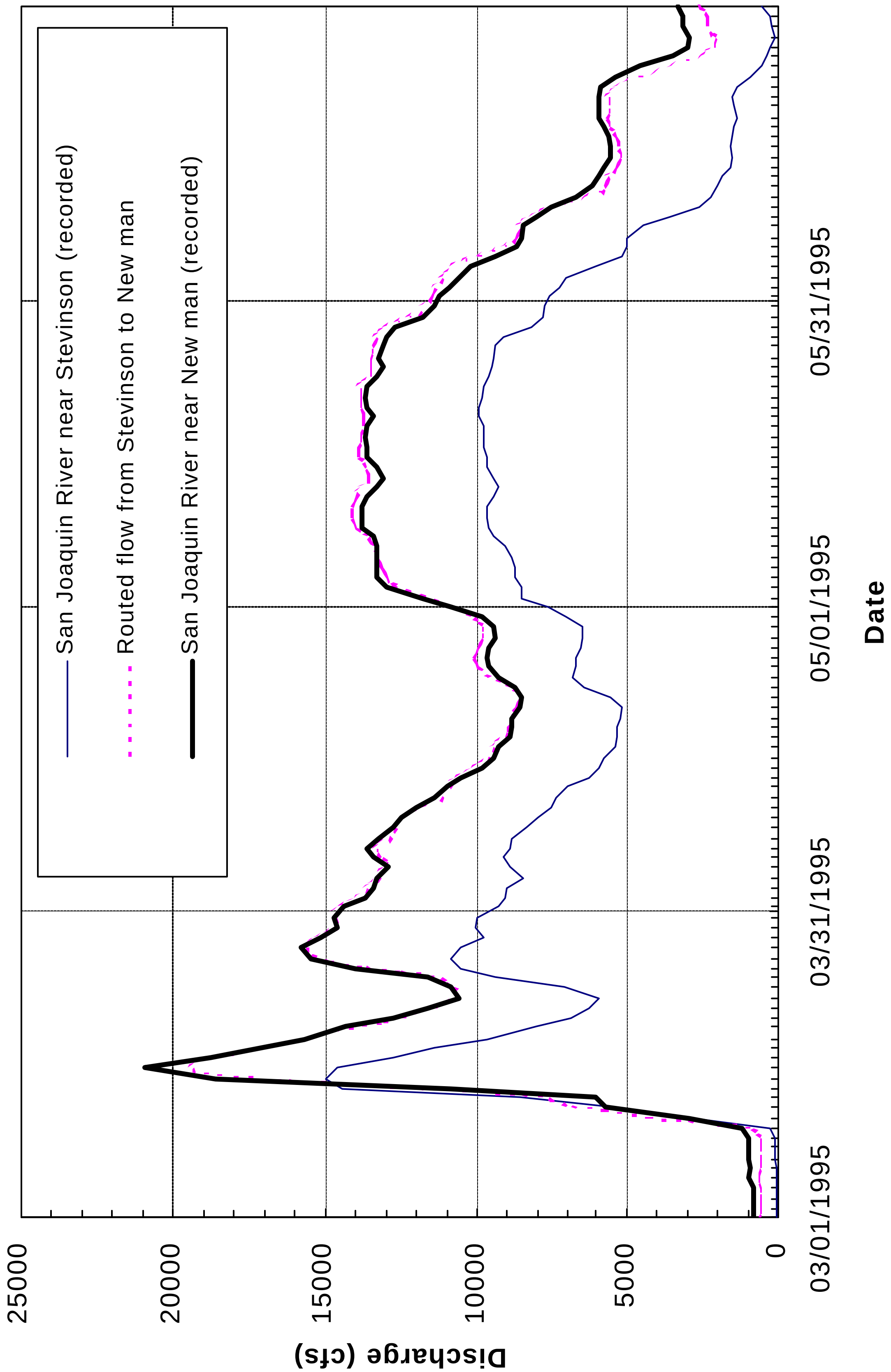

Figure 2-54. Comparison of measured and computed mean daily flow hydrographs at the San Joaquin River near Newman gaging station for March 1-May 31, 1995.

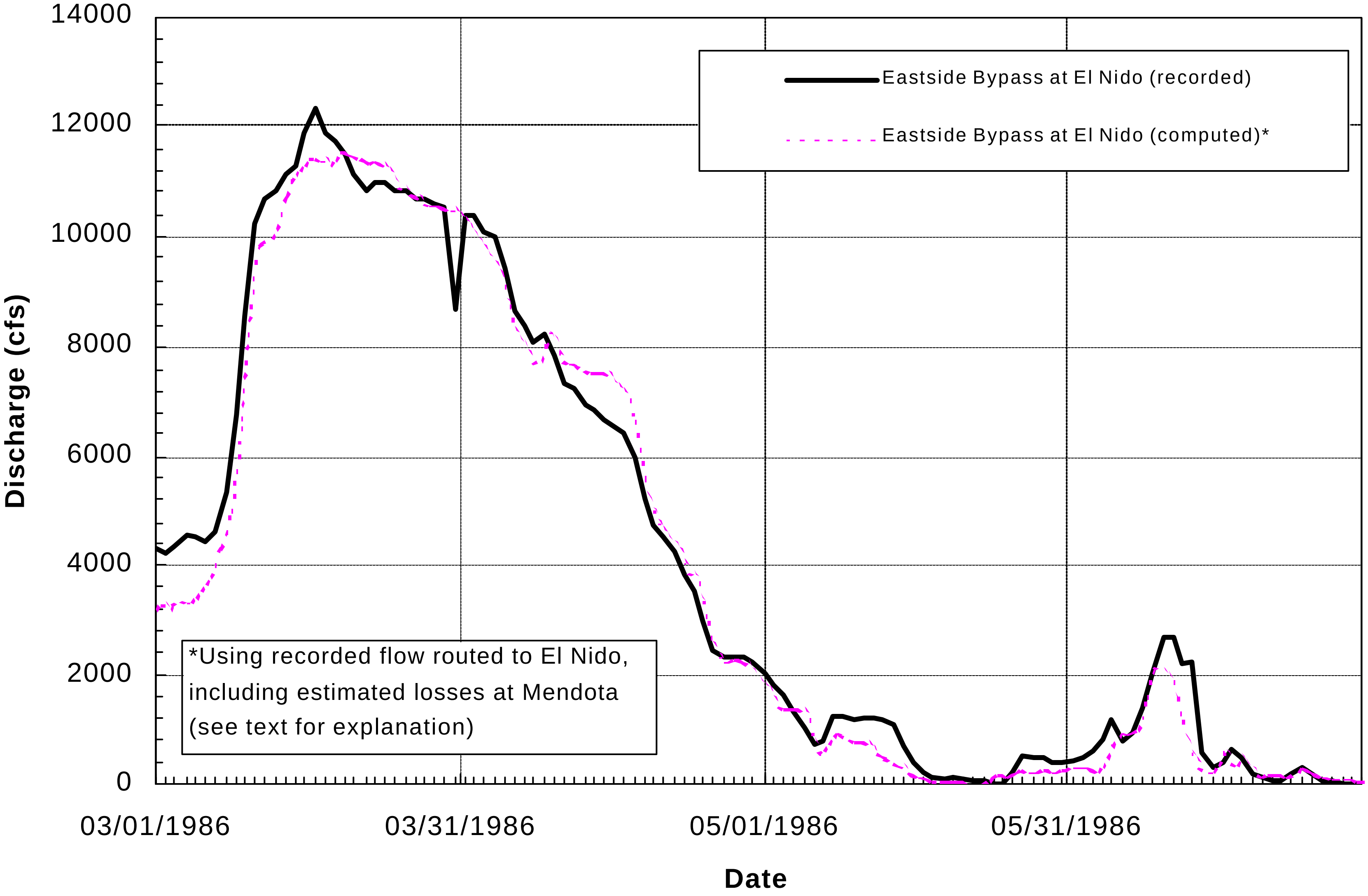

Figure 2-55. Comparison of measured and computed mean daily flow hydrographs at the East Side Bypass at El Nido gaging station for March 1-July 1, 1986.

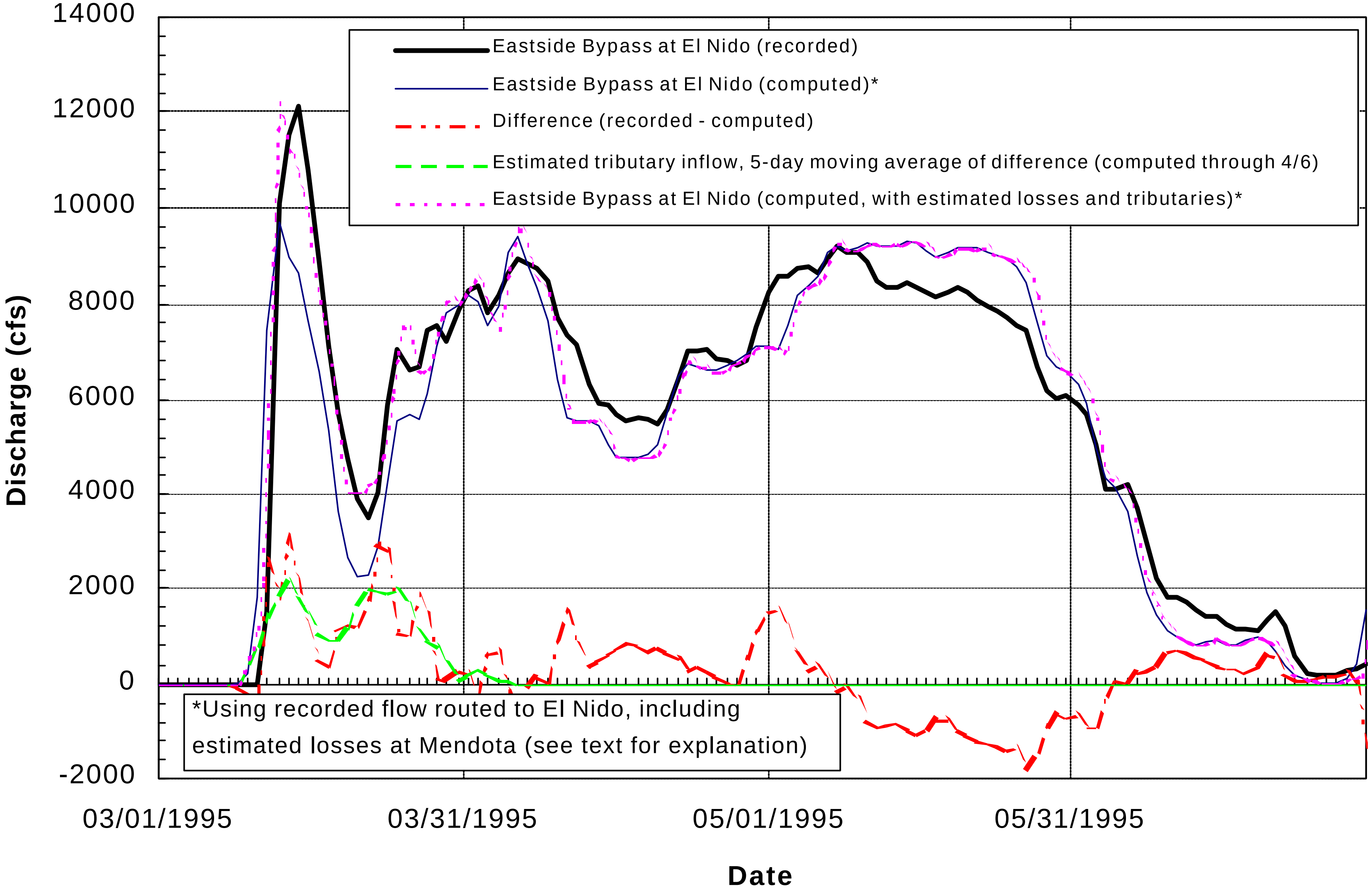

Figure 2-56. Comparison of measured and computed mean daily flow hydrographs at the East Side Bypass at El Nido gaging station for March 1-May 31, 1995.

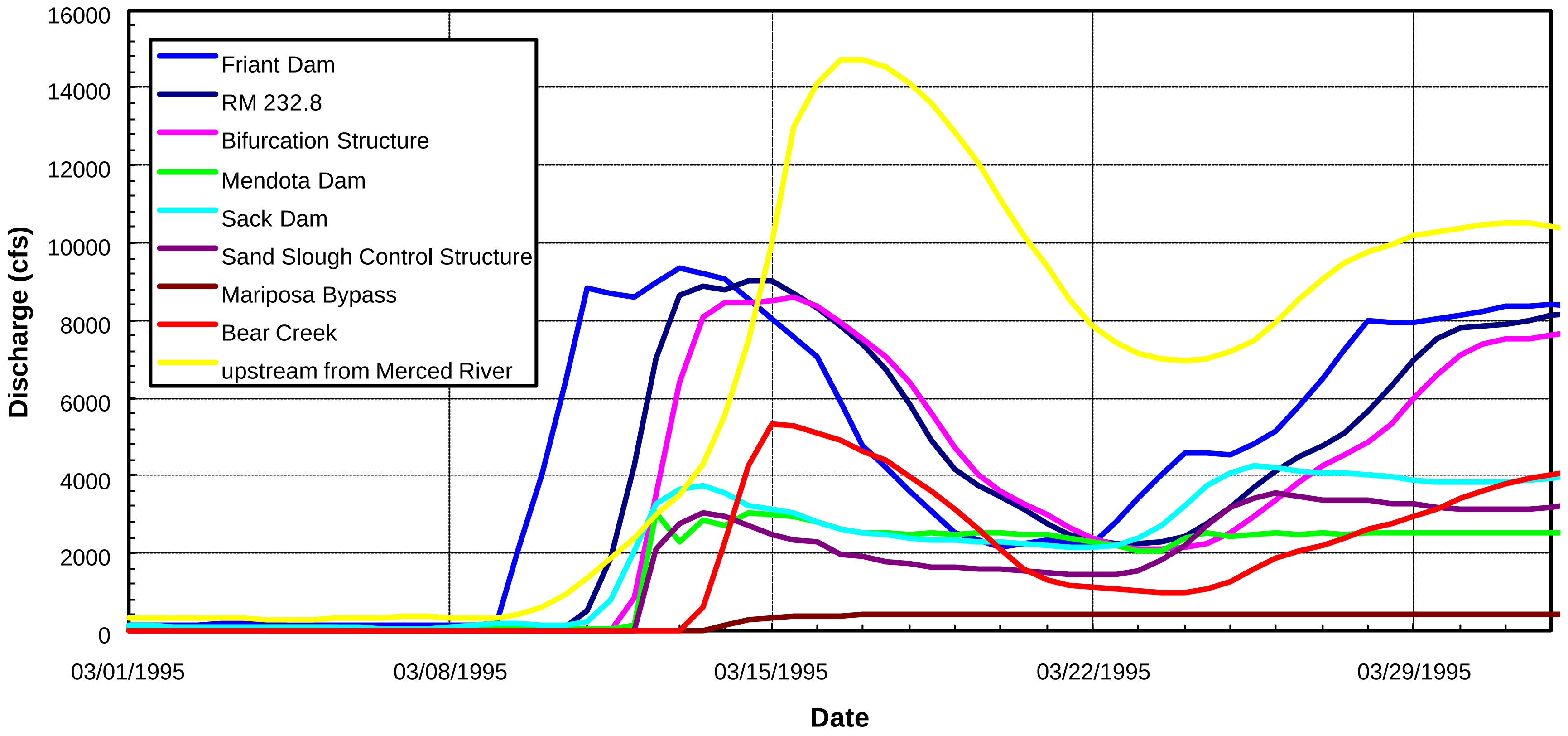

Figure 2-57. Measured flows between March 1 and April 1, 1995, at the Friant gage and the routed hydrographs at eight points along the reach between Friant Dam and the Merced River for existing river conditions.

from 9,350 cfs at Friant Dam to 9,000 cfs at Gravelly Ford to 8,576 cfs at the Chowchilla Bifurcation Structure (Table 2-18). The hydrographs for locations downstream from the Chowchilla Bifurcation Structure show the combined effects of diversions from the main river (e.g., Chowchilla Bypass, losses at Mendota Dam, Arroyo Canal, Eastside Bypass at Sand Slough Control Structure), inflows from the various tributaries along the reach, as well as the routing and attenuation effects in this portion of the overall reach.

Table 2-18. Summary of flood peak attenuation for existing and historic conditions for the 1995 high flow hydrograph. All flood peak magnitudes include tributary inflows for the 1995 high flow.

	Existing conditions		**Historic conditions**	
Gaging location	**Flood peak magnitude (cfs)**	**% flood peak attenuation from Friant (cfs)**	**Flood peak magnitude (cfs)**	**% flood peak attenuation from Friant (cfs)**
At Friant gage	9,350	0.0	39,300	0.0
At Gravelly Ford	9,000	-3.7	32,700	-16.8
At Chowchilla Bifurcation Structure	8,575	-4.7	28,060	-14.2
At Mendota Dam	3,000	N/A	25,930	-7.6
At Sack Dam	3,700	N/A	25,930	0.0
At Sand Slough Control Structure	3,000	N/A	25,000	-3.6
At Mariposa Bypass confluence	400	N/A	21,800	-12.8
At Bear Creek confluence	5,300	N/A	20,300	-6.9
Upstream of Merced River	14,700	N/A	25,000	+23.2

[1] Model diverts flow into bypasses based on operational rules, flood peak attenuation cannot be computed.

2.8.2.4. Flow Routing Results: Attenuation and Storage Effects under Historical Conditions

A routing model was also developed for historical conditions prior to construction of the bypasses, diversions, and levee system based on the 1914 CDC mapping. This model was used to estimate the characteristics of the historical flood hydrographs along the reach. Inflows at the upstream end of the reach at the present location of Friant Dam were taken from the full natural flow record for the 1995 event. The model used the same routing parameters as the existing conditions model to ensure that the results would be comparable. In addition, the tributary inflows that were used in the existing conditions model were also used in the historical conditions model, but the eastside tributaries that are intercepted by the Chowchilla Bypass and Eastside Bypass were input to the river in their approximate historical locations. Diversions into the bypasses and canals along the reach were eliminated from the model. Although the existing tributary inflows are likely quite different from what they would have been in the absence of human influences, the resulting routing model provided a reasonable approximation of the changes in mainstem hydrograph shape along the reach.

Results obtained from the historical conditions model for the period between March 1 and April 1, 1995 are presented in Figure 2-58 for the same eight locations that were presented for the existing conditions model. The hydrographs attenuate significantly along the upstream portion of the reach between Friant Dam and the present location of Mendota Dam, with a peak discharge at Friant Dam of about 39,300 cfs compared to 28,060 at the present location of the Chowchilla Bifurcation Structure, and about 25,930 cfs at Mendota Dam (Table 2-18). The lag time between each of the locations varies from about ½ day to a full day.

2.8.3. Historical Inundation Pattern and Frequency

As described above, the San Joaquin River historically flooded frequently, particularly in Reaches 2-5. Flows during drier years may not have spilled out onto floodplains and floodbasins, whereas wetter years may have inundated Reaches 2-5 for long periods (months). The combined effects of flood flow regulation by upstream dam, levees along the San Joaquin River, and the San Joaquin River Flood Control Project has greatly reduced the magnitude, frequency, and duration of inundation along the study reach. In an effort to quantify the degree of change in inundation, the flood routing model was used to estimate historical and existing inundation patterns for three index floods.

2.8.3.1. Methods

Peak flow-stage relationships were quantified under historical and existing flood conditions to characterize the pre- and post-flood control periods and the pre- and post-dam periods. The areas inundated for various flows were determined for these periods to show the combined effect of levee confinement downstream of Friant Dam and flood frequency changes as a result of flood flow regulation from upstream dams.

The areas inundated for three historical flood flows were calculated using the 1914 mapping, cross sections, and water surface profiles (ACOE 1917). The 1914 profiles show water surfaces associated with discharges of 5,700 cfs and 9,800 cfs, and for an unknown discharge at the “highest known water surface.” To better quantify the effects of the various flood control measures throughout the study reach, the study area was divided into 4 subreaches:

1. Herndon to Chowchilla Bifurcation Structure (Reaches 1B–2A)
2. Chowchilla Bifurcation Structure to Mendota Dam (Reach 2B)
3. Mendota Dam to Sand Slough Control Structure (Reaches 3–4A)
4. Sand Slough Control Structure to Merced River (Reaches 4B–5)

Because the profile for the highest known water surface did not extend to the railroad bridges at Herndon, the upstream reach was truncated at cross section 7 (RM 247.4), approximately 8 miles downstream of the Herndon Railroad Bridge. For each cross section, the water-surface elevation for each of the flows was measured from the profiles. These water-surface elevations were then drawn on the cross sections and the water-surface widths were measured. At numerous locations for the two highest water profiles (9,800 cfs and the “highest known water surface”), the width was greater than the extents of the cross-section plots. The measured widths at these locations are therefore reported as “greater than” the cross-section limits.

The incremental area of inundation between cross sections was calculated by multiplying the measured width and the average of the left and right overbank distances between the cross sections. The overbank distances between the cross sections were measured on the 1914 mapping at approximately the limits of the water surface. Because the detail of the 1914 contours and mapping was not sufficient to accurately map the floodplain, maps showing areas of inundation were not produced.

The areas inundated for the historical flood flows were also calculated for existing conditions to assess the effect of flood control measures and other changes that have occurred throughout the project reach. The water-surface widths were determined from the existing hydraulic model runs for the 5,700-cfs discharge and the 9,800-cfs discharge, assuming the 5,700 cfs and 9,800 cfs values represented Friant Dam releases. The highest known water surface was not included in the present conditions analysis because the discharge is not known. Previously assumed loss rates and operating

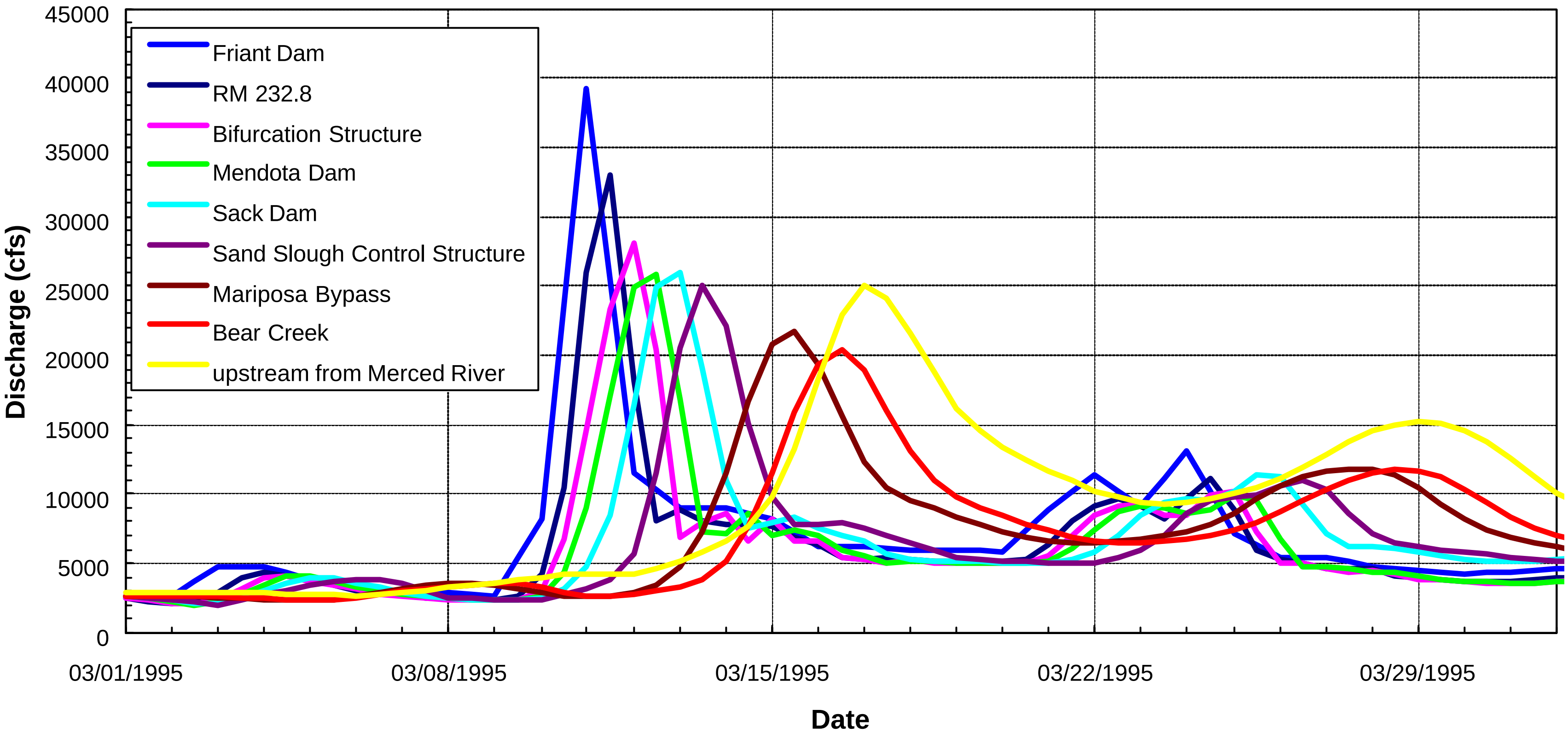

Figure 2-58. Estimated full natural flows between March 1 and April 1, 1995, at the Friant gage and the routed hydrographs at eight points along the reach between Friant Dam and the Merced River for historic river conditions.

rules for the bifurcation structures, control structures, and Mendota Dam were used to determine what discharge remains in the San Joaquin River throughout the reach. It was assumed that flows are limited to 2,500 cfs in the San Joaquin River downstream of the Chowchilla Bifurcation Structure when upstream river flows are less than 8,000 cfs, with flows increasing to 6,500 cfs when the discharge in the upstream river is 12,000 cfs. Discharges remaining in the San Joaquin River after accounting for the various inflows and outflows are summarized in Table 2-19. The incremental areas were calculated by multiplying the water surface width and the overbank distances obtained from the hydraulic model and summed to represent the inundated areas for each of the subreaches.

To evaluate the combined effects of Friant Dam flow regulation and levee confinement on the inundated areas resulting from floods, the inundated areas were calculated in a similar fashion for flows with post-dam frequencies similar to the frequencies of the historical flood events. The historical flood events of 5,700 cfs and 9,800 cfs have pre-Friant Dam recurrence intervals of approximately 1.3 years and 2 years, respectively. Although the discharge and the return period corresponding to the highest known water surface are unknown, for the purposes of this study, it was assumed the discharge had a pre-Friant Dam recurrence interval of 10 years. Under post-Friant Dam conditions, the 1.3-year event below Friant Dam is approximately 240 cfs, the 2-year event is approximately 1,000 cfs, and the 10-year event is approximately 8,000 cfs. The discharges were also adjusted throughout the study reach to include losses and the effects of the assumed operating rules of the bifurcation structure, control structures, and Mendota Dam. The discharge remaining in the San Joaquin River for the three events is summarized in Table 2-19.

Table 2-19. Summary of discharges remaining in the San Joaquin River under present conditions.

			Discharge Below Friant Dam (cfs)					
Section Number	River Mile	Reach	240 cfs	1,000 cfs	5,700 cfs	8,000 cfs	9,800 cfs	Location
596	266.5	1A	240	1,000	5,700	8,000	9,800	<=Friant Dam
225	242.5	1B	149	909	5,609	7,909	9,709	<=Herndon Railroad Bridge
122	235	1B	151	911	5,610	7,909	9,709	
121	235	1B	151	911	5,610	7,909	9,709	<=U/S Limit of “Highest Known Water Surface” Profile
a186	223.6	2A	63	782	5,429	7,714	9,506	<=Chowchilla Bifurcation Structure
a96	215.1	2B	50	728	2,500	2,500	4,006	
								<=Mendota Pool
764	203.7	3	50	728	2,500	2,500	4,006	
474	181.2	4A	1	214	2,020	2,020	3,556	<= Sand Slough Control Structure
302	167.7	4B	1	9	70	70	130	

Table 2-19. cont.

			Discharge Below Friant Dam (cfs)					
Section Number	River Mile	Reach	240 cfs	1,000 cfs	5,700 cfs	8,000 cfs	9,800 cfs	Location
257	164.4	4B	2	10	71	71	130	
252	164	4B	1	9	70	70	130	<=Mariposa Bypass
36	146.6	4B	1	26	373	373	1,013	
7	144.3	4B	1	26	373	373	1,013	Bear Creek
M234	135	5	1	66	910	910	2,416	
M146	128.2	5	21	282	1,213	1,213	2,756	
M117	125.8	5	40	564	2,425	2,425	5,512	Salt Slough
M116	125.7	5	21	283	1,213	1,213	2,756	
M88	123.7	5	28	333	1,335	1,335	2,901	Mud Slough
M87	123.6	5	35	385	1,458	1,458	3,046	
M6	117.3	5	35	385	1,458	1,458	3,046	Merced River
M5	117.3	5	50	728	2,750	2,750	5,009	

2.8.3.2. Results

The inundated areas for the historical flows are summarized for the 1914 conditions and the present conditions in Table 2-20, illustrating the effects of implemented flood-control measures. The results also include the effects of the large number of diversions along the project reach. Results indicate that the flood control and diversions reduce the area of inundation by an average of about 25% for the 5,700-cfs discharge and by a factor of about 10 for the 9,800-cfs discharge. The reach from Herndon to the Chowchilla Bifurcation Structure shows the smallest reduction in flooded area because there is no flow diverted upstream of this reach under both 1914 and existing conditions. Under existing conditions, the effects of flow diversions become more pronounced downstream of Chowchilla Bypass.

Table 2-20. Summary of inundated areas for 5,700 cfs, 9,800 cfs, and "highest known water surface" under (1) 1914 topographic conditions, and (2) existing topographic conditions and flood control system operation rules.

		Inundated Area at Q=5,700 cfs (acres)		**Inundated Area at Q=9,800 cfs (acres)**		**Inundated Area at Highest Known WSE (acres), Unknown Discharge**	
Reach	**RM Limits**	**1914**	**Existing**	**1914**	**Existing**	**1914**	**Existing**
Herndon to Chowchilla	227.7-247	1,319	1,276	>4,133	1,590	>15,846	?
Chowchilla to Mendota	216.7-227.7	726	420	>6,241	1,931	>8,074	?
Mendota to Sand Slough	169.7-216.7	1,530	1,235	>26,356	1,578	>30,414	?
Sand Slough to Merced	130-169.7	2,029	1,437	>16,436	2,872	>53,084	?

Table 2-21 illustrates the combined effects of Friant Dam flow regulation and levee confinement downstream by summarizing the inundated areas for the pre- and post-Friant Dam 1.3-, 2.0-, and 10-year flood events. The present inundated areas are also controlled by the diversions throughout the project reach. The results indicate that the combined effects of Friant Dam and levee confinement are very significant. For the 1.3-year event, the area inundated under present conditions is about an order of magnitude less than the area inundated under the 1914 conditions, and almost two orders of magnitude less for the 2.0- year and the 10-year events.

The subsidence that has occurred in the project reach should not confound the analysis of the inundated areas under the 1914 conditions with respect to the present topography. The analysis of the 1914 flood conditions is based on pre-subsidence topography, and the analysis of the present flood conditions is based on 1997 topography, which accounts for the subsidence. Under present conditions, the subsidence creates a concave shape in the longitudinal profile, resulting in more inundated area at the flatter downstream end of the profile and less inundated area in the steeper upstream end of the profile.

Table 2-21. Summary of inundated areas for the pre- and post-Friant Dam 1.3, 2.0, and 10-year recurrence interval floods under (1) 1914 topographic conditions, and (2) existing topographic conditions and flood control system operation rules.

		Inundated area at approximately 1.3-year event (acres)		**Inundated area at approximately 2.0-year event (acres)**		**Inundated area at approximately the 10-year event (acres)**	
Reach	RM Limits	1913 (Q=5,700 cfs)	Existing (Q=240 cfs)	1913 (Q=9,800 cfs)	Existing (Q=1,000 cfs)	1913 (Unknown Discharge)	Existing (Q=8,000 cfs)
Herndon to Chowchilla	227.7-247	1,319	350	>4,133	626	>15,846	1,461
Chowchilla to Mendota	216.7-227.7	726	238	>6,241	338	>8,074	439
Mendota to Sand Slough	169.7-216.7	1,530	417	>26,356	627	>30,414	1,578
Sand Slough to Merced	130-169.7	2,029	495	>16,436	616	>53,084	2,872

2.9. SUMMARY

The surface water hydrology of the San Joaquin River has undergone tremendous changes since surface water development began in the mid- to late-1800's, which in turn has caused corresponding changes to fish, riparian, and wildlife populations, as well as the fluvial geomorphic processes responsible for creating and maintaining the San Joaquin River ecosystem. The information presented in this chapter begins to document some of these changes, which will provide useful insights to understand how key biota and geomorphic processes have changed, as well as strategies that may improve future restoration efforts. In addition to gathering and summarizing existing data on surface water hydrology, analyses conducted within this chapter illustrated several key findings on changes to surface water hydrology:

- The average annual volume of water released to the San Joaquin River downstream of Friant Dam was reduced from 1,812,000 acre feet to 695,000 acre feet, a 62% reduction in yield. Because the amount of reservoir storage provided by Millerton Reservoir and other upstream reservoirs is relatively small compared to the unimpaired water yield during wetter water years, much of the post-Friant Dam water releases to the river are flood control releases.

These flood control releases are still much smaller than unimpaired conditions, but they are large enough to provide significant restoration opportunities (e.g., riparian restoration flows, geomorphic process flows, fish rearing and migration flows).

- Native San Joaquin River water no longer flows through all reaches of the San Joaquin River. Flows in the lower San Joaquin River (Reaches 3-5) are provided by Delta-Mendota Canal water (Reach 3), and agricultural return flows of Delta-Mendota Canal water (Reach 4 and Reach 5). The current baseflow regime and agricultural diversion infrastructure leaves several reaches dewatered year-round (Reach 2 and portions of Reach 4).
- The contribution of flow from the Kings River via Fresno Slough still occurs, but likely at a much lower magnitude, frequency, and duration compared to unimpaired conditions.
- Tributary flow contribution (baseflow and floodflows) to the lower San Joaquin River are significantly reduced by upstream dams and the flood control project.
- The magnitude, duration, and frequency of flood flows have been dramatically reduced. Ecological impacts of the reduced flood flow regime and flood control project include reduced geomorphic magnitude, duration, and frequency of fluvial geomorphic processes; reduced magnitude, duration, and frequency of overbank flows; reduced area of overbank inundation; reduced recruitment of riparian and wetland vegetation; and higher water temperatures during certain times of the year.
- The large storage capacity of the historic flood basin in Reach 3 through Reach 5 significantly reduced flood peaks; the reduced floodplain storage and increased hydraulic efficiency of the existing flood control project likely reduces flood wave travel time and reduces the degree of flood peak attenuation compared to unimpaired conditions.
- The life history strategy of riparian vegetation, wetland vegetation, native fish, waterfowl, and other biota evolved to the unimpaired flow regime. Changes to the flow regime have interfered with these life history strategies with varying and poorly known impacts. The conceptual relationships between hydrology, fluvial geomorphology, and the biota in this chapter (as well as Chapters 3, 7, and 8) provide opportunities for future restoration strategies to develop an ecosystem approach to restoring the San Joaquin River, increase mutual benefits to target species, and improve overall probability of success of the restoration effort.

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CHAPTER 3. FLUVIAL PROCESSES AND CHANNEL FORM

3.1. INTRODUCTION

As introduced in Chapter 2, the natural characteristics of an alluvial river ecosystem are created and maintained by the interaction of water, sediment, underlying geology, and in some cases, large wood structures (ranging from individual logs to accumulations of logs and branches). Flow and sediment shape the channel, floodplain, and habitat for aquatic and terrestrial species (Figure 3-1). For example, high flows transport sediment, deposit sediment, cause channel migration, cause channel avulsion (rapid relocations of channels), distribute riparian seeds, and cause other large scale geomorphic and biotic processes.

The size, shape, and form of the San Joaquin River (channel morphology) changes in different reaches between Friant Dam and the Merced River. This diversity between the reaches is caused by different geologic factors and the corresponding changes in fluvial processes. For example, the San Joaquin River courses through steep confined canyons of the Sierra Nevada, and the steep gradient and confined valley walls result in a high energy environment that is efficient in transporting most size classes of sediment (up to large boulders). As a result, the channel morphology is typified by high gradient, dominated by large substrate and exposed bedrock (non-alluvial), and small amounts of sediment storage (bars). Riparian vegetation is limited to individual trees in hydraulically sheltered areas, such as behind large boulders and along channel margins at the base of the valley walls. As the river exits the Sierra Nevada foothills, valley confinement and gradient decreases. Resulting channel morphology in this region is mostly alluvial, with a low gradient meandering channel, gravel/cobble substrate, multiple channels, and more extensive riparian vegetation. Further downstream, gradient and confinement continues to decrease, resulting in a more sinuous, sand-bedded channel (Reaches 2 through 5). Riparian vegetation is more extensive, channel migration and avulsion is more pronounced, and sloughs become more common. In the downstream-most reaches along the axis of the San Joaquin River Valley, the low gradient and backwater effect from the Merced River alluvial fan creates a relatively unconfined flood basin several miles wide in some areas that was historically inundated over a prolonged portion of the year. Sediment supply from the upper watershed cumulatively settled out in upstream reaches, such that sediment supply in these lower reaches was low. This resulted in a channel morphology that was still sand-bedded, but had small riparian “levees” that dropped away into extensive tule marshes and sloughs away from the primary channel of the San Joaquin River. This diversity of channel morphology provided habitat for a wide range of aquatic and terrestrial species, making the San Joaquin River Valley one of the most diverse ecosystems in the western United States.

The longitudinal diversity of the San Joaquin River created a dynamic gradient of habitat types over the project reach. Salmonids, their habitats, and other aquatic flora and fauna were distributed in relatively predictable ways along that gradient, according to their specific life history requirements. Hence, describing the historic and contemporary fluvial geomorphic processes that form and maintain alluvial rivers is important for assessing related ecological impacts of human actions. Human “actions” include historic activity conducted as part of resource utilization, agriculture, and/or land development; actions also include future activity conducted as restoration. As with other chapters in this report, understanding how the river formed and functioned, and how historic human activities changed these functions, is important to provide insights on how to restore the San Joaquin River (Kondolf 1995).

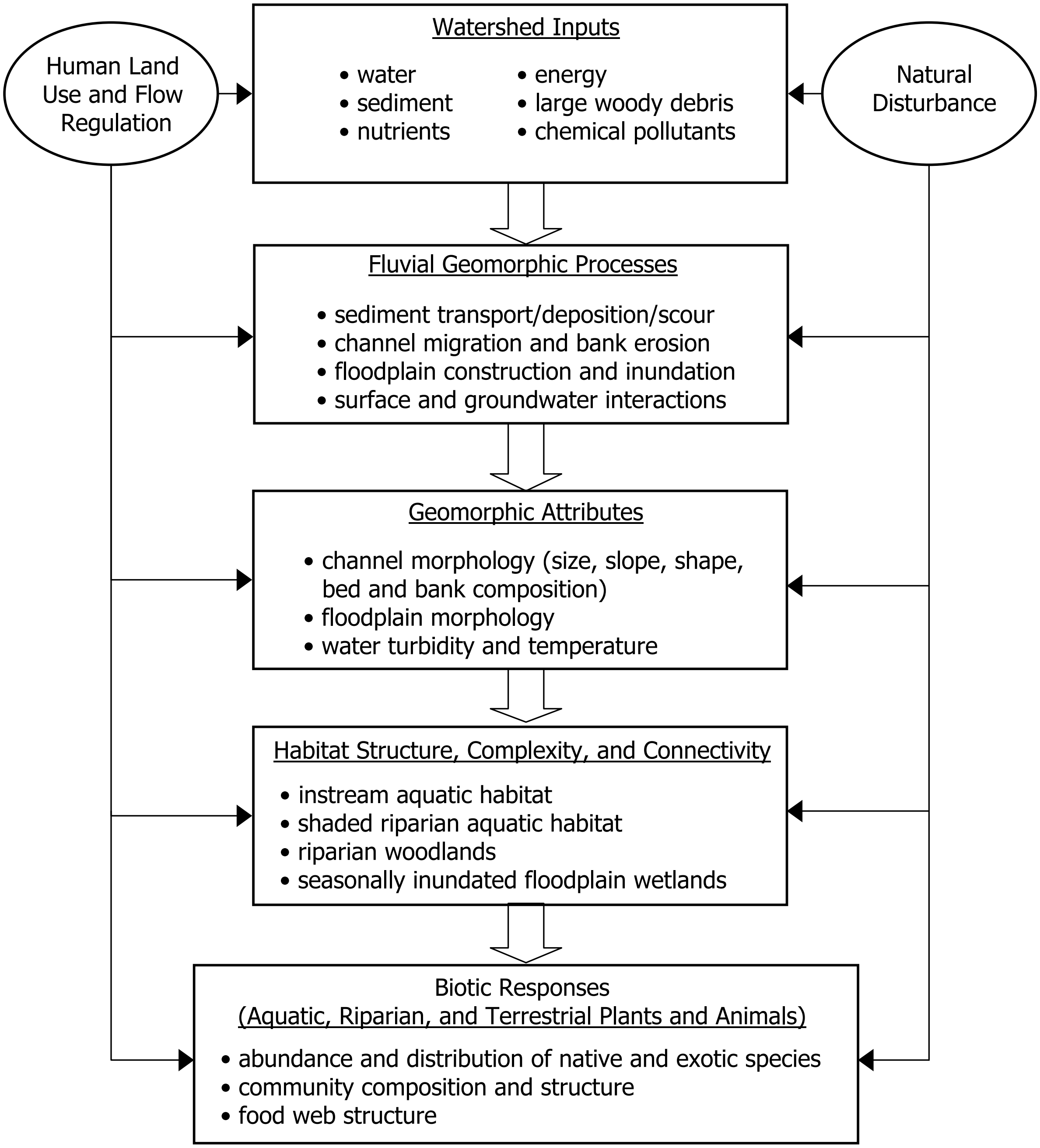


Figure 3-1. Conceptual physical framework of alluvial river ecosystems, showing how natural fluvial geomorphic components and human components cascade to changes in biota.

3.2. OBJECTIVES

The goal of this chapter is to describe and analyze the historical and existing geomorphic conditions to improve our understanding of the physical and environmental processes that have shaped the San Joaquin River ecosystem over time, and to gain insight into the kind of actions necessary to achieve the restoration goals and their subcomponents. As with the hydrology chapter, the products of this chapter are meant to provide insight into the potential benefits of certain geomorphic restoration actions, but not necessarily to provide the historical conditions per se as a restoration goal. Based on the April 2000 Scope of Work, the objectives of this chapter are to:

- Measure and summarize changes in primary, secondary, and high flow channels greater than 1,000 feet long (assess changes in channel length)
- Summarize available substrate composition for each reach
- Summarize sediment budget in all reaches based on results of sediment transport model
- Summarize bed mobility thresholds in Reach 1 based on sediment transport model
- Quantify and describe rates of channel migration and avulsion during the pre-dam, and post-dam period.
- Describe historic and contemporary channel conditions based on historical maps and early explorer accounts.

There have been several hydrologic and geomorphic studies previously conducted that provide information pertinent to these objectives, and information from historical sources and these previous studies is integrated to address these objectives. This chapter does not perform any unique analyses, with the exception of synthesizing information to develop conceptual models of historical channel processes and channel morphology. These conceptual models will be useful in developing and evaluating restoration strategies when developed by the Restoration Study.

3.3. STUDY AREA

As described in Chapter 1, The San Joaquin River is bounded by the Sierra Nevada on the east and Coast Ranges on the west; its southern boundary is on the divide with the Tulare Lake basin, and its northern boundary is the Delta near Stockton (Figure 3-2). Between Friant Dam and the Merced River confluence, the San Joaquin River passes through several reaches differentiated by their geomorphology and resulting channel morphology, and by their human-imposed infrastructure along the river. Therefore, the river has been subdivided into five primary reaches that exhibit similar flows, geomorphology, and channel morphology (Figure 3-2). Primary Reaches 1, 2, and 4 have been further divided into reaches based on distinct geomorphic and morphologic features (Table 3-1). Additionally, these reach delineations are further subdivided by the sediment transport modeling effort, which is discussed further in Section 3.9.2.

Table 3-1. Brief summary of reach and reach locations and general boundary descriptions.

Reach	***Subreach***	***Reach boundary (river mile)***	***General description***
1	1A	267.5 – 243.2	Friant Dam to State Route 99
	1B	243.2 – 229.0	State Route 99 and extends downstream to Gravelly Ford
2	2A	229.0 – 216.1	Gravelly Ford to the Chowchilla Bypass Bifurcation Structure
	2B	216.1 – 204.8	Chowchilla Bypass Bifurcation Structure to Mendota Dam
3	3	204.8 – 182.0	Mendota Dam to Sack Dam. Reach 3 has not been subdivided into subreaches.
4	4A	182.0 – 168.5	Sack Dam to the Sand Slough Control Structure.
	4B	168.5 – 135.8	Sand Slough Control Structure to the confluence with Bear Creek and the Eastside Bypass
5	5	135.8 – 118.0	Confluence with Bear Creek and the Eastside Bypass to the Merced River confluence. No unique reaches are delineated within Reach 5.

The drainage area of the San Joaquin River is 1,638 mi^2 at Friant (upstream end of study area) and 7,615 mi^2 at Fremont Ford (located just upstream of the confluence with the Merced River at the downstream end of the study area). Elevations of the watershed range from sea level at Stockton to over 13,000 feet at the crest of the Sierra Nevada. Within the study area, elevations range from 70 feet at the confluence with the Merced River to 320 feet at the base of Friant Dam.

3.4. INFORMATION SOURCES

This report draws on a number of previous reports, maps, surveys, data, and historical anecdotes to qualitatively and quantitatively describe historic and present geomorphic conditions in the study reach. Over the last 150 years, numerous government agencies surveyed and mapped the river for various purposes, including the Government Land Office (1854-55), the State Engineer (Hall 1870’s), the Army Corps of Engineers (1914), the U.S. Bureau of Reclamation (1938), the State Lands Commission (1989), and the San Joaquin River Riparian Program (Ayres 1998). This report relies on information from this maps and surveys to characterize historical conditions and patterns of change throughout the study reach in the last 150 years. Additional quantitative data for present-day conditions are derived from several studies (e.g., MEI 2000a, MEI 2000b, Cain 1997) as well as unpublished data collected as part of the San Joaquin River Restoration Study.

3.4.1. Early Anecdotal Descriptions

Historical descriptions from early explorers were used to develop some insights of Central Valley channel morphology prior to European settlement. An extensive review of this material did not provide much useful information on historical channel morphology or processes; most descriptions focused on vegetation and soils because resource exploration was the primary purpose of many of the early expeditions. The primary historical descriptions are those of William Brewer (Brewer, 1949), George Derby (Derby 1850), and compilations of Phyllis Fox (Fox, 1987). These sources, coupled with historical maps, form the basis for discussing historical channel conditions in Section

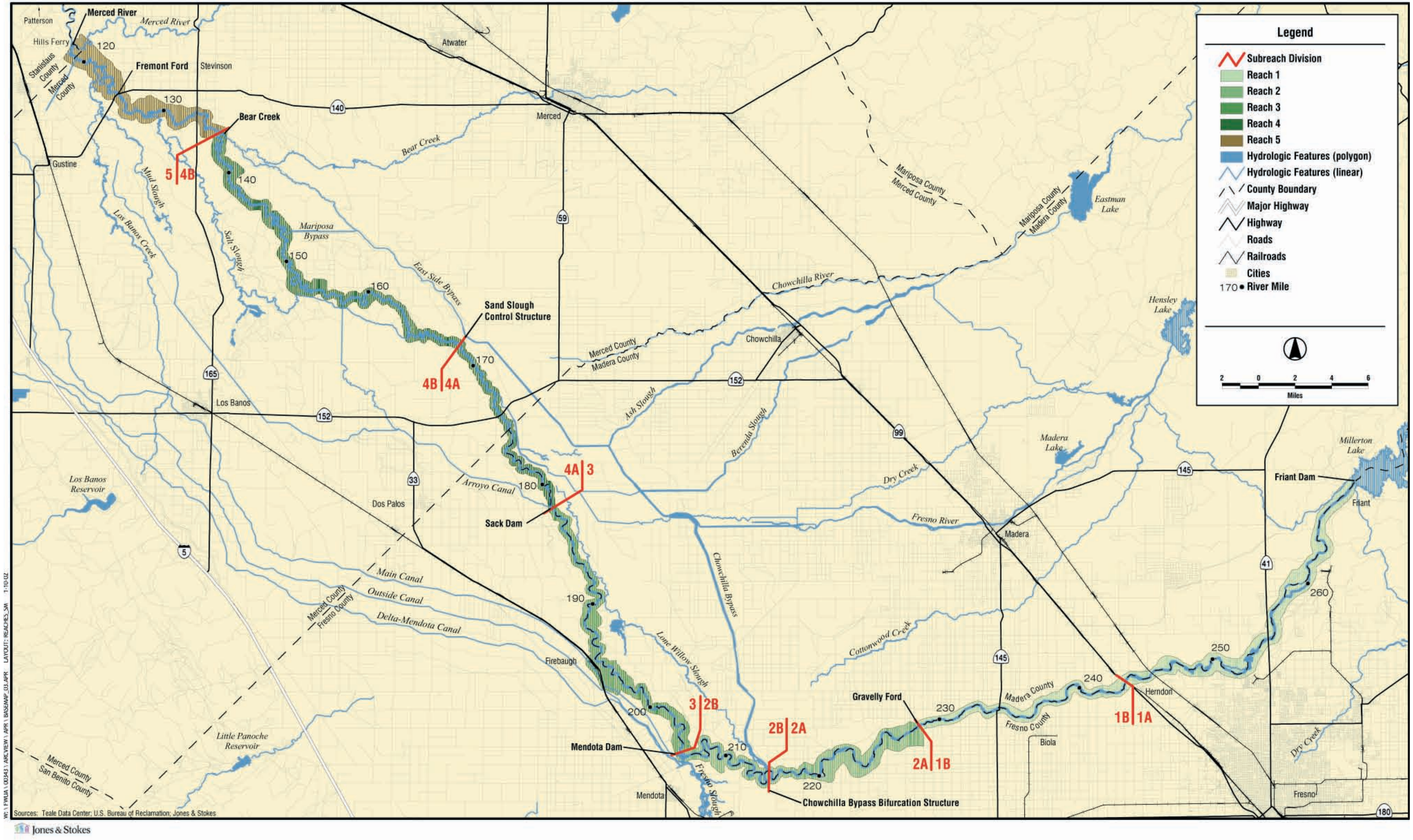


Figure 3-2. Study area for the San Joaquin River Restoration Plan, showing the reach and sub-reach boundaries.

3.6.6. The California Debris Commission (CDC) survey maps (ACOE 1917), which encompass the area from Herndon downstream to the confluence with the Merced River, are another useful source; however, these maps clearly reflect that effects on the riparian environment from relatively extensive land use changes must have already occurred. Maps from the William Hammond Hall surveys have been considered in this report, but extensive field notes and field books prepared during these surveys may contain additional details that could provide further insights to historical conditions on the San Joaquin River. These sources were not investigated in this report due to time constraints. Lastly, a collection of historical descriptions of the San Joaquin River were gathered from the Bancroft Library, Humboldt State University Library, and personal libraries; this compilation is available on CD from the Friant Water Users Authority.

3.4.2. Aerial Photographs

There are many sets of aerial photographs, but the most useful were those of 1937/1938 and 1998 because they best illustrate the historical to current conditions evolution. The 1937 photographs were obtained from the Exchange Contractors, Bureau of Reclamation, and Fairchild Aerial Photo Archives, contact prints have a scale of 1”=1,667’, and extend from the Ledger Island (RM 263) downstream to the end of Reach 4A (photos end at RM 170). The 1938 photographs were obtained from the Army Corp of Engineers, contact prints have a scale of 1”=833’, and extend from the Friant Dam site (RM 268) to Herndon (RM 261). The 1998 photographs were obtained from Bureau of Reclamation, contact prints have a scale of 1”= 333’, and extend from Friant Dam (RM 267.5) to the Merced River confluence (RM 118). The term “Historical” is meant to refer to the date of the data source, and does not infer an unimpaired condition. Because pre-1937 aerial photographs do not exist, unimpaired conditions cannot be documented from aerial photographs, and must be inferred from historical maps, anecdotal descriptions, and professional judgment based on observations of the 1937 and 1938 aerial photographs with appropriate acknowledgement of changes that had occurred between 1848 and 1937 (e.g., clearing of riparian vegetation for steamboats, construction of levees, Miller-Lux grazing, agricultural clearing).

3.4.3. Maps and Surveys

Historical mapping pre-dates the aerial photographs; however, many of the maps are more qualitative and small-scale, and not appropriate for quantitative comparisons. Spanish and Mexican explorers produced the earliest maps in the early 1800’s, with the first maps produced by Americans in the late 1840’s and early 1850’s. The U.S. Government Land Office (GLO) produced the first large-scale quantitative maps in 1854-1855. The purpose of the GLO mapping effort was to subdivide lands in the new State of California, establish range, township, and section lines, and to establish U.S. Meander Lines along the rivers (these lands were subsequently deeded to the State of California to be reclaimed under the Swamp and Overflow Act).

Surveys conducted by William Hammond Hall in the 1870’s resulted in maps of the Sacramento and San Joaquin valleys (See Figure 4-6), but the scale is too large to use for detailed evaluation of channel location or morphology. In 1878, Hall surveyed over a dozen cross sections and a 2,000 ft long longitudinal profile in the upper portion of Reach 1. These are located in a 3-mile reach near Friant Dam and in a 1.25-mile reach near the Highway 99 bridge (Hall 1878 as cited in Cain 1997).

The Army Corps of Engineers (ACOE 1917) produced the next large-scale maps for the California Debris Commission (CDC). These maps were surveyed in 1914 and 1915, extended from Herndon (RM 261) downstream to the Merced River confluence (RM 118), contain channel locations, riparian vegetation, and section corners, and have a scale of 1”=400’. As part of the mapping effort to produce the 1914-1915 maps (ACOE 1917), longitudinal profiles and cross sections were produced. These cross sections and profiles represent the earliest elevational data upon which long-term trends could be compared. The 1914 longitudinal profile is shown in Figure 3-3; cross sections from the 1914 survey effort are shown as needed in subsequent sections.

The Bureau of Reclamation prepared better-scaled topographic maps in 1939, as well as 150 cross sections, between Friant Dam and Gravelly Ford (as cited in Cain 1997). In 1993, the State Lands Commission used these maps and conducted additional surveying in 1989 to develop topographic maps of the reach from Friant Dam to Herndon (RM 243.2). There are also cross sections available at State highway crossings from CalTrans from 1970 and 1997.

The USGS topographic maps provide early (1910’s to 1920’s) elevational information, but the precision of this topography is not very useful for historical comparisons. These USGS quadrangle maps were revised in the 1960’s to 1980’s.

The most recent topographic information was generated by Ayers and Associates as part of the Comprehensive Study (Ayers and Associates 1998). Topography was generated using 1998 photogrammetry and bathymetry. Digital Terrain Models were developed from these surveys, allowing cross sections to be generated at any location between Friant Dam and the Merced River confluence. This topography has a stated accuracy of 2’ contour interval and thus provides much more precise topography than UGSG topographic maps. More recent field-based cross section surveys in Reach 1A (Cain 1997), in Reach 1B and Reach 2 as part of the San Joaquin River Riparian Habitat Restoration Program Pilot Project (JSA and MEI 2002, SAIC 2002), and in Reach 4B (MEI, 2000) provide more precise cross sections than the 1998 Ayers and Associates topography for those selected locations.

For planform comparisons, this chapter emphasizes the 1854 GLO plat maps, 1914 CDC maps, 1937 aerial photographs, and 1998 photographs. For cross section and longitudinal comparisons, this chapter emphasizes the 1914 cross sections and longitudinal profiles, the 1938 USBR cross sections, the 1998 Ayers and Associates topography, and Cain 1997 cross sections.

3.4.4. Previous Reports and Analyses

There are several reports that describe historical and/or existing channel processes and form on the San Joaquin River. Janda (1965) describes the hydrology and geology of the upper San Joaquin River during the Pleistocene (last 2,000,000 years). Cain (1997) provides a more recent comparison of changes in hydrology and channel morphology over the last 100 years in Reach 1, focusing on flow and sediment changes associated with Friant Dam, and reduction in coarse sediment budget due to aggregate extraction. JSA and MEA (1998) provide a summary of physical processes and channel morphology for the entire study area (Friant Dam to the Merced River confluence), assessing changes in cross section and longitudinal profiles by comparing data from the 1914 CDC maps (ACOE 1917) with 1998 topography. MEI (2000a) evaluates hydraulic and sediment transport continuity between Friant Dam (RM 267.5) and Mendota Dam (RM 205), and MEI (2000b) evaluates hydraulic and sediment transport continuity between Mendota Dam (RM 205) and the Merced River confluence (RM 118). These two reports estimate sediment transport capacity, sediment budget surpluses and deficits, hydraulic conveyance capacity, and particle size at select locations. Lastly, more recent data collected by Jones and Stokes Associates and Stillwater Sciences as part of the San Joaquin River Restoration Study are included in relevant sections of this chapter.

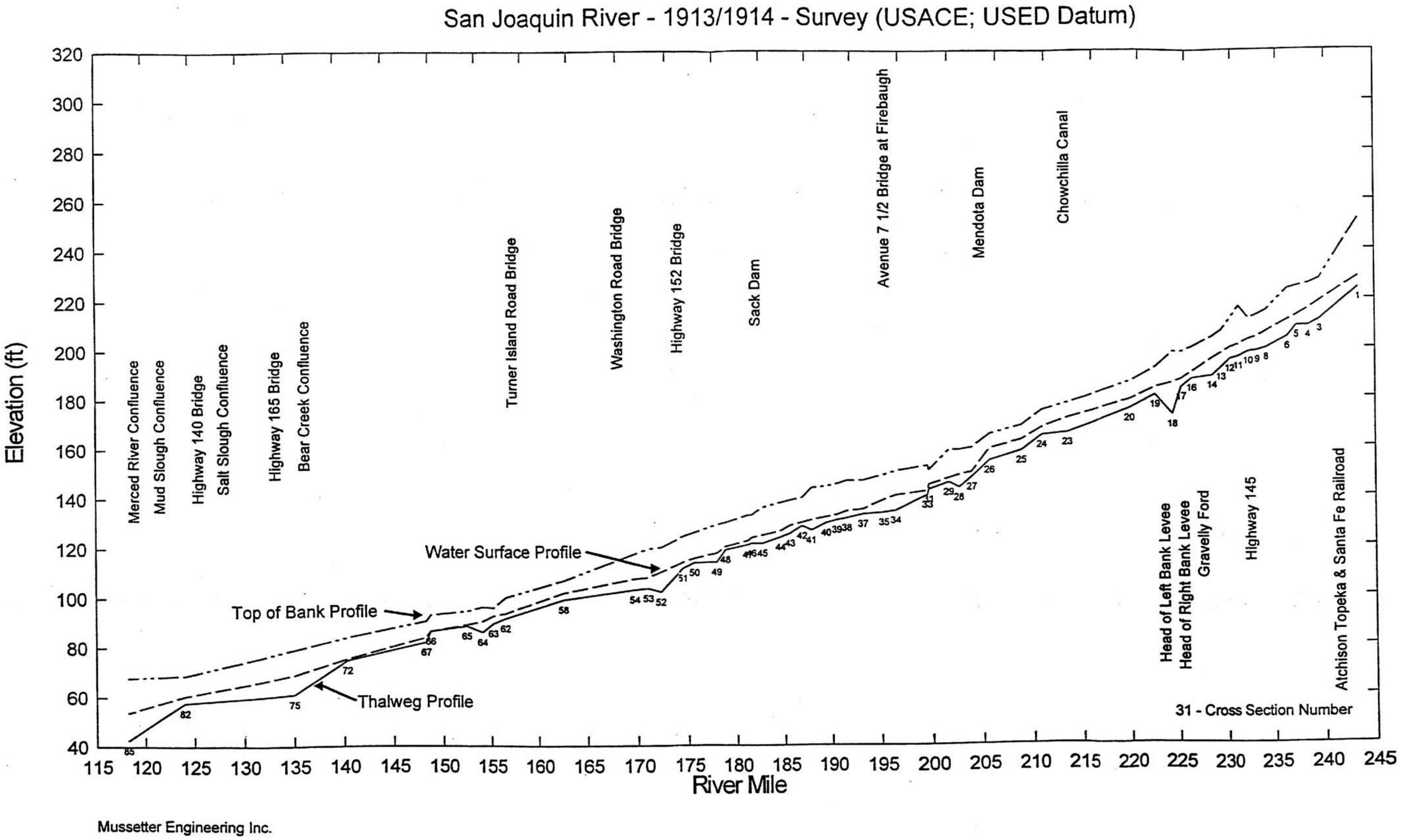


Figure 3-3. Longitudinal profiles from 1914 mapping effort (ACOE 1917) between Herndon and the Merced River confluence. The river mile markers begin at the Merced River confluence (RM 118.2), but the river mile markers and channel length from that point upstream are different than the mile markers used in this report.

3.5. DEFINITION OF TERMS

Geomorphology discussions are prone to terms that may be unfamiliar to many readers; thus, the following definition of terms has been developed to assist readers. To the greatest degree possible, the chapter attempts to minimize jargon and uses standardized terms.

Aggradation: The process of building up a surface by deposition (American Geological Institute 1984). In rivers, the process of the channel bed increasing in elevation by systematic net deposition.

Alluvium: Boulders, cobbles, sand, and silt moved and deposited by a stream or running water (American Geological Institute 1984).

Alluvial Rivers: Rivers whose bed and banks are formed from alluvium, and that have the ability to adjust their dimensions by erosion or deposition of alluvium.

Alluvial fan: An outspread, gently sloping mass of alluvium deposited by a stream, typically formed at the exit of a confined valley (American Geological Institute 1984).

Anastomosing channel: One of two or more channels that cut back and forth across a depositional area, but with the flow primarily concentrated in one dominant channel.

Anabranching channel: One of two or more channels that cuts parallel channels to the mainstem and rejoins the mainstem downstream. The difference between anabraching channels and anastomosing channels is the amount of sediment that the river is transporting. Avulsions are cause by excess sediment building up (aggrading) and creating another channel path (anastomosing channels) while an anabranching system results from sediment starved systems because there is a lack of coarse sediment to plug gaps that are scoured by seasonal flows that exceed channel capacity and scour a new channel in the floodplain.

Bankfull channel: Portion of the channel that conveys flows up to the point where flows begin to spill out of the bank and onto the floodplain. The outer extent of the bankfull channel marks the beginning of the floodplain, and is often correlated with a break in slope in the channel geometry where the width of the channel increases rapidly with increasing discharge (Leopold et al. 1964).

Bankfull discharge: Flow that is conveyed by the bankfull channel. The bankfull discharge often correlates with a flood recurrence of approximately 1.5-years (Leopold 1994), and the flow that transports the most sediment over time (“effective discharge)(Andrews, 1980).

Bedload: The part of a stream’s load that is moved on or immediately above the stream bed, such as the larger or heavier particles rolled along the bottom; the part of the load that is not continuously in suspension or solution (Figure 3-4) (Einstein 1950).

Bed material load: The discharge of sediment particles transported by the flow that are predominately found in the stream bed (Figure 3-4) (Einstein 1950).

Cenozoic: The latest of the four eras into which geologic time is divided; it extends from the close of the Mesozoic era, about 65 million years ago, to the present. The Cenozoic Era is subdivided into Tertiary and Quaternary periods.

Channel morphology: The size, shape, and character of the channel (planform, particle size, etc.).

Channel geometry: The size, shape, and character of the channel cross section.

Channel Slope: Change in elevation between two points along the stream channel divided by the curved line distance along the channel between the two points.

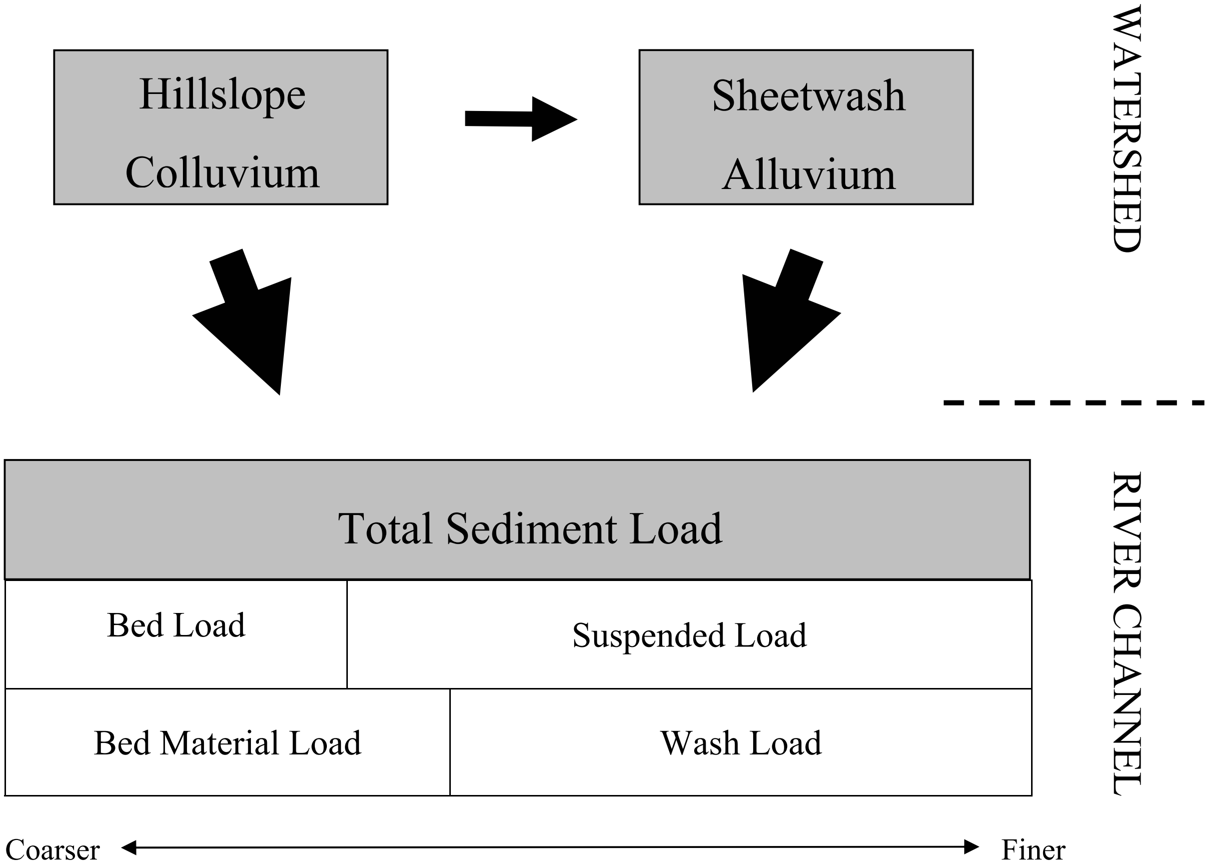


Figure 3-4. Conceptual flowchart showing sediment transfer from hillslope regime to fluvial regime, and subdivisions of total sediment supply.

Colluvium: Loose and incoherent deposits of sediment, usually at the foot of a slope and brought there chiefly by gravity (American Geological Institute 1984). Sediment originating from hillslopes and deposited by gravity rather than wind or water.

D_{84} particle size: Particle size diameter of a distribution of grain sizes in which 84% of the particles are finer. The D_{84} is a larger particle size of the distribution that provides a structural matrix of a gravel/cobble bar.

D_{50} particle size: Particle size diameter of a distribution of grain sizes in which 50% of the particles are finer (thus, the median grain size of a gravel/cobble bar).

Degradation: The process of lowering a surface by erosion (American Geological Institute 1984). In rivers, the process of the channel bed decreasing in elevation by systematic net incision.

Geomorphology: The study of landforms and the processes related to the formation of these landforms.

Holocene: An epoch of the Quaternary period, from the end of the Pleistocene, approximately 11 thousand years ago, to the present time. Also, the corresponding period of rocks and deposits

Fluvial geomorphology: The study of landforms created by fluvial (river) systems, including the study of the processes that create these landforms.

Meander wavelength: The length of a complete meander sequence. The distance between one meander bend and the next meander bend is one-half of a meander wavelength.

Planform: View of the channel looking vertically down from above (as if one was in a balloon).

Pleistocene: An epoch of the Quaternary period, after the Pliocene of the tertiary and before the Holocene; also, the corresponding series of rocks. The Pleistocene began about 2 million years ago and lasted until the start of the Holocene.

Quaternary: The second period of the Cenozoic era, following the Tertiary; also, the corresponding system of rocks. It began approximately 2 million years ago and extends to the present. It consists of two grossly unequal epochs: the Pleistocene, up to about 11 thousand years ago, and the Holocene since that time.

Sediment: Solid fragmental material transported and deposited by wind, water, ice, (or gravity) that forms in layers in loose unconsolidated form (American Geological Institute 1984).

Sinuosity: The degree of curvature in a stream, defined by the ratio of the channel length to the valley length. The higher the sinuosity, the more curved the stream channel.

Suspended load: The part of the total sediment load that is carried for a considerable time in suspension, free from contact with the stream bed; it consists mainly of clay, silt, and sand (Figure 3-4) (American Geological Institute 1984). The discharge of sediment particles that are suspended in the flow current turbulence (Einstein 1950).

Tertiary: The first period of the Cenozoic era (after the Cretaceous of the Mesozoic era and before the Quaternary), thought to have covered the span of time between 65 million and 2 million years ago; also, the corresponding system of rocks. It is divided into five epochs: the Paleocene, Eocene, Oligocene, Miocene, and Pliocene.

Thalweg: The line connecting the lowest (deepest) points along a streambed (American Geological Institute 1984).

Total sediment load: The mass rate of discharge of solid materials, usually referred to as sediment, transported by the water current (Figure 3-4) (Fairbridge 1968).

Valley Slope: Change in elevation between two points along the valley divided by the straight line distance between the two points.

Washload: The very small sediment particles transported by the flow that are not found in significant quantities in the stream bed (Figure 3-4) (Einstein 1950).

3.6. WATERSHED CONTEXT

While the study area of the San Joaquin River Restoration Study and Background Report focuses on the reach from Friant Dam to the Merced River confluence, the unimpaired San Joaquin River in this study reach was influenced by geomorphic processes in the watershed upstream of Friant Dam. Water supply, sediment supply, runoff processes, geology, and tectonics all contributed to channel processes and form in the study reach (Figure 3-1). A brief discussion of this upper watershed context, as well as the geologic foundation of the study reach, is provided in the following sections.

3.6.1. Drainage

The headwaters of the San Joaquin River are located at over 13,000 feet in the Sierra Nevada, near Mt. Davis, and the river descends over 360 miles to its confluence with the Sacramento River in the

Sacramento-San Joaquin Delta. The three largest tributaries to the San Joaquin River are the Merced, Tuolumne, and Stanislaus rivers; each originate in the Sierra Nevada and flow into the San Joaquin River from the east. Los Banos and Oristemba Creeks are the major west side tributaries that drain the east side of the Coast Mountain Ranges, and the Chowchilla River and Fresno River are east-side tributaries that drain the foothills of the Sierra Nevada. Unlike the San Joaquin River, Merced River, and Tuolumne River tributaries that are snow-fed, these tributaries have smaller drainage areas and runoff is nearly entirely driven by rainfall-generated storm events. The drainage area of the San Joaquin River is 1,676 mi^2 at Friant Dam (marking the upstream extent of the study area) and 7,615 mi^2 at Fremont Ford, located upstream of the confluence with the Merced River that forms the downstream project extent (Figure 3-2). Within the study area, elevations range from 320 feet at the base of Friant Dam to 70 feet at the confluence with the Merced River, with an average valley slope of 0.0003 (0.03 percent).

The San Joaquin River watershed drains a large portion of the San Joaquin Valley, except for the southernmost portion of the valley, which is drained by rivers such as the Kings River, Kern River, and others, all of which drain into the Tulare Basin. The Tulare Basin contained a series of terminal lakes (e.g., Tulare Lake, Buena Vista Lake, and Kern Lake), which were drained and reclaimed for agriculture in the late 1800s and early 1900s (Norris and Webb, 1990). Prior to drying up from diversions, Tulare Lake, was normally isolated from the San Joaquin River (Derby 1850). The potential exception of this condition may have been during exceptionally high regional runoff. During these periods, the lake likely overflowed and spilled into the San Joaquin River basin via Fresno Slough; however, the lake elevation would have had to rise from a typical summer low elevation of 176 feet to 205-210 feet for this to occur (DPW, 1931). Under present-day conditions, floods from the Kings River still periodically flow to the San Joaquin River via James Bypass and Fresno Slough during flood control releases from Pine Flat Dam. These flows enter the San Joaquin River via Fresno Slough at Mendota Pool (RM 205).

3.6.2. Climate

California has a Mediterranean climate that is characterized by dry summers and wet winters. Similar to all major rivers flowing out of the Sierra Nevada Mountain Range, the San Joaquin River is a snowmelt-dominated river. Winter storms carrying dense moist air from the Pacific Ocean cause precipitation in the Sierra Nevada in the form of snow, most of which melts and runs off in the spring and summer (see Chapter 2). Typically, the largest flow events are caused by rapid runoff during warm “rain-on snow” storm events. These warm storm events have a snow elevation as high as 10,000 ft, such that rain (and some melting snow) rapidly runs off from the wateshed and causes large magnitude floods downstream. Runoff from the valley floor portion of the watershed is minor, as the topographic relief is low, soils permeable, and rainfall low (5-12 inches/year).

The Mediterranean climate is reflected in the wide range of temperatures that occur within the watershed. On the valley floor, maximum summer temperatures frequently exceed 100ºF, while minimum winter temperatures can sometimes drop below 32ºF. Summer temperatures are more moderate in the upper watershed, typically 10ºF to 30ºF cooler than the valley floor. Winter temperatures are usually less than 32ºF above the 6,000 feet elevation, and temperatures are typically colder as elevation increases towards the crest of the Sierra Nevada.

3.6.3. Geology

The San Joaquin River is a dominant feature of the San Joaquin Valley, which stretches from near Bakersfield in the south to its confluence with the Sacramento River at the Sacramento-San Joaquin Delta to the north. The San Joaquin Valley is approximately 36 miles wide by 250 miles long, and is an asymmetrical, subsiding trough filled with Mesozoic- (~225 to 65 million years ago) and Cenozoic-age (~65 million years ago to present) alluvial sediments up to 5.6 miles thick. Structurally, the San Joaquin River sediment basin is separated from the Sacramento basin to the north by the Stockton fault and Stockton Arch, and is separated from the Maricopa-Tejon basin in the south by the White Wolf Fault and Bakersfield Arch (Bartow 1991). The San Joaquin Valley is bordered by the Sierra Nevada Mountain Range to the east and California Coast Ranges to the west. The Sierra Nevada is composed of crystalline igneous rocks, metamorphic rocks (rocks that have been physically changed by temperature or pressure), and volcanic and meta-volcanic ("meta" infers metamorphosis of the rocks after they were formed) rocks, while folded and faulted Jurassic- (~190 to ~135 million years ago) and Cretaceous-age (~135 to ~65 million years ago) sedimentary rocks typify the Coast Ranges. The west side of the valley is defined by a steep homocline (the bedrock is folded up to create a ridge) to the north that transitions to a belt of folds and faults toward the south (Bartow 1991). A broad and slightly inclined alluvial plain, consisting of a series of coalescing alluvial fans from rivers draining the Sierra Nevada, define the east side of the San Joaquin Valley (Janda 1965). The larger alluvial fans associated with the Merced, San Joaquin, and Kings rivers form local base level controls, which caused historical floods to backwater and thus were a major influence on geomorphic processes between the controls (Hall, 1887). Geologic evidence suggests that that valley has been deforming progressively since the Mesozoic period (Davis and Green 1962, Bull and Miller 1975) and contemporary subsidence is estimated at approximately 0.25 millimeters per year (Janda 1965, Ouchi 1983).

3.6.4. Pleistocene Changes in Channel Processes and Form

The channel morphology of the present-day San Joaquin River, particularly in Reach 1, exists within a framework of climatic changes occurring over the last several million years, and this morphology must be viewed in context with these longer time-scale changes. For example, the San Joaquin River in Reach 1 has recently (last few thousand years) incised within a large-scale alluvial fan exiting the San Joaquin River that was formed during periodic glacial periods with increased sediment yield. The incision has abandoned floodplains, which are now terraces used for agriculture and aggregate mining. In addition to this temporal (time) context, there is a spatial context that must be acknowledged as well that influences channel morphology. Differences in underlying geology, runoff conditions, and geologic controls throughout the San Joaquin River watershed cause differing sediment yields and channel morphologies between the study reach and in the watershed above Friant Dam (upstream of the study reach). This section provides some of this large-scale context.

The watershed of the lower San Joaquin River within the study area is composed of water-bearing Tertiary (~65 to ~2 million years ago) and Quaternary-age (~2 million years ago to present) alluvial sediments. The impermeable middle to late Pleistocene-age (~1.2 million years ago to ~10,000 years ago) Corcoran clay confines some of these water-bearing sediments; however, more recent alluvial deposits have buried the Corcoran clay (Norris and Webb 1990) (see Figure 4-4). Base-level control at the downstream end of the study area is provided by the Merced River alluvial fan. Conversely, the underlying rocks of the Sierra Nevada provide base level control for the San Joaquin River above Friant Dam. These rocks are composed of granitic rocks (75%), metamorphosed (physical change of rocks by temperature or pressure) sedimentary and volcanic rocks (15%) and discontinuous Cenozoic volcanic rocks such as basalt (10%) (Janda 1965). At Friant Dam, the San Joaquin River flows out of the bedrock foothills of the Sierra Nevada and cuts across the Pleistocene alluvial fan sediments of the San Joaquin Valley in a shallow, terraced trench for 35 miles downstream to Mendota (RM 205). Understanding the long-term sediment supply dynamics of the upper watershed in relation to the sediment transport character of the upper project reaches is critical in understanding the interactions between the flow, sediment, and habitat within the project reaches.

By examining rock units of different age that represent (1) a change from deposition, to erosion, and back to deposition again (unconformities), (2) the westward tilt of clay deposits, and (3) interglacial (times between glacial periods) marine beds, Janda (1965) concluded that the alluvial fan formations below the Friant Dam site are related primarily to sediment transport variations during glacial and interglacial periods, rather than to tectonics and eustatic sea level fluctuation (sea level change related to the creation and subsequent melting of continental glaciers). His evidence indicated the following sequence of events:

- *During glaciation*: extensive erosion of mountain slopes, leading to rapid aggradation of mountain canyons and alluvial fans;
- *During glacial waning (glacial retreat)*: reduction in sediment yield from mountain slopes, leading to incision in mountain canyons but continued aggradation of alluvial fans
- *Late glacial/early interglacial*: further reductions in sediment yield lead to major rivers incising into their alluvial fans. Upon reaching a stable gradient, lateral activity commenced.

This cyclic process repeated during different glacial periods, resulting in several depositional units derived from the Sierra Nevada sediments, including the older Turlock Lake Formation, the younger Turlock Formation, Riverbank Formation, Modesto Formation, and recent alluvium. Table 3-2 correlates the glacial history of the Sierra Nevada to the alluvial deposits in the San Joaquin Valley. Glacial deposits near the foothills form a sequence of nested terraces where successively younger deposits fill the canyons carved into the older deposits. A short discussion of the most recent valley fill and incision provides a frame of reference for present-day valley morphology in Reaches 1 and 2. Beginning approximately 100,000 years ago, period of glaciation filled the valley with sediments in Reach 1 to approximately the tops of the bluffs in the Herndon area (RM 261) and extended into the axis of the San Joaquin Valley as a large alluvial fan (Modesto Formation, Table 3-2). Subsequent interglacial periods of low sediment yield resulted in the San Joaquin River incising into the large-scale alluvial fan. Remnants of the Pleistocene fan remain in Reach 1, and terraces in Reach 1 and 2 are remnants of smaller fans created during subsequent glaciations (e.g., Tioga and Tahoe). Further incision of the smaller fans during the post-Tioga glaciation period has resulted in the present-day entrenchment of the San Joaquin River in the smaller Holocene-age alluvial fan. In other words, over the last several hundred thousand years, the San Joaquin River has filled and eroded its valley in Reach 1 and 2 two to three times, and the present-day condition is one of an incised river rather than an aggraded river. The river currently flows through bottomlands entrenched 50-100 feet below its Pleistocene fan surface and bounded on each side by bluffs, and within the bottomlands, flows between 15-30 high terraces of the Holocene fan (Figure 3-5). Gravelly Ford (RM 229) is the downstream extent of the confining terraces of the San Joaquin River.

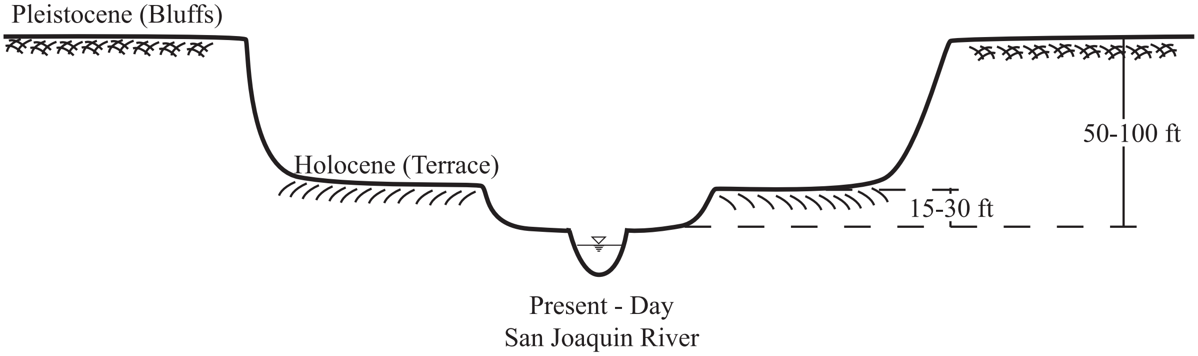


Figure 3-5. Conceptual cross section through Reach 1 illustrating different geomorphic surfaces within the San Joaquin River bottomlands.

Table 3-2. Correlation of glacial history to the alluvial deposits in the San Joaquin Valley (adapted from Janda 1965).

Sierra Nevada		San Joaquin Valley
Glacial Event	Generalized numerical age (years before present)	Alluvial [Volcanic] Deposits
Tioga, Tenaya, Tahoe, & Mono Basin Glaciations	0 – 100,000	Modesto Formation (2 – 3 phases)
Glaciation at Mammoth Mountain, Donner Lake Glaciation?	200,000	Riverbank Formation
Hobart Glaciation?	600,000	Turlock Lake Formation (younger phase) Friant Pumice Member & Corcoran Clay Member]
Sherwin Glaciation	> 700,000	Turlock Lake Formation (older phase)

The numerical ages of Sierra Nevada glacial stages are an active topic of research and debate. Recent work by Pinter et al (1994) summarizes more recent research of Sierra Nevada glacial event ages, and although some of the dates and nomenclature differ slightly from Janda's work, other elements are similar and have persisted through today's research. Because Janda's research focused on relating San Joaquin Valley sediments to the glacial stages listed in Table 3-2, and because the objective of this discussion is to describe the local geology as it relates to sediment production and erosional processes, we use the results of Janda's work (rather than the more recent glacial sequencing and age dating) to estimate sediment production and yield.

3.6.5. Sediment yield

Janda's hypothesis was that sediment yields were high during glacial periods, and low in interglacial periods, particularly in the modern interglacial period prior to the construction of upstream reservoirs. Based on Janda's hypothesis, it is reasonable to assume that the recent unimpaired (pre-dams) sediment yield from the upper watershed to the project reaches below the Friant Dam site is small relative to geologic averages over the last million year, and thus it is not unexpected that the river below the Friant Dam site would incise into its alluvial fan. This is consistent with the bluffs and terrace formations found in this location. Further, the base of the historic alluvial sequence is marked by bedrock outcrops consisting of intrusive granodiorite and, notably, the Friant Pumice resulting from a large rhyolitic (volcanic rock rich in silica) eruption approximately 600,000 years ago. The exposure of these outcrops, acting as base level control in Reach 1A, is assumed as proof that the present day river is as entrenched as at any time in the recent geologic past. Janda (1965) estimated that contemporary denudation (erosion of watershed) rates are only 25-40% of the rate averaged over the last 600,000 years, and only 10-15% of the last 27,000 years. In the absence of glacial erosion and a wetter climate, it is not surprising that the sediment yield from the erosion resistant granite characteristic of most of the upper watershed is low.

Janda (1965) estimated maximum denudation rates of 0.15 feet/1,000 years (0.0018 in/yr) and denudation rates of 0.08 ft/1,000 years (0.0010 in/yr) for snowmelt runoff portions of the watershed. Using the maximum rate as a conservatively high sediment yield, the corresponding total sediment yield would be approximately 260,000 yd^3/yr (Table 3-3). A small proportion of the total sediment load is coarse sediment, usually 5% (gravel bedded rivers) to 50% (sand bedded rivers) (Dunne and

Leopold, 1976). Collins and Dunne (1990) estimate that the coarse sediment component in lowland rivers typically ranges from 2% to 6% of the total sediment load (gradient from 0.0004 to 0.0023), and the coarse sediment proportion in mountainous rivers typically ranges from 8% to 16%. There are no data specifically for the San Joaquin River, so for comparative purposes, it is assumed that the coarse sediment component at a location where the San Joaquin River exits the Sierra Nevada is 10% of the total sediment yield. Using this adjustment value, the San Joaquin River watershed above the Friant Dam site (1,676 mi^2) would have delivered on average approximately 26,000 yd^3/yr of coarse sediment (58,000 tons/yr, or 34.6 tons/mi^2/yr) to the reach prior to Friant Dam and other upstream dams. Corresponding estimates for the Merced River and Tuolumne River using reservoir sedimentation from those rivers (Brown and Thorp 1947) are also computed at the location where the rivers exit the Sierra Nevada to compare with the San Joaquin River (Table 3-3).

Table 3-3. Summary of sediment yield estimates on the San Joaquin River and Tuolumne River.

Location	Unit sedimentation rate used (units below)	Drainage Area (mi^2)	Total sediment yield (yd^3/yr)	Coarse sediment yield assuming 10% of total sediment yield (yd^3/yr)	Sources/method
San Joaquin River at Friant Dam location	0.0015 in/year	1,676	260,000	26,000	Janda (1965) from watershed denudation rate estimates
San Joaquin River at Friant Dam location	0.18 ac-ft/yr	1,676	486,000	48,600	Cain (1997), using a higher value of reservoir sedimentation rates from Brown and Thorpe (1947)
Merced River at Merced Falls, near Snelling	0.17 ac-ft/yr	1,061	291,000	29,100	Brown and Thorpe (1947) from reservoir sedimentation rates
Tuolumne River at LaGrange	0.21 ac-ft/yr	1,538	521,000	52,100	Brown and Thorpe (1947) from reservoir sedimentation rates

All estimates in Table 3-3 assume that coarse sediment is 10% of the total sediment yield. The low values of bedload delivery for the San Joaquin River are much lower than that estimated from the Tuolumne River, even though the San Joaquin River has a larger drainage area. The naturally low sediment yield from the upper San Joaquin River watershed, combined with the very low gradient of the reach immediately below Friant Dam, suggests that the coarse sediment in the study area was characterized by low supply and low transport rates, even before the supply was disconnected by the construction of Friant Dam. Janda (1965) also argued that rates of transport are low, and that sediment sources for alluvial gravel were primarily local (lateral erosion of terraces) on the basis that:

- Little gravel is accumulating as deltas at the head of upstream reservoirs.
- Present day gravel occurs adjacent to gravel-bearing river bluffs.
- Recent gravels are lithologically similar to Pleistocene gravel with the exception of granite (weathered and eroded).

While the point has been made that gravel deposits are found well away from the Pleistocene bluffs (Cain 1997), the balance of evidence, including sediment transport calculations, appears still to favor a low supply-low transport basis for the reach below Friant Dam.

3.6.6. Historical Channel Form and Processes in Study Area

Quantitative data on pre-settlement channel form and processes are virtually non-existent; however, there are several sources of historical information (as described in Section 3.4). Of these historical sources, the 1854 Government Land Office maps are the only source that may reasonably reflect unimpaired channel morphology conditions because more extensive land conversion, levees, and clearing occurred after the mid 1850's. However, the detail of these maps is not extensive, such that the primary use of these maps is to estimate channel location and planform morphology. The latter maps and photographs provide valuable insights to unimpaired channel processes and morphology, but their use to infer unimpaired conditions must be tempered by the fact that substantial land use changes had occurred prior to the dates of the maps and photos (canals, diversions, grazing, land clearing, etc.). Anecdotal information from historical surveys and explorations is also limited; most descriptions focus on soils, water, and riparian vegetation (also see Chapter 8). This anecdotal information is summarized in Section 3.6.6.1, and more quantitative information from the historical mapping sources is provided in the reach descriptions (Section 3.7). Post-Friant Dam information is more readily available, and typically more quantitative. This information is summarized in Section 3.4.

3.6.6.1. Reach-wide Historical Perspective

The first explorers to document conditions along the San Joaquin River were the Spanish, beginning in the 1770s. As the Spanish established missions along the Pacific Coast, several expeditions into the San Joaquin River and Tulare Lake regions provided the first descriptions and maps of these regions. Numerous expeditions by Gabriel Moraga between 1806 and 1810 covered most of the San Joaquin Valley and Tulare Valley; however, descriptions of the river focused mostly on the tule marshes and other types of vegetation, and did not discuss any details about the channel morphology of the San Joaquin River. Jedediah Smith was the first American explorer to travel along the San Joaquin River in 1827, trapping beaver along Tulare Lake, the San Joaquin River, Kings River, and others on his way north through the valley (Brooks 1977). As with Moraga's expeditions, Jedediah Smith did not provide much description of the San Joaquin River channel morphology. The most useful description of the channel is a comparison of the river upstream and downstream of the bend at present-day Mendota:

> *above the bend, the banks were high and the current rapid, but below [the bend] the river had been divided into many small sloughs and channels, the banks low, and the current sluggish. In many places, rushes and mud a mile in width made it impassible for horses.*

C.D. Gibbs, in a letter to the *Stockton Times* in 1850 (as cited in Fox 1987), provides a small description of the natural levees along the San Joaquin River in the flood basin (assumed to characterize Reach 3 through 5):

> *As near as I can judge, the tule land in the upper part of this tract is from 2 to 5 feet lower than the banks of the river*

Later military (e.g., George Derby in 1850), geology (e.g., William Brewer in 1862-1864), and engineering (e.g., William Hammond Hall in the 1880's) expeditions made more observations, but again focused on vegetation, as well as water and soils. These limited descriptions of the channel morphology, combined with our review and interpretation of historical maps and aerial photographs, allows for a general description of channel processes and morphology within the study area. The general descriptions below are supported more in the reach descriptions in Section 3.7.

3.6.6.2. Effect of Slope and Control on Sediment Transport and Routing

As described in Section 3.6.5, unimpaired levels sediment supply from the upper San Joaquin River watershed to the study area appears to be extremely low. Additionally, valley slopes in Reach 1 are very low (0.001 to 0.00063) compared to adjacent tributaries (e.g., comparable Tuolumne River slopes are 0.0015), resulting in historically low sediment transport rates. Although the sediment supply rates from the upper watershed were probably low, the river had a supply of coarse sediment (cobbles and gravels) and fine sediment (sand and silts). Longitudinally, the coarser sediments deposited in Reach 1A and the upper portion of Reach 1B. The lower portion of Reach 1B was a transition zone from gravel-bedded to sand-bedded channel, with Reach 2 through Reach 5 being entirely sand bedded. Because east-side tributaries emptied into the floodbasins in Reach 3 through Reach 5 rather than directly connecting to the San Joaquin River (Carson 1852, as cited in Fox 1987), they deposited their sediment supply well before entering the San Joaquin River. Therefore, as sediment was deposited longitudinally in the channel and on floodplains, the supply of sediment decreased in the downstream direction because there were no tributaries to supply the river with sediment. This decreasing sediment supply and sediment transport capacity (lower slope) in downstream reaches resulted in a changing channel geometry in the downstream direction. The channel is extremely flat in the lower reaches and the river remains within 5 feet of sea level 50 miles upstream of the confluence with the Sacramento River. The low slopes suggest that the channel is slowly aggrading as a result of base level rise from the rising sea level after the end of the last glacial period.

3.6.6.3. Channel Migration and Avulsion

Review of sequences of historical maps and aerial photographs suggests that channel migration rates were small and channel avulsion was infrequent; however, the observations of scroll bars, oxbows, sloughs, and scour channels in various reaches confirm that migration and avulsion did occur. To date, a comprehensive historical channel analysis has not been conducted for the entire study reach, so quantitative estimates of migration rates and avulsion frequency has not been made. Review of historical channel overlays in representative portions of Reach 1 through Reach 3 show that the baseflow channel moves considerably within the bankfull channel, but the meander pattern of the bankfull channel appears to moderately stable. In Reach 4 and 5, the channel location appears to be much more stable, likely a result of the decreasing sediment supply in these downstream reaches. Again, there are oxbows and side channels, so channel migration and avulsion does occur, perhaps just during extreme flood events.

3.6.6.4. Planform Morphology

The San Joaquin river is a moderately sinuous gravel bed river similar to other gravel bed rivers which originate in the Sierra Nevada and flow into the Central Valley. Meanders were poorly defined from Friant Dam downstream to RM 250, then the meander pattern becomes more sinusoidal and begins having a more consistent planform dimension tendency. Numerous split channels (e.g., Cobb Island at RM 258-260), side channels, and high flow scour channels (e.g., Ledger Island at RM 262-263) occurred in Reach 1, with some of the side channels being more than a mile long (Figure 3-6). With the transition of the river into the sand-bedded channel in Reach 2, the planform morphology transitioned into a purely meandering morphology (Figure 3-7). Sinuosity was large, and the river had a single primary channel. The notable exception was at Lone Willow Slough, which may have conveyed baseflows, but was smaller than the mainstem San Joaquin River. High flow scour channels at the downstream end of Reach 2 conveyed overbank flows south to Fresno Slough, which then apparently conveyed flows back to the San Joaquin River at Mendota (Derby 1850). Both Reach

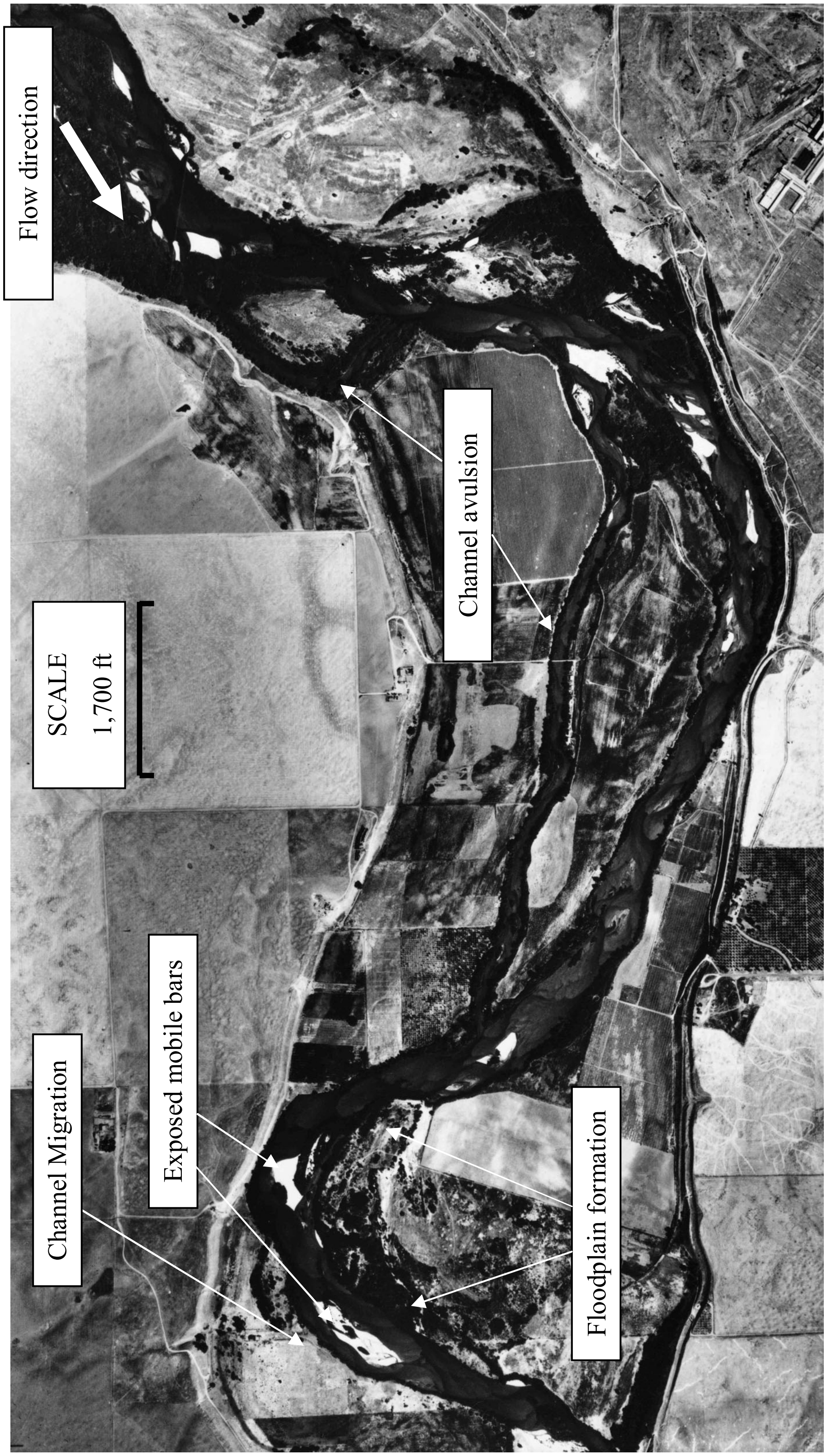


Figure 3-6. 1937 aerial photo of a portion of Reach 1 from RM 249.3 to 254.5 illustrating evidence of fluvial processes under the pre-Friant Dam flow regime.

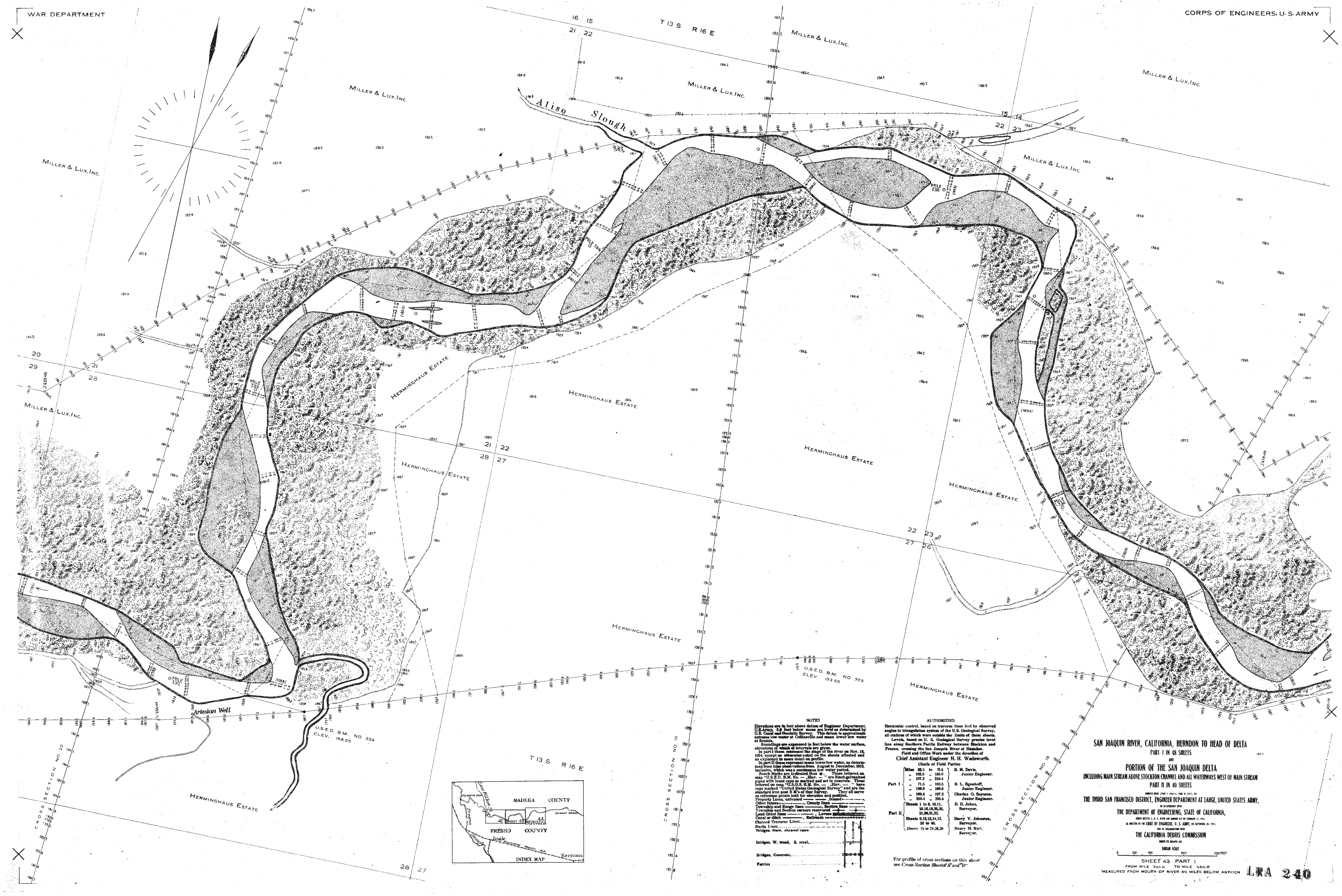


Figure 3-7. 1914 planform maps of Reach 2 from RM 214.7 to 219.5, illustrating meander pattern, bar features, and other morphological features of interest (ACOE 1917).

Figure 3-8. 1914 planform maps of Reach 3 from RM 193.3 to 197.8, illustrating meander pattern, bar features, and other morphological features of interest (ACOE 1917).

1 and Reach 2 are on the prograding alluvial fan of the San Joaquin River; the alluvial fan ends at Mendota, which marks the upstream end of Reach 3.

The 1914 maps (ACOE 1917) and 1937 aerial photographs does not show distinct changes in planform morphology between Reach 2 and Reach 3 despite the slightly lower slope and decreasing sediment supply in Reach 3 (Figure 3-8). The 1914 maps imply that there are more oxbows in Reach 3 than Reach 2, but the aerial photos do not provide the same evidence, suggesting that the additional oxbows are a relic of mapping differences between the reaches. Reach 3 still has high flow scour channels that indicate frequent overbank flows, but does not have numerous anabranching slough channels.

Reach 4 and Reach 5 all have anabranching slough channels, with many of the sloughs originating in Reach 4 (e.g., Pick Anderson Slough, Santa Margarita Slough) and converging back to the mainstem San Joaquin River in Reach 5 (e.g., Salt Slough, Mud Slough). These anabranching channels had a meandering planform morphology and small bar forms, but appeared to migrate at a low rate. Additionally, the 1914 maps and 1937 aerial photographs do show exposed sand bars in both Reach 4 and Reach 5, but they are much less pronounced than the exposed sand bars in Reach 2 and Reach 3 (Figure 3-9 and Figure 3-10).

3.6.6.5. Channel Geometry and Slope

Channel geometry in Reach 1 reflected the meandering gravel-bed channel morphology, having a primary bankfull channel and floodplain, but also contained side channels that conveyed baseflows, as well as higher elevation scour channels that conveyed high flows (Figure 3-6). The river is moderately confined between bluffs downstream to Skaggs Bridge (RM 234.1), then the confining bluffs begin to fall away from the river to the point where they disappear at the downstream end of Reach 1B. Channel geometry in Reach 2 was typified by a single primary channel and perhaps small natural riparian levees along the banks (Figure 3-7). Because Reach 2 is on the San Joaquin River alluvial fan, and has no confining bluffs or high terraces, large flood flows spilled towards the south via scour channels, as well as north through Lone Willow Slough. Reach 3 is moderately confined on the left (west) bank by a terrace, which falls away at the downstream end of the reach. Channel geometry in Reach 3 was similar to Reach 2, having large exposed sand point bars and riparian vegetation at the top of the point bars and on the floodplains (Figure 3-8). The extensive flood basin in Reach 4 through 5 was the dominant feature in channel geometry in these reaches, and marsh delineations are evident on the 1914 maps (Figure 3-9 and Figure 3-10). This flood basin was several miles wide, confined by a terrace on the west side of the valley and by prograding alluvial fans on the east side of the valley, and influenced by the backwater from the Merced River alluvial fan (JSA and MEI 1998). Another prominent feature of channel geometry in these downstream reaches was the natural riparian levees along the channel margins. During high flows that suspended fine sediments, vegetation along the channel margins slowed water velocities, allowing sediments to deposit. Over time, these sediments accumulated to create levees. Katibah (1984) hypothesizes that these levees decreased in size as they progressed downstream due to decreasing energy, decreasing peak flows (due to flood peak attenuation in the flood basin), and decreasing sediment supply.

3.6.6.5.1. 1914 Cross Section, Profile, and Slope Summary

The 1914 survey of the study area by the ACOE (1917) provides a reasonable baseline condition for San Joaquin River channel geometry between the Merced River confluence at RM 118 and Herndon at RM 243 (the results of this data are presented for all reaches for simplicity). Cross sections surveyed by the Bureau of Reclamation in 1939 can be used to document channel geometry for the reach upstream of Herndon. Between 1914 and 1915, the ACOE surveyed 85 cross sections within the study area, and used these to construct longitudinal profiles of the river thalweg (minimum elevation at the cross section), water-surface elevation at the time of the surveys, and the top of bank elevation (Figure 3-3). The top-of-bank profile represents the elevation of the bank at each cross section that defines the bankfull stage of the channel. JSA and MEI (1998) measured the width and depth of the channel at the bankfull stage from the cross sections, and plotted widths and depths against the river mile to show their spatial distribution (Figure 3-11 and Figure 3-12). The channel widths and depths tend to be largest in Reaches 1 and 3, and lowest in Reaches 2, 4, and 5. The combination of low width and low depth indicates areas where overbank flooding frequently occurred; Reach 2 aerial photographs show frequent flooding to the south into Fresno Slough, and Reaches 4 and 5 are the flood basins that were inundated for long periods of time in most years. The width-depth ratio at the bankfull stage was computed for each cross section and plotted against river mile (Figure 3-13). The bankfull stage is estimated from morphological features on each cross section, and not from a computed water surface elevation for a consistent estimate of bankfull discharge. Average values for the valley slope (top of bank), channel slope, bankfull width, bankfull depth, width-depth ratio, and sinuosity were computed for each of the reaches (Table 3-4).

Table 3-4. Channel and planform characteristics for Reaches and sloughs of the San Joaquin River based on the 1914 maps (ACOE 1917).

Subreach	**Valley Slope (feet/feet)**	**Channel Slope (feet/feet)**	**Average Bankfull Width (feet)**	**Average Bankfull Depth (feet)**	**Width-Depth Ratio**	**Sinuosity**
1A	0.0008	0.0007	N/A[a]	N/A[a]	N/A[a]	1.14[b]
1B	0.00077	0.00063	875	18	49	1.22
2	0.00057	0.00031	744	14	53	1.83
3	0.00033	0.00022	564	14	40	1.44
4A	0.00037	0.00028	277	14	20	1.33
Sand/Salt Slough	0.00037	0.0005	150	7	21	
4B	0.00037	0.00022	311	9	35	1.67
Salt Slough	0.00037	0.00033	258	9	29	
5	0.00036	0.00021	386	13	30	1.71
Salt Slough	.00036	0.0002	394	10	39	

[a] 1914 maps did not extend into Reach 1A, no data available.

[b] 1914 maps did not extend into Reach 1A, 1937 aerial photography used.

Previous studies (JSA and MEI 1998, Cain 1997) compared thirteen cross sections from 1914 and 1939 with contemporary cross sections to evaluate changes in channel elevation and shape (Table 3-5). Approximate cross section locations used for this comparison are shown on Figure 3-14. The topographic precision shown on the tables is often greater than the precision of the surveys they are based on (bathymetric surveys in 1914 and 1998), so the results shown in Tables 3-5 and Table 3-6 should be considered approximate. This inherent imprecision of the surveys, combined with complicating factors like ground subsidence and the small sample number of cross sections used, result in there being substantial uncertainty in these estimated changes shown in the tables.

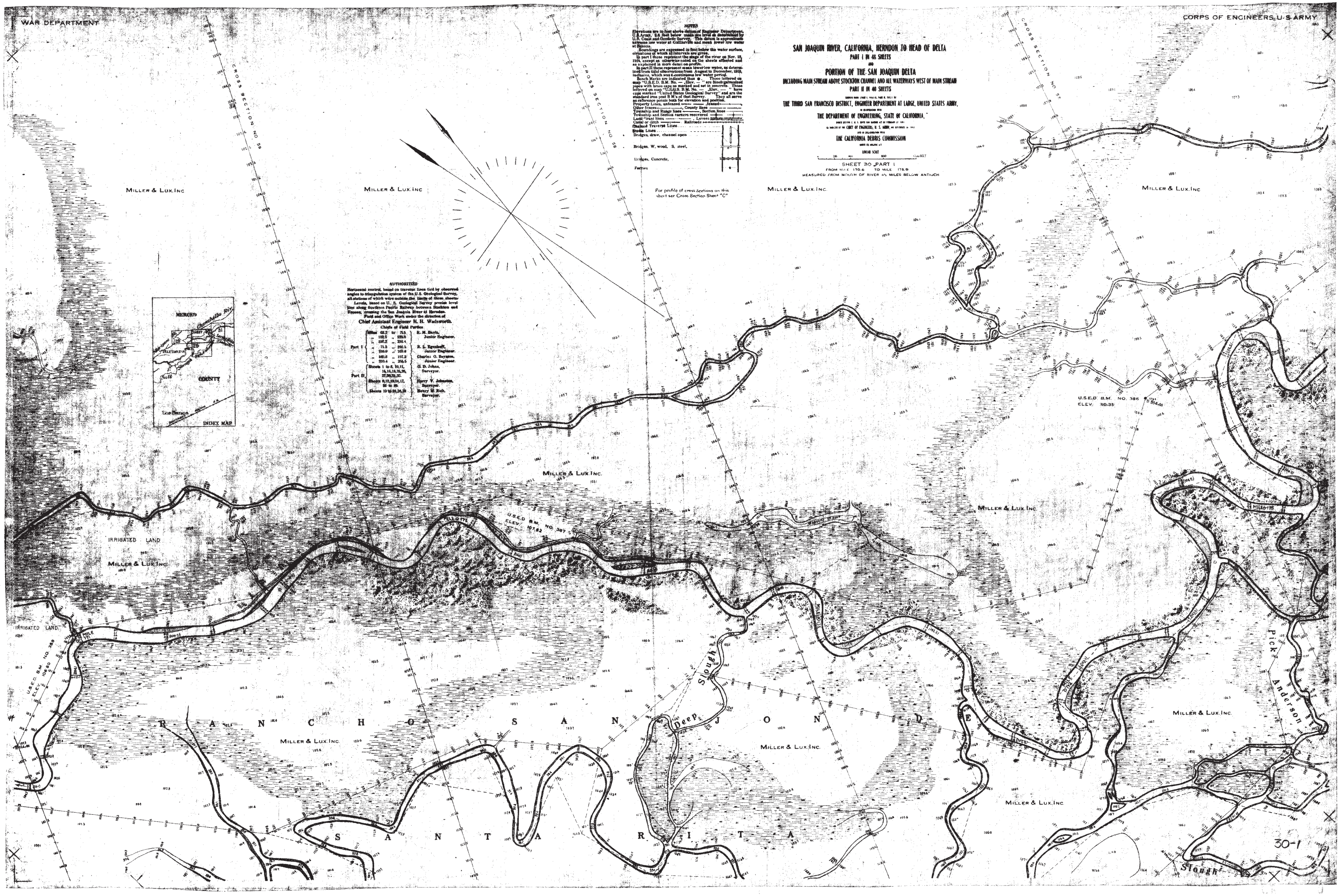
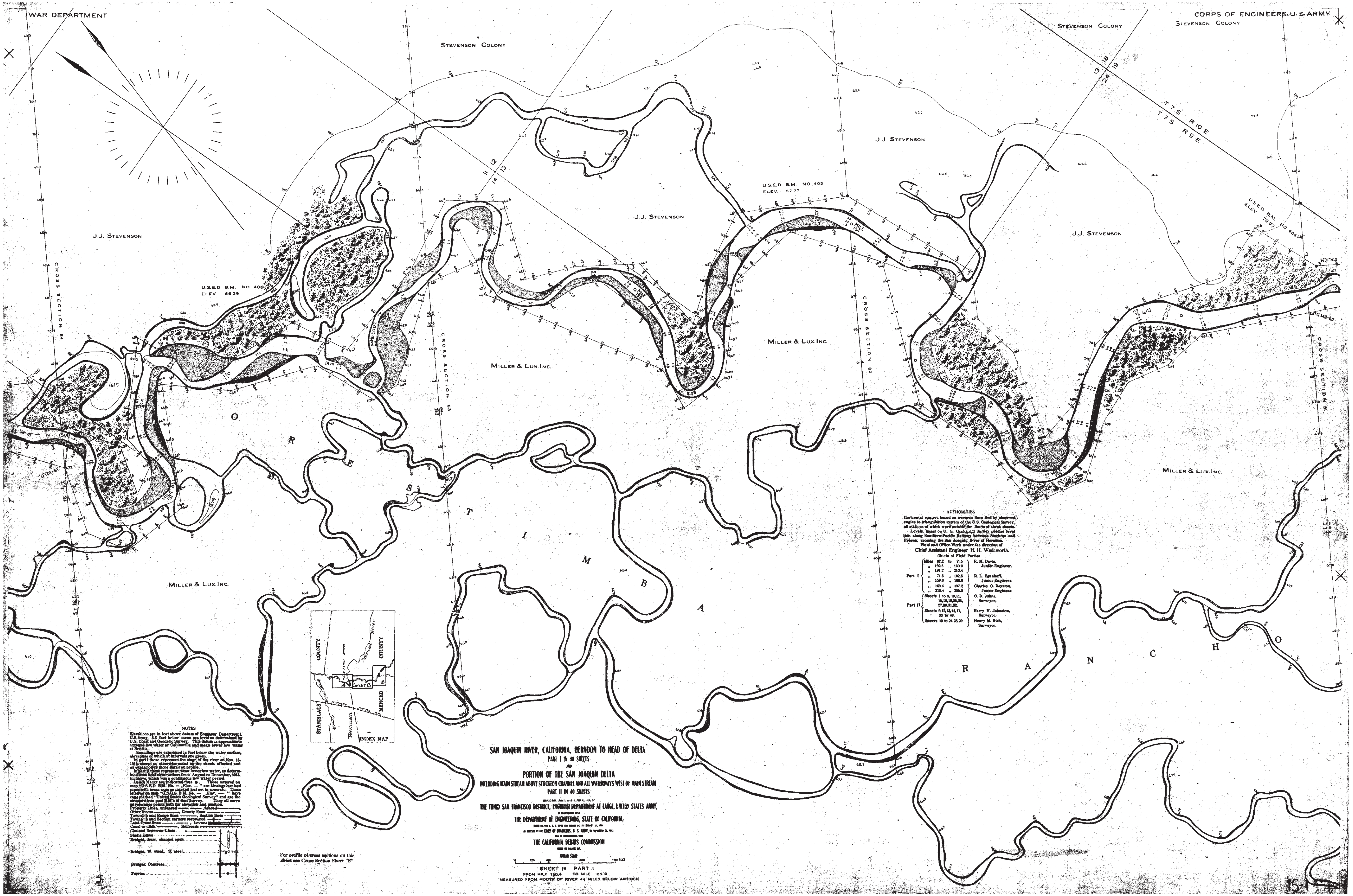


Figure 3-9. 1914 planform maps of Reach 4 from RM 161 to 166, illustrating meander pattern, bar features, and other morphological features of interest (ACOE 1917).



NOTES

Elevations are in feet above datum of Engineer Department, U.S.Army, 3.6 feet below mean sea level as determined by U.S. Coast and Geodetic Survey. This datum is approximate extreme low water at Collinsville and mean lower low water at Benicia.

Soundings are expressed in feet below the water surface, elevations of which at intervals are given.

In part I these represent the stage of the river on Nov. 18, 1914, except as otherwise noted on the sheets affected and as explained in more detail on profile.

In part II these represent mean lower low water, as determined from tidal observations from August to December, 1913, inclusive, which was a continuous low water period.

Bench Marks are indicated thus ●. Those lettered on map "U.S.E.D. B.M. No. — ,Elev. — " are 3 inch galvanized pipes with brass caps so marked and set in concrete. Those lettered on map "U.S.G.S. B.M. No. — ,Elev. — " have caps marked "United States Geological Survey" and are the standard iron post B.M.'s of that Survey. They all serve as reference points both for elevation and position.

Property Lines, unfenced, fenced
Other fences, County lines
Township and Range lines, Section lines
Township and Section corners recovered
Land Grant lines, Levees
Canal or ditch, Railroads
Chained Traverse Lines
Stadia Lines
Bridges, draw, channel open
Bridges, W, wood, S, steel,
Bridges, Concrete,
Ferries

For profile of cross sections on this sheet see Cross Section Sheet "E"

AUTHORITIES

Horizontal control, based on traverse lines tied by observed angles to triangulation system of the U.S. Geological Survey, all stations of which were outside the limits of these sheets.

Levels, based on U. S. Geological Survey precise level line along Southern Pacific Railway between Stockton and Fresno, crossing the San Joaquin River at Herndon.

Field and Office Work under the direction of
Chief Assistant Engineer H. H. Wadsworth.

Chiefs of Field Parties

Part I	Miles 62.2 to 71.5 " 102.5 " 159.0 " 197.2 " 210.4	R. M. Davis, Junior Engineer.
	" 71.5 " 102.5 " 159.0 " 169.6	R. L. Egenhoff, Junior Engineer.
	" 169.6 " 197.2 " 210.4 " 255.5	Charles O. Boynton, Junior Engineer.
Part II	Sheets 1 to 8, 10, 11, 15, 16, 18, 25, 26, 27, 30, 31, 32.	O. D. Johns, Surveyor.
	Sheets 9, 12, 13, 14, 17, 33 to 40.	Harry V. Johnston, Surveyor.
	Sheets 19 to 24, 28, 29	Henry M. Rich, Surveyor.

SAN JOAQUIN RIVER, CALIFORNIA, HERNDON TO HEAD OF DELTA
PART I IN 48 SHEETS
AND
PORTION OF THE SAN JOAQUIN DELTA
INCLUDING MAIN STREAM ABOVE STOCKTON CHANNEL AND ALL WATERWAYS WEST OF MAIN STREAM
PART II IN 40 SHEETS
SURVEYS MADE (PART I, 1914-15, PART II, 1913) BY
THE THIRD SAN FRANCISCO DISTRICT, ENGINEER DEPARTMENT AT LARGE, UNITED STATES ARMY,
IN CO-OPERATION WITH
THE DEPARTMENT OF ENGINEERING, STATE OF CALIFORNIA,
UNDER SECTION 2, U. S. RIVER AND HARBOR ACT OF FEBRUARY 27, 1911
AS DIRECTED BY THE CHIEF OF ENGINEERS, U. S. ARMY, ON SEPTEMBER 26, 1913,
AND IN COLLABORATION WITH
THE CALIFORNIA DEBRIS COMMISSION
UNDER ITS ORGANIC ACT.
LINEAR SCALE
0 200 400 800 1200 FEET
SHEET 15 PART I
FROM MILE 130.4 TO MILE 135.8
MEASURED FROM MOUTH OF RIVER 4½ MILES BELOW ANTIOCH

Figure 3-10. 1914 planform maps of Reach 5 from RM 120 to 125.3, illustrating meander pattern, bar features, and other morphological features of interest (ACOE 1917).

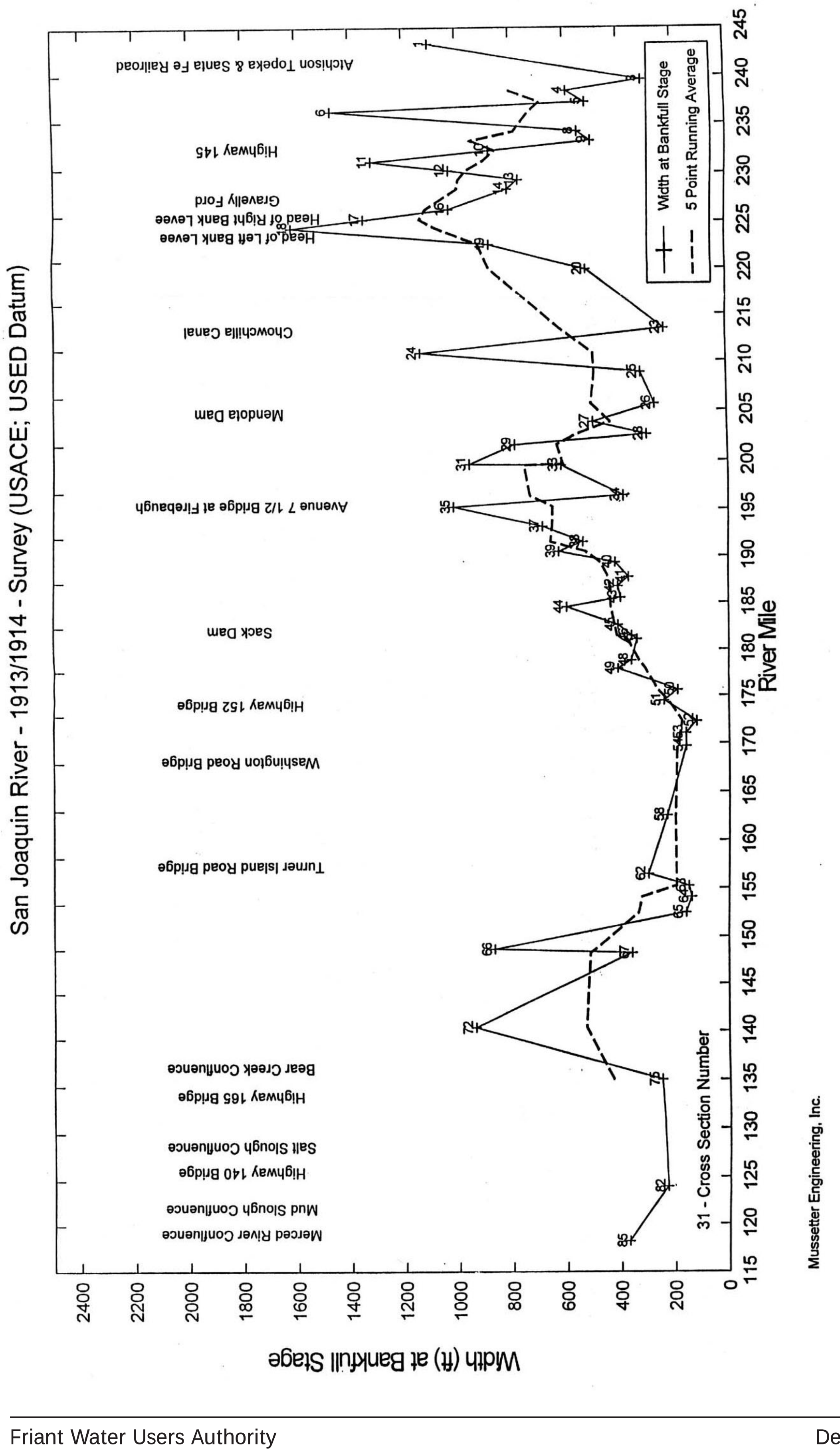


Figure 3-11. Longitudinal changes in channel width from 1914 mapping effort (ACOE 1917) between Herndon and the Merced River confluence. The river mile markers begin at the Merced River confluence (RM 118.2), but the river mile markers and channel length from that point upstream are different than the mile markers used in this report. Bankfull stage is based on field indicators, not a consistent bankfull discharge estimate.

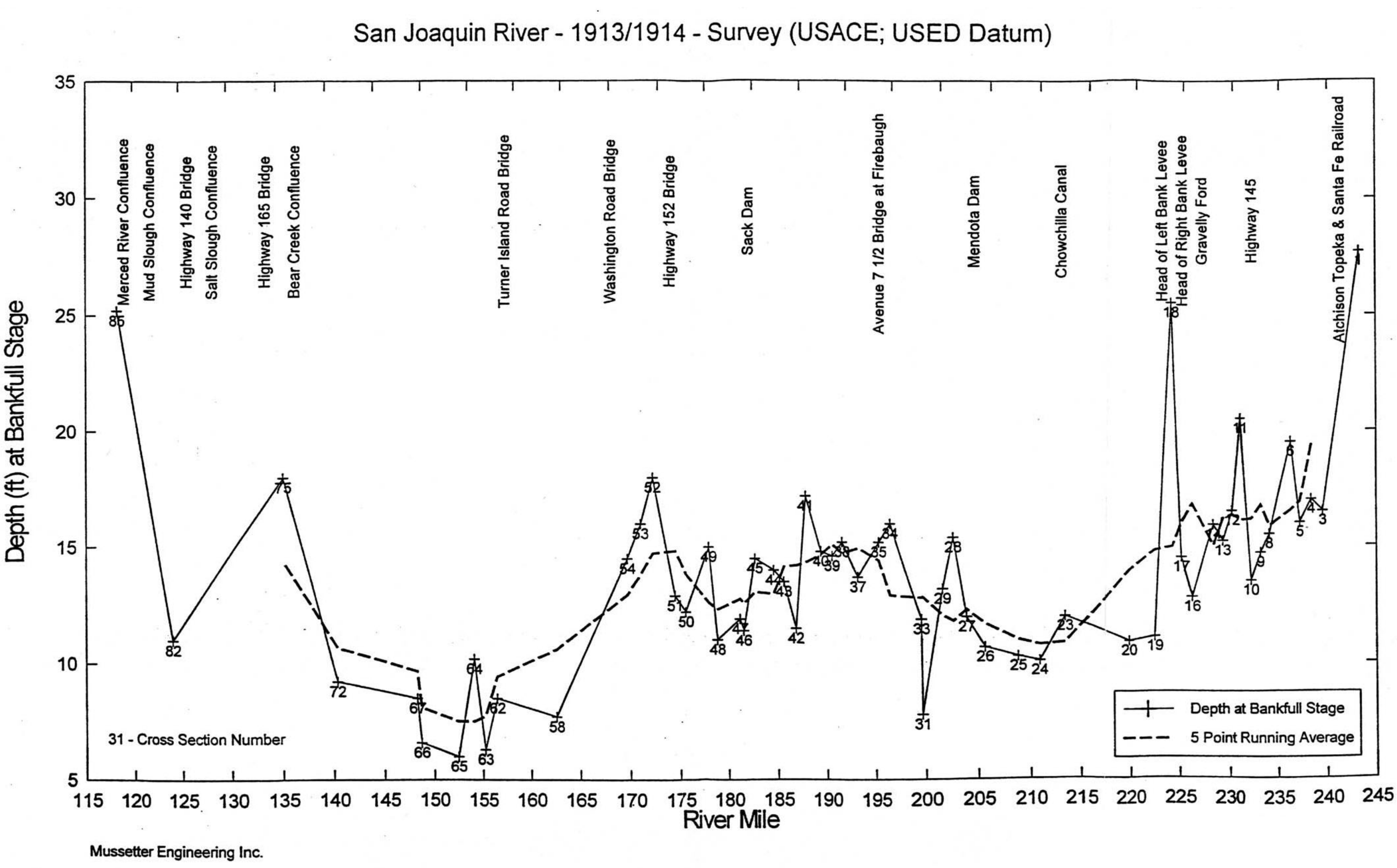


Figure 3-12. Longitudinal changes in channel depth from 1914 mapping effort (ACOE 1917) between Herndon and the Merced River confluence. The river mile markers begin at the Merced River confluence (RM 118.2), but the river mile markers and channel length from that point upstream are different than the mile markers used in this report. Bankfull stage is based on field indicators, not a consistent bankfull discharge estimate.

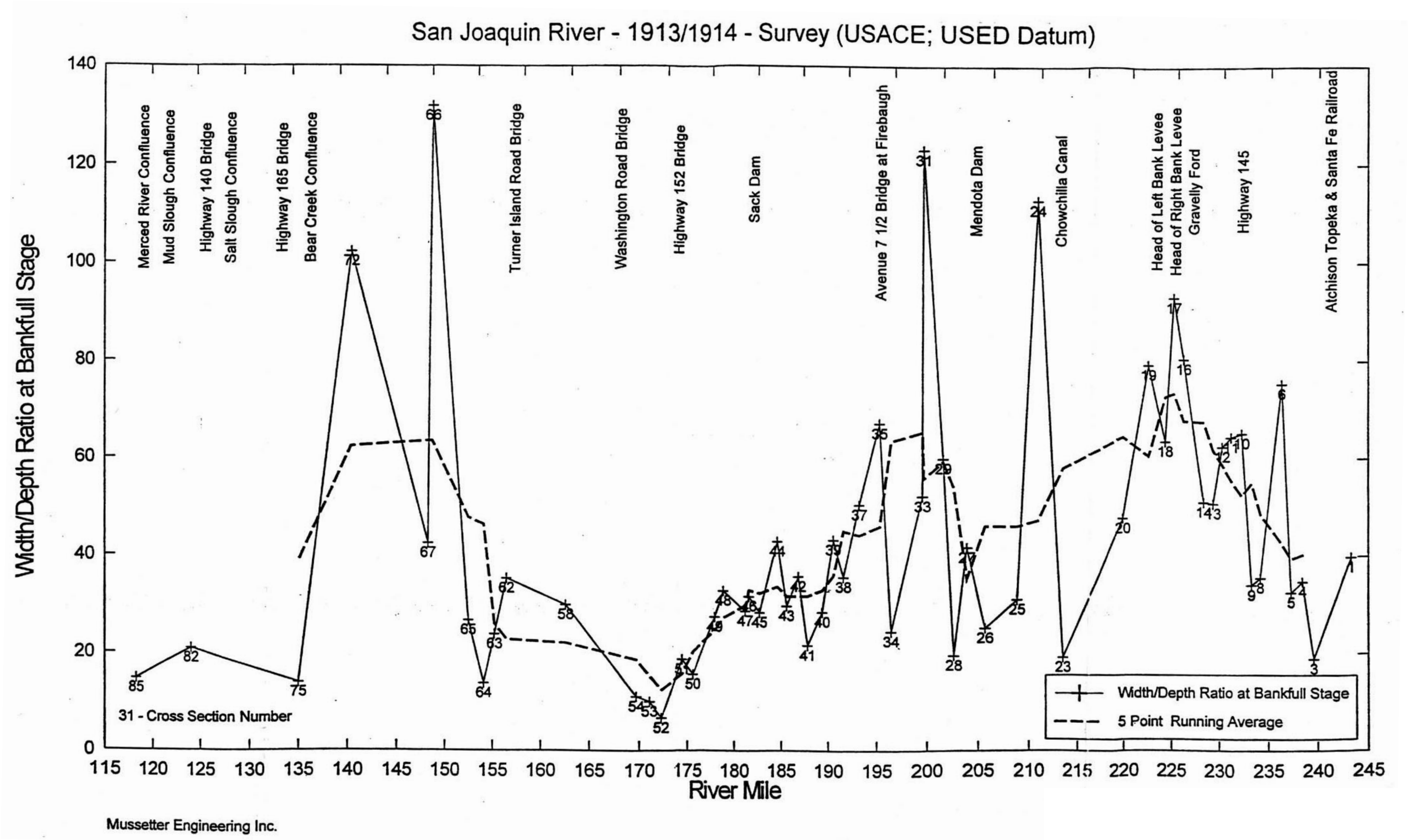


Figure 3-13. Longitudinal changes in width-to-depth (W/D) ratios from 1914 mapping effort (ACOE 1917) between Herndon and the Merced River confluence. The river mile markers begin at the Merced River confluence (RM 118.2), but the river mile markers and channel length from that point upstream are different than the mile markers used in this report. Bankfull stage is based on field indicators, not a consistent bankfull discharge estimate.

Table 3-5. Changes in thalweg elevation at resurveyed representative cross sections in the San Joaquin River study area.

Reach	Cross section	River mile	Period of record	Change in thalweg elevation (feet)
1A	C1[a]	266.6	1939–1996	-6.9
	C2[a]	266.5	1939–1996	-7.0
	C3[a]	265.8	1939–1996	+2.9
	C4[a]	265.4	1939–1996	+3.2
	C5[a]	260.6	1939–1996	+0.8
	C6[a]	259.3	1939–1996	-4.5
	C7[a]	255.3	1939–1996	-5.2
1B	C8[a]	243.7	1939–1996	-18.7[b]
	C9[a]	234.4	1939–1996	-3.0
	2	241.5	1914–1998	0.0
	9	233.3	1914–1998	-16.0[b]
2	14	228.4	1914–1998	-2.1
	19	222.6	1914–1998	-2.1
3	29	201.6	1914–1998	-10.8
	36	193.7	1914–1995	-1.5
4A	48	178.8	1914–1998	-3.9
	53	171.0	1914–1998	-2.2
4B	58	162.6	1914–1998	-1.0
	70	142.7	1914–1998	+6.7
5	78	130.1	1914–1998	-8.5
	81	125.8	1914–1998	+2.0
	85	118.2	1914–1998	0.0

[a] Cross Sections C1 through C9 obtained from Cain (1997)

[b] At instream aggregate mining pit

3.6.6.5.2. Changes in Width and Depth

Twelve cross sections that were originally surveyed in 1914 were resurveyed in 1998 (JSA and MEI 1998). Topographic data were extracted from the 1998 cross sections so that these could be compared with the values established from the 1914 survey (Table 3-6). Because the 1914 surveys did not extend to Reach 1A, Cain (1997) used the 1938 USBR topographic maps and the 1989 State Lands Commission maps to compare changes in channel width at 100 ft increments through Reach 1A. Assuming that the active channel delineated by the State Lands Commission on the 1938 topographic maps was equivalent to the bankfull or dominant discharge channel (Leopold et al. 1964) at that time, Cain (1997) showed that the 1939 average active channel width ranged from 630 feet between Friant Dam and Little Dry Creek to 1,400 feet between Little Dry Creek and Lanes Bridge. The average low flow channel width in the reach in 1939 was more variable, ranging from 220 feet between Friant Dam and Little Dry Creek to 425 feet just upstream of Lanes Bridge (Cain 1997). These “average low flow channel width” estimates are based on the delineation of the State Lands Commission on the 1939 topographic maps.

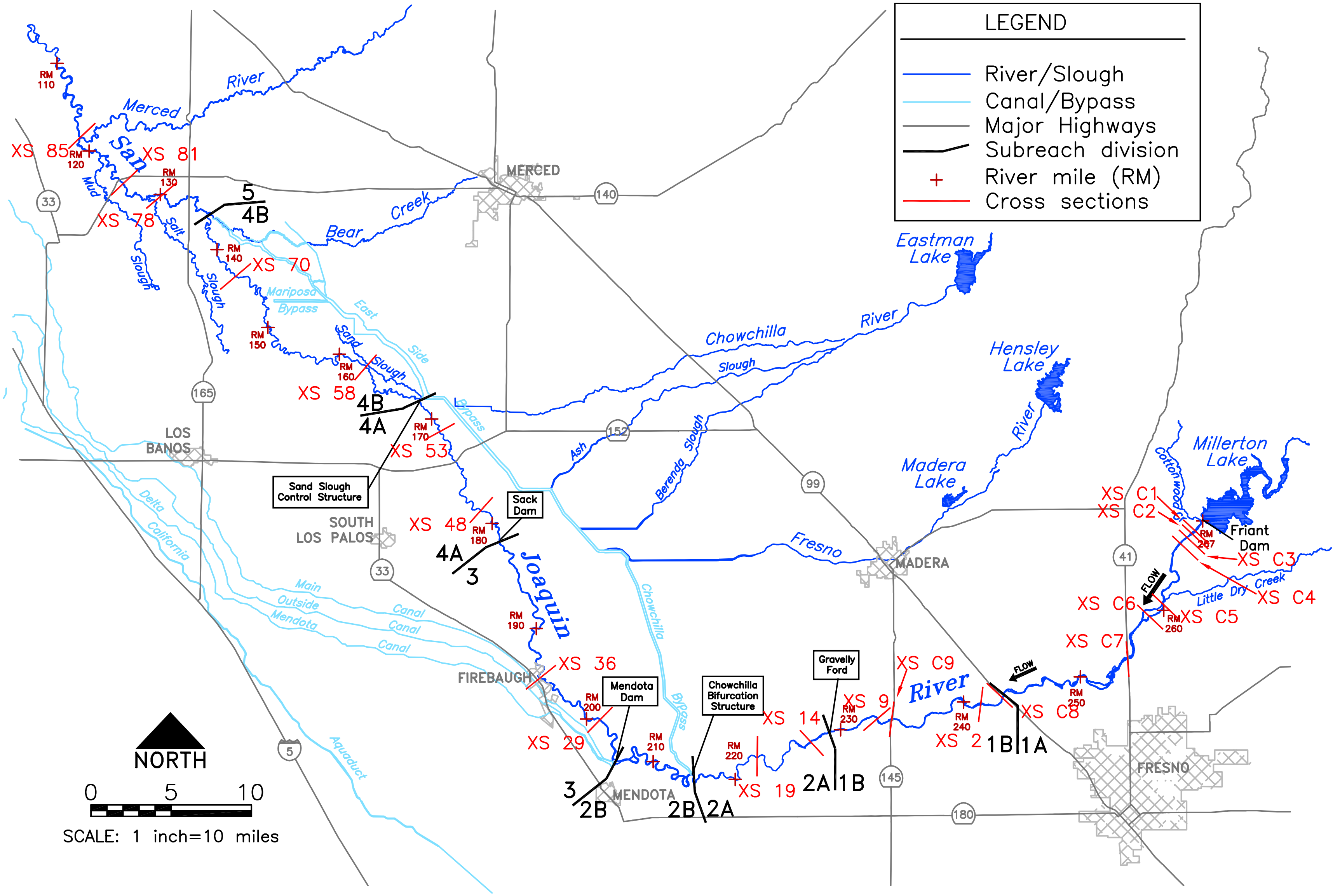


Figure 3-14. Approximate locations of 1914 cross sections (ACOE 1917) and 1939 cross sections (Cain 1997) re-occupied to evaluate changes in bed elevation.

Present-day bankfull channel widths were more problematic because of the riparian encroachment and the limited ability of the post-Friant Dam channel morphology to adjust its dimensions in response to the changed flow and sediment regime. Therefore, Cain used the aerial extent of the 1983 flood extent as captured on aerial photographs. The 1983 flood peak was 12,300 cfs, which was a 1.7-year flood event using the pre-Friant Dam flow regime. Therefore, the 1939 widths should be comparable with the 1983 bankfull widths. Cain (1997) compared the ratios of the low-flow channel widths in 1939 and 1989 to the 1939 active channel widths and the ratio of the 1980 high-flow channel width to the 1939 active channel width and concluded that the channel in Reach 1A had narrowed over time. Results for downstream reaches are solely based on individual cross section comparisons (1914-1998) rather than 100 ft increments as done in Reach 1A, thus results may not be as conclusive as in Reach 1A (Table 3-6).

Table 3-6. Comparison of channel morphology characteristics between 1914 and 1998.

		1913–1914			**1998**		
Reach	**Cross Section**	**Bankfull Width (feet)**	**Bankfull Depth (feet)**	**Width-Depth Ratio**	**Bankfull Width (feet)**	**Bankfull Depth (feet)**	**Width-Depth Ratio**
1B	2	1,327	25.0	53	800	15.7	51
	9	500	14.7	34	680	14.4	47
2	14	810	15.9	51	531	21.4	26
	19	880	11.1	79	1,011	11.4	89
3	29	790	13.2	60	384	14	27
	36	460	19.0	24	307	12.9	24
4A	48	360	11.0	33	279	9.8	29
	53	160	16.0	10	234	18.0	13
4B	58	230	7.7	30	143	8.5	17
	70	210	13.0	16	259	7.6	34
5	78	200	9.6	21	295	15.5	19
	85	370	25.2	15	374	25.0	15

Table 3-6 also illustrates longitudinal changes in bankfull width; bankfull width in 1914 decreases from Reach 1B (875 feet) to Reach 4A (277 feet), where the multichanneled anabranching system commences. Channel widths increase slightly in Reaches 4B (311 feet) and 5 (386 feet) (Figure 3-11). Average channel depths at bankfull stage are remarkably constant from Reach 2 to Reach 4A (14 feet) (Figure 3-12). Depth is highest in Reach 1B (18 feet) and lowest in Reach 4B (9 feet). Channel depth increases to 13 feet in Reach 5. Width-depth ratios show a general decrease in the downstream direction from about 50 in Reach 1B to 20 in Reach 4A (Table 3-6, Figure 3-13). Width-depth ratios increase again in Reaches 4B and 5 to 35 and 30, respectively. The width-depth ratio trends can be correlated with the resistance to erosion of the channel banks (Schumm 1963). The reaches with a higher width-depth ratio have more erodible banks, whereas those with lower values have more erosion resistant banks. The lower values of width-depth ratio in Reaches 4A, 4B, and 5 are also consistent with the required channel adjustments to maintain the continuity of sediment and water through the lower reaches, where there is a rising base level (Nanson and Huang 1997).

3.6.6.6. Particle Size

The total sediment load delivered to the study area by the upper watershed (Figure 3-4) differentially deposited as the river exited the Sierra Nevada and traversed the alluvial fan of the San Joaquin River. Reach 1 is the first reach downstream of the San Joaquin River exit from the Sierra Nevada, and has the highest gradient of all reaches. The dominant particle sizes in Reach 1A are cobbles and gravels (Table 3-7), although a large volume of sand is stored in the reach based on field observations. The low slope of Reach 1A and Reach 1B causes a rapid decrease in particle size across Reach 1B, such that Reach 1B marks the beginning of the transition zone between the gravel-bedded and sand-bedded reach (Table 3-8). There are still gravel patches in Reach 1B (Table 3-8), but a greater proportion of the channelbed becomes predominantly sand downstream of Skaggs Bridge. Gravelly Ford marks the upstream end of Reach 2, and all downstream reaches are sand bedded.

Table 3-7. Summary of D_{16}, D_{50}, and D_{84} particle sizes from surface pebble counts collected in 2002 by Stillwater Sciences in Reach 1.

Sample Location	Sediment Size			Geomorphic unit sampled
	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	
RM 267.07	3	19	65	Point bar (out of the wetted channel)
RM 266.76	72	136	168	Head of riffle
RM 266.67	18	64	108	Riffle
RM 265.51	1	4	23	Shallow area of large pool
RM 265.41	12	26	42	Shallow area of large pool
RM 264.62	9	53	129	Riffle
RM 263.38	7	24	39	Head of riffle
RM 263.36	3	43	120	Riffle
RM 262.96	3	31	85	Shallow portion of a large pool
RM 262.32	2	11	95	Tail of a pool that shallows before a constriction
RM 262.23	11	40	97	Riffle
RM 262.11	19	52	84	Shallow portion of a larger pool
RM 260.65	16	47	73	Head of riffle
RM 260.60	18	60	111	Lower portion of the same riffle
RM 260.19	1	2	33	Depositional zone between the mainstem and secondary channel
RM 259.35	16	40	88	Riffle
RM 259.13	2	23	107	Shallow portion of a large pool
RM 258.87	19	75	116	Head of point bar (out of the wetted channel)
RM 258.36	20	73	101	Riffle
RM 257.96	19	45	109	Run at head of a captured pit
RM 257.33	28	55	97	Shallow pool between two riffles
RM 256.87	12	25	43	Run
RM 256.81	11	19	28	Run
RM 256.52	19	32	66	Shallow portion of a large pool/run
RM 256.17	5	30	74	Shallow portion of a large pool

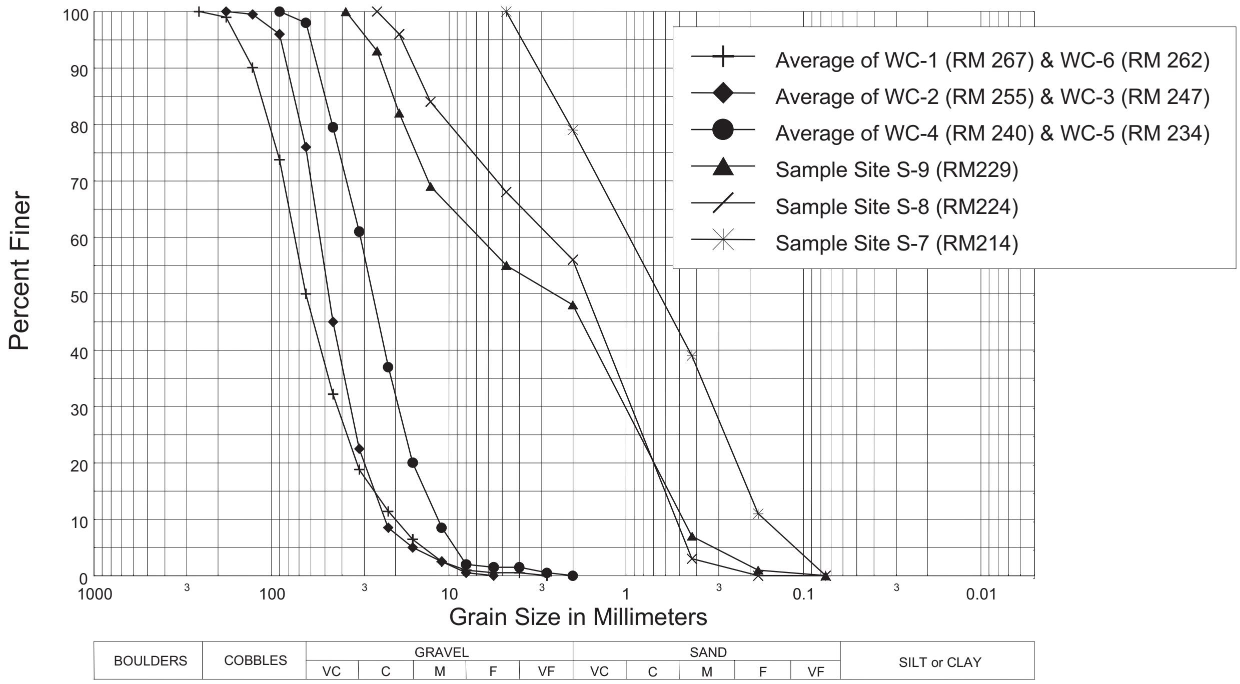
Grain size data for the San Joaquin River is limited to recent data collection efforts, with most data located in Reach 1. Data collected by MEI (2000a) and MEI (2000b) provide grain size data in all reaches, as well as a few locations in the flood control bypass system (Table 3-8). In hydraulic modeling segments in Reach 1 and Reach 2 where the bed materials are coarser grained, the modificed Wolman pebble count procedure (Wolman 1954, Leopold 1970) was used to determine grain size gradations. For the remainder of the river, bulk samples of the bed material were collected for subsequent laboratory analysis. Representative bed material gradations for the hydraulic modeling segments between Friant Dam and the Merced River are shown in Figure 3-15. The bed materials in Reach 1A and the upstream portion of Reach 1B are primarily composed of gravel- and cobble-size materials, whereas the bed material in downstream reaches are composed primarily of finer gravels and sands.

Table 3-8. Summary of D16, D50, and D84 of bed material sediment samples collected along in the study area by Mussetter Engineering (MEI 2000a and MEI 2000b). "S" denotes bulk sample, and "WC" denotes a Wolman pebble count.

	Sediment Size		
Sample Number (Location)	**D_{16} (mm)**	**D_{50} (mm)**	**D_{84} (mm)**
WC-1 (RM 266.8)	45	90.5	138
WC-6 (RM 262)	27	52	80
WC-2 (RM 255)	27	44	64
WC-7 (RM 251)	23	40	57
WC-3 (RM 247)	11.2	19	30
WC-4 (RM 240)	19.5	46	74
WC-5 (RM 234)	9.6	18	29
S-9 (RM 229)	0.6	2.6	20
S-8 (RM 223.5)	0.62	1.7	12.7
S-7 (RM 215)	0.21	0.65	2.5
S-6 (RM 199)	0.54	1.56	6.2
S-5 (RM 197)	0.53	0.96	1.77
S-4 (RM 174)	0.32	0.73	1.49
S-1 (RM 133)	0.25	0.6	1.38
S-2 (Bravel Slough/Eastside Bypass)	0.24	0.5	1.31
S-3 (Eastside Bypass at Sand Slough)	0.53	1.3	3.36

In the summer of 2002, Stillwater Sciences collected additional grain size data in Reach 1 (Table 3-7, Figure 3-16). All samples were surface samples collected using the modified Wolman pebble count method (Wolman 1954, Leopold 1970), and type of geomorphic unit sampled was recorded to help explain the grain size variability in the samples.

Reach 1 and 2



Reach 3, 4, 5, and Eastside Bypass

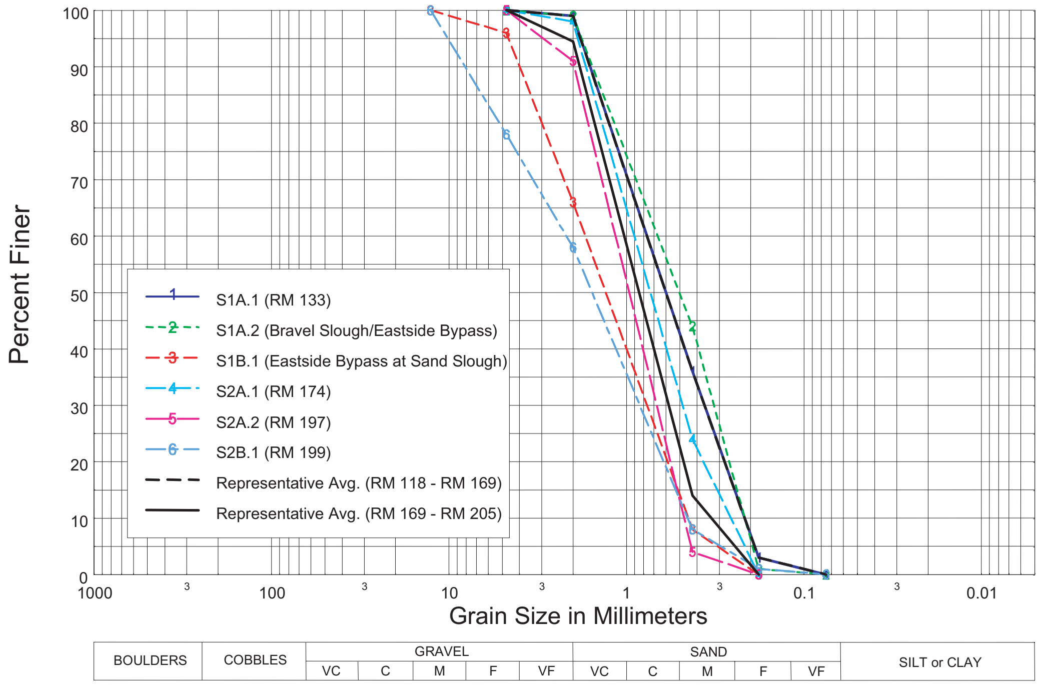


Figure 3-15. Bed material grain size gradations for samples collected between Friant Dam and the Merced River confluence (MEI 2000a and MEI 2000b).

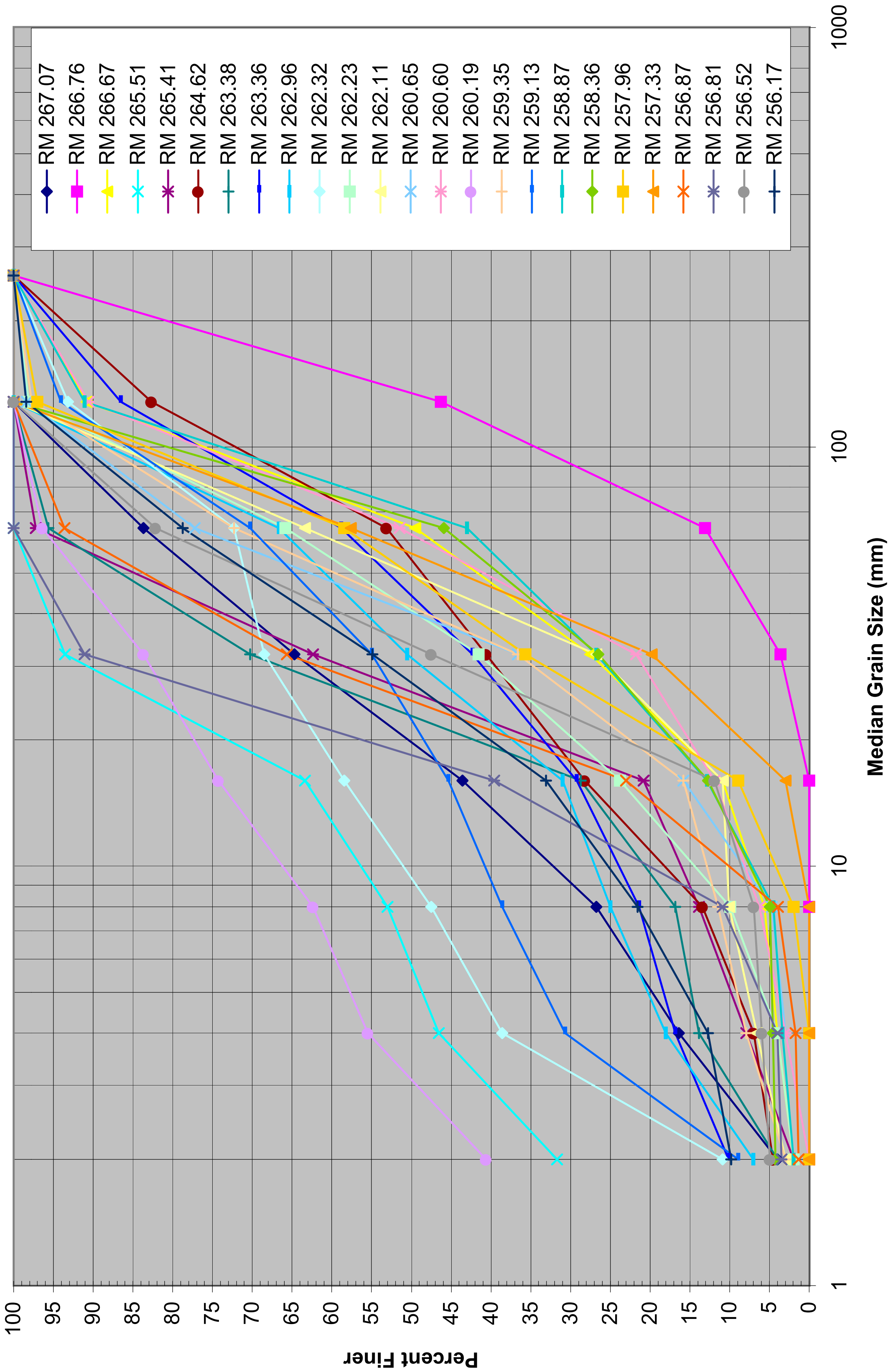


Figure 3-16. Bed material grain size gradations for samples collected between Friant Dam and the Lanes Bridge (HWY 41) collected by Stillwater Sciences in 2002.

3.7. HISTORICAL AND EXISTING CONDITIONS

The following sections synthesize much of the historical information and recent studies to describe reach-specific conditions within the San Joaquin River study area. These sections describe: (1) the high flow regime largely responsible for initiating fluvial processes and creating and maintaining channel form, (2) changes in the sediment regime as a function of dams, diversions, bypasses, and aggregate extraction, (3) changes in fluvial processes, channel morphology and planform morphology as a function of changes in flow regime, sediment regime, aggregate extraction, and infrastructure, (4) present-day bed mobility thresholds in Reach 1, and (5) inundation patterns based on the changes in flow regime and channel geometry.

3.7.1. Reach 1

Reach 1 is subdivided into two reaches: Reach 1A extends from Friant Dam (RM 267.5) to the Highway 99 Bridge (RM 243.2), and Reach 1B extends from the Highway 99 Bridge to Gravelly Ford (RM 229.0) (Figure 3-2). Reach 1 has the steepest slopes in the study area and would contain the most likely area for salmonid spawning if they were re-introduced. The river channel is moderately confined by terraces and bluffs throughout this reach. The gravel/sand transition begins in Reach 1B, and is sand-bedded by Gravelly Ford. Reach 1 is the only reach that provides spawning gravels for anadromous salmonids; thus, Reach 1 is a critical reach for efforts to restore anadromous salmonid production on the San Joaquin River.

3.7.1.1. High Flow Regime

The unimpaired flow regime is presented in Chapter 2; changes to the high flow regime have had the greatest impact to channel form and processes. The winter storm events and snowmelt peak hydrograph components were responsible for most fluvial geomorphic work on the San Joaquin River. Flood frequency curves are often used to characterize the high flow regime, as well as to evaluate changes to the high flow regime. A common conceptual model for alluvial river processes is that the common flood having a recurrence interval of approximately 1.5 to 2.0 years is responsible for (1) transporting the most sediment over time (e.g., Andrews 1980), (2) defining trends in channel geometry (e.g., channel width, meander wavelength) (Leopold et al. 1964), and (3) maintaining the channel morphology (Rosgen 1986). Less frequent floods (e.g., 10-yr flood) were also important in creating and maintaining channel features in the floodway. Thus, changes to the high flow regime would have an impact on channel processes, channel form, and channel scale. The pre-Friant Dam 1.5-year flood was 11,400 cfs, and the post-Friant Dam 1.5-yr flood was 400 cfs, reflecting a 96% reduction (See Table 2-2). The corresponding pre-Friant Dam 10-year flood was 34,400 cfs, and the post-Friant Dam 10-year flood was 8,950 cfs, reflecting a 74% reduction. In addition, the duration of high flows that are large enough to initiate large-scale geomorphic processes has been greatly reduced; in the 35 years from 1908-1942 representing pre-Friant Dam conditions, there were 391 days (3.06% of all days) over 10,000 cfs, whereas in the 51 years from 1950-2000 representing post-Friant Dam conditions, there were only 31 days (0.166% of all days) over 10,000 cfs. More detailed information on changes to surface water hydrology can be found in Chapter 2.

3.7.1.2. Sediment Regime

The sediment regime for the San Joaquin River strongly influences channel morphology, fluvial processes, aquatic habitat, and terrestrial habitat. The coarse sediment supply (gravels and cobbles) form bars, riffles, pool tails, side channels, and other important geomorphic features critical for salmonid habitat. As shown in Figure 3-1, changes to the sediment regime propagate to salmonid habitat and other aquatic and terrestrial habitats. While the most common example of dam induced changes to the sediment regime is loss of spawning habitat, perhaps the most important impact is the cumulative impact of reduced coarse sediment supply to channel morphology. Reduced coarse sediment supply, combined with impaired ability to move the remaining coarse sediment due to reduced high flow regime, typically causes: (1) riparian vegetation to encroach into the low flow channel (see Section 3.10.6), (2) simplification of channel morphology, (3) reduced rates of channel migration, and (4) reduced storage of coarse sediment in the channel.

The predominant pre-Friant Dam sediment source was the upstream watershed and erosion of Pleistocene terraces in Reach 1 and 2 (Janda 1965). Unimpaired estimates of coarse sediment yield based on watershed denudation rates from Janda (1965) are a maximum of 26,000 yd^3/year assuming coarse sediment is 10% of the total sediment load. Corresponding fine sediment yield would have been approximately 234,000 yd^3/year. Watershed denudation rates are not necessarily the most accurate way to estimate sediment yield for recent climatic conditions, and recent reservoir sedimentation surveys provide a better estimate of yield.

Based on sedimentation rates from regional reservoirs, Cain (1997) estimated an average unimpaired coarse supply estimate (assuming 10% of total sediment yield is coarse sediment) of approximately 48,600 yd^3/year. This volume of average annual sediment supply is smaller by a factor of nearly 2 compared to estimates by Janda (1965) (Table 3-3). Tributary streams downstream of Friant Dam (e.g., Cottonwood Creek and Little Dry Creek) provided sediment to the San Joaquin River, but the magnitude of sediment delivery was most likely small compared to that delivered by the upper watershed. Cain (1997) estimates average annual unimpaired coarse sediment yield for Cottonwood Creek as 55 yd^3/year, and 335 yd^3/year for Little Dry Creek, assuming coarse sediment is 10% of total sediment yield. Corresponding fine sediment estimates for Cottonwood Creek is 495 yd^3/year and 3,015 yd^3/year for Little Dry Creek. Assuming reasonable accuracy of these estimates, Cottonwood Creek would have delivered approximately 0.113% of the coarse sediment contributed by the upper San Joaquin River watershed (55/48,600), and Little Dry Creek would have delivered approximately 0.69% of the coarse sediment contributed by the upper San Joaquin River watershed (335/48,600). The sediment yield estimate from the watershed upstream of Friant Dam in Cain (1997) are derived from NRCS measurements and estimates of numerous Central Valley reservoirs including Millerton Reservoir (Brown and Thorp, 1947). Brown and Thorps' measurements and estimates were for the purpose of predicting how fast reservoirs would fill under modern reservoir conditions. Sedimentation estimates for Millerton Reservoir were based on other San Joaquin watersheds where mining activity and other watershed disturbances may have been far greater. Cain's estimate using Brown and Thorps (1947) regional sedimentation estimates results in a value (48,600 yd^3/yr) is almost twice as large higher than Janda's unimpaired estimate (26,000 yd^3/yr). This difference may likely be a result of the Brown and Thorp data being derived from more disturbed watersheds than the upper San Joaquin River watershed, and application of this data to the San Joaquin River may over-estimate sediment yield from the upper San Joaquin River watershed.

Lateral erosion of terraces after Friant Dam was completed may have also augmented sediment supply in Reach 1, but qualitative review of channel migration from historical maps and photos suggests that migration rates were low, thus sediment contribution from terrace erosion was also likely low. A careful quantitative analysis has not been performed, and performing this analysis would better document the potential contribution of sediment by terrace erosion. As previously stated, the unimpaired sediment regime appears to have been small based on Janda (1965) and Brown and Thorp (1947). Elimination of this sediment supply from the upper watershed was combined with a reduction in high flow regime, which may have also reduced recruitment of sediment from terrace erosion. While these two sediment sources were small compared to other Central Valley rivers, their reduction still represents a substantial change from impaired conditions. The low gradient and low sediment transport capacity of downstream reaches has likely reduced the impact to coarse sediment storage in the reach. Remaining sediment sources downstream of Friant Dam include the following:

- Cottonwood Creek (confluence at RM 267.4)
- Little Dry Creek (confluence at RM 261)
- Lateral erosion of terraces
- Vertical incision of the bed surface

Cottonwood Creek is unregulated and continues to deliver sediment to the San Joaquin River, and because upstream sediment supply has been eliminated, the small amount of sediment that Cottonwood Creek delivers to the San Joaquin River has become the primary sediment source (other than the bed itself). As presented above, Little Dry Creek should have historically contributed more sediment to the San Joaquin River than Cottonwood Creek based on its larger drainage area and unit sediment yield; however, gravel mining in the lower portions of Little Dry Creek since at least the 1930’s has likely greatly reduced sediment delivered to the San Joaquin River (Figure 3-17). Recent reconnaissance by JSA and MEI (2001) has suggested that these gravel pits trap sediment transported by Little Dry Creek; however, during large floods (e.g., 1995), there were field observations of evidence suggesting high rates of coarse sediment transport, and some coarse sediment may still be delivered to the San Joaquin River during high flows on Little Dry Creek (Cain, personal communication).

Compared to the loss of sediment supply from the upper San Joaquin River watershed and Little Dry Creek, the impact of instream aggregate extraction on coarse sediment storage is many times larger than the impact of upstream dams and reductions from Little Dry Creek (Figure 3-18). For Reach 1A, Cain (1997) estimated that 1,562,000 yd^3 were removed from the active channel of the San Joaquin River between 1939 and 1989 (3,124 yd^3/yr), and 3,103,000 yd^3 were removed from the floodplain and terraces. Reach 1B does not have nearly the level of aggregate extraction, with 107,000 yd^3 removed from the active channel, and 72,000 yd^3 removed from floodplains and terraces. When comparing the volume of aggregate removed from the active channel with the unimpaired volume of coarse sediment supplied from the upper San Joaquin River watershed, gravel extraction between 1939 and 1989 in the active channel of Reach 1A alone has removed two-thirds of the predicted volume of unimpaired coarse sediment yield to the lower river if upstream dams were not in place (31,240 yd^3/yr compared to 48,600 yd^3/yr). Because the sources from the upstream watershed have been blocked by Friant Dam and other dams, there is a substantial deficit in the coarse sediment budget.

Discussion of changed sediment regime in Reach 1 has focused on the reduction in coarse sediment. However, upstream dams have also impacted the fine sediment budget. First, these dams have trapped the washload component of the sediment regime, which consist of very fine sands and silts. The loss of washload to downstream reaches of gravel-bedded rivers is usually ignored because of the desire to reduce fine sediment (primarily sands) in salmonid spawning areas. However, these finer sediments typically transport as washload (Figure 3-4) and do not tend to deposit in the active channel, but do deposit on floodplains due to riparian vegetation roughness and a wide floodplain. These finer sediments are very important for riparian vegetation regeneration (both woody and herbaceous) on floodplains and high flow scour channels. Loss of this finer sediment source by blockage from upstream dams reduces or eliminates fine sediment deposition on floodplains, impairing natural regeneration processes of woody and herbaceous riparian vegetation.

The second impact to the fine sediment budget is that while upstream dams trap all fine sediments, downstream tributaries continue to deliver fine sediment, particularly coarse sand eroded from the sandy loam watershed. Review of 1937 aerial photos show large sand dunes within the low

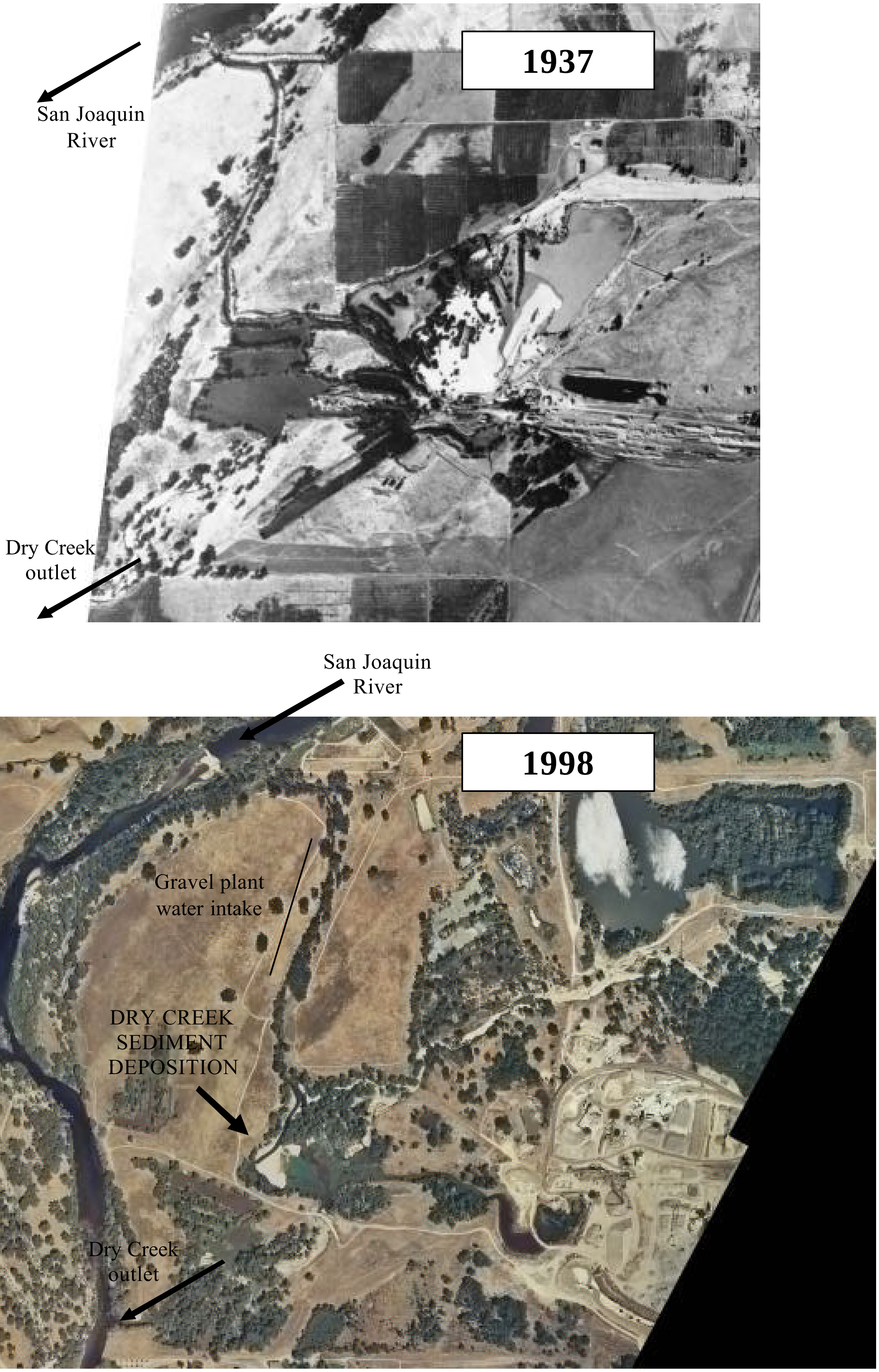


Figure 3-17. 1937 and 1998 aerial photography of lower Little Dry Creek, showing long-term gravel mining impacts on potential sediment delivery to the San Joaquin River.

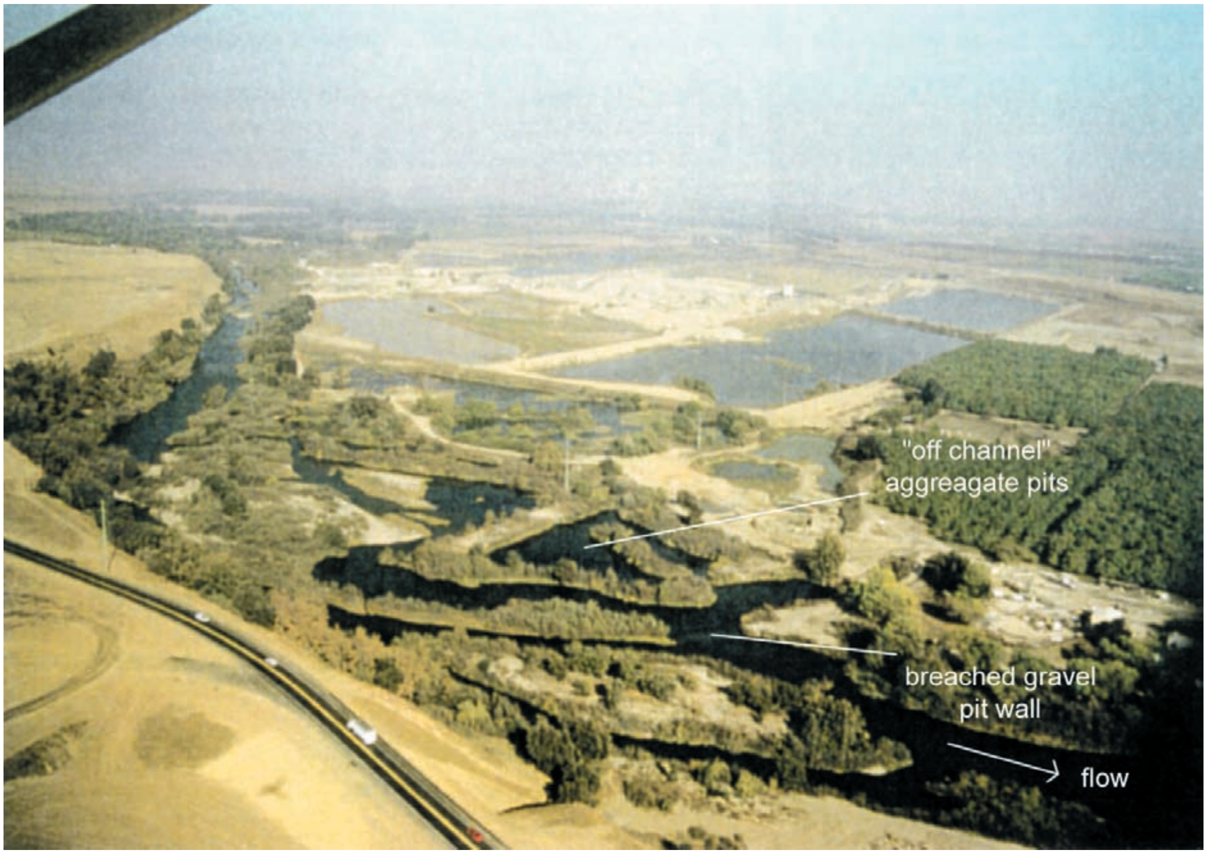


Figure 3-18. View upstream of the effects of historical in-channel sand and gravel mining at RM 257. Breaching of pit walls has led to the formation of a multi-channeled reach of the river. Active mining of the two lower terraces can be seen in the background. The highest terrace confines the channel along the right bank (looking downstream). From JSA and MEI (1998).

flow channel, and field observations by William Hammond Hall (1887) suggests that even under unimpaired conditions, sand storage in Reach 1 (partially due to the low gradient) was substantial. Reduction of the sand transport capacity occurred when the high flow regime was impaired by upstream dams, such that sands in the channel had low transport rates (thus high residency times) and sand contributed by tributaries was slow routing through the system. Field observations under current conditions illustrate a channel with substantial but unquantified volumes of sand storage within the low flow channel, even in the upstream-most portions of Reach 1 near the base of Friant Dam. Cottonwood Creek is a likely source of this sand, as it delivers its sediment load virtually at the base of Friant Dam. This sand storage may be a impediment to salmonid reproduction because: (1) it impairs gravel quality in habitats needed by spawning and rearing salmonids, and (2) future gravel cleaning or introduction efforts may have a short life-span as the in-channel sands are transported downstream and infiltrate into the cleaned gravels.

3.7.1.3. Fluvial Processes

Several conceptual models have been developed for fluvial processes on gravel-bedded reaches of San Joaquin River tributaries: the Merced River (Stillwater Sciences 2002) and the Tuolumne River (McBain and Trush, 1998). McBain and Trush summarize a list of “attributes of alluvial river integrity" for the Tuolumne River that summarizes important fluvial processes that are appropriate for both gravel-bedded reaches and sand-bedded (although the frequency differs between the two reaches). They include the following:

ATTRIBUTE No. 3. Frequently mobilized channel bed surface.

In gravel-bedded reaches, channel bed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years. In sand-bedded reaches, bed particles are in transport much of the year, creating migrating channel-bed "dunes" and shifting sand bars.

ATTRIBUTE No. 4. Periodic channel bed scour and fill.

Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channel bed topography following a scouring flood usually is minimal. In gravel-bedded reaches, scour was most likely common in reaches where high flows were confined by valley walls.

ATTRIBUTE No. 5. Balanced fine and coarse sediment budget.

River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channel bed must be transported through the river reach.

ATTRIBUTE No. 6. Periodic channel migration

The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber (Figure 3-19). In gravel-bedded reaches, channel relocation can also occur by avulsion, where the channel moves from one location to another, leaving much of the abandoned channel morphology intact. In sand-bedded reaches, meanders decrease their radius of curvature over time, and are eventually bisected, leaving oxbows.

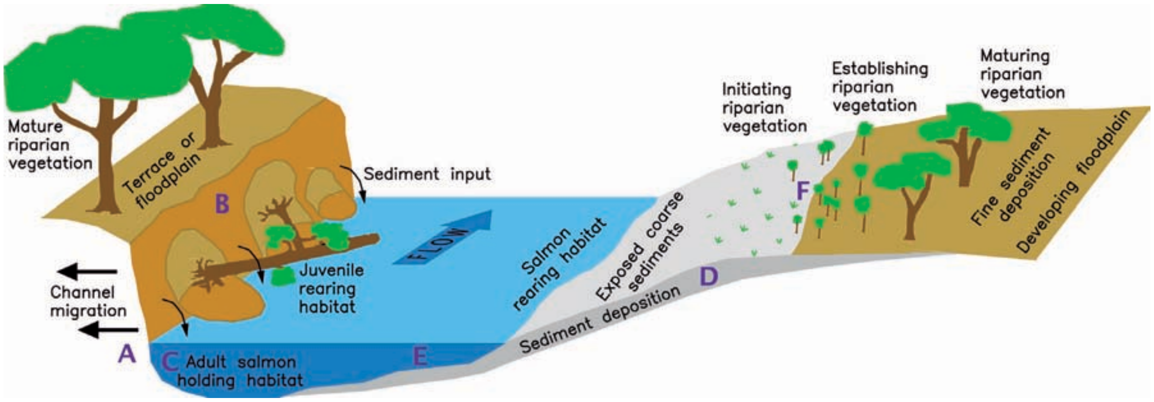
ATTRIBUTE No. 7. A functional floodplain

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terraces (Figure 3-19).

ATTRIBUTE No. 8. Infrequent channel resetting floods

Single large floods (e.g., exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenate mature riparian stands to early-successional stages, form and maintain side channels, and create off-channel wetlands (e.g., oxbows). Resetting floods are as essential for creating and maintaining channel complexity as lesser magnitude floods, but occur less frequently.

These attributes cumulatively provide the physical foundation for salmonid habitat: diverse, high quality, and abundant aquatic habitat for all life stages (spawning, egg incubation, fry rearing, and juvenile rearing) of salmonids. These attributes are unique to each river system, and should not be directly applied to the San Joaquin River without further analysis; however, these attributes provide a good starting point for evaluating primary components of the fluvial system. Some notable differences between the Tuolumne River and the San Joaquin River are discussed below.



Conceptual linkages between channel migration and fish habitat. (A) A channel with adequate space to migrate erodes the channel bank on the outside of the meander bend during high flows, (B) encouraging mature riparian trees to topple into the channel. (C) The pool along with large wood on the outside of the bend provide structural complexity for good fish habitat. As bank erosion continues, the pool "migrates" laterally and downstream, but high quality habitat is maintained. (D) On the inside of the bend high flows scour and redeposit sediments (gravel in Reach 1, sand in downstream reaches), forming a shallow bar on the inside of the bend. (E) In Reach 1, this area provides slow-water rearing conditions for fry and juvenile chinook salmon, as well as habitat for aquatic insects (fish food), amphibians and reptiles. (F) Progressively higher up the gravel bar surface, receding water levels during the spring snowmelt allow riparian seedlings to establish. Newly established woody riparian seedlings are sporadically scoured out, but those established high enough on the bank become mature to eventually topple into the channel as the river migrates back across the valley (A). Large floods create scour channels on upper bar surfaces and inundate floodplains, providing juvenile salmon rearing habitat during higher flows.

Figure 3-19. Conceptual role of channel migration in creating spatially and temporally complex riparian corridor habitat (from McBain and Trush, 1998).

The gravel-bedded portion of these streams (spatially analogous to Reach 1 of the San Joaquin River) is steeper than Reach 1 of the San Joaquin River; thus some of these attributes are not directly applicable. The slope of the Tuolumne and Merced rivers in the gravel bedded reaches are approximately 0.0015 (0.15%), whereas the steepest local slope for Reach 1 is 0.0010 (0.1%), the average slope for Reach 1A is 0.00065 (Figure 3-20), and the average slope for Reach 1B is 0.00045 (Figure 3-21). These slopes are based on modeled water surface slopes for an 8,000 cfs release using present-day topography, thus these slopes differ from the 1914 values shown in Table 3-4. The lower slope (less than ½ the slope of the Merced and Tuolumne rivers) potentially results in less energy expended on the channel during periods of high flows (in reaches with similar valley or terrace confinement), such that higher flows would be required to initiate the fluvial processes described in the attributes of alluvial river integrity above than on the Tuolumne and Merced rivers. Correspondingly, the frequency of these fluvial processes being accomplished under unimpaired conditions was likely less than on the Tuolumne and Merced rivers. Examining the 1937 aerial photographs provides evidence that fluvial processes characterized by the attributes above did occur during historic flow regime.

Figure 3-6 shows a portion of Reach 1 that illustrates some of these fluvial processes. First, exposed and submerged gravel bars are clearly visible on the photograph, demonstrating that the channel bed is mobilized (Attribute 3). The aerial photographs cannot prove that bed scour occurs (Attribute 4), but the absence of riparian vegetation on the exposed bars suggests that some degree of bed scour occurs that removes riparian seedlings. Likewise, the aerial photographs cannot prove that there is a

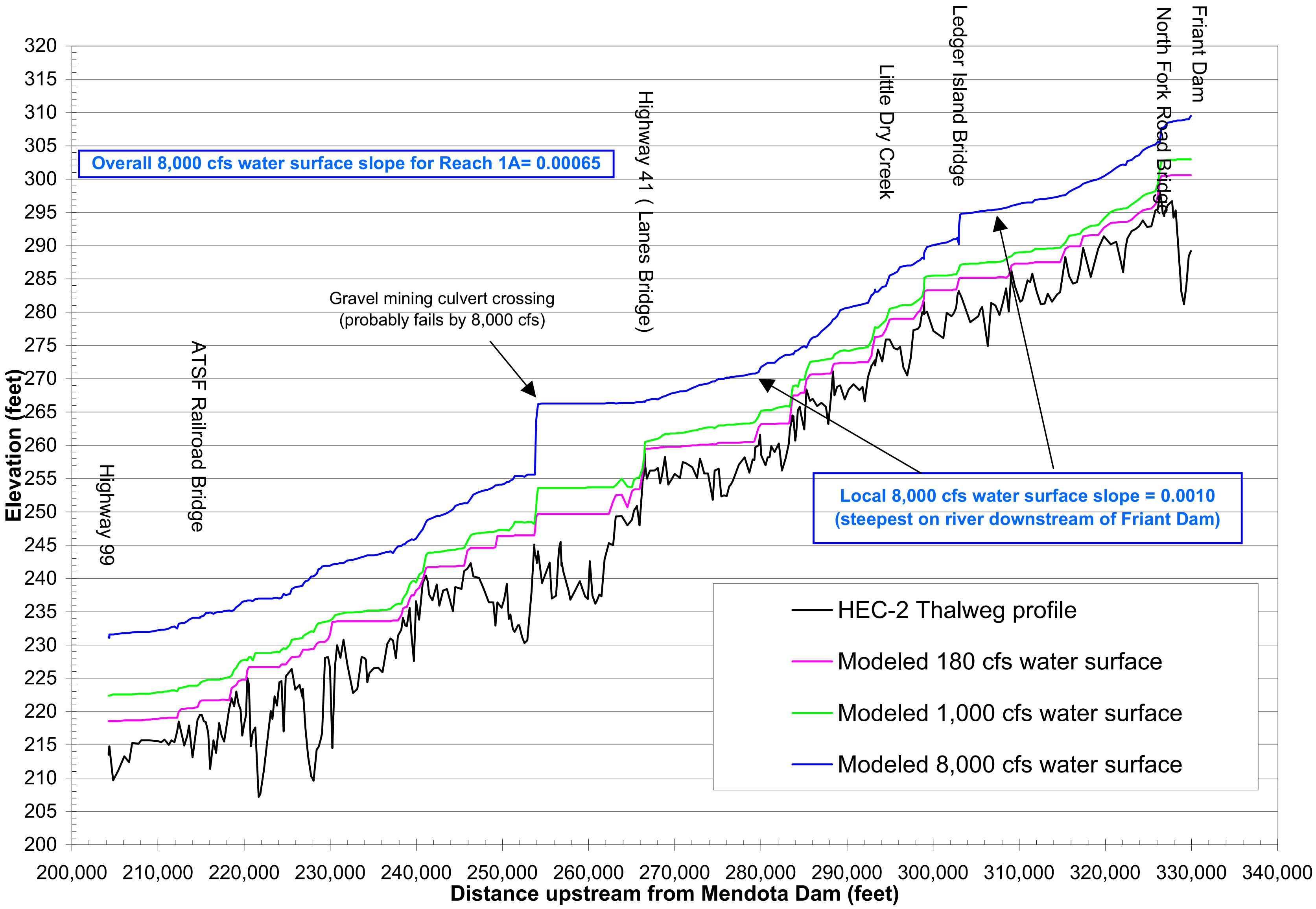


Figure 3-20. Thalweg and modeled water surface profiles for Reach 1A, showing overall reach slope and short reach representing the steepest slope in the entire study area (from MEI 2000a).

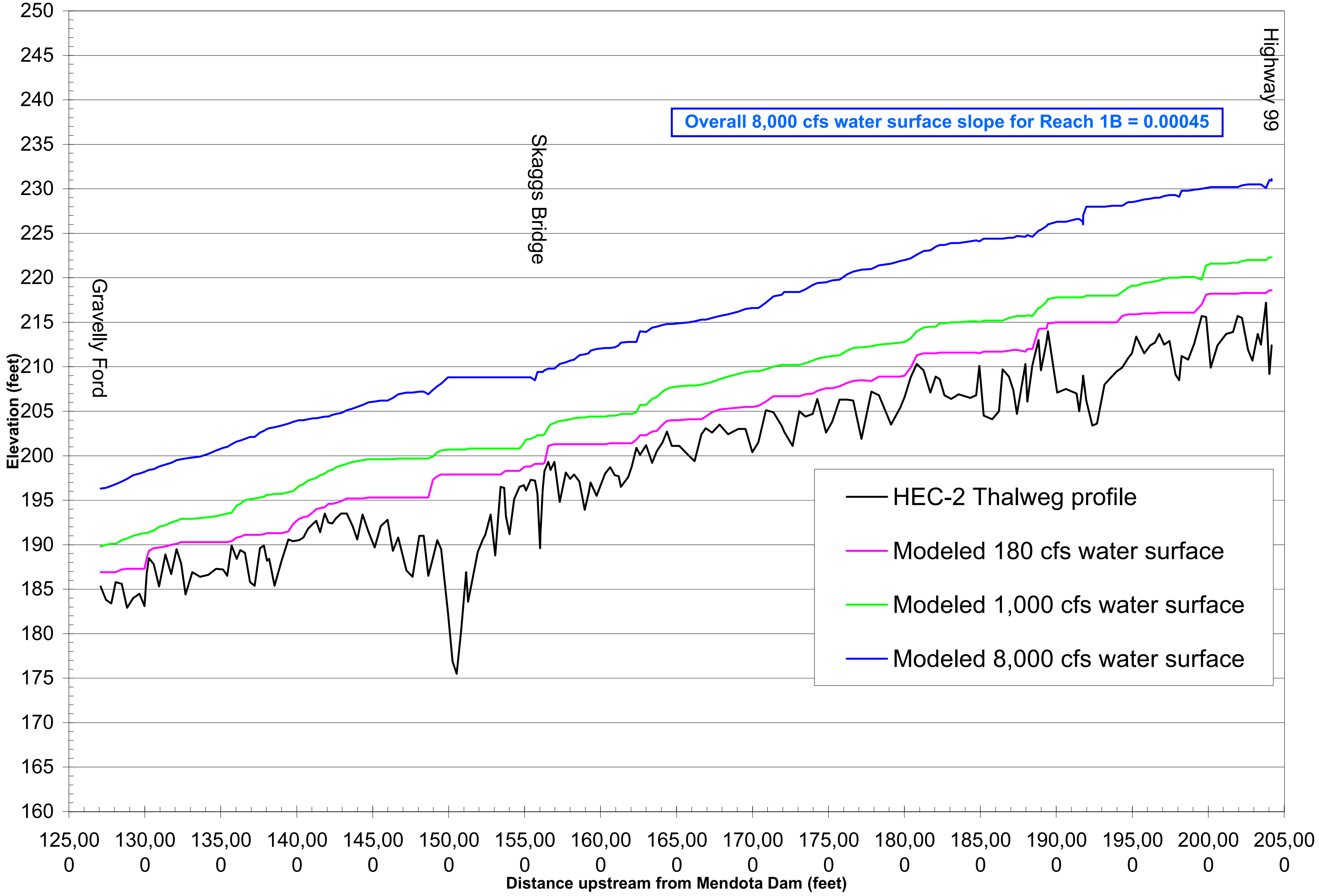


Figure 3-21. Thalweg and modeled water surface profiles for Reach 1B, showing overall reach slope (from MEI 2000a).

balanced sediment budget; there is no evidence that there is any substantial channel aggradation in the reach, although there could be degradation of the channel bed. A small amount of channel migration (Attribute 7) is observable on the downstream end of the photograph, where the channel migration is creating a medial bar as the channel widens. There are no scroll bars or new floodplains visible, so the rate of migration is likely very low. In the not so recent past, a high flow created the side channels in the center and upstream end of the photograph (Attribute 8). The frequency of these avulsion events is not known, but is likely much greater than the 10 to 20-year recurrence interval estimated for Attribute 8. Lastly, channel migration and avulsion, albeit slow and infrequent, allow functional floodplains to form (e.g., downstream end of photo where channel has migrated). The observations on this photo need to be considered in context of the high flow events preceding the date of the photo. On February 6, 1937, a short duration high flow event of 36,400 cfs (daily average = 17,900 cfs) occurred, which was approximately a 9.5-year flood event under the pre-Friant Dam flood frequency. Additionally, there were seven days during the subsequent snowmelt runoff hydrograph that were larger than 10,000 cfs. Therefore, it is safe to assume that these high flows mobilized the bed surface due to the clearly active bar features evident shown on Figure 3-6, and floodplain inundation likely occurred, but it is difficult to determine if other fluvial geomorphic thresholds (e.g., channel migration, bed scour) were surpassed by high flows in water year 1937.

The rates of these fluvial processes under historic conditions are not estimated due to the lack of data under these historic conditions. The possible exception is that channel migration and avulsion rates and frequency could be estimated by conducting an historic channel analysis using maps and aerial photographs dating back to 1854. This analysis was not performed for this report, but an example can be observed on Figure 3-22 where one map (1854) and two aerial photographs (1937 and 1998) show the limited change in channel location over time at RM 259. The only large-scale channel location change between 1937 and 1998 occurred in the southern channel, where the meander bends migrated downstream a short distance. This minimal movement over the 49 intervening years is likely due to the low slope and sediment supply in the reach, and perhaps to some unknown extent, stabilization efforts by adjacent landowners.

3.7.1.4. Incipient Motion Analyses

A potential objective of future restoration efforts may include increasing the frequency and duration of bedload transport. Mobilizing the bed surface is one of many important geomorphic processes, and can benefit salmonids by creating and maintaining high quality spawning and rearing habitat, and contributes to channel migration and bar formation that provides complex aquatic habitats for salmonids and other species. In unimpaired alluvial rivers, the gravel bed often mobilizes by a flow of approximately 1.2 to 1.5 year recurrence (Parker et al,, 1982). Several analyses have been conducted to estimate the bed mobility threshold (incipient motion) under current channel morphology and particle size conditions.

Contemporary bed mobility thresholds have been estimated empirically by Cain (1997), and more recently estimated by modeling approaches by Mussetter Engineering (in JSA 2002). Cain (1997) placed tracer rocks representing the D_{84} particle size at three separate cross sections at a study site at approximate RM 266.3. After placement, a peak flow of 8,000 cfs occurred, which did not mobilize any of the rocks (Cain, personal communication). Later, a 12,500 cfs flow occurred, mobilizing a portion of the tracer rocks. Marked rocks were recovered at two of the cross sections, but not at the third cross section (presumably because the rocks were buried, per Cain 1997). The D_{84} at one of the two remaining cross sections was 215 mm, and the D_{84} at the other cross section was 220 mm. A total of 13 rocks were placed at the two cross sections, and of these 13 sets, nine of the rocks (76%) were mobilized from the cross section, suggesting that the 12,500 cfs flood event was moderately

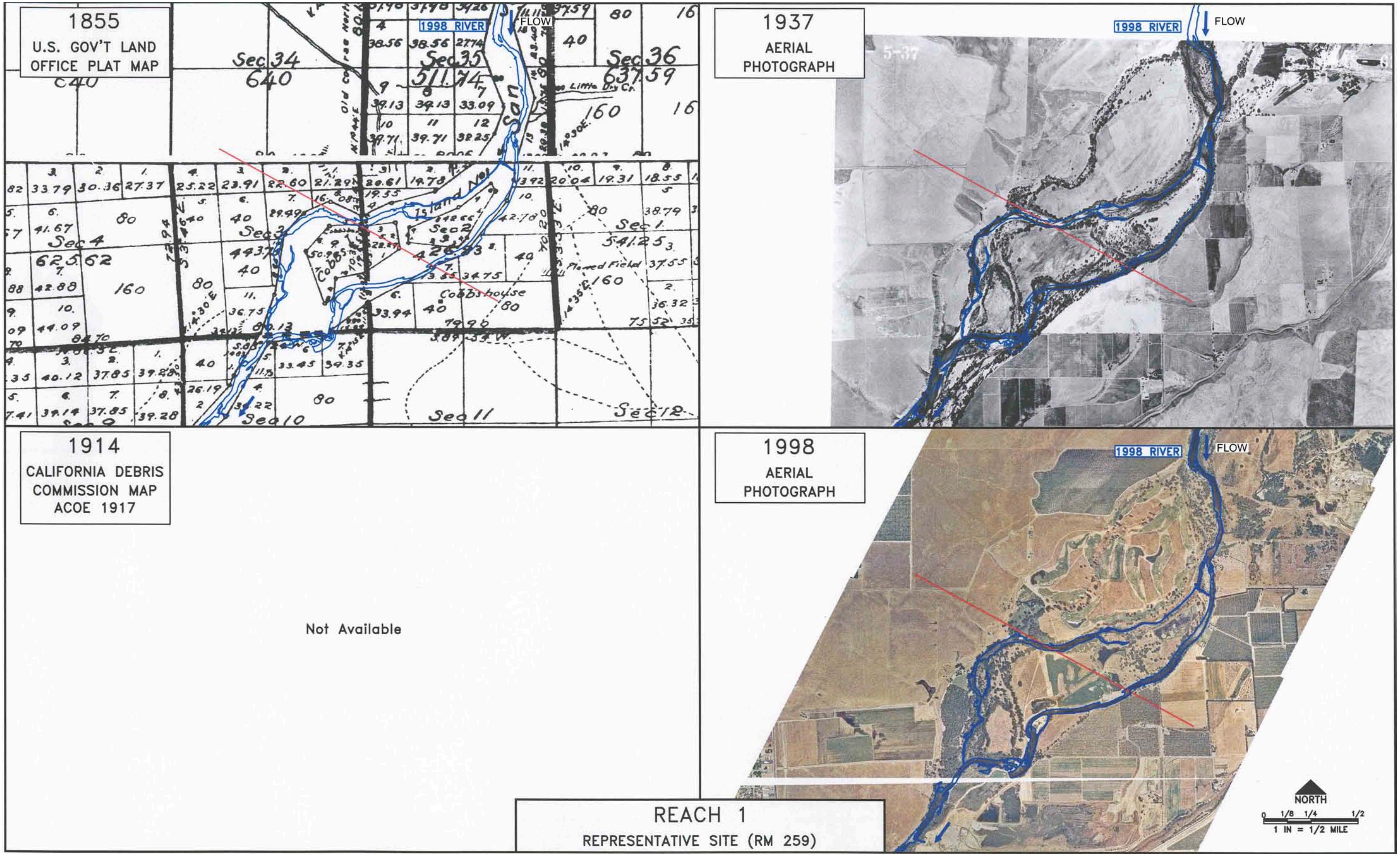


Figure 3-22. Example planform evolution in Reach 1A (RM 259), showing 1855 plat map, 1937 air photo, and 1998 air photo.

sufficient to mobilize rocks exceeding 200 mm diameter. This conclusion is somewhat tempered in that the rocks were not placed fully within the armored bed surface due to the degree of armoring (Cain, 1997). Therefore, the tracer rocks may have been artificially protruding from the bed surface to a larger degree than the surrounding parent rocks. Additionally, they were likely not as tightly packed as the surrounding parent rocks.

The incipient motion analysis conducted by Mussetter Engineering (in JSA 2002) used a standard tractive force approach to estimate bed mobility thresholds (Shields 1936). The incipient motion analysis was performed by evaluating the effective shear stress on the channel bed in relation to the amount of shear stress that is required to move the sediment sizes that are present. This was accomplished by computing the grain shear stress ratio, which is the ratio of the grain shear stress to the critical shear stress for particle mobilization. Theoretically, when this ratio exceeds a value of 1.0, the particle size mobilizes. This ratio is dependent on channel velocity, the energy slope, and gravel size. The grain shear stress was used in the calculations rather than the total shear stress because the grain shear stress is a better representation of the near-bed hydraulic forces acting on the individual sediment particles on the bed. The total shear stress over-estimates the forces that are effective in mobilizing sediment because it includes the effects of form roughness associated with irregularities in the channel bed and banks, and other obstructions such as vegetation, that reduce energy in the flow.

In gravel and cobble bed streams, when the critical shear stress for the median (D_{50}) particle size is exceeded, the bed is mobilized, and all sizes up to about 5 times the median size are capable of being transported by the flow (Parker et al., 1982; Andrews, 1984). At lower shear stresses, the bed is effectively immobile. Considering Neill's (1968) observations, when the grain shear stress ratio is approximately 1.0, the bed begins to mobilize, and substantial transport of the bed material occurs when the shear stress ratio exceeds about 1.3. Flow thresholds to achieve a ratio of 1.0 and 1.3 were computed, providing a range of flow predictions for gravel mobilization.

Shear stress is estimated from the output of the HEC-2 hydraulic model prepared by MEI (2000a). Because the HEC-2 model is a one-dimensional hydraulic model, the accuracy of the shear stress predictions is best at locations with simple channel morphology that best approaches uniform flow conditions. Riffles tend to provide the best channel conditions for applying this model. Therefore, only cross sections in riffles were used to perform the estimates. Results of the modeling suggest that most riffles do not mobilize up to the maximum flow modeled (16,400 cfs), with only a small number of riffles in all reaches predicted to mobilize by flows less than 8,000 cfs (Figure 3-23 and Figure 3-24). The wide variability of incipient motion thresholds shown in Figure 3-23 is likely due to a combination of factors, including (1) inaccuracies in applying a one-dimensional hydraulic model to predict hydraulic conditions in a complex channel morphology, (2) insufficient detail in local particle size estimates, and (3) inappropriate precision in ground topography used in the hydraulic model. More detailed ground surveys of hydraulically simple riffles would likely improve these predictions, as would more empirical studies of bed mobility; regardless, the results of both analyses strongly suggest that flows greater than 12,000 cfs are required to cause mobility of cobbles and gravels in most of Reach 1.

To estimate differing assumptions in Shields equation, as well as narrowing channel dimensions and reducing particle size via simulated gravel introduction projects, the incipient motion analysis was run for a single hypothetical cross section with varying (1) slopes, (2) Shields parameter for incipient motion, (3) particle size, (4) width-to-depth ratio, and (5) shear ratio (shear stress on the D_{50} versus shear stress needed to mobilize the D_{50}). A matrix was developed of results (Table 3-9), showing that due to the inherently low slope for the reach, developing combinations of (1) through (5) to achieve bed mobility thresholds is still very difficult with a reasonable width-to-depth ratio (width-to-depth ratio>25) appropriate for Reach 1. This analysis suggests that under best-case scenario (steepest reach shown in Figure 3-20, smallest particle size, and most mobile estimate of Shields parameter), flows greater than 7,600 cfs would be required to mobilize the D_{50} particle size.

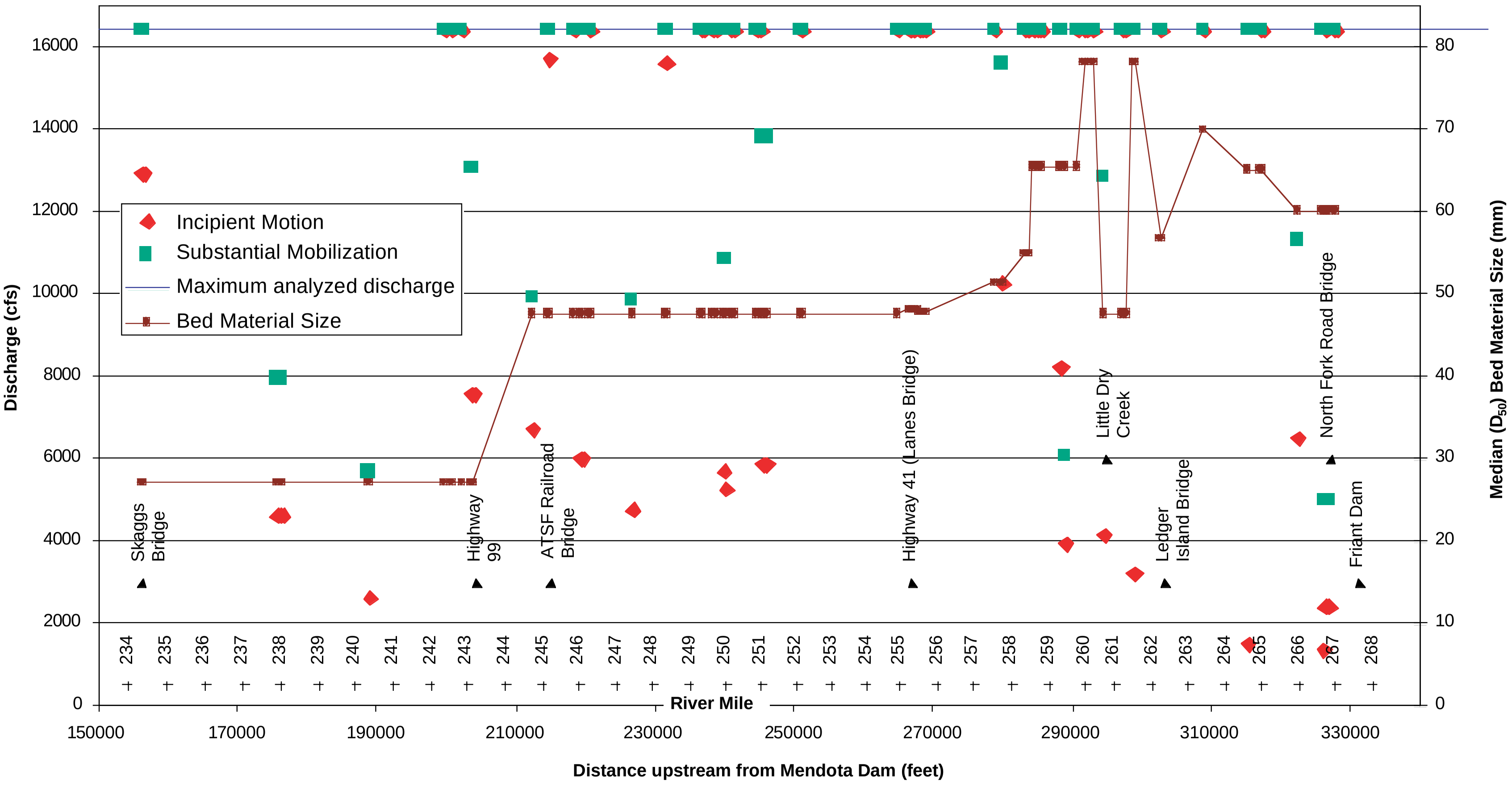


Figure 3-23. Predicted discharge to initiate motion of D_{50} particle size (shear ratio=1.0) and cause substantial transport of D_{50} particle size (shear ratio=1.3). D_{50} particle size used to model incipient motion at each riffle is shown on secondary axis.

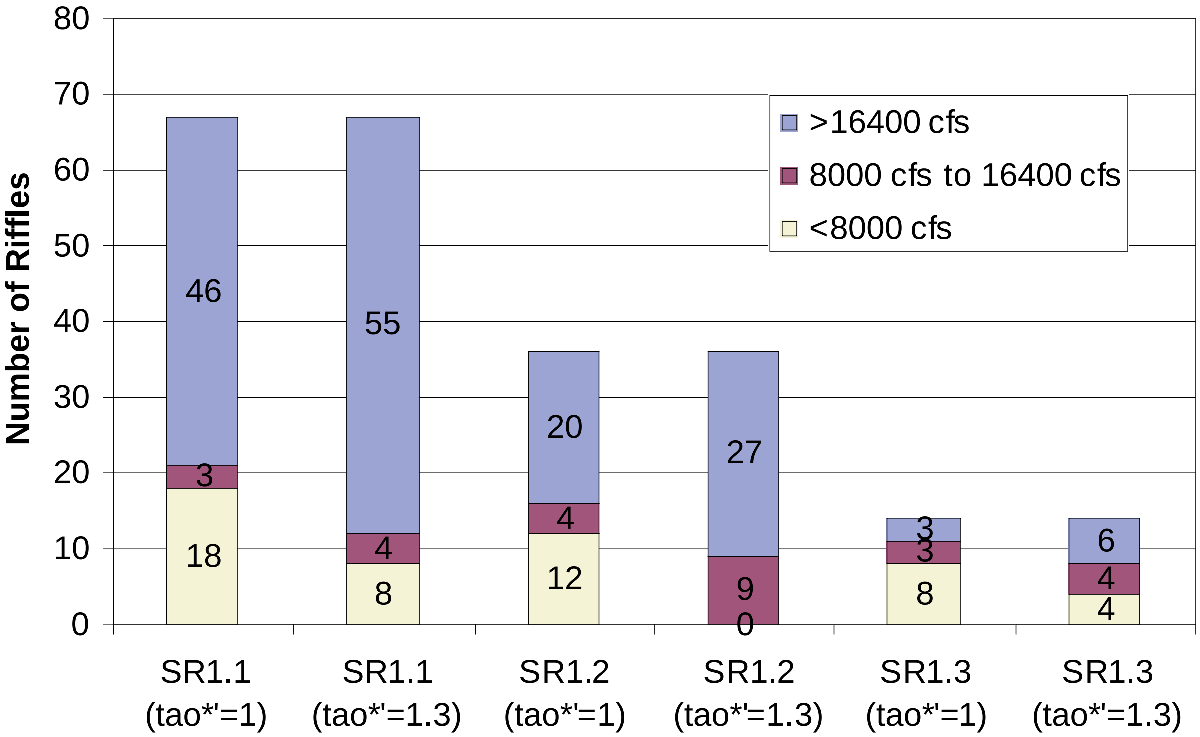


Figure 3-24. Number of riffles in which the critical discharge for incipient motion (shear ratio=1.0) and substantial transport (shear ratio=1.3) under existing D_{50} bed particle size conditions.

Table 3-9. Summary matrix of predicted incipient motion thresholds for a single cross section using a variety of slopes, particle sizes, width-to-dept ratios, Shields parameter, and shear ratio.

Assume Shields parameter = 0.030						
Slope	D_{50} (mm)	Depth (feet)	Width-to-Depth ratio	Width (feet)	Discharge (cfs) if shear ratio=1.0	Discharge (cfs) if shear ratio=1.3
0.0007	40	11.2	15	168	10,500	16,700
0.0010	40	7.6	15	115	4,600	7,300
0.0007	50	13.2	15	198	16,400	26,000
0.0010	50	9.0	15	135	7,100	11,400
0.0007	40	11.2	25	279	17,600	27,800
0.0010	40	7.6	25	191	7,600	12,100
0.0007	50	13.2	25	330	27,400	43,300
0.0010	50	9.0	25	225	11,900	18,900
Assume Shields parameter = 0.035						
Slope	D_{50} (mm)	Depth (feet)	Width-to-Depth ratio	Width (feet)	Discharge (cfs) if shear ratio=1.0	Discharge (cfs) if shear ratio=1.3
0.0007	40	13.1	15	197	10,500	16,700
0.0010	40	9.0	15	135	4,600	7,300
0.0007	50	15.5	15	233	16,400	26,000
0.0010	50	10.6	15	160	7,100	11,400
0.0007	40	13.1	25	329	17,600	27,800
0.0010	40	9.0	25	225	7,600	12,100
0.0007	50	15.5	25	388	27,400	43,300
0.0010	50	10.6	25	266	11,900	18,900

3.7.1.3. Planform Morphology

Channel morphology in Reach 1 is similar to gravel-bed rivers draining from the Sierra Nevada to the north (Tuolumne River, Merced River), with a few notable exceptions. The primary difference is that the San Joaquin River channel morphology is likely much more stable, and less dynamic than its northern cousins under unimpaired conditions. This is largely due to the smaller slope downstream of Friant Dam and lower sediment supply. The following sections further develop conceptual models of channel morphology, as well as changes resulting from human land use in the watershed.

Historical channel morphology for Reach 1 is best provided by 1937 aerial photographs (Figures 3-6 and Figure 3-22). Reach 1B is supplemented by the ACOE (1917) maps from Herndon downstream to Gravelly Ford (Figure 3-25). While these historic maps and aerial photographs do not provide true representation of unimpaired channel morphology on the San Joaquin River, they do provide useful insights to what the unimpaired channel morphology would have been. The aerial photographs and ACOE maps show that the river has multiple channels around islands and river bends. The channel morphology from the Friant Dam site downstream approximately 4 miles is straight, confined between the bluffs to the north and a terrace on the south. Downstream of RM 263, the San Joaquin River is a meandering alternate bar morphology, but the meanders are variable in size and morphology, typical of gravel-bedded reaches of rivers exiting the Sierra Nevada. Channel sinuosity is defined as the ratio of channel length to valley length, and based on the 1914 maps, sinuosity in Reach 1B is 1.2. Reach 1A sinuosity was estimated from 1937 aerial photographs, and had a sinuosity of 1.14.

Alternate bars are evident on the photographs and 1914 maps. Alternate bars and other complex channel features are important in providing diverse, high quality habitat for salmonids. Figure 3-26 illustrates some of the conceptual relationships between features within an alternate bar sequence and (1) particle sorting, (2) salmonid habitat, and (3) riparian vegetation. The complex particle sorting, hydraulics, and bar features provides complex and diverse habitat for all life stages of salmonids (spawning, egg incubation, fry rearing, juvenile rearing). Observations of the 1937 aerial photographs show riparian vegetation absent from some point bars and in-channel islands, suggesting that high flows scour these features frequently, but many other bars are heavily vegetated, even after a 9.5 year flood (Figure 3-6 and Figure 3-22). Compared to similar reaches of the Tuolumne River and Merced River, the planform morphology appears much more influenced by riparian vegetation, or from another perspective, fluvial geomorphic processes are not as effective at removing riparian vegetation as steeper rivers to the north (Figure 3-6). Backwater channels are associated with most channel bends, and at many locations, the channel has migrated to the terrace or bluff control on the outside of the bend. These meander bends have corresponding point bars that were not colonized by vegetation, but intervening reaches between point bars tend to be well vegetated.

Side channels were also very common in the unimpaired channel morphology. Cain (1997) estimated that the main channel length in 1939 for Reach 1A was 16.3 miles; secondary channel and high flow channel lengths added another 7.8 miles of channel. These secondary channels likely provided high quality fry and juvenile salmonid rearing habitat during winter baseflows, as well as some high velocity refugia areas during higher flows. By 1989, the total channel length (main channel + secondary channel + high flow channels) was reduced from 24.1 miles to 16.3 miles, a 32% reduction. Many of these historic secondary channels have been converted to diversion intakes. The net result of reduced side channel length is a corresponding reduction in existing fry and juvenile salmonid rearing habitat.

The current channel morphology is greatly altered from its historic state. The channel form has been simplified to a single channel that only splits at a few islands or when the channel has been captured by adjacent or in-stream gravel pits. The channel is much narrower than the historic channel and

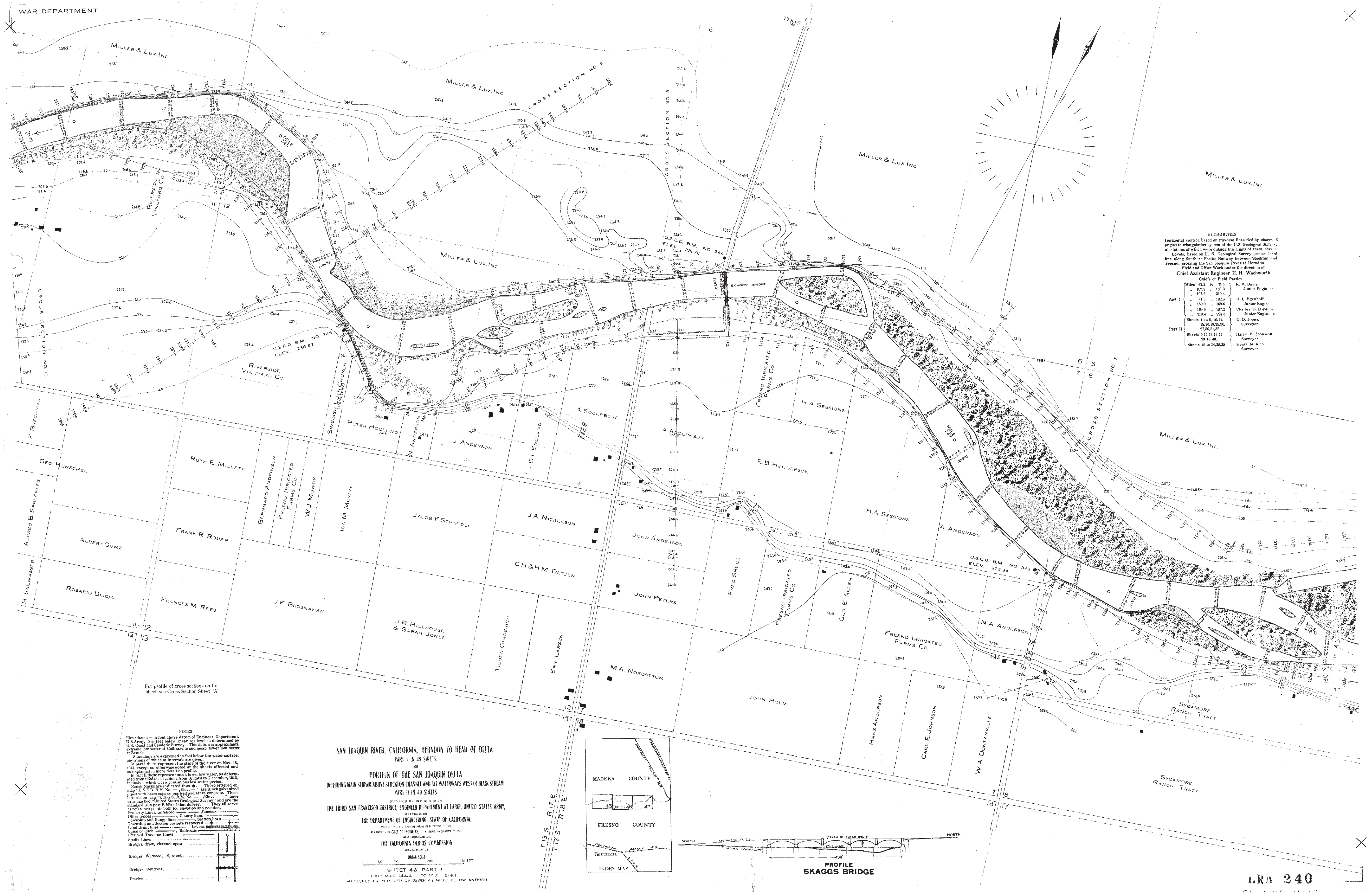


Figure 3-25. 1914 CDC map (ACOE 1917) showing Reach 1B planform morphology and cross section 9 location.

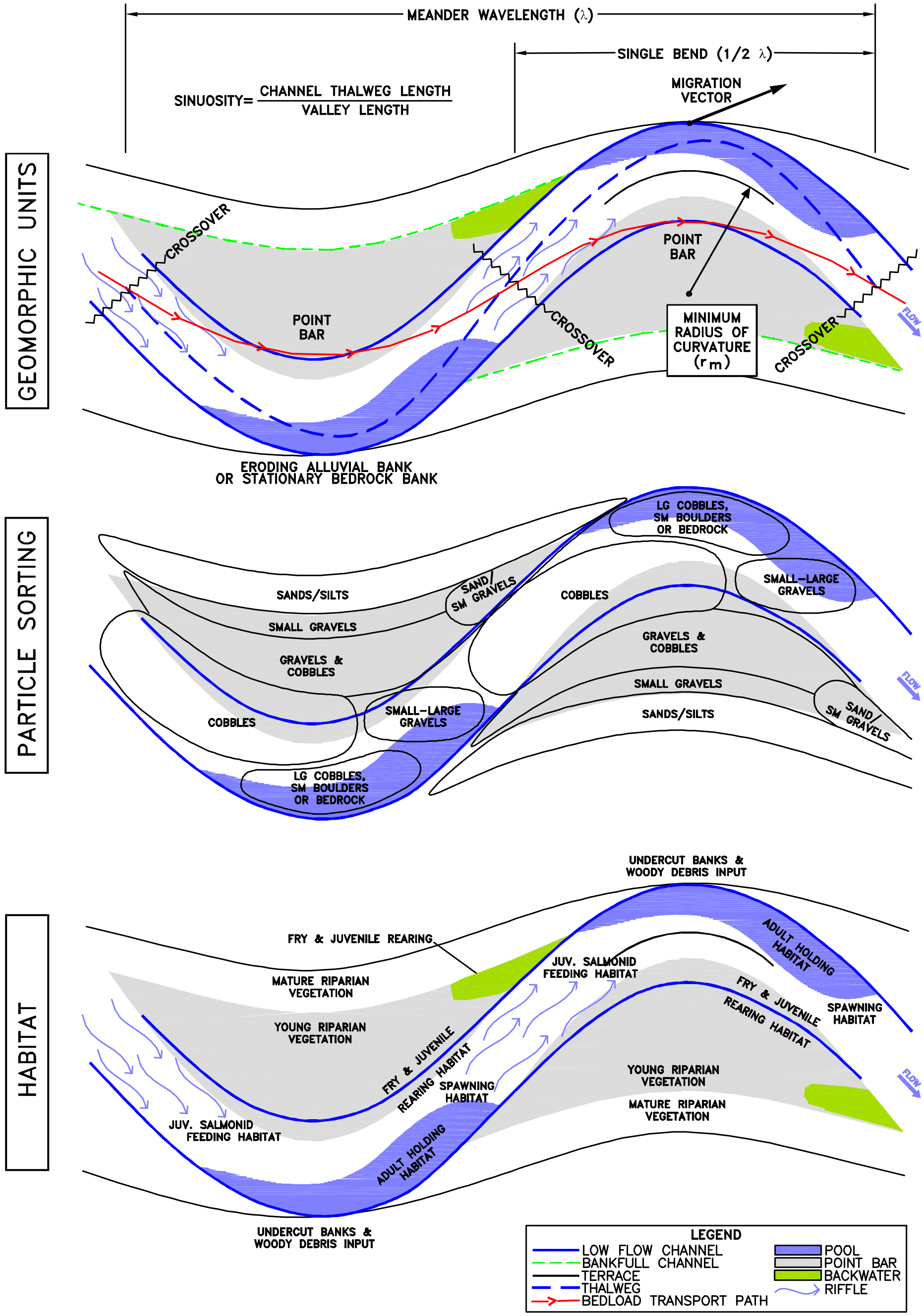


Figure 3-26. Idealized alternate bar unit, modified from Dietrich (1987) and McBain and Trush (1997). Morphological components of alternate bar correspond to tendencies in particle sorting, fish habitat, and riparian vegetation.

is armored with riparian vegetation (Figure 3-27). Exposed gravel point bars are virtually non-existent because infrequent bed mobility and scour has permitted riparian encroachment of these formerly exposed gravel bars. Another striking difference is the reduction in the number of small in-stream islands between the historical maps and the current aerial photographs (Figure 3-22). The few remaining small in-channel islands are now heavily vegetated, while the historical islands were primarily scoured of riparian vegetation (Figure 3-22). These remaining small in-channel islands are not naturally formed features, but rather mostly related to eddys and hydraulics associated with breached gravel pit levees (Figure 3-18). Large sections of riparian forest have been replaced by active and abandoned gravel mines and large sections of the channel have been radically altered by dredging for gravel, in-channel gravel mining, and the capture of gravel pits by the active channel (Figure 3-18). In the reach between Lane’s Bridge (RM 255.2) and two miles downstream, the channel appears more similar to a lake than a river because of the captured gravel pits. Very few of the backwater complexes still exist; however, in one or two cases, permanent channels have been established around major islands or gravel mining complexes. Gravel mining continues downstream to Skagg’s Bridge, but in lesser extent than the two mile reach downstream of Skagg’s Bridge. Downstream of Skagg’s Bridge, gravel mining activity tapers off, and the river is still moderately confined by terraces (Figure 3-28).

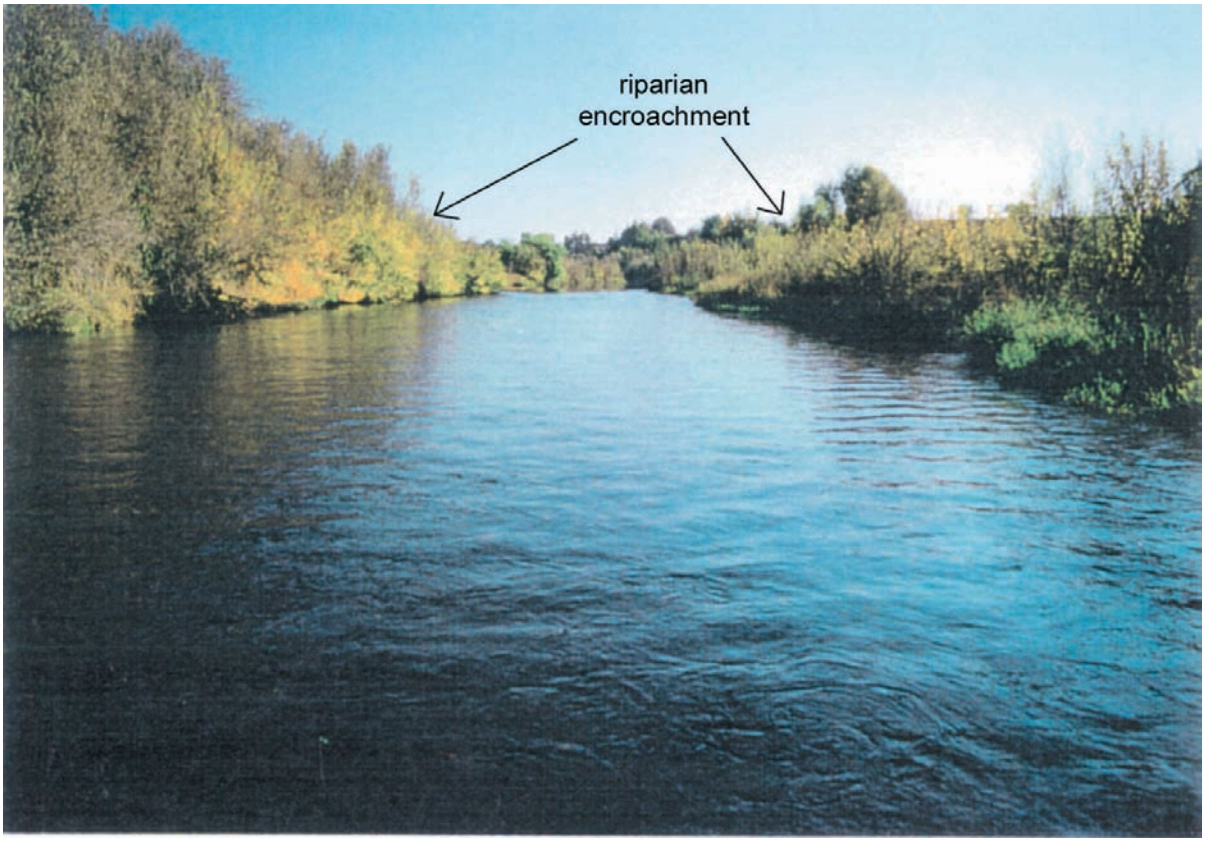


Figure 3-27. View upstream of the San Joaquin River at RM 240. The narrow strip of riparian vegetation that borders the channel is maintained by the in-stream flows required for maintenance of water rights. The D_{50} of the bed material in this reach is 40mm (from JSA and MEI 1998).

Figure 3-28. View upstream of the San Joaquin River at about RM 237. The channel is bounded by alluvial terraces, and has not been mined for sand and gravel in this specific location. From JSA and MEI (1998).

3.7.1.5. Channel Geometry

Referring to Table 3-4 and Table 3-5, cross section data indicate a net degradational trend in the two upstream cross sections immediately downstream of Friant Dam, then cross sections C3 and C4 show slight aggradation (Figure 3-29). Gravel was extracted from the reach represented by these two cross sections in the 1930s, and the aggradation shown there may be a function of the pits filling in slightly through 1996. These cross sections are also located between two bedrock ridges, such that if these ridges were controlling grade in 1939, one would expect these grade controls to discourage channel incision from 1939-1996. Cross sections C1 and C2 are upstream of these grade controls, such that channel downcutting from 1939-1996 would be expected. Cross sections C5 and C6 are located in a reach that is less disturbed than the rest of Reach 1; the slight aggradation at C5 is not considered significant, although the thalweg has shifted from the right bank to the left bank. The downcutting at cross section C6 appears more substantial, possibly influenced by downstream gravel mining (Figure 3-30). The large negative values at cross sections C7, C8, C9, and 9 result directly from sand and gravel mining. Lesser negative values through the reach are the result of general degradation induced by the sand and gravel mining (Cain 1997). Degradation in the reach may well have been greater if outcrops of bedrock at RM 255.5 and RM 265 had not provided local base level control (Cain 1997).

3.7.1.6. Changes in Width and Depth

Cain (1997) used the USBR 1939 survey records of the river below Friant Dam as a baseline condition for his comparative analysis of changes in channel geometry in Reach 1A, and JSA and

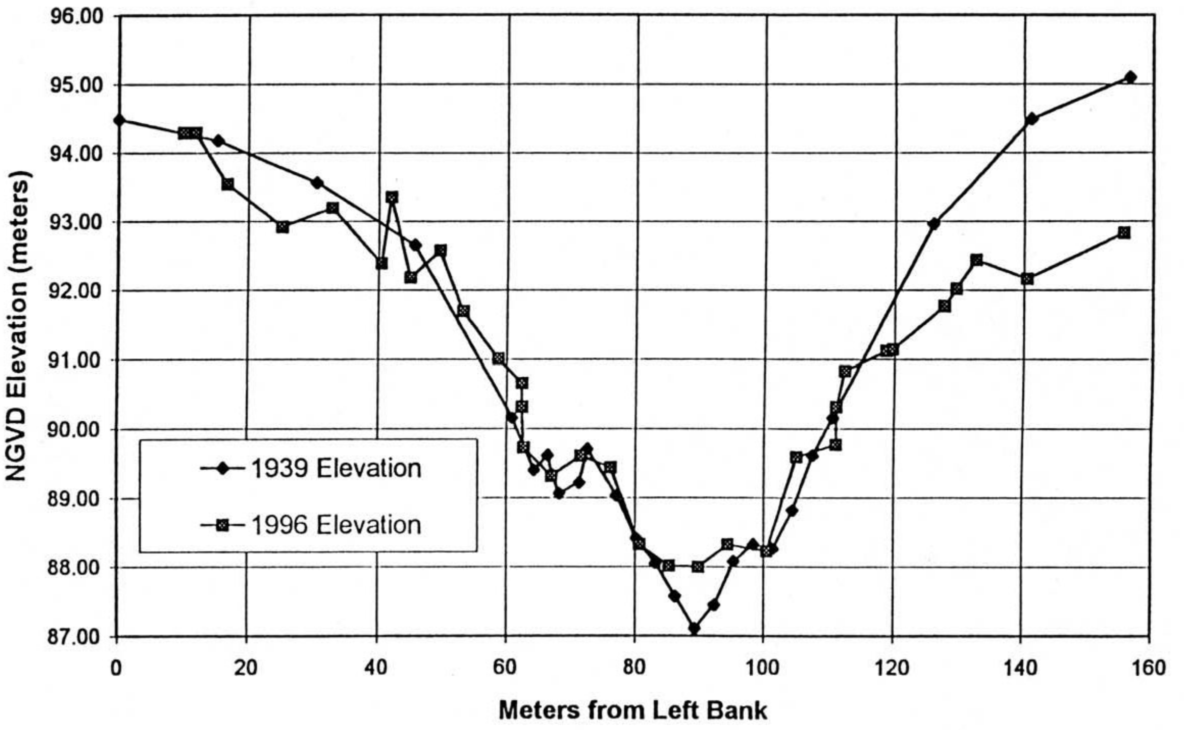


Figure 3-29. Comparison of 1939 and 1996 cross section C3 in Reach 1 (RM 265.4), showing example of cross section that has incised since 1939 (1 meter = 3.2808 feet).

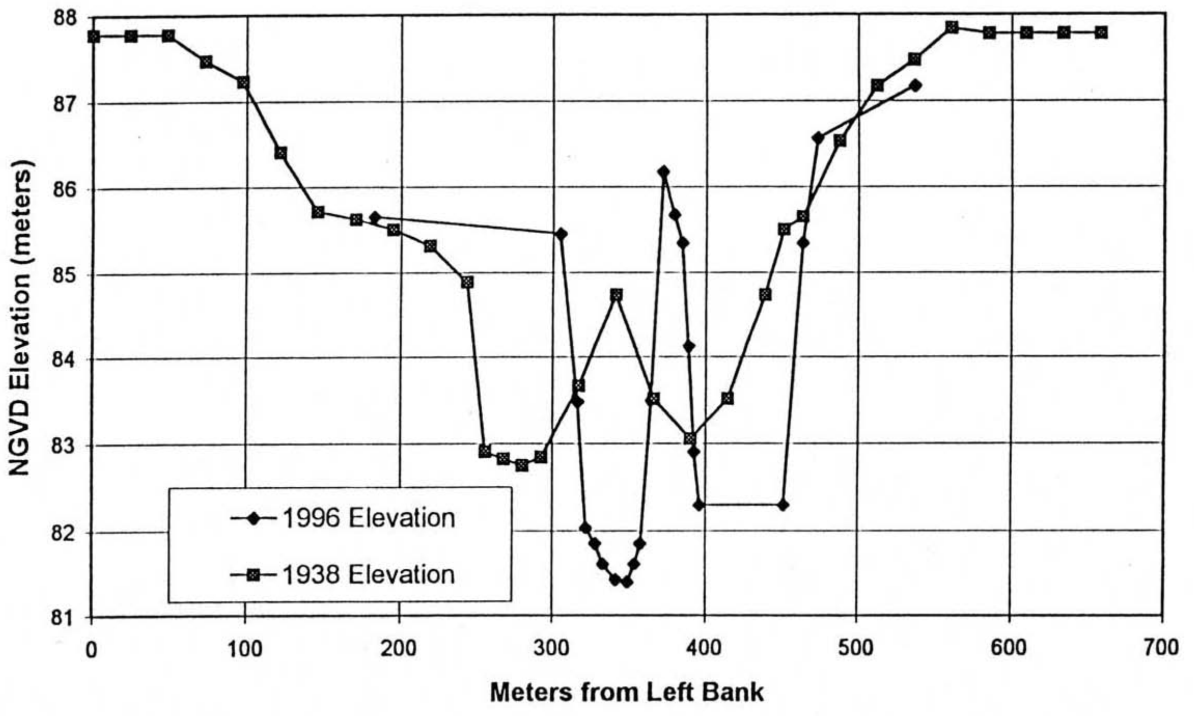


Figure 3-30. Comparison of 1939 and 1996 cross section C6 in Reach 1 (RM 259.3), showing example of cross section that has aggraded slightly since 1939 (1 meter = 3.2808 feet).

MEI (1998) used the 1914 ACOE cross sections for comparisons in Reach 1B (Table 3-6). Assuming that the active channel was equivalent to the bankfull or dominant discharge channel (Leopold et al. 1964), Cain (1997) showed that the average active channel width in the reach was about 1,200 feet in 1939. The average low flow channel width in the reach in 1939 was about 300 feet (Cain 1997). Cain (1997) compared the ratios of the low-flow channel widths in 1939 and 1989 to the 1939 active channel widths and the ratio of the 1980 high-flow channel width to the 1939 active channel width and concluded that the channel in Reach 1A had narrowed over time.

The width of the wetted channel from four representative ACOE (1917) cross sections in Reach 1B averaged 400 feet (flow approximately 500 cfs). Two of these Reach 1B cross sections are used to compare changes in width between 1914 and 1998 (Table 3-6), which do not indicate a clear trend between 1914 and 1998. This unclear trend is not unexpected, considering the extent of sand and gravel mining that has occurred in the reach (Cain 1997). Cross section 9 is located in an area that was mined and the channel appears to have widened. At cross section 2, the channel appears to have become narrower and shallower. Bankfull depth has decreased at cross section 2, but change in bankfull depth at cross section 9 was virtually zero.

Table 3-6 also illustrates longitudinal changes in bankfull width; bankfull width in 1914 decreases from Reach 1B (875 feet) to Reach 4A (277 feet), where the multichanneled anabranching system commences. Channel widths increase slightly in Reaches 4B (311 feet) and 5 (386 feet) (Figure 3-11). Average channel depths at bankfull stage are remarkably constant from Reach 2 to Reach 4A (14 feet) (Figure 3-12). Depth is highest in Reach 1B (18 feet) and lowest in Reach 4B (9 feet). Channel depth increases to 13 feet in Reach 5. Width-depth ratios show a general decrease in the downstream direction from about 50 in Reach 1B to 20 in Reach 4A (Table 3-6, Figure 3-13). Width-depth ratios increase again in Reaches 4B and 5 to 35 and 30, respectively. The width-depth ratio trends can be correlated with the resistance to erosion of the channel banks (Schumm 1963). The reaches with a higher width-depth ratio have more erodible banks, whereas those with lower values have more erosion resistant banks. The lower values of width-depth ratio in Reaches 4A, 4B, and 5 are also consistent with the required channel adjustments to maintain the continuity of sediment and water through the lower reaches, where there is a rising base level (Nanson and Huang 1997).

3.7.1.7. Historic Inundation Thresholds

Frequent and prolonged inundation of floodplains provides important juvenile and smolting salmonid rearing habitat during winter and spring months. Research conducted on the Yolo Bypass has shown that juvenile salmonid rearing on inundated floodplains can greatly increase growth rates (and thus survival) due to the expanded food base. Historically, the San Joaquin River frequently inundated floodplains (in Reach 1 and 2) and floodbasins (in Reach 3, 4, and 5). JSA and MEI (1998) estimated historical inundation patterns for Reaches 1-5 by applying a normal depth analysis with the HEC-RAS hydraulic model to a subset of 1914 cross sections assumed to be representative of the reach. Additionally, Cain (1997) estimates that the historical bankfull discharge was probably in the range of 11,600 cfs to 22,000 cfs, but does not identify the source of these estimates. The JSA and MEI (1998) analysis of 1914 cross section at RM 233.3 (Reach 1B) suggests that a small floodplain on the right bank is inundated by a flow of 10,000 cfs (approximately a 1.5-year pre-Friant Dam flood), but terrace inundation does not occur until flows exceed 43,000 cfs (approximately a 18-year pre-Friant Dam flood) (Figure 3-31). Even though these two estimates of floodplain inundation are similar, there is uncertainty in the estimates because of the limited amount of data used in the analysis, and the topographic variability inherent in Reach 1. Regardless, the frequency and long duration of the historic snowmelt runoff hydrograph, and periodic rainfall-generated storm events, inundated floodplains in Reach 1 from days to weeks. The virtual elimination of the snowmelt runoff period

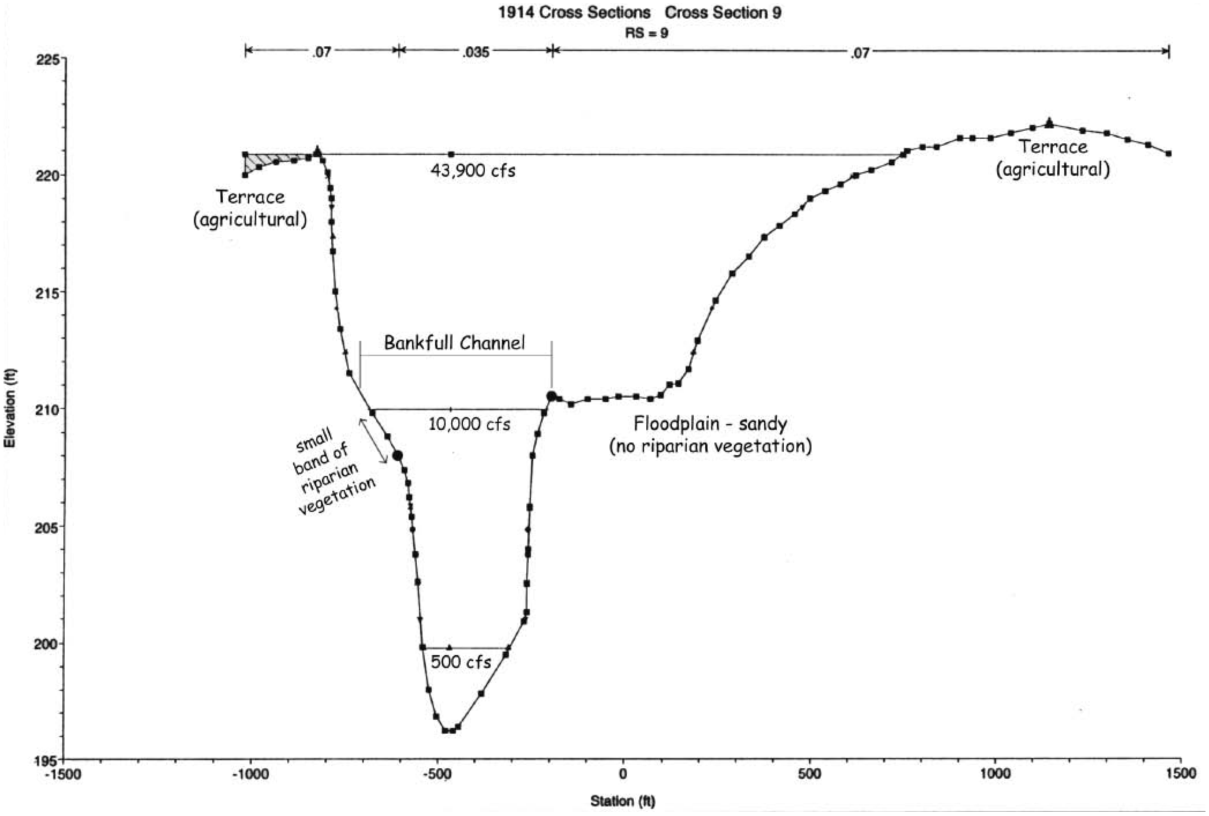


Figure 3-31. ACOE (1917) cross section 9 in Reach 1B (RM 233.3), showing predicted discharge thresholds to inundate key geomorphic surfaces in historic channel morphology.

downstream of Friant Dam (except during very wet years when flood control releases are required) has greatly reduced the duration and frequency of floodplain inundation, thus reduced juvenile salmonid rearing potential.

3.7.2. Reach 2

Reach 2 is subdivided into two reaches: Reach 2A extends from Gravelly Ford (RM 229.0) to the Chowchilla Bifurcation Structure (RM 216.1), and Reach 2B extends from the Chowchilla Bifurcation Structure to Mendota Dam (RM 204.8) (Figure 3-2). Reach 2 is the beginning of the sand-bedded reach, and the bluffs that confined the channel in Reach 1 no longer confine the channel. The downstream boundary of Reach 2 is located at Mendota Pool, which also marks the location where the San Joaquin River turns north as it leaves the San Joaquin River alluvial fan and hits the prograding alluvial fans of the Coast Range. The northern branch of the Kings River overflow also joins the San Joaquin River at this location via Fresno Slough (Figure 3-32). Channel morphology is sand-bedded, with moderate meandering in Reach 2A (Figure 3-33), and highly sinuous meanders in Reach 2B (Figure 3-34) as the San Joaquin River begins to be influenced by the collision with the alluvial fans of the Coast Range (lower slope due to backwater effect from fans and Fresno Slough).

3.7.2.1. Sediment Regime

Quantification of the historical sediment regime has not been estimated for Reach 2; however, sediment supply likely decreased from Reach 1B through Reach 2 as it deposited on floodplains

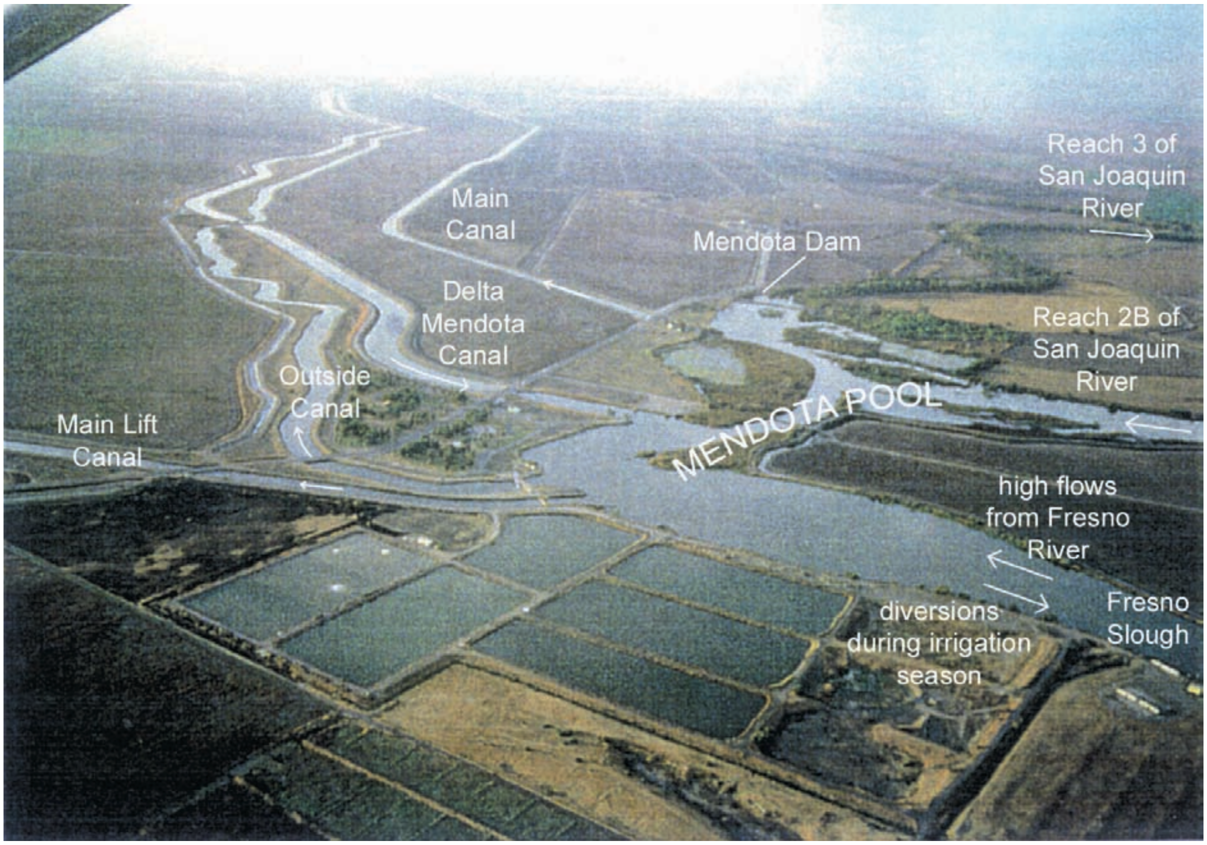


Figure 3-32. View of Mendota Pool at the Reach 2B/3 boundary (RM 205), looking north (downstream) into Reach 3 of the San Joaquin River. From JSA and MEI (1998).

comprising the larger-scale alluvial fan of the San Joaquin River. Sediment was clearly routing through Reach 2 to Reach 3 based on the 1914 ACOE maps, as evidenced by exposed sand bars in both reaches.

Construction and operation of Chowchilla Bifurcation Structure has greatly reduced sediment supply to Reach 2B, as most high flows and sediment are routed through the Chowchilla Bypass. Mendota Dam may also cause temporary interruption of sediment routing from Reach 2 to Reach 3. Review of longitudinal profiles through Mendota Pool does not indicate long-term aggradation in the pool (compared to the magnitude of sediment deposited and mechanically removed from the Chowchilla Bypass), suggesting that periodic pulling of boards on Mendota Dam during high flows, as well as scheduled draining of Mendota Pool for dam inspection, allows sediment to eventually be routed through the pool to Reach 3.

3.7.2.2. Fluvial Processes and Channel Morphology

The transition from Reach 1 to Reach 2 results in key changes in fluvial processes and channel morphology. The high flow gradient is reduced to 0.000415 in Reach 2A and even lower (0.00023) in Reach 2B (Figure 3-35). Additionally, valley slope decreases from 0.0077 in Reach 1B to 0.0057 in Reach 2 (these slopes are based on modeled water surface slopes using present-day topography, thus these slopes differ from the 1914 values shown in Table 3-4). This reduction in slope from the steeper, moderately confined, and predominately gravel-bedded Reach 1 causes the channel to shift

Figure 3-33. View looking upstream of sediment deposition in bed of the San Joaquin River in Reach 2A (RM 223) near the upstream end of the project levees and upstream of the Chowchilla Bifurcation Structure. This reach is usually dry most of the year. Erosion of the floodplain is the source of the majority of the sediment. From JSA and MEI (1998).

to a sand-bedded, meandering channel morphology. The ACOE (1917) maps show that the active channel narrows and the meander frequency increases compared to Reach 1 (Figure 3-7, Figure 3-36). The channel form changes from a wide channel with multiple islands to a narrower channel with large, alternating, and exposed sand point bars. Review of all 1914 maps and 1937 aerial photographs shows that channel morphology is straight at the upstream end of Reach 2 (Gravelly Ford) to RM 228, and meander amplitude increases in the downstream direction. The size of the exposed point bars decreases as the channel meanders grow in size and in frequency in the downstream direction, and the meanders increase in amplitude and are more sinuous (compare Figures 3-33 to Figure 3-34). As the channel narrows, the number of instream islands decreases. The large unvegetated point bars in the 1914 maps and 1937 aerial photographs suggest that the channel is either actively migrating across its floodplain or flow is sufficiently high and frequent to scour riparian vegetation from the bars (Figure 3-36). Review of the representative reach in Figure 3-36, as well as the recent photo in Figure 3-33, shows that the baseflow channel migrates within the overall meanders of the bankfull channel, but that migration of the bankfull channel is minimal. Oxbow lakes are not observed on either the ACOE (1917) maps or the 1937 aerial photographs, further supporting the assertion that the channel was migrating at a very slow rate under historic conditions (and perhaps under unimpaired conditions).

This reach was moderately confined, and the flow required to exceed channel capacity decreased in the downstream direction through Reach 2. Flows exceeded channel banks when discharges exceeded

Figure 3-34. View looking downstream of a high amplitude bend in the San Joaquin River in Reach 2B (RM 215). Channel capacity is reduced by sediment deposition in the bed of the channel. Within-levee design capacity within this reach of the river is about 2,000 cfs. This reach is usually dry most of the year. From JSA and MEI (1998).

8,000 to 14,000 cfs in the upper portion of Reach 2A, but were somewhat confined by the declining terraces (see Section 3.6.4). Downstream of RM 225 (still in Reach 2A), the terraces on both banks merge into floodplains to the point where evidence of high flows flowing north (Lone Willow Slough) and south (eventually into Fresno Slough) is clear (Figure 3-36). The boundary of Reach 2A and 2B at the present-day location of Chowchilla Bifurcation Structure also marks the beginning evidence of large-scale sloughs (e.g., Lone Willow Slough) characteristic of the lower portions of the San Joaquin River study area. However, the entrance elevations to sloughs in Reach 2 appear to be a greater distance above the low flow channel than those in Reach 4, thus flow into the sloughs would occur at discharges greater than typical baseflows. The larger amplitude and more sinuous meander pattern evident in Reach 2B are likely due to the reduced slope as the San Joaquin River approaches the prograding Coast Range alluvial fans.

The sloughs in Reach 2 have been converted to irrigation canals in the 1914 maps and 1937 aerial photographs. These sloughs were later abandoned as irrigation canals as upstream surface supplies were developed (Friant Unit of the Central Valley Project) and increased groundwater resources continued to develop. With the construction of the San Joaquin River Flood Control Project, some of the northern sloughs were incorporated into the Chowchilla Bypass system. This conversion of sloughs, reduction of the high flow regime, and agricultural conversion of formerly active flood plains in Reach 2B and the lower portions of Reach 2A eliminated the high flow scour channels and flood

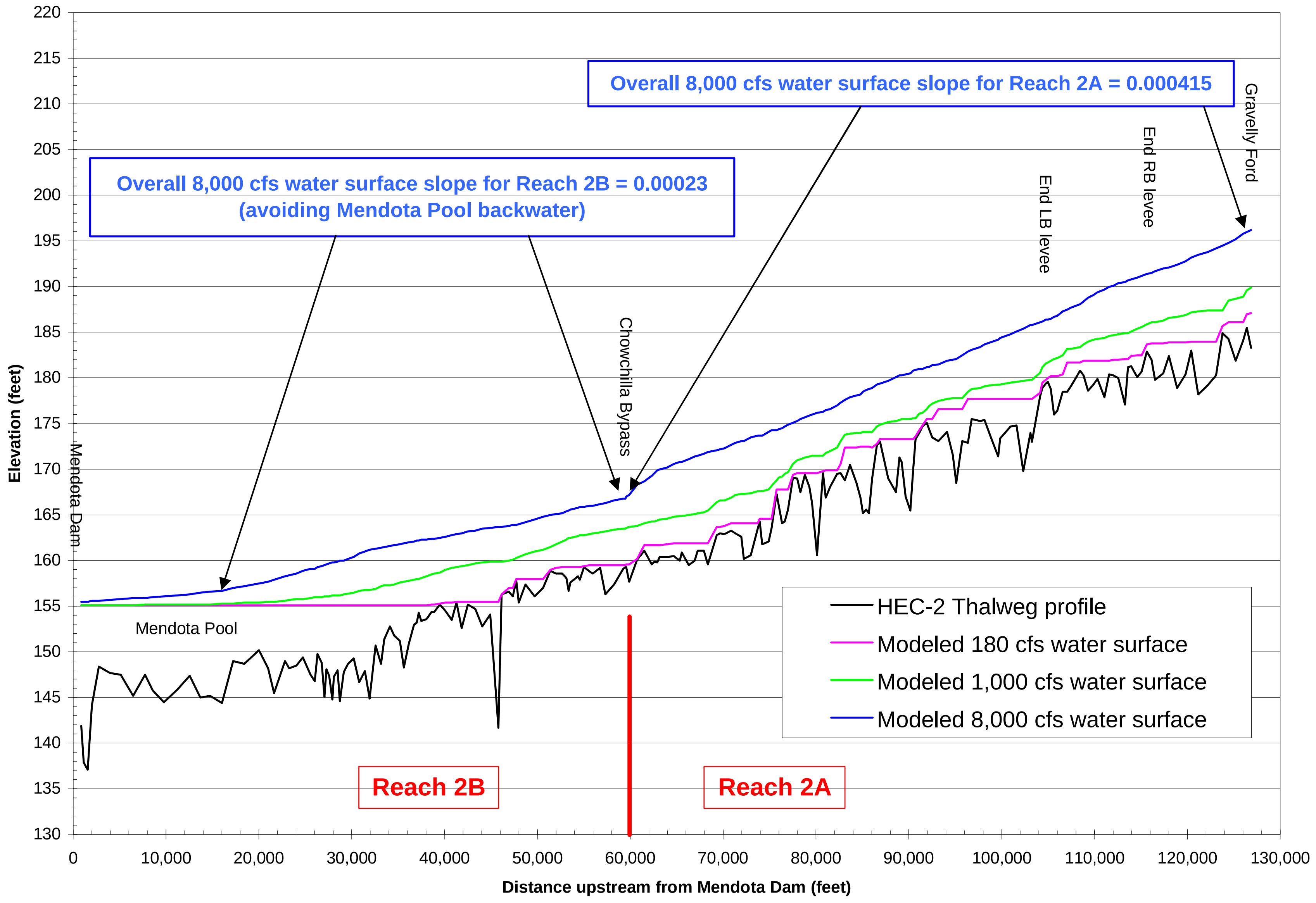


Figure 3-35. Thalweg and modeled water surface profiles for Reach 2A and Reach 2B, showing overall reach slope and slope change caused by the backwater effect of Mendota Pool (from MEI 2000a).

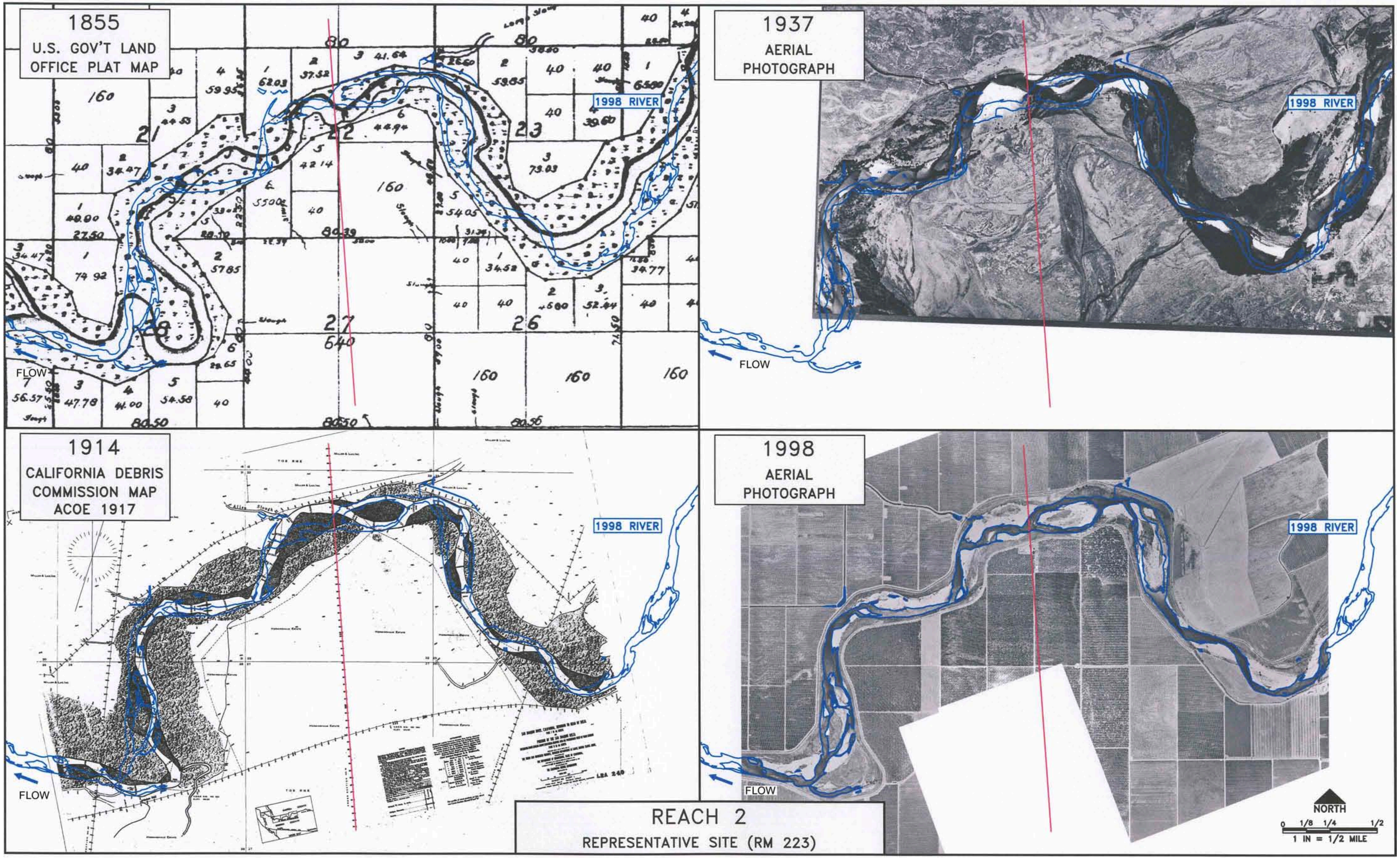


Figure 3-36. Example planform evolution in Reach 2 (RM 223), showing 1855 plat map, 1914 CDC map, 1937 air photo, and 1998 air photo.

access to the Fresno Slough (except during very large floods as occurred in 1997). Construction of project levees and additional agricultural reclamation along lower surfaces in Reach 2 further reduced the channel footprint, reducing the length of primary and secondary channels (channel simplification and fossilization). Reach 2 is now normally dewatered most of the time and groundwater overdraft has greatly reduced the elevation of the shallow groundwater aquifer in this reach (see Chapter 4). The combination of vegetation removal within the floodway and loss of surface and subsurface hydrology has cumulatively discouraged riparian recruitment and survival in this reach. Review of historical maps and photographs shows that riparian vegetation in this reach has been reduced (Figure 3-36).

The perseverance of exposed sand bars between 1914 and 1998 has occurred for different reasons. The pre-Friant Dam high flow regime scoured bars on a frequent basis, preventing riparian encroachment of the bars; the post-Friant Dam flow regime and depressed shallow groundwater aquifer has prevented riparian vegetation from initiating and surviving in this reach, such that the sand bars are still maintained relatively free of riparian vegetation. Periodic riparian clearing for flood control and local sediment accumulation upstream of the Chowchilla Bypass, may also contribute to reduced riparian vegetation on the bars. While there is no data available to quantify historic or contemporary thresholds of key fluvial processes, such as bed mobility, bed scour, channel migration, and avulsion, the thresholds of bed mobility and scour are likely low. Bed mobility likely occurs at most baseflows, and bed scour likely occurs at moderate flows in the few thousands of cubic feet per second. Channel migration and avulsion can still occur within the confining project levees, and still occurs in part because the lack of riparian vegetation allows the banks to erode easily.

Change in bankfull channel width and depth has been mixed in Reach 2 (JSA and MEI 1998). Cross sections 19 and 14 show opposing trends (Table 3-6). Cross section 19, located upstream of the Chowchilla Bifurcation Structure at RM 222.6, shows channel widening (880 feet to 1,110 feet) but little change in channel depth (11.1 feet to 11.4 feet). In contrast, the channel narrowed and deepened at cross section 14 (RM 228.4). Channel width at cross section 14 narrowed from 810 feet to 530 feet, and depth increased from 15.9 feet to 21.4 feet. The changes at cross section 14 could be a result of local extraction of sand and gravel from the channel between 1986 and 1995 (Hill pers. comm.).

Thalweg elevations for the two cross sections in Reach 2 have decreased slightly (2.1 feet decrease for both). Both are located upstream of the Chowchilla Bifurcation Structure. These two cross sections are located upstream of the short section immediately upstream of the Chowchilla Bifurcation Structure where field observations suggest local channel aggradation caused by the backwater effect of the bifurcation structure. JSA and MEI (1998) did not compare any cross sections downstream of the Chowchilla Bifurcation Structure but slight degradation may have occurred in the upper portions of Reach 2B due to reduced sediment supply (due to the Chowchilla Bifurcation Structure diverting high flows and sediment into the bypass system).

3.7.2.3. Historic Inundation Thresholds

JSA and MEI (1998) estimated historical inundation patterns for Reach 2 by applying a normal depth analysis with the HEC-RAS hydraulic model to a subset of 1914 cross sections assumed to be representative of the reach. Two cross sections were analyzed in Reach 2A, and no cross sections were analyzed in Reach 2B. The analysis of cross section 14 at RM 228.4 suggests that a small floodplain on the left bank is inundated by a flow of 8,000 cfs (approximately a 1.3-year pre-Friant Dam flood), but terrace inundation does not occur until flows exceed 26,000 cfs (approximately a 5-year pre-Friant Dam flood assuming no flood peak attenuation). Analysis of cross section 19 at RM 222.6 suggests that the floodplain on the left bank is inundated by a flow of 13,800 cfs (approximately a 2.0-year pre-Friant Dam flood) (Figure 3-37). There are no higher elevation flat surfaces shown on cross section 19, so an evaluation of terrace inundation could not be conducted.

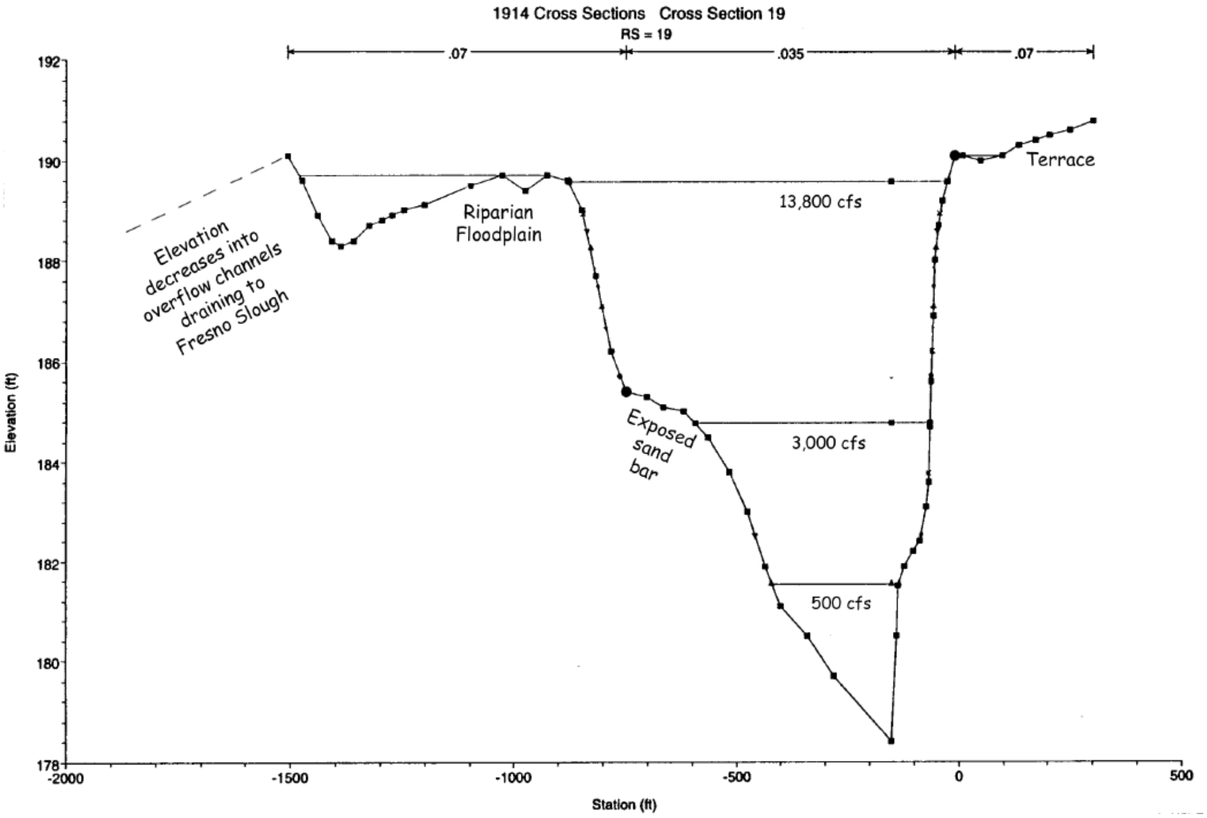


Figure 3-37. ACOE (1917) cross section 19 in Reach 2A (RM 222.6), showing predicted discharge thresholds to inundate key geomorphic surfaces in historic channel morphology.

3.7.3. Reach 3

Reach 3 extends from Mendota Dam (RM 204.8) to Sack Dam (RM 182.0) (Figure 3-2), and flows north along the axis of the San Joaquin Valley. Reach 3 was a meandering sand-bedded channel, with a fairly consistent meander pattern. The reach is entirely alluvial, with no geologic control other than the left (west) bank where prograding alluvial fans from streams draining the Coast Range historically confined the river.

3.7.3.1. Sediment Regime

As with Reach 2, there has been no quantification of the historical sediment regime for Reach 3. Sediment supply likely decreased from Reach 2 through Reach 3 as it deposited on floodplains predominately on the right (east) bank of the San Joaquin River as the river flowed down the axis of the San Joaquin Valley. Floodplains appear to be extensive and confining as in Reach 2, indicating that sediment supply was large enough to build floodplains. Sediment was clearly routing through Reach 3 to Reach 4 based on the 1914 ACOE maps, as evidenced by exposed sand bars in both reaches.

Construction and operation of Chowchilla Bifurcation Structure has greatly reduced sediment supply to Reach 3, as flows and sediment are routed through the Chowchilla Bypass. As described for Reach 2, Mendota Dam may also cause temporary interruption of sediment routing from Reach 2 to Reach 3, but eventually routes into Reach 3.

3.7.3.2. Fluvial Processes and Channel Morphology

The transition from Reach 2 to Reach 3 resulted in another slight decrease in slope, from 0.00023 in Reach 2B to 0.00022 based on modeled water surface profiles (Figure 3-38). Additionally, valley slope again decreases, from 0.0057 in Reach 2 to 0.0033 in Reach 3 (these slopes are based on the 1914 values shown in Table 3-4). Review of the 1914 maps and 1937 aerial photographs do not indicate a significant change in channel morphology between the two reaches. Channel morphology continues to be meandering, sand-bedded channel morphology. The meanders are still highly sinuous, but the meander wavelength and patterns are not as consistent as with Reach 2B (Figure 3-39 and Figure 3-8). Channel migration and avulsion processes are evident in the 1914 map and 1937 aerial photographs, but comparison with the 1998 aerial photographs suggests that the migration rates are low (albeit the comparison period occurs during extensive flow regulation and land management activities). Reviewing the historical maps and aerial photographs can be deceiving; the abandoned channel evident at the downstream end of the 1914 map (Figure 3-39) appears to have recently avulsed when observing the 1937 photo. However, this avulsion had occurred at least 23 years earlier. Although no oxbow lakes are mapped between Mendota Dam and Firebaugh, high flow cut-off channels are mapped, and one meander above Firebaugh has been cut off (Figure 3-8), but much of the original 1914 channel was still wetted in 1998.

By 1914, levees and canal embankments had already begun confining much of Reach 3 and additional confinement has occurred since then. Between Mendota and Firebaugh, canals confine the channel, but the canals are set back further from the historic bankfull channel. Below Firebaugh, the channel is tightly confined by levees and the channel is much straighter. The levees and canals tend to follow the meandering pattern of the historic bankfull channel, dissecting the floodplain from the bankfull channel. Figure 3-40 shows a current photograph of Reach 3 upstream of Firebaugh (RM 200), showing the canals dissecting the historic floodplain on both banks, and agricultural reclamation of the floodplain on both sides of the canals. To protect the agricultural lands between the canals (within the river corridor), small dikes have been constructed to prevent flows up to 4,500 cfs from inundating these lands (JSA and MEI 1998). These nonproject levees further confine the channel and reduce the frequency of overbank flows, channel migration, and channel avulsion. The photo shown in Figure 3-41 is in a reach with a remnant point bar and portion of the historic floodplain still remaining; most of Reach 3 is more confined between canals and nonproject levees. Figure 3-41 shows the reach at Sack Dam (boundary between Reach 3 and 4A), with more extensive confinement by canals and levees.

Changes in bankfull width and depth are estimated by comparing the 1914 cross sections with 1998 resurveys (Table 3-5). Two cross sections were compared; cross section 29 at RM 201.6 and cross section 36 at RM 193.7. The channel width consistently narrowed at cross sections 29 and 36. Channel width at cross section 29 decreased from 790 feet in 1914 to 384 feet in 1998, and channel width at cross section 36 decreased from 460 feet in 1914 to 307 feet in 1998. Changes in depth were inconsistent. Channel depth at cross section 29 increased slightly from 13.2 feet in 1914 to 14 feet in 1998, and channel depth at cross section 36 decreased from 19 feet in 1914 to 12.9 feet in 1998. The substantial change in channel width at cross section 29 could be as result of a slight change in the alignment of the repeat cross-section survey. However, channel narrowing is the expected response of the reduction in flows resulting from the flood bypasses and reduction of flood flows delivered to the San Joaquin River from the Kings River North.

Thalweg elevations for the two cross sections in Reach 3 have decreased to varying degrees (Table 3-6). Cross section 29, located approximately 3 miles downstream of Mendota Dam, had 10.8 feet of channel degradation, whereas cross section 36 only had a slight channel degradation of 1.5 feet. The large amount of channel degradation at cross section 29 may be caused by a combination of factors. First, base level changes due to subsidence are large in this reach, where 5-6 feet of subsidence has

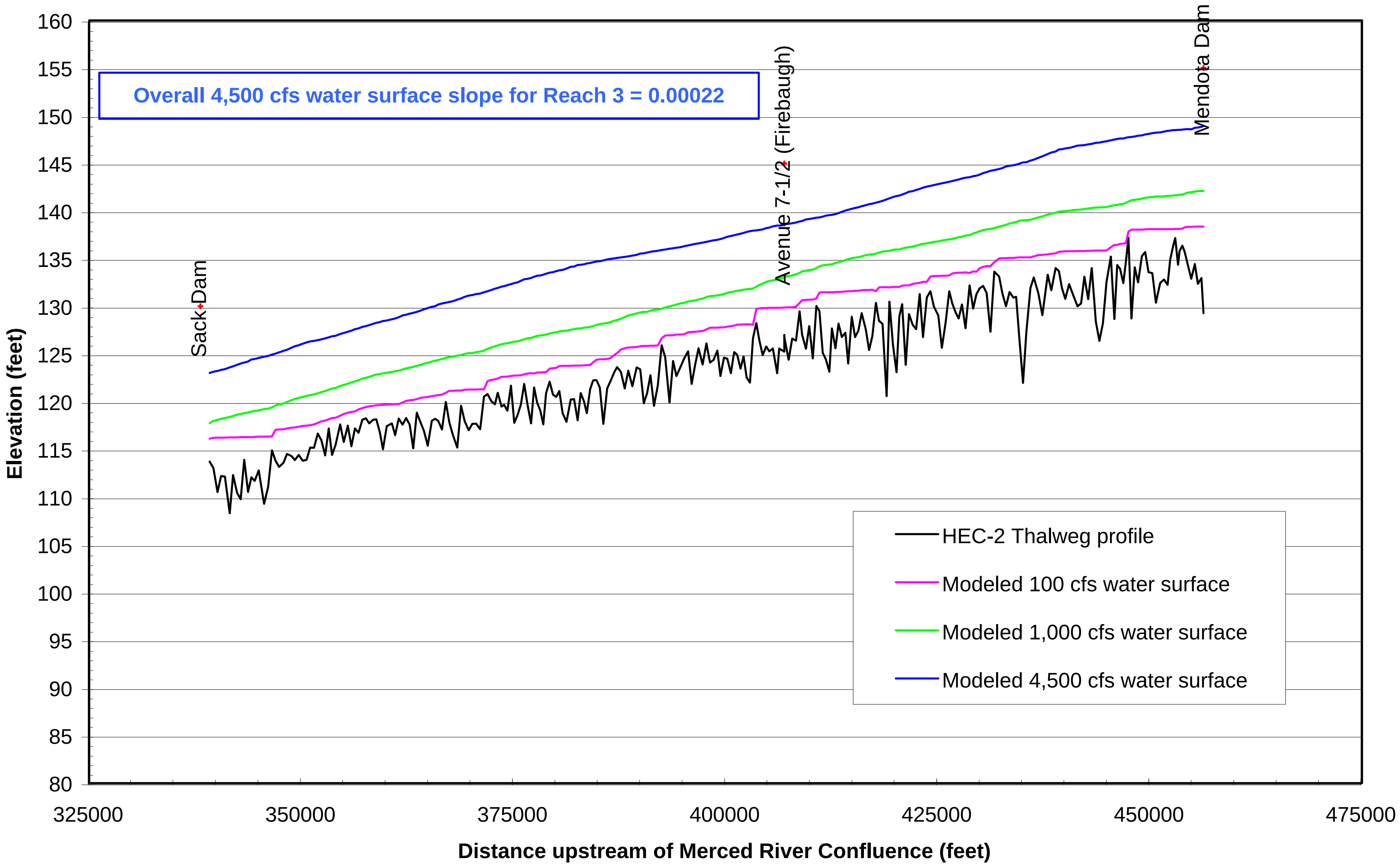


Figure 3-38. Thalweg and modeled water surface profiles for Reach 3, showing overall reach slope downstream of Mendota Pool (from MEI 2000a).

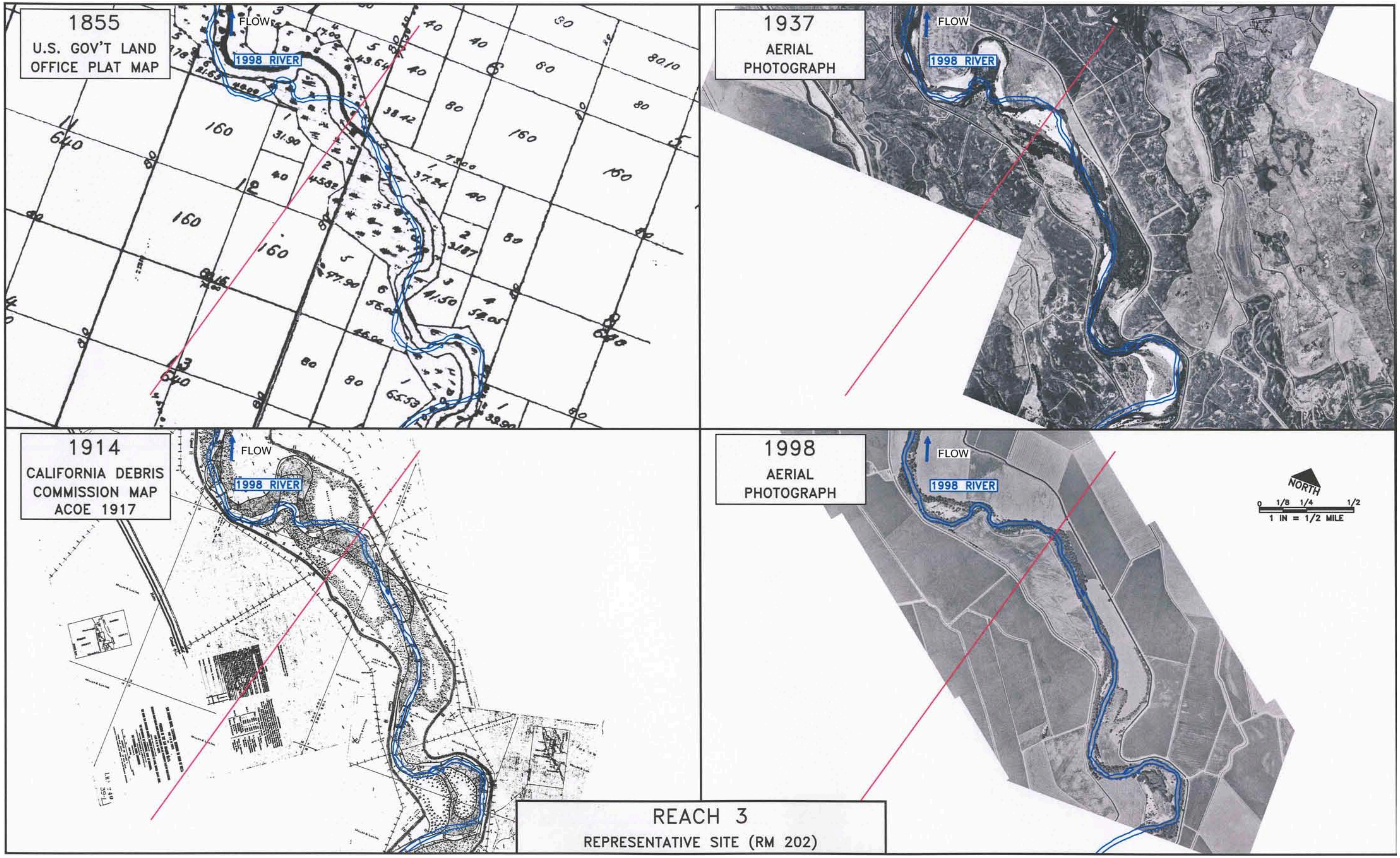


Figure 3-39. Example planform evolution in Reach 3 (RM 202), showing 1855 plat map, 1914 CDC map, 1937 air photo, and 1998 air photo.

Figure 3-40. View looking downstream of the San Joaquin River at RM 200. The Columbia Canal is located on the right bank and the Helm Ditch is located on the left bank (looking downstream). The area between the river and the Helm Ditch is part of the historical floodplain of the river that has been isolated by a local levee. The Helm Ditch is situated on the margin of a terrace with about 8 feet of relief. From JSA and MEI (1998).

been reported (Ouchi 1983). Second, reduction of sediment supply from the Chowchilla Bifurcation Structure, combined with augmented sediment-free flows from the Delta Mendota Canal, has likely cause sediment transport capacity to exceed supply (causing channel degradation). The reported subsidence diminishes in the downstream direction to about one foot at about the Sand Slough Control Structure, which correlates fairly well with the data in Table 3-5.

3.7.3.3. Historic Inundation Thresholds

JSA and MEI (1998) estimated historical inundation patterns for Reach 3 by applying a normal depth analysis with the HEC-RAS hydraulic model to a subset of 1914 cross sections assumed to be representative of the reach. Two cross sections were analyzed in Reach 3. The analysis of cross section 29 at RM 201.6 suggests that a small bench on the left bank is inundated by a flow of 5,000 cfs; this small bench appears to be within the bankfull channel rather than being a true floodplain. The floodplain surface on the left bank is inundated by a flow of 13,000 cfs (approximately a 1.9-year pre-Friant Dam flood assuming no flood peak attenuation or flow contribution from Fresno Slough), with the higher surface (terrace?) on the right bank inundated at a slightly higher flow in the 18,000 cfs to 20,000 cfs range (Figure 3-42). Analysis of cross section 36 at RM 193.7 shows that the floodplain on the left bank is inundated by a flow of 10,000 cfs (approximately a 1.5-year pre-Friant Dam flood).

Figure 3-41. View looking downstream of Sack Dam and the headgates for the Arroyo Canal at RM 182. The dam is the terminus for Delta-Mendota water conveyed down the San Joaquin River. The Poso Canal parallels the river on the left bank. From JSA and MEI (1998).

There are no higher elevation flat surfaces shown on either cross section, so an evaluation of terrace inundation (if they even exist) could not be conducted. The inundation thresholds for Reach 2 and 3 show some consistency, in that it requires a moderate flood (>10,000 cfs) to exceed the banks of the channel and spill onto the floodplain.

3.7.4. Reach 4

Reach 4 is subdivided into two reaches: Reach 4A extends from Sack Dam (RM 182.0) to the Sand Slough Control Structure (RM 168.5), and Reach 4B extends from the Sand Slough Control Structure to the Bear Creek/Eastside Bypass confluence (RM 135.8) (Figure 3-2). Reach 4 continues to flow north along the axis of the San Joaquin Valley. Reach 4 was a meandering sand-bedded channel, but also marked the beginning of the extensive flood basin of the lower San Joaquin River. Numerous anabranching sloughs conveyed summer and winter baseflows along with the primary San Joaquin River channel. The reach is entirely alluvial, and possibly beginning to be influenced by the Merced River alluvial fan entering at the downstream end of Reach 5. Riparian levees provided moderate confinement of the river on both banks, with extensive tule marsh flood basins beyond the riparian levees.

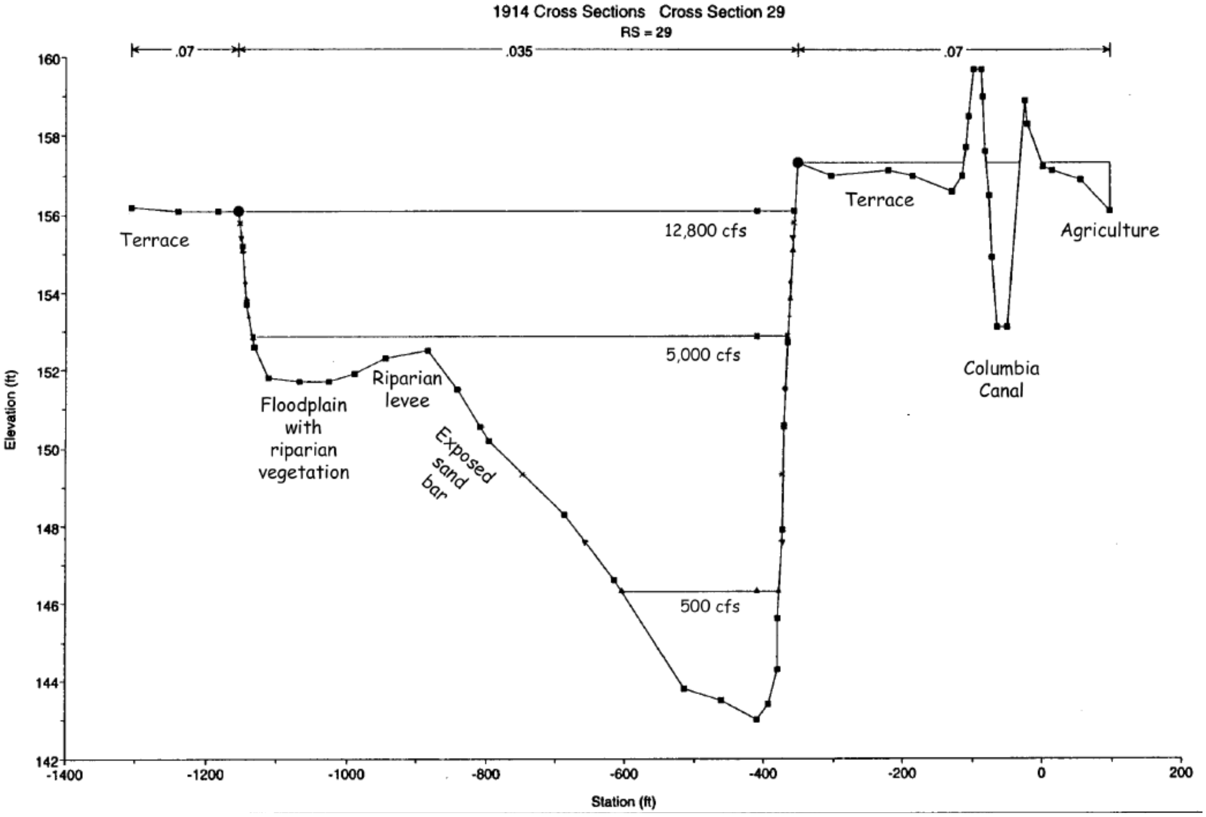


Figure 3-42. ACOE (1917) cross section 29 in Reach 3 (RM 201.6), showing predicted discharge thresholds to inundate key geomorphic surfaces in historic channel morphology.

3.7.4.1. Sediment Regime

Again, there has been no quantification of the historical sediment regime for Reach 4. Sediment supply was likely decreasing from Reach 3 through Reach 4 as it deposited on floodplains as the river flowed down the axis of the San Joaquin Valley. Review of 1914 cross sections suggests that unimpaired confinement and floodplain development decrease in the upper portions of Reach 4 (Figure 3-43), marking a transition from floodplains to the flood basins typical of Reach 4 and 5. The confining floodplains in the upper portions of Reach 4 transition into riparian levees along the primary channels in most of Reach 4. This transition is indicative of a cumulatively reduced sediment supply in the longitudinal direction; sediment supply is too small to create large-scale depositional floodplains, and sediment only accumulates along the rough vegetated boundaries of the primary channels. Areas behind the riparian levees remain low elevation tule marshes that had a small sediment supply. Within the primary channels, sediment routed through Reach 4 based on the 1914 ACOE maps, as evidenced by exposed sand bars in all reaches. Sediment appears to be transported and routed through the anabranching channels/sloughs in Reach 4, as the 1914 maps show exposed sand bars in the larger sloughs (e.g., Mariposa Slough, Pick Anderson Slough, Salt Slough).

Construction and operation of Chowchilla Bifurcation Structure has greatly reduced sediment supply to Reach 4, as flows and sediment are routed through the Chowchilla Bypass, and Mendota Dam may also cause temporary interruption of sediment routing from Reach 2 to Reach 4. Sack Dam, at the boundary between Reaches 3 and 4, may also divert some sediment from the San Joaquin River into Arroyo Canal, but because the capacity of Arroyo Canal is low (approximately 600 cfs), high flows

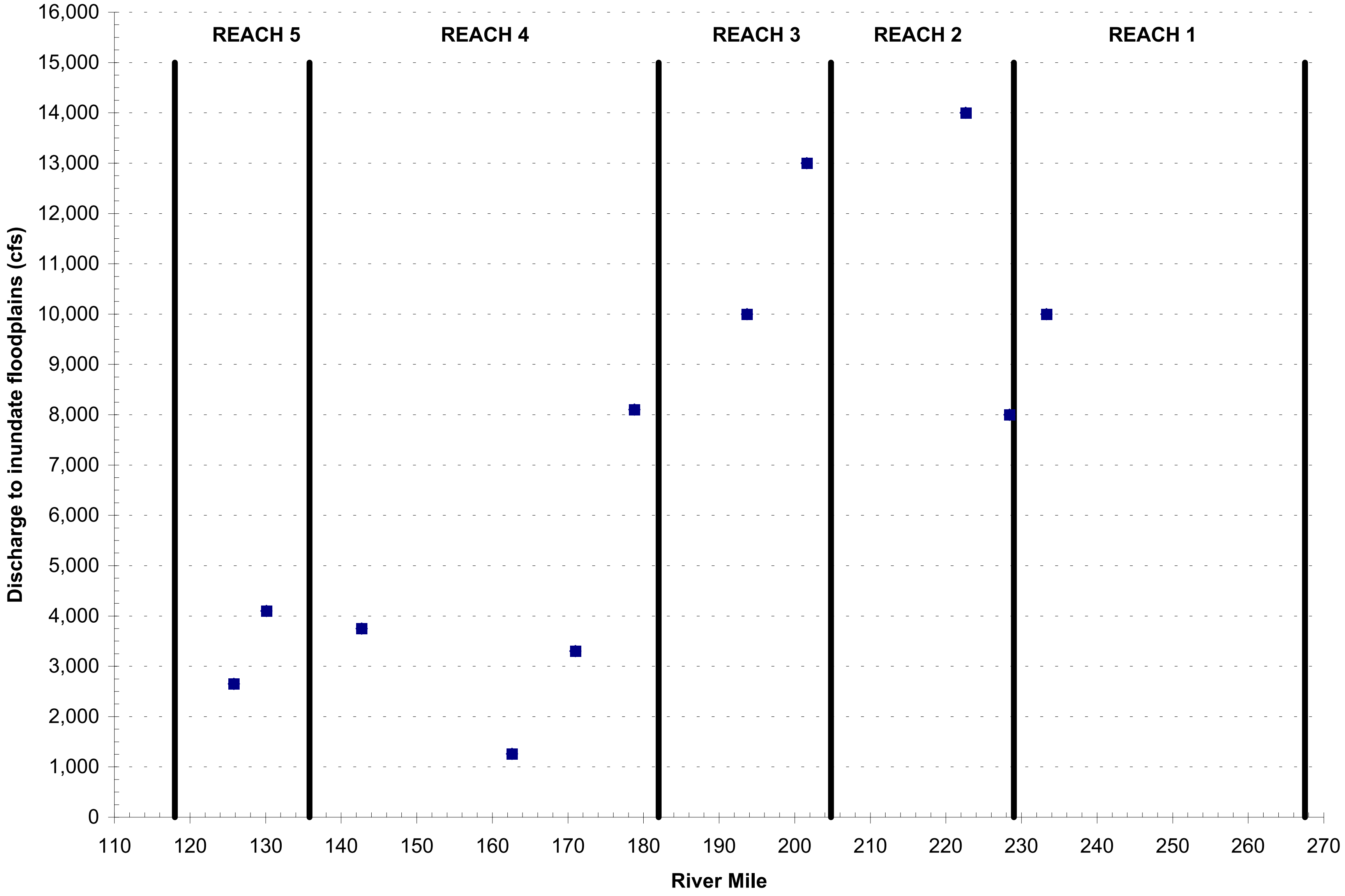


Figure 3-43. Longitudinal plot over Reach 1 to Reach 5 of flow threshold needed to initiate overbank flow on 1914 cross sections.

(and likely a majority of the sediment supply) route past Sack Dam into Reach 4A. The Sand Slough Control Structure, located at the boundary between Reach 4A and 4B, routes all flows and sediment into the Eastside Bypass, such that sediment supply into Reach 4B is zero. Mariposa Bypass delivers flow and sediment from Reach 4A and the bypass system back into Reach 4B. An undetermined amount of additional sediment is supplied to Reach 4B downstream of the Mariposa Bypass by (1) sediment derived from erosion of the Chowchilla and Eastside bypasses (JSA and MEI 1998), and (2) agricultural return flows in Reach 4B.

3.7.4.2. Fluvial Processes and Channel Morphology

The transition from Reach 3 to Reach 4 resulted in a small changes in channel slope, where Reach 3 channel slope is 0.00022, Reach 4A channel slope is 0.00028, and Reach 4B channel slope is 0.00022 based on 1914 surveys (Table 3-4). Additionally, valley slope remains similar, with a valley slope of 0.00033 in Reach 3, and valley slope in both Reach 4A and 4B of 0.00037. Longitudinal profiles of modeled water surfaces under current conditions estimate high flow gradient is 0.00023 in Reach 4A (Figure 3-44), and is approximately the same in the upper portion of Reach 4B (Figure 3-45) and lower portion of Reach 4B (Figure 3-46).

While the valley slope and channel slope does not significantly change between Reach 3 and Reach 4, channel morphology undergoes a transition in the upstream portion of Reach 4A. The moderately confined channel geometry typical of Reaches 2 and 3 transitions into the extensive flood basin morphology of much of Reach 4 and all of Reach 5. The channel confinement reduces the flow (such that overbank flows are much more frequent), riparian levees provide the channel confinement rather than the bankfull channel and floodplains, and numerous large-scale anabranching sloughs originate in the reach (Figure 3-47 and Figure 3-9). The 1914 maps also illustrate the narrow riparian levees along the primary channel margins, and the extensive marsh vegetation (tules) beyond the riparian levees (although outer boundaries are not noted). In the upstream portion of Reach 4, large point bars similar to those in Reach 3 still exist; however, after the confluence with Santa Rita Slough (RM 176.3), the size of the point bars decreases. Below Santa Rita Bridge, extensive areas of marsh designation are delineated on the 1914 maps. The marsh area continues for approximately 30 river miles, and the marsh area is typically mapped as being confined to the area between the mainstem and adjacent sloughs or canals. The channel form is simplified for this same 30-mile reach. The channel is narrow and relatively straight, with only a few point bars that are much smaller than the point bars mapped in upstream reaches. By the confluence with the Mariposa Slough at RM 148, oxbow lakes become a common feature and the channel has regained its large meander bends and unvegetated point bars. Again, these maps do not reflect unimpaired conditions, because extensive reclamation had already occurred by 1914.

The primary San Joaquin River channel and associated anabranching sloughs are sand-bedded. Exposed sand bars are still evident based on review of the 1914 maps, but they are much less extensive than Reach 2 and Reach 3. This reduction in exposed sand bar extent, and transition from extensive floodplains to smaller-scale riparian levees are indicative of the cumulative attrition of sediment supply by upstream deposition and lack of re-supply from tributaries or terrace erosion. Many of the large-scale sloughs are illustrated with exposed sand bars on the 1914 maps. The threshold for mobilizing the sand deposits in the channel was probably low (less than 1,000 cfs), but may have required a slightly larger discharge to mobilize than Reaches 2 and 3 due to smaller sediment supply and more cohesive finer-grained sediments. Larger flows (in the few thousands of cfs) also likely caused enough bar scour to prevent riparian encroachment onto the bars.

Channel morphology measurements of the sloughs were also made from the ACOE (1917) cross sections in Reaches 4A and 4B (Table 3-4). In Reaches 4B and 4A, the slough slopes were about 50%

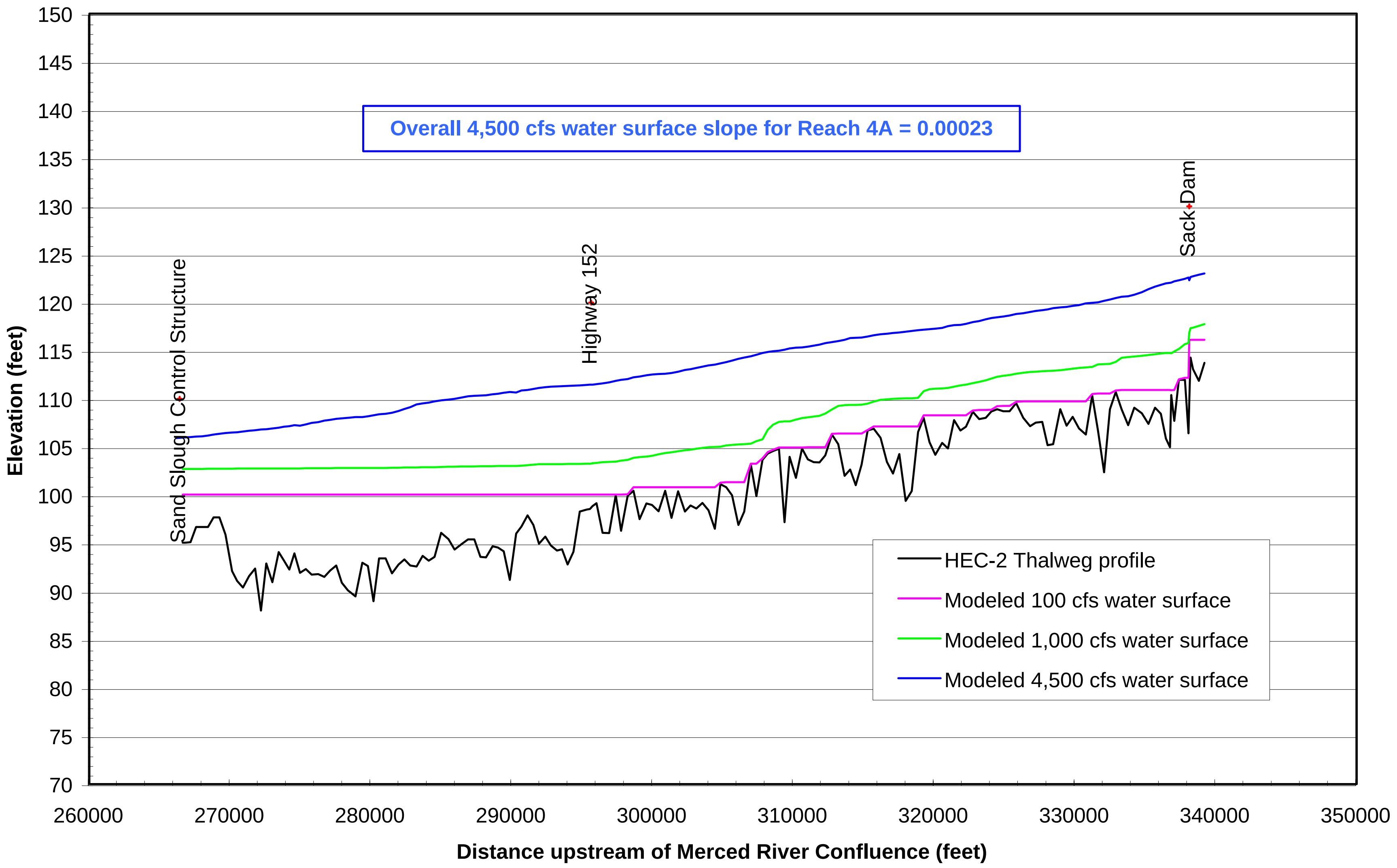


Figure 3-44. Reach 4A plot of thalweg and water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Sack Dam to the SR 152 Bridge, lower graph (B) is from the SR 152 Bridge to the Sand Slough Control Structure.

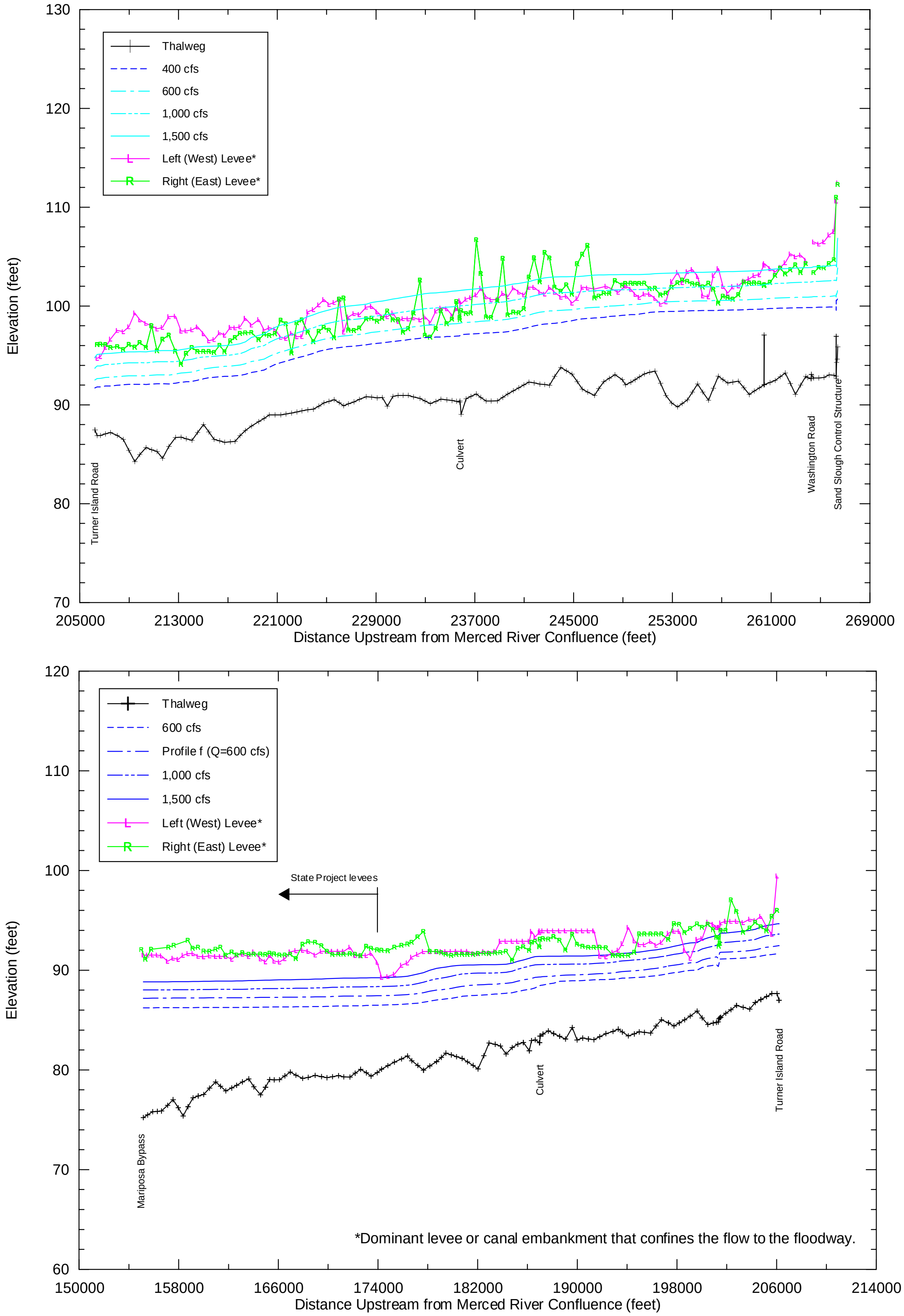


Figure 3-45. Upper portion of the Reach 4B plot of thalweg and water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Sand Slough Control Structure to the Turner Island Bridge, lower graph (B) is from the Turner Island Bridge to the Mariposa Bypass confluence.

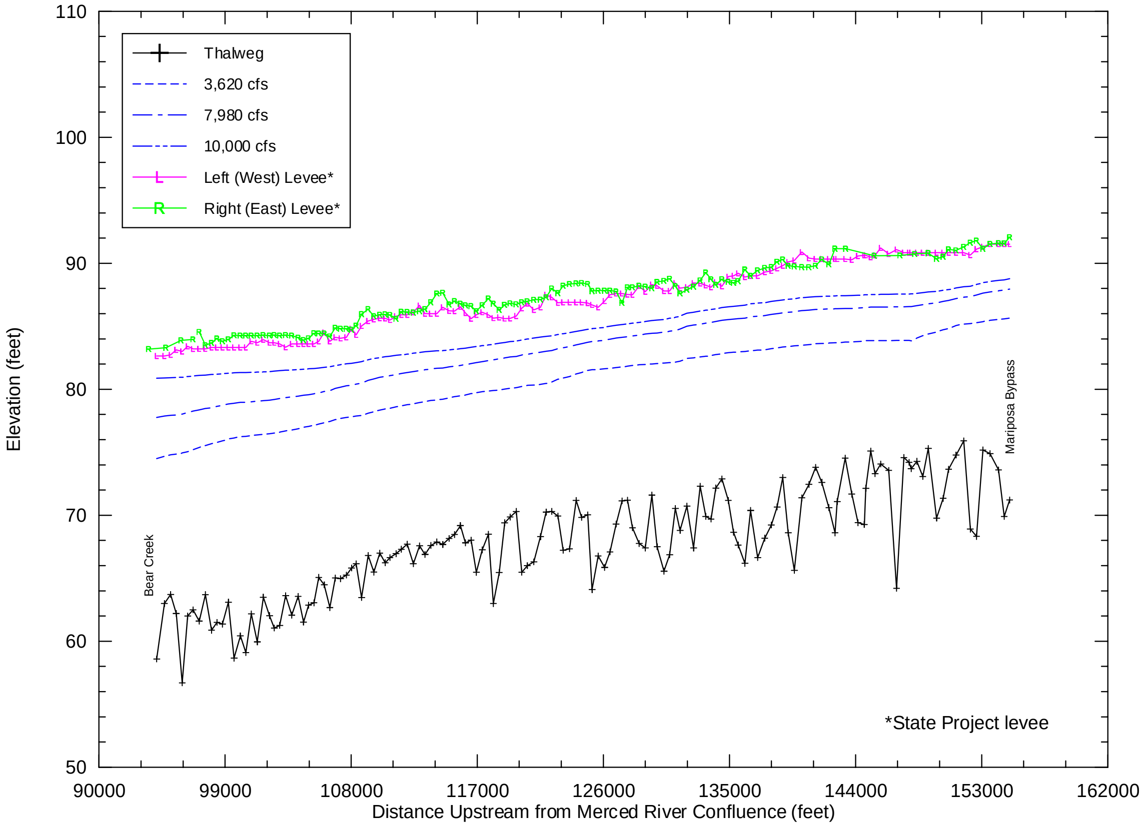


Figure 3-46. Lower portion of the Reach 4B plot of thalweg and water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Graph is from the Mariposa Bypass confluence to the Bear Creek and Eastside Bypass confluence.

steeper than the mainstem channel slope, which again is consistent with channel adjustment in an anabranched reach (Nanson and Huang 1997). Table 3-4 shows that the average widths and depths of the sloughs in Reaches 4A and 4B are less than those of the mainstem river. Width-depth ratios are similar for the sloughs and the mainstem, but because the sloughs are steeper, the sediment transport capacities of the sloughs were likely higher in these reaches (Colby 1964).

There is some uncertainty whether these sloughs flowed at low baseflows. Anabranching channels typically convey baseflows, and it is likely that the sloughs in Reach 4 conveyed winter baseflows and high summer baseflows. Review of the 1914 maps shows some of the sloughs as dry (noted as dry on the maps), the Santa Rita slough as dry via exposed sand bars at its entrance, but many other sloughs as flowing. Because of the extensive manipulation of the sloughs for agricultural irrigation efforts by 1914, the 1914 maps are of limited use in definitively concluding how these sloughs functioned during historic baseflows. One useful piece of evidence to suggest that these sloughs did flow during typical baseflows is an 1841 sketch map of the Santa Rita Ranch (Figure 3-48). This map clearly shows the Santa Rita Slough as a dominant channel feature of the lower river, as well as another slough between the Santa Rita Slough and the San Joaquin River. There is no precise date or general season noted on the map; however, it is assumed that the mapping would have been conducted when land-based travel through the extensive bottomlands and tule marshes would have been easiest, which would have been during late summer or fall baseflows rather than during winter or spring snowmelt floods.

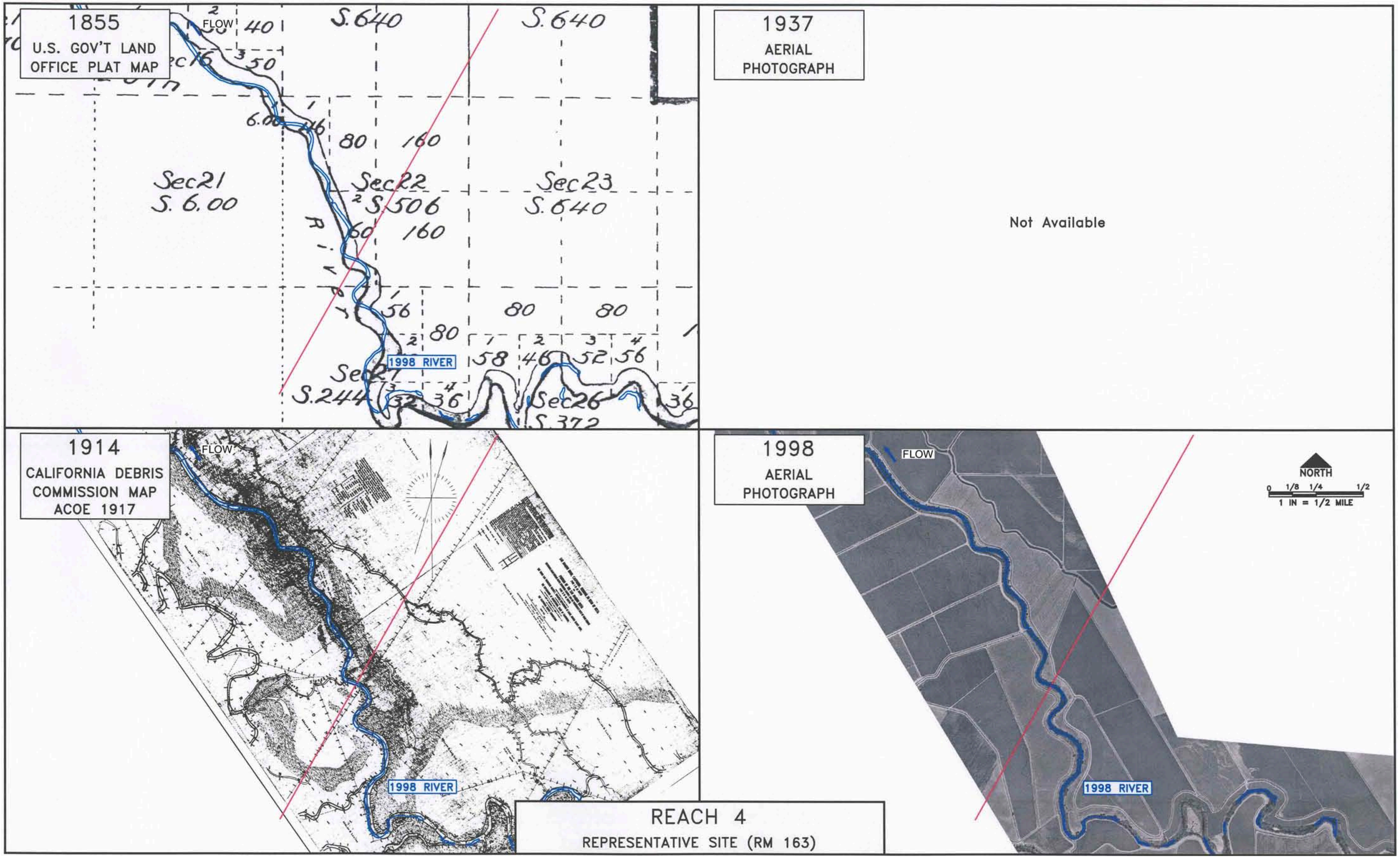
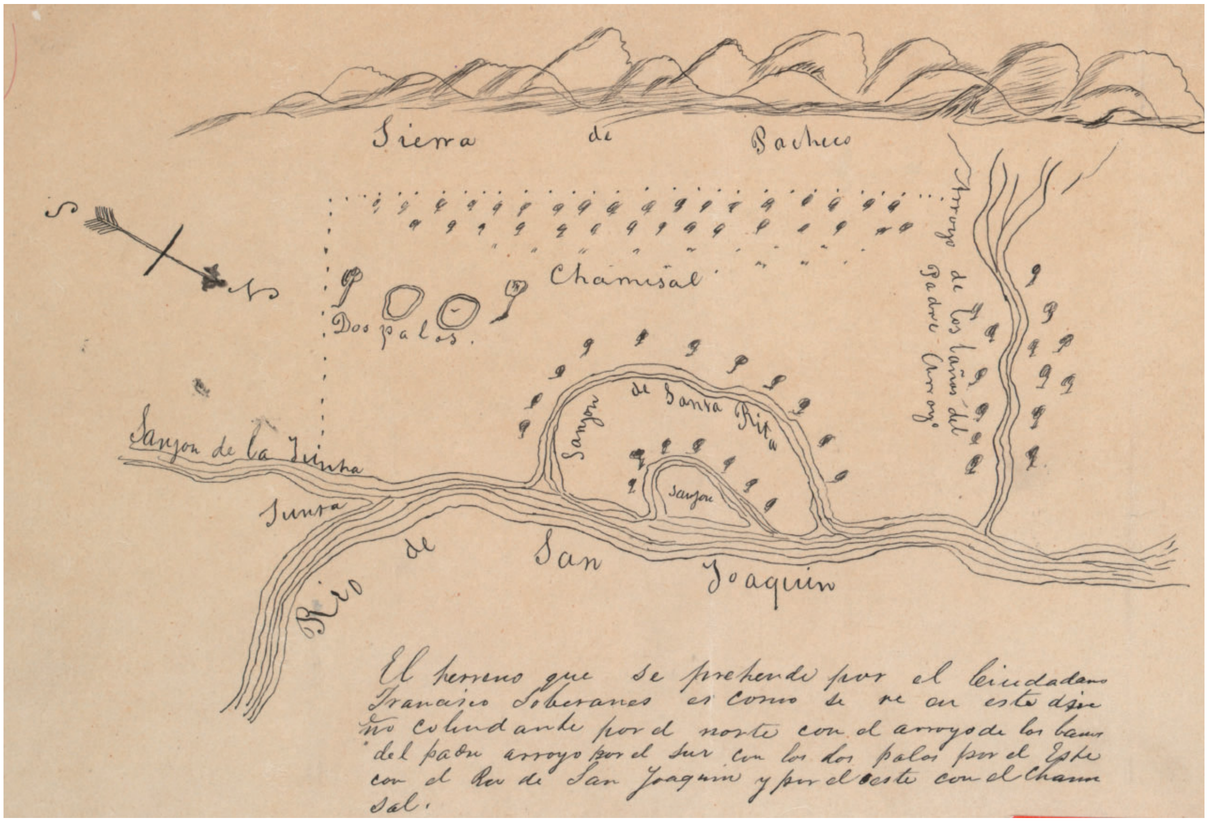


Figure 3-47. Example planform evolution in Reach 4 (RM 163), showing 1855 plat map, 1914 CDC map, and 1998 air photo.



El terreno que se pretende por el Ciudadano
Francisco Soberanes es como se ve en este dise-
ño colindante por el norte con el arroyo de los baños
del padre arroyo por el sur con los dos palos por el Este
con el Rio de San Joaquin y por el oeste con el Chami-
sal.

Figure 3-48. 1841 sketch of Rancho Santa Rita, suggesting that Santa Rita Slough and others were flowing at typical baseflows. There is no precise day or season of the sketch; it is assumed that the sketch would be made during a time when travel across the valley would have been easiest (summer baseflows) rather than during the winter flood season.

Historical channel migration and avulsion were likely very slow and infrequent, and probably less frequent than in Reaches 2 and 3 due to the low sediment supply and low stream energy as high flows spilled out into the flood basins. Comparison of the 1855 maps with 1914 maps and 1998 aerial photographs show virtually no change in channel location over that time (Figure 3-47). The 1855 map for this reach had poor control points, so the exact location of the channel needs to be adjusted by eye. The most dramatic change that has occurred since 1855 has been the complete reclamation of the flood basin to agriculture. The San Joaquin River and its flood basin extended for miles in both directions in Reaches 4 and 5; the contemporary floodway in this reach under current conditions (excluding the Eastside Bypass) is now less than 300 feet in most locations. Photos of these more confined conditions are illustrated in Figure 3-49 through Figure 3-51. Figure 3-49 shows the present-day channel in Reach 4A. Sack Dam typically diverts all flows up to 600 cfs from the San Joaquin River, such that flows in Reach 4A are typically limited to seepage and agricultural return flows (which are subsequently pumped from the river and re-used). Sack Dam allows high flows to route to Reach 4A, but the lack of baseflows discourages riparian vegetation on floodplains (Figure 3-49). The Sand Slough Control Structure, located at the boundary between Reach 4A and Reach 4B, diverts all flow into the Eastside Bypass, such that Reach 4B no longer receives any flows (Figure 3-50). The remaining portions of the San Joaquin River channel in Reach 4B is often choked with riparian vegetation because flows are no longer routed through the upper portion of the reach. Further downstream in Reach 4B, agricultural return flows and the confluence of the Mariposa Bypass return flows to the channel (Figure 3-51).

Figure 3-49. View looking upstream at sediment deposition in the bed of the San Joaquin River at about RM 175. Much of the sand appears to be derived from bank erosion. The within-levee capacity in this reach of the river is about 4,500 cfs. From JSA and MEI (1998).

Changes in bankfull width and depth are estimated by comparing the 1914 cross sections with 1998 resurveys (Table 3-5). Two cross sections were compared for Reach 4A; cross section 48 at RM 178.8, and cross section 53 at RM 171.0. Channel width changes at cross sections 53 and 48 show opposing trends. Channel width at cross section 48 decreased from 360 feet in 1914 to 279 feet in 1998, and channel width at cross section 53 increased from 160 feet in 1914 to 234 feet in 1998. Changes in depth were inconsistent. Channel depth at cross section 48 decreased slightly from 11.0 feet in 1914 to 9.8 feet in 1998, and channel depth at cross section 53 increased slightly from 16.0 feet in 1914 to 18.0 feet in 1998. Two additional cross sections were compared for Reach 4B; cross section 58 at RM 162.6, and cross section 70 at RM 142.7. Channel width changes at cross sections 53 and 48 again show opposing trends. Channel width at cross section 58 decreased from 230 feet in 1914 to 143 feet in 1998, and channel width at cross section 70 increased from 210 feet in 1914 to 259 feet in 1998. Changes in depth were also inconsistent. Channel depth at cross section 58 increased slightly from 7.70 feet in 1914 to 8.5 feet in 1998, and channel depth at cross section 53 decreased from 13.0 feet in 1914 to 7.6 feet in 1998. The cause of channel width and depths are unclear; it may be caused by locally variable manipulation of channel geometry as part of agricultural or levee maintenance activities.

Thalweg elevations for three of the four cross sections in Reach 4 have decreased slightly, with one cross section showing a substantial increase in elevation (Table 3-6). Cross sections 48, 53, and 58

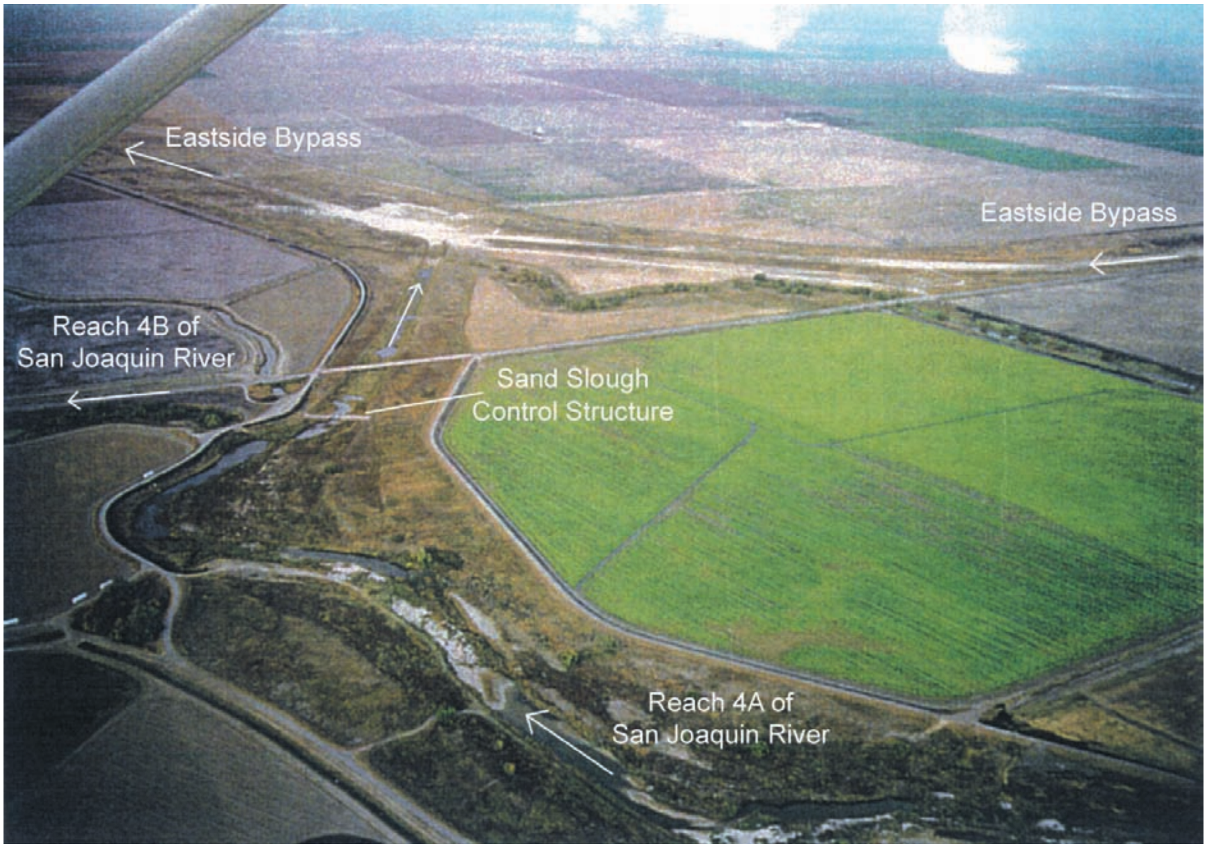


Figure 3-50. View looking downstream at the Sand Slough control structure reach of the San Joaquin River at RM 168. The San Joaquin River upstream of the structures bifurcates into San Joaquin River (left channel, well vegetated banks), Sand Slough (center channel, unvegetated banks), and the Eastside Bypass. Note sediment deposit deposition in the bypass channel. Design capacity of the bypass channel is about 16,500 cfs. From JSA and MEI (1998).

degraded by 3.9 feet, 2.2 feet, and 1.0 feet, respectively, while cross section 70 aggraded 6.7 feet. The small amount of channel degradation at cross sections 48, 53, and 58 may be caused by the small amount of subsidence in this reach. Degradation at cross sections 48 and 53 in Reach 4A may also be influenced by a combination of reduced sediment supply from upstream sources, and increased transport capacity due to levee confinement. Cross section 58 is located in a portion of Reach 4B that no longer receives flood flows, so fluvial causes of degradation are unlikely. Cross section 70 is downstream of the Mariposa Bypass confluence, so sediment derived from erosion of the Eastside Bypass may be depositing in this portion of Reach 4B, causing the aggradation.

3.7.4.3. Historic Inundation Thresholds

JSA and MEI (1998) estimated historical inundation patterns for Reach 4 by applying a normal depth analysis with the HEC-RAS hydraulic model to a subset of 1914 cross sections assumed to be representative of the reach. Two cross sections were analyzed in Reach 4A, and two cross sections were analyzed in Reach 4B. The analysis of cross section 48 at RM 201.6 (Reach 4A) suggests that the floodplains on both banks are inundated by a flow of 8,100 cfs. In contrast, cross section 53 at RM 171.0 (Reach 4A, just 8 miles downstream) shows that the floodplains on both banks are inundated

Figure 3-51. View looking upstream at the San Joaquin River at Turner Island Road crossing, RM 157. Design capacity of the channel and levees is about 1,500 cfs; however, actual capacity in many portions of this reach is much less. From JSA and MEI (1998).

by a flow of 3,300 cfs. Analysis of cross section 58 at RM 162.6 (Reach 4B) shows that the floodplain on both banks are inundated by a flow of 1,260 cfs (Figure 3-52), and floodplains at cross section 70 at RM 142.7 are inundated by a flow of 3,750 cfs. Terraces do not exist in this reach. The inundation thresholds for the latter three cross sections are consistently lower than all the upstream cross sections. This is most likely documenting the transition into the Reach 4 and Reach 5 flood basin. Moderate confinement by the bankfull channel and floodplain decreases at the upstream end of Reach 4, and downstream reaches are inundated by moderate flows at a very frequent recurrence interval (<1.2-year flood).

3.7.5. Reach 5

Reach 5 extends from the Bear Creek/Eastside Bypass confluence (RM 135.8) to the Merced River confluence (RM 118.0) (Figure 3-2). Reach 5 continues to flow north along the axis of the San Joaquin Valley. Reach 5 was within the extensive flood basin of the lower San Joaquin River and had numerous anabranching sloughs that conveyed summer and winter baseflows along with the primary San Joaquin River channel. The reach is entirely alluvial, with the Merced River alluvial fan entering at the downstream end of Reach 5 and influencing base level control of the river (JSA and MEI 1998). Riparian levees provided moderate confinement of the river on both banks, with extensive tule marsh flood basins beyond the riparian levees.

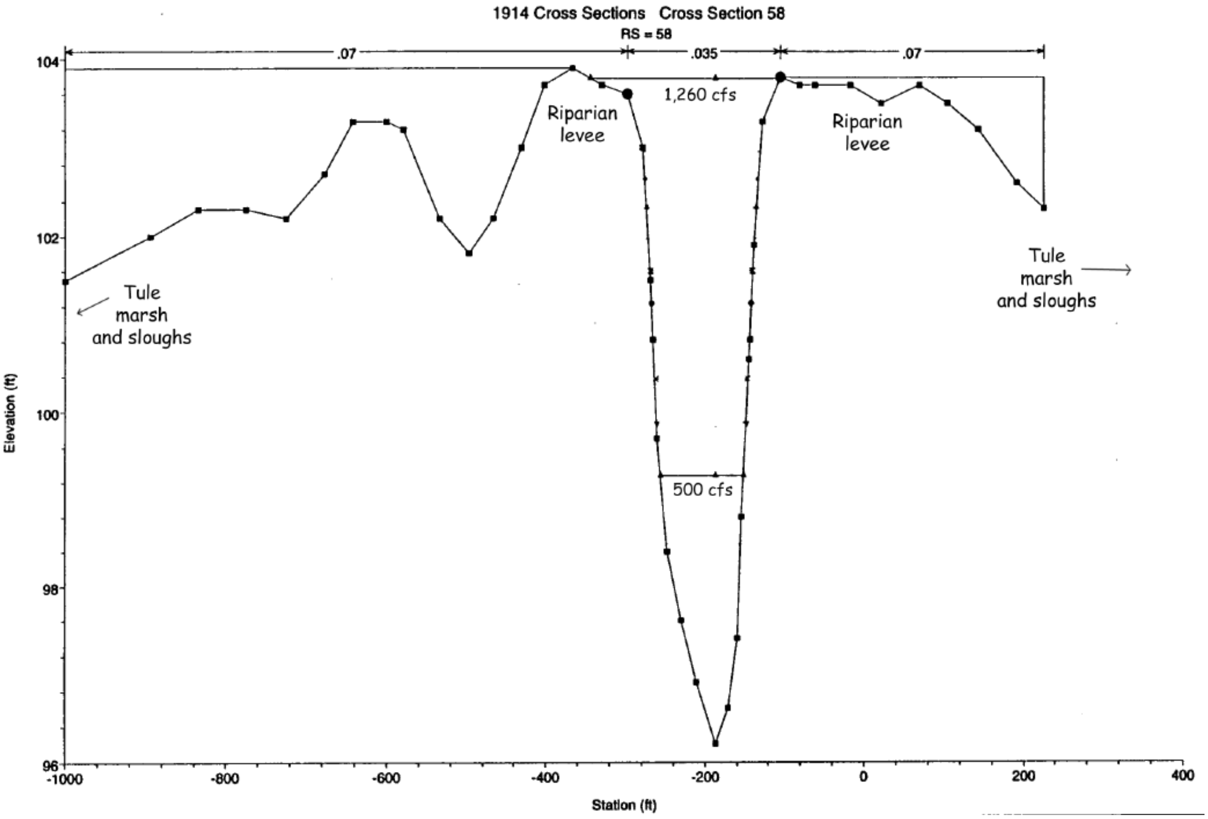


Figure 3-52. ACOE (1917) cross section 58 in Reach 4B (RM 162.6), showing predicted discharge thresholds to inundate key geomorphic surfaces in historic channel morphology.

3.7.5.1. Sediment Regime

Again, there has been no quantification of the historical sediment regime for Reach 5. Historical sediment supply delivered to Reach 5 from Reach 4 likely continued to be low as it deposited on riparian levees adjacent to primary channels of the San Joaquin River. Review of 1914 cross sections show that unimpaired confinement and floodplain development is low in all portions of Reach 5 (Figure 3-43), typical of the riparian levees and flood basin morphology of Reach 4 and Reach 5. Areas behind the riparian levees remain low elevation tule marshes with low sediment supply. Within the primary channels, sediment routed through Reach 4 based on the 1914 ACOE maps, as evidenced by exposed sand bars in all reaches. Sediment transport and routing through the anabranching channels/sloughs appeared to occur in Reach 5 as well as Reach 4, as several of the sloughs on the 1914 maps show exposed sand bars, particularly on the lower portions of Salt and Mud sloughs.

The cumulative impacts of upstream structures (Chowchilla Bifurcation Structure, Mariposa Bifurcation Structure, Sack Dam, etc.), as well as the reduction in sediment supply by Friant Dam, has reduced sediment supply to Reach 5. However, sediment contribution from agricultural return flows along the river and from Mud and Salt sloughs, as well as erosion of the bypass system, has likely increased sediment supply to Reach 5. The net effect on the sediment regime in Reach 5 is therefore unknown.

3.7.5.2. Fluvial Processes and Channel Morphology

The transition from Reach 4 to Reach 5 again results in minor changes in channel slope, where Reach 4B channel slope is 0.00022, Reach 5 channel slope is 0.00021 based on 1914 surveys (Table 3-4). Additionally, valley slope remains similar, with a valley slope of 0.00037 in Reach 4B and valley slope in Reach 5 of 0.00036. Longitudinal profiles of modeled water surfaces under current conditions predict a consistent high flow gradient from the upstream end of Reach 5 downstream to Fremont Ford, downstream of which the slope flattens as the San Joaquin River approaches the Merced River confluence (Figure 3-53).

The valley and channel slopes do not significantly change between Reaches 3 and 4, and historic channel morphology appears to be very similar between Reaches 4 and 5. The extensive flood basin morphology of Reach 4 continues through Reach 5 to the Merced River confluence. The additional sediment supply provided by the Merced River, as well as removal of a downstream base level control downstream to the tidal zone, eliminated the flood basin morphology downstream of Reach 5, and extensive floodplains are again evident between the Merced River and the Stanislaus River. The low channel confinement continues in Reach 5, such that overbank flows are frequent, and riparian levees provide some limited channel confinement rather than the bankfull channel and floodplains. Many of the numerous large-scale anabranching sloughs that originated in Reach 4 converge back to the San Joaquin River in Reach 5 (e.g., Mud Slough, Salt Slough). The 1914 maps continue to illustrate the narrow riparian levees along the primary channel margins, and the extensive marsh vegetation (tules) beyond the riparian levees (although outer boundaries are again not noted) (Figure 3-54 and Figure 3-10). Small scale exposed point bars are still evident in the primary San Joaquin River channel in Reach 5, and small bars are also evident on some of the sloughs (Figure 3-10). There are many side channel and sloughs that connect meanders to one another. Salt Slough has more than one confluence with the mainstem, and in other areas it appears that the two channels could be connected during high flow events. Oxbow lakes are a common feature throughout much of Reach 5, and the channel has large, highly sinuous, irregular meander bends. Compared to the agricultural development in Reach 4, the Reach 5 maps show less agricultural development; however, these maps should not be interpreted to precisely represent “unimpaired conditions”.

As with Reach 4, the threshold for mobilizing the sand deposits in the channel is probably low (less than 1,000 cfs), and again may require a slightly larger discharge to mobilize than Reaches 2 and 3 due to lower slope, smaller sediment supply, and more cohesive finer-grained sediments. Larger flows (in the few thousands of cfs) also have likely caused enough bar scour to prevent riparian encroachment onto the bars.

Of all reaches in the San Joaquin River study area, Reach 5 is the least disturbed. Large tracts of public lands (Fremont Ford State Park and San Luis Wildlife Refuge) encompass much of Reach 5, and agricultural reclamation of these lands has been limited compared to upstream reaches. While these lands are largely managed differently than under unimpaired conditions (waterfowl habitat), much of the natural channel morphology remains (Figure 3-55). Remnant abandoned channels, scroll bars, and riparian vegetation are common in much of Reach 5.

Changes in bankfull width and depth are again estimated by comparing the 1914 cross sections with 1998 resurveys (Table 3-5). Two cross sections were compared for Reach 5; cross section 78 at RM 130.1, and cross section 85 at RM 125.8. Channel width has increased at both cross sections; width at cross section 78 increased from 200 feet in 1914 to 295 feet in 1998, and channel width at cross section 85 increased slightly from 370 feet in 1914 to 374 feet in 1998. Channel depth at cross section 78 increased substantially from 9.6 feet in 1914 to 15.5 feet in 1998, and channel depth at cross section 85 remained virtually unchanged at 25 feet. The width-depth ratio remained essentially the same at cross section 78 (21 versus 19). The changes in width and depth at cross section 78

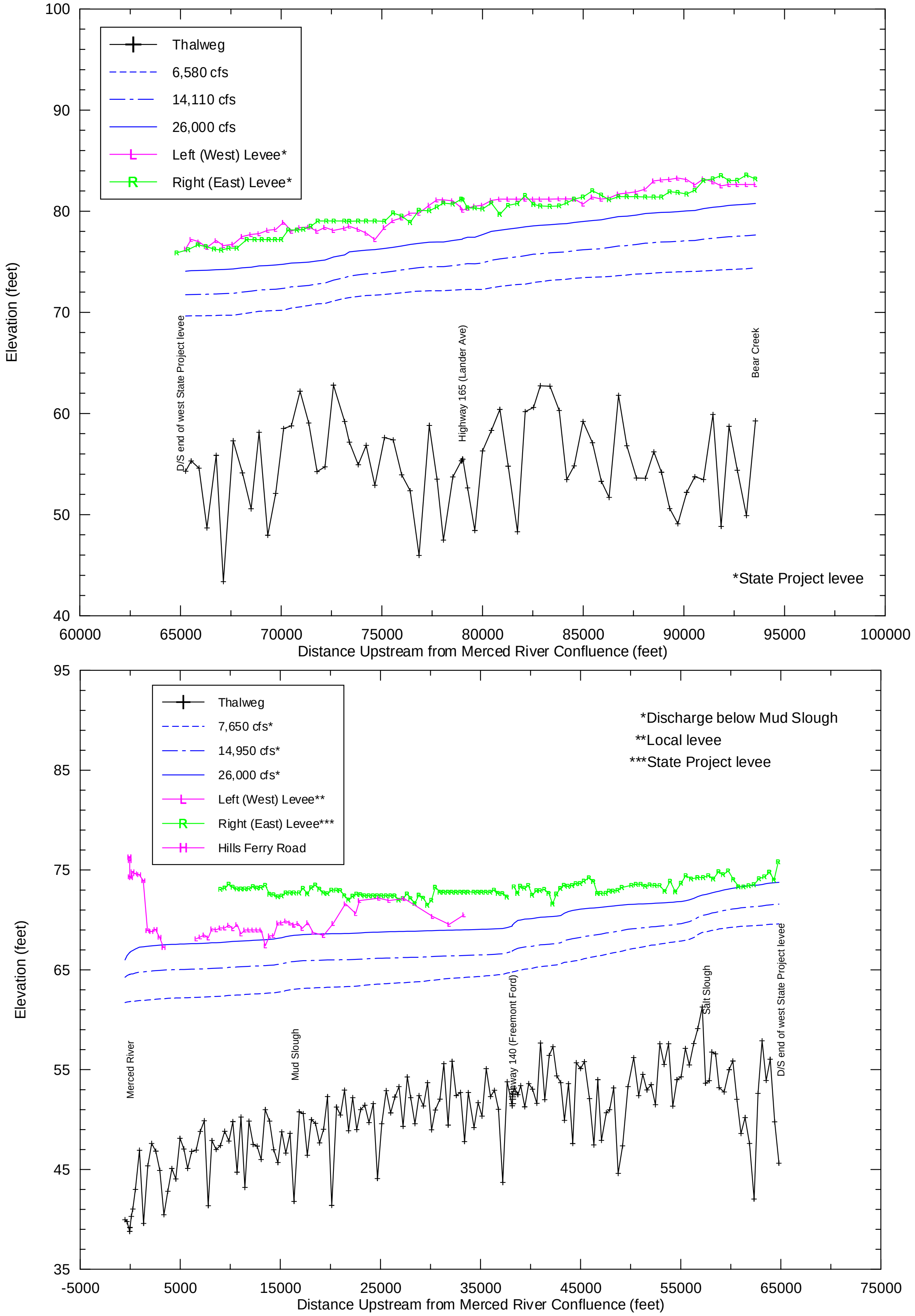


Figure 3-53. Reach 5 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Bear Creek and Eastside Bypass confluence to the end of the project levee on the left (west) bank of the river, lower graph (B) is from the end of the project levee on the left (west) bank of the river to the Merced River confluence.

could be the result of the hydrological changes imposed by the bypass system. Historically, the flows were distributed at this latitude among the sloughs and the San Joaquin River. The Eastside Bypass now conveys a large portion of flood flows to a point at the head of the reach where flood flows are discharged back to the San Joaquin River. The concentration of flows in this area, as well as the reduction in flood peak attenuation by loss of the historic flood basin, may be partially responsible for the increased channel size. There is no apparent physical manipulation of channel geometry for either cross section that would cause this change in width and depth between the two periods.

Thalweg elevations for three cross sections were compared between 1914 and 1998 (Table 3-5). Cross sections 78 degraded by 8.5 feet, cross section 81 aggraded 2.0 feet, and there was no change at cross section 85. Cross section 85 is at the mouth of the Merced River and thus reflects combined conditions between the two rivers. The substantial amount of channel degradation at cross section 78 may be caused by the concentration of high flows from the bypass system, which would be consistent with the increase in channel size at this location. Changes in thalweg elevation at cross sections 81 and 85 are minor.

3.7.5.3. Historic Inundation Thresholds

JSA and MEI (1998) estimated historical inundation patterns for Reach 5 by applying a normal depth analysis with the HEC-RAS hydraulic model to a subset of 1914 cross sections assumed to be representative of the reach. Two cross sections were analyzed in Reach 5. Analysis of cross section 78 at RM 130.1 suggests that the floodplain on the right bank is inundated by a flow of 4,100 cfs and the riparian levee on the left bank is overtopped by a flow of approximately 5,100 cfs. Analysis of cross section 81 at RM 125.8 shows that the floodplain on the right bank is inundated by a flow of approximately 2,400 cfs, and the floodplain on the left bank inundated at a discharge slightly larger than 2,650 cfs (Figure 3-56). Terraces do not exist in this reach, with the exception of near the Merced River delta. The inundation thresholds for these two cross sections are consistent with the lower three in Reach 4, again reflecting the low flow threshold required for inundation of the flood basin in Reaches 4 and 5. The flood magnitude required to inundate flood basins in Reaches 4 and 5 is moderate, and occurred at a very frequent recurrence interval (<1.2-year flood). The Fremont Ford gaging station had an insufficient pre-Friant Dam period of record to be more precise on the flood recurrence estimate needed to cause overbank flows.

3.8. HISTORICAL CHANNEL MORPHOLOGY CONCEPTUAL MODELS

Based on the limited anecdotal and quantitative historical information, and more recent quantitative information, descriptions and conceptual models of channel form and processes are developed for each reach in the following sections. These sections attempt to summarize available information collected to date on a reach-by-reach basis. These conceptual models focus on the relationship between historical channel geometry, fluvial processes, and hydrograph components. In other words, “What surfaces were inundated by different parts of the unimpaired flow regime, and what geomorphic processes occurred during those flows?” Each conceptual model is based on a representative historic cross section obtained from the ACOE surveying effort in 1914-1915 (ACOE 1917). These conceptual models are also developed based on the hydraulic modeling results on the 1914 cross sections, review of 1937 aerial photographs, field observations, pre-Friant Dam hydrology (see Chapter 2), and the general understanding of gravel-bedded and sand-bedded rivers (Figures 3-57 through 3-61). The conceptual cross sections are located within the example planform series for each reach (Figures 3-22, 3-36, 3-39, 3-47, and 3-54). These cross sections are also used in Chapter 8 to develop similar conceptual model of historic relationships between hydrology, channel morphology, and riparian vegetation for each reach.

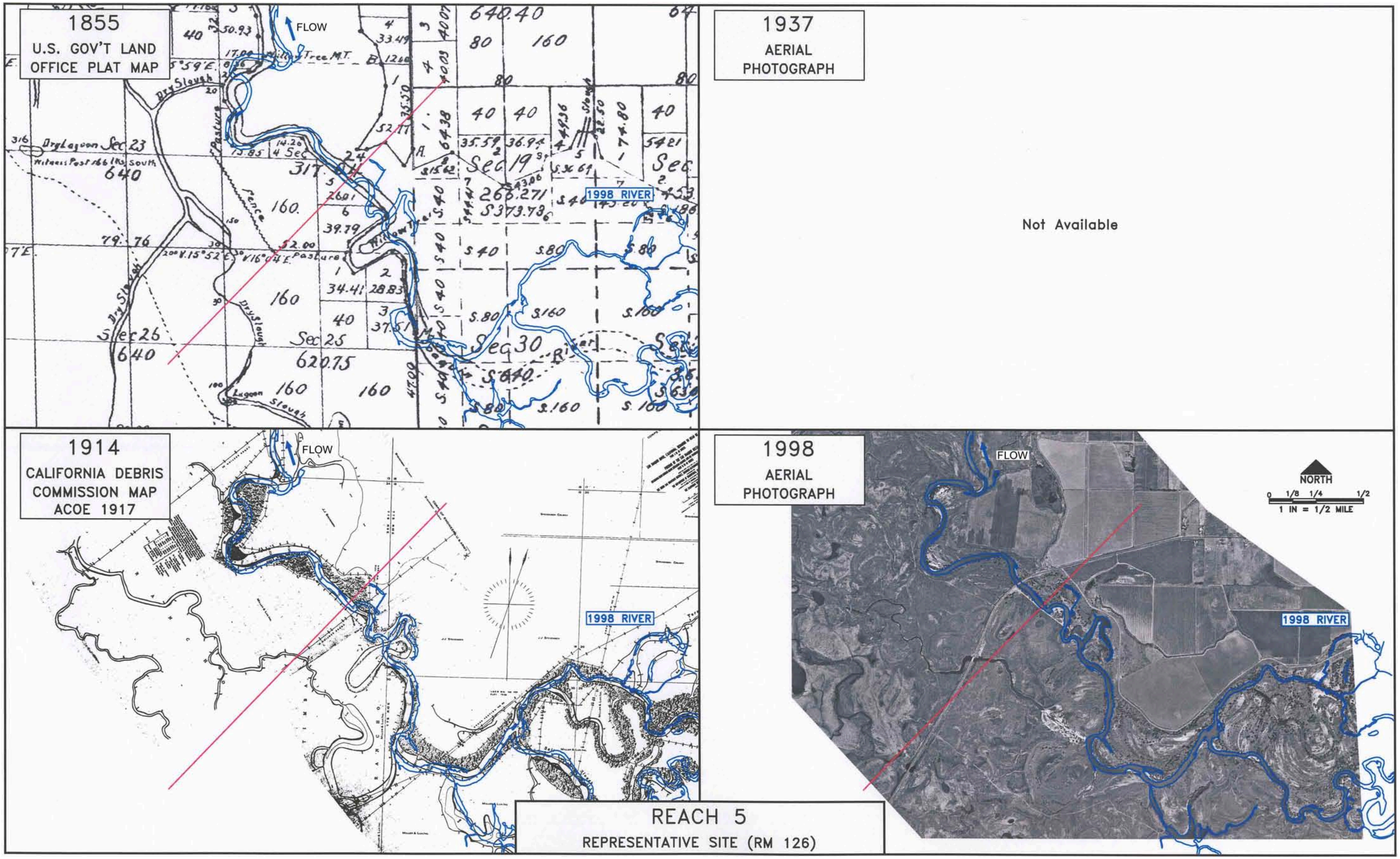


Figure 3-54. Example planform evolution in Reach 5 (RM 126), showing 1855 plat map, 1914 CDC map, and 1998 air photo.

Figure 3-55. View looking downstream at confluence of Salt Slough (left channel) and San Joaquin River at RM 127.7. Note the multiple anabranch channels(sloughs)and the meander scroll topography on the floodplain. From JSA and MEI (1998).

In addition to the conceptual cross section, a pre-Friant Dam hydrograph was chosen to help related hydrograph components to fundamental fluvial processes and inundation of geomorphic surfaces. The water year 1938 hydrograph was chosen because (1) it is an Extremely Wet year that has high winter floods as well as a large snowmelt hydrograph that likely exceeded many fluvial process thresholds, and (2) gaging stations at Friant and Fremont Ford documented flows at the upstream and downstream ends of the study reach for this water year. Because we wished to illustrate how conceptual flow-geomorphology relationships change among the five reaches, we needed to estimate how the 1938 hydrographs changed through the reaches, as there were no other gaging stations available other than the Friant and the Fremont Ford stations. In order to approximate flows in each reach, hydrographs for Reaches 2, 3, and 4 were “interpolated” between the Reach 1 hydrograph at Friant and the Reach 5 hydrograph at Fremont Ford (Figure 3-62). This was done by assigning a portion of the total peak flow lag time between the two stations (9 days) to each reach (i.e., 2-day lag for Reach 2, 4-day lag for Reach 3, and 7-day lag for Reach 4). The longer lag was given to Reach 4 due to its long length and it marks the beginning of the flood basin that would have greatly attenuated flood peaks. We know that between these two gaging stations, flood peaks attenuated, tributaries augmented flows (Fresno Slough, Orestimba Creek, Fresno River, Chowchilla River, and Bear Creek), and diversions occurred for irrigation. Additionally, some flows periodically bypassed the Fremont Ford gage through Salt Slough during periods of high flow, based on the USGS gaging station summary. Regardless of these uncertainties, the hydrographs give a general illustration of how a wetter year annual hydrograph would have adjusted longitudinally along the San Joaquin River.

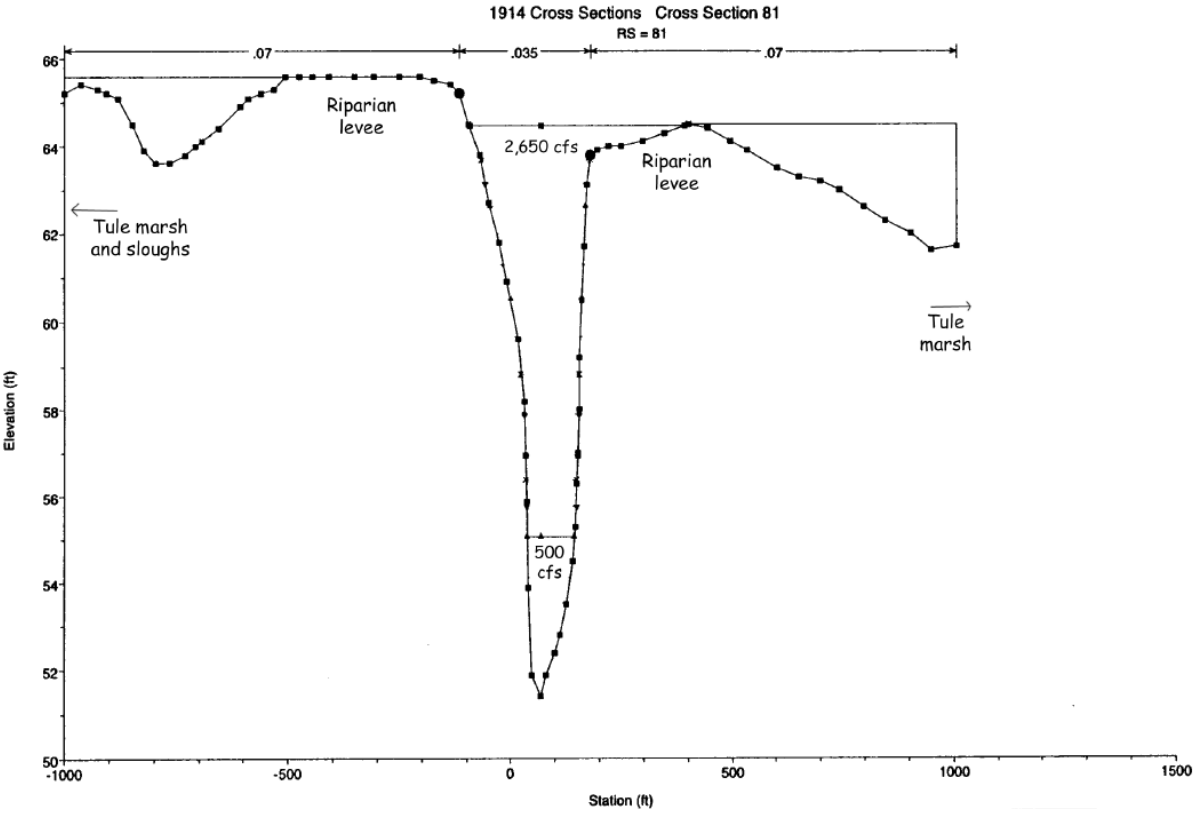


Figure 3-56. ACOE (1917) cross section 81 in Reach 5 (RM 125.8), showing predicted discharge thresholds to inundate key geomorphic surfaces in historic channel morphology.

These conceptual models are largely qualitative due to the limited historical information on the reach, and not intended to serve as the definitive argument on how Reach 1 functioned under unimpaired conditions, but can serve as a beginning point in understanding how the historic channel functioned. Furthermore, this conceptual model is not intended to serve for specific restoration goals per se, but to provide insights on how the river historically functioned that may improve and help guide future restoration efforts.

3.8.1. Reach 1

Figure 3-57 illustrates a conceptual cross section at river mile 259, which is shown on Figure 3-22). The cross section illustrates the primary channel, plus a side channel that flows during high summer baseflows and typical winter baseflows. The channel bed is comprised of cobbles and gravels, and because the slope in Reach 1 of the San Joaquin River is lower than other regional rivers exiting the foothills of the Sierra Nevada, the threshold for bed mobility is likely equal to or larger than the bankfull discharge (10,000 cfs to 16,000 cfs). Bed scour would have required an even larger flood event, perhaps near the discharge that would be required to initiate channel migration or channel avulsion. The threshold for initiating channel migration or avulsion in Reach 1 is unknown, but is likely equal to or larger than the 45,000 cfs indicated on Figure 3-57. The bankfull discharge begins inundating floodplains and high flow scour channels, and the 1914 cross sections suggest that the bankfull discharge is approximately 10,000 cfs. This corresponds to the pre-Friant Dam 1.5-year flood of 10,200 cfs (see Figure 2-5). This conceptual figure illustrates that floodplains were likely inundated for short periods of time during winter floods (days), and a bit longer for the snowmelt peak runoff

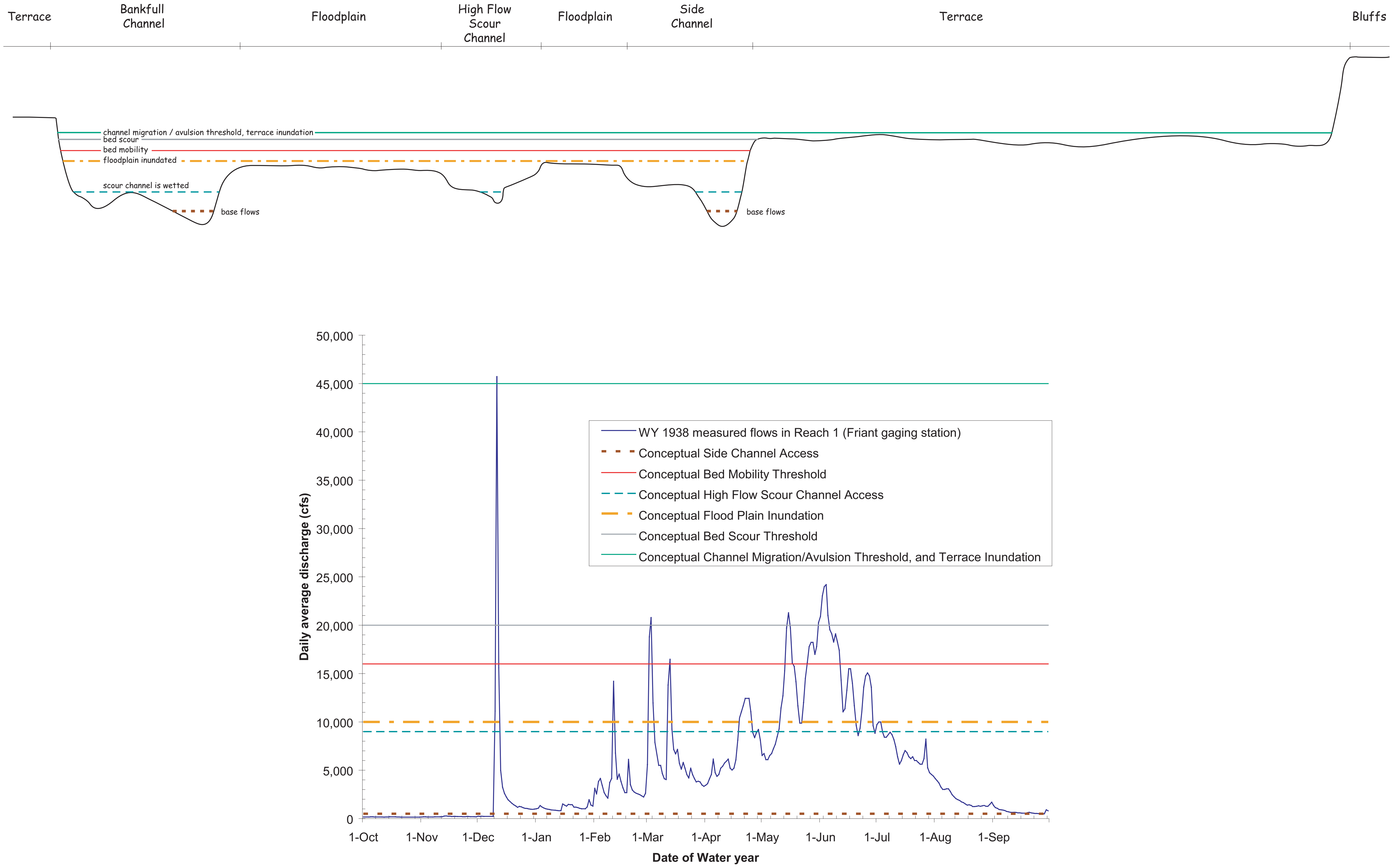


Figure 3-57. Conceptual cross section morphology of Reach 1, showing relationship between hydrograph components, fluvial geomorphic thresholds, and channel morphology. Relationship is purely conceptual, not based on measured data, and is subject to refinement.

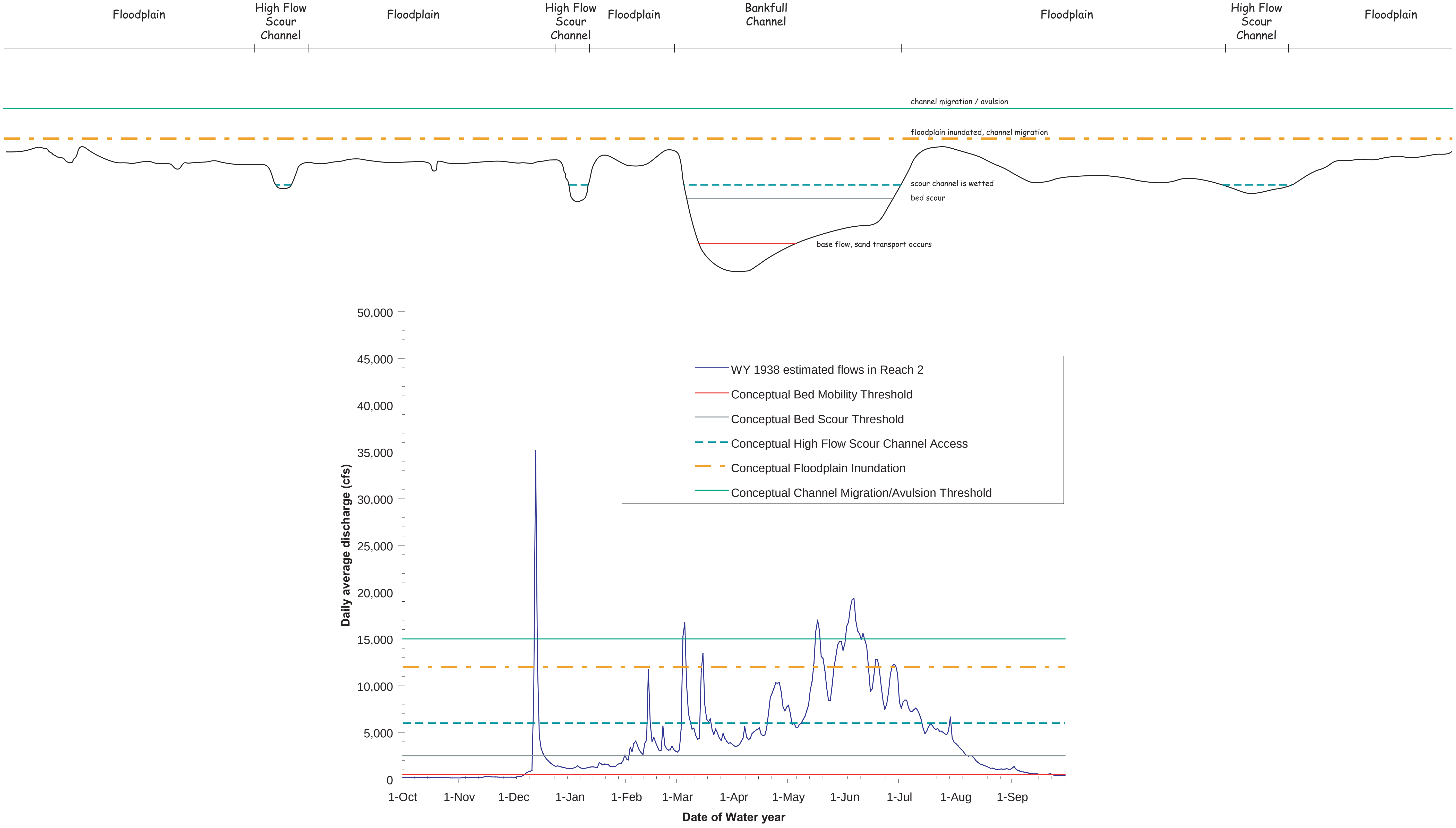


Figure 3-58. Conceptual cross section morphology of Reach 2, showing relationship between hydrograph components, fluvial geomorphic thresholds, and channel morphology. Relationship is purely conceptual, not based on measured data, and is subject to refinement.

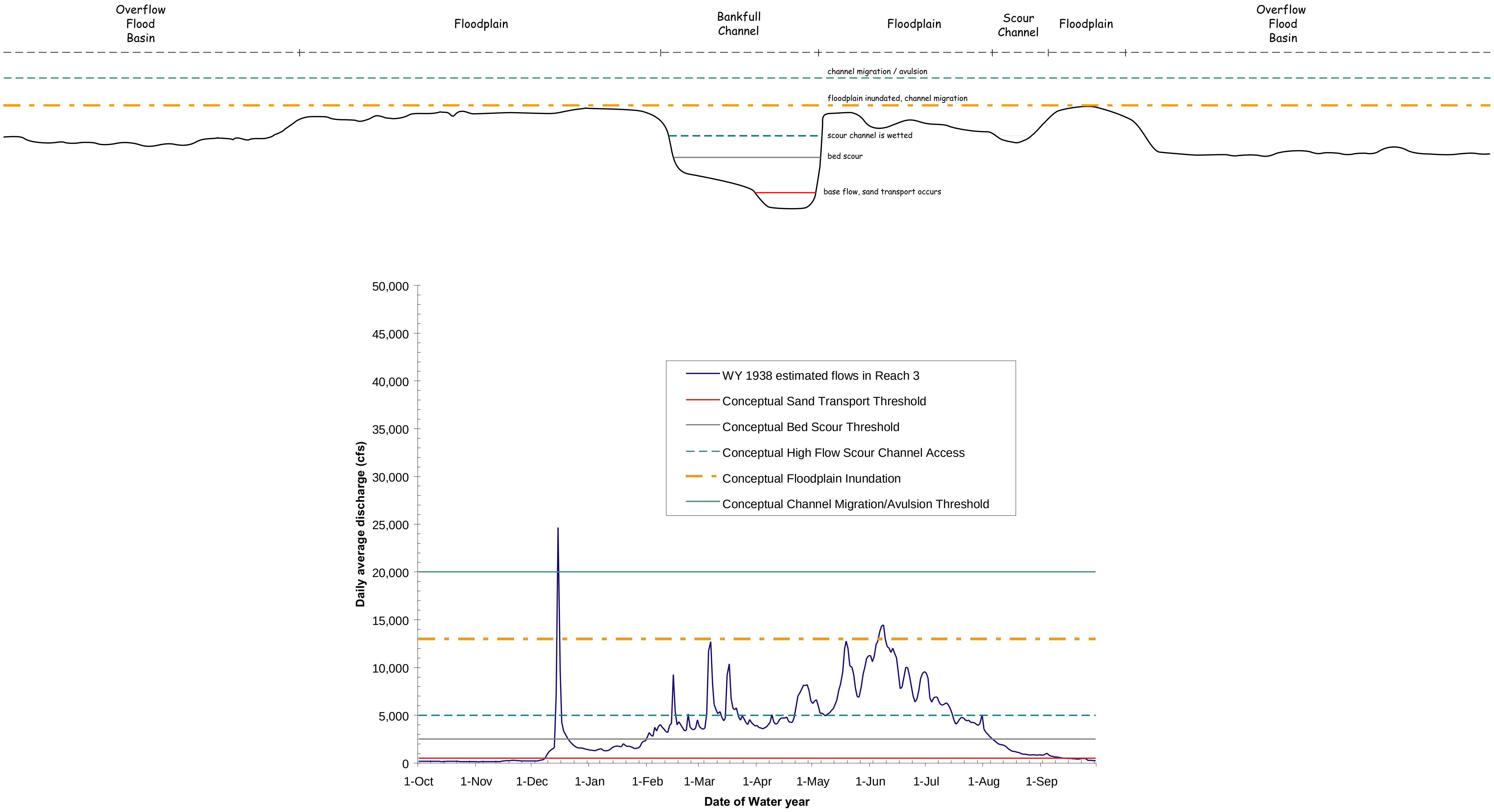


Figure 3-59. Conceptual cross section morphology of Reach 3, showing relationship between hydrograph components, fluvial geomorphic thresholds, and channel morphology. Relationship is purely conceptual, not based on measured data, and is subject to refinement.

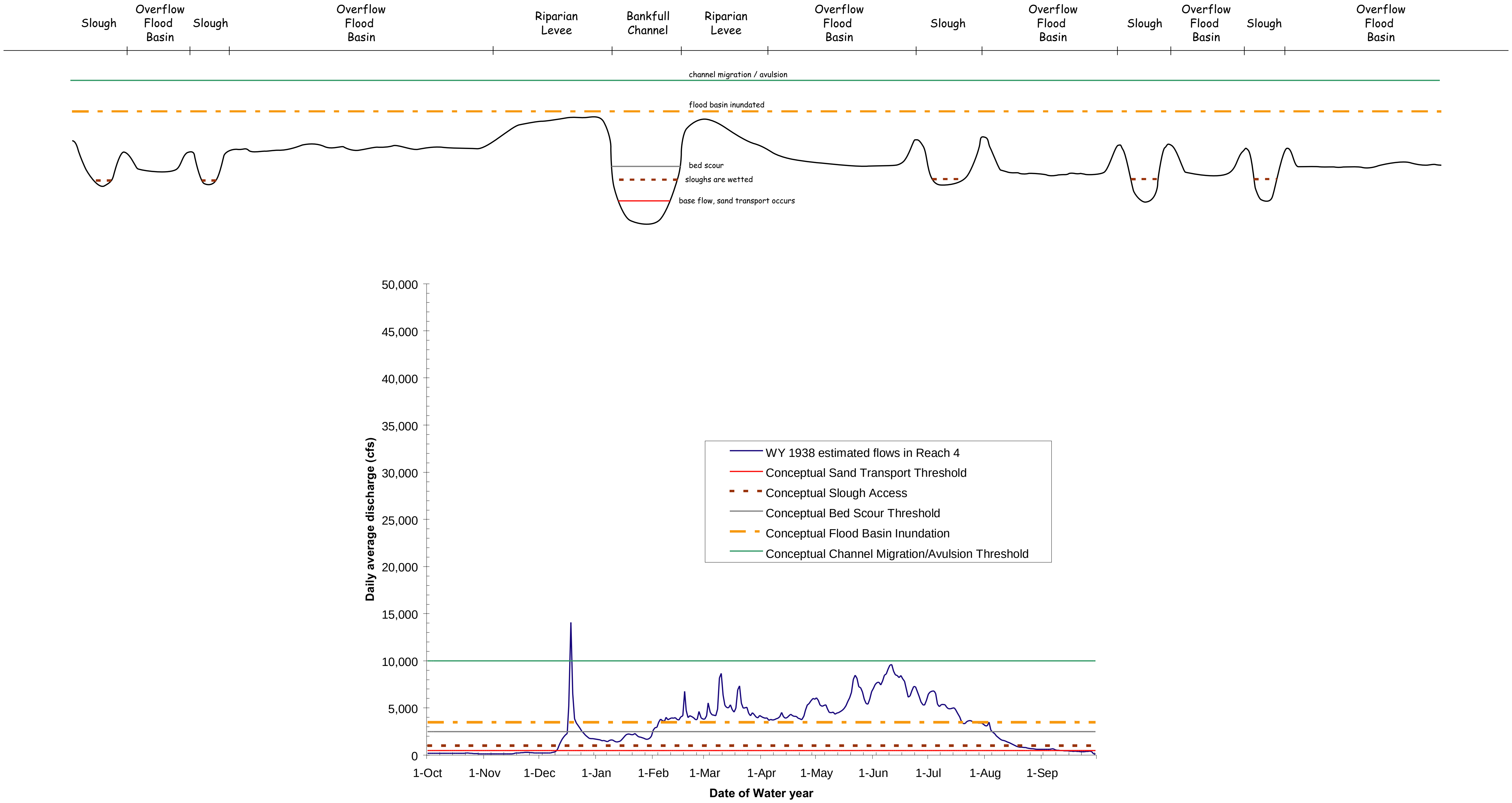


Figure 3-60. Conceptual cross section morphology of Reach 4, showing relationship between hydrograph components, fluvial geomorphic thresholds, and channel morphology. Relationship is purely conceptual, not based on measured data, and is subject to refinement.

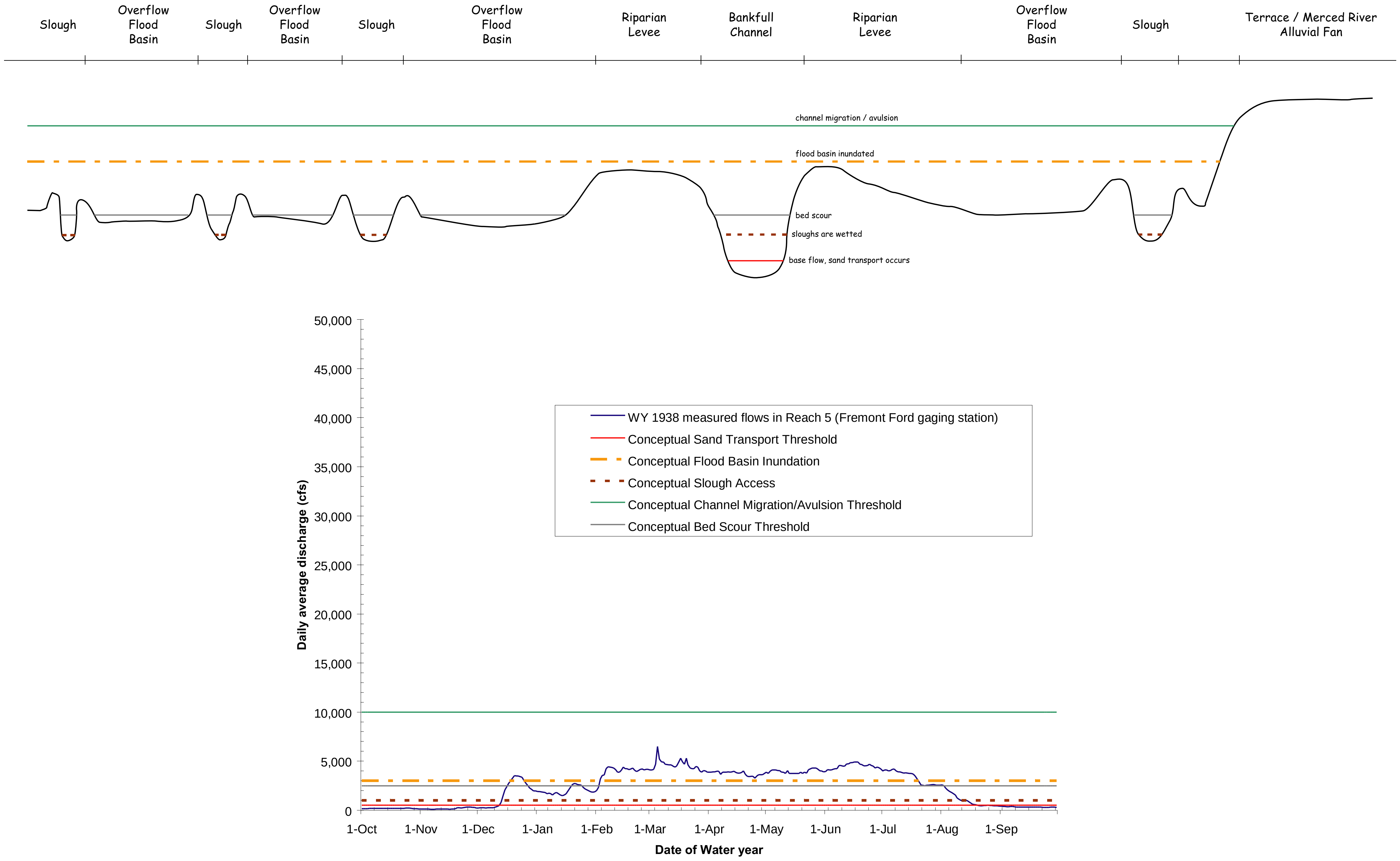


Figure 3-61. Conceptual cross section morphology of Reach 5 showing relationship between hydrograph components, fluvial geomorphic thresholds, and channel morphology. Relationship is purely conceptual, not based on measured data, and is subject to refinement.

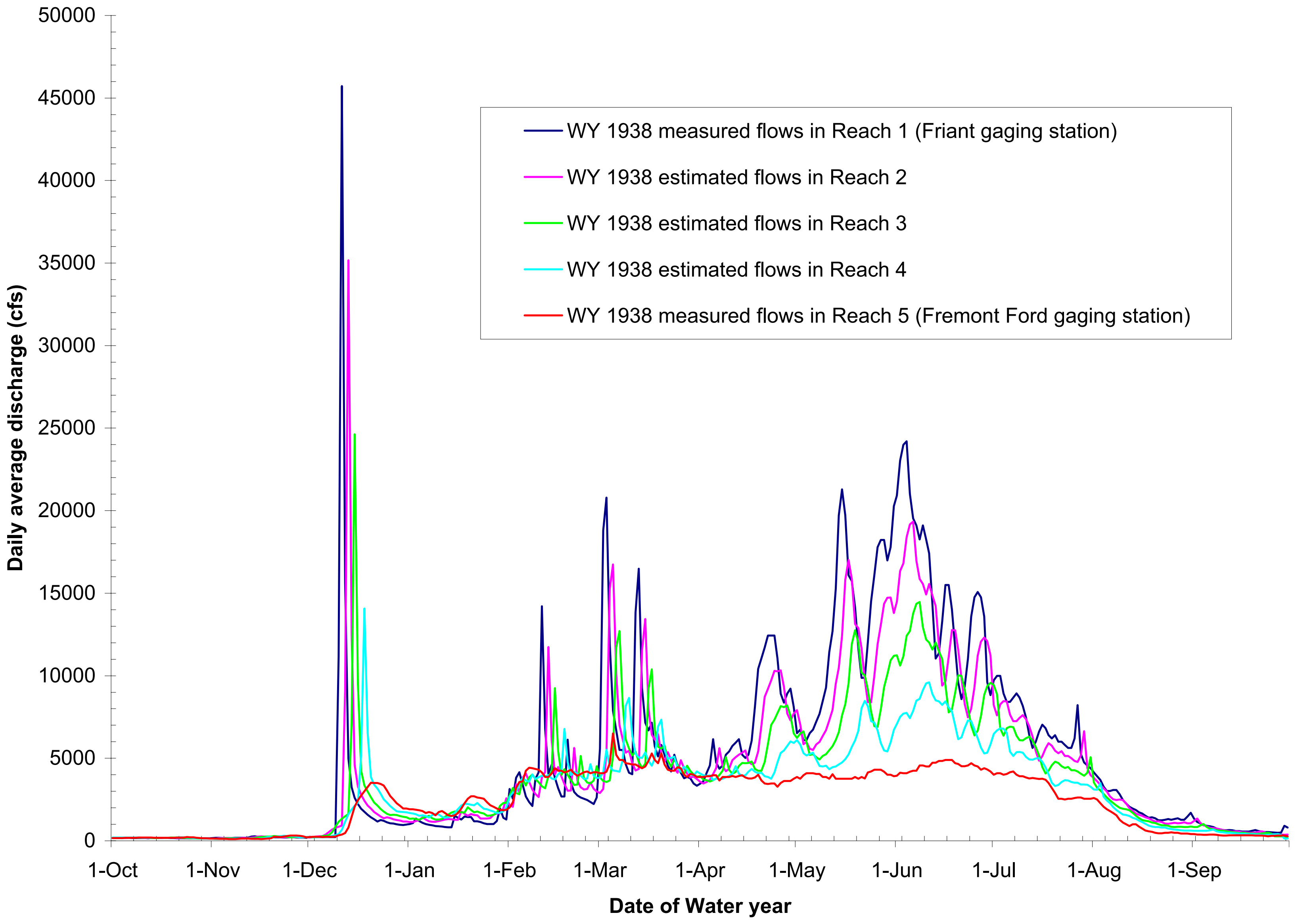


Figure 3-62. Measured 1938 hydrographs at the USGS gaging stations at Friant (Reach 1) and Fremont Ford (Reach 5), with hydrographs in Reaches 2-4 estimated by interpolating between the two USGS gaging stations. Estimated hydrographs are used to help illustrate conceptual relationships between hydrology and channel morphology in the different reaches.

season (week). High flow scour channels and side channels were likely inundated much longer, particularly during the spring snowmelt hydrograph. This prolonged inundation of these channels likely provided high flow refugia habitat for salmonids, as well as high quality rearing habitat. The prolonged inundation of high flow scour channels and gradual draining during the snowmelt hydrograph recession was likely important for natural woody and herbaceous riparian vegetation recruitment in these areas.

3.8.2. Reach 2

Based on the hydraulic modeling results on the 1914 cross sections, 1937 aerial photographs, field observations, pre-Friant Dam hydrology, and general understanding of sand-bedded rivers, a conceptual model of unimpaired channel morphology, geomorphic processes, and hydrograph component relationships was developed (Figure 3-58). This conceptual cross section is located at river mile 223 (Figure 3-7) and is intended to be representative of channel morphology in Reach 2. The cross section illustrates that channel morphology in Reach 2 was comprised of a single primary channel, an inner channel bench with riparian vegetation, and extensive floodplains that were not confined by bluffs. Review of 1937 aerial photographs suggests that the left (south) bank was lower and that high flows spilled overbank and flowed south to Fresno Slough. This reach is sand-bedded, and sand transport likely occurred during high summer baseflows and typical winter baseflows. Correspondingly, moderate bed scour would have occurred during moderate flows by migrating dunes, and greater scour during higher flows. The threshold for initiating channel migration or avulsion in Reach 2 is unknown, but probably occurred during flows equaling or exceeding bankfull discharge (greater than 12,000 to 15,000 cfs as indicated on Figure 3-58). The bankfull discharge begins inundating floodplains and high flow scour channels, and the 1914 cross sections suggest that the bankfull discharge is approximately 12,000 cfs to 14,000 cfs.

Recalling that floodplains on lowland alluvial rivers tend to inundate at flows larger than the 1.5-year flood, the bankfull estimates from the 1914 cross sections can be compared to this conceptual model. The 12,000 cfs to 14,000 cfs bankfull discharge estimate from the 1914 cross sections is slightly smaller than the pre-Friant Dam 1.5-year flood of 10,200 cfs (see Figure 2-5), but tributary accretion downstream of the Friant gage may have increased the magnitude of the 1.5-year flood slightly. Additionally, the bankfull discharge estimates are based on the hydraulic analysis of only a few of the 1914 cross sections. This conceptual figure illustrates that floodplains were also likely inundated for short periods of time during winter floods (days), and a bit longer for the snowmelt peak runoff season (week). High flow scour channels and side channels were likely inundated much longer, particularly during the spring snowmelt hydrograph. This prolonged inundation of these channels may have provided high flow refugia habitat for salmonids, as well as high quality rearing habitat, but this is subject to debate among salmonid biologists. The prolonged inundation of high flow scour channels and gradual draining during the recession of the snowmelt hydrograph was likely important for natural recruitment of woody and herbaceous riparian vegetation on lower benches in Reach 2, but there did not appear to be extensive riparian vegetation on the floodplains based on historical description, the 1914 maps, and the 1937 aerial photographs (see Chapter 8 for more discussion).

3.8.3. Reach 3

The cross section illustrates that channel morphology in Reach 3 was comprised of a single primary channel, an inner channel bench with riparian vegetation, and extensive floodplains that were not confined by bluffs. Review of the 1914 maps and 1937 aerial photographs show that Reach 3 had more abandoned channels (oxbows) and high flow scour channels that were likely accessible during high summer baseflows and typical winter baseflows. This reach is sand-bedded, and sand transport likely occurred during high summer baseflows and typical winter baseflows. Correspondingly, moderate bed scour would have occurred during moderate flows by migrating dunes, and greater scour during higher flows. The threshold for initiating channel migration or avulsion in Reach 3 is unknown, but probably occurred during flows equaling or exceeding bankfull discharge (greater than 12,000 cfs indicated on Figure 3-59). The 1938 hydrograph shown on Figure 3-59 suggests that overbank inundation was short and infrequent; however, this may simply be a relic of the process used to estimate the Reach 3 hydrograph. Flood peak attenuation for flows less than bankfull would have been moderate due to floodplain confinement, and considerable contribution of high flows would likely have been provided by the Kings River via Fresno Slough. Therefore, the hydrograph shown for Reach 3 may be underestimated, which would result in floodplains being inundated for short periods during winter floods (days), and a bit longer for the snowmelt peak runoff season (week) in a similar manner to Reach 2. High flow scour channels and recently abandoned channels were likely inundated longer, particularly during the spring snowmelt hydrograph. This prolonged inundation of these channels may have again provided high flow refugia and rearing habitat for salmonids. The prolonged inundation of high flow scour channels and gradual draining during the recession of the snowmelt hydrograph was likely important for natural recruitment of woody and herbaceous riparian vegetation on Reach 3 floodplains.

3.8.4. Reach 4

The transition from Reach 3 to Reach 4 results in a pronounced change in channel geometry as the Reach 3 floodplains gradually reduce to riparian levees, resulting in extensive tule marshes and sloughs in the flood basin. The representative cross section illustrates that channel morphology in Reach 4 was comprised of a primary channel with several lesser sloughs. Review of the 1914 maps and 1937 aerial photographs show that Reach 4 has numerous anabranching channels (sloughs), such as Santa Rita Slough, Pick Anderson Slough, and others. The 1914 maps illustrate that these sloughs are being used to deliver irrigation water, thus there is uncertainty whether these sloughs conveyed baseflows under unimpaired conditions. The 1914 maps note that the Pick Anderson Slough was dry on October 25, 1915; however, the hand-drawn 1841 map of the Rancho Santa Rita indicates that the Santa Rita Slough and a lesser slough are flowing at some unknown discharge (Figure 3-48). We assume that because the maps showing the sloughs flowing would have been prepared during baseflow period rather than during flood flow period, these slough channels were likely accessible during high summer baseflows and typical winter baseflows. This reach is sand-bedded, and as with upstream sand bedded reaches, sand transport likely occurred during high summer baseflows and typical winter baseflows. Correspondingly, moderate bed scour would have occurred during moderate flows by migrating dunes, and greater scour during higher flows. The threshold for initiating channel migration or avulsion in Reach 4 is unknown, but probably occurred during very rare floods that would breach the riparian levee and scour a new channel location (probably greater than the 10,000 cfs indicated on Figure 3-60). Due to the loss of channel confinement in the upstream portions of Reach 4A, overbank inundation of the flood basin probably occurred most years and was of long duration (months). Because of the loss of confinement and large flood storage available in the flood basin, flood peak attenuation for flows greater than bankfull would have been considerable. Therefore, the hydrograph shown for Reach 3 may overestimate flow magnitude in the lower portions of Reach 4B, which would result in floodplains being inundated for longer periods of time. The prolonged inundation of sloughs and flood basins may have again provided high flow refugia and rearing habitat for salmonids, as well as other native fishes (splittail, delta smelt). The prolonged inundation of the flood basins and gradual draining during the recession of the snowmelt hydrograph was likely important for propagation of the extensive tule marshes, as well as the riparian vegetation on Reach 4 levees along the primary channels.

3.8.5. Reach 5

The low confinement and flood basin morphology of Reach 4 continues into Reach 5. Riparian levees continue to provide a small degree of confinement, with extensive tule marshes and sloughs in the flood basin. Like Reach 4, the representative cross section illustrates that channel morphology in Reach 5 was comprised of a primary channel with several lesser sloughs. Many of the numerous anabranching channels (sloughs) originating from Reach 4 merge with Salt Slough and Mud Slough, rejoining the San Joaquin River in Reach 5. Based on review of the maps, it is again assumed that these slough channels were likely accessible during high summer baseflows and typical winter baseflows. This reach is sand-bedded, and as with upstream sand bedded reaches, sand transport likely occurred during high summer baseflows and typical winter baseflows. Correspondingly, moderate bed scour would have occurred during moderate flows by migrating dunes, and greater scour during higher flows. The threshold for initiating channel migration or avulsion in Reach 5 is unknown, but as with Reach 4, probably occurred during very rare floods that would breach the riparian levee and scour a new channel location (probably greater than the 10,000 cfs indicated on Figure 3-61). Overbank inundation of the flood basin probably occurred in most years and was of long duration (months). The low confinement and large flood storage available in the flood basin continued to attenuate flood peaks for flows greater than bankfull. The prolonged inundation of sloughs and flood basins may have again provided high flow refugia and rearing habitat for salmonids, as well as other native fishes (splittail, delta smelt). The prolonged inundation of the flood basins and gradual draining during the recession of the snowmelt hydrograph were likely important for propagation of the extensive tule marshes, as well as the riparian vegetation on Reach 5 levees along the primary channels.

3.9. BANK EROSION AND SEDIMENT CONTINUITY INVESTIGATIONS

As part of the San Joaquin River Restoration Study, a field reconnaissance was conducted to evaluate channel migration potential through the study reach. This evaluation was a reconnaissance level evaluation, and did not include any predictive modeling, nor did it include a rigorous historic channel analysis to document migration from 1854-1998 maps and air photos. Additionally, the sediment transport analysis conducted between Friant Dam and Mendota Dam (MEI 2000a) and between Mendota Dam and the Merced River confluence (MEI 2000b) is summarized below.

3.9.1. Bank Erosion Investigation

As part of the field reconnaissance of the study area for the San Joaquin River Restoration Study, a qualitative evaluation of channel erosion/migration was undertaken. During the field reconnaissance in 2001, sediment samples were collected along the San Joaquin River and in the bypasses to characterize the sedimentology of the system. Sample locations are indicated by river mile location in Table 3-8. In the upstream reaches, where the bed material was coarser, Wolman pebble counts (Wolman 1954, Leopold 1970) were used to develop bed surface particle size distributions, whereas in downstream reaches, bulk samples were used to develop bed surface particle size distributions.

Along the lower reaches of the San Joaquin River, bank erosion is ubiquitous on the outsides of bends. Bank erosion rates are locally high during high flow events in areas where the toes of the eroding banks tend to be composed of cohesionless sands (Reach 2 and 3). The highly contorted shape of many of the bends in both the San Joaquin River and the sloughs is a result of differential erodibility of the floodplain sediments. More erosion-resistant, cohesive flood basin sediments in Reach 4 and 5 are eroded by mass wasting processes rather than by fluvial entrainment. The bank erosion appears to be a meaningful source of sediment that is deposited on the floodplain during larger flood events, such as in 1997.

Erosion of agricultural fields that border the channel is a meaningful source of sediment for the river and sloughs. Downstream transport of sediment is greatly complicated by the control structures that are used to split floodflows between the mainstem San Joaquin River and the Chowchilla Bypasses. Because the majority of sediment in transport is sand-sized and finer, the sediment is probably distributed in proportion to the flows at the bifurcation points.

The locations of bank erosion are controlled to a large extent by the local flow magnitude at any given reach. Downstream of Sack Dam, where the channel is dry most of the time, the distribution of the sediment, derived primarily from upstream bank erosion, is dependent on the duration of floodflows. Upstream of Sack Dam, the sand-sized sediment derived from bank erosion can be conveyed downstream via the river by the 500 cfs to 600 cfs of Delta-Mendota Canal flows released into Reach 3. Riparian vegetation is well established in the reach because of the perennial flows and, where present, it increases the resistance to erosion of the banks. A considerable amount of sediment is diverted from the San Joaquin River upstream of Mendota Dam at the Chowchilla Bifurcation Structure. This loss of sediment, combined with the sediment-free water contributed to Reach 3 by the Delta Mendota Canal, results in a rate of erosion of nonvegetated banks in Reach 3 that is probably larger than if upstream sediment supply were not diverted into the Chowchilla Bypass. General bed degradation, as seen from the comparative surveys of the reach (Table 3-5), may be a result of the clear water releases from Mendota Dam. Wherever hydraulic energy in the reach is reduced, either as a result of backwater generated by a sharp radius of curvature bend or by a flow expansion zone, sediment is deposited in the channel or in the overbank areas.

Upstream of Mendota Dam, the high-amplitude meander bends store a considerable volume of sediment. The combined effects of the Chowchilla Bifurcation Structure and the low channel slope associated with the high channel sinuosity are likely responsible for the aggradation in the reach immediately upstream of the Chowchilla Bifurcation Structure.

Bank erosion is the primary source of sediment upstream of the Chowchilla Bifurcation Structure. Considerable volumes of sediment are stored in the bed of the channel upstream of the Chowchilla Bifurcation Structure (up to 500,000 yd^3/mile of channel). It has been estimated that the sediment retention basin at the head of the Chowchilla Bypass (with a capacity of about 200,000 yd^3) fills up with sediment every 2 to 3 months during a high flow event (Hill pers. comm.).

Upstream of Gravelly Ford, the bed material in the channel of the San Joaquin River becomes coarser. The coarser bed material is probably derived from bank erosion and, to some extent, residual sediment contributed by Little Dry Creek prior to aggregate extraction at the mouth of Little Dry Creek. Perennial flow releases from Friant Dam have caused riparian encroachment along the low flow channel, armoring the banks and discouraging channel migration.

3.9.2. Sediment Continuity Modeling

Empirical measurements of sediment transport rates have not been collected. In order to generate a rough understanding of sediment transport capacity in the study area, a sediment continuity model was developed for the reach from Friant Dam to Mendota Dam (MEI 2000a) and for the reach from Mendota Dam to the Merced River confluence (MEI 2000b). The sediment transport analysis of the study area describes sediment transport capacity, and patterns of aggradation and degradation of the San Joaquin River. Understanding these physical processes is an important part of developing a river restoration plan and for evaluating salmonid spawning gravel availability and quality.

An important clarification of model output needs to be made in order to avoid misinterpretation of results: The sediment transport capacity predicts <u>possible</u> sediment transport rates if upstream supply is not limiting and other sediment transport discontinuities (e.g., instream aggregate pits) are negligible. While this is not the case in the San Joaquin River, the model provides a useful comparison of hydraulic transport capability between the different reaches. Therefore, results should not be interpreted literally or with any precision, but merely as a means to compare the potential sediment transport capacity between the reaches. The following analyses are fundamentally derived from hydraulic models, which in turn are based on moderately accurate topographic surveys (this is not to say that the topographic surveys are faulty, just that their level of accuracy influences the hydraulic and sediment transport capacity predictions). Additionally, the sediment transport capacity modeling results for several segments were based on only one or two sediment samples from each segment, which may introduce some substantial uncertainty into modeling results in reaches that have a large amount of variability in particle size (e.g., Reach 1). Local particle size adjusts to local hydraulic conditions; therefore, using average particle size for many cross sections in a reach with diverse particle size may add to variability in model predictions. Sediment transport is moderately sensitive to local particle size, so a small number of sediment samples may reduce the accuracy of model predictions. Therefore, it must be clearly stated that modeling results are simply predictions of sediment transport capacity, are not to be interpreted as absolute predictions, and have not been calibrated or validated with empirical field measurements.

On the basis of geomorphic, hydrologic, and hydraulic criteria, the five reaches of the study area were further subdivided into six hydraulic modeling segments for Reaches 1-2 and nine segments for Reaches 3-5 (MEI 2000a, MEI 2000b) (Figure 3-2, Table 3-10). For Reaches 3-5, a single representative particle size gradation was developed from samples S1 through S6 for use in the sediment transport computations. This gradation had D_{84}, D_{50} and D_{16} sizes of 0.78 mm, 0.45 mm, and 0.2 mm, respectively (Table 3-8). For Reaches 1 and 2, a combination of individual samples and averaged samples were used for sediment transport capacity computations (Table 3-11). The sediment transport capacity analysis for existing conditions was carried out for the mean daily flow analysis period (1986–1999) and for the hydrographs developed for the spring 1986 and 1995 flows. For further details on the modeling methods, see MEI 2000a and MEI 2000b.

Table 3-10. Reach limits of hydraulic modeling segments used in the hydraulic model and sediment transport capacity analysis.

Hydraulic Modeling Segment	Reach	Upstream Limit Station (feet)	Upstream Limit River Mile	Downstream Limit Station (feet)	Downstream Limit River Mile	Length Feet	Length Miles	Description
				Between Friant Dam and Mendota Dam				
1A.1	1A	331,050	267.5	266,540	255.2	64,510	12.2	Friant Dam to SR 41 Bridge (SR 41)
1A.2	1A	266,540	255.2	204,220	243.2	62,320	11.8	SR 41 Bridge (SR 41) to Herndon (SR 99)
1B.1	1B	204,220	243.2	146,500	232.8	57,720	10.8	Herndon (SR 99) to RM 232.8
2A.1	2A	146,500	232.8	105,020	225.0	41,480	7.9	RM 232.8 to end LB levee
2A.2	2A	105,020	225.0	59,200	216.1	45,820	8.7	End LB levee to Bifurcation Structure
2B.1	2	59,200	216.1	–	204.8	59,200	11.2	Bifurcation Structure to Mendota Dam
Total						331,050	62.7	

Table 3-10. cont.

Hydraulic Modeling Segment	Reach	Upstream Limit Station (feet)	Upstream Limit River Mile	Downstream Limit Station (feet)	Downstream Limit River Mile	Length Feet	Length Miles	Description
Between Mendota Dam and the Merced River								
3.1	3	456,330	204.7	406,910	195.2	49,420	9.4	Mendota Dam to Avenue 7-1/2 (Firebaugh)
3.2	3	406,910	195.2	338,290	182.0	68,620	13.0	Avenue 7-1/2 to Sack Dam
4A.1	4A	338,290	182.0	295,640	173.9	42,650	8.1	Sack Dam to SR 152 (Santa Rita Bridge)
4A.2	4A	295,640	173.9	266,620	168.5	29,020	5.5	SR 152 (Santa Rita Bridge) to Sand Slough Control Structure
4B.1	4B	266,280	168.5	206,210	157.3	60,070	11.4	Sand Slough Control Structure to Turner Island Bridge
4B.2	4B	206,210	157.3	155,080	147.6	51,130	9.7	Turner Island Bridge to the Mariposa Bypass
4B.3	4B	155,080	147.6	93,840	135.9	61,240	11.6	Mariposa Bypass to Bear Creek
5.1	5	93,840	135.9	65,030	130.4	28,810	5.5	Bear Creek to the downstream limit of State Project levee on west side
5.2	5	65,030	130.4	180	118.3	64,850	12.3	Downstream limit of State Project levee on west side to the Merced River
Total						455,810	86.3	

Table 3-11. Summary of representative bed material size gradations for the San Joaquin River, by hydraulic modeling segment between Friant Dam and Mendota Dam

Hydraulic Modeling Segment	**Representative Particle Size**			
	D_{16} (mm)	**D_{50} (mm)**	**D_{84} (mm)**	**Remarks**
1A.1	27.8	64.0	112.2	Based on average of Samples WC-1 and WC-6
1A.2	26.9	47.6	73.4	Based on average of Samples WC-2 and WC-3
1B.1	14.0	27.0	49.0	Based on average of Samples WC-4 and WC-5
2A.1	0.60	2.6	20.1	Based on Sample S-9
2A.2	0.62	1.7	12.7	Based on Sample S-8
2B.1	0.21	0.65	2.5	Based on Sample S-7

3.9.2.1. Friant Dam to Mendota Dam

The three upstream-most hydraulic modeling segments below Friant Dam have bed material that is coarser than downstream segments because Reach 1 is gravel-bedded, and locally armored due to impacts of flow and sediment regulation by upstream dams. In-channel and floodplain aggregate mining has affected the morphology and hydraulics of these upstream modeling segments, which has had a very disruptive effect on the continuity of coarse sediment transport. As a result of the elimination of the upstream coarse sediment supply, the primary supply of coarse sediment to the river is from the bed itself and a small number of locations where bank erosion of floodplains and terraces occur. However, operation of Friant Dam for flood control purposes has greatly reduced peak discharges and, consequently, reduced the amount of bank erosion as well. Elimination of frequent flood flows and maintenance of base flows have caused riparian encroachment between Friant Dam and Gravelly Ford (see Section 3.10.5). This vegetation has, through root reinforcement of the sediments, further reduced the availability of sediment (Cain 1997).

The bed of the channel is armored for the range of commonly occurring flows in the gravel- and cobble-bed portion of Reach 1. At the highest flows associated with the existing operating rules for Friant Dam, some local reworking of the bed occurs, but substantial reworking and gravel recruitment does not appear to occur.

Table 3-12 summarizes the results of the sediment continuity calculations for existing conditions. The results show that the computed transport capacities of hydraulic modeling segments 1A.1–1B.1 are negligible, attributable largely to the coarse bed material in this portion of the river and the controlled releases from Friant Dam. These results are consistent with the incipient motion analysis that showed that shear stresses necessary to mobilize the bed material are exceeded only in localized areas at discharges larger than 12,000 cfs to 16,000 cfs (or greater). The coarse sediment that is mobilized is transported over relatively short distances and does not constitute a large volume of sediment movement through the segments. In addition, in-channel gravel pits in this portion of the river capture all coarse sediment load that is transported. The coarse sediment supply to the upstream end of Reach 1 was eliminated with the closure of Friant Dam in 1944, which has contributed to the coarsening of the bed material in the river below Friant Dam. There are also two tributaries that can theoretically contribute sediment to the upper portion of Reach 1: Cottonwood Creek and Little Dry Creek. Both tributaries enter into the hydraulic model segment 1A.1. Cain (1997) provides estimates of the potential coarse sediment supply from these tributaries, which range from about 55 yd^3/year for Cottonwood Creek and from about 335 yd^3/year for Little Dry Creek, assuming the coarse sediment load is 10% of total sediment load. Gravel pits near the downstream end of Little Dry Creek may limit the sediment supply from this source. A large portion of the sediment supply from Little Dry Creek and Cottonwood Creek is fine sand and silt, which may move through the upper hydraulic modeling segments between the gravel pits as wash load during high flows. This finer material may be captured by the pits along with any other transported coarser bed material load, with very little bed material-sized sediment being delivered to downstream segments of the river. Comparison of available spawning gravel areas between 1957 and 1996 (Cain 1997) indicates that there has been an order-of-magnitude decrease, which tends to support the observation that the supply of gravel-sized material to the river has been reduced.

Because of finer material in the bed of the channel in Reach 2, the transport capacities of hydraulic modeling segments 2A.1–2B.1 are much higher than the reaches upstream. The transport capacity of hydraulic modeling segment 2A.1 is the highest in the overall study reach, which is consistent with the high main-channel velocities computed for this segment. Because of the low coarse sediment supply from upstream, this result indicates that hydraulic modeling segment 2A.1 has a sediment deficit. In the absence of geological controls or coarse sediment armoring, the segment should respond to the deficit by degradation or by channel widening. The computed sediment deficit for average annual conditions (about 32,500 tons/year) corresponds to about 0.09 feet/year of average degradation for the entire segment, or about 0.7 feet/year of channel widening (assuming an average bank height of 20 feet). These numbers are quite low, which is consistent with historical data (JSA and MEI 1998) that show that only minor amounts of degradation (an average of about 2 feet except in the vicinity of gravel pits) and little or no overall channel widening have occurred since 1914.

The transport capacity of hydraulic modeling segment 2A.2 is lower than hydraulic modeling segment 2A.1, indicating a potential for channel aggradation. This is consistent with evidence of bed aggradation above the Chowchilla Bifurcation Structure. The computed average annual aggradation (about 13,400 tons/year) corresponds to an average aggradation rate for the entire segment of about 0.02 feet/year. As the aggradation is not uniform, greater amounts will occur in some areas (such as the segment just above the Chowchilla Bifurcation Structure). Based on the flow split at the Chowchilla Bifurcation Structure, about 9,300 tons/year of bed-material load is diverted into the Chowchilla Bypass, with the remainder (about 9,800 tons/year) being delivered to the river downstream from the bypass. The volume of bed material diverted into the bypass on an average annual basis (approximately 160,000 yd^3) is large enough to fill a large portion of the approximately 200,000 yd^3 capacity sediment detention basin just downstream of the diversion point. The volume of bed-material sediment diverted during individual storm events can be even greater than the average annual estimate (about 280,000 yd^3 for the 1986 release hydrograph, and about 510,000 yd^3 for the 1995 release hydrograph), filling the basin in a single event. Also, at least a portion of the finer material that was considered to be wash load, and therefore not considered in the sediment continuity analysis (less than 0.5 mm), would settle in the detention basin, further shortening the filling time.

The low transport capacity of hydraulic modeling segment 2B.1 results in about 6,700 tons/year of aggradation. This corresponds to about 0.01 feet per year if the aggradation were uniform throughout the segment. Again, higher rates exist locally (such as in Mendota Pool) because the aggradation is not uniform.

Table 3-12 shows that the predicted sediment transport capacity for the 1986 and 1995 flow release hydrographs are higher (about 50% higher for the 1986 hydrograph and about 140% to 170% higher for the 1995 hydrograph) than the average annual sediment transport capacity estimates. Examination of recorded releases from Friant Dam shows that flows are very low in most years, with occasional years of high flows similar to those that occurred in 1986 and 1995. The bulk of the sediment that is carried by the river is carried during the high flow years, with little or no transport during the dry years.

3.9.2.2. Mendota Dam to Merced River

The same analysis as above was conducted for the modeling segments between Mendota Dam and the Merced River confluence. Table 3-12 summarizes the results of the sediment transport capacity calculations for existing channel conditions. The results predict that hydraulic modeling segments 3.1 and 3.2 downstream of Mendota Dam are degradational, with a computed sediment deficit for average annual conditions ranging from about 2,300 tons/year to 2,700 tons/year. These estimates are quite low, corresponding to less than 0.01 feet/year of average degradation for each segment. Historical surveys suggest that general bed degradation has occurred in this reach of the river (JSA and MEI 1998), although valley floor subsidence may be responsible for a majority of this observed trend. Bridge inspection reports obtained from Caltrans for the 7½ Avenue Bridge in Firebaugh indicate that scour has occurred at the bridge during the last decade, although the reports are not conclusive as to whether the observed scour indicates general bed degradation. The computed slight

Table 3-12. Summary of sediment transport capacity modeling results for existing channel conditions.

Hydraulic Modeling Segment	**Average Annual (1986-1999)**		**1986 Hydrograph**		**1995 Hydrograph**	
	Sediment transport capacity (tons/year)	**Sediment transport capacity surplus (+) or deficit (-) (tons/ year)**	**Sediment transport capacity (tons)**	**Sediment transport capacity surplus (+) or deficit (-) (tons)**	**Sediment transport capacity (tons)**	**Sediment transport capacity surplus (+) or deficit (-) (tons)**
1A.1	0	0	0	0	0	0
1A.2	0	0	0	0	0	0
1B.1	3	-3	1	-1	4	-4
2A.1	32,500	-32,600	49,400	49,400	87,100	87,100
2A.2	19,100	13,400	29,700	19,700	51,900	35,200
Supply to 2B.1[a]	9,800	--	13,200	--	22,300	--
2B.1	2,700	6,600	4,970	11,500	7,900	21,700
3.1	5,000	-2,300	15,500	-10,500	18,300	-10,500
3.2	7,700	-2,700	22,300	-6,800	27,300	-8,950
Split to Arroyo Canal[a]	2,100	--	2,000	--	2,170	--
4A.1	6,300	-570	22,900	-2,600	28,000	-2,900
4A.2	2,900	3,400	16,000	6,850	17,800	10,300
Split to Eastside Bypass[a]	2,200	--	14,700	--	16,000	--
4B.1	60	600	54	1,250	56	1,650
4B.2	14	44	10	44	9	47
Mariposa Bypass[b]	5,900	--	10,900	--	14,300	--
4B.3	5,900	0	10,900	0	14,300	0
Bear Creek[b]	56,100	--	111,000	--	147,000	--
5.1	62,000	0	122,000	0	162,000	0
5.2	23,100	38,900	33,600	88,800	42,300	119,000

[a] Transport capacity is the volume of sediment exported out of river based on the flow split at the junction.

[b] Estimated supply assuming equilibrium in mainstem reach just downstream.

degradational tendency of hydraulic modeling segments 3.1 and 3.2 is attributable in part to diversion of sediment from the San Joaquin River into the Chowchilla Bypass at the Chowchilla Bifurcation Structure. This degradational trend could indicate the possibility of increased bank erosion. However, sustained flows from imported Delta Mendota Canal releases from Mendota Dam have contributed to the maintenance of well-established riparian vegetation along the channel banks in this reach of the river (JSA and MEI 1998). Where present, the vegetation roots increase the resistance of the banks to erosion, which may limit any increased bank erosion that would occur as a result of the computed sediment deficit.

The sediment transport capacity computations predict that hydraulic modeling segment 4A.1, downstream of Sack Dam, is nearly in equilibrium, predicting only very small sediment deficit. The sediment transport capacity computations predict that hydraulic modeling segment 4A.2, upstream of the Sand Slough Control Structure, is aggradational under existing conditions, with a predicted average annual aggradation of about 3,400 tons per year, which corresponds to about 0.01 foot/year if the aggradation were uniform throughout the segment. Higher rates may exist locally (e.g., the area just above the entrance to the Sand Slough Control Structure) because the aggradation is not uniform. The predicted aggradation in this segment is supported by field observation and bridge inspection reports for the SR 152 Bridge (Santa Rita Bridge) at the upstream end of the segment (JSA 1998). The computed aggradation is the result of backwater caused by high bed elevations in the Eastside Bypass near the junction with the San Joaquin River. This portion of the Eastside Bypass has had a historical aggradational problem because of erosion of the bed of the bypass channel upstream (ACOE 1993). The sediment transport capacity computations predict an average of 2,200 tons/year diverted into the Eastside Bypass from the San Joaquin River via the Sand Slough Control Structure.

Predicted sediment transport capacities of hydraulic modeling segments 4B.1 and 4B.2 are negligible compared to other sections of the river, the result of all of the river flow being diverted into the Eastside Bypass at the upstream end of Reach 4B. The small amount of bed-material load that would theoretically enter Reach 4B at the Sand Slough Control Structure would be trapped by vegetation growing in the channel bed; however, the headgates controlling flow into Reach 4B have not been opened in the recent past, so these predicted result would not apply unless headgates were opened in the future. Inflows from the Mariposa Bypass and Bear Creek (Eastside Bypass) increases sediment transport capacities of hydraulic modeling segments 4B.3 and 5.1. The assumption of zero aggradation/degradation for these segments, used to estimate the existing conditions of bed-material/sediment supplies from the Mariposa Bypass and Bear Creek, was based on the assumption of overall stability of this portion of the river under existing conditions. The computed transport capacity of segment 5.2 is less than segment 5.1, with a computed aggradation of about 38,800 tons/year on an average annual basis. This corresponds to about 0.06 foot/year if the aggradation was uniform throughout the segment. Segment 5.2 covers the portion of river below the end of the State Water Project levee on the west side (RM 130) of the river where high flows are able to spread out into the historical anabranched channels. While anabranched river systems are not typically aggradational (Nanson and Huang 1997), the computed net aggradational trend in this segment may be the result of proportionally larger reductions in transport capacity (compared to historical conditions) resulting from reduced flood flows (assuming upstream sediment supply remained constant). However, upstream sediment supply may have increased over historical conditions due to erosion of the Eastside Bypass, which may further cause aggradation in downstream reaches.

Table 3-12 shows that the computed sediment transport capacity for the 1986 and 1995 hydrographs are higher than the average annual estimates, with the largest volumes occurring during 1995, which had a longer duration of high flows (larger runoff volume). Hydraulic modeling segments 4B.1 and 4B.2 are exceptions, where computed sediment transport capacity is similar (very small) for each case, the result of the flow limitation caused by the operation of the Sand Slough Control Structure.

The bulk of the predicted sediment transport capacity in the river occurs during the high flow years, with little or no predicted transport during the dry years. Thus, changes in the river as a result of erosion and deposition of sediment would be expected to occur only during years with larger than normal flood flows.

3.10. HUMAN CHANGES TO THE CHANNEL AND ASSOCIATED IMPLICATIONS

This section provides a description of the human modifications to the San Joaquin River and its floodplain. Most modifications have been made to provide:

- transportation pathways (highways, bridges, and culverts),
- water supply infrastructure elements (dams, canals, and diversions),
- flood control (state project levees, nonproject levees, flow bifurcation structures, flood bypasses), and
- sand and gravel materials for construction.

In contrast to other Central Valley rivers draining the Mother Lode of the Sierra Nevada, gold mining activities have had a minimal impact on the San Joaquin River. Although some placer mining did occur at the Friant townsite, Temperance Flat adjacent to the mainstem above Friant, Fine Gold Creek, and Big Dry Creeks (Gudde, 1975), these resulted in small amounts of sediment delivery to the San Joaquin River. More importantly, the San Joaquin River was spared the extensive dredging of floodplains in the gravel-bedded reaches exiting the foothills of the Sierra Nevada (e.g., compare with the Yuba River or Merced River).

Other secondary impacts from human manipulations to surface and groundwater hydrology have caused the following impacts:

- Riparian encroachment along the low flow channel margins, and
- Excessive groundwater withdrawal since the 1920s has caused over 30 feet of subsidence in portions of the San Joaquin Valley (Poland et al. 1975, Basagaoglu et al. 1999), and impaired riparian vegetation regeneration and survival in Reach 2 (JSA and MEI 1998).

The impact of groundwater withdrawal is discussed in Chapter 5 and Chapter 8; a summary of the process of riparian encroachment and associated impact is provided in a following section. The natural flow character and channel morphology of the San Joaquin River have been affected by five main categories of human impact (JSA, 2002):

- transportation pathways (highways, bridges, and culverts);
- water supply infrastructure (dams, canals, and diversions);
- flood control initiatives (state project levees, non-project levees, flow bifurcation structures, flood bypasses);
- mining for construction aggregates (sand and gravel)
- groundwater abstraction above groundwater recharge rates

The direct effects of these major human impacts are varied. Some bridges and culverts cause flows to backwater and in-channel sediment deposition, whereas other culverts are probably washed out at high flows after causing temporary effects on the ascending limb of the high flow hydrograph (JSA, 2002). The major water supply impact is from Friant Dam, which supplies water to the Friant-Kern Canal and Madera Canal. Consequently, flow reductions in the San Joaquin River cause the mainstem to be generally dry between Gravelly Ford (RM 229) and Mendota Pool (RM 206) except during flood events. Imported flows from the Delta Mendota Canal ensure water between Mendota Dam (RM 204.6) and Sack Dam (RM 182.1), but downstream flows are again generally absent downstream to the Sand Slough Control Structure (RM 168.5) whereupon irrigation return discharges provide some flow. Friant Dam also reduces the magnitude of the flood flows and eliminates the supply of coarse sediment to downstream reaches (see Chapter 2).

Elsewhere, between Mendota Dam (RM 204.6) and the Sand Slough Control Structure (RM 168.5) canals bordering the river serve to reduce the effective width of the floodplain. Constructed bypasses on the east side of the San Joaquin River (Chowchilla, Eastside, and Mariposa Bypasses) and nearly 200 miles of associated levees alter the natural flood inundation and routing processes, and isolate approximately 240,000 acres of floodplain from the river (ACOE 1993) as part of the San Joaquin River Flood Control Project. Other impacts include the in-channel and floodplain mining of sand and gravel construction aggregate between Friant Dam (RM 267.5) and Skaggs Bridge (RM 234.1), which since the early 1940s has caused local channel degradation (see Section 3.7.1.2). Larger-scale channel degradation has only been limited by the presence of bedrock outcrops close to the channel bed in Reach 1A (Cain 1997) and the low sediment transport rate resulting from the low slope in Reach 1A and 1B. As a result, historic channel floodplains are now terraces in locations that have not been mined for aggregate or disrupted by agricultural land conversion. Overall, the channel in much of Reach 1 is a “hydraulically disrupted flood conveyance system composed of single channel segments, multi-channel segments, and breached pits” (JSA, 2002). The aggregate pits trap sediment transported from upstream reaches, resulting in headcutting on the upstream side of the pit and channel degradation downstream of the pit due to loss of sediment supply (Figure 3-62). In downstream portions of Reach 1B and portions of Reach 2, aggregate extraction has been smaller scale, and focused within the active floodway. While impacts in these reaches have not been as severe as in Reach 1A and the upper portion of Reach 1B, these smaller scale extraction operations reduces sediment supply to downstream reaches.

3.10.1. Transportation Pathways

Between Friant Dam and the Merced River, a number of bridges and culverts have been constructed for vehicular and railroad crossings of the San Joaquin River (Table 3-13). Some of the bridges cause backwater effects at higher flows, which changes upstream water surface elevations and causes sediment deposition in the channel. Most of the culvert crossings are probably washed out at high flows, but they do cause some backwater and upstream ponding at lower flows, which has implications for both flow routings, and possibly water temperatures as well. These bridges and culverts that constrict the river cause discontinuities in the longitudinal distribution of energy of the river, such that some areas are severe depositional areas, and some areas are higher energy scour areas. Unimpaired channels distribute the energy dissipation more gradually, and important channel processes (bedload transport, gravel cleansing) occur in a more consistent basis throughout the river channel.

Comparison of channel bed elevation data collected for the National Bridge Safety Inspection Program by Caltrans indicates that the bed has lowered between Friant Dam and Skaggs Bridge (SR 145), most likely as a result of sand and gravel mining (Cain 1997, JSA and MEI 1998). Although there has been about one foot of bed lowering at the Avenue 7½ Bridge at Firebaugh, it is not clear whether there has been degradation or whether the difference in elevations is caused by local subsidence (MEI 2000b). At the Santa Rita Bridge (SR 152), there is little doubt that there has been aggradation, probably as a result of backwater caused by a narrow channel section downstream. Within the Eastside Bypass, the SR 152 bridge crossing shows clear evidence of up to 3.5 feet of degradation between 1972 and 1997. The degradation of the Eastside Bypass channel near State Route 152 is responsible for aggradation and loss of hydraulic capacity in the bypass immediately downstream of the Sand Slough Control Structure. In the lower reaches of the San Joaquin River, there is no clear evidence for either aggradation or degradation of the channel associated with road crossings. Comparative survey data at the SR 165 Bridge indicate no change between 1972 and 1997, but the comparative data at the SR 140 Bridge show about 1.6 feet of degradation in the same time period.

Table 3-13. Listing of bridge and culvert crossings of the San Joaquin River between Friant Dam and the Merced River.

Transportation Element	Location (River Mile)	Comments
North Fork Road Bridge	266.7	
Ledger Island Bridge	262.2	
Culvert	258.5	Probably washed out at high flows, causes backwater at lower flows
SR 41 Bridge (Lane's Bridge)	255.3	Recently replaced with bridge with greater conveyance capacity. 5.4 feet of channel degradation between 1940 and 1997 (Cain 1997).
Culvert	252.8	Probably washed out at high flows, causes backwater at lower flows
AT & SF Railroad Bridge	245.1	
SR 99	243.2	5.6 feet of channel degradation between 1970 and 1997 (Cain 1997)
SR 145 (Skaggs Bridge)	234.1	Causes some backwater at higher flows
Bifurcation Structure	216.1	Causes backwater at higher flows
Concrete Dip Crossing at San Mateo Road	211.8	Barrier to fish passage at low flows
Avenue 7½ Bridge, Firebaugh	195.2	Two bridge openings. 2.2 feet of channel degradation between 1970 and 1997 (JSA and MEI 1998)
SR 152 Bridge (Santa Rita Bridge)	173.9	3.3 feet of channel aggradation between 1972 and 1997 (JSA and MEI 1998)
Culvert	163.1	Probably washed out at high flows
Turner Is. Road Bridge	157.2	
Culvert	153.4	Probably washed out at high flows, causes backwater at lower flows
SR 165 Bridge (Lander Avenue)	132.9	Causes some backwater at higher flows
SR 140 Bridge (Freemont Ford)	125.1	Causes some backwater at higher flows; 1.6 feet of channel degradation between 1972 and 1997 (JSA and MEI 1998)

Bridge and culvert crossings that constrict flow tend to have the following impacts to fluvial processes and channel form (Figure 3-63):

- Channel constrictions cause backwater effects upstream of the constriction, encouraging sediment deposition at the upstream extent of the backwater,
- The channel constriction elevates water surface elevation and increases velocity, causing local scour at the constriction,
- Flow expansion downstream of the constriction causes sediment deposition, such that splayed bars often form immediately downstream of the constriction,
- Fill associated with bridge or culvert abutments eliminates large portions of function floodplain and reduces flood conveyance capacity.

Cumulatively, constrictive road crossings impair sediment routing through the reach, and cause dramatic changes in the local slope. Figure 3-20 illustrates these impact on the longitudinal thalweg profile, as well as impacts on the water surface profile at high flows. Bridges that do not constrict the floodway tend to have few impacts on sediment routing and the longitudinal profile.

3.10.2. Water Supply Infrastructure

Water-supply infrastructure elements along the San Joaquin River between Friant Dam and the Merced River include dams, diversions, and canals. Table 3-14 identifies the locations of the major structures in the study area.

Table 3-14. Summary of major water-supply elements between Friant Dam and the Merced River that may influence fluvial processes and channel form.

Element	Location (River Mile)	Comments
Friant Dam	267.5	Millerton Lake has 530,000 acre-ft of storage, 170,000 acre-ft is be reserved for flood control during the winter months. Reservoir eliminates sediment supply to the study area from the upper watershed. Most stored water is delivered via Friant-Kern and Friant-Madera Canals. Barrier to upstream fish passage.
Big Willow Unit Diversion	261.3	Cobble and rock weir structure diverts flow to the CDFG fish hatchery
Rank Island Diversion	260	Cobble weir structure diverts about 5 cfs
Unnamed Diversion	247.2	Rock weir provides head for a pump upstream
Unnamed Diversion	228.2	Sand and gravel berm constructed to provide head for upstream pump, extends across most of river and forces river flow through narrow slot on right bank.
Mendota Dam	204.6	Low-head dam that provides the headworks for distributing water brought into the system through the Delta Mendota Canal. Mendota Pool has no flood storage capacity. Barrier to upstream fish passage at all flows with boards installed and without replacing old fish ladder.

Table 3-14. cont.

Element	Location (River Mile)	Comments
Sack Dam	182.0	Low-head earth and concrete structure with wooden flap gates that diverts Delta Mendota Canal flows into the Arroyo Canal. Fish ladder could be easily modified to permit fish passage. Sack Dam likely has small to no impact to sediment routing over the long-term
Columbia Canal	206-183	Right bank canal that borders the river, dissecting the historic floodplain and confines high flows
Helm Ditch	204.6-197.5	Left bank canal that borders the river, dissecting the historic floodplain and confines high flows
Poso Canal	194-176.3	Left bank canal that borders the river, dissecting the historic floodplain and confines high flows
Riverside Canal	176.3-168.5	Left bank canal that borders the river, dissecting the historic floodplain and confines high flows
Arroyo Canal	182.1	Left bank canal conveys DMC water, does not border the river, thus has no direct impact on high flows.

The major water-supply-related impacts on the San Joaquin River are caused by Friant Dam. Because most of the runoff stored in Millerton Lake is diverted from the San Joaquin River system via the Friant-Kern and Madera Canals, the bed of the river is usually dry in most years between Gravelly Ford (RM 229) and Mendota Pool (RM 206). Water imported via the Delta Mendota Canal provides flows to the San Joaquin River between Mendota Dam (RM 204.6) and Sack Dam (RM 182.1), but the bed of the river is again dewatered as far downstream as the confluence of the Mariposa Bypass (RM 147.2) in most years. Agricultural tailwater conveyed to the San Joaquin River via drains provides some flow in the river downstream of the Mariposa Bypass confluence. Smaller infrastructure associated with riparian diversions (pumps, gravel berms) does not have significant geomorphic impacts to the river, unless there is rip-rap protection of the infrastructure that could impair the ability of the channel to migrate.

The canal embankments that border both sides of the San Joaquin River between Mendota Dam (RM 204.6) and the Sand Slough Control Structure (RM 168.5) effectively form a set of nonproject levees that have greatly reduced the width of the floodplain, primarily on the east side of the river. In addition to the direct impact of dissecting the historic floodplain from the San Joaquin River, the confinement of the canal embankments increases water depths and velocities during infrequent periods of high flow, which increases sediment transport capacity. Combined with the reduction in sediment supply by upstream dams, the cumulative impacts of the confinement and reduced sediment supply can result in accelerated channel incision, bed armoring, and channel simplification (McBain and Trush, 1998). Canal embankments and associated bank protection also halts channel migration and avulsion processes, which reduces or eliminates floodplain and oxbow formation processes. Elimination of floodplain and oxbow formation processes can have negative impacts on species that depend on these large-scale formative processes for habitat creation (Greco 1999).

3.10.3. Flood Control Projects

The State of California constructed the Eastside Bypass project from the Merced River upstream to the head of the Chowchilla Bypass between 1959 and 1966. The bypass system and its associated levees isolated about 240,000 acres of floodplain from the river (ACOE 1993). The bypass system consists primarily of human-made channels. The Chowchilla Bifurcation Structure diverts most flood

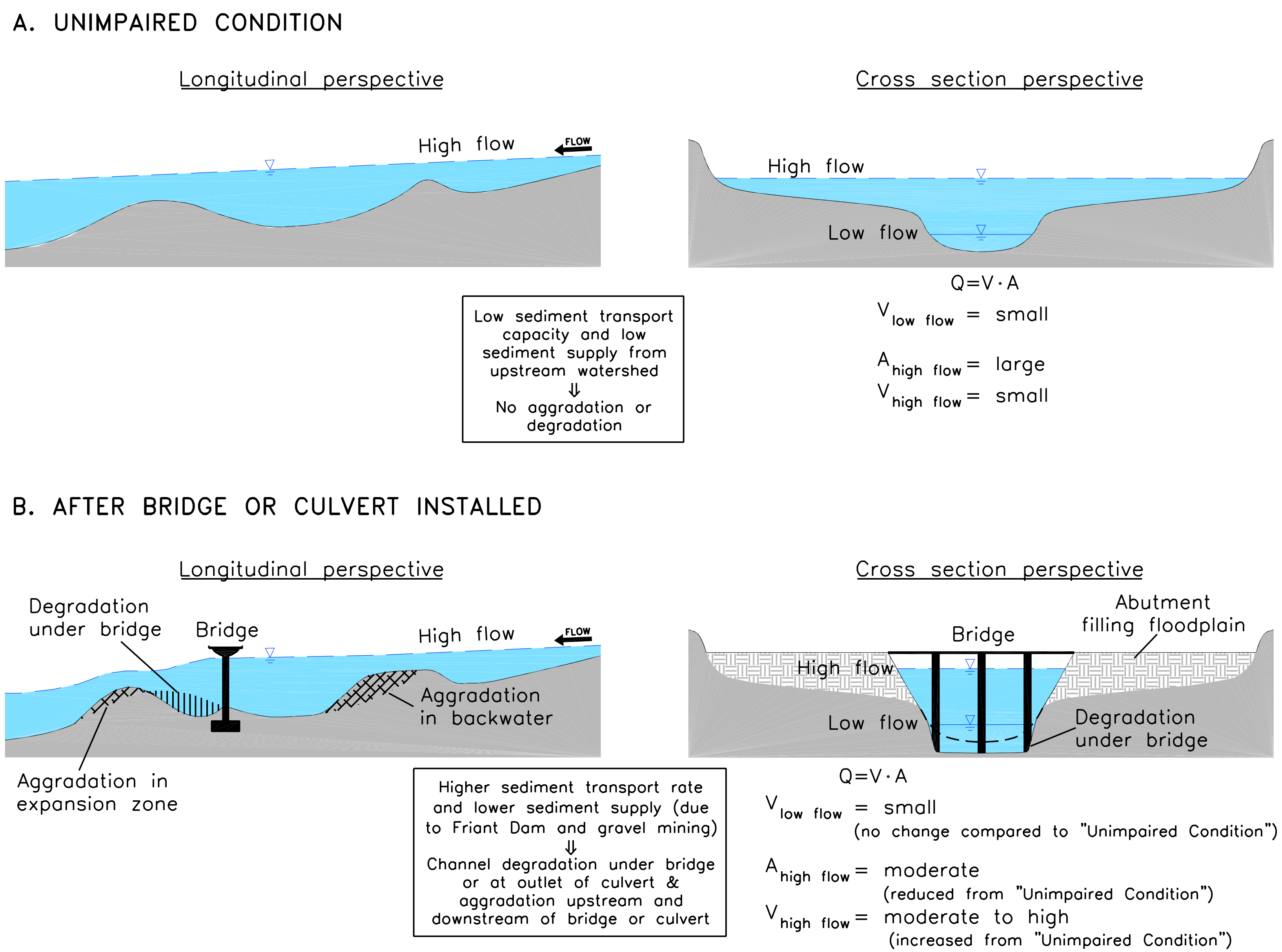


Figure 3-63. Conceptual impacts of local floodway constrictions (bridges and culverts) to hydraulics, local bed scour/degradation, and local bed deposition/aggradation.

flows and sediment from the San Joaquin River at the Reach 2A/2B boundary into the Chowchilla Bypass. The Sand Slough Control Structure again diverts flood flows and sediment from the San Joaquin River at the Reach 4A/4B boundary into the Eastside Bypass. The Mariposa Bifurcation Structure is located within the Eastside Bypass, and diverts a portion of flood flows and sediment load in the Eastside Bypass back into the San Joaquin River via the Mariposa Bypass (Figure 3-2). The San Joaquin River Flood Control Project consists of about 193 miles of levees, several control structures (Chowchilla Bifurcation Structure, Sand Slough Control Structure, Mariposa Bifurcation Structure) and other appurtenant facilities (Mariposa Bypass Drop Structure, Ash Slough Drop Structure). The system was designed to provide a 50-year level of protection (Hill pers. comm.).

Nonproject levees have been constructed on both sides of the river by local landowners from the Chowchilla Bifurcation Structure (RM 216.1) to Mendota Pool (RM 206) and from Mendota Dam to the Sand Slough Control Structure (RM 168.5). Local levees also border the channel between Sand Slough Control Structure and the downstream end of the Mariposa Bypass where the project levees begin (RM 147.2)

During flood periods, additional flood flows enter Mendota Pool from the Kings River North via James Bypass and Fresno Slough. Flows in the Kings River North are controlled by the operation of Pine Flat Dam, where a weir directs flows to the north up to the channel capacity of the James Bypass and then directs any additional flows into the south channel into the Tulare Lake area. Although early studies indicated that the capacity of the Kings River North was about 4,500 cfs, flows up to 6,000 cfs have passed through the reach (ACOE 1993). Under impaired conditions, the flow contribution from the Kings River North and Fresno Slough to the San Joaquin River was likely considerably more than present conditions; thus, flood control operations on the Kings River (as well as Fresno River, Chowchilla River, and other tributaries) has reduced the high flow contribution to Reaches 3-5 of the San Joaquin River.

The Sand Slough Control Structure, located at RM 168.5, controls the flow split between the mainstem San Joaquin River and the Eastside Bypass. There are no published operating rules for the structure during low flows, but the rules theoretically limit high flows routed to Reach 4B to the design discharge of 1,500 cfs. However, the headgates controlling flows into Reach 4B have not been opened recently, which causes all flows to be diverted into the Eastside Bypass. Even if the headgates were opened during high flows, the present capacity of portions of Reach 4B is limited, and the channel could only convey 300 to 400 cfs (MEI 2000b).

The State of California also has a designated floodway program that is administered by the Reclamation Board. The designated floodway provides a nonstructural means of reducing potential flood damages by preventing encroachments into flood-prone areas. Designated floodways are located along the Kings River North, and between Friant Dam and the head of the project levees (RM 227), as well as between Salt Slough confluence (RM 168) and the Merced River confluence (RM 118.3). Regulatory requirements of the Reclamation Board require that the San Joaquin River Levee District maintain the capacity of the designated floodway. “Maintenance” includes periodically removing riparian vegetation and removal of large wood debris that may impair flood conveyance.

Hydraulic capacities of the leveed reaches, without regard to freeboard requirements or to the stability of the levees, were estimated with 1-D hydraulic models (HEC-2) (MEI 2000a, MEI 2000b). Upstream of the Chowchilla Bifurcation Structure (RM 216.1), the project levees extend as far as RM 225 on the left (south) bank and RM 227 on the right (north) bank. The maximum levee capacity predicted from the hydraulic models without any freeboard is about 16,000 cfs in this reach (see Figure 5-7). The ACOE criteria provide 3 feet of freeboard, with a maximum design capacity of 8,000 cfs. However, San Joaquin River Levee District staff have observed piping and seepage problems well before the design flow of 8,000 cfs. Eleven levee breaks occurred in this reach during the 1997 flood as a result of piping failure (See Figure 5-6). Because of aggradation in the channel as a result of the levee confinement and the backwater generated by the Chowchilla Bifurcation Structure, the bed of the channel in the downstream portion of Reach 2A is elevated above some of the orchard lands adjacent to the levees in the lower part of the reach. Periods of sustained high flows in the river result in seepage damage in the orchards (Hill pers. comm.).

Between the Chowchilla Bifurcation Structure (RM 216.1) and Mendota Pool (RM 206), the San Joaquin River is bounded by nonproject local levees. Current operating rules for the flood control system limit flows in the river to 2,500 cfs when the discharge in the river upstream of the Bifurcation Structure is 8,000 cfs. When the discharge in the river upstream of the Bifurcation Structure reaches 12,000 cfs, the release into the river is increased to 6,500 cfs. Water-surface profiles predicted from hydraulic models (see Figure 5-7) indicate that about 4,500 cfs could be released into the river without overtopping of the nonproject levees. At higher discharges, a number of the levees would be overtopped. However, even if the levees were not overtopped, it is likely that they would fail as a result of piping. Seepage problems are reported to occur in Reach 2B at discharges in excess of 1,300 cfs (White pers. comm).

Between Mendota Dam (RM 204.6) and the Sand Slough Control Structure (RM 168.5), the San Joaquin River is bordered by canal embankments that act as nonproject levees. The hydraulic capacity of the channel between these levees, without any freeboard considerations or taking into account the stability of the levees themselves, was determined with an HEC-2 model (MEI 2000b). Between Mendota Dam and Avenue 7½ Bridge at Firebaugh (RM 195.2), the channel capacity is on the order of 8,000 cfs, except for a short reach where the capacity is closer to 6,000 cfs (see Figure 5-8). The design discharge for the reach is 4,500 cfs, which was set to minimize flooding of agricultural lands between the canals (Hill pers. comm.). Between Avenue 7½ Bridge and Sack Dam (RM 182.1), the channel capacity is about 8,000 cfs (see Figure 5-8). Between Sack Dam and SR 152 (RM 173.9), the channel capacity is also about 8,000 cfs (Figure 3-44). Between SR 152 and the Sand Slough Control Structure (RM 168.5), the channel capacity is also about 8,000 cfs (Figure 3-44).

Between the Sand Slough Control Structure and Turner Island Road (RM 157.2), the channel is bounded by local levees, and the capacity is about 600 cfs (Figure 3-45). Design discharge for this reach of the river is 1,500 cfs, but because of agricultural encroachments in the channel and extensive riparian vegetation, the effective capacity is much less. In recent years, the headgates controlling flows into Reach 4B at the Sand Slough Control Structure have not been opened. Between Turner Island Road and the start of the project levees upstream of the Mariposa Bypass (RM 151), the capacity is between 600 and 1,000 cfs. Within the project levees, the capacity increases to more than 1,500 cfs (Figure 3-46). From the Mariposa Bypass confluence (RM 147.2) to the Eastside Bypass confluence (RM 136), the channel capacity is in excess of the 10,000-cfs design flow (Figure 3-46). Between Eastside Bypass confluence and the downstream end of the project levee on the left bank of the river, the capacity is in excess of the 26,000-cfs design flow level (Figure 3-53). In the floodway section from the downstream end of the project levee to the Merced River confluence, the capacity is about 26,000 cfs (Figure 3-53).

In addition to the direct impact of dissecting the historic floodplain from the San Joaquin River, the structural confinement caused by nonproject dikes and San Joaquin River Flood Control Project levees increase water depths and velocities during infrequent periods of high flow, which increases sediment transport capacity. Combined with the reduction in sediment supply by upstream dams, the cumulative impacts of the confinement and reduced sediment supply can result in accelerated channel incision, bed armoring, and channel simplification (McBain and Trush, 1998). Levee, dikes, and associated bank protection also halts channel migration and avulsion processes, which reduces or eliminates floodplain and oxbow formation processes. Elimination of floodplain and oxbow formation processes can have negative impacts on species that depend on these large-scale formative processes for habitat creation (Grecco 1999, McBain and Trush 1998).

3.10.4. Sand and Gravel Mining

Between Friant Dam (RM 267.5) and Skaggs Bridge (RM 234.1), there has been considerable in-channel and channel-margin (floodplain and terraces) mining for sand and gravel. The mining began in earnest in the early 1940s. For Reach 1A, Cain (1997) estimated that 1,562,000 yd^3 were removed from the active channel of the San Joaquin River between 1939 and 1989, and 3,103,000 yd^3 were removed from the floodplain and terraces. Reach 1B does not have nearly the level of aggregate extraction, with 107,000 yd^3 removed from the active channel, and 72,000 yd^3 removed from floodplains and terraces. Based on comparative cross sections, it is apparent that the channel has locally degraded since 1939 (Table 3-5) and that channel degradation may well have been greater from the combined effects of the sand and gravel mining and elimination of the upstream sediment supply by Friant Dam had it not been for the presence of bedrock outcrops in the bed of the channel in Reach 1A (Cain 1997). The bed of the channel has degraded in many locations, with former floodplains now functional terraces in reaches where the historic floodplain has not been mined or modified by agricultural activities.

The captured pits and floodplain pits provide some flood peak attenuation benefits, but have had negative impacts on the continuity of sediment transport and routing (Figure 3-64), availability of spawning gravels, and potentially elevated water temperatures (Kondolf and Swanson, 1993). Table 3-15 summarizes the total mined area along the river, including the breached pits through which the river currently flows, and Table 3-16 identifies the specific locations where the river has captured the pits. Based on the available data, it appears that under existing conditions about 3.3 miles of channel (17,424 feet) would have to be reconstructed to provide a single continuous channel and fully restore sediment routing through Reach 1.

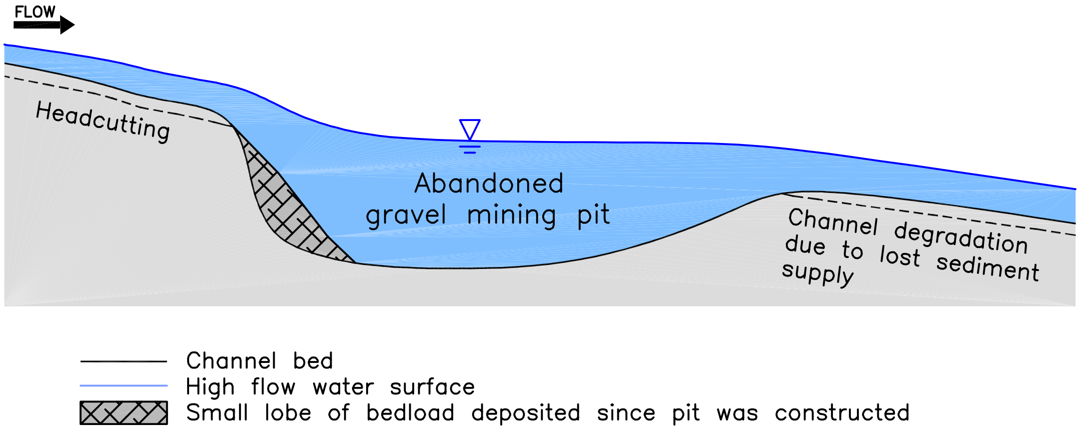


Figure 3-64. Conceptual impact of instream gravel pit or captured "off-channel" gravel pit on bedload routing through Reach 1 of the San Joaquin River. Upstream sediment supply and transport is so small that it would take centuries for the river to naturally fill these large pits.

Table 3-15. Aggregate mining areas along the San Joaquin River between Friant Dam and Skaggs Bridge.

Reach	Total area of mining pits (acres)	Area of pits captured by river (acres)	Percentage of pits captured
Friant Dam (RM 267.5)—SR 41 (RM 255.2)	494.5	7.5	1.5
SR 41 (RM 255.2)—SR 99 (243.2)	784.4	155.4	19.8
SR 99 (RM 243.2)—Skaggs Bridge (232.8)	76.2	26.8	35.1
Total	1,355.1	189.7	14.0

Table 3-16. Locations of captured mining pits captured along the San Joaquin River between Friant Dam and Skaggs Bridge.

Location (RM–RM)	Pit/channel length (feet)	Pit area (acres)
258.5–258.8	1,584	7.7
253.4–254.2	4,224	67.3
252.8–253.4	3,168	23.7
252.3–252.8	2,640	42.5
246.3–246.5	1,056	9.2
243.9–244.1	1,056	2.8
243.8–243.9	528	9.9
240.9–241.3	2,112	11.3
233.2–233.4	1,056	15.5
Total	17,424	189.7

Some sand mining by local landowners occurs in Reach 2 within the levees. However, even though the pits are sometimes as deep as 10–15 feet, they appear to be filled during a single flood control release from Friant Dam. A 200,000 yd^3 sediment detention basin is located in the upstream section of the Chowchilla Bypass, and it was designed to store about 1.5 times the project storm bedload yield. Sediment continuity analyses indicate that the trap will fill within a 2 to 3-month period (MEI 2000a). Additionally, aggradation is occurring in the Eastside Bypass immediately downstream of Sand Slough Control Structure, and this sediment is periodically removed because of the ongoing aggradation problem and its impacts on the conveyance capacity of the bypass (ACOE 1993). Most of the deposited sediment is derived from erosion of the bed of the Eastside Bypass (JSA and MEI 1998). Subsidence-induced sediment deposition required the Corps to remove about 1 million cubic yards of deposited sand from the lower 1.5 to 2 miles of the Eastside Bypass in 1985 because the bypass capacity had been reduced from about 16,500 cfs to 6,000 to 7,000 cfs (ACOE 1993).

3.10.5. Subsidence

The geologic evidence indicates that the San Joaquin Valley has been undergoing almost continuous deformation since the Mesozoic age (Davis and Green 1962, Bull and Miller 1975). Geologically driven subsidence of the valley is ongoing and is on the order of 0.25 mm per year (Janda 1965, Ouchi 1983). The combination of excessive groundwater pumping and hydrocompaction of lands adjacent to the San Joaquin River due to irrigation and agriculture has led to accelerated subsidence in and around Los Banos–Kettleman City since the 1920s (Poland et al. 1975, Bull 1964, Basagaoglu et al. 1999), resulting in levee subsidence and possible impairment sediment routing through Reach 2 and 3. Maximum amounts of subsidence (about 30 feet since the 1920s) have occurred in the Los Banos–Kettleman City area, but from 1 to 6 feet of subsidence have occurred along portions of the San Joaquin River between Mendota and about Los Banos, a rate of 35 to 45 mm/year (Ouchi 1983). Levee subsidence and sediment accumulation had reduced flood capacity of the lower 1.5 to 2 miles of the Eastside Bypass to about 6,000 to 7,000 cfs from the design capacity of 16,500 cfs (ACOE 1993). To correct the problem, the ACOE removed about 1 million cubic yards of sediment, and the Lower San Joaquin Levee District (LSJLD) raised the levee height by 3 feet. Subsidence is discussed in more detail in Chapter 5; no quantitative evaluation of the effect of subsidence on sediment routing has been performed to date.

Comparison of thalweg elevations at cross sections that were originally surveyed by the ACOE (1917) in 1913/1914 with 1998 ACOE survey data indicate that there has been general bed lowering in Reaches 4A and 3 (JSA and MEI 1998). The bed has lowered from 1.5 to 10.8 feet, with the higher values of bed lowering being recorded closer to Mendota, where the recorded subsidence has been on the order of 6 feet. However, because of the subsidence, it is not known whether the apparent degradation is a result of subsidence or is attributable to human-induced changes to sediment supply and hydrology. As part of the Sacramento and San Joaquin River Basins Comprehensive Study, the ACOE is running first order cross valley survey traverses to determine the degree and extent of subsidence in the valley. Until these traverses are completed, it will not be possible to resolve many of the apparent datum problems in the valley or to determine whether the San Joaquin River has truly degraded downstream of Mendota Dam.

3.10.6. Riparian Encroachment

Riparian levees are naturally found along rivers and streams (Russel 1902), and are often caused by riparian-induced roughness above the bankfull margins (e.g., historical conditions in Reach 4 and 5). In an unregulated river, these berms often mark the transition from coarse mobile alluvial deposits in the active channel to fine-grained floodplain deposits, typically near the edge of the bankfull channel. Shear stresses within the bankfull channel are usually sufficient to scour riparian seedlings under unimpaired flow and sediment conditions, such that exposed sand and gravel bars are maintained relatively free of riparian vegetation. However, the reduction of the high flow regime initiates a riparian encroachment process. This process is illustrated from conceptual drawings of the riparian encroachment process on the Trinity River, in northern California, from Bair (2001) (Figure 3-65):

- Under unimpaired conditions, initiating riparian plants on lower bar surfaces in the summer months would be scoured away by large winter floods or snowmelt peaks in the coming year(s)
- Woody riparian plants germinate along the low flow edge of exposed sand and gravel bars. Once flow regulation begins, the frequency of large winter floods and snowmelt peaks decrease, allowing riparian vegetation to establish and grow. The first woody plant to establish along the low flow channel is typically narrowleaf willow (*Salix exigua*), a willow shrub that tends to form dense monotypic stands (Pelzman 1973).
- As the plants grow, they begin to influence hydraulics during those infrequent periods when fine sediment is transported, causing deposition of fine sediment along these rougher areas along the low flow channel. Narrowleaf willow shrubs typically have a high stem density,

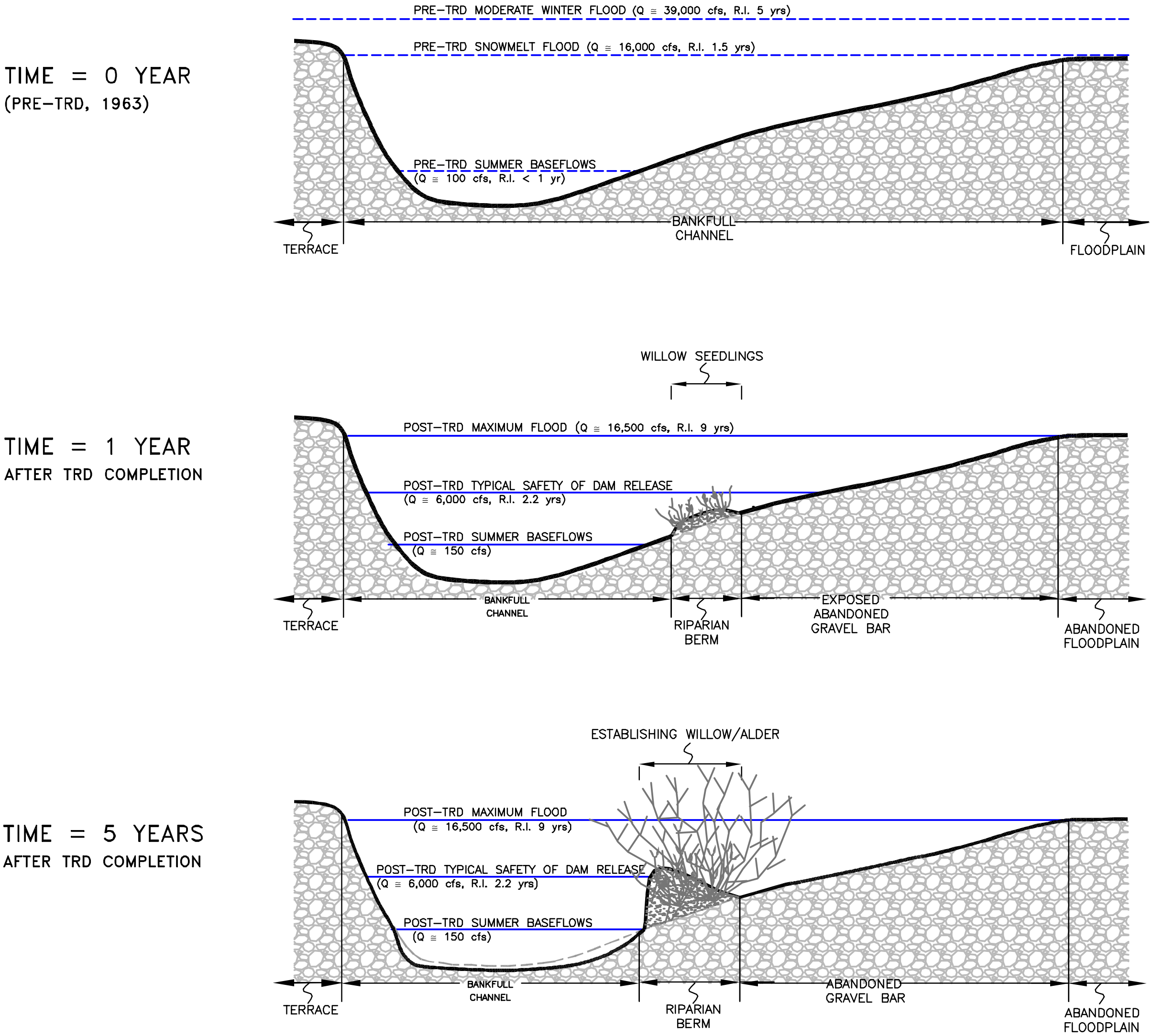


Figure 3-65. Riparian encroachment process on an alluvial river resulting from severe flow regulation (Bair 2001).

which reduce water velocities and facilitates coarse sand deposition. A small sand berm quickly develops within the narrowleaf willow stands (Ritter 1968), and with time and infrequent high flows, the riparian berm grows in width and elevation. As fine sediments deposit, more seedlings establish in the favorable seedbeds, and a self-perpetuating process begins (more riparian vegetation inducing more sediment deposition). As narrowleaf willow stands develop, white alder (*Alnus rhombifolia*) seed deposits in the sandy berm. These seeds germinate and an overstory of white alder becomes established.

- Within 5-10 years, the riparian vegetation is sufficiently large that the post-dam flood flow regime can no longer remove the plants. If an adequate fine sediment supply is available, the berms can continue to grow in height and width until they reach a height where post-dam floods rarely overtop them.

Sediment captured by mature riparian woody plants creates berms that may reach heights of 15 feet from the channel bed (McBain and Trush 1997, Peltzman 1973). The degree of berm development depends on the magnitude of the fine sediment supply and the high flow regime. Riparian encroachment on the San Joaquin River occurs, but the degree of berm development does not appear as severe as on the Trinity River. In some cases, the riparian encroachment process increases the amount of riparian vegetation on larger gravel bedded rivers compared to unimpaired conditions; in other cases, the riparian vegetation on historic floodplains eventually die off, such that there is a net decrease in riparian vegetation. There are also many geomorphic and ecological impacts of riparian berms. The riparian berms confine the river during moderate flows, increasing shear stress fields and sediment transport compared to the channel if no berm was in place. Because upstream dams eliminate sediment supply from the upper watershed, the combination of reduced sediment supply and higher transport rate due to channel confinement accelerates channel incision and/or armoring (McBain and Trush 1997, McBain and Trush 1998). Furthermore, the riparian vegetation armors the bars to the point where sediment stored in the bars is functionally taken out of production for use as aquatic habitat. Riparian encroachment also eliminates channel migration. Ecologically, there are benefits to avian and mammal habitat by the increased riparian vegetation. However, there are negative impacts to salmonids by the change in channel morphology caused by the riparian berms (USFWS 1999). The fossilization of alluvial deposits by riparian vegetation, and corresponding confinement-induced changes to sediment transport rates, tends to simplify channel morphology and associated aquatic habitat. Gently sloping gravel bars, backwater channels, median bars, and other formerly dynamic and complex alluvial features are lost, replaced with a simplified, rectangular channel morphology (USFWS 1999).

3.11. SUMMARY

The unimpaired fluvial processes and resulting channel form created a complex river ecosystem along the San Joaquin River that supported a wide range of aquatic and terrestrial species. The unimpaired conditions provided reach-specific channel complexity (bars, backwaters, side channels, etc.), as well as longitudinal changes in channel morphology (e.g., gravel-bedded reach to sand bedded reaches to flood basins). Cumulative changes from flow and sediment management, land use, and infrastructure have reduced both types of complexity, making the five reaches more similar to each other than under unimpaired conditions. Based on review of historical information, the following major points can be made about historical channel form and processes of the San Joaquin River:

- Unimpaired sediment supply to Reach 1 from the upper watershed was low compared to other comparable Central Valley rivers exiting the Sierra Nevada.
- Reach 1 has an unusually low gradient compared to other comparable Central Valley rivers exiting the Sierra Nevada, which results in low predicted sediment transport rates and large predicted discharges for bed mobility (12,000 cfs to 16,000 cfs or greater)
- Channel migration rates and avulsion frequency appeared to be low in most reaches, with the largest amount of lateral movement occurring in Reaches 2 and 3.
- Sediment supply decreased in the downstream direction as sediment deposited in Reaches 1, 2, and 3. The low sediment supply in Reach 4 and 5, combined with the backwater effect of the Merced River alluvial fan, created the flood basin morphology characteristic of Reach 4 and 5. The low sediment supply in Reach 4 and 5 resulted in small (compared to other Central Valley rivers) natural levees along the primary and secondary channels, which was the primary establishment location for woody riparian vegetation.

The cumulative effects of flow and sediment regulation, aggregate extraction and agricultural conversion of adjacent floodplains, local dikes, and infrastructure of the San Joaquin River Flood Control Project have (1) reduced floodway width and area, (2) simplified channel morphology on a reach-specific scale, and (3) simplified channel morphology on a river-wide scale (loss of longitudinal diversity in channel morphology). Furthermore:

- Instream and floodplain aggregate extraction has had a major impact on channel form and processes in Reach 1 (and lesser impact on Reach 2), extracting much greater volumes of sediment than would have been delivered to the San Joaquin River under unimpaired conditions. This impact is even greater now that Friant Dam blocks all sediment supply from the upper watershed. Instream pits or breached floodplain pits have eliminated riparian habitat, destroyed natural channel form, interrupts coarse sediment continuity through the river, and provides habitat for fish species that prey on juvenile salmonids.
- Friant Dam has eliminated sediment supply from the upper watershed, which has likely reduced coarse sediment storage in Reach 1 and silt supply to all reaches. The impact of this reduced coarse sediment supply is mitigated to a large degree by the huge reduction of peak flows capable of transporting sediment and by the naturally low slope in Reach 1 (small coarse sediment transport capacity).
- Associated channel aggradation and degradation has been locally variable, with most significant degradation (incision) associated with instream aggregate extraction, and most significant aggradation associated with the backwater effect of the Chowchilla Bifurcation Structure in the lower portion of Reach 2A.
- The extensive tule marshes in Reaches 3, 4, and 5 have been largely eliminated. While the bypass still provides some “overbank” flow, the prolonged flooding of flood basins and floodplains rarely occurs. In addition, the confinement of the river channel and bypasses by levees provides varying levels of protection to agricultural lands; however, the levees tend to reduce the flood peak attenuation benefits of the historic flood basins and floodplains, as well as reducing inundated riparian/wetland habitats.
- Channel migration and avulsion functionally no longer occurs; in limited areas where it does occur (primarily Reach 2), waste concrete is often placed along the banks in an attempt to cease migration.
- The width of the floodway and extent of functional floodplain has been greatly decreased by levees, dikes, bypasses, and agricultural reclamation.
- Sediment routing through Reach 2 is largely diverted into the Chowchilla Bypass, and remaining sediment supply into Reach 3 is periodically impaired by Mendota Dam.

The following sections summarize historical/unimpaired conditions, characterize changes from these historical/unimpaired conditions, and summarize associated opportunities and constraints to future restoration efforts.

3.11.1. Sediment Regime

The unimpaired sediment regime changes longitudinally through the study reach. Unimpaired sediment supply to Reach 1 includes a wide range of grain sizes (cobbles to silts), which results in the gravel-bedded channel morphology in Reach 1. As slope and confinement decreases between Reach 1 and Reach 2, coarser sediments have been deposited in Reach 1, such that Reaches 2 through 5 are sand-bedded. The magnitude of the sand supply to downstream reaches continues to decrease with decreasing slope and absence of tributaries contributing sediment. The longitudinal reduction of sediment supply had implications on channel morphology. By Reach 4, the sediment supply has been reduced to the point where floodplains were replaced with flood basins, and sediment deposition is concentrated along riparian levees along the primary channels. The flood basin and low slope prevents tributary streams (e.g., Chowchilla River, Fresno River) from contributing sediment to the mainstem San Joaquin River in downstream reaches. Only at the confluence of the Merced River does sediment supply rapidly increase.

The unimpaired sediment supply from the upper watershed is most likely small compared to other Central Valley rivers. Upstream dams have eliminated this small sediment supply from the upper watershed. Loss of coarse sediment (cobbles and gravels) from the upper watershed, combined with large-scale aggregate removal from the channel, floodplain, and tributaries (Little Dry Creek), has reduced the amount of coarse sediment storage in Reach 1 and likely caused local channel incision and armoring of the channel bed. The loss of coarse sediment supply has likely reduced spawning habitat in Reach 1 and contributed to the reduced magnitude, duration, and frequency of geomorphic processes (bedload transport, channel migration, floodplain formation). Additionally, the loss of fine sediment supply (silts) from the upper watershed, combined with the reduced magnitude, duration, and frequency of overbank flows, may impair floodplain formation processes and riparian regeneration success in all reaches.

Field observations in the late 1800s and 1937 aerial photographs suggest that in-channel sand storage in Reach 1 was large even under unimpaired conditions; reduction of the high flow regime by upstream dams and continued contribution of fine sediment from Cottonwood Creek and other sources caused in-channel storage of sand to remain large. Quantitative estimates of contemporary sand storage in Reach 1 have not been performed, but qualitative observations show extensive storage of sand on bars, in pools, in long runs, and in some riffles. Additionally, quantitative estimates of sand sources and the relative volumes contributed by each source has not been performed, and should be an important consideration for future restoration efforts of salmonid spawning and rearing habitat. This extensive sand storage in Reach 1 may represent a significant constraint on future salmonid production, as well as negating many of the benefits of salmonid spawning and rearing habitat restoration efforts (e.g., large sand supply reversing restoration efforts). Lastly, the transition from gravel-bedded channel to sand-bedded channel under unimpaired conditions likely occurred in the lower portions of Reach 1B downstream to Gravelly Ford. The reduction of the high flow regime and maintenance of fine sediment supply by tributaries and land use downstream of Friant Dam have likely functionally moved the gravel-bed-to-sand-bed transition upstream. No specific location of this new transition zone has been estimated.

Human structures in the floodway have also impacted the sediment regime on the San Joaquin River. The Chowchilla Bifurcation Structure is operated to divert most flood flows from the San Joaquin River into the Chowchilla Bypass. Because sediment transporting and routing is roughly proportional to the volume of flow, most sediment transported in Reach 2A is routed into the Chowchilla Bypass, resulting in large-scale deposition of sediment in the bypass, and associated large-scale removal of sediment supply to Reach 2B. The sediment supply and transport capacity in Reach 2B have been reduced by how the Chowchilla Bifurcation Structure is operated. Sediment that is transported in Reach 2B during high flows deposits in Mendota Pool if the boards in Mendota Dam are not removed during the high flow. Storage volume in Mendota Pool is low, and review of historic longitudinal profiles in Mendota Pool indicate that sediment is not filling the pool; thus it must be routing through the pool when the boards are pulled during high flows, or when the pool is periodically drained for inspection. Nonetheless, the Chowchilla Bifurcation Structure removes a large portion of sediment supply to Reach 3 and may represent a future constraint in restoring sediment supply to downstream reaches.

3.11.2. Fluvial Processes

Review of historical maps and aerial photographs suggests that rates of channel migration and frequency of channel avulsion were historically low, but did occur based on a moderate number of oxbows in Reaches 3 and 5, side channels and scour channels in Reach 1, and anabranching channels in Reaches 4 and 5. Small amounts of channel migration may have occurred in Reach 2, with more channel movement within the meander planform, rather than the meander planform migrating. The low migration rates in Reaches 4 and 5 were likely due to a combination of flows spreading out across the flood basin, low sediment supply, and cohesive bank sediment (JSA and MEI 1998); this condition of low migration rates is expected to continue in the future. Channel migration still occurs at local locations in Reaches 1, 2, and 3, but the rates are small. Restoring channel migration and avulsion processes in Reaches 1, 2, and 3 is constrained by local dikes and project levees. However, levee setbacks and removal of associated bank protection to improve flood control conveyance will also provide opportunities for restoring modest amounts of channel migration.

The channel slope in the reaches of the Tuolumne River, Merced River, and Stanislaus River exiting the Sierra Nevada foothills is steeper (0.0015) than Reach 1 of the San Joaquin River (0.00065). While the channel morphology between the San Joaquin River and these tributaries to the lower San Joaquin River is similar, the low slope of Reach 1 makes achieving fluvial geomorphic processes more difficult under the contemporary highly regulated flow and sediment regime downstream of Friant Dam. Modeling and empirical data suggest that under the existing particle size distribution in Reach 1A, flows exceeding 12,000 to 16,000 cfs would be needed to initiate mobilization of the gravel/cobble-bed surfaces. Modeling conducted to evaluate bed mobility thresholds have predicted that different combinations of (1) reduced particle size via gravel introduction, (2) reconstruction of channel geometry, (3) different assumptions on bed mobility model parameters, and (4) slope variations within Reach 1A could lower the discharge required to mobilize the bed surface, but discharges exceeding 12,000 cfs would still be required to mobilize the bed surface in portions of Reach 1 with the lowest slopes. Therefore, the low slope of Reach 1A is a major constraint in achieving fluvial geomorphic thresholds, even with extensive manipulation of channel geometry and gravel introduction.

3.11.3. Channel Morphology

Channel morphology under unimpaired conditions varied longitudinally from Reach 1 to Reach 5. Reach 1 was a predominately a gravel-bedded reach, with variable meanders and side channels. Bedrock control occurred in portions of Reach 1A, but all downstream reaches were purely alluvial. Floodplains and terraces occurred between moderately confining bluffs in Reach 1, with floodplains inundated by 1.5-year and less frequent floods (>10,000 cfs). Progressing downstream, the confining bluffs and terrace fall away from the river corridor in Reach 2. Extensive floodplains occurred in Reaches 2, 4, and upstream portions of Reach 4A; however, extensive tule marsh-dominated flood basins occurred downstream of Reach 3. Riparian levees provided some confinement to the primary channels in Reaches 4 and 5, but overbank flow occurred in most years, with flows greater than 2,000 to 4,000 cfs overtopping the levees and flooding the flood basins behind the levees.

Levees along the San Joaquin River, the bypass system, aggregate extraction, and agricultural land conversion have greatly reduced the surface area of functional floodplains and flood basins. Surface acreages of floodplain and flood basin loss have not been quantified in this report, but floodplain and flood basin widths have been reduced from 1,000’s of feet (Reach 1) to miles (Reaches 2-5) to as low as zero in many reaches (e.g., Reach 4). Efforts to increase the width and area of functional floodplains will be constrained by the infrastructure of the flood control system, as well as agricultural use on former floodplains. The narrow width of the floodway in Reach 4 represents a constraint to increasing floodway width, and the reduced hydrology of the system will make restoration of the historic tule marshes difficult. While restoring tule marshes in Reach 4 may face similar constraints, the wider floodway widths in the lower portions of Reach 4B downstream of the Mariposa Bypass and in Reach 5 may represent opportunities for local restoration of tule marsh and riparian habitat. However, restoration of tule marsh in these reaches will require some restoration of the hydrology that historically supported it. Lastly, the upstream portion of Reach 4B from the Sand Slough Control Structure to the Mariposa Bypass no longer receives flows from Reach 4A. This reach has a rated channel capacity for the San Joaquin River Flood Control Project of 1,500 cfs, so restoring this rated channel capacity in the upstream portion of Reach 4B represents an opportunity for restoring channel morphology and floodplains. Restoration of floodplains in these downstream reaches will be constrained by agricultural uses on these floodplains; however, as described in Chapter 10, opportunities for floodplain restoration is highest on lands farmed for lower value row crops, and those lands of marginal value due to poor soils or frequent flooding.

The extensive aggregate extraction in Reach 1 provides both restoration opportunities and constraints. While extensive aggregate extraction has occurred in many portions of Reach 1, this reach provides a floodplain restoration opportunity in that infrastructure encroachment into the former floodway is minor (due to periodic flood control releases from Friant Dam), the land purchase price is low because the valuable aggregate has been removed, and the societal conflicts to purchase mined lands is low. However, the cost of restoring these mined lands can be very high, up to several million dollars per mile based on recent restoration efforts on the Merced and Tuolumne rivers, and represents a large financial constraint.

Recreating a dynamic alternate bar morphology in Reach 1 is primarily constrained by the impaired high flow regime, but (1) lack of coarse sediment supply, (2) the naturally low slope of the reach, (3) infrastructure in the channel, and (3) frequent instream aggregate pits that function as bedload traps during infrequent periods of high flow sufficient to transport coarse sediment also constrain rehabilitation of this desirable morphology. Restoring bedload transport continuity through Reach 1 will be expensive due to the large number and volume of instream aggregate pits, and even if these pits are filled, flows greater than 7,600 cfs to 16,000 cfs will be required to begin mobilizing coarse sediments that create and maintain channel morphology. Therefore, efforts to restore dynamic alluvial features (bars, riffles, sidechannels) will be constrained by the risk of fossilization by encroaching riparian vegetation.

3.11.4. Floodplain Inundation Patterns

Based on 1914 maps and cross sections by the ACOE (1917), historic channel geometry was moderately confined by bluffs and terraces in Reach 1, less confined by floodplains in Reaches 2 and 3, and unconfined in Reaches 4 and 5. While the surveys that form the basis of these maps and cross sections occurred over 60 years after the first Euro-American manipulation of the river corridor, the inundation trends most likely reasonably represent unimpaired conditions (the primary change since 1850s being canal confinement in Reach 3 and 4A). Overbank flows in Reaches 1, 2, and 3 were moderately infrequent (> 10,000 cfs, approximate pre-Friant Dam 1.5-year flood) and of short duration (days during winter storms, week during snowmelt peaks). Overbank flows in Reaches 4 and 5 were more frequent (2,000 to 4,000 cfs, probably occurred on nearly a yearly basis with Fresno Slough flow contribution from the Kings River) and of long duration (a week during winter storms, weeks to months during snowmelt runoff). This pattern of inundation has dramatically changed with the San Joaquin River Flood Control Project. The combination of upstream dams, levees and dikes along the river, and the bypass system, has greatly reduced the magnitude, duration, and frequency of overbank flow in all reaches. Flows necessary to inundate floodplains in Reaches 1, 2, and 3, rarely occur, and while the duration of these higher flood control releases from Friant Dam can still be of long duration (days to weeks), the duration is still much less than unimpaired conditions (see Chapter 2).

Restoring floodplain inundation may require a combination of modifications to the high flow regime, levee setbacks, and/or mechanical restoration of floodplains. Additionally, mechanically creating floodplains in Reach 1 by lowering pre-dam gravel bars and floodplains can generate large quantities of gravel and cobbles, which could be screened and used for gravel introduction projects in Reach 1. The large monetary and land cost of restoring floodplains represents a constraint; however, existing flood control infrastructure is inadequate in most reaches to safely convey the 100-year flood (ACOE 1998), so a combined effort of floodplain restoration and floodway expansion represents an opportunity to achieve the multiple objectives of restoration and improved flood protection.

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CHAPTER 4. SHALLOW GROUNDWATER HYDROLOGY

4.1. INTRODUCTION

The surface water-groundwater interactions in the San Joaquin River corridor and the Tulare Lake basin were important in supporting the historical wetland and riparian habitats in the San Joaquin Valley. Additionally, the San Joaquin River and Tulare Lake basis was atypical compared to other Central Valley Rivers based on the periodic connectedness of surface flows between the two basins: (1) overflow from the San Joaquin River towards the Tulare Lake, (2) Kings River overflow into the San Joaquin River, and (3) Tulare Lake overflow into the San Joaquin River. Surface flows in the San Joaquin River and rivers draining into Tulare Lake provided substantial surface flows to the river during winter, spring, and early summer months, but the shallow groundwater table played a key role in supporting riparian vegetation, and providing baseflow augmentation to the mainstem rivers. Discontinuous semi-permeable clay lenses provided a semi-confined shallow groundwater aquifer, while a deeper clay layer provided a confined groundwater aquifer. In winter, spring, and early summer months, surface water percolated into these aquifers from the Sierra Nevada foothills, and the aquifers provided an important groundwater contribution to the San Joaquin River. The flood basins in Reaches 3, 4, and 5 remained inundated or moist enough to support extensive tule marshes. High groundwater tables and artesian springs allowed most reaches of the San Joaquin River to gain flow year round.

Since the late 1800s, groundwater pumping, has withdrawn large volumes of water from both the semi-confined shallow aquifer and the deeper confined aquifer. Dramatic decreases in groundwater elevation resulted, and many reaches were converted from “gaining” reaches (streamflows increasing from groundwater contribution) to “losing” reaches (streamflows decreasing due to infiltration into the bed of the stream).

These human-induced changes to the shallow groundwater table have impacted the riparian corridor in several ways, and will impair future restoration efforts on the San Joaquin River. Therefore, the goals of this chapter are to: 1) summarize historical and contemporary groundwater conditions in the San Joaquin Valley, 2) discuss how the regional groundwater system has changed, and 3) analyze the implications of this change to restoration efforts. Groundwater conditions in the San Joaquin Valley as a whole must be considered because they influence local groundwater conditions along the study area of the San Joaquin River. To accomplish these goals, available groundwater literature for the San Joaquin Valley will be reviewed to gain insight into how the shallow groundwater system may influence restoration opportunities and constraints on riparian vegetation and fishery habitat in the San Joaquin River corridor.

4.2. STUDY AREA

To describe the overall groundwater hydrology, the study area would need to be the entire San Joaquin Valley. With our emphasis on the shallow groundwater system adjacent to the San Joaquin River, our study area is from Friant Dam downstream to the Merced River (Figure 4-1), and within the approximate pre-Friant Dam 100-year floodway. Because quantitative data on the shallow groundwater system are limited, studies of groundwater conditions downstream of the Merced River were included in this evaluation because this downstream reach displays similar geologic and hydrogeologic conditions to the study area upstream of the Merced River, particularly Reaches 2 through 5.

4.3. OBJECTIVES

The primary objectives of this chapter, derived from the April 2000 scope of work, are to:

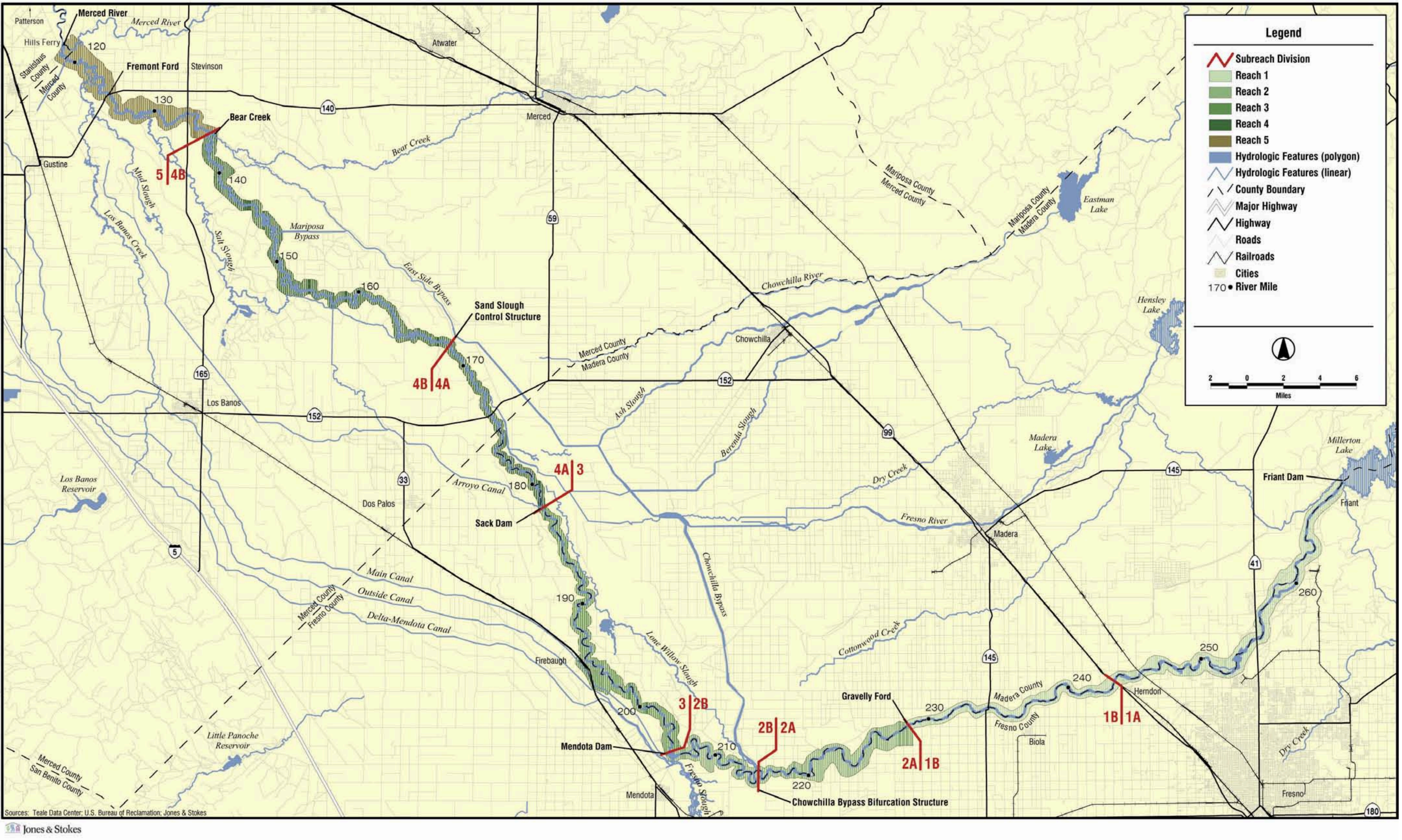
- Describe the geology and hydrogeology of the San Joaquin Valley.
- Describe how the San Joaquin Valley groundwater system has changed over time emphasizing the shallow unconfined groundwater aquifer.
- Identify how groundwater-pumping affects shallow groundwater flow and water quality.
- Identify "gaining" and "losing" reaches along the study reach.
- Discuss how the existing shallow groundwater system will affect riparian and fishery restoration efforts in the study area.

4.4. SAN JOAQUIN VALLEY GEOLOGY

The San Joaquin Valley is a large, asymmetrical basin aligned north-south, and is bordered on the east by crystalline rocks of the Sierra Nevada and on the west by folded and faulted marine sedimentary rocks of the Coast Ranges. The Tehachapi and San Emidio mountains mark the southern boundary of the San Joaquin Valley, while the delta of the San Joaquin and Sacramento Rivers lies to the north. The part of the valley trough with the deepest alluvial fill generally lies closer to the Coast Ranges than to the Sierra Nevada. The San Joaquin River and the Sacramento-San Joaquin River delta drain the northern half of the San Joaquin Valley. The Tulare Lake Basin occupies the southern half of the valley.

The San Joaquin Valley is filled with up to 32,000 feet of marine and continental sediments, the result of millions of years of inundation by the Pacific Ocean, and of erosion of the surrounding mountains (Planert and Williams 1995). Up to two to three million years ago, the Pacific Ocean had already deposited up to about 20,000 feet of marine deposits in the Central Valley (Planert and Williams 1995). These deposits are are mostly consolidated, and have minimal permeability (Figure 4-2 and Figure 4-3). A generalized stratigraphic section of the rocks and sediments underlying the San Joaquin Valley is summarized in Table 4-1 and described in more detail below.

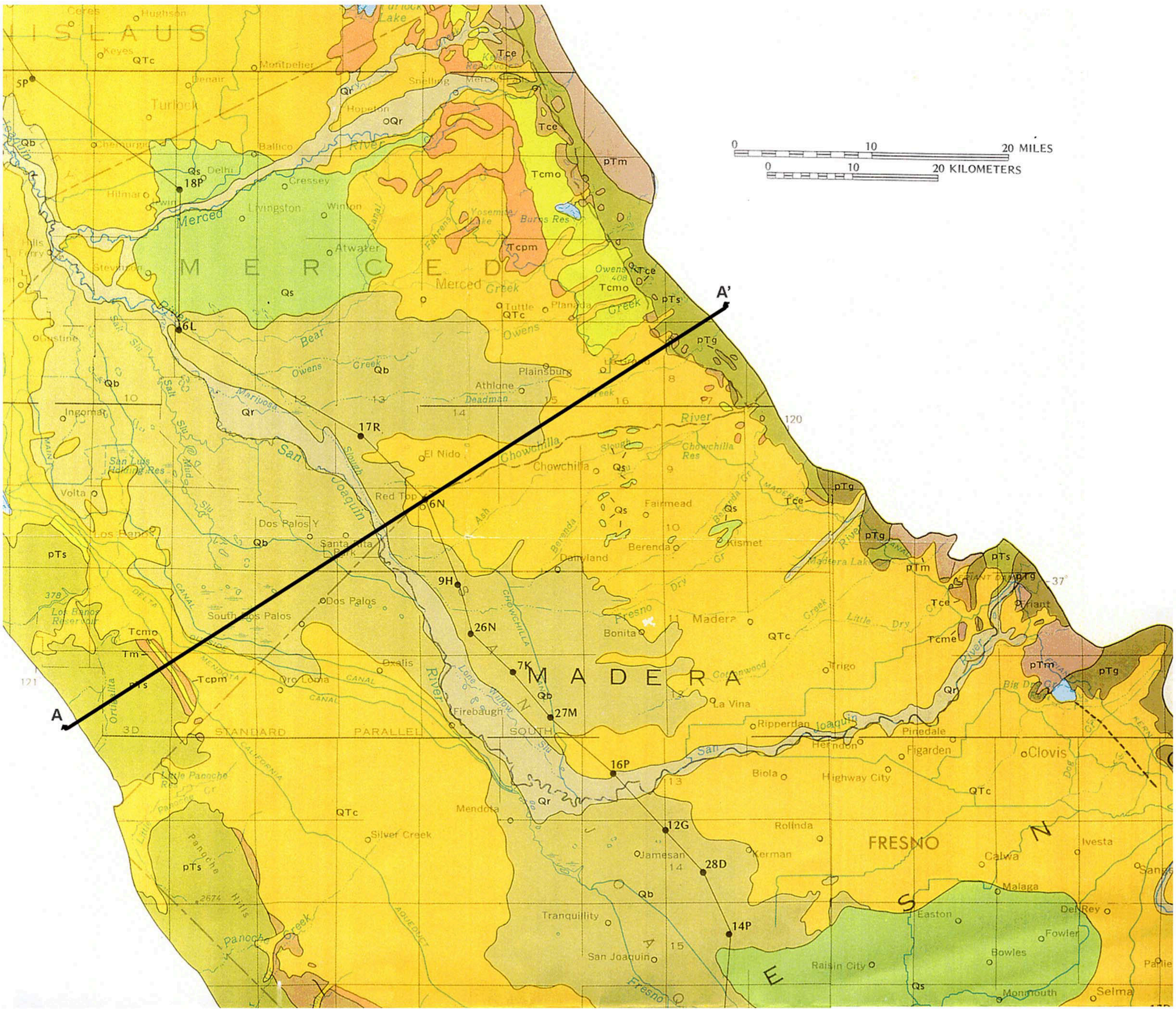
The remaining upper (shallower) portion of the San Joaquin Valley is filled with alluvium eroded from the Coast Ranges and Sierra Nevada, lacustrine and marsh-deposits, dune sands, and river and flood-basin deposits. In the central part of the San Joaquin Valley, alluvium derived from the Coast Ranges intermingles with material derived from the Sierra Nevada (commonly referred to as Sierran Sand) (Belitz and Heimes 1987). Modern (in geologic time) alluvium is deposited along the outer margins of the San Joaquin Valley as alluvial fans and plains. San Joaquin River tributaries flow into the valley, most from the Sierra Nevada, and commonly bisect the alluvial fans and valley uplands. The valley deposits made from the Coast Range and Sierra Nevada alluvium form an important aquifer system within the valley. These deposits are interbedded and intermixed with clay and silt layers that settled in paleo-lake beds, which occupied local depressions on the valley floor. Some of the lacustrine clay and silt deposits are thick and laterally extensive. On average, fine-grained deposits make up 50 percent or more of the valley-fill sediments in the basin (Planert and Williams 1995, Page 1986). Generally, the alluvial deposits in the San Joaquin basin are a heterogeneous mixture of coarse- and fine-grained sediments that vary widely over short distances and depths.



Sources: Teale Data Center; U.S. Bureau of Reclamation; Jones & Stokes

Jones & Stokes

Figure 4-1. Project area of the San Joaquin River Restoration Study showing Reach and Subreach boundaries.



DESCRIPTION OF MAP UNITS

Qs **Sand dunes (Holocene)** Windblown sand and dune sand

Qb **Flood-basin deposits (Holocene)** Clay, silt, and some sand; near Stockton consist of muck, peat, and other organic soils. In places may include part of the Modesto Formation (Pleistocene)

Qr **River deposits (Holocene)** Gravel, sand, silt, and minor amounts of clay; deposited along channels, flood plains, and natural levees of main streams. In places may include part of Modesto Formation (Pleistocene)

QTl **Lacustrine and marsh deposits (Pliocene to Holocene)** Clay, silt, and some sand; in subsurface include three widespread clays: A clay (Pleistocene and Holocene?); C clay (Pleistocene); and modified E clay (Pleistocene), includes Corcoran Clay Member of Tulare and Turlock Lake Formations

QTc **Continental rocks and deposits (Miocene to Holocene)** Heterogeneous mix of generally poorly sorted clay, silt, sand, and gravel; some beds of claystone, siltstone, sandstone, and conglomerate. Include some informal units: younger alluvium (Holocene), older alluvium (Pleistocene and Holocene?) and continental deposits (Pliocene and Pleistocene); three formations of Pleistocene age: Modesto, Riverbank, and Turlock Lake; Tulare Formation (Pliocene and Pleistocene) on western side of valley, Laguna Formation (Pliocene) on eastern side, and Kern River Formation (Miocene to Pleistocene?) on southeastern part

Tvd **Volcanic rocks and deposits (Miocene and Pliocene)** Massive tuff with large fragments of vesicular basalt northwest of Tracy; tuff, and volcanic breccia at south end of valley

Tcpm **Continental rocks and deposits (Miocene and Pliocene)** Gravel, sand, silt, clay, conglomerate, sandstone, siltstone, and claystone, contain andesitic material. Principally Mehrten Formation (Miocene and Pliocene) on eastern side of valley; include continental equivalents of Etchegoin Formation (Miocene and Pliocene) on western side of valley, and Chanac Formation (Miocene) on southern part

Tcmd **Continental and marine rocks and deposits (Miocene and Pliocene)** Gravel, sand, silt, clay, silty sandstone, and siltstone. Include continental and marine equivalents of San Joaquin Formation (Pliocene) and Etchegoin Formation (Miocene and Pliocene)

Tm **Marine rocks and deposits (Eocene, Oligocene, Miocene, and Pliocene)** Sand, clay, silt, sandstone, shale, mudstone, and siltstone. On western side of valley include the San Joaquin and Etchegoin Formations, Temblor Formation (Oligocene and Miocene) and Kreyenhagen Formation (Eocene). On southeastern side include the Santa Margarita Formation of various authors, the Round Mountain Silt, the Olcese Sand, the Freeman Silt, and the Jewett Sand (including the Pyramid Hill Sand Member) (all Miocene), and the Vedder Sand (Oligocene)

Tcmo **Continental rocks and deposits (Oligocene and Miocene)** Gravel, conglomerate, sand, tuffaceous sand, clay, and sandy clay; contain rhyolitic material on eastern side of valley. Principally Valley Springs Formation (Oligocene and Miocene) on eastern side of valley; unnamed fanglomerates (Miocene) and Bena Gravel (Miocene) in the southern part

Tcme **Continental rocks and deposits (Eocene to Miocene)** Conglomerate, sandstone, consolidated fanglomerate, claystone, tuff and tuff breccia; near Fresno consist of tuffaceous sand and gravel. Near Bakersfield include the Bealville Fanglomerate (Oligocene and Miocene) and the Walker Formation (Eocene to Miocene)

Tce **Continental rocks and deposits (Eocene)** Conglomerate and sandstone; along eastern side of valley contain anauxite. Principally Ione Formation (Eocene) on eastern side of valley

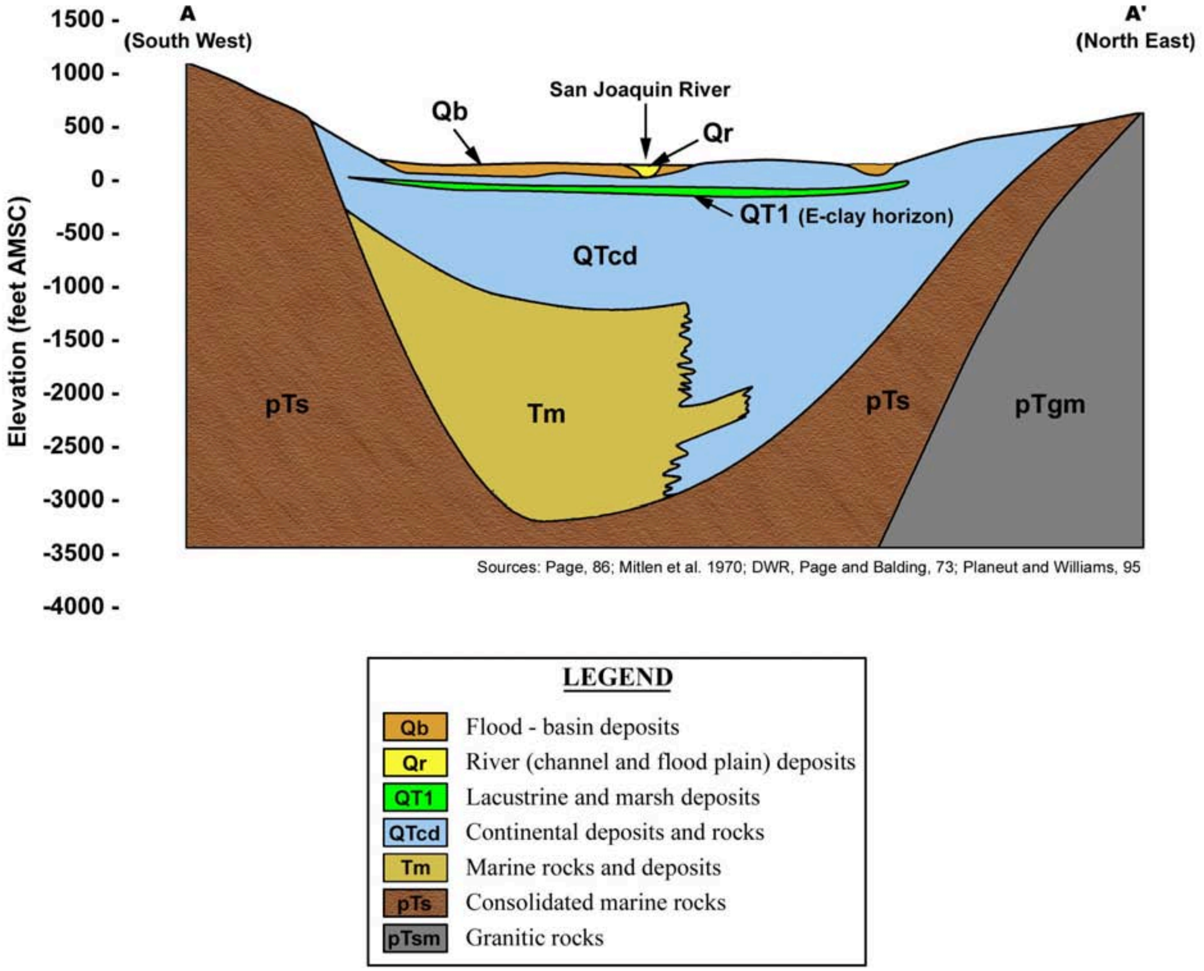
Unconformity

pTs **Marine rocks (Pre-Tertiary)** Sandstone, shale, siltstone, and some limestone, chiefly on western side of valley; in places contain abundant secondary gypsum. Include Moreno Formation (Cretaceous and Paleocene) and Panoche Formation (Cretaceous)

pTg **Granitic rocks (Pre-Tertiary)** Chiefly granitic rocks on eastern side of valley, in places consists of mafic intrusive rocks

pTm **Metamorphic rocks (Pre-Tertiary)** Metasedimentary, metavolcanic and other metamorphic rocks on eastern side of valley

Figure 4-2. Geologic units of the San Joaquin Valley, and location of cross section shown in Figure 4-3. Modified from Bertoldi et al., 1991 and many others.



Sources: Page, 86; Mitlen et al. 1970; DWR, Page and Balding, 73; Planeut and Williams, 95

Figure 4-3. Diagrammatic geologic cross section A – A' through the San Joaquin Valley showing underlying rocks and valley fill material. Modified from Bertoldi et al., 1991 and many others.

The San Joaquin Valley surface along the river corridor is covered by a thin veneer of sediments, described by Page (1986), Page and Balding (1973), Mitten et al. (1970), Phillips et al. (1991), and Belitz and Heimes (1987). The sediment veneer is river, flood-basin, and/or dune sand deposits (Figure 4-2). Page (1986) indicates that river deposits consist of both river channel and flood plain deposits. The river deposits still accumulate except in areas where human activity intervenes (e.g., during on- and off-stream gravel mining, or sediment trapping behind dams). In the absence in these human interventions, these accumulations would still be occurring. River deposits are dominated by sand and gravel, and range in width from a few feet to nearly 1,000 feet (Page 1986). The flood plain deposits are finer grained than the channel deposits and consist of interbedded and discontinuous layers of fine sand and silt. The band of flood plain deposits paralleling the San Joaquin River range in width from a few hundred feet to three miles. Although difficult to determine from boring logs, the estimated thickness of the river deposits are between 50- and 115-feet (Mitten et al. 1970 and Page 1986).

Table 4-1. Generalized stratigraphy of San Joaquin Valley (from Planert and Williams 1995).

System and Series		**Map Unit**	**Geologic Unit**	**Description**	**Maximum Thickness (feet)**	**Comments**
QUATERNARY	Holocene	Qs	Sand dunes	Dune sand	140	Generally lie above saturated zone but are highly permeable.
		Qb	Flood-basin deposits	Clay, silt, and fine sand with locally organic rich zones.	100	Low permeability with low yields to wells.
		Qr	River deposits	Gravel, sand and silt with minor amounts of clay.	100+	Among most permeable deposits in Valley; include both channel and flood plain deposits; generally, few, if any, wells completed in this unconfined unit.
TERTIARY AND QUATERNARY	Pleistocene	QT1	Lacustrine and marsh deposits	Clay, silt and some sand	100	Deposited in lakes and marshes; thickest sections beneath Tulare Lake Bed. Includes widespread E-clay horizon or "Corcoran clay" member as well as A- and C-clays of Tulare Lake basin.
	Eocene through Pleistocene	QTcd	Continental deposits and rocks	Upper layers of unconsolidated and interbedded gravel, sand, silt and clay; deeper layers of interbedded consolidated sandstone, conglomerate, tuff, siltstone, shale, and claystone.	1,000-3,000+	Upper unconsolidated units have low to high permeabilities; grade from unconfined to confined conditions with depth. Sierran sand deposits on east side of basin are coarser grained and generally have higher permeability and better water quality than Coast Range alluvial deposits. Deeper consolidated units have low to moderate permeabilities and wide range of salinity.
		Tm	Marine rocks and deposits	Sand, clay, silt, sandstone, shale, mudsone, and siltstone	2,000+	Mix of continental and marine sediments deposited as Ocean advanced and retreated. Locally yield large quantities of fresh water to wells.
PRETERTIARY		pTs	Consolidated Marine rocks	Sandstone, shale, siltstone, and some limestone.	20,000+	Outcrops appear primarily on western side of valley. Low yields of poor quality water to wells.
		PTgm	Granitic rocks	Chiefly granitic rocks with mafic intrusions in places.	n/a	Outcrops appear primarily on eastern side of valley. Yield low quantities of good quality water to wells where fractured.

Flood-basin deposits in the low-lying basins of the San Joaquin Valley were mapped and described by Page (1986) and Mitten et al. (1970) (Figure 4-2). These deposits were created by floods in recent (Holocene) times and consist of fine sand, fine silt, clay, and organic matter. The flood-basin deposits average between 5 and 35 feet thick (Phillips et al. 1991, and Gronberg and Belitz 1992) but may be as much as 100 feet thick (Page 1986, and Mitten et al. 1970).

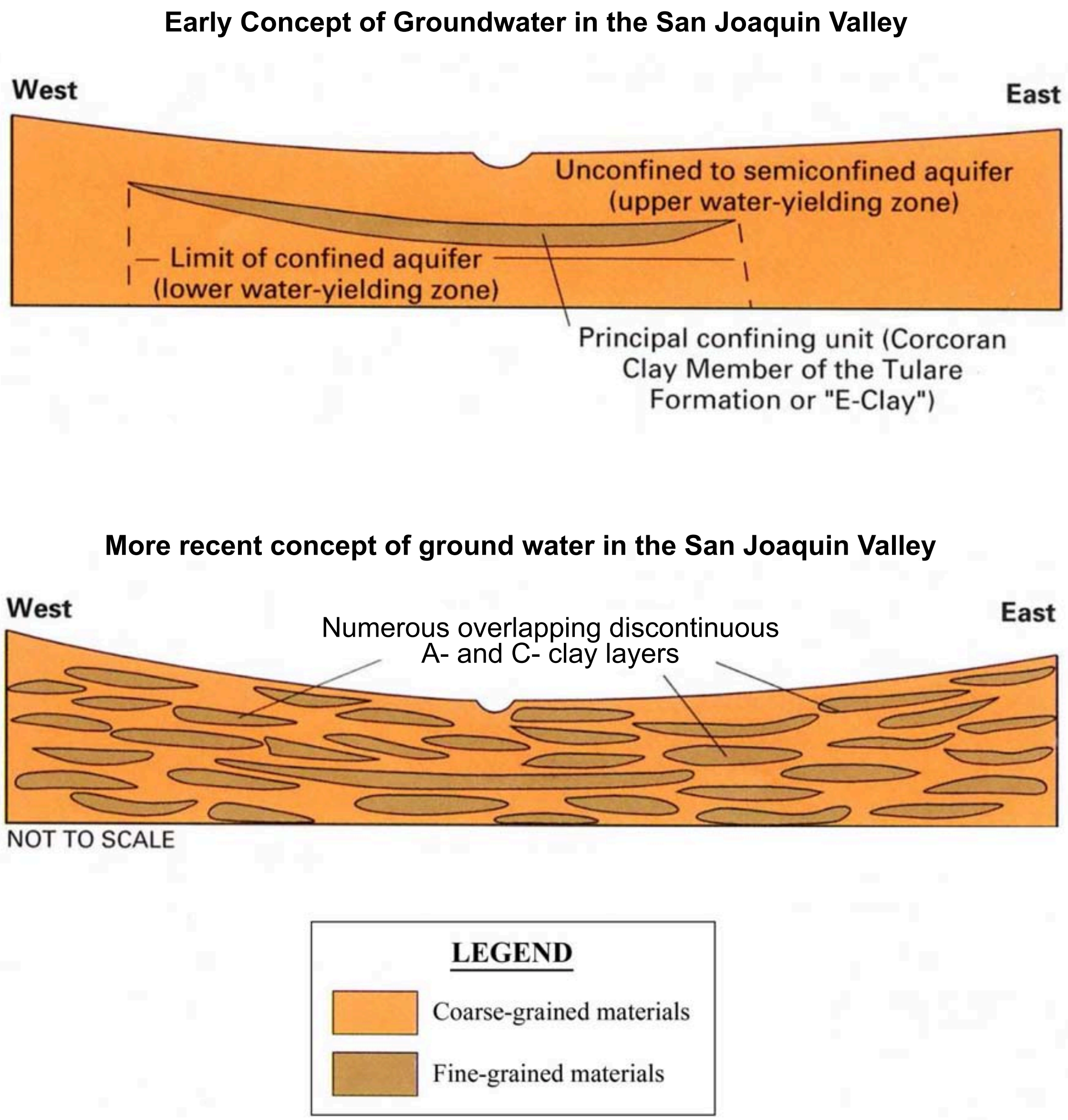
A large area of dune sand deposits is exposed along the south side of the Merced River in the north central part of the study area (Figure 4-2). These sand deposits range in thickness from 0 to 140 feet and consist of layers of well-sorted fine to coarse-grained sand and silt. Page (1986) indicates that, in most places, the dune sands lie above the saturated zone and do not serve as aquifers. However, the dune sands have high permeability and readily permit recharge of runoff, direct precipitation, and irrigation water.

4.5. SAN JOAQUIN HYDROGEOLOGY

Bordering and underlying the San Joaquin Valley, the consolidated marine sediments of the Coast Ranges and crystalline bedrock of the Sierra Nevada are virtually impermeable; groundwater flow through these units is insignificant. The marine and consolidated continental deposits that fill and occupy the deeper portions of the valley (Figure 4-3) are also less important aquifers because they commonly contain saline water and/or are of low permeability. The younger and shallower continental rocks and alluvial deposits contain most of the fresh groundwater in the basin. Because of its fine-grained nature, chemical components of the soil, and quality of recharge water, the Coast Range alluvium produces poor quality groundwater, particularly in the upper 50 feet. The Sierran Sand is coarser and more permeable. Where Sierran Sand exceeds a thickness over 200 feet, groundwater is preferentially pumped because of the high permeability of the sand (Gronberg and Belitz 1992, Groundwater Management Technical Committee 1999).

On a regional scale, early San Joaquin Valley studies suggested a simple groundwater conceptual model of an unconfined to semiconfined aquifer in the unconsolidated deposits, located above a laterally extensive impermeable clay layer, with a confined aquifer below this clay layer (top of Figure 4-4). The E-clay was thought to be a single laterally extensive and relatively thick zone of clay layers deposited as part of a thick sequence of lacustrine and marsh deposits underlying Pleistocene-era Tulare Lake. More recent studies have identified additional, less extensive clay layers in the valley (bottom of Figure 4-4). Within the Tulare Lake Basin, six clay layers were designated from youngest to oldest (shallowest to deepest) by the letters A through F. The Quaternary age A, C, and E clays were designated as extensive, with the E-clay being the most extensive, underlying most of the San Joaquin Valley. The E-clay is considered equivalent to the Corcoran Clay member of the Tulare Formation (Mitten et al. 1970). The top of the E-clay was defined at about 80 feet deep near Chowchilla and deepens to the southwest (Mitten et al. 1970). The A- and C-clay layers are confined to the Tulare Lake Basin and do not appear to extend further north than the southern city limits of Fresno, based on data presented by Page (1986). However, if present beneath the area, the A-clay horizon may act to create perched unconfined groundwater conditions very close to the ground surface.

Recent studies suggest that, because the basin sediments are so heterogeneous, the aquifer contains water under unconfined conditions at shallow depths and then grades through semiconfined and confined aquifer conditions as depth increases. The confined aquifer conditions result from numerous overlapping and discontinuous lenses of clay. Detailed analyses of wells logs indicate that the E-clay is not a single homogeneous unit, but is better characterized as a zone of multiple clay layers interbedded with more permeable units (Groundwater Management Technical Committee 1999). In addition, differences in hydraulic head measured directly above and below the E-clay are relatively



Early Concept of Groundwater in the San Joaquin Valley

More recent concept of ground water in the San Joaquin Valley

Figure 4-4. Diagrammatic cross sections showing aquifers of the San Joaquin Valley. According to early concepts of the aquifer system (upper figure), it was generally considered to be confined under the Corcoran Clay Member of the Tulare Formation ("E-clay"); however, recent studies suggest that the entire aquifer system is a single heterogeneous system in which vertically and horizontally scattered lenses of fine-grained materials provide increasing aquifer confinement with increasing depth. Modified from Bertoldi et al., 1991 and many others.

small, when compared to head differentials observed in wells monitoring shallow and deep portions of the aquifer system (Planert and Williams 1995). The pre-Euro-American settlement and current groundwater flow conditions in the regional unconfined and confined groundwater systems are described in Sections 4.6.1 and 4.6.2. The net implications to historical shallow groundwater conditions along the San Joaquin River of the two conceptual models is that (1) while the more complicated model is technically more correct, the simple model adequately explains the processes that created the artesian springs along the axis of the valley, and (2) the more complicated model helps explain the heterogeneity of artesian springs along the valley.

River deposits are the most permeable deposits in the San Joaquin Valley, and they appear to be hydraulically connected to adjacent stream channels and flood plain deposits (Page 1986). River deposits are also hydraulically connected with deeper portions of the unconfined aquifer zone. However, because of their fine-grained nature, flood-basin deposits yields are low and these deposits tend to impede the downward vertical movement of water.

4.6. EVOLUTION OF GROUNDWATER FLOW CONDITIONS

This section examines historical and post-development groundwater supply conditions. Important components include groundwater use pre- and post-development, land subsidence, and water quality.

4.6.1. Pre-groundwater development conditions (approx. pre-1860)

Prior to development and extensive pumping, groundwater flowed from the high elevations of the valley margins towards the San Joaquin Valley trough. Water originating from mountain rain and snowmelt entered the valley aquifer system and recharged the shallow unconfined aquifer along the valley margins (Figure 4-5). As a result, at the valley margins, the unconfined aquifer had a higher hydraulic head than that of the deeper confined aquifer. Belitz and Heimes (1987) report that early geologic surveys indicate marshland along most of the valley trough, and numerous early explorers describe expansive tule marshes along much of the river, from present-day Firebaugh to the Merced River confluence (summarized in Fox, 1987). In the valley trough, however, hydraulic head in the unconfined aquifer was less than that in the confined aquifer. The head differential in the valley trough created an upward pressure gradient (artesian condition), allowing groundwater to discharge to the river and valley marshes (Figure 4-5). This groundwater contribution process was also noted in early engineering surveys. For example, Hall (1886) mapped the approximate zone of artesian potential and the approximate boundaries of swamp and overflowed lands throughout the Sacramento, San Joaquin, and Tulare Lake basins (Figure 4-6). During periods of low surface flow, the shallow unconfined aquifer of the valley trough would contribute significant baseflows to the San Joaquin River (Figure 4-7); therefore, much of the river in the valley trough was a “gaining” reach (Figure 4-8). Marshlands and artesian conditions at this time confirm that the valley trough was a discharge area under predevelopment conditions. These groundwater conditions were applicable to Reaches 3, 4, and 5, and portions of Reach 2. Reach 1 was upslope from the confined aquifer (in the recharge area), thus spring flows were likely gravity flow and not artesian.

The San Joaquin River and Tulare Lake basins were periodically connected during periods of high river flow and/or high lake levels (see Chapter 2). During high flows on the Kings River, a portion of the flow would empty into Tulare Lake, but a portion would also flow north, joining the San Joaquin River via Fresno Slough at the present-day location of Mendota. During high flows on the San Joaquin River, flows would spill out on the southern bank and flow south into the Fresno Slough. From that point, the flow appears to have flowed back to the north via Fresno Slough re-joining the San Joaquin River at Mendota. There is also some suggestions that during periods of

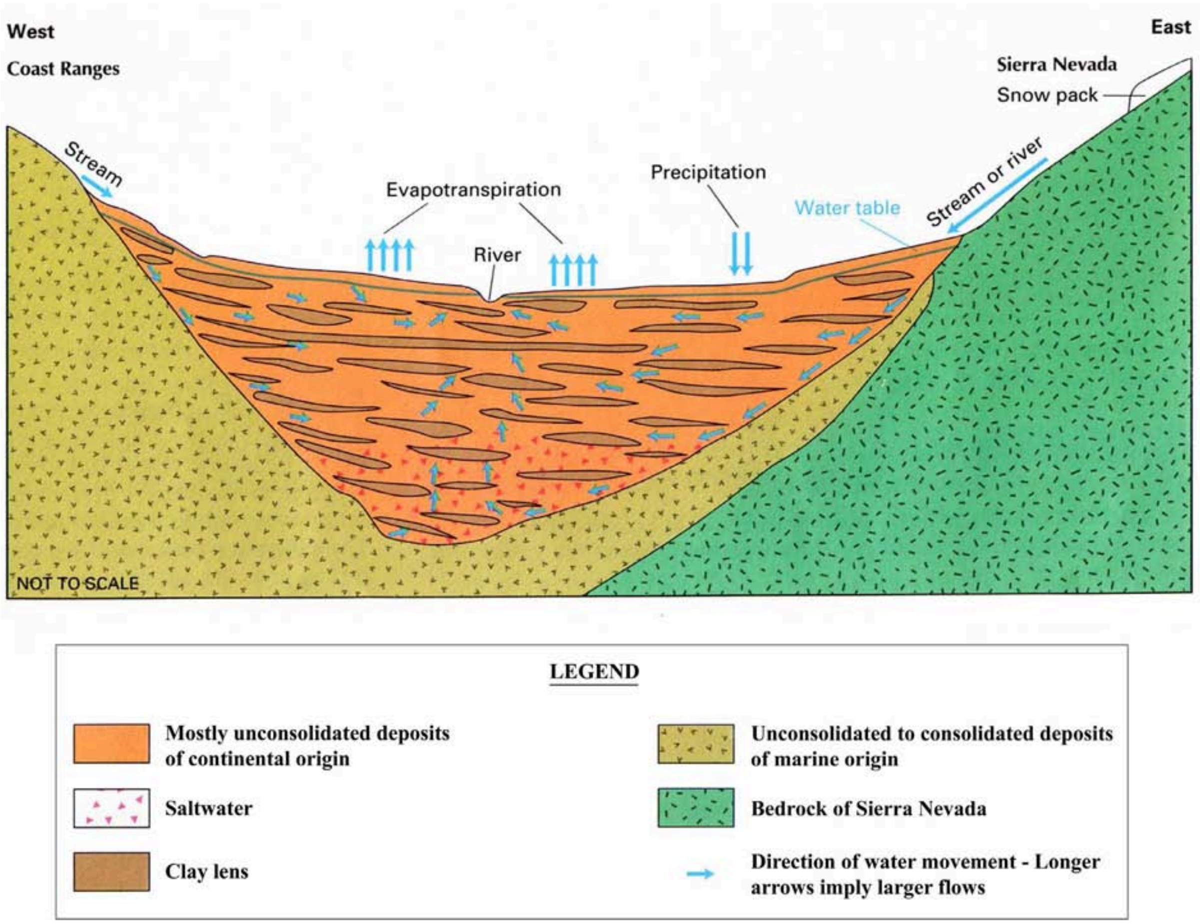


Figure 4-5. Diagrammatic hydrogeologic section showing that before development: 1) surface water recharged the aquifer at the valley margins, 2) moved downward and laterally into the aquifer system, and 3) then moved upward to discharge at rivers and marshes at the valley axis. Modified from Bertoldi et al., 1991 and many others.

high water elevations in Tulare Lake, that surface water would flow from the lake to the San Joaquin River via Fresno Slough. Additionally, there has been some statements that there was a groundwater contribution from Tulare Lake to the San Joaquin River. Fox (1987) summarized a statement from Anonymous (1873) that “the San Joaquin receives an important accession of volume from underground storage – probably from the Tulare Lake drainage”. This assumption is discounted by later surveyors (e.g., Mendenhall et al. 1916). This “accession of volume” described by Anonymous (1873) may have been the shallow groundwater and artesian contribution from the San Joaquin River aquifer rather than the Tulare Lake aquifer.

To substantiate historical accounts of the shallow unconfined aquifer being close to ground surface, contour maps of pre-development groundwater surface and ground surface were compared. Pre-development shallow groundwater contours were estimated by Williamson et al. (1989). The existing ground surface was generated from the most recent USGS 30 meter grid Digital Elevation Model for 7.5-minute quadrangles along the river (Figure 4-9). The USGS data were used to create a Digital Terrain Model (DTM), and 10 ft contours were generated from the DTM. The existing ground surface

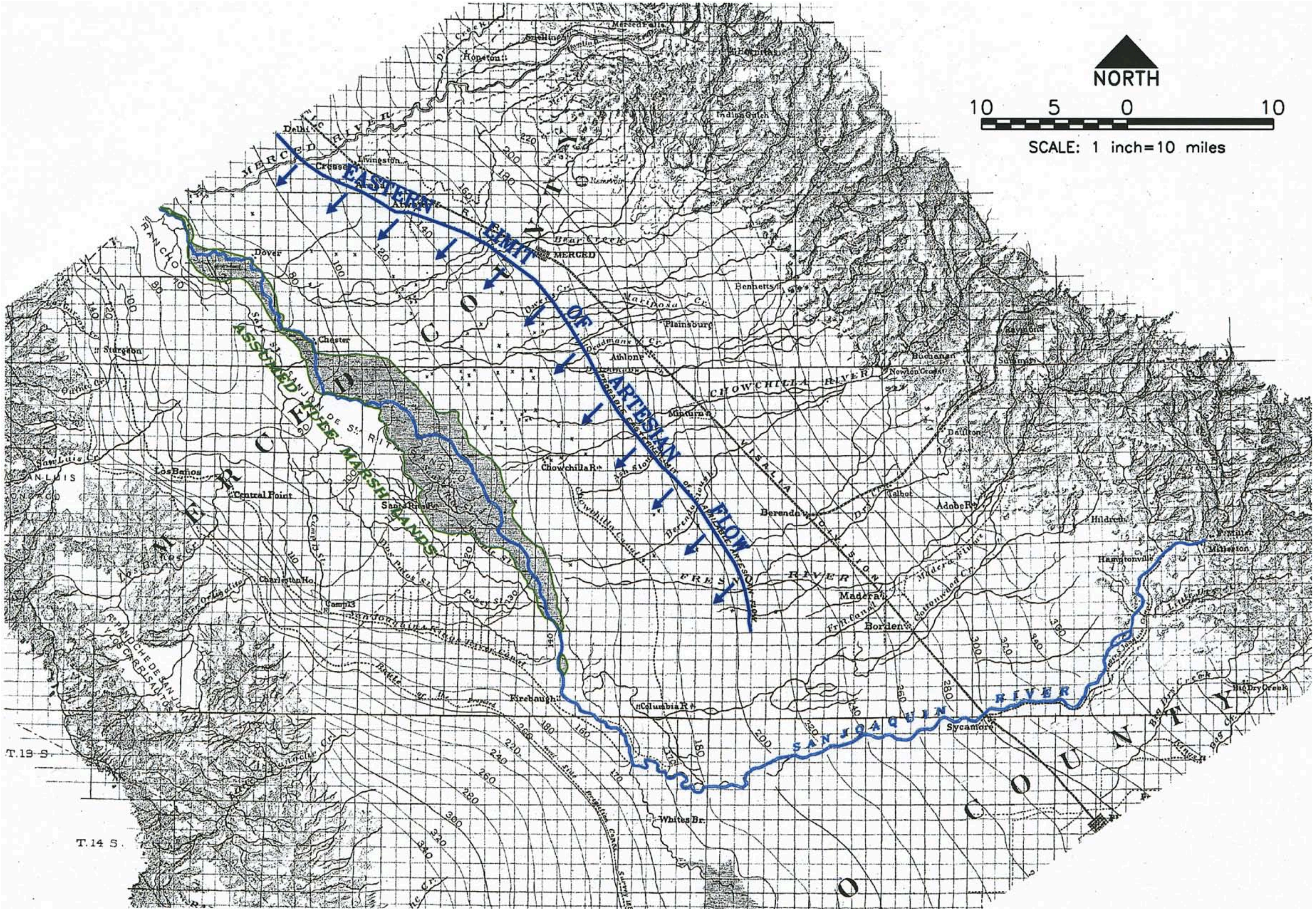


Figure 4-6. Approximate artesian zone and tule marshland based on W.H. Hall map (1886). Artesian potential was between this line and the San Joaquin River, but artesian springs were most likely closer to the river than to the line drawn by Hall.

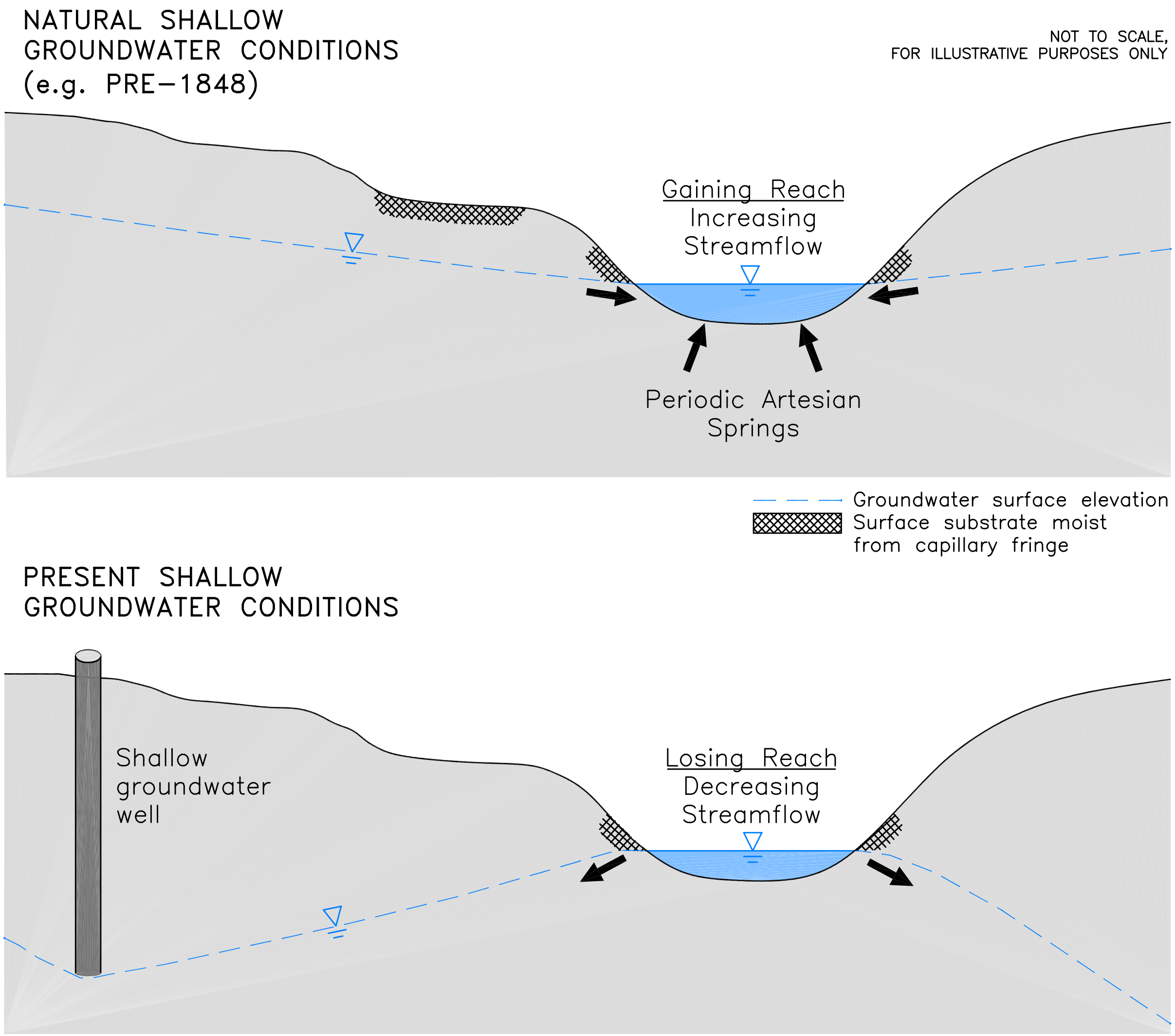


Figure 4-7. Diagrammatic cross section of the relationship of the shallow groundwater table to the San Joaquin River under historical conditions, as well as current conditions with significant shallow groundwater pumping adjacent to the river.

DTM does not accommodate recent subsidence-induced changes in ground surface elevations. Pre-development groundwater contours were used to create another DTM, and the two DTM's were used to generate "cut/fill" contours between the existing ground and pre-development water table. These contours represent "depth to groundwater surface" from ground surface, for pre-development conditions (Figure 4-10).

These contours show that the pre-development groundwater elevations were virtually the same elevations as the river downstream of SR 99 (RM 245), and were close to the ground surface elevations of adjacent lands downstream of RM 230. These contours corroborate historical accounts of the shallow groundwater being very close or above the river surface; however, this coarse scale of mapping does not incorporate finer scale seasonal trends that certainly occurred between winter and summer periods, as well as local topographical and groundwater table variability.

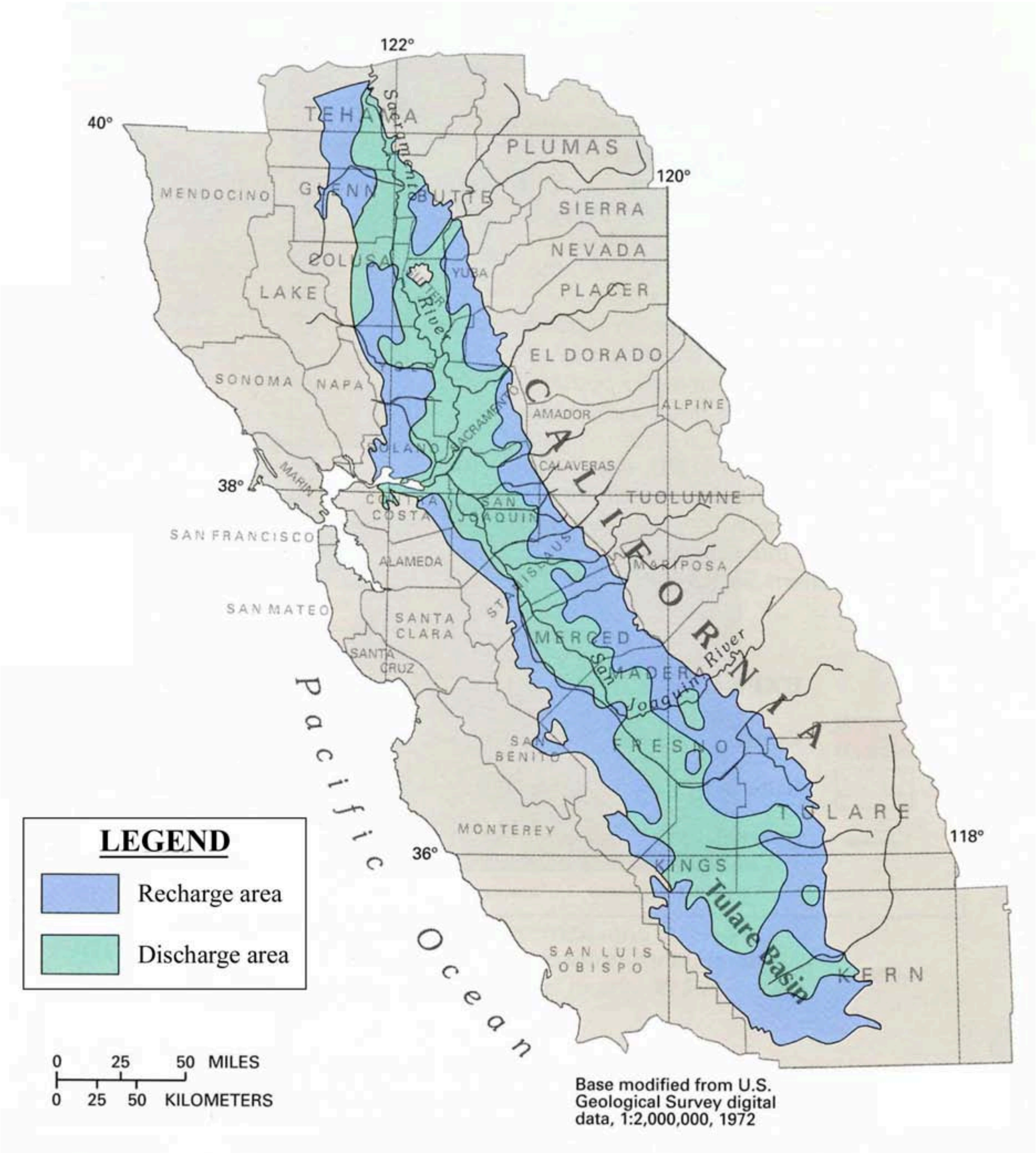


Figure 4-8. Zones of groundwater recharge and discharge in the Central Valley. Before groundwater pumping and surface water diversions, most of the recharge to the Central Valley aquifer system was from rain and snowmelt in the mountains at the valley margins, and discharge was to rivers and marshes near the valley axis. Modified from Williamson et al. (1989).

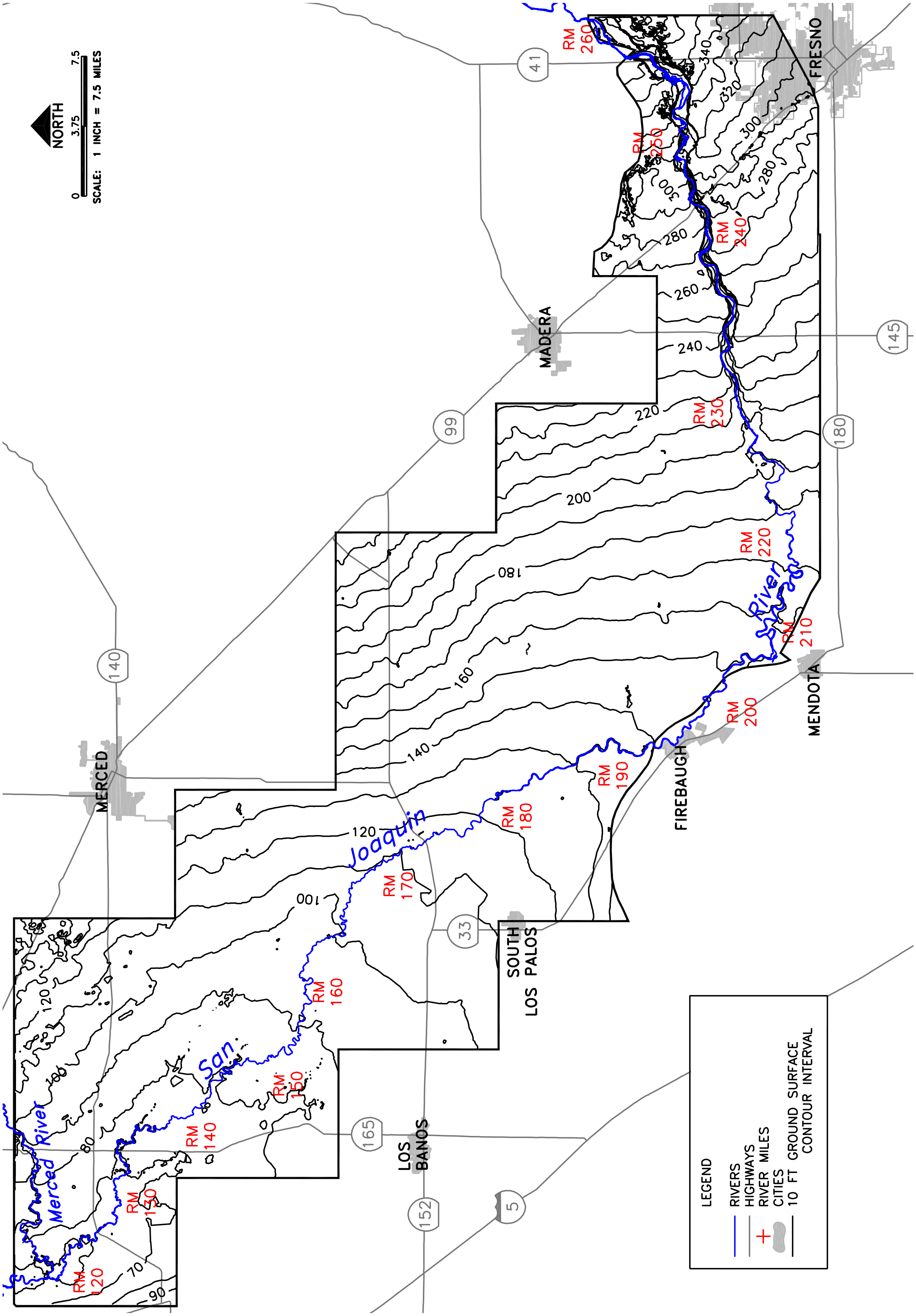


Figure 4-9. Existing ground topography from USGS 30 Meter grid digital elevation models. Not corrected for present-day subsidence.

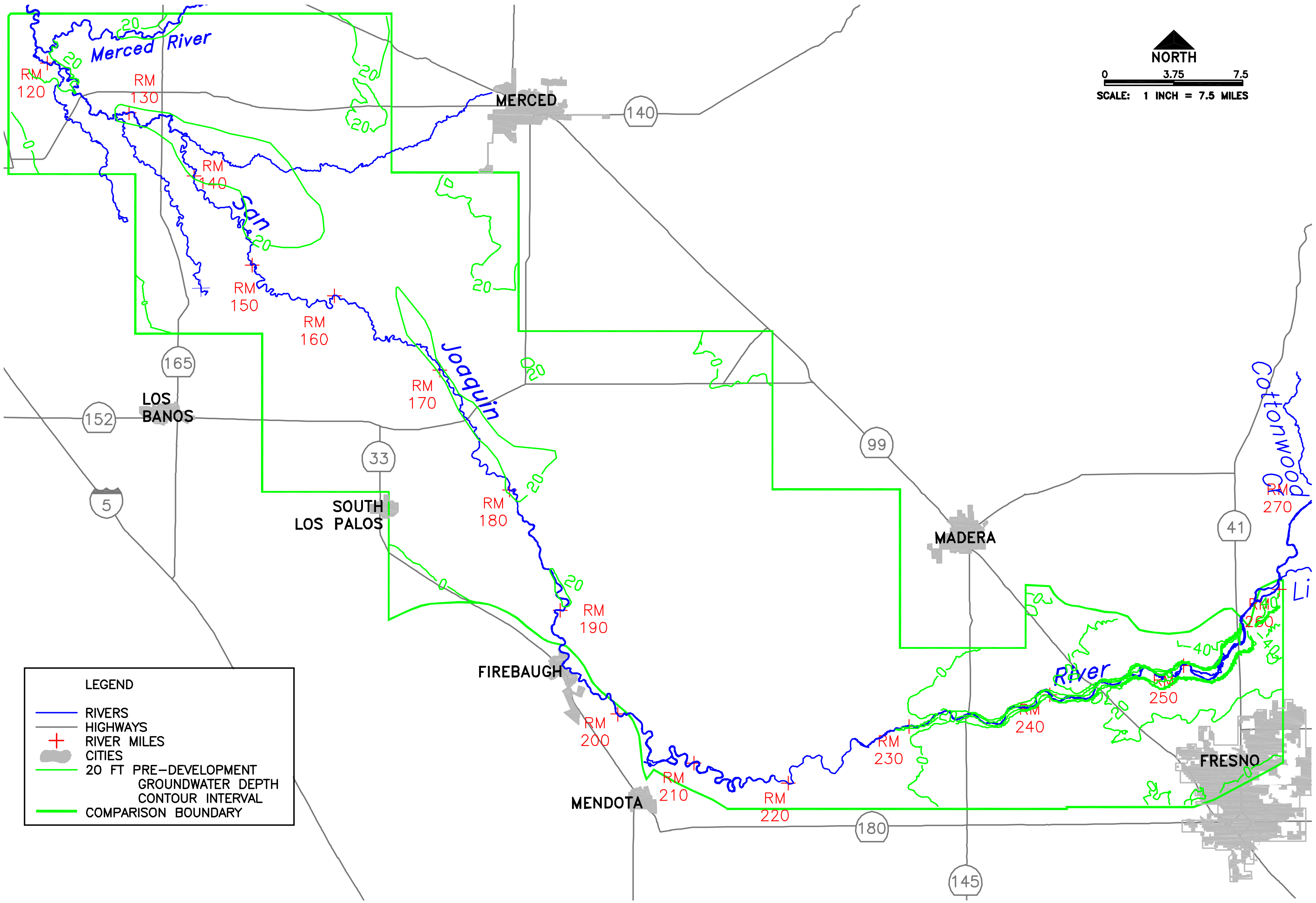


Figure 4-10. Estimated pre-development groundwater contours from Williamson et al. (1989), shown as a depth from the existing ground surface (from Figure 4-9).

4.6.2. Post-development conditions

Use of groundwater resources began in the 1870s when wells were dug by hand or by steam powered drill rigs. Deeper wells extended through the Concoran Clay layer, and took advantage of the hydraulic head of the artesian zone to avoid any need for pumps. By 1885, these artesian wells lost pressure due to overdraft, and by 1900, many of the former artesian wells required pumps (Mendenhall, 1908). Significant groundwater withdrawals began in the mid-1910s and increased steadily through the early 1940s. After World War II, groundwater withdrawals escalated dramatically in the San Joaquin Valley (Belitz and Heimes, 1987). Most pumping occurred in the lower confined aquifer, but pumping also occurred in the upper unconfined zone. By the mid-1960s, groundwater pumping had significantly decreased hydraulic head, increased depth to groundwater, and altered groundwater flow directions (Figure 4-11). While most springs in the study reach have disappeared, there are supposedly a few remaining springs in the Los Banos area (Wolfe, personal communication).

Similarly, increases in depth to groundwater in the unconfined aquifer in the San Joaquin Valley currently exist, in areas of intense groundwater pumping. Shallow groundwater contours for 1953 and 1996 illustrate the trend in increasing depth to groundwater. Similar to the process for the obtaining a pre-development conditions map, the 1953 and 1996 groundwater elevation contour maps were converted to “depth to groundwater” contour maps (Figures 4-12 and 4-13). Differences between Figure 4-10, Figure 4-12, and Figure 4-13 document that the first stage of significant increase in depth to groundwater (1953) was minor (zero to 40 ft), downstream of RM 215. By 1996, increase in depth to groundwater was much more severe closer to the river between Friant Dam (RM 267) and RM 170. Figure 4-13 demonstrates a linear trough of depressed groundwater elevations east of and parallel to the San Joaquin River, extending from approximately El Nido on the north to Mendota to the south. Groundwater elevations are also depressed in Chowchilla and at a groundwater pumping center located southeast of Madera Lake.

In both the unconfined and confined aquifer zones, groundwater overdraft has changed flow direction from <u>toward</u> the San Joaquin River (Figure 4-5) to <u>away</u> from the San Joaquin River towards pumping/withdrawal centers (Figure 4-7, Figure 4-14). In the southern portion of the study area, the altered groundwater flow direction is likely a result of intense groundwater pumping from the unconfined zone, along the east side of the river (Figures 4-12 and 4-13). Belitz and Heimes (1987), and Phillips et al. (1991), report that due to groundwater pumping from this region, there is now a strong component of horizontal flow from west to east across the valley trough and under the San Joaquin River (Figure 4-14). There is a substantial volume of surface water contributed to the San Joaquin River from agricultural return flows; in addition to the surface flow contribution, a portion of the total water applied to adjacent agricultural lands flows to the San Joaquin River as a shallow groundwater contribution.

In the confined aquifer, overdraft has also caused a decrease in the regional hydraulic head of the confined aquifer, reversing the vertical gradient over much of the San Joaquin Valley. Vertical groundwater flow is now preferentially downward, from the upper unconfined zone of the aquifer system through the confining beds towards the lower confined portion of the aquifer system (Figure 4-14). A factor compounding this reversal in the vertical gradient is the completion of thousands of wells that are screened over both the unconfined and confined aquifer zones. Many of these cross-connected wells allow virtually unrestricted flow between zones. Although surface-water imports increased in the 1940s and 1960s, as of 1996, groundwater flow patterns in the San Joaquin Valley were the same as those described for the 1960s (Planert and Williams 1995). The implication of excessive overdraft is clear: water in the upper unconfined zone that once flowed towards the river and marshlands under predevelopment conditions, now flows vertically downward and away from the river and marshlands, eliminating natural discharge of shallow groundwater to the San Joaquin River over many reaches (Figure 4-7).

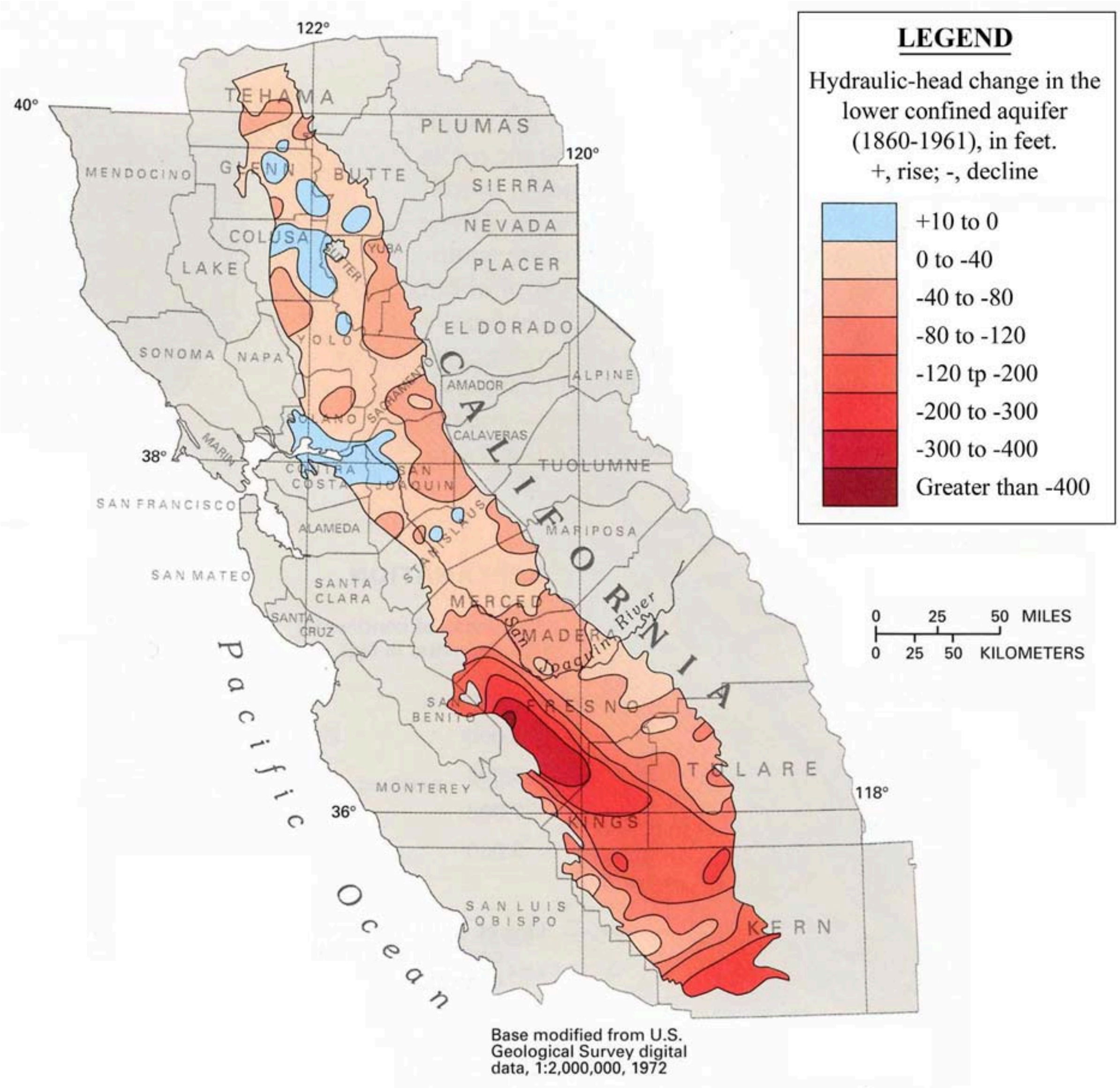


Figure 4-11. Zones of hydraulic head changes between 1860 and 1961 due to groundwater pumping and surface water regulation. Ground-water withdrawals from 1860 to the 1960's caused water levels in the confined part of the aquifer system to decline over most of the Central Valley, in some areas more than 400 feet. Modified from Williamson et al. (1989).

Long-term periods of dry weather reduce natural recharge of the aquifer system, and correspondingly tend to reduce surface water deliveries for irrigation from the CVP. When imported surface water deliveries for irrigation are limited, more groundwater is pumped to make up the shortfall. During the drought of the late 1980s and early 1990s, surface water deliveries were drastically reduced to most water districts in the San Joaquin Valley, resulting in increased groundwater pumping from the entire (confined and unconfined zones) aquifer system (Groundwater Management Technical Committee 1999). A regional response to drought in the San Joaquin Valley is a notable decrease in groundwater elevations due to increased pumping, followed by a regional rise in groundwater elevations once wetter precipitation years resume (Figure 4-15).

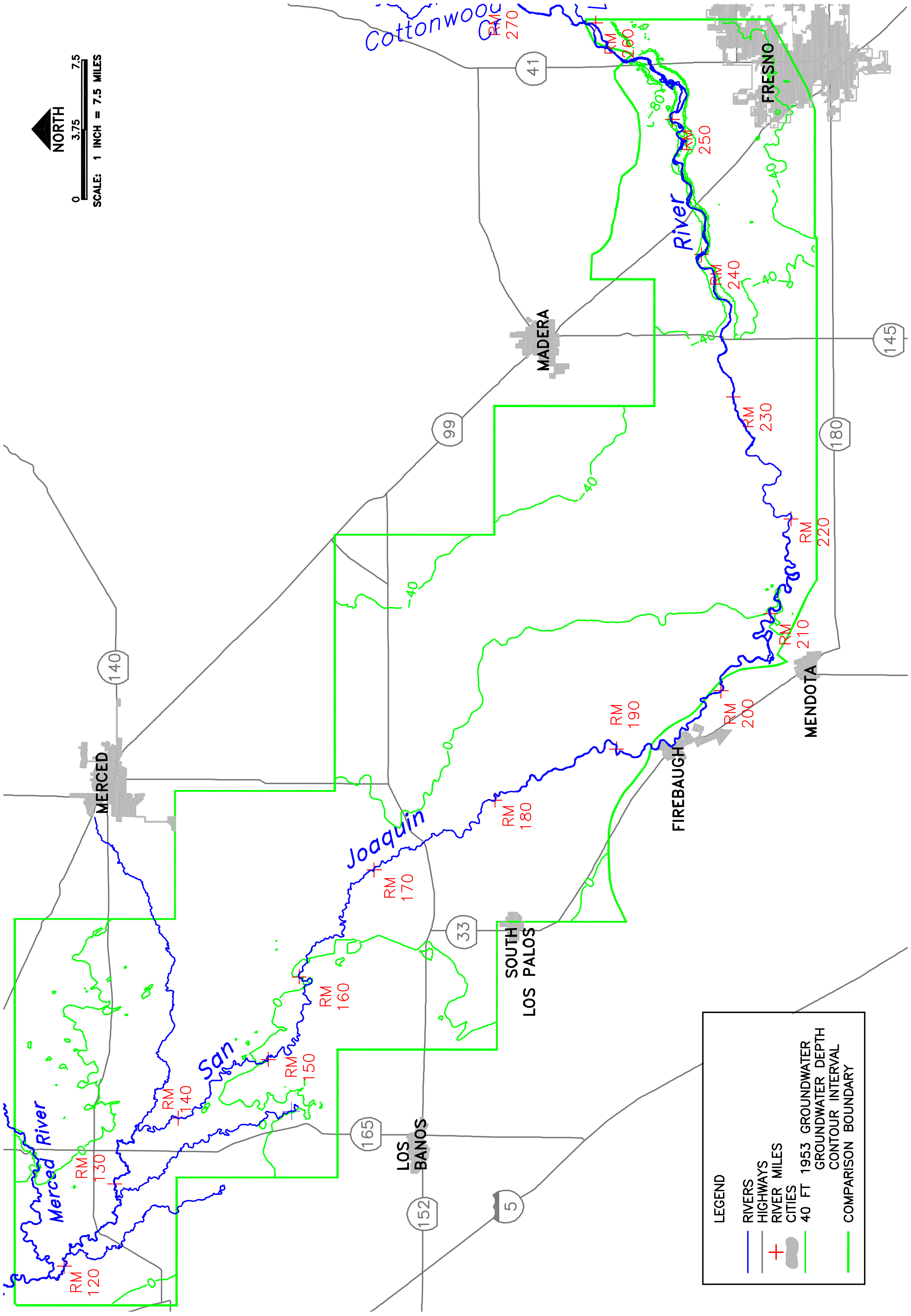


Figure 4-12. Estimated 1953 groundwater contours from Williamson et al. (1989), shown as a depth from the existing ground surface (from Figure 4-9).

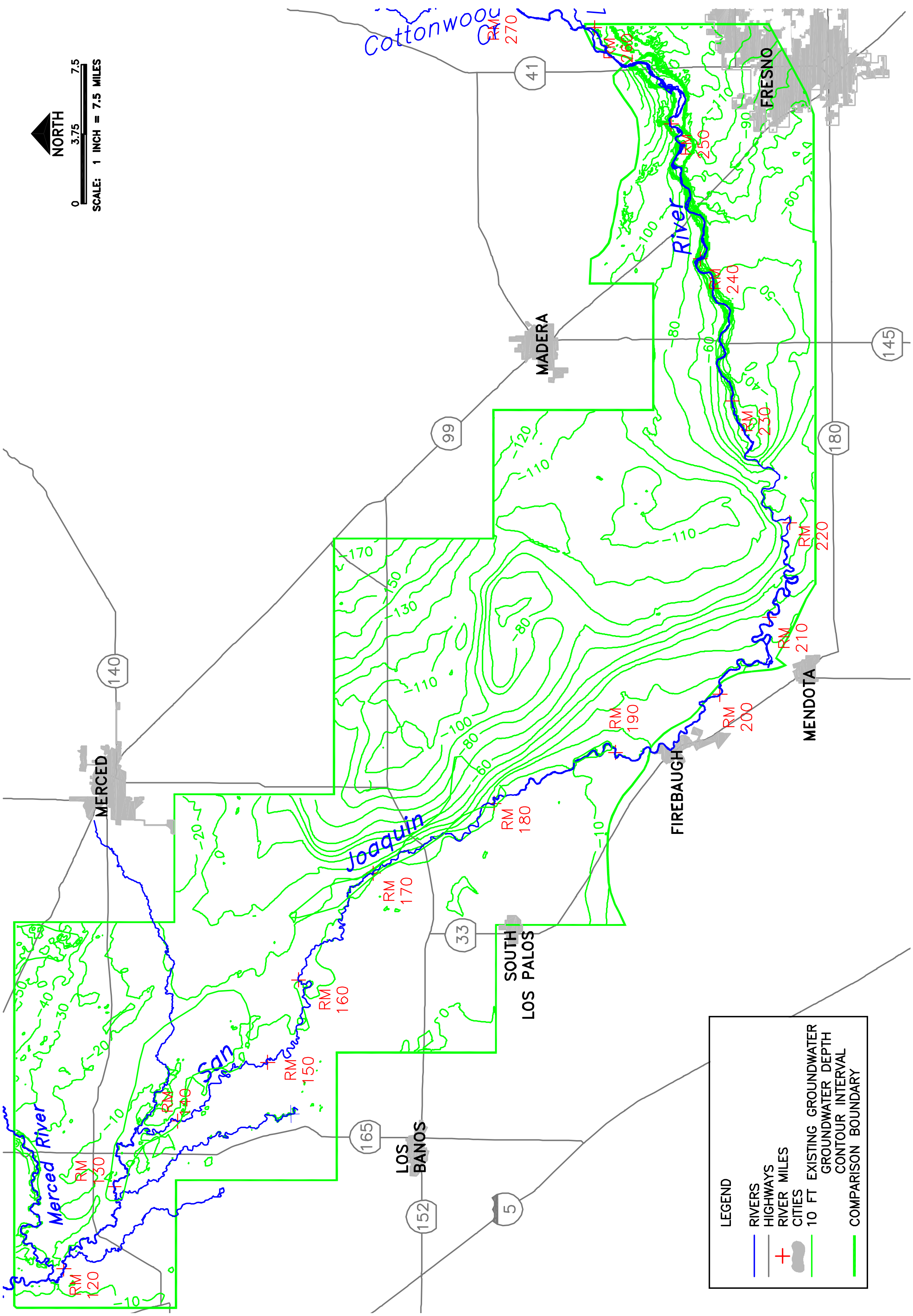


Figure 4-13. Estimated 1996 groundwater contours from Williamson et al. (1989), shown as a depth from the existing ground surface (from Figure 4-9).

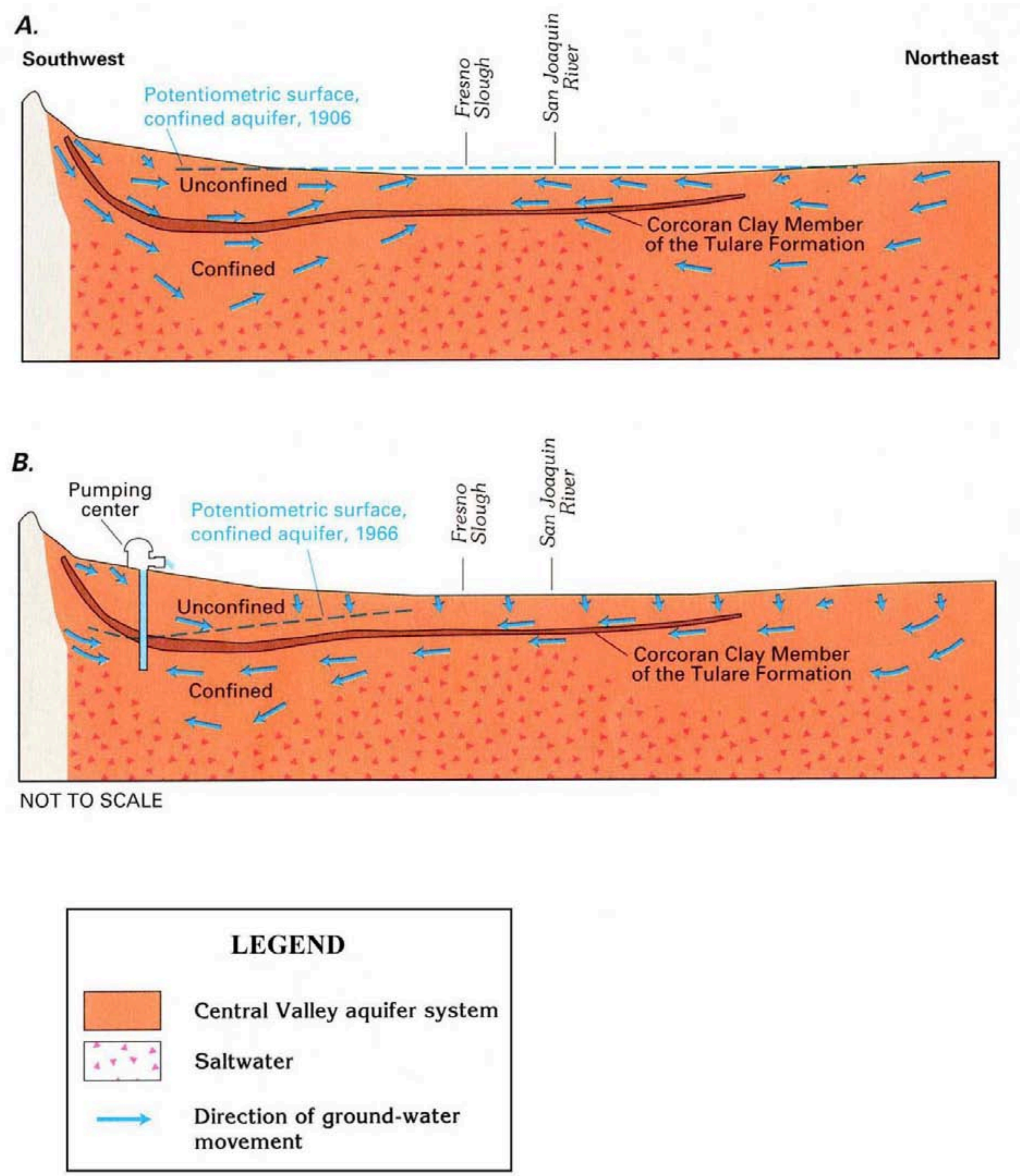


Figure 4-14. Diagrammatic cross section of the San Joaquin Valley showing pre-development groundwater conditions, and impact of pumping on present-day groundwater conditions.

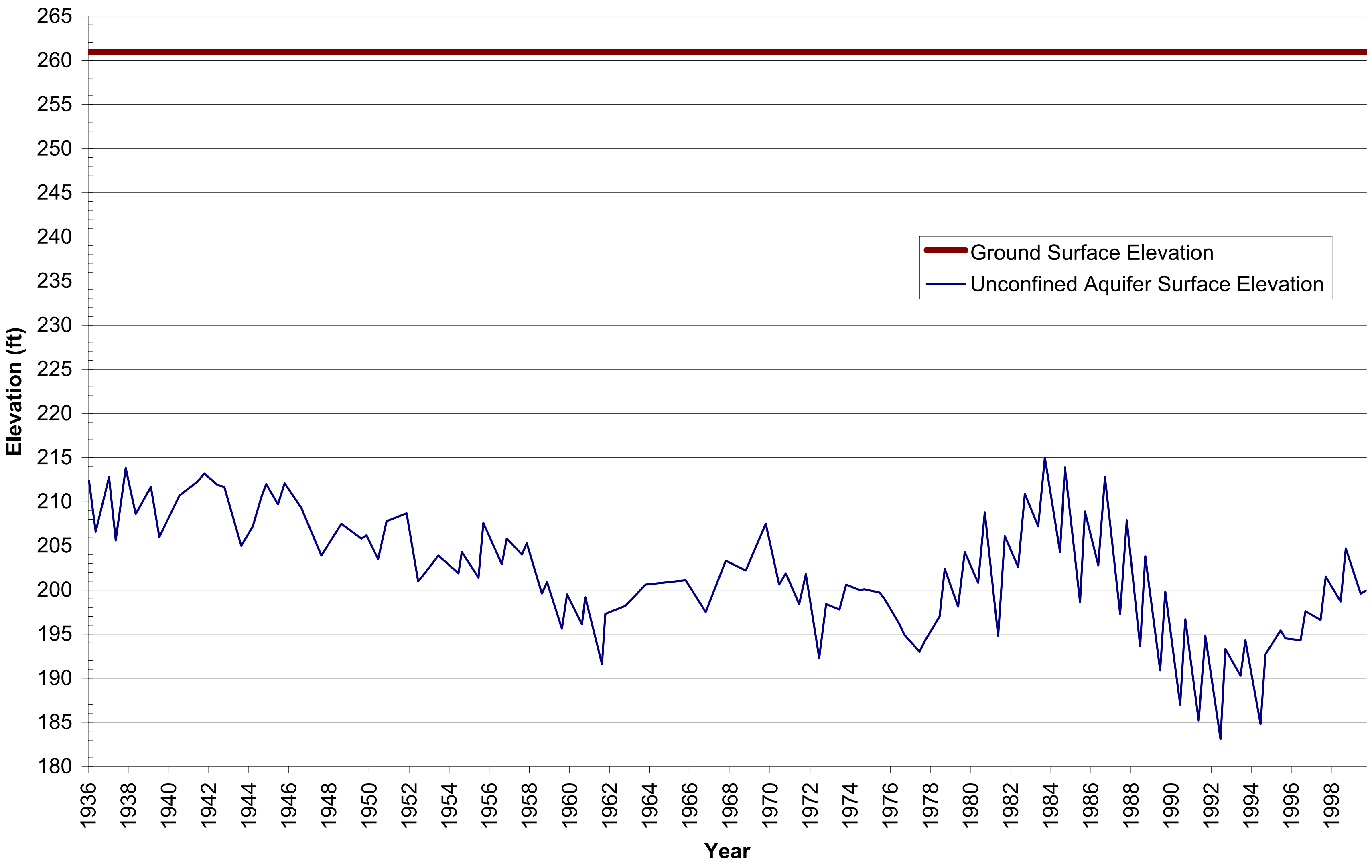


Figure 4-15. Example well showing drought and wet-year fluctuations in water table elevation within a general decline of water table caused by pumping overdraft. Well location is on north side of San Joaquin River at River Mile 237 (T.13S., R.18E., Section 4), downstream of Herndon.

In addition to groundwater pumping, application of irrigation water for agricultural practices may have locally significant effects on shallow groundwater levels within the study area. Irrigation is the primary source of groundwater recharge in the San Joaquin Valley. Although most irrigation recharge is located at distance from the San Joaquin River (e.g., eastern and western San Joaquin Valley), irrigation of cultivated fields and pasture near the river occurs within the study area. Phillips et al. (1991) observed localized and seasonal rises in shallow groundwater table elevations along the river during their study of shallow groundwater conditions. In both June and July 1989, although there were pumping-induced drops in groundwater elevations in intermediate and deep wells at one monitoring location, they observed a corresponding rise in the shallow water table associated with recharge of irrigation water. In spite of these spatially and temporal increases in shallow groundwater elevations due to irrigation, the net result in shallow groundwater table elevations has been a decline over time.

There is a considerable amount of data on shallow groundwater in the study reach, although much of the data is not immediately adjacent to the river. Maps of DWR well locations can be found at: http://well.water.ca.gov/gw/gw_data/hyd/Rpt_Bas_Well_AllCal.asp. Clicking to finer scaled maps at this site will eventually lead to the individual well locations, and selecting a certain well will download all water elevation measurements over the period of record. Recent groundwater elevation contour maps are at: http://www.dpla.water.ca.gov/sjd/groundwater/basinlst.html. For a large number of wells, long-term trends of groundwater elevations are available (Figure 4-15), some of which is available on-line at the above web sites. However, because of the severe overdraft of the shallow groundwater aquifer, many of these wells have been extended into deeper aquifers, and thus are not as useful for evaluating potential ramifications to restoration efforts along the San Joaquin River. More pertinent data is available from the San Joaquin River Pilot Projects monitoring efforts in Reach 2 and the lower portion of Reach 1B (see Section 4.6.5). Additional data may be available in the shallower private wells along the river, but this data may be more difficult to obtain.

4.6.3. Land Subsidence

Land subsidence is another impact of intense groundwater development in the San Joaquin Valley. From 1961 to 1977, the rate of groundwater withdrawal from the aquifer system was greater than the net recharge from all sources (Planert and Williams 1995). Some of the loss in groundwater storage is permanent because pumping of deep wells dewatered clay beds; once drained, the clay beds become compacted. Dewatering the clay layers reduces the clay's pore pressure and the weight of the overlying sediments compact the clay. Loss in porosity of the clay layers is permanent and causes irreversible land subsidence.

Significant subsidence due to groundwater withdrawals began in the San Joaquin Valley in the 1920's. By 1977, approximately half of the valley subsided at least a foot, with the most severely affected areas located in the southern and western parts of the valley, outside of the study area (Figure 4-16). Some areas south of Mendota had subsided by nearly 30 feet (Figure 4-17).

4.6.4. Groundwater-Surface Water Interaction

Since the 1950s, San Joaquin River flows have been controlled by Friant Dam, located upstream of Fresno, and by dams on tributary streams. Much of the water stored in Millerton Reservoir is diverted through the Friant-Kern and Madera canals. As described in Chapter 2, streamflows in the San Joaquin River have been greatly reduced, and the channel is perennially dry in Reach 2 and Reach 4B in most years. Downstream of Reach 4B, river flows are replenished by irrigation return flows, local runoff, and groundwater inflow (Groundwater Management Technical Committee 1999).

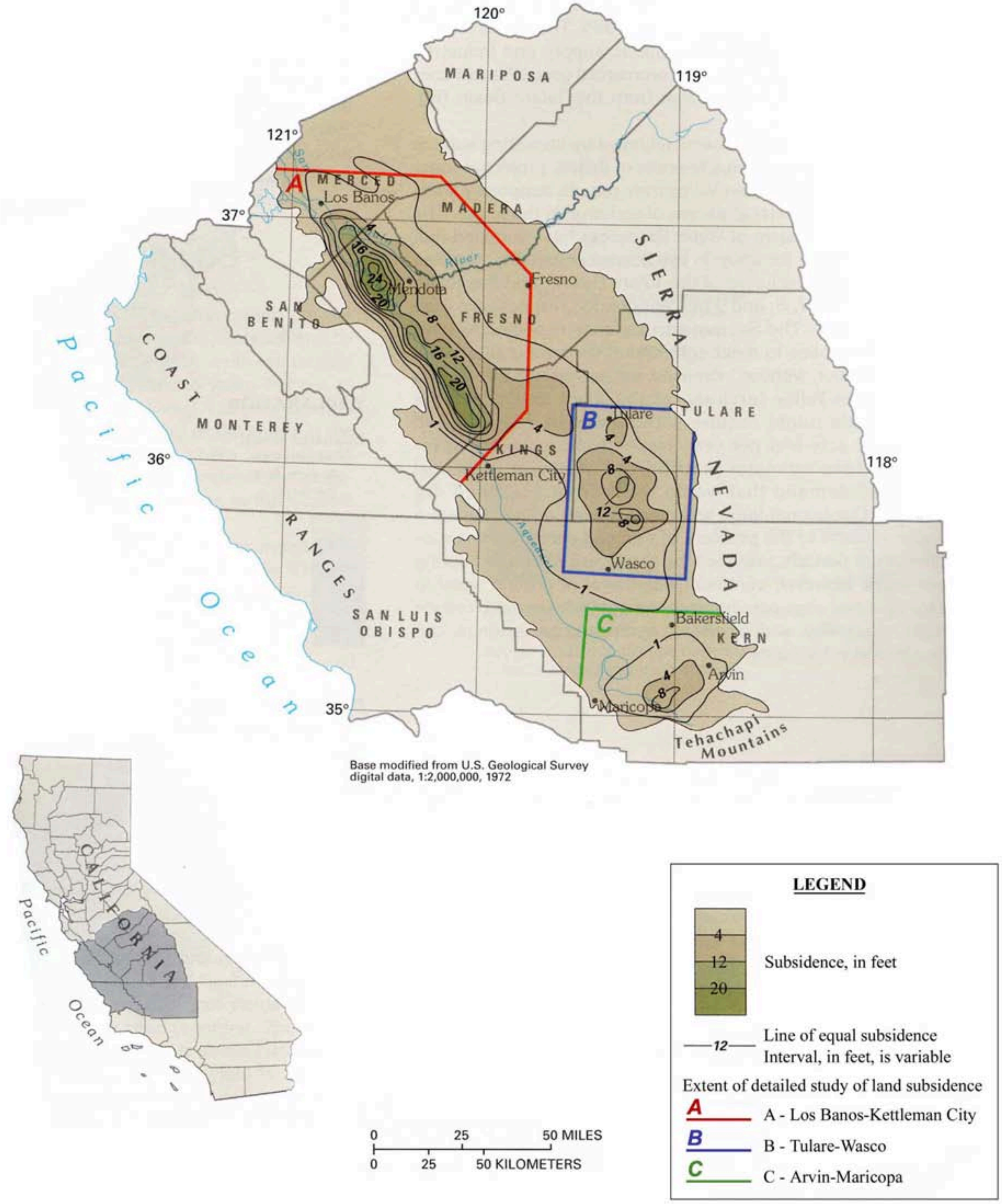


Figure 4-16. Zones of land subsidence in the San Joaquin Valley due to groundwater pumping. Land subsidence is most severe in the southern portion of the San Joaquin River corridor and Tulare Lake basin between Los Banos and Kettleman City. Modified from Ireland (1986).

A limited number of studies have evaluated groundwater and surface water interaction within the study reach. Generally, under present day conditions, groundwater elevations are significantly lower than the San Joaquin River channel and tributary channel elevations (e.g., Fresno, Chowchilla, Merced Rivers) in Reach 1 and 2, and moderately lower in Reach 3. The hydraulic head differential between stream water elevations and the underlying groundwater elevations induces seepage losses from the stream (Figure 4-7). This type of river reach is termed a “losing reach” or “losing stream”. Conversely, in the river reaches flowing through the lower valley trough, shallow groundwater levels at or above the elevation of adjacent stream channels will induce groundwater accretion into the river channels. Stream reaches that receive groundwater inflow are termed “gaining reaches” or “gaining streams”.

Historically, most of the San Joaquin River was a gaining reach (Figure 4-8); however, the significant decrease in groundwater elevations has reversed this condition, so most reaches are now losing reaches. However, some localized gaining reaches still remain on the lower river. The 1998 thalweg elevation of the San Joaquin River (developed from topographic data gathered by the Corps of Engineers Comprehensive Study) was compared to the 1996 groundwater elevations. Reaches where the 1996 shallow groundwater elevations were greater than the 1998 thalweg (lowest portion of river bed) elevation of the stream were considered to be potentially gaining reaches (Figure 4-18). The most pronounced potentially gaining reaches occurs in the reach between RM 195 (Firebaugh) and RM 165, and the reach between RM 148 (Mariposa Bypass) and RM 118 (Merced River confluence). Another potentially gaining reach occurs between RM 243 (Herndon) and RM 234 (SR 145), although the elevation difference was not as great as the two other reaches; plus the reach between RM 243 and RM 234 is a reach identified by DWR as a likely losing reach.

Figure 4-17. Illustration of maximum subsidence at a site 10 miles southwest of Mendota, showing 29.6 feet of subsidence between 1925 and 1977.

Based on synoptic streamflow monitoring conducted during the San Joaquin River Pilot Projects between 1999 and 2001 (JSA and MEI 2002, FWUA and NRDC 2002), seepage and riparian diversion losses were estimated for Reach 1 and 2. Between the Friant gaging station and Gravelly Ford (approximately 38 river miles), a minimum flow of 105 cfs is needed at the Friant gage to obtain a measurable flow at the Gravelly Ford gage, suggesting that the minimum seepage loss outside the irrigation season is 105 cfs (2.8 cfs/mile). Flow losses increase during the irrigation season as riparian diversions are utilized. Flow losses increase to approximately 130 cfs (3.42 cfs/mile) to 250 cfs (6.6 cfs/mile) during the summer and fall irrigation season.

Between the Gravelly Ford gaging station and Above Chowchilla Bifurcation Structure gaging station (approximately 13 river miles), a minimum of 75 cfs is needed at the Gravelly Ford gage to get a measurable flow at the Above Chowchilla Bifurcation Structure gage, suggesting that the minimum seepage loss outside the irrigation season is 75 cfs (5.8 cfs/mile). This reach has had the greatest depletion in shallow groundwater aquifer due to overdraft, which is likely reflected in the larger unit-length seepage loss rate. There do not appear to be as significant seasonal pattern to flow losses between the irrigation season and winter season (as occurred between Friant and Gravelly Ford). Maximum flow losses are approximately 250 cfs (6.6 cfs/mile), likely due to varying degrees of riparian withdrawals in the reach during those times when there are flows in the river. One other important relationship is the effect of Mendota Pool on the shallow groundwater table in Reach 2B. Because water is imported into Mendota Pool by the Delta-Mendota Canal, Mendota Pool is nearly always filled and locally recharges the shallow groundwater table in much of Reach 2B.

The location and rate of water exchange between gaining and losing reaches may be highly variable, due to pumping induced groundwater fluctuations. Fluctuating groundwater elevations may cause the net flow between stream channel and adjacent aquifer to change direction seasonally or over multiple years. When seasonal or annual fluctuations occur, river gains and losses will vary correspondingly. Seasonal and long-term droughts will also cause large groundwater elevation fluctuations in the river-aquifer system; droughts compound the variability in surface and groundwater interactions. Therefore, an important question is: in the San Joaquin Valley aquifer system, to what degree does pumping in either the upper unconfined or deeper confined zones affect the shallow groundwater elevations in the adjacent floodplain deposits?

DWR developed reach-specific water budgets that quantified major inflows (e.g., groundwater supplied in a gaining reach) and outflows (e.g., channel outflow, diversions) for data available from 1970 to 1977, to quantify the long-term accretion and seepage rates to/from selected river reaches in the San Joaquin Valley (Table 4-2) (DWR 1985). The seepage estimates derived from the Pilot Projects (using 1999 to 2001 data), as well as the Phillips et al. (1991) estimates, are based on only three years of data (Table 4-2). DWR’s seven-year seepage/accretion rates indicate that the San Joaquin River was a losing river from the Friant gage downstream to at least Dos Palos gage, and the river was a gaining river downstream of the Dos Palos gage. These conditions are in general agreement with qualitative and quantitative estimates of gains and losses to/from the River presented by Mitten et al. (1970).

The seepage estimates estimated by the Pilot Projects and other studies helped develop the San Joaquin River water budget flow model described in Chapter 2. Seepage rate estimates were based on USGS, USBR, and Pilot Project stream flow measurements, and thus the records represent a combination of seepage loss due to recharge of the shallow groundwater table and cumulative riparian diversions. Therefore, the seepage rates determined from the pilot projects may not be directly comparable to DWR’s seepage estimates.

Two aquifer tests were conducted by K.D. Schmidt & Associates near Mendota to determine the extent of hydraulic connection between the shallow fine grained deposits (approximate 10 feet) and the underlying coarse-grained deposits (located at 20 and 50 feet below ground surface). One pump test documented that pumping groundwater from the deeper coarse-grained deposits caused substantial and relatively rapid groundwater drawdown in piezometers monitoring the shallow fine-grained deposits (one foot of drawdown in a piezometer located several hundred feet from the pumping well), indicating good hydraulic communication between the two units. In the second aquifer test, a large capacity well screened from 122 to 244 feet below the ground surface was pumped and monitored. Responses in two nearby observation wells that were screened to monitor the

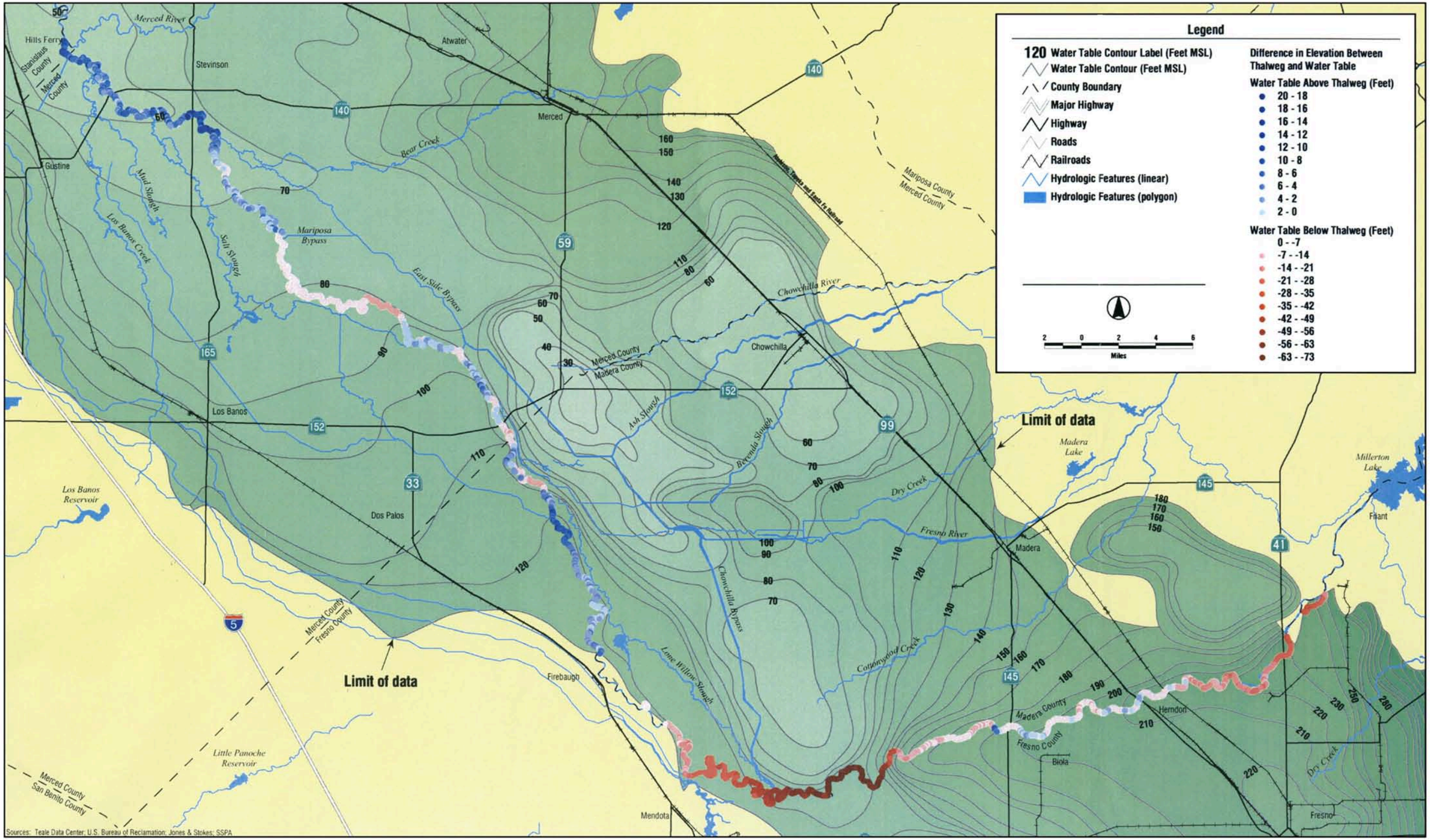


Figure 4-18. Potentially gaining and losing reaches based on Spring 1996 water table conditions and 1998 channel thalweg conditions. From JSA (2000).

Table 4-2. Estimated rates of seepage and accretion to select river reaches.

San Joaquin River Reach	**Reach Length (miles)**	**1970-77 Gain/Loss (cfs/mi.)****	**1999-2001 Gain/Loss (cfs/mi.) ****	**1986-89 Gain/Loss (cfs/mi.) ****
Friant Dam to Gravelly Ford	38	-0.58	-2.8*	n/a
Gravelly Ford to Chowchilla Bifurcation Structure	13	-2.07	-5.8*	n/a
Mendota to Dos Palos (Sack Dam)	23	-0.43	n/a	n/a
Dos Palos (Sack Dam) to Fremont Ford	56	+0.38	n/a	n/a
Fremont Ford to Newman	7	+13.93	n/a	n/a
Newman to Patterson	19	n/a	n/a	+3.2 to +6.7
Data Source		DWR 1985	FWUA and NRDC 2002; JSA and MEI 2002	Phillips et al. 1991

Notes:
*minimum seepage rates used to better approximate losses under equilibrium conditions and to reduce effects of riparian diversions in loss computations
**negative numbers indicate seepage out of river and positive numbers indicate groundwater accretion into the river.

deeper aquifer zone, and in eight piezometers, each screened to approximately 12-feet below ground surface, were documented. The test results indicated that pumping from the deeper Sierran sands could cause shallow groundwater elevations to decrease. Groundwater drawdown was approximately one foot in the shallow zone, due to downward, pumping-induced leakage. These results are likely conservative because canal seepage, a significant recharge source to the shallow groundwater zone, was observed during the pumping test. In summary, pumping from the deeper Sierran sands can cause decreases in the shallow groundwater elevations, which, in turn, can impact the water availability to adjacent river and to riparian habitat.

Phillips et al. (1991) also analyzed the hydrogeologic characteristics of the groundwater flow in 22 wells screened from unconfined (11.5 feet below ground surface) through confined deep (107.5 feet below ground surface) zones adjacent to and beneath the San Joaquin River, along a 19-mile stretch between Newman and Patterson. Boring logs indicate that deposits of Sierran sands were above the E-clay, and overlying the Sierran sands were 10 to 30 feet of flood-basin deposits. Although the Phillips et al. study reach (downstream of the confluence with the Merced River) is downstream of our study area, the findings are applicable to reaches with similar deposits. The shallow flood basin deposits within the Newman to Patterson portion of Phillips et al. study area consist of interbedded sand, silt, and clay; its permeability is highly variable. Within the flood-basin deposits, individual layers could not be correlated between boring/well locations, however, interbedded clay and sand layers of variable thickness were documented at each boring/well location. Phillips et al. (1991) concluded that the consistent occurrences of finer grained, lower permeability layers are probably are the key controls over the groundwater flow system near the river. Significant findings of the Phillips et al. study include:

- The water elevation hydrographs and hydraulic gradients indicate that groundwater pumping, even from deeper zones, has a significant effect on the groundwater system near the San Joaquin River. The component of groundwater flowing from west to east underneath the San Joaquin River is significant; this flow would have naturally discharged to the River. The cause for this flow pattern is groundwater overdraft and a large cone of depression developed in the unconfined zone northeast of the study reach (Figure 4-13).
- Irrigation from surface water delivery is the primary source of groundwater recharge. It supplements some of the historical infiltration recharge from surface sources (streams, precipitation), but at a lower rate, such that decreasing shallow groundwater elevations are the net effect.
- The effects of irrigation and groundwater overdraft can be observed in the regional groundwater elevations (e.g., Figure 4-13) and in elevations recorded in shallow observation wells (e.g., Figure 4-15).
- At the time of the Phillips et al. (1991) study, groundwater inflow was a substantial component to the net gain in stream flow in the reach from Newman to Patterson. Seasonally, water contributions to the reach were greatest from spring and summer irrigation return flows. Simulated average water inflow rates to the San Joaquin River in the Phillips’ study reach ranged from 3.2 to 6.7 cfs/mile (Table 4-2).
- Groundwater elevations show a seasonal variation to some degree, with decreasing elevations in the late summer and early autumn, and increasing elevations in the late winter and early spring.
- In general, horizontal hydraulic gradients between the unconfined aquifer wells and the San Joaquin River are toward the river and they generally do not have a strong seasonal trend. Exceptions include: 1) localized groundwater recharge and mounding adjacent to an irrigation ditch, where the horizontal gradient increases rapidly during the late spring and summer irrigation periods, and 2) short term reversals on both sides of the river, when river stage height increases sharply. Short-term bank storage and release is associated with the rise and fall of a flood peak.

S.S. Papadopulos & Associates (2000) provides insight into the variables that affect water levels in the shallow San Joaquin River-aquifer and riparian zone system. They performed a groundwater model sensitivity analysis to evaluate the impact of different hydrologic, hydrogeologic, and land-use variables over simulated shallow groundwater elevations. The Papadopulos groundwater model extended from Friant Dam to the Merced River. Water elevations and flow directions varied depending on factors such as: starting boundary conditions (water elevation), evapotranspiration, characteristics of certain crop types, regional and local irrigation-soil moisture contents, regional and local groundwater pumping rates, river flow rates, seasonal and long-term variability in rainfall and evapotranspiration, and soil permeability. The Papadopulos model provides a coarse level evaluation of the shallow groundwater surface elevations along the study reach.

4.6.5. San Joaquin River Riparian Pilot Projects

Recent monitoring efforts in Reaches 1B, 2A and 2B of experimental flow releases have also provided data for evaluating surface flow and unconfined groundwater flow interactions adjacent to the river. This monitoring effort was conducted as part of the San Joaquin River Pilot Projects between 1999 and 2001, and the monitoring effort established ground-surveyed cross sections, monitored water surface elevations in the San Joaquin River and in off-channel wells and piezometers, and documented riparian seedling initiation on different surfaces of the cross sections (FWUA and NRDC 1999, JSA and MEI 2002, and SAIC 2002). Particularly important is concurrently tracking surface water elevations in the river and adjacent shallow groundwater elevations, which illustrates correlations between the two under present-day groundwater conditoins. Because many reaches of the San Joaquin River are losing reaches, surface flows and subsequent lateral seepage determine the depth to groundwater. This relationship is important for future natural riparian regeneration and estimation of seepage losses (needed for consideration in restoring future flow continuity).

In the 1999 pilot project, the goal of the flow releases from Friant Dam were to establish riparian vegetation on upper sand bar surfaces, primarily in Reach 2. Monitoring focused on evaluating whether managed flow releases promoted riparian tree growth along those subreaches that had very limited riparian vegetation due to long periods of dewatered conditions in the river, and at what locations vegetation established. In 2000, the goal of the pilot project flow release was primarily to maintain vegetation that had initiated during the previous years' pilot project release. In 2001, the goal of the pilot project flow releases was primarily vegetation maintenance and evaluation of hydrologic routing and shallow groundwater characteristics. The primary objectives of the monitoring was to evaluate vegetation at the beginning and end of the growing season, to determine the response of vegetation to augmented flows released into the San Joaquin River during the summer and fall of 1999-2001 (JSA and MEI, 2002), and to evaluate and calibrate hydraulic and flow routing models. In order to satisfy the monitoring objectives, groundwater wells and piezometers were installed to document seasonal fluctuations in the shallow groundwater table along the floodway, as well as to evaluate the relationships between surface water flows in the San Joaquin River and the shallow groundwater table on potential riparian recruitment surfaces on floodplains and bars.

The first set of transects was established during September 1–5, 1999 (FWUA and NRDC 2002). These transects were resurveyed in November 1999 and April 2000. During 2000, additional permanently marked transects were established, for a total of 13 sites and 24 transects between River Miles 212 and 234.4 (Figure 4-19) (JSA and MEI 2002). Monitoring methods were also greatly revised in 2000 in order to better quantify vegetation changes. Transects were perpendicular to the channel and of varied length. They were monitored in 1999, 2000, and 2001 (JSA and MEI 2002, SAIC 2002). At each study site, the following data was collected:

- Cross section geometry
- Water surface elevation in the channel
- Shallow groundwater surface elevation at one or more locations on each cross section
- Presence of riparian vegetation, plant numbers, plant size (size class), species, and cover class.

Hydrology was monitored with a variety of techniques. Streamflow was estimated at the Gravelly Ford gaging station, discharge measurements were made at the Gravelly Ford gaging station, and spot discharge measurements were made at various locations in Reach 2 to evaluate gains and losses. Water surface elevations at cross sections were manually observed from staff gages, and shallow groundwater elevations were monitored by hand measurements in alluvial groundwater wells and instream and floodplain piezometers through 2002; pressure transducers and continuous water stage recorders monitored shallow groundwater elevations thereafter.

A brief summary of results is presented that focus on the 2001 monitoring season, as some of the more interesting observations were made during this monitoring season. Readers are directed to FWUA and NRDC (2002), SAIC (2002), and JSA and MEI (2002), for more details on monitoring methods and results of 1999, 2000, and 2001 pilot projects.

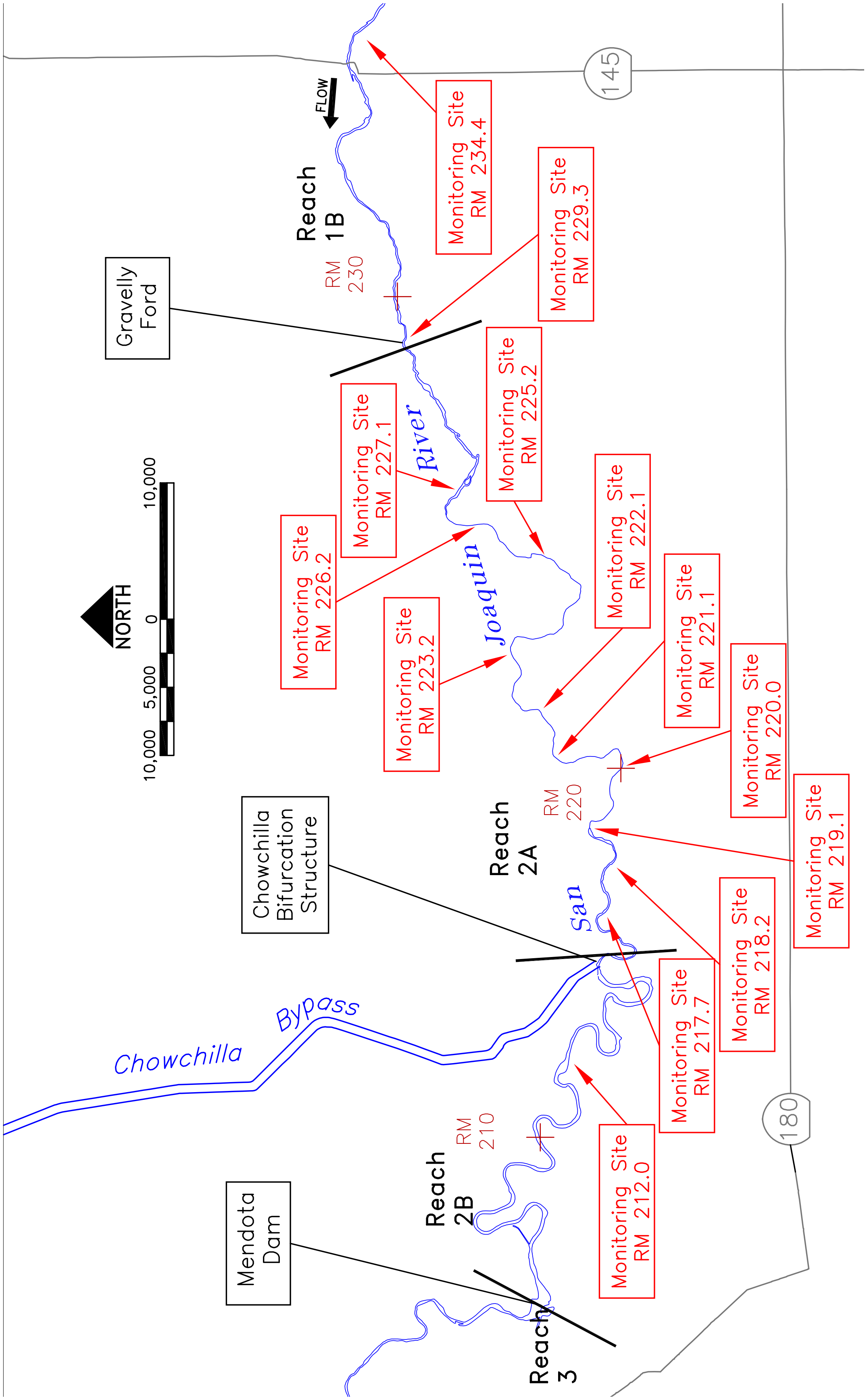


Figure 4-19. Location of 1999-2001 San Joaquin River Riparian Habitat Restoration Program Pilot Project study sites.

4.6.5.1. Results of pilot projects

Flows were released from Friant Dam during the summers of 1999-2001 for the respective pilot projects (Table 4-3). Because the one of the primary objectives of the 1999 and 2001 pilot projects was hydrologic routing and groundwater response, the following discussion focuses on results from the those two monitoring efforts.

Table 4-3. Summary of hydrology during 1999-2001 releases for pilot projects.

Water Year	Dates of pilot project flows	Date of peak Friant Dam release	Peak release from Friant Dam (cfs)	Peak flow at Gravelly Ford (RM 227.5) (cfs)	Peak flow at Chowchilla Bifurcation Structure (RM 216.1) (cfs)
1999	July 3 – Oct 6	June 4-6	813[1]	550[1]	434[1]
2000	June 5-June 21	June 18	2,590	1,760	Not reported
2001	June 1-June 25	June 17-23	400[1]	181[1]	0[3]
2001	Aug 27-Sept 9	Sept 5-7	880[1]	640	0[4]

[1] Daily average flow, steady flow so roughly equal to instantaneous peak

[2] Daily average flow, short duration flow so less than instantaneous peak

[3] Flow extended downstream to at least RM 223.2 (SAIC 2002)

[4] Flow extended downstream to at least RM 217.7 (SAIC 2002)

In 1999, a single pulse release from Friant Dam was released, with a target flow of 800 cfs at Friant Dam and 600 cfs target at the Gravelly Ford gaging station (Figure 4-20). Although there were substantial flow attenuation and seepage losses, flow continued through the entire reach to Mendota Pool (434 cfs). Highlights from the 1999 hydrologic monitoring relevant to shallow groundwater issues include:

- Seepage losses in Reach 2A during the pulse (after the shallow groundwater was “primed”) were approximately 70 cfs when Friant Dam releases were less than 100 cfs, and approximately 100 cfs when Friant Dam releases exceeded 100 cfs. Initial seepage losses were considerably higher at the beginning of the pulse flow release.
- The shallow groundwater table in Reach 2A was strongly linked with surface flows in the San Joaquin River (Figure 4-21 and 4-22); when river flows increased, shallow groundwater table elevation rose to near the same elevation. A slight decrease in lateral gradient in the shallow groundwater table away from the river suggests that the river is “filling” the shallow groundwater table, which is corroborated in the seepage losses computed from longitudinal streamflow gaging. The shallow groundwater table in Reach 1B adjacent to the river may higher than the river water surface (Figure 4-23), resulting in Reach 1B being a gaining reach rather than a losing reach (as is Reach 2A). However, a single cross section leaves considerable uncertainty whether this site-specific trend is applicable to the rest of the reach.

In 2001, two pulse flows were released from Friant Dam (Figure 4-24): 1) a flow of 200 to 250 cfs between June 1 to June 24, with a short peak flow of approximately 400 cfs, 2) a shorter peak flow of 880 cfs between August 27 and September 9. The flow averaged approximately 40 cfs at Gravelly Ford between the two pulses, but flows approached zero during short periods of time (Figure 4-24). Continuous water stage recorders were installed in many of the piezometers, allowing more detailed evaluation of seasonal shallow groundwater table fluctuations in 2001. Highlights from the 2001 hydrologic monitoring relevant to shallow groundwater issues include:

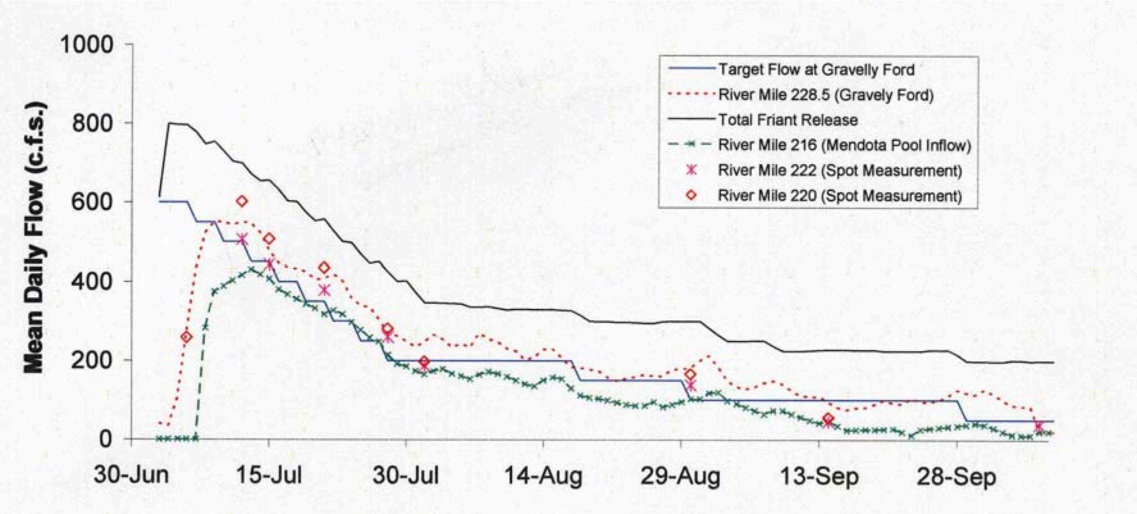


Figure 4-20. Friant Dam release (July to October 1999) and San Joaquin River discharge below Friant Dam and at the Gravelly Ford gage. From FWUA and NRDC (2002).

- There was a strong relationship between the river flows and shallow groundwater table within the floodway and the transition between floodway and agricultural lands. Monitoring wells were not installed at any significant distance beyond the floodway margins, so the relationship between river flows and regional shallow groundwater elevations cannot be quantified. The severe depletion in the regional shallow groundwater aquifer suggests that the groundwater flow gradient away from the river is strong, re-filling the depleted shallow groundwater aquifer. However, no data have been collected as part of the pilot project to confirm or reject this assumed gradient.
- Prior to the release, the river was dry downstream of the Gravelly Ford gaging station (RM 227.5). The limit of flowing water in the river extended five miles downstream to RM 223.2 during the June pulse flow (peak release = 400 cfs). The September pulse flow (peak release = 880 cfs) extended farther downstream, with flowing water ending between the RM 217.7 and the RM 212.0 sites. Therefore, surface flows did not necessarily reach the downstream-most transects.
- In-river water surface elevations increased between 1 and 3 feet during the pulse releases.
- Corresponding shallow groundwater fluctuations depended on location. At sites upstream of Gravelly Ford, the June pulse increased shallow groundwater elevations by 1 to 2 feet, while the September pulse increased elevations by 2 to 3 feet (Figure 4-25). Shallow groundwater elevations naturally tapered off after the peak streamflow occurred, within one month after the pulse. This plateau occurred because flow is perennial upstream of Gravelly Ford (i.e., the river supports the local shallow groundwater table).
- Downstream of Gravelly Ford, sites do not normally have river flows except during Pilot Project pulse flows and flood control releases. The groundwater response to the Pilot Project flows was different compared to the upstream study site with its perennial flows. Due to groundwater overdraft, groundwater elevations are far below the thalweg of the San Joaquin River downstream of Gravelly Ford. Therefore, when streamflows are released, the shallow groundwater aquifer rapidly fills up (up to 15 feet) as it is recharged (Figure 4-26 and 4-27).

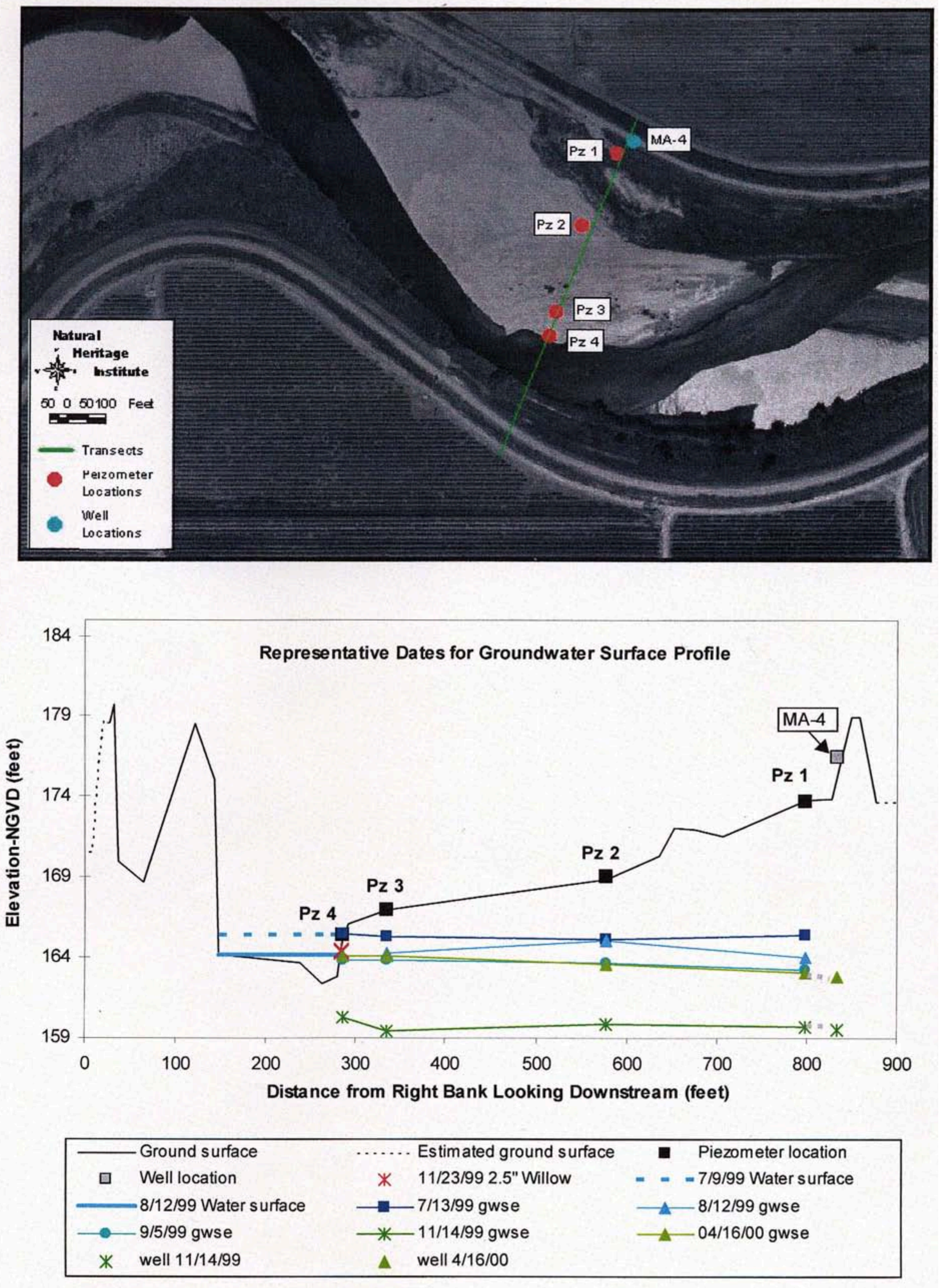


Figure 4-21. Aerial photograph and subset of 1999 groundwater measurements at the RM 217.7 monitoring site. From FWUA and NRDC (2002).

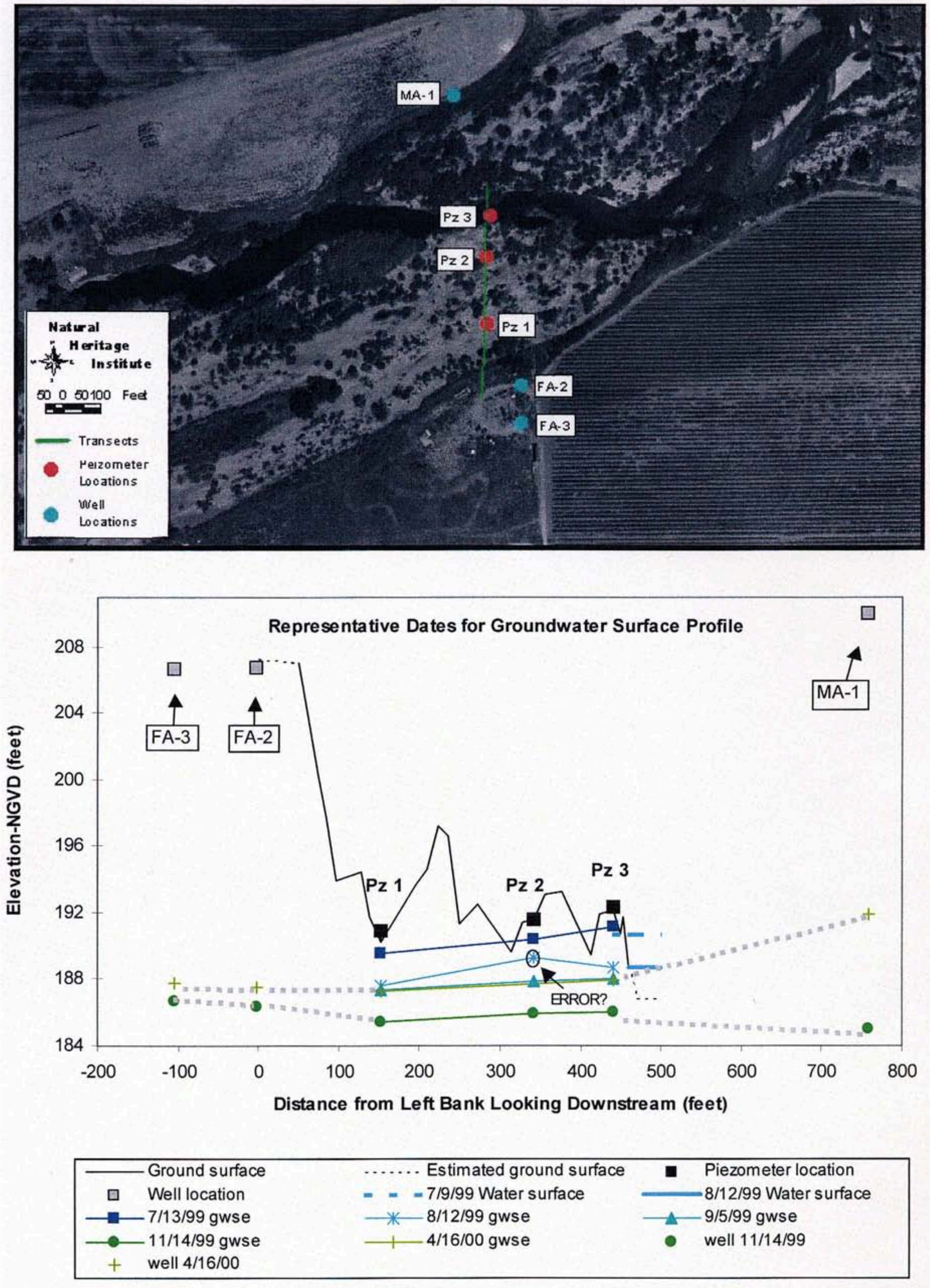


Figure 4-22. Aerial photograph and subset of 1999 groundwater measurements at the RM 229.3 monitoring site. From FWUA and NRDC (2002).

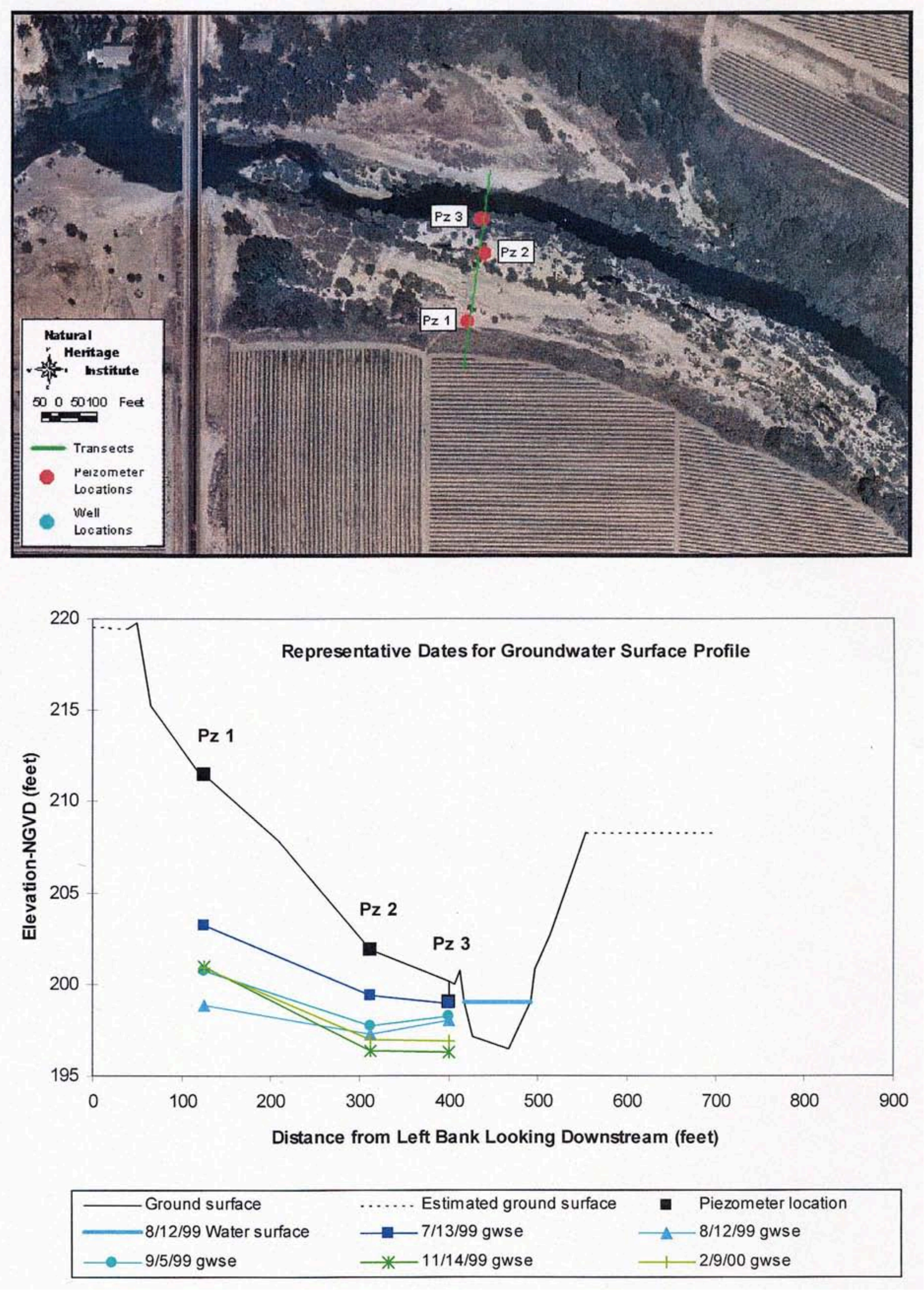


Figure 4-23. Aerial photograph and subset of 1999 groundwater measurements at the RM 234.3 monitoring site. From FWUA and NRDC (2002).

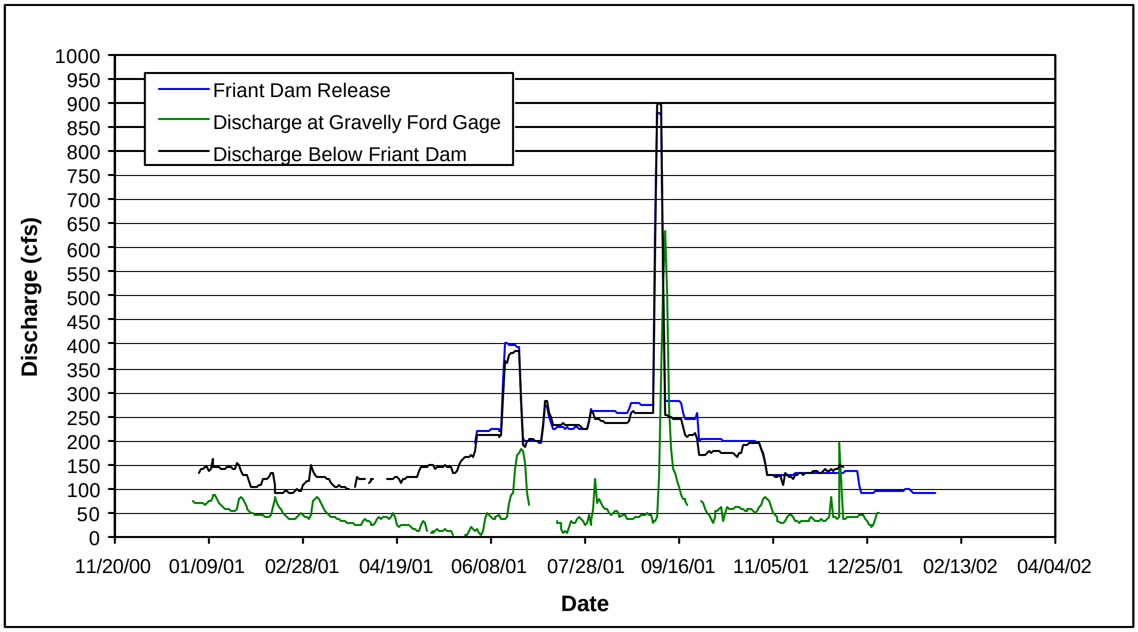


Figure 4-24. Friant Dam release (May to September 2001) and San Joaquin River discharge below Friant Dam and at the Gravelly Ford gage (January to December 2001). From SAIC (2002).

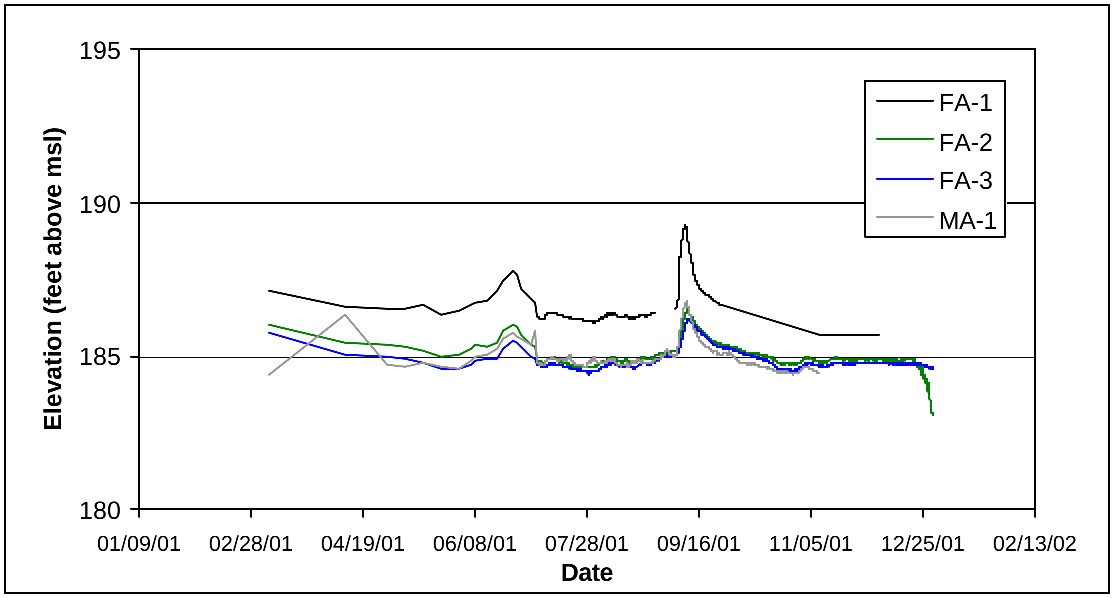


Figure 4-25. Summer 2001 Groundwater elevation trends from four alluvial wells at the RM 229.3 (Lake Avenue) study site (upstream of Gravelly Ford). Cross section thalweg elevation is 181.66 ft. From SAIC (2002).

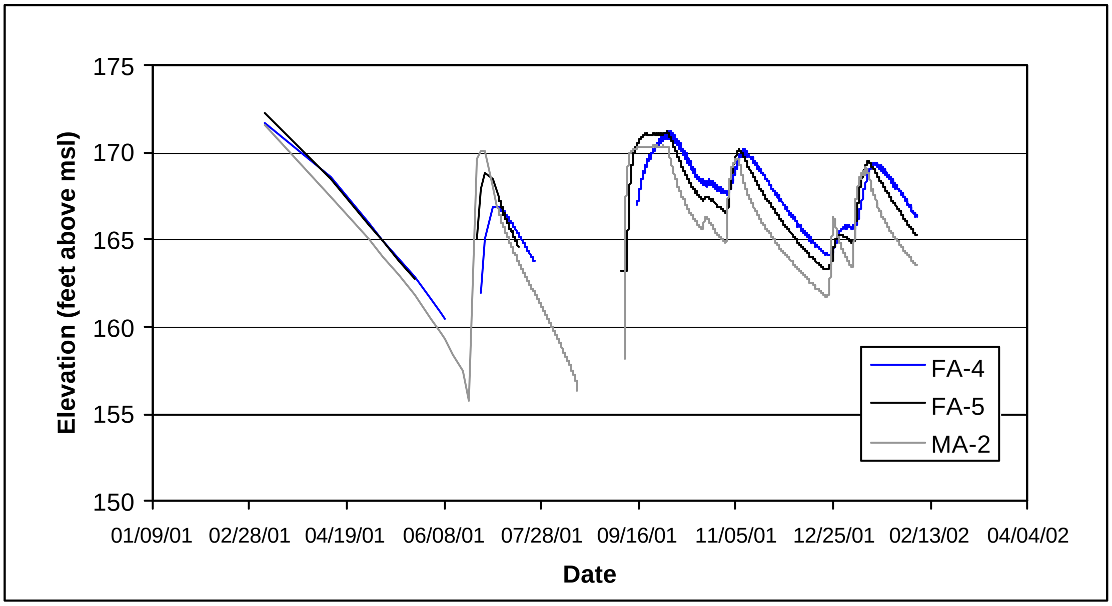


Figure 4-26. Summer 2001 Groundwater elevation trends from three alluvial wells at the RM 222.1 study site (downstream of Gravelly Ford). Cross section thalweg elevation is 171.33 ft. From SAIC (2002).

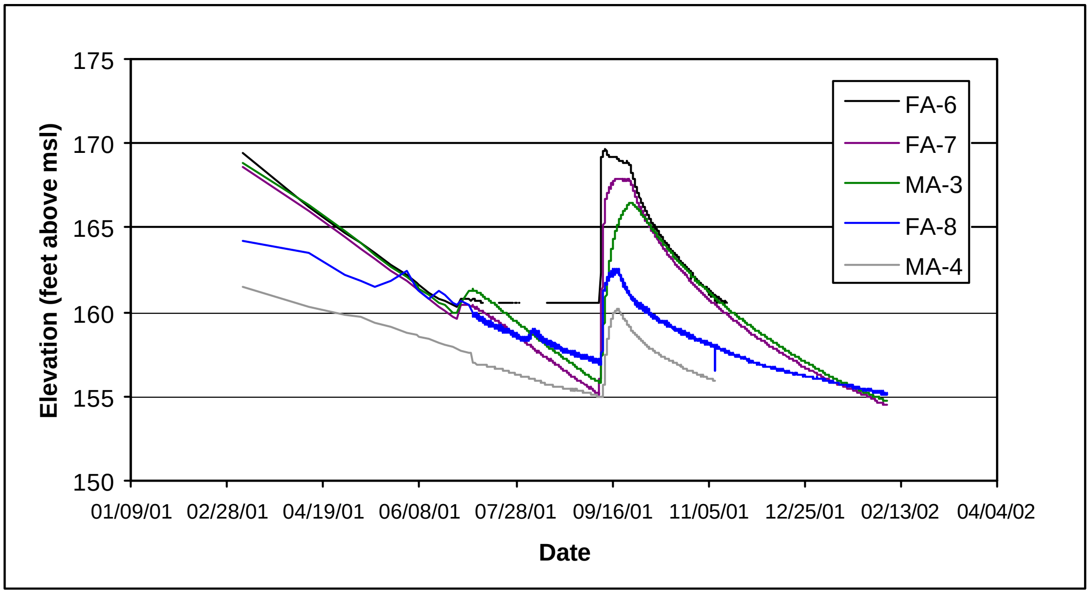


Figure 4-27. Summer 2001 Groundwater elevation trends from five alluvial wells at the RM 220.0, RM 218.2, and RM 217.7 study sites (downstream of Gravelly Ford). Cross section thalweg elevations are 168.83 ft (FA-6, FA-7, MA-3), 163.66 ft (FA-8), and 161.60 ft (MA-4). From SAIC (2002).

This likely results in significant flow attenuation and flow loss until this shallow groundwater "hole" is filled. The peak flow at the Gravelly Ford gaging station (RM 227.5) during the September pulse was approximately 630 cfs, but flow ended between RM 217.7 and 212.0, such that 630 cfs was "lost" to this hole in 11 to 16 river miles (Figure 4-24). Once the initial groundwater recharge occurs with surface flows, the steady-state seepage loss rate decreases to approximately 100 cfs in Reach 2A based on 1999 synoptic flow measurements described above. Recharging the shallow groundwater aquifer could require a substantial flow from the river, and the recharge effects could be hampered by shallow groundwater pumping nearby based on the response of shallow groundwater tables shown in Figure 4-26. Continued pumping of the adjacent shallow groundwater table will impair future flow restoration and continuity efforts through this reach.

- The shallow groundwater response to the June 2001 pulse was strong downstream to the RM 222.1 site, but the response was very small at the RM 220.0 site (Figure 4-27). Recalling that the surface flow during the June 2001 pulse ended at approximately RM 223, the small groundwater response observed at RM 220.0 suggests that the longitudinal groundwater response ended at approximately RM 220.
- Local influences on shallow groundwater elevations at the RM 222.1 site (Figure 4-26) are not apparent at the other sites during the Pilot Project flows (Figure 4-25). Shallow groundwater elevations rose in response to the June and September pulse flows, but there are other rises in the shallow groundwater table in November, December, and January that are not related to instream releases (Figure 4-26). Perhaps the groundwater elevation increases are due to cessation of local groundwater pumps, and/or irrigation with surface water that recharges the shallow groundwater aquifer. Regardless, in Reach 2, shallow groundwater monitoring results illustrate that shallow groundwater elevations fluctuate greatly through the year.

4.6.6. Groundwater Quality

The term "freshwater" is defined for this chapter as water with a total dissolved-solids (TDS) concentration of less than 1,000 milligrams per liter. Under pre-development, unimpaired conditions, the quality of freshwater in an aquifer was controlled by 1) the source of water recharging the aquifer system, and 2) the geochemistry of the sediments that comprise the aquifer system. For example, runoff from the granitic Sierra Nevada mountains, has much lower TDS concentrations than runoff from the Coast Ranges, which are primarily composed of marine sedimentary rocks. Thus, groundwater in the east side of the San Joaquin Valley generally has lower TDS concentrations (200 to 500 mg/l) than groundwater in the west side of the valley (500 to >1,500 mg/l) (Planert and Williams, 1995). In general, TDS concentrations increase with depth in the San Joaquin Valley, because the upper sediments are of continental origin.

Agriculture, irrigation, and import of water from the Delta have caused much of the shallow groundwater in the San Joaquin Valley to become more saline. This salinity first increases because much of the irrigation water now comes from the Delta. Compounding this, evaporation of irrigation water and evapotranspiration of soil moisture and shallow groundwater tends to concentrate salt in the soils and the shallow unconfined aquifer. Shallow irrigation wells worsen the problem by recirculating the increasingly more concentrated saline groundwater, which further concentrates dissolved solids. Thus, agricultural drainage return flows likely cause TDS concentrations to rise in the San Joaquin River. This phenomenon is further pronounced because flows into the San Joaquin River have been reduced during most seasons; thus, dilution is less likely to reduce TDS concentrations. Besides increasing TDS concentrations, irrigation has also increased the concentrations of selenium, boron, chromium, molybdenum, and mercury in the shallow unconfined aquifer in the western part of the San Joaquin Valley (Planert and Williams 1995; Phillips et al. 1991). These minerals and metals were leached from the soil and marine rocks which are found along the western margin of the aquifer. Poor quality shallow groundwater that originates from the western margin flows into the San Joaquin River, but at a higher than natural flow rate due to the existing regional west-to-east groundwater flow direction beneath the river (Belitz and Heimes 1987; Phillips et al. 1991). Phillips et al. (1991) estimated that average concentrations of groundwater inflow to a 19-mile reach of San Joaquin River, between Newman and Patterson (just downstream of the Merced River confluence), are 1,590 mg/l TDS, 1,321 micrograms per liter (ug/l) boron, 0.9 ug/l selenium, and 6.6 ug/l molybdenum. Excessive nitrate concentrations have also been sporadically recorded throughout the San Joaquin Valley, and are usually attributed to septic tanks, feed lots, and dairies (Planert and Williams 1995).

4.7. GROUNDWATER CONDITIONS’ RELEVANCE TO BIOTA

Groundwater conditions (elevations, flow direction, water quality) are relevant to all wildlife and plants, through their dependence on the hydrologic cycle. Two biotic groups in particular, riparian and wetland vegetation, and fisheries, will be discussed below.

4.7.1. Riparian and Wetland Vegetation

The loss of artesian springs and the decline in shallow groundwater elevations have readily apparent implications to wetland vegetation, particularly to perennial wetland vegetation. Even if land use had not transformed to agriculture and residential uses, and if the conversion of vast tule swamps, sloughs, and oxbows had not occurred, the loss of artesian springs and the decrease in groundwater elevations would impair our ability to restore and sustain pre-development wetland communities in some areas without substantial water supplementation. These changes in groundwater regime are obvious constraints to wetland restoration. Opportunities for restoring perennial wetland vegetation arise primarily: 1) where the shallow unconfined groundwater surface remains at or above the river-bed (e.g., in gaining reaches in Reaches 4 and 5), or 2) where perennial river flow increases groundwater elevations at the riparian corridor margins (e.g., Reaches 1 and 3). Opportunities for restoring seasonal wetlands may not be as highly dependent on the shallow groundwater regime, but seasonal inundation from surface flows are likely very important, as is available space, land ownership, land use, supplemental flows, and soils.

Riparian vegetation is also impacted by the loss of artesian springs and the decline in groundwater elevations. Within the riparian corridor, the depth between potential seedbeds, the groundwater surface, and the capillary fringe is an important variable that will strongly influence whether riparian plants can regenerate naturally. Soils are also important factors, because the capillary fringe is a function of soil texture and groundwater elevation (Figure 4-7). Riparian vegetation dies when the groundwater table and capillary fringe are too far below the plant root zone. Drawdown or overdraft of the shallow groundwater reduces or eliminates water available to riparian vegetation in the absence of surface flows in the San Joaquin River. The depth to groundwater also affects the rate at which plants remove water from the system (transpiration rate). When the entire root zone contains freely available water, plants transpire efficiently and are less stressed. Gaining river reaches are more promising restoration candidates than are losing reaches because the shallower groundwater elevation should greatly increase riparian revegetation success. However, simply identifying gaining reaches is insufficient for restoration planning. Plant life histories and seasonal water needs of riparian vegetation must be matched to available shallow groundwater conditions, along priority reaches. Natural pattern of seasonal variability in groundwater elevations may be an important component for the long term viability of certain riparian plant species (see Chapter 8 for riparian plant life histories and water supply needs of key woody riparian species). Reach 2 is perhaps the most impacted reach, due to the combined loss of river surface flows and severe decline in shallow groundwater elevations. In Reach 4, riparian vegetation is less impacted by the dewatered sections because the shallow groundwater elevation has not decreased as dramatically as in Reach 2 (compare Figure 4-10 with Figure 4-13). Therefore, Reaches 1B and 2 present the greatest constraints to riparian and wetland restoration because these reaches have the greatest depth to groundwater. However, the results of the 1999 Pilot Project has shown that management of surface flows in the San Joaquin River can be used to successfully establish riparian vegetation if the surface flows are maintained. Reaches 4 and 5 represent areas with significant opportunity for riparian and wetland restoration, due to groundwater availability in the shallow unconfined aquifer.

4.7.2. Fish Habitat

The pre-groundwater development and unimpaired unconfined aquifer probably served several important functions for native fishes. First, during the late summer of drier water years, surface flows from the upper watershed would be fairly low (see Chapter 2), and so the unconfined aquifer and its artesian springs likely augmented stream flows in most reaches (Figure 4-8). These naturally augmented flows likely allowed year-round migration opportunities for all native species. Second, water from the artesian springs and seeps of the unconfined aquifer may have created numerous islands of thermal refugia for native cold-water fish species. These springs may have lasted far enough into the salmonid smolt outmigration period to extend their migration period into summer, as snowmelt hydrograph transitioned to summer baseflows. The springs may have also provided local opportunities for juvenile salmonids to over-summer in an otherwise inhospitable location (Reaches 1 through 5), where they could later outmigrate as yearlings. However, no historical literature has been found to support or reject this hypothesis.

Presently, large portions of Reaches 2 and 4 are completely dry most years. In Reaches 1 and 2, declines in the shallow unconfined groundwater have resulted in Reaches 1 and 2 becoming primarily losing reaches; therefore, flow releases from Friant Dam or Mendota Dam are required to create perennial flow through Reaches 1 through 4. In Reach 5, where agricultural return flows and groundwater seepage cause the river to gain flows, water quality is very poor (see Chapter 6), which further constrains future fish restoration efforts.

The opportunities provided, and constraints imposed, by the shallow unconfined aquifer are similar to those on riparian and wetland vegetation; opportunities exist in gaining reaches, and constraints exist in losing reaches. The contemporary groundwater elevations probably do not provide many opportunities to cold-water fish species, because any remaining shallow groundwater contributions are small volume, subject to rapid thermal warming, and of poorer water quality. Pre-development artesian springs and unconfined shallow groundwater originating from the valley’s east side probably were cooler and had better water quality than today’s available flow. Opportunities likely favor native, warm water fish species. Therefore, Reaches 3, 4, and 5 provide good opportunities for restoring native, warm water fishes because these gaining reaches can maintain or supplement any dam release provided for fishery habitat restoration.

4.8. SUMMARY

The available background literature and data clearly indicates that regional and localized groundwater uses in the San Joaquin Valley have had a significant impact on shallow, unconfined groundwater flow, and its interaction with the deeper, more confined zone and with the San Joaquin River. A summary of natural and anthropogenic factors influencing the shallow aquifer area summarized in Table 4-4.

Table 4-4. Factors influencing groundwater conditions in the shallow aquifer system adjacent to the San Joaquin River, California.

Natural Factors	Anthropogenic Factors
1. Seasonal variability in rainfall and runoff	1. Irrigation (local and regional)
2. Long-term drought	2. Groundwater pumping (local and regional)
3. Evapotranspiration	3. Changes in surface water flow regime (dams and diversions)
4. Variability in water bearing properties of aquifer material	4. Agricultural return flows
	5. Leakage from conveyance canals
	6. Surface water imports
	7. Changes in land-use and evapotranspiration rates
	8. Cross-connection from wells screened in both shallow and deep aquifer zones
	9. Land subsidence (loss of aquifer storage capacity)
	10. Changes in water quality

Of these factors, loss of the pre-development artesian hydraulic head, and the decrease in unconfined groundwater elevations, represent the most dramatic changes of groundwater contribution to flows in the San Joaquin River. Since the late 19th century, San Joaquin Valley groundwater elevations and surface water flow conditions have drastically reduced by large-scale pumping, storage, and diversions that supply agricultural and urban water demands. The San Joaquin River historically gained flow from the shallow groundwater aquifer and artesian springs over most of its length; groundwater use has converted much of the river to a losing reach, and probably greatly reduced the contribution from remaining gaining reaches in lower reaches of the river (e.g., Reach 3 through 5).

The shallow unconfined aquifer adjacent to the river is most important to fish and riparian uses due to its connectivity with the river. The groundwater elevation of this aquifer varies considerably along the river, and is largely correlated with long-term regional irrigation and pumping trends. The impacts of pumping on the groundwater elevation can be amplified by natural drought cycles because drought typically coincides with periods of increased groundwater pumping. Thus, although groundwater levels may partially rebound during wetter water years, they quickly lower during drier years. The lowering of groundwater elevations over most reaches within the study area have many biological implications that may constrain future restoration opportunities, particularly for native fish, riparian vegetation, and wetland vegetation. The pre-development, shallow groundwater conditions (including the artesian processes) cannot realistically be restored, so opportunities based on favorable groundwater conditions for fish, riparian vegetation, and wetland vegetation are broadly identified as those areas where the shallow groundwater elevations are near the existing river bed elevations (Reaches 3 through 5). Overdrafted groundwater, combined with coarse alluvial soils, in Reaches 1 and 2 present the most significant constraint.

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CHAPTER 5. WATER-RELATED INFRASTRUCTURE AND HUMAN CHANNEL MODIFICATION

5.1. INTRODUCTION AND BACKGROUND

Since the 19th century, significant levels of agricultural and economic growth have spurred the development of water related infrastructure and modifications along the San Joaquin River. In response to the increased irrigation demands from urban and agricultural needs, many large storage dams, small diversion dams, seasonal diversions and pumps, canals, bypasses, and other control structures have been constructed. Additionally, many of the historic sloughs and side channels were used for irrigation water conveyance in the later 1800s and early 1900s, and these channels continue to be used for agricultural conveyance, tailwater conveyance, and/or flood control bypasses. Some have been filled in and reclaimed for agricultural use. Today, the San Joaquin River is managed primarily with irrigation and flood control objectives, leaving the overall ecological health of the San Joaquin River ecosystem in a degraded condition.

During this development, the San Joaquin River has been transformed into a system of leveed channels with a highly managed flow regime. Floodways have been narrowed, sloughs and side channels have been modified or eliminated, sediment transport processes have been altered, certain reaches have been dewatered, and fish passage barriers have been constructed. These factors have imposed substantial constraints on future restoration efforts along the San Joaquin River corridor.

The development of the modern San Joaquin River began in the mid 1800’s as the search for gold brought small-scale hydraulic and placer mining to the watershed. By 1879 an estimated 53 million cubic yards of material were being washed down the Sacramento and San Joaquin rivers by hydraulic mining operations (ACOE 1999a). The excessive amount of mining debris was transported downstream, where it settled, reduced channel capacities, and increased the amount of flooding of lower lying areas. Because the scale of hydraulic mining operations along the upper San Joaquin River mainstem were relatively small compared to mining activity along the San Joaquin River tributaries and the Sacramento River, direct impacts of gold mining was much less than the Central Valley rivers north of the San Joaquin River. Timber harvesting during the gold rush era may have also elevated sediment loads to the upper San Joaquin River, but there is no quantitative data to verify potential impacts.

Throughout the gold rush, agricultural development was also prominent near the banks of the San Joaquin River to feed the gold miners and new settlers. As agricultural uses began to expand, more of these newly developed areas were being damaged during winter flooding. Thus, landowners began to protect their developments by constructing their own levees. Water surface elevations continued to rise as channels became narrower from levee construction and shallower from the accumulation of mining debris. Throughout this period, landowners were regularly inundated with flood waters and mining debris. In 1884, the Sawyer Decision stopped virtually all mining activities throughout California. In 1893, the Federal Government modified the original court ruling and allowed hydraulic mining to continue under the supervision of the California Debris Commission (CDC).

By 1894, many miles of levees had been constructed and many flood control districts had been developed along the San Joaquin River to provide some level of flood protection. The high flow regime was still largely unregulated at this time, so these early efforts in flood protection were generally inadequate. The first comprehensive flood management plan for the Central Valley was sent to Congress in 1910. Under this plan, flood flows would be routed away from developed areas through a series of bypass channels and overflow basins. On the San Joaquin River, this plan included:

- Construction and repair of levees along the riverbanks in Reaches 2A, 4B, and 5;
- Construction of artificial channels or “bypasses” used to convey floods;
- Construction of hydraulic control structures to divert water from the main channel.

The next phase of development occured when the Central Valley Project (CVP) was authorized by Congress in 1933 to meet the increasing water demand in southern and central California. This plan included an extensive water conveyance and storage system that would provide irrigation water to the Central Valley and increase domestic water supply to southern California. As part of this plan, construction of Friant Dam was completed in 1941 to store and divert water from the San Joaquin River.

The San Joaquin River and Tributaries Project (SJRTP) was authorized in the Flood Control Act of 1944. Construction of the SJRTP was initiated in 1956. The SJRTP included the construction of levees along the San Joaquin River below the Merced River confluence, the Stanislaus River, Old River, Paradise Cut, and Camp Slough. The Chowchilla and Eastside Bypasses were constructed under the SJRTP by the State of California during the same time period.

The Flood Control Act of 1944 authorized other projects that would effect flooding in the San Joaquin River. After significant flooding events in 1955, construction of levees and bypasses along the upper San Joaquin River was authorized. Pine Flat Dam on the Kings River was completed in 1954, Buchanan Dam on the Chowchilla River was completed in 1975, and Hidden Dam on the Fresno River was completed in 1975. All of these reservoirs were constructed to provide domestic and agricultural water supplies, flood control, and in some cases, power generation (ACOE 1999a).

The last three decades have been devoted entirely to the repair of levee damage that has occurred as the result of many recent flooding events (1970, 1974, 1983, 1986, 1995, and 1997). Most of this work has been conducted on the Sutter Bypass and the Feather, Yuba, Sacramento Rivers. Little work has been done to repair and/or construct new levees along the San Joaquin River corridor. Most of these repair projects have been overseen by the U.S. Army Corps of Engineers (ACOE) and have been conducted in response to potential situations that pose immediate danger to life or developed property.

As a consequence of the past and ongoing infrastructure development along the San Joaquin River, there have been large-scale impacts on the geomorphological and ecological processes of the San Joaquin River. These impacts continue, and will have a significant influence on future efforts to rehabilitate the river. This chapter describes the basics of flood control and water supply infrastructure in the San Joaquin River, and provides a brief description of some of the broad geomorphic and ecological impacts of the infrastructure components. Discussion of opportunities and constraints is also provided.

5.2. STUDY AREA

The project study area includes the main channel of the San Joaquin River and the corresponding diversion channels and flood control bypasses from Friant Dam to the Merced River confluence. The adjacent flood control bypasses are also included because they may provide future fish passage opportunities and constraints to future restoration efforts. This area covers approximately 150 miles of river corridor through the Fresno, Merced, and San Joaquin Counties within the Central Valley of California. The study area begins at the base of Friant Dam at river mile (RM) 267.5, and ends near the Merced River confluence at RM 118 (Figure 5-1). A brief discussion of infrastructure, and restoration opportunities and constraints downstream of the Merced River confluence is presented in Chapter 12 rather than this chapter.

5.3. OBJECTIVES

The objectives of this chapter focus on describing opportunities and constraints of infrastructure along the San Joaquin River study reach. From the April 2000 scope of work, primary objectives of this chapter are:

- describe and evaluate flood control infrastructure of the San Joaquin River from Friant Dam to the Merced River confluence, including outlet works constraints for Friant Dam, operating criteria for structures, capacities of channels and bypasses, and future infrastructure and flood control changes;
- describe and evaluate water supply infrastructure of the San Joaquin River from Friant Dam to the Merced River confluence, including typical operations for Friant Dam, Mendota Dam, and Sack Dam;
- describe and evaluate other existing engineered infrastructure (e.g., bridges, mining pits) affecting the San Joaquin River from Friant Dam to the Merced River confluence;
- describe and map riparian water right holders and diversion infrastructure that may constrain restoration;
- describe, evaluate, and map lands along the river where seepage is or may be a potential problem;
- describe potential direct impacts of infrastructure components on the San Joaquin River, and discuss how these potential impacts may influence future restoration efforts along the San Joaquin River corridor; and
- identify potential opportunities and constraints of infrastructure components on restoration efforts from Friant Dam to the Merced River confluence.

5.4. DESCRIPTION OF WATER-RELATED INFRASTRUCTURE AND HUMAN CHANNEL MODIFICATIONS

Each component of water related infrastructure within the San Joaquin River corridor was constructed for the purpose of either flood control or water supply. Dams have been constructed to eliminate or reduce peak flood flows, store water, and divert water from the mainstem San Joaquin River. Canals and pipes are used to convey water to other regions. Canals and ditches are also used to drain agricultural lands, many of which return flows back to the San Joaquin River. Levees line the edge of the channel to protect low-lying agricultural lands from flooding, and bypasses have been constructed to direct floodwaters away from other agricultural lands and urban developments. These structures have impaired the natural ecological processes of the river by changing the flow regime and by making physical modifications to the floodway. The following sections provide an overview of existing information relating to the water supply and flood protection structures along the San Joaquin River.

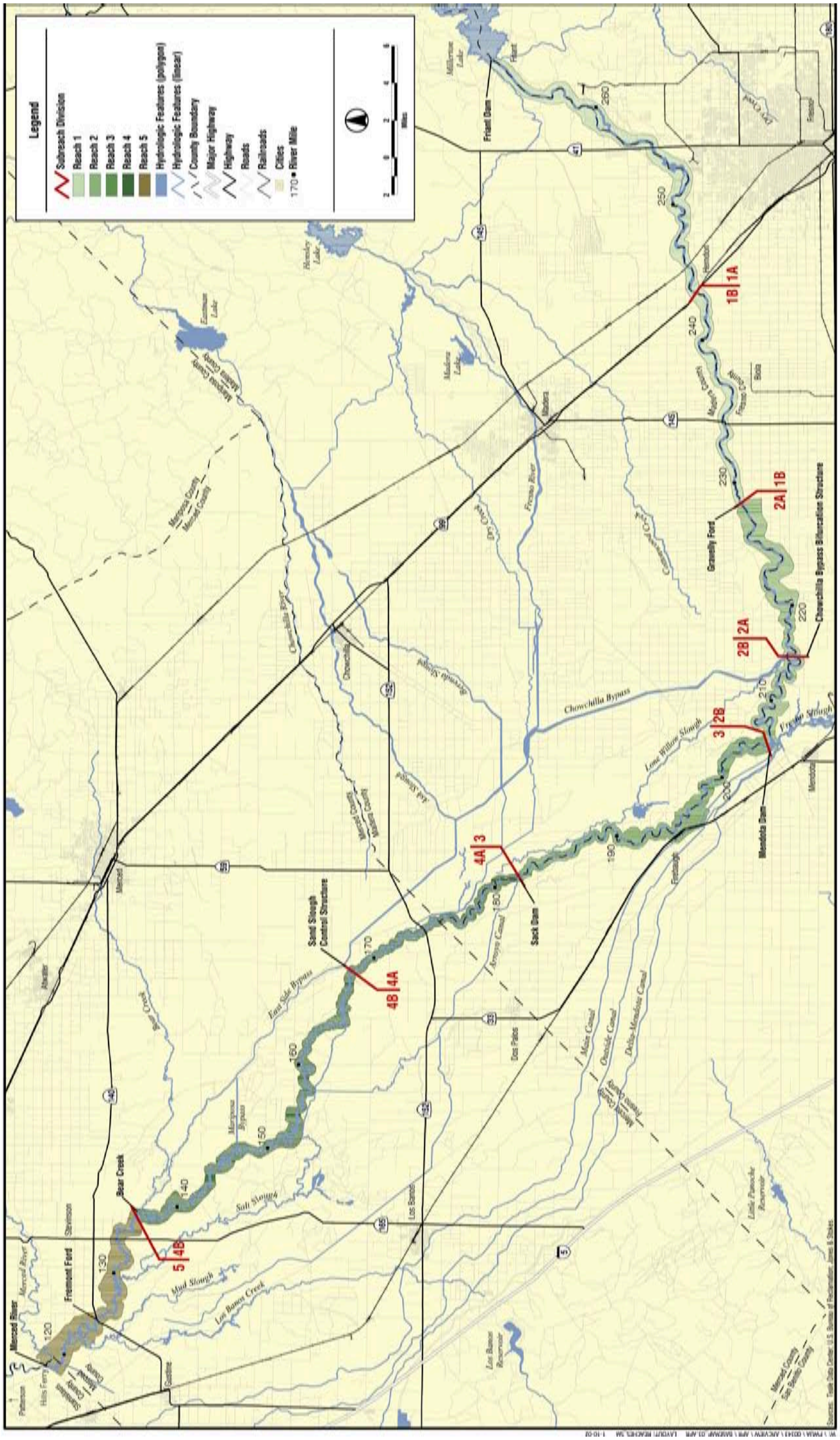


Figure 5-1. Project area of the San Joaquin River Restoration Study showing Reach and Subreach boundaries.

5.4.1. Overview of the San Joaquin Water Supply System

Runoff from the upper reaches of the San Joaquin watershed flow into Millerton Reservoir. Millerton Reservoir is created by Friant Dam and has a total storage of 520,500 acre-feet (DOI 1981), and average annual “full natural flow” computed by USBR from 1906-2002 at Friant Dam is approximately l,801,000 acre-feet (USBR 2002). Using a consistent time period of 1950-1989, the average annual output of water (diversions+downstream releases into the San Joaquin River) is 1,795,000 acre-ft, the full natural flow is 1,812,000 acre-ft, for a deviation of 17,000 acre-ft (Figure 5-2). Nearly all of the water stored in Millerton Reservoir is used for agriculture, municipal, and industrial purposes, and major water infrastructure components are listed in Table 5-1.

At Friant Dam, water is diverted into the Friant-Kern Canal and Madera Canal for delivery to water users in Tulare, Madera, Merced, Fresno, and Kern counties (Figure 5-2). The capacity of the Friant-Kern Canal and Friant-Madera Canal is 5,300 cfs and 1,200 cfs, respectively.

Friant Dam releases flows into Reach 1 to supply riparian water right holders. Under the terms of the water rights holding contracts, the Bureau of Reclamation is required to maintain at least 5 cfs past each riparian diverter. The downstream-most riparian diverter is located just upstream of Gravelly Ford (RM 228), so the Bureau of Reclamation uses the Gravelly Ford gaging station as a check to ensure that it is meeting its flow release obligations. This normally results in a 40 to 100 cfs release from Friant Dam in the winter and ranges from approximately 180 to 250 cfs in the summer. The larger summer release supplies riparian water right holders between Friant Dam and Gravelly Ford. During typical summer seasons, the river is dry between Gravelly Ford and Mendota Pool (Reach 2A and Reach 2B).

Mendota Pool receives flow from the Delta Mendota Canal and sometimes receives flow from Fresno Slough when the Kings River is flooding and from the San Joaquin River when operations at the Chowchilla Bifurcation Structure dictate. Mendota Dam releases up to 600 cfs during the irrigation

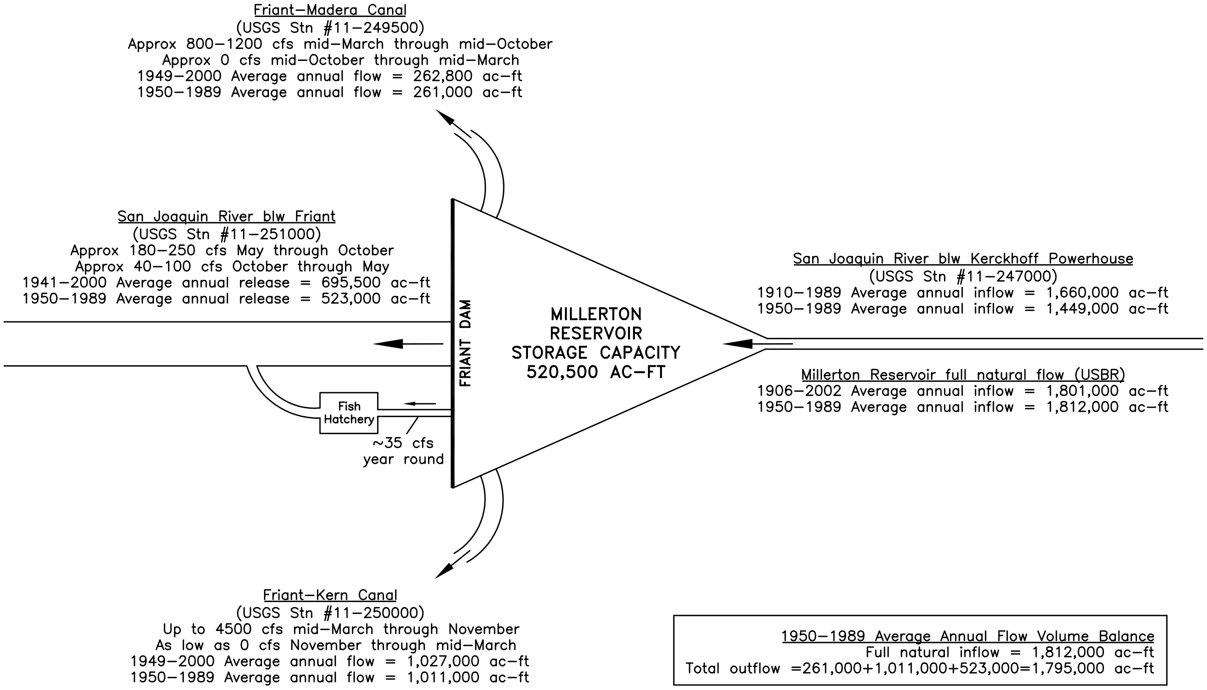


Figure 5-2. Diagrammatic of typical river releases and diversions from Friant Dam during summer irrigation season and winter non-irrigation season.

season, which is conveyed northward in the San Joaquin River through Reach 3 to Sack Dam (about 30 miles). At Sack Dam, all flow above 600 cfs is diverted into Arroyo Canal for delivery to various irrigation districts (exchange contractors), to refuges, and to wetlands in the western Grasslands area. Flows are intermittent in the reach immediately below Sack Dam (Reach 4A) and consist almost entirely of agricultural return water from the San Luis Unit. This water is again pumped from the channel and reused for local irrigation. Downstream of the Sand Slough Control Structure (Reach 4B), the river is again perennially dry.

Table 5-1. Major water-supply infrastructure components from Friant Dam to the Merced River.

Element	Location (River Mile)	Description and Comments
	Reach 1A	
Friant Dam	267.5	Forms Millerton Lake. Total storage is 520,500 acre-feet (af) of which 170,000 acre-feet can be reserved for flood control. Most stored water is delivered via Friant-Kern Canal (capacity = 5,300 cfs) and Friant-Madera Canal (capacity = 1,200 cfs). Friant Dam has blocked fish access to upstream reaches since 1941.
Big Willow Unit Diversion	261.3	Cobble and rock weir structure diverts flow to the Department of Fish and Game DFG fish hatchery.
Rank Island Diversion	260	Cobble weir structure diverts about 5 cfs from the main channel.
Unnamed Diversion	247.2	Rock weir provides head for a pumping station upstream.
	Reach 1B	
Unnamed Diversion	228.2	Sand and gravel berm constructed to provide head for upstream pumping facility
	Reach 2B	
Columbia Canal	206-183	Right bank canal that borders the river, intake from Mendota Pool (typical irrigation season diversion = 200 cfs)
Helm Ditch	204.6-197.5	Left bank ditch, intake from Mendota Pool (typical irrigation season diversion = 5 to 10 cfs)
Mendota Dam	204.6	Headworks for regulating water that is conveyed into the system through the Delta-Mendota Canal. Has no flood storage capacity. Barrier to upstream fish passage with boards in dam. Has fish ladder that is non-functional. Mendota Dam is scheduled to be rebuilt soon.
Fresno Slough	204.6	Left bank slough, intake from Mendota Pool (typical irrigation season diversion= 300 cfs)
Delta-Mendota Canal	204.6	Delivers 800 to 2,800 cfs to left bank of Mendota Pool from Delta
FCWD Canal	204.6	Left bank canal, intake from Mendota Pool (typical irrigation season diversion = 300 cfs)
Main Canal	194.5	Left bank canal, intake from Mendota Pool (typical irrigation season diversion = 1,500 cfs).
Outside Canal	198.0	Left bank canal, intake from Mendota Pool (typical irrigation season diversion = 300 cfs).
	Reach 3	
Sack Dam	182.0	Low-head earth and concrete structure with wooden flap gates that diverts Delta-Mendota Canal flows into the Arroyo Canal.
Arroyo Canal	182.0	Left bank canal, intake from Sack Dam, diverts Delta-Mendota Canal (typical irrigation season diversion = 500 to 600 cfs, diverts all flows up to 600 cfs)
	Reach 4	
Reach 4B headgate	168	Earthfill plug of San Joaquin River with headgate culverts controlling flow into Reach 4B of the San Joaquin River.

Friant Dam, Mendota Dam, Sack Dam, and several other small diversion dams located between Friant Dam and the Merced River confluence are discussed in the following sections.

5.4.1.1. Friant Dam and Associated Diversions

The U.S. Bureau of Reclamation (USBR) constructed Friant Dam (RM 267) in 1941, creating Millerton Lake. This reservoir has a published storage capacity 520,500 acre-feet (DOI, 1981). During typical irrigation seasons, approximately 180 to 250 cfs is released to the San Joaquin River for downstream riparian water rights holders (Figure 5-2). Flows between 50 and 100 cfs typically released during the winter months to meet a lower diversion demand. In both cases, the releases must maintain at least 5 cfs past all riparian diversions. Because the downstream-most diversion is just upstream of Gravelly Ford, the Bureau of Reclamation tends to use the Gravelly Ford gaging station to ensure that they are meeting the 5 cfs requirement. Water is also distributed to the Friant-Madera and Friant-Kern canals during the irrigation season, with rated capacity of the Friant-Kern Canal of 5,300 cfs, and the rated capacity of the Friant-Madera Canal of 1,200 cfs. Typical irrigation diversions into the Madera Canal are 800 to 1,200 cfs, and typical irrigation diversions into the Friant-Kern Canal is up to 4,500 cfs (USGS gaging records from 1948-2000). Diversions into the canals during the winter months are often zero, but the canals are sometimes used to convey flows during flood control releases.

As mentioned above, typical flow releases from Friant Dam are typically less than 250 cfs. The exception is during periods of large inflows from the watershed that encroach into the flood control space in Millerton Lake. The outlet works capacity of Friant Dam varies with reservoir elevation, with maximum release capacity of 16,400 cfs at a reservoir elevation of 578 ft (Figure 5-3); therefore, most flood control releases are made through the outlet works. Larger floods, like the 60,000 cfs flood in 1997, exceed the capacity of the outlet works and enter the San Joaquin River via the spillway. The present operating rules during flood events for Friant Dam require that releases from the dam be restricted to levels that will not cause downstream flows to exceed, insofar as possible, either of the following criteria (ACOE 1980):

- a combined flow of 8,000 cfs to the San Joaquin River from Friant Dam, Cottonwood Creek, and Little Dry Creek, and
- a flow of 6,500 cfs at the gage near Mendota (below Mendota Dam).

The construction and operation of Friant Dam has impacted the San Joaquin River in three significant ways. First, reduced San Joaquin River releases from the Friant Dam, combined with downstream riparian diversions, have dewatered most of Reach 2 and Reach 4, preventing fish use and passage in most years. Second, even if fish could migrate up river, Friant Dam is a barrier for upstream fish migration, and thus the furthest upstream boundary for salmonid migration. Lastly, Friant Dam has reduced the high flow regime and eliminated sediment supply from the upper watershed. The recurrence interval of an 8,000 cfs flow at Friant has been increased from 1.3-year flood (pre-Friant Dam) to a 6-year flood by cumulative dams upstream of and including Friant Dam. Most of the coarse sediment supply is trapped in Millerton Reservoir and upstream reservoirs rather than routed downstream to provide salmonid spawning habitat. Therefore, coarse sediment available for other fluvial processes such as channel migration, riffle-pool formation, and sediment deposition must come from the coarse sediment stored in the channel itself. Hydrology, geomorphology, fishery, and riparian impacts of Friant Dam are discussed in more detail in Chapters 2, 3, 7, and 8, respectively.

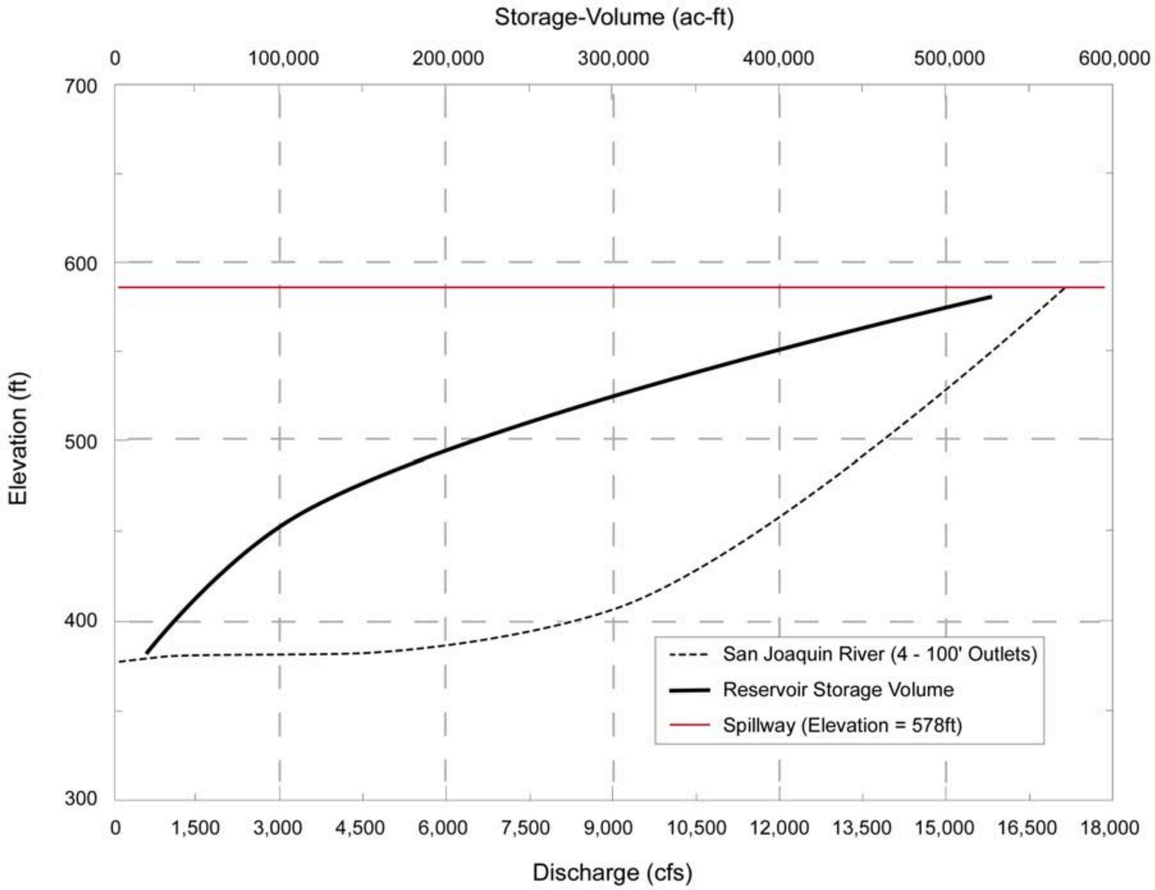


Figure 5-3. Friant Dam storage curve and outlet works release rating as a function of Millerton Reservoir stage.

5.4.1.2. Mendota Dam and Pool

Mendota Dam (RM 204.6) is located at the confluence of the San Joaquin River and Fresno Slough (Figure 5-1, Table 5-1). Fresno Slough connects the Kings River to the San Joaquin River, and delivers water to the south from Mendota Pool during the irrigation season, and delivers water to Mendota Pool and the San Joaquin River from the Kings River when the Kings River is flooding. Mendota Pool is the small reservoir created by Mendota Dam (3,000 acre-ft) and has a surface area of approximately 1,200 acres. The pool behind the dam redistributes water delivered by the Delta-Mendota Canal to canals that convey water for agricultural use. Mendota Pool does not provide any appreciable flood storage. The water surface elevation in the pool is maintained by a set of manual gates and flashboards that are manually opened/removed in advance of high flow conditions. This process lowers the water level in the pool to pass high flows to reduce seepage impacts to adjacent lands, but hinders distribution of flows into the canals.

Mendota Dam serves as a complex water distribution manifold to many diversions and riparian pumps, all of which are unscreened or do not meet National Marine Fisheries Service (NMFS) and California Department of Fish and Game (CDFG) screening criteria for salmonids. This complex area of water diversions will be a considerable constrain to salmonid restoration efforts due to the unscreened diversions and large volume of water exchanged in the Mendota Pool. Mendota Dam and Mendota Pool have been used for irrigation diversions since the late 1800s, and had historically depended on San Joaquin River and Fresno Slough flows to divert into irrigation canals originating from Mendota Pool. After completion of Friant Dam in 1948, flows to Mendota Pool from the San Joaquin River was greatly decreased. Completion of the Delta-Mendota Canal in 1951 delivered water pumped from the Bay-Delta to Mendota Pool. The DMC has a rated capacity of 4,600 cfs (DOI, 1981); however, typical water delivery by the DMC during the irrigation season is approximately 2,500 to 2,800 cfs (Figure 5-4), with no water delivered to Mendota Pool by the San Joaquin River or Fresno Slough during the irrigation season. Five diversion canals extract all but 500 to 600 cfs of water delivered to the Mendota Pool complex by the DMC. Mendota Dam releases this remaining flow into Reach 3 of the San Joaquin River. This release flows approximately 22 miles downstream to Sack Dam, where it is diverted into the Arroyo Canal.

Although Mendota Dam is much smaller than Friant Dam, it is substantial barrier to the upstream and downstream migration of salmonids. While there is a fish ladder on the dam, it has been inoperable since the late 1940’s, and erosion on the downstream side of the dam has perched the entrance to the ladder above the water surface. Therefore, adult salmonids (and other fish) cannot migrate upstream past the dam during typical flow conditions (it is potentially passable when all the boards are pulled, but water velocities may still be too great for passage) and the fish ladder would need to be reconstructed to be usable. In addition, downstream migrating juvenile fish would likely incur high entrainment losses through the unscreened diversions and canals.

The water delivered by the DMC contains much higher concentrations of Total Dissolved Solids and is more saline than San Joaquin River water released from Friant Dam. In addition to potential impacts on fishery restoration efforts by poorer water quality, there may be problems with juvenile salmonids imprinting on Delta-Mendota Canal water rather than San Joaquin River water.

Over time, Mendota Dam has partially filled with sediment during infrequent high flow releases from Friant Dam. During these higher flows when the flashboards have been pulled, some unknown portion of this sediment is able to flush and route downstream, such that Mendota Pool has retained much of its storage capacity. If the flashboards are not been pulled prior to a high flow from the San Joaquin River or Fresno Slough, the increased water surface elevations cause seepage problems on upstream and adjacent properties. Additionally, there have been recurring problems with water seeping under Mendota Dam, threatening the structural integrity of the dam. Mendota Pool is drained every other year to inspect the dam footings. These combined problems with Mendota Dam have led to preliminary designs of a new Mendota Dam approximately 300 ft downstream of the existing structure. Hoping to incorporate solutions to some of the fishery and sediment routing constraints imposed by the current Mendota Dam and diversions, the San Joaquin Restoration Oversight Team (ROST) has initiated technical discussions for solutions that could be integrated with the USBR effort to replace Mendota Dam. Future restoration hurdles include adult and juvenile fish passage, sediment routing, operations of pool during high flows in San Joaquin River and Fresno Slough, screening to prevent juvenile fish entrainment into the canals, and alleviating seepage problems occurring through nearby non-project levees during higher flows.

5.4.1.3. Sack Dam

Sack Dam (RM 178) is a low-head structure used to control water released from the DMC as part of the diversion into Arroyo Canal. All flows conveyed through Reach 3 less than 600 cfs are typically diverted into Arroyo Canal. Larger flows continue downstream through Reach 4A and are diverted into the Eastside Bypass at the Sand Slough Control Structure (RM 168.5). Because of their similar operational objectives, many impacts associated with Sack Dam are similar to those of Mendota Dam (see Section 5.4.1.2). The major difference between the two structures is that Sack Dam is much smaller, and the fish ladder can be easily fixed to be fully functional. Therefore, adult fish passage is not a significant constraint. Juvenile fish entrainment into the Arroyo Canal, however, represents a

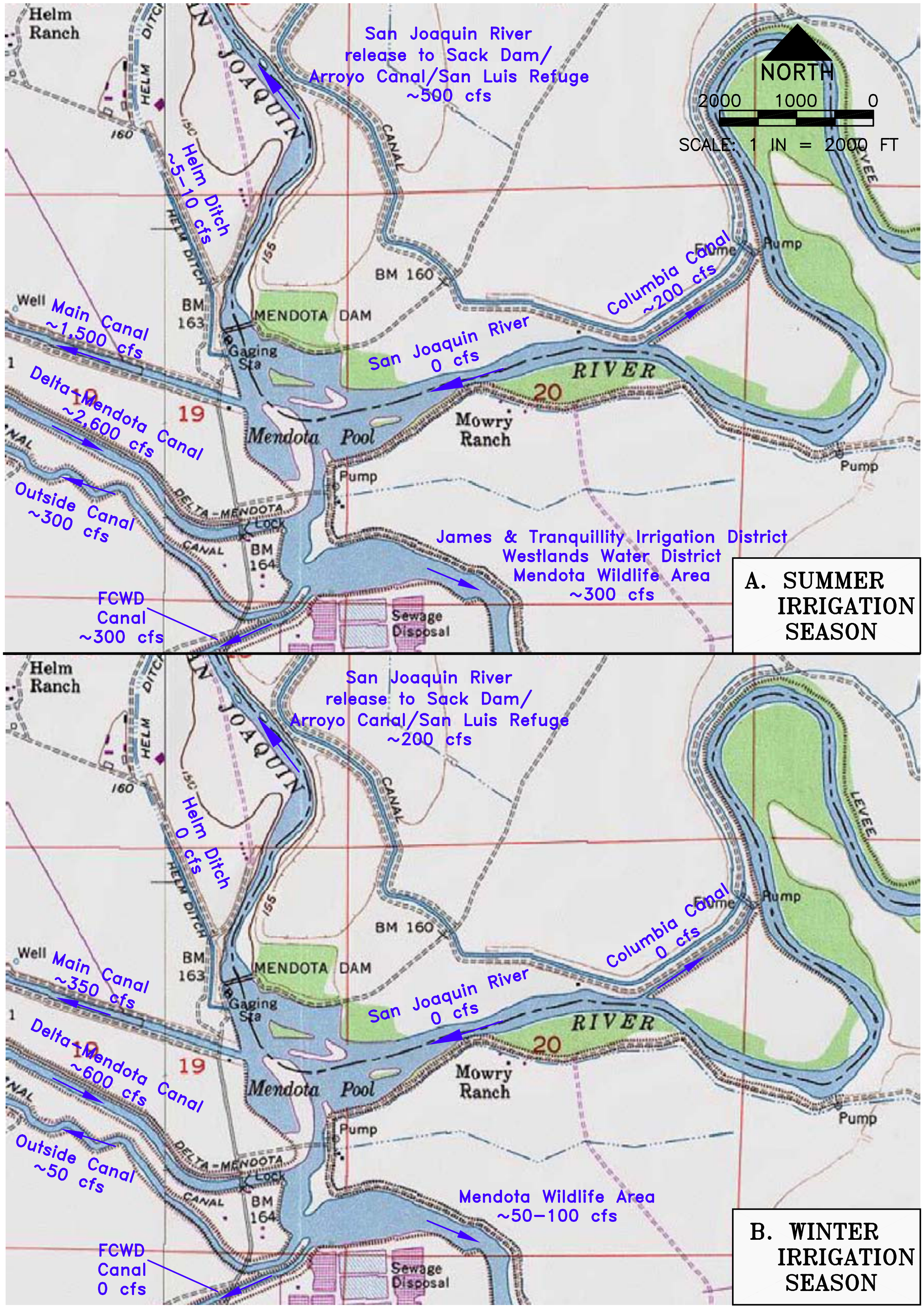


Figure 5-4. Diagrammatic of typical river releases and diversions from Mendota Dam during summer irrigation season and winter season. Winter diversions and releases are largely for wildlife refuges.

more significant hurdle. This diversion will either need to be screened, or potentially plumbed directly into the DMC, to alleviate anticipated juvenile entrainment into the canal.

5.4.1.4. Riparian Diversions

A search of the State Water Resources Control Board's (SWRCB) Riparian Rights GIS database (State Water Resources Control Board, 2000) listed 54 riparian water rights holders within the San Joaquin River corridor between Friant Dam and Merced River. Only 13 of these riparian rights holders divert water directly from the San Joaquin River. The other 41 riparian water rights are located on several adjacent sloughs and bypasses that are supplied by the San Joaquin River. The SWRCB GIS database provided the locations of these Riparian Water Rights.

Mussetter Engineering also identified the location of three weir structures just downstream of Friant Dam and verified their locations. The Big Willow Unit Diversion (RM 261.3) is a cobble-type weir that diverts a small amount of water to the Fish Hatchery. The Rank Island Unit is a cobble weir located at RM 260. The Rank Island Unit diverts approximately 5 cfs to property on the north side of the river. The Milburn Unit Diversion is a small concrete-rubble weir located at RM 247.2. A small pump is located just upstream.

In 2001, CDFG inventoried riparian diversions along the project reach, and are summarized in Table 5-2. This represents the most complete inventory performed to date on the San Joaquin River. This inventory does not include potential alternative pathways that have been or are being considered for fish routing. Old sloughs and bypasses in Reaches 2 through 4 have been discussed for alternative pathways for fish routing (e.g., Pick Anderson Slough, Salt Slough, Lone Willow Slough); however, many of these sloughs function as agricultural return channels and the water is subsequently re-used by riparian pumps. Field observations of Pick Anderson Slough showed numerous pumps that would potentially constrain their use as alternative pathways for fish routing (e.g., they have similar number of riparian pumps as the main channel). Other alternative pathways being considered are the flood bypasses. CDFG did not include the sloughs or flood bypass system in their inventory; however, visual observation of the flood bypasses shows that there are far fewer riparian diversions in the bypasses than the sloughs and mainstem San Joaquin River, which may provide a restoration opportunity for juvenile fish routing.

In summary, impacts associated with riparian diversions include the following:

- Diversions cause cumulative reduction in flows, most notably during low baseflow periods.
- Hardpoints associated with extraction/diversion facilities often reduce the ability of the channel to migrate or adjust its dimensions.
- Many of the diversions along the San Joaquin River remain unscreened. During out-migration periods, juvenile fish may be entrained within the irrigation, water supply, or other conveyance systems attached to the main channel, causing functional mortality because the fish are distributed onto irrigated fields.
- On those diversions that may be screened, they may exceed entrance velocity criteria, impinging fish on the screen itself and causing mortality or stress.

Table 5-2. Summary of riparian diversions mapped by CDFG in 2001.

River Mile	Primary Use	Bank Location	Diversion Type	Intake Size (inches)	Estimated Maximum Diversion Capacity (cfs)
266.76	Agricultural	Right	Pump	6	1
266.57	Agricultural	Left	Pump	8	2
265.73	Recreation	Left	Pump	12	4
265.20	Recreation	Left	Pump	7	1
265.19	Agricultural	Right	Pump	15	6
265.13	Agricultural	Right	Pump	12	4
265.13	Agricultural	Right	Pump	12	4
265.13	Agricultural	Right	Pump	12	4
264.75	Recreation	Left	Pump	7	1
263.45	Agricultural	Right	Pump	12	4
263.45	Agricultural	Right	Pump	12	4
263.08	Agricultural	Left	Pump	10	Removed
262.9[a]	Agricultural	Left	Pump	12	4
262.72	Agricultural	Right	Pump	6	1
262.46	Agricultural	Left	Pump	6	1
262.46	Agricultural	Left	Pump	10	3
262.31	Agricultural	Left	Pump	10	3
262.16	Agricultural	Right	Pump	36	35
262.15	Agricultural	Right	Pump	8	2
262.14	Agricultural	Left	Pump	60	Removed
261.65	Unknown	Left	Pump	unknown	
261.65	Unknown	Left	Pump	8	2
261.65	Unknown	Left	Pump	unknown	
261.55	Not in use	Left	Pump	8	2
261.3	Hatchery	Left	Weir	unknown	<5
261.25	Agricultural	Left	Pump	3	<1
261.21	Agricultural	Right	Pump	12	4
261.05	Agricultural	Right	Pump	24	16
261.00	Industrial	Left	Pump	8	2
261.00	Industrial	Left	Pump	8	2
260.25	Agricultural	Right	Pump	7	1
260.25	Agricultural	Right	Pump	7	1
260.00	Agricultural	Right	Weir	unknown	5
259.95	Agricultural	Left	Pump	3	<1
259.84	Unknown	Right	Pump	10	3
259.77	Agricultural	Left	Pump	9	2
259.67	Agricultural	Left	Pump	10	3
259.48	Agricultural	Left	Pump	6	1
259.48	Agricultural	Left	Pump	10	3
259.48	Recreation	Right	Pump	6	1
259.47	Agricultural	Left	Pump	10	3
259.47	Not in use	Left	Pump	6	1
259.20	Recreation	Right	Pump	4	<1
259.00	Agricultural	Left	Pump	7	1
259.00	Recreation	Right	Pump	4	<1
258.72	Not in use	Left	Pump	3	Removed
258.70	Agricultural	Left	Pump	12	4

Table 5-2. cont.

River Mile	Primary Use	Bank Location	Diversion Type	Intake Size (inches)	Estimated Maximum Diversion Capacity (cfs)
257.49	Agricultural	Right	Pump	30	25
256.77	Agricultural	Left	Pump	8	2
256.33	Agricultural	Right	Pump	7	1
256.32	Agricultural	Right	Pump	10	3
256.31	Domestic	Left	Pump	3	<1
255.84	Agricultural	Left	Pump	unknown	
254.90	Agricultural	Right	Pump	7	1
254.90	Agricultural	Right	Pump	7	1
253.95	Agricultural	Left	Pump	13	5
253.40	Agricultural	Left	Pump	16	7
252.28	Industrial	Right	Pump	8	2
251.60	Industrial	Right	Pump	7	1
251.57	Agricultural	Right	Pump	15	6
251.37	Agricultural	Right	Pump	8	2
251.16	Agricultural	Right	Pump	7	1
249.66	Agricultural	Right	Pump	7	1
249.23	Not in use	Left	Pump	6	Removed
248.00	Agricultural	Right	Pump	36	35
247.20	Agricultural	Unknown	Weir	unknown	<5
246.88	Agricultural	Right	Pump	48	63
246.29	Not in use	Right	Pump	12	Removed
245.73	Agricultural	Right	Pump	12	Removed
245.41	Agricultural	Right	Pump	36	35
242.57	Not in use	Left	Pump	7	Removed
242.16	Not in use	Left	Pump	8	Removed
241.62	Not in use	Left	Pump	6	1
240.56	Agricultural	Left	Pump	12	4
239.62	Not in use	Left	Pump	6	Removed
230.89	Unknown	Left	Pipe	5	1
230.13	Agricultural	Right	Pump	5	1
230.06	Agricultural	Right	Pump	10	3
230.06	Agricultural	Right	Pipe	10	3
229.85	Not in use	Right	Pump	10	3
229.56	Agricultural	Right	Pump	4	<1
229.35	Agricultural	Left	Pump	8	2
229.35	Agricultural	Left	Pump	8	2
228.89	Agricultural	Right	Pump	12	4
228.78	Agricultural	Right	Pump	24	16
228.78	Agricultural	Right	Pump	24	16
227.72	Agricultural	Right	Pump	10	3
223.25	Not in use	Left	Pump	12	Removed
222.75	Agricultural	Right	Pump	12	4
215.50	Agricultural	Right	Pump	unknown	
210.89	Agricultural	Left	Pipe	19	10
210.89	Agricultural	Left	Pipe	19	10
210.70	Agricultural	Left	Pipe	11	3
210.43	Agricultural	Left	Pipe	10	3
209.61	Agricultural	Left	Pipe	20	11

Table 5-2. cont.

River Mile	Primary Use	Bank Location	Diversion Type	Intake Size (inches)	Estimated Maximum Diversion Capacity (cfs)
209.61	Agricultural	Left	Pipe	16	7
209.61	Agricultural	Left	Pipe	16	7
209.61	Agricultural	Left	Pipe	11	3
209.61	Agricultural	Left	Pipe	11	3
208.83	Agricultural	Right	Pump	24	16
208.83	Not in use	Right	Pump	36	Removed
207.73	Agricultural	Right	Pump	12	4
207.06	Agricultural	Right	Pump	unknown	
206.50	Agricultural	Left	Pump	12	4
206.50	Agricultural	Left	Pump	12	4
206.00	Agricultural	Right	Pump	10	3
205.95	Agricultural	Right	Dam/Pump	Columbia Can.	200
204.90	Agricultural	Left	Dam	Fresno Slough	300
204.90	Agricultural	Left	Dam	FCWD Can.	300
204.90	Agricultural	Left	Dam	Outside Can.	300
204.85	Agricultural	Left	Dam	Main Can.	1,500
204.80	Agricultural	Left	Dam	Helm Ditch	10
202.07	Agricultural	Left	Pump	3	<1
202.00	Domestic	Right	Pump	3	<1
195.38	Municipal	Right	Pump	8	2
194.70	Agricultural	Left	Pump	7	Removed
193.50	Agricultural	Right	Pump	unknown	
182.00	Agricultural	Left	Dam	Arroyo Can.	600
180.60	Agricultural	Left	Pump	17	8
173.79	Agricultural	Right	Pump	5	1
170.75	Agricultural	Right	Pump	10	3
169.95	Agricultural	Left	Pump	10	Removed
159.90	Agricultural	Right	Pump	10	3
159.60	Agricultural	Right	Pump	12	4
156.92	Domestic	Right	Pump	6	1
156.87	Agricultural	Right	Flashboard riser	18	9
156.67	Unknown	Right	Flashboard riser	18	9
155.30	Agricultural	Left	Pump	10	3
154.70	Agricultural	Left	Pump	9	2
154.70	Agricultural	Left	Pump	9	2
147.20	Recreation	Right	Pump	16	7
144.00	Wildlife Refuge Enhance	Right	Pump	36	35
131.00	Not in use	Right	Pump	8	Removed
130.30	Agricultural	Right	Pump	18	9
125.00	Agricultural	Right	Pump	16	7
118.80	Not in use	Left	Pump	5	Removed

[a] River mile location is approximate

5.4.1.5. Agricultural Return Flows

The quantity and quality of San Joaquin River water is strongly influenced by the discharge of agricultural drainage. Agricultural return flows are minor in Reaches 1 and 2, with some small amounts of return flows from Fresno Irrigation District occurring near Biola (RM 236.1) and others. Most agricultural return flows occur downstream of Mendota Pool. During the irrigation season (March through September), water is imported from the Delta and delivered through the DMC to the Mendota Pool to supply the San Joaquin River Exchange Contractors along the San Joaquin River, and to the San Luis Reservoir and San Luis Canal to supply the majority of the San Luis Unit contractors. Friant Dam releases very good water quality, but during typical operations, these flows tend to terminate just downstream of Gravelly Ford and do not reach Mendota Pool. Mendota Dam then releases 500 to 600 cfs of DMC water, and accumulation of agricultural return flows with poorer quality DMC water causes water quality to decline downstream of Mendota Dam (see Chapter 6 for more detail).

Because of underlying geology, agricultural return flows, and urban runoff, the lower reaches of the San Joaquin River has some of the poorest quality water in the Central Valley. Downstream of Sack Dam, the primary sources of stream flows are irrigation returns and groundwater discharged either directly to the main channel or via Mud Slough and Salt Slough. Average annual discharges are 54,000 acre-feet for Mud Slough and 204,000 acre-feet for Salt Slough. Irrigation returns from Mud Slough and Salt Slough accounts for 44 percent of the flow in the San Joaquin River above its confluence with the Merced River during normal water years (e.g., 1979) (Moore et al. 1990). In a dry year (e.g., 1981), Mud Slough and Salt Slough account for 70 percent of the flow. The historic contribution of Mud Slough and Salt Slough (prior to construction of Friant Dam) to the San Joaquin River flows were below one percent of those total annual flows (SJVDP 1990).

Addition of agricultural drainage water to the lower reaches of the San Joaquin River results in reduced water quality due to accumulations of salinity, trace elements such as selenium, and nutrients. Many of these constituents impair natural nutrient cycles and biological processes. Selenium has been found to bioaccumulate in fish and birds. Resident fish collected from the Mud and Salt Slough during the mid 1980's showed elevated levels of selenium in their tissues. Aggregate geometric mean (dry weight) selenium concentrations in whole bluegill samples ranged from 4.4 parts-per-million (ppm) at Salt Slough to 10.4 ppm at Mud Slough (North). Selenium concentrations in freshwater fishes in the United States average 0.5 ppm. It has been estimated that selenium concentrations of 2.0 ppm could cause toxic effects in fish (Saiki 1986a). Based on data collected during 1986, Saiki (1986b) and Moore et al. (1990) noted that selenium concentrations in bluegill gonads from samples collected in the western Grasslands area were sufficiently elevated to impair the reproduction of this species. Refer to Chapter 6 for a more detailed discussion of water quality impacts.

5.4.2. Overview of Flood Control System

The flood control system along the San Joaquin River is composed of a series of dams, bifurcation structures, bypasses, levees, and the main river channel. Flood control efforts were initiated in the late 1800's to protect structures and agricultural lands from the regular inundation of winter and spring floods along the San Joaquin River corridor. By 1894, several flood control districts had been formed to construct the first several miles of levees with the hope to provide adjacent landowners some level of flood protection. Early efforts in flood protection were generally inadequate.

In 1933, the first phase of flood control development progressed when the Central Valley Project (CVP) was authorized by Congress. As part of this plan, construction of Friant Dam was completed in

1941 to store and divert water from the San Joaquin River. Congress authorized the Flood Control Act of 1944, which included the San Joaquin River and Tributaries Project (SJRTP).

The Lower San Joaquin River Flood Control Project was authorized by Congress in 1944 to protect irrigated agricultural lands and associated developments. The original plan prepared by the Chief of Engineers and reported to Congress recommended that an area of approximately 118,000 acres of grassland floodplain between Friant Dam and the Merced River be retained as flood detention basins, in lieu of flood protection works (Reclamation Board, 1966). The Corp of Engineers estimated the cost of this floodplain area at $800,000.

Several events following this original flood detention basin plan resulted in a revised flood control approach in the study area. Friant Dam was completed in 1948, and experienced difficulties in November and December of 1950 operating for flood control purposes. Following World War II, the completion of Friant Dam, Delta Mendota Canal, and associated water delivery systems, the demand and value of reclaimed lands along the San Joaquin River dramatically increased. In February 1952, the Reclamation Board held a public hearing to present the flood control plan proposed by the Corp of Engineers. There was local opposition to the ACOE plan authorized by Congress due to the large area of lands to be retained for flood detention, which would preclude its use for reclamation and agricultural utilization. Although supporting data is not provided, the Reclamation Board estimated that the land value of the 118,000 acres identified for flood detention use increased from $800,000 in 1944 to $18,300,000 in March 1953. This increase in value was due to land reclamation and development, changes in land use, and accelerated demand for irrigable land (Reclamation Board 1966).

In response to these increased land values and public opposition to the ACOE plan, the California Department of Water Resources prepared an alternative plan that reduced the land need for flood plains and bypasses to 22,000 acres, allowing 96,000 acres of the original 118,000 acres to be reclaimed. Additional public opposition to bypass alignments and capacities resulted in another modification to the flood control plan in 1957. Additional desires for flood control protection in Reach 2 and 3 resulted in the adoption of the Chowchilla Canal Bypass Plan in May 1961. Control structures, levees, and right-of-ways were firmly established in January 1964, and the project was dedicated on October 6, 1966. The project was intended to provide approximately 50-yr flood frequency protection, protecting approximately 96,000 acres of land previously subjected to annual flooding. The project claimed “prolonged periods of inundation and ponding following floods will now be eliminated and reduce the severity of crop damage, crop planting delays, and limitations of access” (Reclamation Board 1966). History has shown that many of these claimed benefits of the flood control project has been achieved; however, flood and seepage damage still occurs in many locations at a frequency greater than the original 50-year protection objective of the flood control project (see Section 5.4.2.2).

Dams were also constructed on tributaries to the San Joaquin River that contributed to the Flood Control Project, including Pine Flat Dam on the Kings River (completed in 1954), Buchanan Dam on the Chowchilla River (completed in 1975), and Hidden Dam on the Fresno River (completed in 1975). While these reservoirs are located on tributaries of the San Joaquin River, they provide flood control function to the San Joaquin River as well as the tributaries they are located on (ACOE 1999a). Pine Flat Dam provides baseflows to the Kings River downstream of the dam; however, Buchanan Dam and Hidden Dam dewater the Chowchilla River and Fresno River over much of the year.

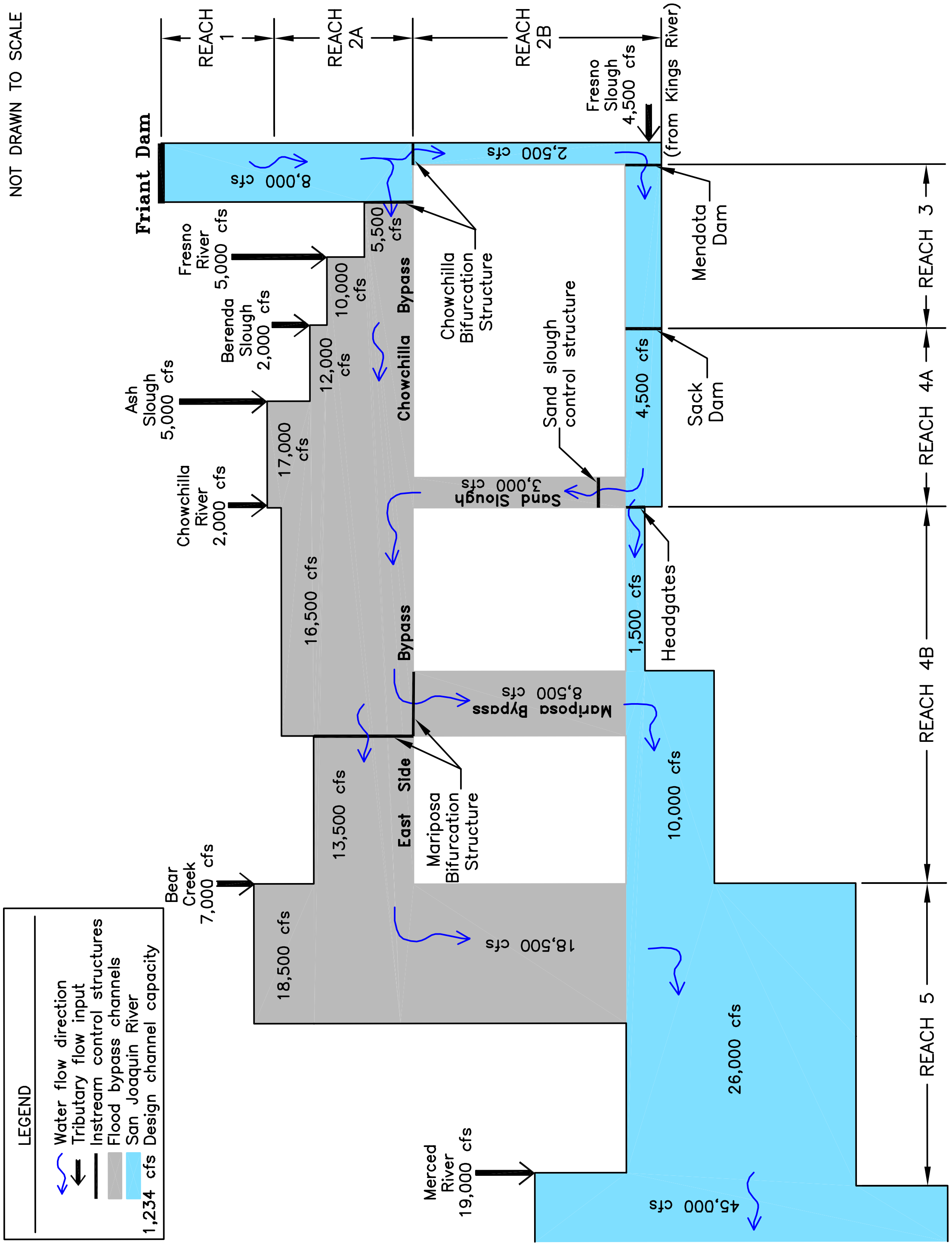


Figure 5-5. Schematic map of structures and reach hydraulic capacity rating within the study reach of the San Joaquin River.

Within the last three decades the ACOE has oversaw the repair of the existing levee system along the Sutter Bypass and the Feather, Yuba, and Sacramento rivers. Little work has been done to repair and/or construct new levees along the San Joaquin River corridor. Much of the work has been conducted in response to potential situations that pose immediate danger to life or developed property.

The following paragraphs discuss the overall flood control system within the San Joaquin River study area and the associated impacts on restoration efforts. A summary of flood control system components is provided in Table 5-3 and Figure 5-5.

Table 5-3. Summary of flood control components along the San Joaquin River

Element	Location (River Mile)	Description and Comments
	Dams	
Mammoth Pool, Shaver Lake, Florence Lake, and others	Upstream of Friant Dam	Total storage of 560,000 acre-ft, and provides some incidental flood control functions. Some of the 170,000 acre-ft of flood control space in Millerton Reservoir can be transferred to Mammoth Pool.
Friant Dam	267.5	Forms Millerton Reservoir. Total storage is 520,500 acre-feet of which 170,000 acre-feet can be reserved for flood control. Significant barrier to upstream fish passage.
Pine Flat Dam		Dam on Kings River that provides flood control purpose to Tulare Lake basin, and portion of flood control release is conveyed to the San Joaquin River via James Bypass and Fresno Slough. Total storage 1,001,000 acre-feet, flood control storage 475,000 acre-ft.
Buchanan Dam		Dam on Chowchilla River that provides flood control purpose. Flood control releases into the Fresno River are delivered to the Chowchilla Bypass. Total storage 150,600 acre-feet, flood control storage 45,000 acre-ft.
Hidden Dam		Dam on Fresno River that provides flood control purpose. Flood control releases into the Fresno River are delivered to the Chowchilla Bypass. Total storage 90,600 acre-feet, flood control storage 65,000 acre-ft.
	Diversion Structures	
Chowchilla Bypass Bifurcation Structure	216.1	Diverts flood flows from the mainstem of the San Joaquin to Chowchilla Bypass Canal
Mariposa Bypass Bifurcation Structure	147	Diverts flood flows from the East Side Bypass / Mariposa Bypass confluence back to the San Joaquin River
	Other Hydraulic Control Structures	
Sand Slough Control Structure	East Side Bypass	Low head control structure in Sand Slough between San Joaquin River and East Side Bypass.
Eastside Bypass Control Structures	East Side Bypass	Low head grade control structures within the East Side Bypass
Mariposa Bypass Control Structures	Mariposa Bypass	Low head grade control structures within the Mariposa Bypass
Reach 4B Headgates	168	Low-head control structure within the mainstem San Joaquin River that controls flows into Reach 4B.
	Bypasses	
James Bypass/Fresno Slough	204.6 (outlet)	Conveys flood flows from the Kings River North to Mendota Pool
Chowchilla Bypass	216.1 (inlet)	Currently functions solely as a flood conveyance system conveying flood flows from the Chowchilla Bifurcation Structure (RM 216.1) to the East Side Bypass canal.
Mariposa Bypass	147.2 (outlet)	Conveys water from the Mariposa Bypass Bifurcation Structure back to the San Joaquin River.

Table 5-3. cont.

Element	Location (River Mile)	Description and Comments
East Side Bypass	136 (outlet)	Conveys water from the Chowchilla Bypass to the Mariposa Bypass Bifurcation structure and back to the San Joaquin River.
Levees		
Project Levees	225 - 118	Project levees line the Chowchilla Bypass and East Side Bypass, as well as the San Joaquin River from 4 miles downstream of Gravelly Ford to the Chowchilla Bifurcation Structure, then again from Mariposa Bypass confluence downstream to the Merced River confluence.
Non-Project Levees	216.1 - 147.2	Non-project levees have been constructed on both sides of the river by local landowners from the Chowchilla Bifurcation Structure to the confluence of the Mariposa Bypass.

5.4.2.1. Flood Control Dams

There are many dams contributing to flood control on the San Joaquin River. Friant Dam is the keystone of this system, but flood control is also provided by dams on the upper San Joaquin River, and dams on the Kings River, Fresno River, and Chowchilla River (Table 5-3). The space allocated to flood control in Millerton Lake increases from 0 acre-feet on October 1 to 170,000 acre-feet during the rain flood season (November 1– February 1), and decreases again to 0 acre-feet on April 1 (Figure 5-6). A portion of the 170,000 acre-ft flood control space reserve for Millerton Reservoir can be transferred to Mammoth Pool (i.e., storage space available in Mammoth Pool can be used to allow Millerton Reservoir to “encroach” or fill into the reserved flood control space). For example, rain flood space of up to 85,000 acre-feet can be transferred to Mammoth Pool, allowing Millerton Reservoir to store more water through the rain flood season. In addition, up to 390,000 acre-ft of conditional flood control space is reserved for the snowmelt runoff period (Figure 5-6). The mandated releases from Friant Dam when the reservoir storage encroaches into flood control space depends on tributary flows downstream of Friant Dam, irrigation demand, runoff forecasts, future precipitation forecasts, and discussions with the ACOE.

Flood flows from the Kings River basin are sometimes delivered to the San Joaquin River via James Bypass and Fresno Slough. Flows in the Kings River North are controlled by the operation of Pine Flat Dam. Although early studies indicated that the capacity of the James Bypass and Fresno Slough was about 4,500 cfs, flows up to 6,000 cfs have passed through this reach (ACOE, 1993). This contribution from the Kings River, combined with tributary accretion from Cottonwood Creek (RM 267) and Little Dry Creek (RM 261), sometimes creates complicated flood control operations from Friant Dam. ACOE criteria require flood releases from Friant Dam limited so that: (1) the combined maximum flow to the San Joaquin River from Friant Dam, Cottonwood Creek, and Little Dry Creek does not exceed 8,000 cfs, and (2) the flow at the San Joaquin River near Mendota gage below Mendota Dam (USGS #11-254000) does not exceed 6,500 cfs (ACOE, 1980). Theoretically, if the Fresno Slough and downstream tributaries are contributing high flows, flow releases from Friant Dam could be constrained to the capacity of the Chowchilla Bypass (5,500 cfs) because flow conveyance for Fresno Slough and tributary contributions takes precedence over Friant Dam releases.

During wet years, large inflows into Millerton Lake sometimes encroach into flood control storage space. Flood operating criteria during these periods result in a release hydrograph with flows of near 8,000 cfs for an extended time (see San Joaquin River hydrographs in Appendix A). Since completion of Friant Dam and the Friant-Madera and Friant-Kern canals in the late 1940s, gage records show releases of 8,000 cfs or greater occurred in 10 of the 52 post-Friant Dam years during the spring snowmelt period between March and July (1952, 1958, 1967, 1969, 1978, 1982, 1983, 1986, 1988,

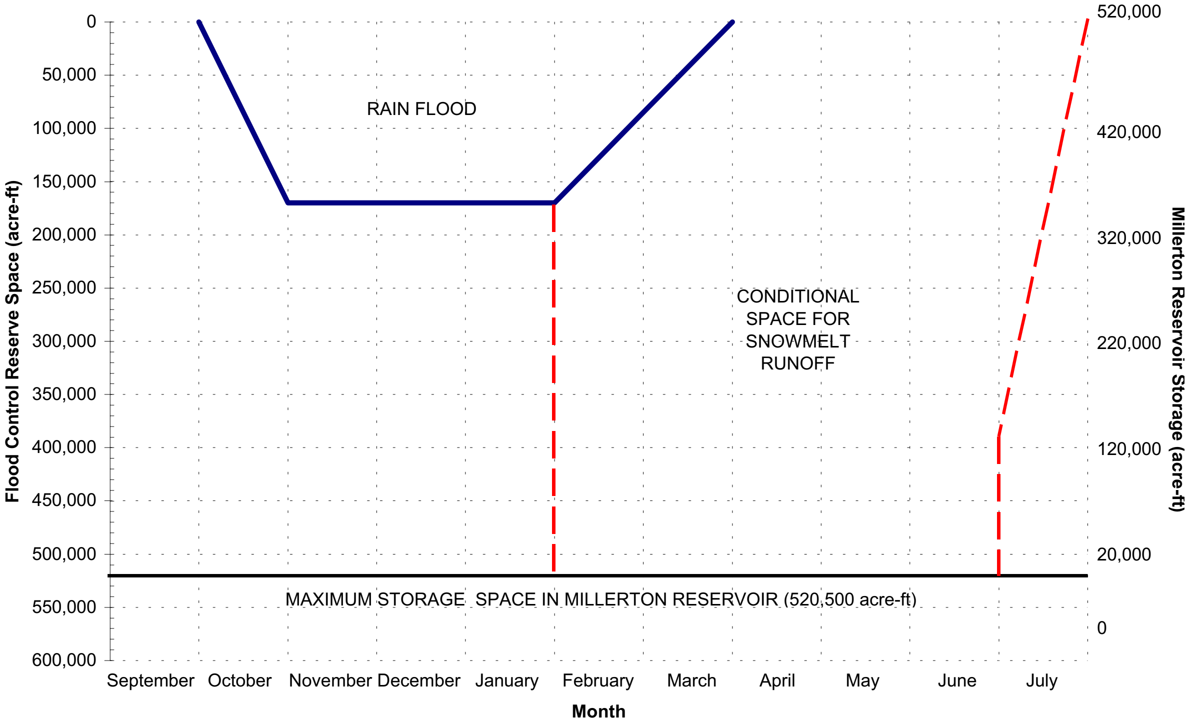


Figure 5-6. Flood control reserve space in Millerton Reservoir as required by the Army Corps of Engineers. The volume of water released during encroachment into either flood control space varies depending on tributary inflows downstream of Friant Dam, irrigation demand, forecasted runoff, and discussions with the Corps of Engineers.

1995, and 1998). In three other years (1980, 1996, and 1997), flows reached or exceeded the 8,000 cfs during the winter rather than the snowmelt runoff period. Flows were greater than 8,000 cfs in water year 1969 (peak flow=12,400 cfs), 1983 (peak flow=12,300 cfs), 1986 (peak flow=15,500 cfs), 1995 (peak flow=12,500 cfs), and 1997 (peak flow=60,300 cfs). Consistent with the peak flood frequency analysis, these results indicate that discharges in the 8,000 cfs range are reached or exceeded during the winter flood season and spring snowmelt season approximately 13 of 49 years. Using the flood frequency analysis in Chapter 2, the recurrence interval of an 8,000 cfs flow at Friant has been increased from 1.3-year flood (pre-Friant Dam) to a 6-year flood by cumulative dams upstream of and including Friant Dam.

5.4.2.2. San Joaquin River Levees and Dikes

There are two classes of levees and dikes along the San Joaquin River study area: (1) those associated with the San Joaquin River Flood Control Project, and (2) those constructed by individual landowners to protect site specific properties, and thus are not associated with the San Joaquin River Flood Control Project. The San Joaquin River Flood Control Project consists of a parallel conveyance system: (1) leveed bypass system on the east side of the San Joaquin Valley, and (2) leveed flow conveyance system in the San Joaquin River. This section describes levees and dikes that have been constructed along the San Joaquin River, and does not describe the bypass system of the San Joaquin River Flood Control Project.

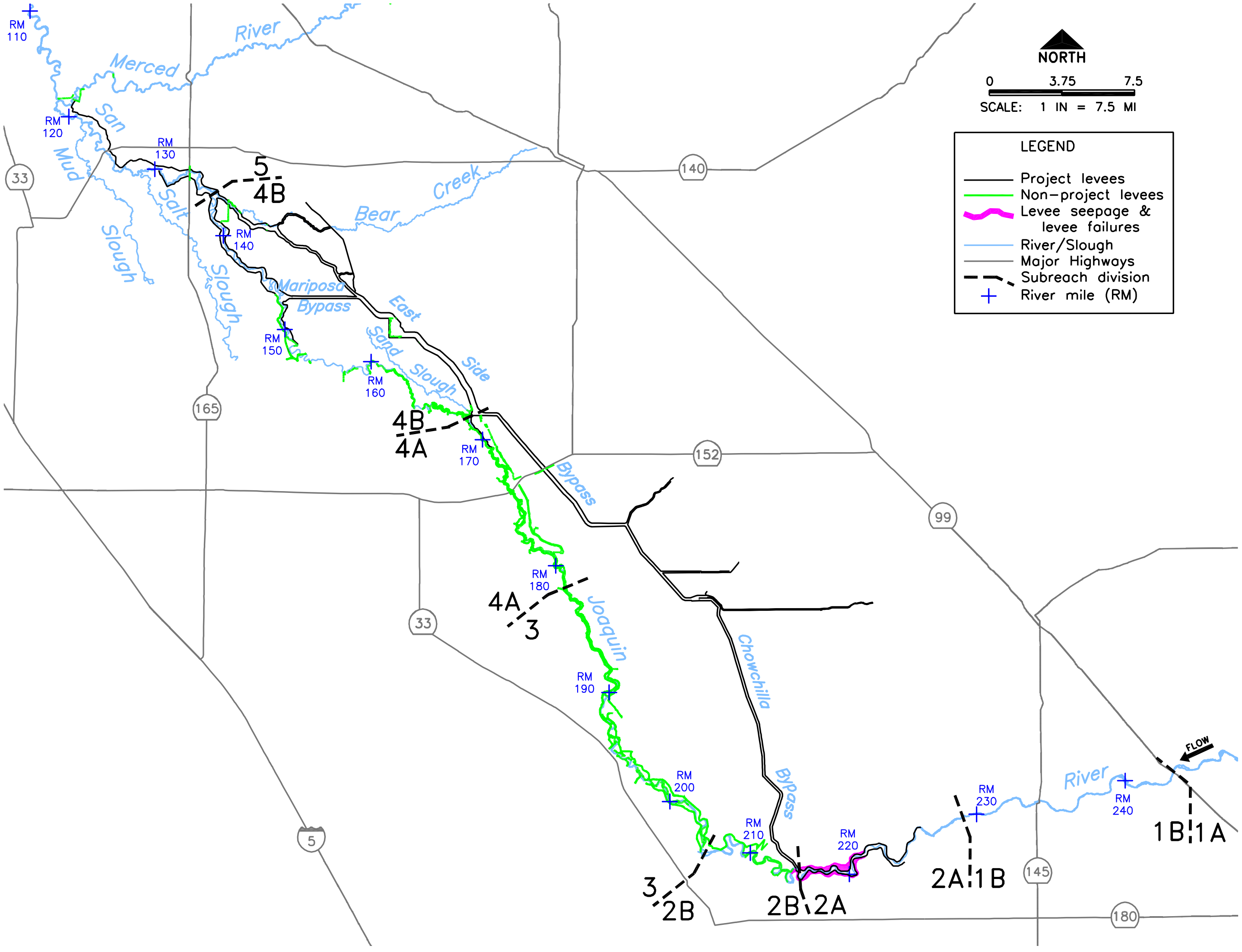


Figure 5-7. Map of study reach showing locations of Project and Non-project levees, locations of levee breaches during the 1997 flood (from ACOE 1999), and areas of seepage problems.

The mainstem San Joaquin River levee system within the study area is composed of approximately 192 miles of project levees and various non-project levees located upstream of the Merced River confluence (ACOE 1999b) (Figure 5-7). Project levees are levees constructed as part of the San Joaquin River and Tributaries Flood Control Project by the ACOE, and occur in Reach 2A downstream of Gravelly Ford from RM 225 on the south bank and RM 227 on the north bank, and extend downstream to the Chowchilla Bifurcation Structure (RM 216.1), then begin again in Reach 4B and 5 at the Mariposa Bypass confluence (RM 148) downstream to the Merced River confluence (RM 118.5) (Table 5-4). All project levees in the study area are contained within the Lower San Joaquin River Levee District. Non-project levees are typically associated with levees and dikes constructed by early flood control districts and adjacent landowners between the Chowchilla Bifurcation Structure (RM 216.1) and the Mariposa Bypass confluence (RM 148).

Canal embankments bordering both sides of the San Joaquin River between Sand Slough Control Structure (RM 168.5) and the Mendota Dam (RM 204.6) effectively form a set of non-project levees that have significantly reduced the width of the floodplain, primarily on the east side of the river. An alluvial terrace, 6 feet higher than the floodplain of the river, confines the right side of the river. Local landowners have constructed other low-elevation berms within the corridor that tend to confine contain flows up to 4,500 cfs. Flows exceeding 4,500 cfs spill onto agricultural lands up to the canal embankments.

The ACOE has established flood control objective flows for the San Joaquin River tributaries, bypasses, and flood control operations of reservoirs within the system. “Objective” flows are generally considered to be safe carrying capacities, but some damages to adjacent land developments do occur when passing objective flows. “Design capacity” is defined by the ACOE as the amount of water that can pass through reaches of the San Joaquin River with a levee freeboard of 3 feet. Design capacity was intended to provide protection against the 50-year storm (Reclamation Board 1966), and these intended design capacities are illustrated in Table 5-4 and Figure 5-5. Table 5-4 also summarizes ACOE design flow capacities and modeled objective flow capacities for various reaches throughout the San Joaquin flood control system.

Table 5-4. Comparison of objective flow capacity from Mussetter (2000a and 2000b) with design channel capacities for the San Joaquin River Flood Control Project (ACOE, 1993)

Reach Along San Joaquin River	**River Mile**	**Reach**	**ACOE design capacity with 3 ft freeboard**	**Estimated hydraulic capacity with no freeboard (top of levee)**
Friant Dam Gravelly Ford	267.5 – 229	1	8,000 cfs	16,000 cfs
Gravelly Ford to the Chowchilla Bifurcation Structure	229 – 216.1	2A	8,000 cfs	Approximately 16,000 cfs
Chowchilla Bifurcation Structure to Mendota Dam	216.1 – 204.6	2B	2,500 cfs	Approximately 4,500 cfs
Mendota Dam to Sand Slough and Chowchilla Bypass	204.6 – 168.5	3, 4A	4,500 cfs	6,000 cfs to 8,000 cfs
Sand Slough to Mariposa Bypass Confluence	168.5 – 148	Upper 4B	1,500 cfs	400 cfs to 1,500 cfs
Mariposa Bypass confluence to East Side Bypass confluence	148 – 136	Lower 4B	10,000 cfs	Exceeds 10,000 cfs
East Side Bypass confluence to Merced River confluence	136 – 118.5	5	26,000 cfs	Exceeds 26,000 cfs
Downstream of Merced River	118.5 – 84	n/a	45,000 cfs	Not modeled

Objective flow capacities of the leveed reaches were estimated with 1-D hydraulic models (HEC-2) (Mussetter Engineering 2000a, 2000b). Modeling was conducted in all reaches in the study area, and

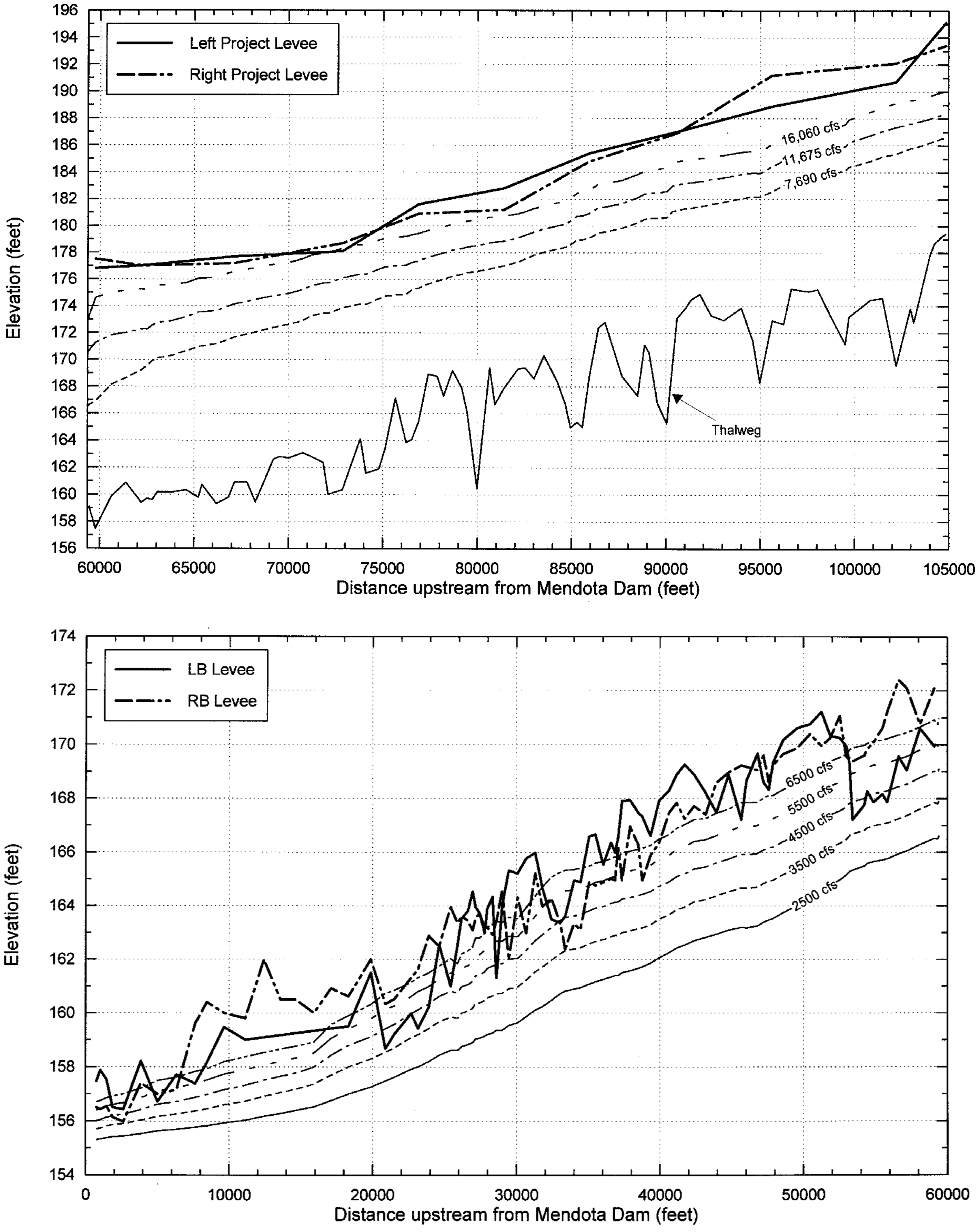
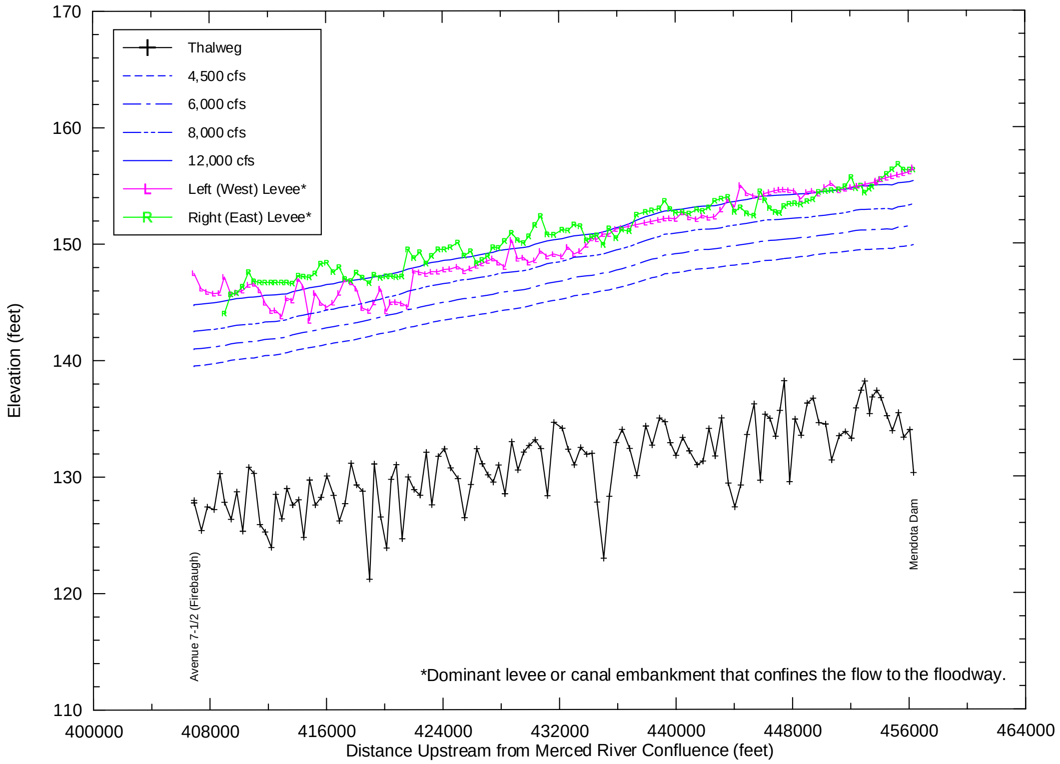


Figure 5-8. Reach 2 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is the downstream portion of Reach 2A (design capacity 8,000 cfs), lower graph (B) is Reach 2B from the Chowchilla Bifurcation Structure to Mendota Dam (design capacity 2,500 cfs).



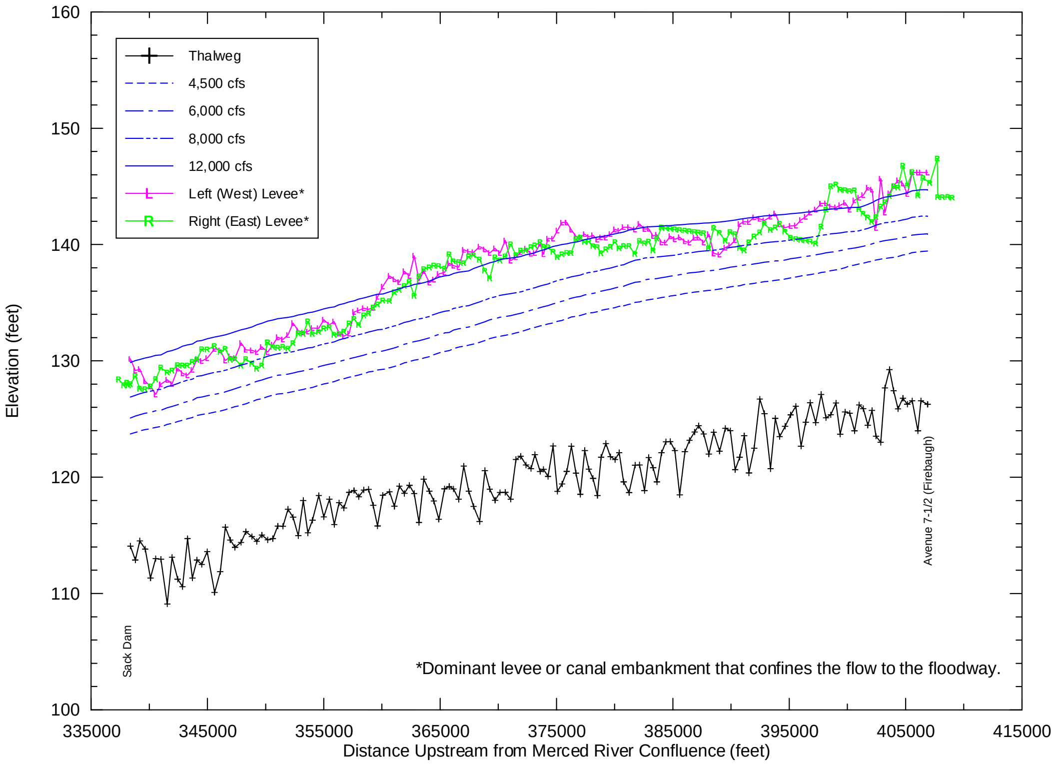


Figure 5-9. Reach 3 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Mendota Dam to Firebaugh (design capacity 4,500 cfs), lower graph (B) is from Firebaugh to Sack Dam (design capacity 4,500 cfs).

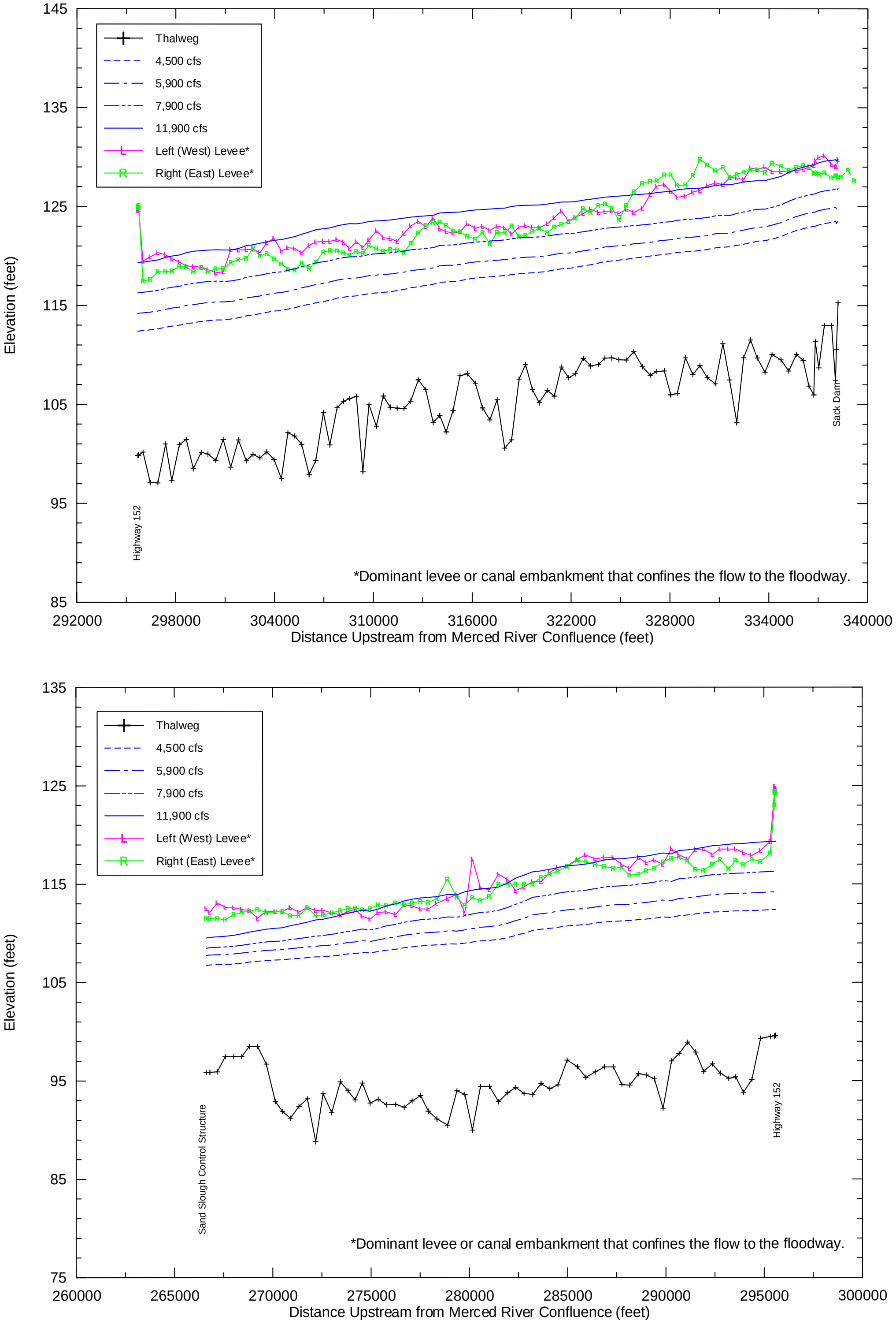


Figure 5-10. Reach 4A plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Sack Dam to the SR 152 Bridge (design capacity 4,500 cfs), lower graph (B) is from the SR 152 Bridge to the Sand Slough Control Structure (design capacity 4,500 cfs).

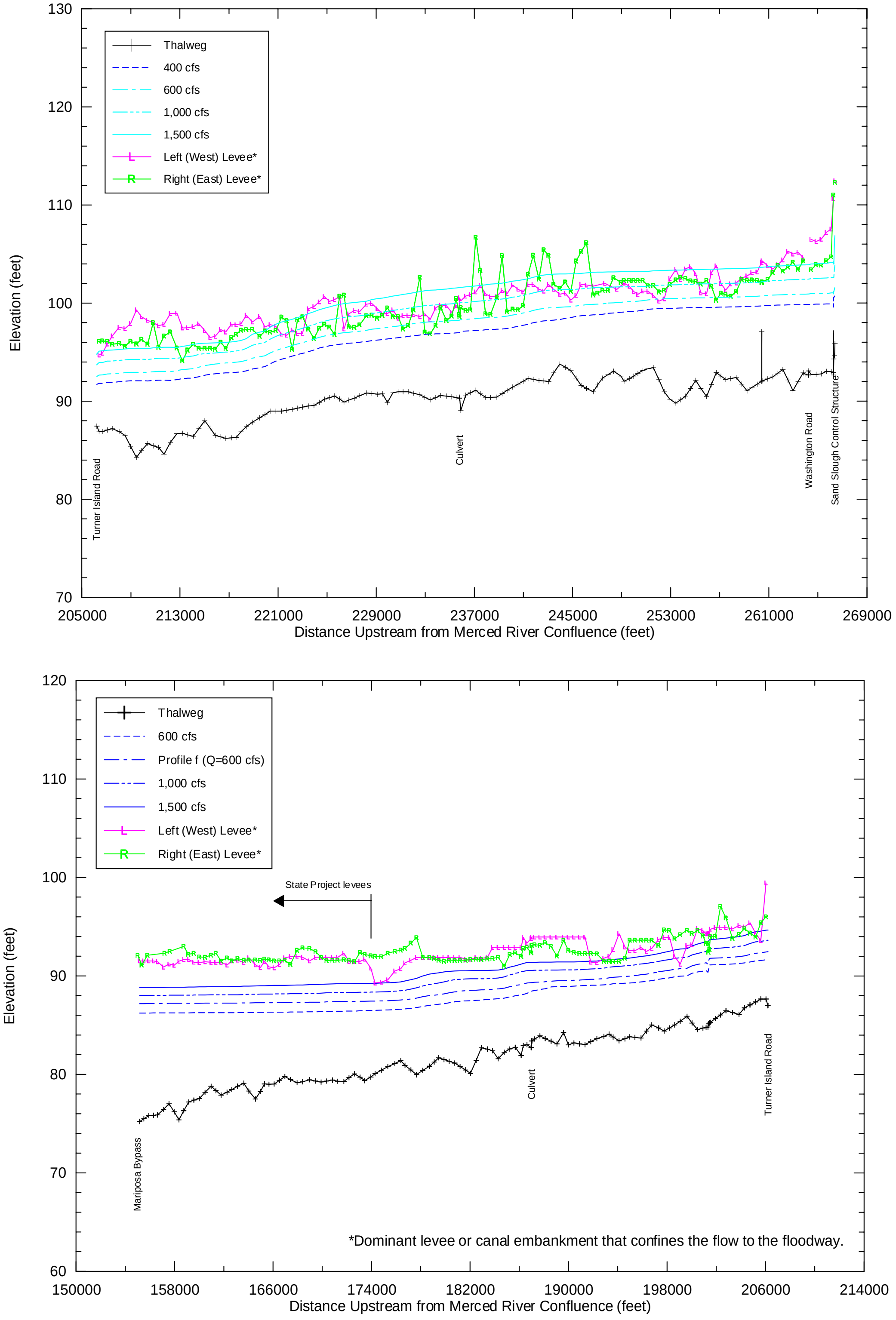


Figure 5-11. Upper portion of the Reach 4B plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Sand Slough Control Structure to the Turner Island Bridge (design capacity 1,500 cfs), lower graph (B) is from the Turner Island Bridge to the Mariposa Bypass confluence (design capacity 1,500 cfs).

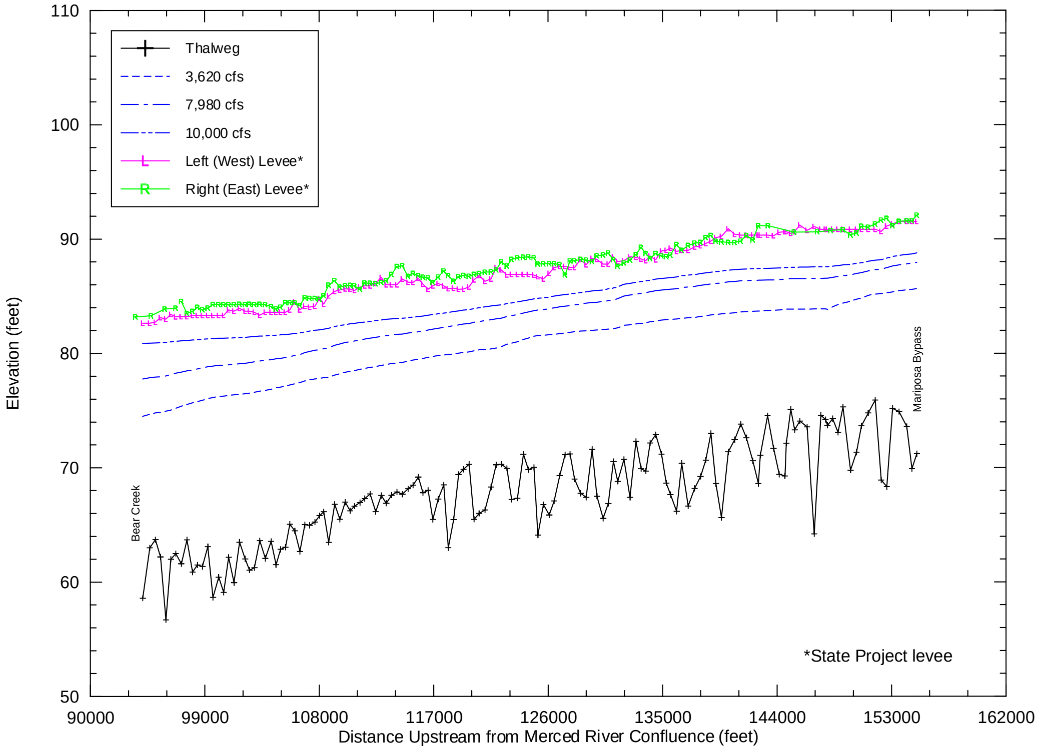


Figure 5-12. Lower portion of the Reach 4B plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Graph is from the Mariposa Bypass confluence to the Bear Creek and Eastside Bypass confluence (design capacity 10,000 cfs).

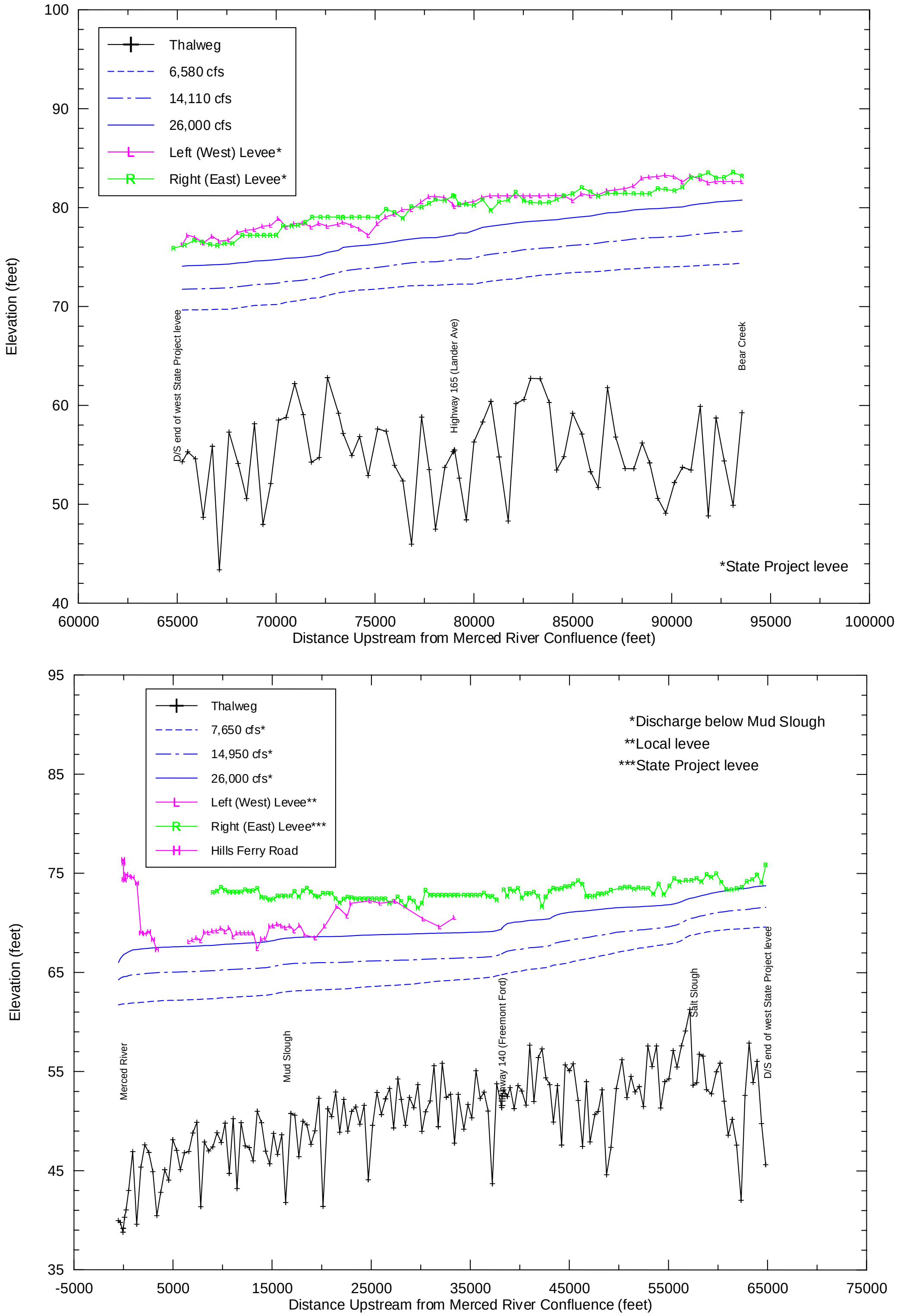
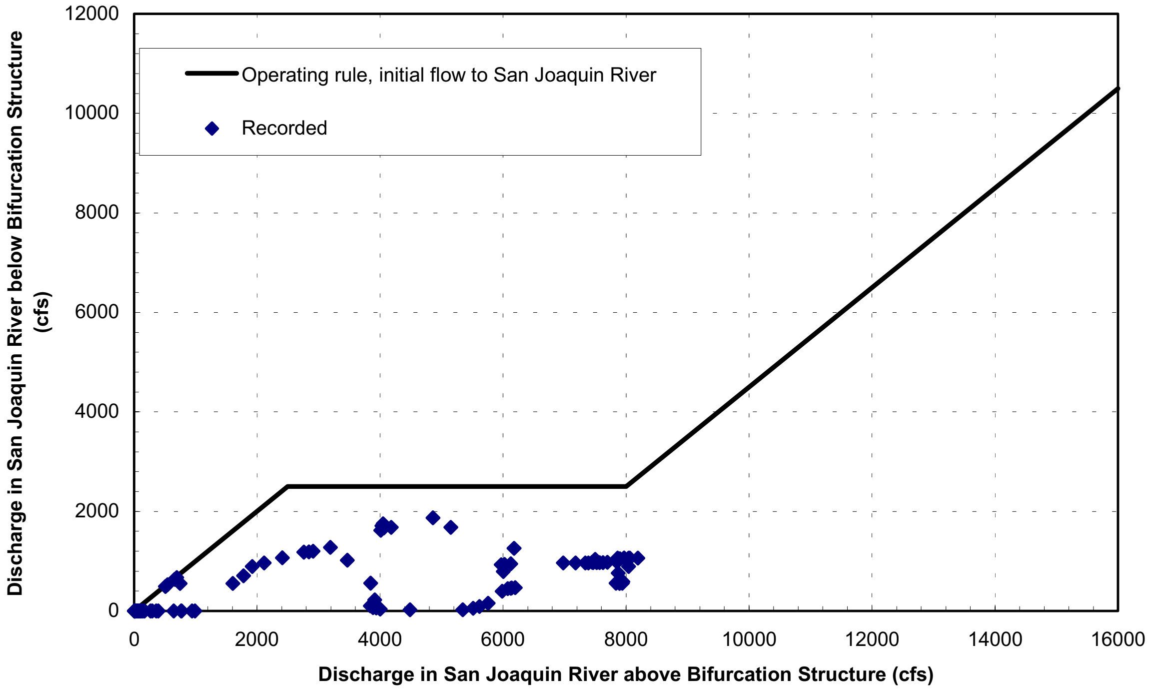


Figure 5-13. Reach 5 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Bear Creek and Eastside Bypass confluence to the end of the project levee on the left (west) bank of the river (design capacity 26,000 cfs), lower graph (B) is from the end of the project levee on the left (west) bank of the river to the Merced River confluence (design capacity 26,000 cfs).



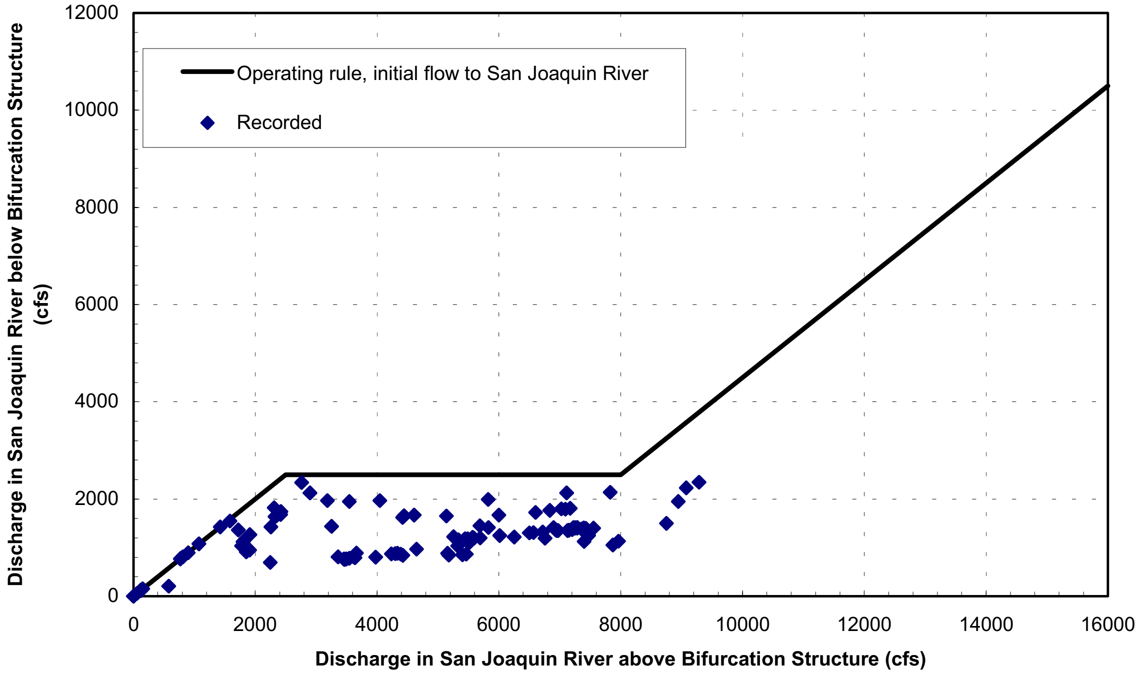


Figure 5-14. Operating rules for the Chowchilla Bifurcation Structure based on San Joaquin River flows upstream of the structure, and actual operations for the Chowchilla Bifurcation Structure during (A) the 1986 high flow event and (B) the 1995 high flow event.

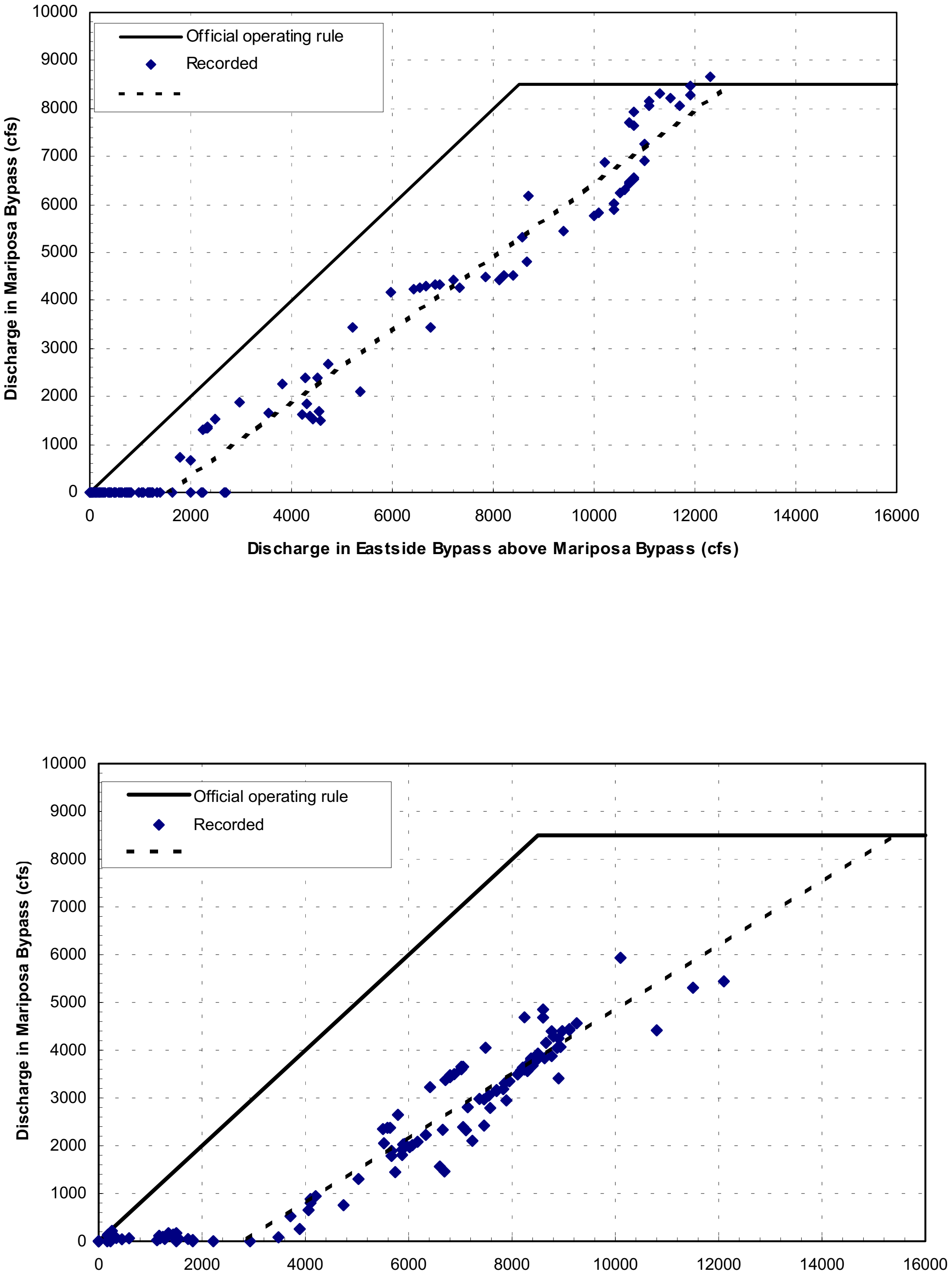


Figure 5-15. Operating rules for the Mariposa Bifurcation Structure based on Eastside Bypass flows upstream of the structure, and actual operations for the Mariposa Bifurcation Structure during (A) the 1986 high flow event and (B) the 1995 high flow event.

Reaches 2 through 5 have levees and dikes. Reach 1 has dikes attempting to isolate gravel pits from the river, but does not have any significant levees or dikes protecting agricultural lands. Hydraulic modeling in Reach 1 indicates that some flooding of a sewage disposal pond at RM 245.5 (16,300 cfs), and at a trailer park just upstream of Highway 41 at RM 255.5 (8,000 to 12,000 cfs) (Mussetter Engineering 2000a). Upstream of the Chowchilla Bifurcation Structure (RM 216.1), the project levees extend as far as RM 225 on the left (south) bank and RM 227 on the right (north) bank. The maximum levee capacity predicted from hydraulic models without any freeboard was about 16,000 cfs in this reach (Figure 5-8), exceeding the ACOE design capacity of 8,000 cfs. However, levee district staff has observed piping and seepage problems in this reach well before the design flow of 8,000 cfs. Eleven levee breaks occurred in this reach during the 1997 flood as a result of piping failure (Figure 5-7). Because of aggradation in the channel as a result of the backwater generated by the Chowchilla Bifurcation Structure, the bed of the channel in the lower portion of Reach 2A is elevated at or above some of the adjacent orchard lands. Periods of sustained high flows in the river have been reported to cause seepage damage in certain orchards (Hill pers. comm.).

Downstream reaches were also modeled by Mussetter Engineering (2000a, 2000b), and objective flow capacities evaluated by plotting various water surface profiles against levee/dike profiles in Reach 2 through 5 (Figures 5-8 through 5-13, Table 5-4). Between the Chowchilla Bifurcation Structure (RM 216.1) and Mendota Pool (RM 206), the San Joaquin River is bounded by non-project local levees. Current operating rules for the flood control system limit flows in the river to 2,500 cfs when the discharge in the river upstream of the Bifurcation Structure is 8,000 cfs. The water-surface profiles shown on Figure 5-7 indicate that approximately 4,500 cfs could be released into the river without significant overtopping of the local levees. However, even if the levees were not overtopped, the levees would likely fail as a result of piping and seepage. During the irrigation season when Mendota Pool is full, the elevated water surface and backwater may cause seepage problems when San Joaquin River discharges into Mendota Pool are as low as 1,300 cfs (White pers. comm).

Between Mendota Dam (RM 204.6) and the Sand Slough Control Structure (RM 168.5), the San Joaquin River is bordered by canal embankments that act as non-project levees. The hydraulic capacity of the channel between these levees was estimated without any freeboard considerations or taking into account the stability of the levees themselves (Mussetter Engineering 2000b). Between Mendota Dam and Avenue 7½ Bridge at Firebaugh (RM 195.2), the predicted hydraulic channel capacity is approximately 8,000 cfs, except for a short reach where the capacity is approximately 6,000 cfs (Figure 5-9). The design discharge for the reach is 4,500 cfs, which was set to minimize flooding of agricultural lands between the canals (Hill pers. comm.). Between Avenue 7½ Bridge and Sack Dam (RM 182.1), the predicted hydraulic channel capacity is approximately 8,000 cfs (Figure 5-9). Between Sack Dam and SR 152 (RM 173.9), the predicted hydraulic channel capacity is also approximately 8,000 cfs (Figure 5-10), and between SR 152 and the Sand Slough Control structure (RM 168.5), the predicted hydraulic channel capacity is also approximately 8,000 cfs (Figure 5-10).

Between the Sand Slough Control Structure and Turner Island Road (RM 157.2), the channel is bounded by local levees, and the predicted hydraulic capacity is approximately 400 to 1,000 cfs (Figure 5-11). Design discharge for this reach of the river is 1,500 cfs, but because of agricultural encroachments, the effective capacity is much less. In practice, flows are no longer accessible to the San Joaquin River because the headgates controlling flow into this reach have not been opened for many years. All flows exiting Reach 4A are discharged into the East Side Bypass at the Sand Slough Control Structure. Between Turner Island Road and the start of the project levees upstream of the Mariposa Bypass (RM 151), the predicted hydraulic capacity is approximately 1,000 to 1,500 cfs. Within the project levees, the capacity exceeds 1,500 cfs (Figure 5-11). From the Mariposa Bypass (RM 147.2) to the Bear Creek confluence where the remaining Eastside Bypass flows are returned to the San Joaquin River (RM 136), the predicted in-levee hydraulic capacity is in excess of the 10,000-cfs design flow (Figure 5-12). Between Bear Creek and the downstream end of the project levee on the left bank of the river, the predicted hydraulic capacity exceeds the 26,000-cfs design flow level (Figure 5-13). In the floodway section from the downstream end of the project levee to the Merced River confluence, the predicted hydraulic capacity is approximately 26,000 cfs (Figure 5-13).

The estimates of hydraulic conveyance capacity compare modeled water surface elevations with the tops of adjacent dikes and levees, rather than the 3 feet freeboard required by the ACOE. Therefore, the hydraulic capacity estimates for many of the above reaches underestimates the actual conveyance capacity if the ACOE freeboard requirement were to be satisfied. Additionally, the levees in Reach 2 are constructed primarily of sandy soils that begin to seep into adjacent agricultural lands once flows access the toe of the levee. Therefore, based on hydraulic modeling and field observations during high flows, Reach 4B, Reach 2A, and Reach 2B are the primary constraints to meeting the existing design capacity of the San Joaquin River Flood Control Project. Current investigations by the ACOE for the Sacramento and San Joaquin Comprehensive Plan should update estimates of the channel capacities.

5.4.2.3. Bypass System

The State of California constructed the Eastside Bypass project from the Merced River upstream to the head of the Chowchilla Bypass between 1959 and 1966. The bypass system and its associated levees isolate about 240,000 acres of floodplain from the river (ACOE, 1985). The bypass is composed primarily of man-made channels and converted sloughs: the Chowchilla Bypass Channel, Eastside Bypass Channel, and the Mariposa Bypass Channel (Figure 5-5). Several structures are located along the bypass system to control the flow within of the system. Structures within the bypass system include the Chowchilla Bypass Bifurcation Structure, Sand Slough Control Structure, Mariposa Bypass Bifurcation Structure, and several associated drop structures (Table 5-3 and Figure 5-5).

The bypass system was constructed with the objective to divert and carry floodflows from the San Joaquin River at the Chowchilla Bifurcation Structure, along with flows from the eastside tributaries, downstream to the mainstem San Joaquin River upstream of the Merced River confluence (Figure 5-5). The system was designed to provide a 50-year level of protection (Reclamation Board 1966), and the flood capacities for each portion of the bypass system is illustrated in Figure 5-5. The rain generated flood frequency curve shows that the 50-year flood is approximately 24,000 cfs (ACOE 1999a), and comparing this 50-year flood magnitude with the design capacity of the current flood control system suggests that the 50-year flood protection design capacity is insufficient in Reach 1, Reach 2, Reach 3, the Chowchilla Bypass and the Eastside Bypass down to the Mariposa Bifurcation Structure (Figure 5-5). This probable lack of capacity assumes that all river reaches and bypasses functioned according to design capacity, no other flood flow contributions from tributaries occurs, and no flood peak attenuation occurs along the reaches. The ACOE Comprehensive Study was intending on further evaluating flood conveyance limitations, and developing remediation options, but it is unclear whether the ACOE will assume a larger role in flood protection, or will delegate responsibility for developing remediation options to local agencies.

5.4.2.4. Chowchilla Bypass Bifurcation Structure

The Chowchilla Bypass Bifurcation Structure is a gated structure that controls the proportion of flood flows into the Chowchilla Bypass and Reach 2B of the San Joaquin River. The bifurcation structure has a drop (plunge pool) on the downstream side of the San Joaquin River, and has no fish passage facilities. The Chowchilla Bypass Bifurcation Structure is operated to attempt to keep flows in Reach

2B less than 2,500 cfs due to operational problems at Mendota Dam (see Section 5.4.1.2). Therefore, the operating rules for the Chowchilla Bypass Bifurcation Structure are based on the initial flow to the San Joaquin River and the initial flow to the Chowchilla Bypass (Reclamation Board 1969). The operational flow split rules, as well as example actual operations for 1986 and 1995 high flow events are shown in Figure 5-14. The present operations limit flows to 2,500 cfs in the San Joaquin River downstream from the bypass when upstream river flows are less than 8,000 cfs, with flows increasing to 6,500 cfs when the discharge in the upstream river is 12,000 cfs. The bypass operation is ultimately based on the current overall flood control needs in the project area, thus may deviate from the operating rules shown in Figure 5-14 (Reclamation Board, 1969).

5.4.2.5. Sand Slough Control Structure and Reach 4B Headgate

The Sand Slough Control Structure, located in the short connection between the San Joaquin River at RM 168.5 and the East Side Bypass, helps control the flow split between the mainstem San Joaquin River and the Eastside Bypass. The control structure conveys all flows from the San Joaquin River to the East Side Bypass. The Sand Slough Control Structure does not appear to be a significant constraint to fish passage based on our field observations.

There is also a headgate at the entrance to Reach 4B of the San Joaquin River. There are no documented operating rules for the structure during low flows, but downstream flows in the mainstem San Joaquin River are theoretically limited to the design discharge of 1,500 cfs (Figure 5-5). However, the headgates have not been opened for many years, including during the 1997 flood. Even if it were open, the structure would pose a significant barrier to fish migration. The present capacity of the downstream channel is severely limited (300 to 600 cfs) due to extensive vegetation (Figure 5-11). Flows into Reach 4B are augmented by agricultural tailwater and seepage from canals, but are pumped and reused for irrigation.

5.4.2.6. Mariposa Bypass Bifurcation Structure

The Mariposa Bypass Bifurcation Structure is a gated structure that controls the proportion of flood flows continuing down the East Side Bypass and through the Mariposa Bypass back into Reach 4B of the San Joaquin River. The bifurcation structure has a drop (plunge pool) on the downstream side into the Mariposa Bypass, and has no fish passage facilities. The Mariposa Bypass delivers flow back into the river from the Eastside Bypass near RM 148. The operating rule for the Mariposa Bypass is for all flow to be diverted back into the San Joaquin River at discharges in the Eastside Bypass up to 8,500 cfs, with any higher flows remaining in the Eastside Bypass and eventually discharging back into the San Joaquin River at the Bear Creek Confluence at the end of Reach 4B (Figure 5-15). However, actual operations seem to deviate from this rule, with all flows up to 2,000 cfs to 3,000 cfs staying in the East Side Bypass, after which approximately one-quarter to one-third of the flow is allowed to flow into the Mariposa Bypass (Figure 5-15). Flood flows that are not diverted back to the San Joaquin River via the Mariposa Bypass continue down the East Side Bypass and are returned to the San Joaquin River via Bravel Slough and Bear Creek. Bravel Slough reenters the San Joaquin at RM 136 and is the ending point of the bypass system.

There are also a series of drop structures to dissipate energy during high flows in the Mariposa Bypass, which are presently fish barriers. The channel elevation of the Mariposa Bypass is also at the shallow groundwater table in this reach, which allows for more frequent baseflows and has resulted in a somewhat more defined channel than exists in the East Side bypass. Although most of the bypass channel appears to allow fish passage, the drop structures are barriers and would have to be modified before fish passage would be attainable.

5.4.2.7. Summary of Fish Passage Impacts by the Flood Control System

The bypass system provides a variety of fish passage complications. These complications are both flow and structurally related. Since portions of the main San Joaquin River are dry, flows are generally released into the bypass system before Reach 2B and 4B. This could lead fish into channels that have several control structures and that are operated to be quickly dewatered once the flood control event is over. With the possible exception of the Sand Slough Control Structure, the control structures do not presently facilitate fish passage during low to moderate flows. The current configuration of structures in the river and in the bypass system will require substantial work to remove barriers or construct fish ladders to provide fish passage to the upper reaches of the San Joaquin River.

Despite the constraints imposed by the bypass system for fish routing, the bypass system could show promise for use as a fish passage corridor for portions of the San Joaquin River between the Merced River confluence and the Chowchilla Bypass Bifurcation Structure. Although considerable modification of structures would be needed to allow fish passage, there are few to no diversions that may entrain migrating salmonids (adult and/or juvenile) compared to numerous large diversions at Mendota Pool, Sack Dam, and small riparian pumps. Furthermore, juvenile salmonids (as well as resident warm water species) may realize significant growth and survival benefits by being able to access the bypasses in the winter and early spring (See Chapter 7 for more detail). Routing or raising fish in the bypass system could lead to conflicts with the primary use of the bypass system (flood routing and hydraulic conveyance). For example, the bypasses are largely devoid of habitat due to hydraulic conveyance maintenance efforts, and may not be able to support the food base for fish as well as the Yolo Bypass on the Sacramento River. Additional drawbacks may include releasing additional water to reduce stranding and allow enough time for juveniles to migrate downstream back to the San Joaquin River, and flow losses may be greater in the bypasses than if flows were routed through the San Joaquin River channel. These options should be further considered in the Restoration Study.

5.4.3. Bridges and Culverts

There are many bridges and culverts in the study reach, the primary seventeen of which are listed in Table 5-5. Many of these culverts and smaller bridges are undersized to the flood flow regime downstream of Friant Dam. Culverts and smaller bridge crossings often wash out during high flows, and those that do not wash out may cause backwater effects at both high and low flows. Chapter 3 discusses the geomorphic constraints imposed by the extremely low channel gradient in Reach 1. The elevation drop provided by this low slope is critical for creating spawning and rearing areas for salmonids. One of the most significant impacts of undersized bridges and culverts is the effect they have on sediment transport and deposition, and the resulting impacts they have on stream gradient distribution along the river. The unconstricted river channel is connected to its floodplain, such that as flows increase, water spills onto floodplain surfaces and moderates stream energy over the reach (Figure 5-16). However, once a constricting bridge or culvert is installed, two processes tend to occur. First, a backwater forms upstream that causes sediment to deposit at the upstream end of the backwater. Second, the constriction locally disconnects the river from its floodplain, which increases local water velocities and sediment transport. At a constricted bridge (e.g., North Fork Bridge immediately downstream of Friant Dam), sediment is scoured underneath the bridge at the constriction, and is then immediately deposited downstream, causing local aggradation at that location (Figure 5-16). Over numerous high flow events, this tends to concentrate much of the elevation drop over a given reach over a very short distance, with long flat pools connecting these locations. In extreme cases, the aggrading sediment creates a steep riffle that is much less suitable for salmonid spawning than the unimpaired condition where gentle riffles were better distributed over the reach (McBain and Trush 2000).

Table 5-5. Bridge and Culvert Crossings of the San Joaquin River between Friant Dam and the Merced River.

Transportation Element	Location (River Mile)	Comments
Reach 1		
North Fork Road Bridge	266.7	Very Narrow opening due to confining abutments
Ledger Island Bridge	262.2	
Culvert	258.5	Probably washes out at high flows, causes backwater at lower flows
SR 41 Bridge (Lane's Bridge)	255.3	Recently replaced with bridge with greater conveyance capacity. 5.4 feet of channel degradation between 1940 and 1997 (Cain 1997).
Culvert	252.8	Probably washed out at high flows, causes backwater at lower flows
AT & SF Railroad Bridge	245.1	
SR 99	243.2	5.6 feet of channel degradation between 1970 and 1997 (Cain 1997)
SR 145 (Skaggs Bridge)	234.1	Causes some backwater at higher flows
Reach 2A		
Bifurcation Structure	216.1	Causes backwater at higher flows
Concrete Dip Crossing at San Mateo Road	211.8	Barrier to fish passage at low flows
Reach 3		
Avenue 7½ Bridge, Firebaugh	195.2	Two bridge openings. 2.2 feet of channel degradation between 1970 and 1997
Reach 4A		
SR 152 Bridge (Santa Rita Bridge)	173.9	3.3 feet of channel aggradation between 1972 and 1997
Reach 4B		
Headgates	168	Culvert / Control Structure, probable fish barrier even when opened
Culvert	163.1	Probably washed out at high flows
Turner Island Road Bridge	157.2	
Culvert	153.4	Probably washed out at high flows, causes backwater at lower flows
Reach 5		
SR 165 Bridge (Lander Avenue)	132.9	Causes some backwater at higher flows
SR 140 Bridge (Fremont Ford)	125.1	Causes some backwater at higher flows; 1.6 feet of channel degradation between 1972 and 1997

Improperly installed culverts may also significantly impact upstream fish migration. Current National Marine Fisheries Service fish passage criteria requires culverts to have less than a 1 ft drop (with accompanying jump pool depth greater than 2 ft), average velocity less than 6 ft/sec for adult passage, average velocity less than 2 ft/sec for juvenile passage, greater than a 1 ft depth for adult passage, and greater than a 6-inch depth for juvenile passage (NMFS 2001). Many culverts do not meet these criteria and will have to be replaced once the Restoration Study commences.

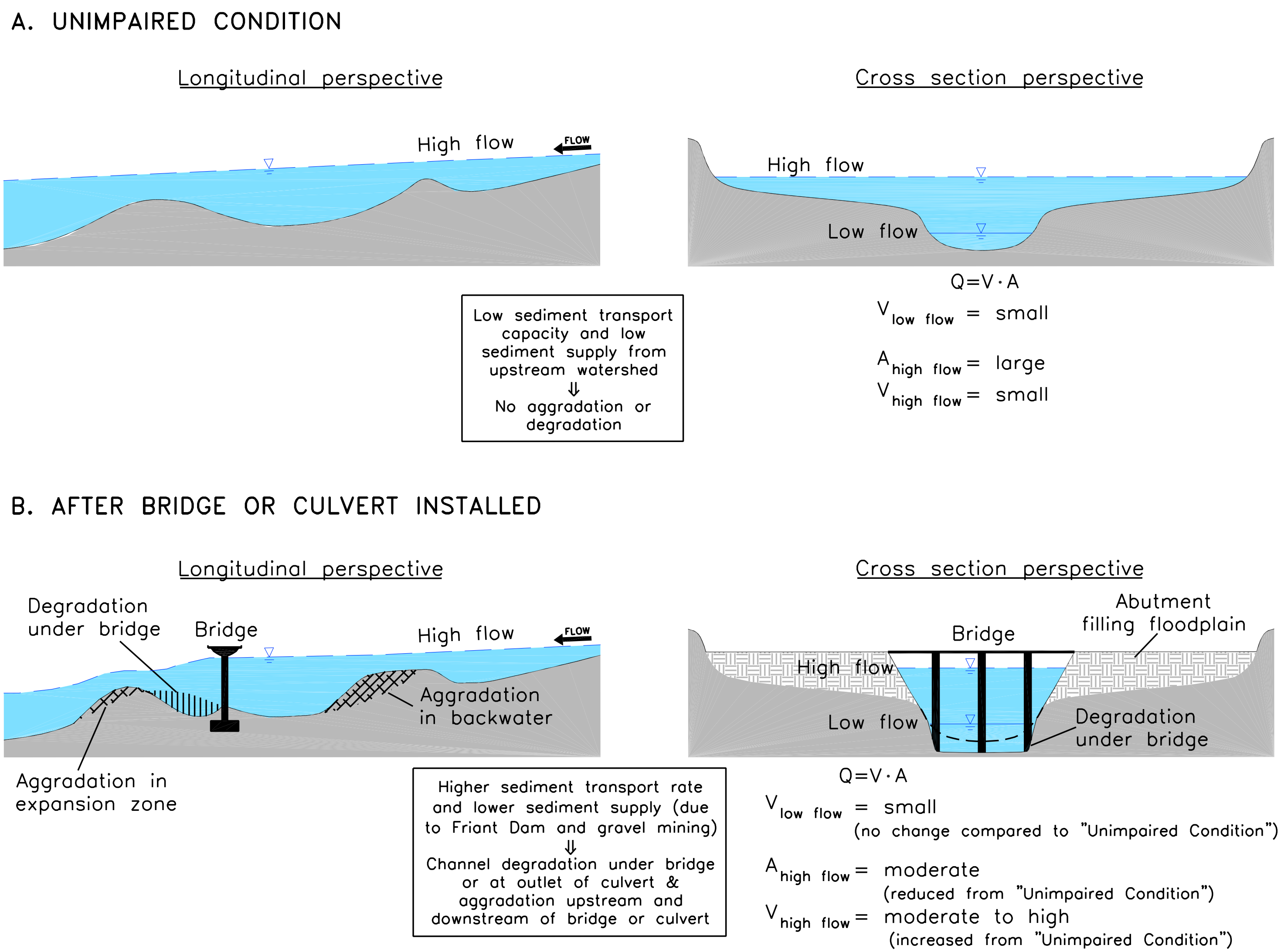


Figure 5-16. Conceptual impacts of local floodway constrictions (bridges and culverts) to hydraulics, local bed scour/degradation, and local bed deposition/aggradation.

5.4.4. Sand and Gravel Mining

Sand and gravel mining occurs from Friant Dam downstream to the Chowchilla Bifurcation Structure. Reach 1 is predominately gravel and sand mining, while Reach 2 is exclusively sand mining. Both are discussed briefly below.

5.4.4.1. Reach 1

Between Friant Dam (RM 267) and Skaggs Bridge (RM 234.1), there has been considerable in-channel and floodplain mining for sand and gravel. Cain (1997) estimated that mining resulted in a sediment deficit on the order of 163,000,000 cubic yards between 1939 and 1996. Based on comparative cross sections, it is apparent that the channel has significantly degraded in several locations since 1939, and that the combined effects of the gravel mining and elimination of the upstream sediment supply by Friant Dam may have been greater had it not been for the presence of local bedrock outcrop and controls in the bed of the river channel (Cain, 1997). Overall, the bed of the channel has degraded to varying degrees based on local bedrock control, and in many locations, the former floodplain is now a terrace about 5 to 10 feet above the bed of the channel. Table 5-6 summarizes the total mined area along the river, including the breached “off channel” pits through which the river currently flows. Table 5-7 identifies the specific locations where the river has captured the pits. Based on the available data, it appears that about 3.3 miles of channel (17,424 feet) has been altered due to gravel mining activities.

Table 5-6. Mined Areas along the San Joaquin River between Friant Dam and Skaggs Bridge

Reach	Total Mined Area (acres)	Mined Area Captured by River (acres)	Percentage of Captured Pits
Friant Dam (RM 267)—SR 41 (RM 255.2)	494.5	7.5	1.5
SR 41 (RM 255.2)—SR 99 (243.2)	784.4	155.4	19.8
SR 99 (RM 243.2)—Skaggs Bridge (232.8)	76.2	26.8	35.1
Total	1,355.1	189.7	14.0

Table 5-7. Locations of Pit Capture along the San Joaquin River between Friant Dam and Skaggs Bridge

Location (RM–RM)	Pit/Channel Length (feet)	Pit Area (acres)
258.5–258.8	1,584	7.7
253.4–254.2	4,224	67.3
252.8–253.4	3,168	23.7
252.3–252.8	2,640	42.5
246.3–246.5	1,056	9.2
243.9–244.1	1,056	2.8
243.8–243.9	528	9.9
240.9–241.3	2,112	11.3
233.2–233.4	1,056	15.5
Total	17,424	189.7

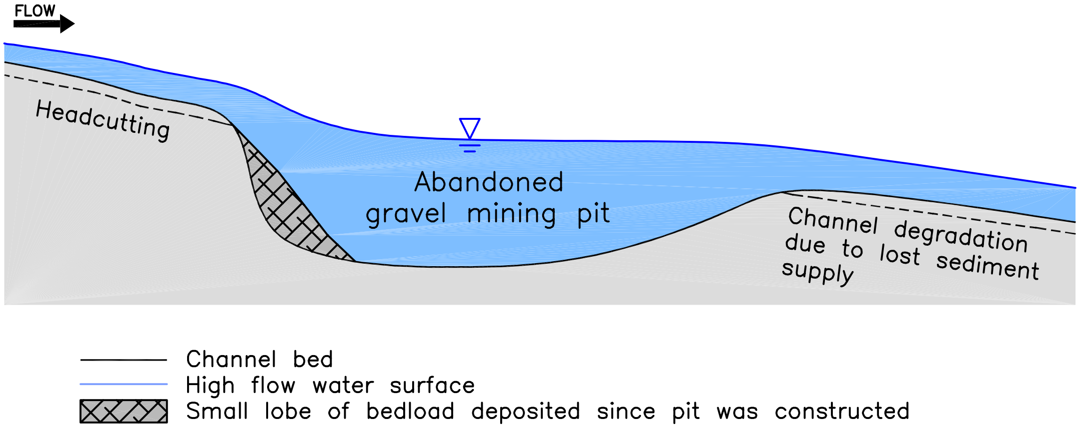


Figure 5-17. Conceptual impact of instream gravel pit or captured "off-channel" gravel pit on bedload routing through Reach 1 of the San Joaquin River. Upstream sediment supply and transport is so small that it would take centuries for the river to naturally fill these large pits.

The fluvial geomorphic impacts of gravel mining are fairly well documented (e.g., Collins and Dunne 1990, Kondolf 1994); however, the biological impacts are often indirect and not as well documented. Direct biological impacts include loss of aquatic habitat, or transformation of aquatic habitat from a riverine condition to a ponded condition. Direct geomorphic impacts include loss of instream gravel storage, loss of gravel bars and riffles, and bedload transport impedance reaches (gravel pits). Gravel mining pits cause indirect impacts, including trapping gravel transported from upstream reaches (Figure 5-17), and bed coarsening and channel degradation downstream of the pits due to loss of gravel supply. Gravel mining has transformed much of Reach 1 from a single-thread, moderate-sinuosity, meandering channel to a conveyance system composed of short single-thread channel segments connecting mining pits (see Reach 1 aerial photograph in Chapter 3). In addition to these biological and geomorphic impacts, gravel mining in Reach 1 may also:

- Increase evaporative water losses due to increased surface area of the river;
- Increase habitat for invasive fish species that prey on juvenile salmonids;
- Allow small lateral movement of the river to capture "off-channel" mining pits;
- Increase water temperatures; and
- Physically remove floodplains and riparian vegetation, thereby preventing future possible riparian vegetation in those areas.

5.4.4.2. Reach 2A

Sand mining activities have primarily been performed in Reach 2A by local landowners. Sand is excavated by skimming sand bars within the Project levees, with excavation sometimes as deep as 10 to 15 feet. For the most part, excavation does not appear to extend below the thalweg elevation of the river, and these excavated areas can fill quickly during a single high flow event. Sand tends to accumulate in the backwater upstream of the Chowchilla Bypass Bifurcation Structure, as well as in the Chowchilla Bypass itself. A 200,000 cubic yard sediment detention basin is located in the upstream section of the Chowchilla Bypass, and is commonly excavated following high flow events. Sand deposition is also removed from the Eastside Bypass immediately downstream of Sand Slough Control Structure because of deposition of materials scoured from the upstream portion of the East Side bypass. This aggradation has caused impacts on the conveyance capacity of the bypass (ACOE 1993).

5.4.5. Subsidence

Groundwater withdrawal for agricultural uses and hydrocompaction of the soils by agricultural activity has led to accelerated subsidence since the 1920s (Poland et al. 1975, Bull 1964, Basagaoglu et al. 1999). Maximum subsidence of nearly 30 feet has occurred in the Los Banos–Kettleman City area, with 1 to 6 feet of subsidence occurring along portions of the San Joaquin River between Mendota and about Los Banos (Ouchi 1983) (see Figure 4-16 in Chapter 4). As the valley floor has subsided, project and non-project levees have also subsided. Levee subsidence coupled with sediment accumulation has reduced the capacity of the lower 1.5 to 2 miles of the Eastside Bypass to about 6,000 to 7,000 cfs from the design capacity of about 16,500 cfs (ACOE 1993). To correct the problem, the Lower San Joaquin Levee District (LSJLD) has raised the levee height by three feet.

Comparison of thalweg elevations at cross sections that were originally surveyed by the California Debris Commission (CDC) in 1913/1914 with 1998 ACOE survey data indicate that there has been general bed lowering in reaches 4A and 3. The changes in elevation range from 1.5 to 10.8 feet with the higher numbers being recorded closer to Mendota, where the recorded subsidence has been on the order of 6 feet. Some of the potential bed lowering within Reaches 3 and 4A may also be due to subsidence. However, it is not known whether the apparent degradation is a result of subsidence or is incision due to human-induced changes to the sediment supply and hydrology of the San Joaquin River. One of the problems in distinguishing subsidence driven channel lowering from other sources (e.g. dams) has been associated with the level of survey accuracy, differing datum used for historical surveys, and lowering of local vertical control points.

As part of the Sacramento and San Joaquin River Basins Comprehensive Study, the ACOE is running first order cross valley survey traverses to determine the degree and extent of subsidence in the valley. Until these traverses are completed it will not be possible to resolve many of the apparent datum problems in the valley, to determine whether the San Joaquin River has degraded downstream of Mendota Dam, and to determine the causes of degradation.

Primary impacts of subsidence to potential restoration efforts on the San Joaquin River are primarily related to hydraulic and geomorphic impacts of differential subsidence. For example, if Reach 3 subsides at a greater rate then Reach 4, the river gradient will decrease, which will reduce flow conveyance capacity and sediment transport capacity. This compounds the problems presented by natural deposition and scour processes that may be a result of hydrologic changes and changes in the sediment regime from land use or diversion dams. Additionally, potential future physical manipulation of the river channel and floodway may have to contend with future reach-scale changes in valley gradient. Lastly, groundwater extraction will continue into the foreseeable future, and the degree of over-extraction will dictate the amount of additional subsidence. Assuming a similar rate of over-extraction, subsidence will continue in all historical subsidence areas, but at lower rates because much of the overall subsidence potential in the soil (voids previously filled with water) has already occurred (Swanson 1998). Increasing flows in the river may reduce the depletion of (or even begin to replenish) the shallow groundwater table depending on the amount of flows released and the future rate of groundwater pumping.

5.4.6. Levee Seepage

Seepage occurs when the hydrostatic pressures within the river channel become large enough to push water through the strata underlying adjacent levees. Historically, the strata beneath the levees consisted of several layers of sands and silts. Over time, the silts have been removed by seepage processes and have been deposited in the various interceptor ditches lining the backside of each levee. During annual maintenance, the silts are removed from the system. Thus, in many areas, levee foundations are now composed of well-washed layers of sands. These sands convey water under the levee structures once the water surface in the San Joaquin River reaches a sufficient height to cause a differential in hydrostatic pressure.

Levee seepage generally occurs along a 6-mile corridor of the San Joaquin River from Mendota Pool to the Chowchilla Bifurcation Structure (Figure 5-7). Seepage is a direct effect of diversion operations occurring at the Mendota Pool (Harvey, 2000), the diversion at the Chowchilla Bifurcation Structure, and the flow release regime at Friant Dam.

Operations at Mendota Pool effect seepage by raising the water surface level in the pool. This produces a backwater effect and increases the water surface elevations upstream. During irrigation seasons when the Mendota Pool is in operation, 1,300 cfs may pass through the south diversion of the Chowchilla Bifurcation Structure without significant seepage into adjacent lands. However, larger flows begin to cause seepage problems. During the non-irrigation season when the boards can be pulled from Mendota Dam, 2,500 cfs may pass through the Reach 2B portion of the Chowchilla Bifurcation Structure with minor amounts of seepage problems.

The Chowchilla Bifurcation Structure also contributes to the upstream backwater affect and increases the potential for seepage in Reach 2A. At the design discharge of 8,000 cfs through the Chowchilla Bifurcation Structure, seepage has been observed to occur up to 3 to 4 miles upstream. In an effort to reduce backwater-induced seepage problems, the trash racks in the Chowchilla Bypass structure have been removed. This was conducted in hopes of reducing the water surface elevation by decreasing the roughness factor of the Bifurcation Structure.

Overall, discharges and the associated seepage are dictated by the releases at Friant Dam. Large storm events that require large releases of water have a significant effect. For instance, during the storm of 1986, significant amounts of seepage conveyed underneath and through levees flooded six miles of adjacent lands for a period of two weeks. Eleven levee failures were recorded during over the area of seepage (Figure 5-7). The estimated peak discharge from Friant Dam was approximately 14,000 cfs.

As a result of seepage problems, interceptor ditches and tile drains have been constructed on the back side of the levees in Reach 2A. Many of the interceptor ditches along the backside of the levees have been modified for irrigation purposes, such that seepage through the levees is pumped out periodically to reduce root inundation and irrigate crops elsewhere. According to Batty (2000), landowners often collect water in these interceptor sumps (apparently from the shallow groundwater recharge from surface flows in the river) even during the summer months.

5.5. OPPORTUNITIES AND CONSTRAINTS

Summary of water supply and flood control infrastructure on important restoration components of the San Joaquin River are listed in Table 5-8.

Table 5-8. Summary of water supply and flood control infrastructure on important restoration components of the San Joaquin River.

INFRASTRUCTURE TYPE	**IMPACT TO RIVER AND/OR RESTORATION EFFORTS**
Large Storage Dams (Friant Dam)	o Prevents adult passage, impairs sediment routing, causes local aggradation and degradation (See Chapter 2, 3, and 7). o Promotes riparian encroachment (See Chapter 8). o Reduces floodplain inundation, baseflows, and the overall flood flow regime (see Chapter 2). o Limits opportunities to increase or improve salmonid habitat to areas below Friant Dam. o Smaller flow regime is a constraint to achieving fluvial geomorphic objectives that create and maintain aquatic and terrestrial habitat. o Upstream watershed is permanently blocked. o Due to pre-existing water supply and flood protection objectives, dam operations are very difficult to modify for restoration efforts. o Minimum flow, ramping, and temperature requirements must be able to adapt to existing coldwater pool and water supplies.
Small Diversion Dams (Mendota Dam, Sack Dam)	o Impedes or prevents adult passage. o Impairs sediment routing. o Creates salmonid predator habitat, thus may increase invasive/predatory populations. o Increases water temperatures. o Reduces base flows. o Fish passage structures are typically not cost effective when multiple barriers exist over short reaches. o Fish screens designed for juveniles are very expensive. o Alternate fish passage routes are difficult to implement.
Pumping Facilities (Numerous pumps along the entire study reach)	o Entrains and impinges juvenile salmonids. o Reduces base flows during low-flow conditions. o May create habitat that harbors invasive/predatory species. o Hardpoints may have been added to stabilize riverbanks near pumping facilities. o Channel restoration efforts must accommodate pumping operations and water supply. o May require another means of diversion to properly restore function of channel section.

Table 5-8. cont.

INFRASTRUCTURE TYPE	IMPACT TO RIVER AND/OR RESTORATION EFFORTS
Flood Control Project Levees (Reach 2A, lower Reach 4B, and Reach 5)	o Prevents sediment and nutrient transfer between the river and its floodplain. o Limits flow access to large floodplain areas that are highly valuable for spawning, rearing, and feeding for fish. o Changes natural flood hydrograph and routing, which increases flood depths, reduces flood peak attenuation, reduces flood routing time, reduces residence time on floodplain. o Impairs life history of certain fish species that depend on inundated floodplains. o Physically removes riparian vegetation during construction, maintenance continually removes new vegetation within levees. o Inhibits the recruitment of large woody debris. o Concentrates shear stress between levees, promoting channel incision and reducing aquatic habitat diversity. o Bank protection measures simplify channel and habitat diversity. o Confinement limits ability of future channel migration or avulsion. o Levee removal or setback removes land from agricultural production and/or may require property or conservation easement purchases. o Adjacent developments may significantly constrain opportunities to reconfigure levees. o Levee removal or setback may be costly due to earthworks and property/conservation easement purchase. o Vegetation removal for flood conveyance hampers riparian regeneration efforts.
Non-Project Levees and Dikes (Reach 1, Reach 2B, Reach 3, Reach 4A, and upper Reach 4B)	o Prevents sediment and nutrient transfer between the river and its floodplain. o Limits flow access to floodplain area that is highly valuable for spawning, rearing, and feeding for fish. o Impairs life history of certain fish species that depend on inundated floodplains. o Physically removes riparian vegetation during construction, maintenance continually removes new vegetation. o Confines lateral migration of river if maintained. o Frequent failure of non-project levees and dikes during moderate to high flows. o Levee removal or setback removes land from agricultural production and/or may result in property or conservation easement purchase. o Adjacent developments may significantly constrain opportunities to reconfigure levees and dikes. o Bank protection measures simplify channel and habitat diversity. o Levee removal or setback may be costly due to earthworks and property/conservation easement purchase.
Agricultural Return Drains (Primarily in Reach 3, Reach 4, and Reach 5)	o Degrades water quality by discharging excess nutrients, pesticides, herbicides, and heat into river. o Unscreened channel discharge points may provide false pathways for fish passage. o Non-point source pollution problems are generally difficult to remediate. o Eliminating false pathways may require additional in-stream structures (screens or weirs).

5.5.1. Summary of Opportunities

The myriad of infrastructure components on the San Joaquin River study reach makes restoration opportunities few and constraints many. Restoration opportunities do exist, and are listed below:

- One of the most significant challenges facing salmonid restoration to the upper San Joaquin River is restoring continuous streamflow to all reaches in order to provide adequate adult and juvenile salmonid passage. Releases already made from Friant Dam (Reach 1) and Mendota Dam (Reach 3) already provide year-round baseflows. Additionally, agricultural returns provide continual baseflows in Reach 5 and the lower portion of Reach 4B, although the quality of this water is poor.
- Friant Dam outlet works have controlled release capacity of up to 16,400 cfs, which could be used to improve geomorphic processes in downstream reaches in the event that the numerous constraints and impacts are alleviated.
- The size of Millerton Lake is sufficient to provide cold hypolimnial releases in most water years, with the possible exception of driest years due to reservoir drawdown (being evaluated as part of the Restoration Study). These cold water releases can be provided throughout the summer months to provide adequate summer rearing temperatures in Reach 1, as well as potentially influencing water temperatures in the early spring and late fall for juvenile outmigration and adult immigration, respectively.
- Mendota Dam and diversions from Mendota Pool would require extensive modifications to protect downstream migrating salmon from being entrained in the diversions, as well as providing adult migration past the dam. The Bureau of Reclamation is considering alternative designs for rebuilding Mendota Dam, and opportunities to improve adult and juvenile salmonid routing through or around Mendota Dam and Mendota Pool could be integrated into the Bureau of Reclamation effort. Diversion screens are a viable (but expensive) option as they have been constructed and operated successfully throughout the Central Valley. Additionally, as part of the Mendota Dam reconstruction, there may be opportunities to directly connect the Arroyo Canal to the DMC, thus eliminating a large diversion from the mainstem San Joaquin River. However, this would also eliminate the source of Reach 3 perennial flows of approximately 200 cfs during the non-irrigation season, and up to 600 cfs during the irrigation season.
- Adult salmonid passage could easily be restored at Sack Dam by simply placing boards back into the fish ladder. No significant retrofitting or construction would appear warranted.
- Efforts are underway to improve water quality in the lower San Joaquin River (Reaches 3 through 5, as well as reaches downstream of the Merced River confluence). Actions include reductions in effluents from treatment plants and dairies/feedlots. Wetland restoration along the river floodplain such as that being undertaken by the San Joaquin National Wildlife Refuge (with support from the CALFED program), as well as other programs, may help to reduce these loadings.
- The Chowchilla Bypass, East Side Bypass, and Mariposa Bypass may provide some favorable opportunities for juvenile salmonid rearing during winter and early spring months when ambient air temperatures are low and there is flow in the bypasses. Recent research conducted on the Yolo Bypass has shown that fish growth is greater in the bypass than in the mainstem Sacramento River. While the San Joaquin River bypasses are much different than the Yolo Bypass, there may still be benefits to considering a strategy that uses the bypasses

for juvenile rearing and outmigration. Additionally, the number of riparian diversions and pumps is substantially less than that on the mainstem San Joaquin River, which may reduce diversion and pump entrainment losses to juvenile and adult salmonids.

- The San Joaquin River channel and bypass system presently lacks the capacity to convey the design 50-year flood release from Friant Dam, thus will surely incur local failures again someday as occurred in 1997 and other years. Furthermore, portions of the levee system do not provide reliable flood protection because of structural instability, poor foundation conditions, and excessive seepage. Future efforts to alleviate these flood control problems could provide restoration opportunities if these efforts integrate levee setbacks and floodplain conveyance as part of the flood control solution.
- The ACOE Comprehensive Study provides the opportunity to coordinate improvements in the flood management system in the study area with restoration efforts, since ecosystem restoration is one of the many goals of the Comprehensive Study. The ACOE effort may also be a mechanism to apply Federal funds to develop projects that benefit both flood conveyance and restoration efforts on the San Joaquin River.
- Buchanan Dam, Hidden Dam, and/or Madera Canal could provide flows to the San Joaquin River at certain times of the year that would benefit salmonids (e.g., smolt outmigration period); however, there are ecological and geomorphic constraints that would need to be considered (among others). If flows from these sources occurred during the smolt outmigration period, juvenile imprinting on non-San Joaquin River water could lead to some unknown amount of straying of returning adults. If flows occurred during the adult migration time, adults could be attracted into non-San Joaquin River channels rather than their intended destination in Reach 1. Additionally, the lower portions of the Chowchilla and Fresno rivers are not adequately connected to the San Joaquin River, and defined channels would need to be created in the lower portions of these two rivers.

5.5.2. Summary of Constraints

Constraints imposed by the water related infrastructure within the study reach of the San Joaquin River are numerous, and include:

- Lack of continual streamflows in Reach 2 and Reach 4, and lack of continuous streamflow connectivity amongst all reaches, due to diversions from Friant Dam, Mendota Dam, Sack Dam, and numerous riparian pumps. Streamflow is the initial limiting factor to restoring salmon and steelhead in the San Joaquin River study reach. Infrequent flood control releases that provide full flow routing (and enable fish migration) are insufficient to achieve salmonid restoration goals.
- Lower streamflows due to flow regulation will also cause a constraint to restoring salmonid populations in the San Joaquin study reach. Even if adequate water for fish passage is released from Friant Dam, water temperatures over the late spring, summer, and early fall months would too high to permit adult and juvenile salmonid migration.
- Juvenile and adult salmonid entrainment in water diversions will be a constraint for restoration efforts given that, at present, all non-flood water released from Friant Dam and Mendota Dam is captured by riparian diversions, leaving much of Reach 2 and 4 dewatered. Diversions at Mendota Pool, Sack Dam, and many small diversion dams and pumps would divert a significant portion of downstream migrating juvenile salmon into canals and agricultural fields. Remediating potential future entrainment losses will be a significant task.

- Water quality studies have shown that concentrations of dissolved solids and selenium, along with low dissolve oxygen in agricultural drainwater impair growth and survival of salmonids and other native fishes (See Chapter 6). Furthermore, non-native fish species are often better suited to survive these degraded water quality conditions, thus out-compete the native fishes.
- The transformation of the San Joaquin River from a natural riparian and tule marsh floodway to a leveed water supply and flood control channel has completely altered the hydrology, geomorphology, and channel morphology of the river. Reversing this cumulative impact will be a major constraint. Portions of the stream channel upstream of the mouth of the Merced River have been dewatered, and the lower reaches have been maintained more as an agricultural drain than a river. Wetlands and riparian habitats have been lost, which along with changes in flow, have greatly altered the character and structure of the stream channel and floodplain terraces. Gravel mining in Reach 1 has reduced sediment supply, created enormous bedload traps, and increased channel degradation. Reversing the impacts of gravel mining, even for a scaled-down floodway, will be a lengthy and expensive effort.
- The Mariposa Bypass, Chowchilla Bypass, and Eastside Bypass all have bifurcation structures or drop structures that may constrain upstream adult salmonid migration and downstream juvenile salmonid migration (as well as other native fish species). Adult salmonids may be attracted to bypass outfalls and then become stranded in the bypass when flows recede too quickly. If adult salmonids are intended to be routed through the bypasses, all drop structures and bifurcation structures in the bypass will need fish passage modifications.
- Larger irrigation returns (e.g., Mud Slough, Salt Slough) may attract adult and juvenile salmonids. Adults are known to move far upstream in irrigation systems only to eventually become trapped or forced to retrace their path. Weirs at the downstream ends of these return channels are reasonably inexpensive fixes, but still may cause harmful delays to upstream adult migration.
- Given the limited water supply in the San Joaquin River, and structures potentially concentrating fish, poaching may become problematic at these locations.
- The travel time of flood releases from Friant Dam is several days longer than releases from the tributaries (Tuolumne River, Merced River, Stanislaus River), further confounding flood control operations and increasing the risk of flood damage in the lower San Joaquin River.

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CHAPTER 6. WATER QUALITY

6.1. INTRODUCTION

The San Joaquin Valley depends on water of good quality from the San Joaquin River to support agricultural production and provide domestic water supplies, and to support the fish and wildlife resources that inhabit the river. Historically, clean and abundant water supplies flowed from the Sierra Nevada, fed by the large volume of unimpaired snowmelt runoff from the pristine upper watershed.

Water quality has decreased markedly in recent decades, however, resulting primarily from major land use changes. The first significant land disturbance by European and East Coast immigrants was cattle and sheep ranching. By the 1870s, wheat farming began to eclipse ranching as the dominant land use. Throughout the 20th century, agriculture diversified, with wheat replaced by more water-intensive crops, such as truck crops, orchards, grain, and other products.

Prior to the last 50 years of rapid agricultural and urban expansion, water quality information was infrequently collected. In recent decades, however, water quality deterioration has been better documented, and has generally coincided with San Joaquin River flow reductions, population growth, and expanded agricultural production. For example, in 1988, 52.8 million pounds of restricted-use pesticides, of 350 different types, were used in the San Joaquin basin (Brown 1998). Nitrate concentrations in the San Joaquin River have increased over the last 40 years (Dubrovsky et al. 1998). Selenium, boron, and mercury concentrations are elevated in agricultural drain waters in the study area. Chapter 2 of this report documents changes in streamflow hydrology in the San Joaquin River, and Chapter 10 provides a complete description of the historical and contemporary land uses in the San Joaquin Valley.

Despite these dramatic changes to water quality in the San Joaquin basin, few studies have linked water quality to the health of aquatic resources (Dubrovsky et al. 1998). Intensified studies in recent years has advanced our knowledge of the sources and distribution of water quality and contaminants, and have identified a number of water quality parameters that may pose significant limits on the long-term restoration goals for the San Joaquin River. Our purpose in this chapter is to describe historical and existing water quality conditions from Friant Dam to the confluence with the Merced River and to analyze how these water quality conditions could affect restoration of riparian vegetation, fish resources, and other target species.

6.2. STUDY AREA

The study area considered in this chapter extends from Friant Dam below Millerton Lake at San Joaquin River Mile (RM 267), downstream to the confluence with the Merced River (RM 118) (Figure 6-1). Much of the available water quality information used in this analysis is derived from sampling at Newman and Vernalis, outside of the study area, and downstream of the influence of the Stanislaus, Tuolumne, and Merced rivers.

In addition to the study reaches in the mainstem San Joaquin River, this assessment also discusses several tributaries within the general study area because they are specific contaminant sources. South of the Merced River, many of the eastside tributaries now have dams and reservoirs, including Bear Creek (confluence within Reach 5), Chowchilla River, Fresno River, and Dry Creek (confluences within Reach 4). These tributaries are included in our assessments. Westside tributaries include Los Banos Creek, Mud Slough, and Salt Slough (confluences within Reach 5). The water quality monitoring station at Vernalis is the point of compliance of several water quality objectives, and the lower San Joaquin River is therefore included in our assessments. Water quality data from the remaining tributary streams to the San Joaquin River from the Merced River confluence (RM 118) northward to Chipps Island (RM 0), as well as other sources outside the study area, were excluded from this assessment. On the Westside, excluded sites are Orestimba, Del Puerto, Ingram and Hospital Creeks; on the eastside, these are the Merced River (and tributary Owens Creek), Tuolumne River (and tributary Dry Creek), Stanislaus River, Littlejohns Creek, Calaveras River, Mokelumne River, and Cosumnes River.

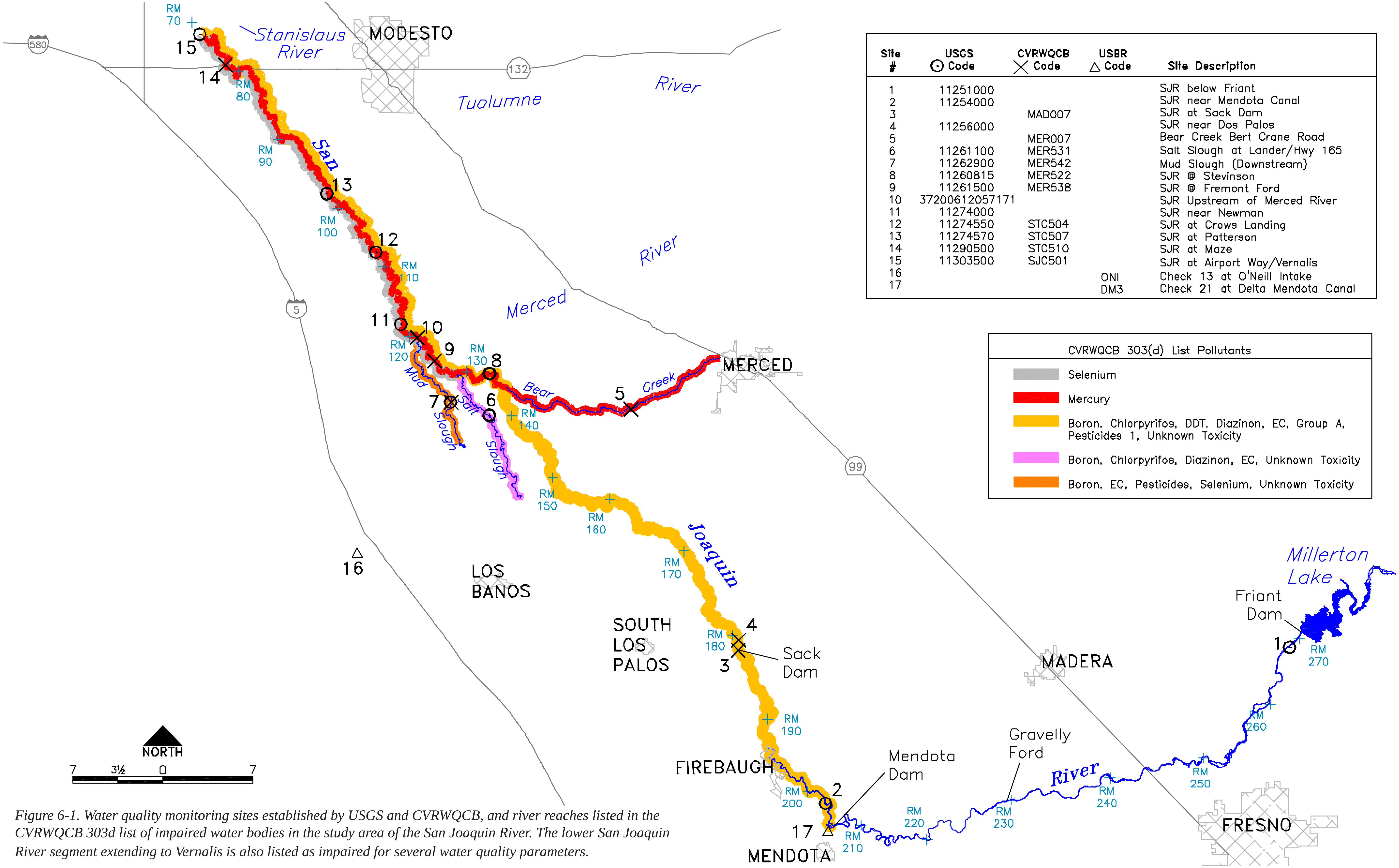
6.2.1. Surface and Groundwater Sources

The San Joaquin River basin is drained by its principal tributaries that flow from the Sierra Nevada range on the basin's east side, the Coast Range on the west side, and the Tulare Lake basin on the south side. Historically, tributaries that drain the basin's west and south edges were intermittent, due to low rainfall over the Coast Range and the Tehachapi Mountains. Maximum flow in the San Joaquin River and its eastside tributaries historically occurred in May and June, and was primarily snowmelt (Jackson 1972; USGS 1998). With the completion of Friant Dam in 1941 and the Friant-Kern canal in 1948, most of the San Joaquin River flow was diverted, leaving the river channel upstream of Mendota Pool dry, except during wetter water years when flood control releases were required. Currently, releases from Friant Dam provide 5 cubic feet per second (cfs) down to Gravelly Ford (RM 229). Farther to the south, the Kings, Kaweah, Tule, and Kern Rivers drained into Tulare Lake, which often spilled into the San Joaquin basin via Fresno Slough. Flood flows from the Kings River is still sent north to Fresno Slough and into the San Joaquin River.

Groundwater resources of the San Joaquin River Basin include all or part of 10 major groundwater basins: Kings, Madera, Chowchilla, Merced, Modesto, Eastern San Joaquin County, Tracy, Delta-Mendota, Westside, and Sacramento County basins. Poorer quality (higher salinity) water is imported from the south Delta via the CVP and SWP; this water is used for irrigation along the west side of the San Joaquin River. Irrigation water drains via Salt and Mud Sloughs, and Bear Creek. Reaches 2 and 4 are dry most years; Reaches 1 and 3 have perennial flows from Friant Dam and Mendota Dams, respectively. During the irrigation season (May through October), river flows between the Mendota Pool and Salt Slough largely originate from groundwater and tile drainage of Westside agricultural developments. Concentrations of Total Dissolved Solids (TDS), sodium, sulfate, boron, chloride, carbonate/ bicarbonate, and trace elements (e.g., selenium) all increase as CVP-delivered water is applied to westside soils, and as deep percolation returns to the San Joaquin River (Phillips et al. 1991). Besides these agricultural discharges to the river, impacts also result from the largest urban water users in the San Joaquin Valley, the cities of Fresno, Modesto, and Stockton. To the north of the Merced River, flows from the three major eastside tributaries (Merced, Tuolumne, and Stanislaus) substantially dilute negative effects on the water quality of the San Joaquin River. Chapter 2 discusses surface water hydrology, and Chapter 4 discusses groundwater resources in the study area.

6.3. DATA SOURCES

Several state and federal agencies have direct or indirect responsibility for assessing water quality in the San Joaquin basin, including the State Water Resources Control Board (SWRCB), Central Valley Regional Water Quality Control Board (CVRWQCB), the U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA), and the State Department of Water Resources (DWR). Within the study area of this chapter, monitoring stations' periods of record vary, as do the stations' types of water quality parameters (Table 6-1). In addition to the SWRCB and Regional Board data, we have compiled historical data found in DWR files, USGS data and reports (e.g., NAWQA and Water Supply Papers), the California Department of Fish and Game (CDFG) files, agency publications, and journal articles.



Site #	USGS ⊙ Code	CVRWQCB ✕ Code	USBR △ Code	Site Description
1	11251000			SJR below Friant
2	11254000			SJR near Mendota Canal
3		MAD007		SJR at Sack Dam
4	11256000			SJR near Dos Palos
5		MER007		Bear Creek Bert Crane Road
6	11261100	MER531		Salt Slough at Lander/Hwy 165
7	11262900	MER542		Mud Slough (Downstream)
8	11260815	MER522		SJR @ Stevinson
9	11261500	MER538		SJR @ Fremont Ford
10	37200612057171			SJR Upstream of Merced River
11	11274000			SJR near Newman
12	11274550	STC504		SJR at Crows Landing
13	11274570	STC507		SJR at Patterson
14	11290500	STC510		SJR at Maze
15	11303500	SJC501		SJR at Airport Way/Vernalis
16			ONI	Check 13 at O'Neill Intake
17			DM3	Check 21 at Delta Mendota Canal

CVRWQCB 303(d) List Pollutants

⬜	Selenium
🟥	Mercury
🟨	Boron, Chlorpyrifos, DDT, Diazinon, EC, Group A, Pesticides 1, Unknown Toxicity
🟪	Boron, Chlorpyrifos, Diazinon, EC, Unknown Toxicity
🟧	Boron, EC, Pesticides, Selenium, Unknown Toxicity

Figure 6-1. Water quality monitoring sites established by USGS and CVRWQCB, and river reaches listed in the CVRWQCB 303d list of impaired water bodies in the study area of the San Joaquin River. The lower San Joaquin River segment extending to Vernalis is also listed as impaired for several water quality parameters.

Table 6-1. Water quality monitoring stations along the San Joaquin River.

New Site Number	Gage Name	CVRWQCB Code	USGS Code	Water Temperatures (Table 5)	General Water Quality (Table 7)	Inorganics (Table 8)	Pesticides and Herbicides (Tables 9 and 10)
1	SJR Below Friant		11251000	2000-2001	1951-1984	1951-1984	
2	SJR Near Mendota		11254000	2000-2001	1951-1984		
3	SJR @ Sack Dam	MAD007		2000-2001			
4	SJR Near Dos Palos		11256000		1951-1959	1951-1959	
5	Bear Creek Bert Crane Rd.	MER007					
6	Salt Slough @ Lander/Hwy 165	MER531	11261100	1985--2002	1985-1994	1984-2002	1993-1994
7	Mud Slough (Downstr)	MER542	11262900	1985--2002	1985-1999	1985-2002	1994-1999
8	SJR @ Stevinson	MER522	11260815	1985--2002	1985-2000	1985-2002	1994-2000
9	SJR @ Fremont Ford	MER538	11261500	1979--2002	1955-1994	1955-2002	
10	SJR Upstream of Merced R.		372006120571701	2000--2000	2000-2000	2000-2000	
11	SJR Near Newman		11274000	1984--1988	1958-1988	1958-1993	
12	SJR @ Crows Landing	STC504	11274550	2000--2000	1962-2000	1962-2000	
13	SJR @ Patterson	STC507	11274570	1985--2002	1962-2000	1962-2002	1994-2000
14	SJR @ Maze	STC510	11290500	1985--2002	1951-1994	1951-2002	
15	SJR @ Airport Way/Vernalis	SJC501	11303500	1961--2002	1950-2000	1950-2002	1972-2000

1 Not all parameters measured for entire periods of record shown.

6.4. OBJECTIVES

The primary objective of this chapter is to summarize water quality parameters, then 1) evaluate how these parameters impact aquatic resources, 2) link these water quality parameters with source contributions, and 3) assess how sensitive these parameters are to changes in increased instream flows and other potential restoration actions. This chapter assesses numerous water quality parameters, including temperature, salinity, dissolved oxygen (DO), and trace constituents such as metals, pesticides, and other contaminants. Historical water quality conditions are described where information is available, and then they are compared to existing water quality conditions.

6.5. EXISTING WATER QUALITY IMPAIRMENTS

The SWRCB and the CVRWQCB are responsible for ensuring implementation and compliance with the provisions of the federal 1972 Clean Water Act (CWA) and California's Porter-Cologne Water Quality Control Act. Water quality impairments arise from many sources, including instream flows, land use, and direct contaminant discharge. To better manage these responsibilities, the CVRWQB has grouped the study reaches in the San Joaquin River as follows (CVRWQCB 1998a):

1) Friant Dam to Mendota Pool (Reaches 1 and 2)
2) Mendota Dam to Sack Dam (Reach 3),
3) Sack Dam to the Merced River (Reaches 4 and 5).

Designated beneficial uses for the San Joaquin River and its tributaries include municipal and domestic drinking water supplies, and cold freshwater habitat use for Reaches 1–2; for Reaches 1–5, warm freshwater habitat is designated (Table 6-2). Other designated beneficial uses include agricultural supply, industrial process water, contact and non-contact recreation, migration of aquatic organisms, spawning habitat, and habitat for other wildlife (Table 6-2). In 2001, each of California's nine RWQCBs was asked to assist the SWRCB in preparing an update to the state's Clean Water Act Section 303(d) List of Water Quality Limited Segments (SWRCB 2001). Several reaches and tributaries within the study area currently do not meet the water quality criteria applicable to the designated beneficial uses and are therefore on the CVRWQCB's 303 (d) list (Table 6-3). These impaired segments include the San Joaquin River from Mendota Dam to the Merced River (and to Vernalis), Bear Creek, Salt Slough, and Mud Slough. No impairments were listed for Reaches 1 and 2.

Specific water quality objectives (WQOs) for the San Joaquin River and its tributaries are set forth in the Water Quality Control Plan for the Sacramento and San Joaquin River basin (Basin Plan) prepared by the CVRWQCB (1998a), currently in its fourth revision. WQOs are required under the Clean Water Act and are numerical or narrative limits for constituents or characteristics of water designed to protect beneficial uses of the water under the authority of the California Porter-Cologne Water Quality Control Act. Several water quality objectives have been established for the San Joaquin River by the CVRWQCB (Table 6-4). Although the WQOs define the least stringent standard that the Regional Water Board applies to protect regional waters for all beneficial uses, the WQOs may also be set for beneficial uses that require a more stringent standard than needed for fish restoration.

We assume that if the CVRWQCB does not list a river reach as impaired, then the existing water quality conditions are adequate for aquatic resources. This is the case for the WQO for salinity and molybdenum, because water quality criteria for drinking water and agriculture are more stringent than for aquatic resources.

Table 6-2. The designated beneficial uses of waters established by the Central Valley Regional Water Quality Control Board in the San Joaquin River study reaches. MUN=Municipal and Domestic Supply; AGR=Agricultural Supply; PRO=Industrial Process Supply; REC=Recreation ;WARM=Warm Freshwater Habitat ; COLD=Cold Freshwater Habitat ;MIGR=Migration of Aquatic Organisms ; SPWN=Spawning, Reproduction, and/or Early Development ; WILD=Wildlife Habitat.

Reach No.	Reach Name	River Miles	MUN	AGR	PRO	REC	WARM	COLD	MIGR
1	Friant Dam to Gravelly Ford	RM 267 to RM 229	X	X	X	X	X	X	X
2	Gravelly Ford to Mendota Dam	RM 229 to RM 205	X	X	X	X	X	X	X
3	Mendota Dam to Sack Dam	RM 205 to RM 182		X	X	X	X		X
4	Sack Dam to Bear Creek	RM 182 to RM 136		X	X	X	X		X
5	Bear Creek to the Merced River	RM 136 to RM 118		X	X	X	X		X

Table 6-3. San Joaquin River reaches within the study area designated as impaired and placed on the CVRWQCB Section 303(d) list.

Water Body	Pollutant	Segment (Reach #)
San Joaquin River	Selenium	Salt Slough to Merced River (Reach 5)
San Joaquin River	Mercury	Bear Creek to mouth of Merced River (Reach 5)
San Joaquin River	Boron, Chlorpyrifos, DDT, Diazinon, EC, Group A Pesticides[1], Unknown Toxicity	Mendota Dam to Merced River (Reaches 3, 4, and 5)
Bear Creek	Mercury	28 miles of Bear Creek (Reach 5)
Salt Slough [2]	Boron, Chlorpyrifos, Diazinon, EC, Unknown Toxicity	15 miles of Salt Slough (Reach 5)
Mud Slough	Boron, EC, Pesticides, Selenium, Unknown Toxicity	16 miles of Mud Slough (Reach 5)

[1] Group A pesticides = One or more of the Group A pesticides. The Group A pesticides include aldrin, dieldrin, chlordane, endrin, heptachlor, epoxide, hexachlorocyclohexane (including lindane), endosulfan and toxaphene.

[2] Selenium in Salt Slough was taken off the 303(d) list during the YR 2001 review due to implementation of the Salt Slough Total Maximum Daily Load (TMDL).

Table 6-4. The Water Quality Objectives established by the Central Valley Regional Water Quality Control Board in the San Joaquin River study reach.

Water Body	Pollutant	Water Quality Objective (WQO)1	Segment (Reach #)
Salt Slough, Mud Slough, and San Joaquin River	Molybdenum (heavy metal from eastside soils)	0.050 (mg/l) (maximum concentration) 0.019 (monthly mean)	Salt Slough, Mud Slough (north), and San Joaquin River from Sack Dam to the mouth of Merced River (Reaches 4 and 5)
San Joaquin River	EC (measure of salinity by electrical conductivity)	Shall not exceed 150 µS/cm from Friant Dam to Gravelly Ford (90th percentile)	San Joaquin River, Friant Dam to Mendota Pool (Reaches 1 and 2)

[1]Molybdenum objectives are total (unfiltered) concentrations.

6.6. WATER TEMPERATURE

Virtually all biological and ecological processes are affected by water temperature (Spence et al. 1996). Not only does temperature directly influence chemical equilibria, but invertebrate and fish communities are also extremely sensitive to temperature. Temperature has direct but often subtle effects on life history timing, habitat suitability, reduced growth rates, increased rates of infection, mortality from disease and toxic chemicals, and increased exposure to predators better adapted to warm water temperatures. The effects of temperature on specific species are discussed in Chapter 7 (Section 7.6.6). The historical and existing temperature conditions and their implications for the protection and restoration of aquatic resources of the San Joaquin River are described below.

6.6.1. Historical Conditions

Above the study area, the upper reaches the San Joaquin River were historically described as a cold water mountain stream (Blake 1857, from Yoshiyama et al. 1996 [Appendix C]). The river’s valley portion was generally characterized by warm, meandering waterways with sluggish river channels, oxbow and floodplain lakes, and marshes and sloughs (Moore, 1990). The transition from cold to warm water conditions likely occurred where flows exited the foothills and drained to the valley bottom. This transition zone probably encompasses Reaches 1 and 2 of the study area, from Friant Dam downstream to Gravelly Ford. When runoff flowed unimpaired to the Delta, late summer and early fall water temperatures were recorded well above of 70°F (21°C) at Friant Dam, and were even higher on the lower river reaches (Clark, 1942). Within the study area, documentation indicating temperature refugia locations is scarce. Yoshiyama (et al. 1998), citing California Fish Commission reports from 1921, mentioned that the area near Friant Dam contained large pools “where the spring-run fish congregated after their upstream migration in May to early July, awaiting the fall.” From the historical numbers of the spring-run escapements, we can assume that cold water holding habitat was available and adequate, and that spawning conditions sustained the spring-run Chinook population from year to year. Another hypothesis described in Chapter 4 of this report discusses the numerous artesian springs and groundwater seeps that were historically distributed throughout Reaches 2-5 of the study area (see Figure 4-6). These springs may have provided localized temperature refugia along the mainstem San Joaquin River. However, we found no historical documentation to support or refute this hypothesis.

6.6.1.1. Temperature Data Collected Prior to Friant Dam Construction

Other than these secondary and tertiary references, our ability to *quantitatively* describe the historical water temperature conditions of the San Joaquin River is limited by a lack of data. In our literature review, for the period prior to the construction of Friant Dam, only two sources of historical temperature data were found:

(1) Two reports of the Commissioners of Fisheries of the State of California (CFC) for 1874-75 and 1876-77 (Commissioners of Fisheries 1875, 1877)

(2) Four volumes (1880-1882) of the “State Engineers Dept.: River Records field books. SJR at C.P.R.R. bridge” authored by W.H. Hall.

The Fish Commissioners reports contain data from two San Joaquin River sites at railroad crossings; one is at the existing Atchison, Topeka, and Santa Fe Railroad Line just upstream of the State Highway 99 bridge, near Fresno at RM 244. The other is the Western Pacific Railroad crossing just south of the Hwy 120 Bridge near Tracy at RM 57. The data are maximum and minimum monthly mean water surface and water bottom temperatures, and corresponding mean air temperatures for August and September, during 1875, 1876, and 1877. Data collection methods, actual sampling dates, time of day, etc. were not recorded. The relevant information from the CFC Reports (Table 6-5) is summarized below:

- Little or no significant differences in water temperatures were apparent between upstream and downstream measurement sites; the upstream site frequently had slightly higher recorded temperatures and a wider temperature range. At the downstream site, temperature may have been moderated by streamflow from the Merced, Tuolumne, and Stanislaus Rivers, and/or inflow from groundwater sources.
- August maximum temperatures ranged from 76 to 84°F (24 to 29^{o}C) at the upstream site, and from 78 to 82°F (26 to 28^{o}C) at the downstream site. September maximum temperatures were slightly lower, ranging from 77 to 83°F (25 to 28^{o}C), and from 75 to 78°F (24 to 26^{o}C) in the upstream and downstream sites, respectively. Minimum daily temperatures generally fell to within the upper range considered suitable for salmonids. Maximum daily temperatures occasionally attained levels that are known to cause acute mortality to salmonids.
- At the downstream site, mean temperature dropped several degrees (°F) from August to September; at the upstream site, changes from August to September are less evident and mean temperatures actually increase in some instances.

6.6.1.2. Estimates of Water Temperatures under Unimpaired Flow Conditions

To qualitatively assess historical temperature conditions, unimpaired streamflows must be considered. Using data modeled from the Kings River, a hydrograph component analysis of unimpaired flows was completed for the USGS San Joaquin River at Friant Dam (presented in Chapter 2). The hydrograph analysis allowed a number of inferences. First, unimpaired spring snowmelt floods generally peaked during May and June, but the snowmelt recession would likely have extended through July and into August of wetter years. These sustained flows likely provided cooler water (about 60 to 70°F or 15 to 20^{o}C) from Friant Dam toward the valley floor during wet (and perhaps normal) water year types. Median summer baseflows (occurring between July 15 and September 30) ranged from 200 to 600 cfs, depending on water year conditions, occasionally dropping to 100 cfs in dry years. Flows this low would likely have contributed to elevated water temperatures, probably approaching the maximum water temperatures presently observed in the lower reaches of the San Joaquin River, below Gravelly Ford (from 76 to 84°F or 24 to 29^{o}C). Median fall baseflows (from October 1 to December 20) were

Table 6-5. Historical temperature data reported in the California Fish Commission Reports for years 1875-1877 for two sites in the San Joaquin River study area.

Lower Railroad Crossing, San Joaquin River, latitude 37° 50' N, longitude 121° 22' W [near Hwy-120 bridge, downstream of Reach 5 and the Stanislaus River, RM 57]

	AUGUST (Monthly value in °F)								SEPTEMBER (Monthly value in °F)								
	1875		1876			1877			1875			1876			1877		
	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom
Maximum	82	81	97	79	78	95	81	81	94	78	78	93	75	75	102	78	78
Minimum	72	71	75	75	74	78	71	71	73	72	72	73	70	69	70	71	71
Mean	79.7	78.6	86.2	76.9	76.1	89.6	77.9	77.9	85.6	74.1	74.4	83.4	72.5	72.1	87	73.8	73.8

Upper Railroad Crossing, San Joaquin River, latitude 36° 52' N, longitude 119° 54' W [upstream of Hwy-99 bridge in Reach 1, RM 244]

	AUGUST (Monthly value in °F)								SEPTEMBER (Monthly value in °F)								
	1875		1876			1877			1875			1876			1877		
	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom
Maximum	84	83	111	77	76	112	77	76	104	82	83	108	78	77	105	78	77
Minimum	74	73	81	73	72	90	73	72	82	74	73	80	74	73	76	75	74
Mean	80.7	79.7	101	75	73.9	99.6	75.8	74.8	95.5	78.3	77.9	94	76.8	75.8	92.9	76.6	75.8

Conversion Equations: F = 9/5(C+32) or C = 5/9(F-32) lower than summer baseflows, and ranged from approximately 250 to 400 cfs. Minimum baseflows during this period were estimated to approach 100 cfs, with water temperatures in fall controlled by gradually decreasing air temperatures, and continually declining baseflows. Air temperature and declining baseflows allowed a broad range of seasonal variability. For example, unseasonably high ambient air temperatures and dry water year conditions may have pushed water temperatures near Friant Dam above 80°F (27°C) in September, while the opposite conditions (cooler air temperatures, wet water year) would have produced colder water temperatures. Streamflows during late fall through the spring snowmelt runoff were also generally higher than those of summer and fall, and water temperatures were likely relatively cold during winter and spring (<65°F or 18°C). Lastly, temperature stratification in pools and groundwater inflow may have also provided zones of colder water.

6.6.2. Existing conditions

Currently, water temperatures are lower in Reach 1 due to hypolimnial releases from Friant Dam. This temperature “benefit” is short-lived, however, because reductions in streamflow allow water temperatures to warm much faster.

6.6.2.1. Friant Hatchery Temperatures

Daily water temperatures were recorded at the Friant hatchery from 1993 to 2001 (Figure 6-2). Water used at the Friant hatchery is a mixture of Millerton Lake’s deeper (cooler) water from the San Joaquin River outlet sluice gates (380 feet above MSL), and the higher (warmer) Kern Canal outlet (465 feet above MSL). Because the Friant hatchery staff control the water mixture (and therefore temperature) from these two elevations, potential reservoir release temperatures are difficult to predict from this record. However, minimum annual temperatures recorded at the hatchery in winter months range between 45°F and 50°F (6–10°C) from January through March. Hatchery water temperatures increase during the spring from about 50°F to 55°F (10–13°C) by the end of June. Summer hatchery temperature remains below 60°F, with the maximum daily temperatures often recorded at the end of September. Lastly, hatchery water temperatures decrease during the fall from about 60°F (16°C) to about 50°F (10°C) by the end of December. No other temperature data are available in the vicinity of Friant Dam, for either the pre- or post- Friant Dam era.

6.6.2.2. USGS and CVRWQCB Temperature Records

Daily temperatures were summarized for all months within the period of record for USGS and CVRWQCB data (Table 6-6). The longest period of record was collected at Vernalis (USGS 11303500), which began reporting maximum, minimum, and average water temperatures in 1961. Maximum temperatures recorded at Vernalis above 68°F (20°C) occurred between April 1 and November 1, with daily maxima occasionally approaching 85°F (30°C) (Figure 6-3). Although other long term records under the current (post Friant Dam) flow regime exist, most data reporting did not occur until 1985 (Table 6-5).

Under the current flow regime, mean monthly temperatures generally remain suitable for salmonids and other sensitive fish species (<65°F or 18°C) from November to April in most years. However, temperatures rise above 68°F (20°C) from May through October, which is generally above the range suitable for juvenile salmonids. Note that these mean monthly values do not reflect daily or monthly maxima at these sites, which can be much higher if cold water pools or other refugia are unavailable for cold water fish species. However, since 2001, the Vernalis Adaptive Management Plan (VAMP) has increased instream flows in the San Joaquin River below the Merced River during May of each year; the increased flows have decreased temperatures in May, compared with data at Vernalis prior to VAMP.

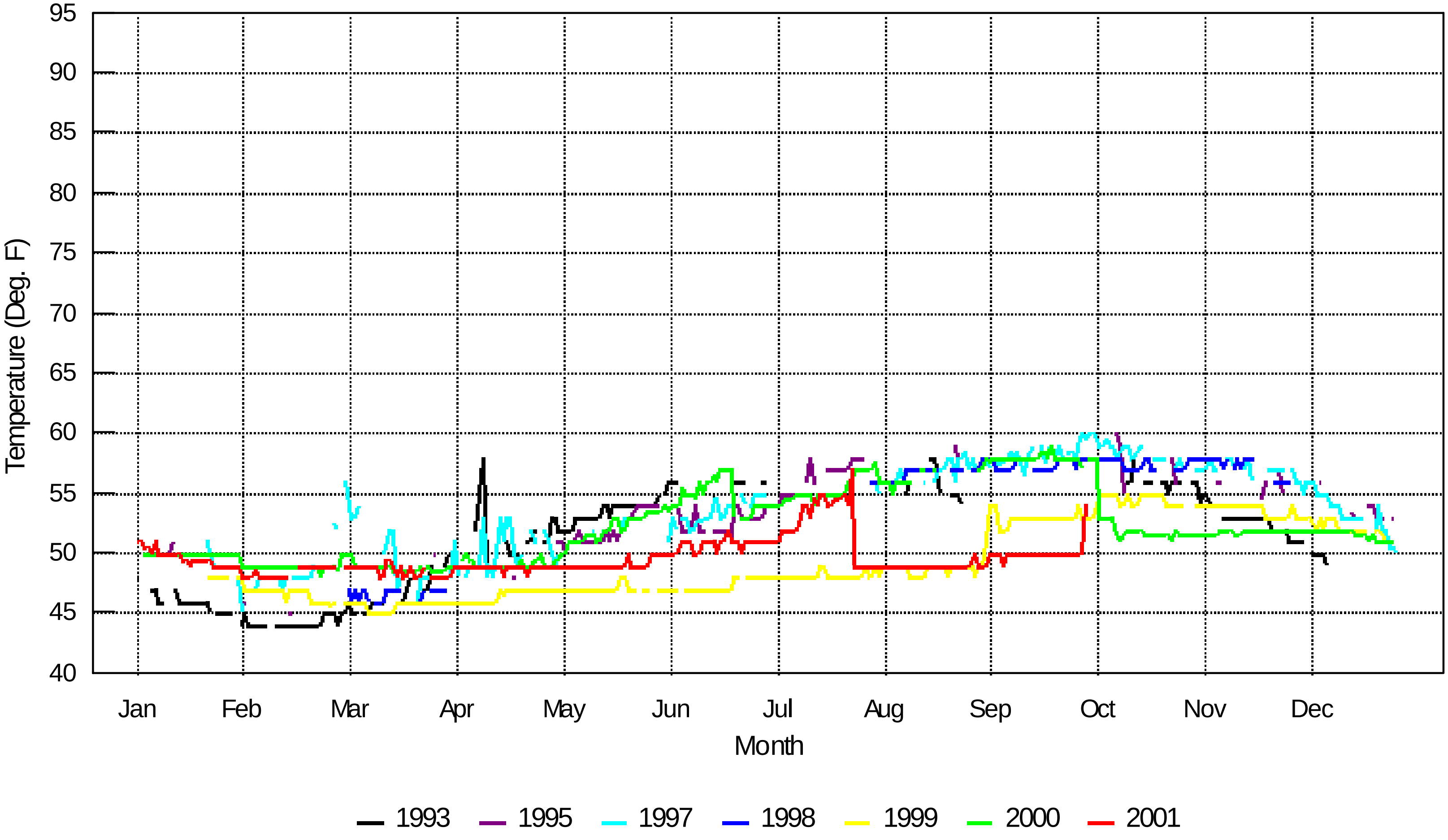


Figure 6-2. Mean daily water temperatures at the Friant Fish Hatchery from 1993 to 2001.

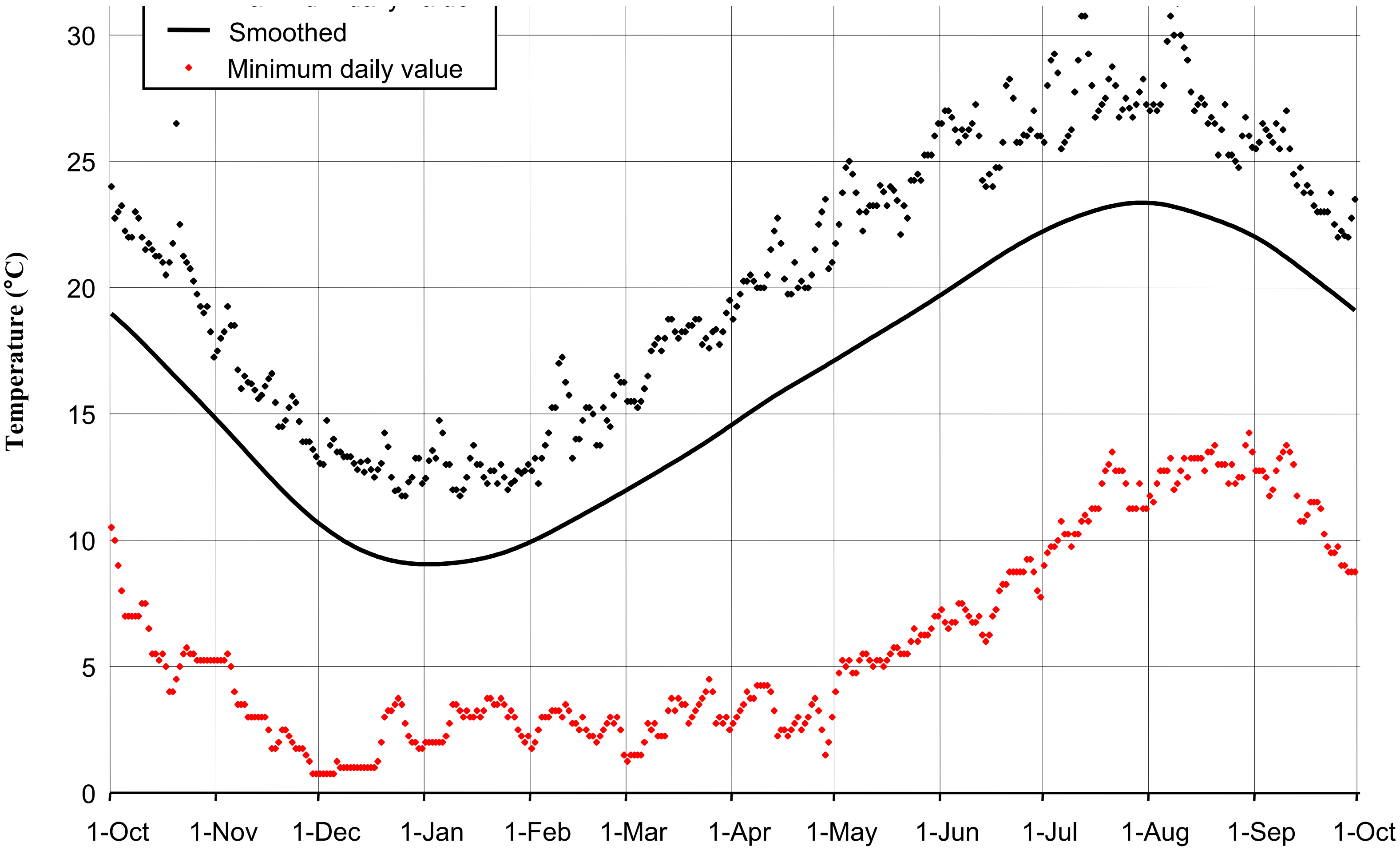


Figure 6-3. Summary of water temperature data from 1961 to 1997 for the San Joaquin River at Vernalis (USGS 11303500).

Table 6-6. Monthly water temperatures in the upper San Joaquin River for winter and summer conditions.

A. Winter Conditions

Site Number	Site Name	USGS Period of Record	CVRWQCB Period of Record	Monthly Water Temperatures (deg C)													
				Nov		Dec		Jan		Feb		Mar		Apr		May	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant[1]			11.0		10.9		9.8		9.2		9.2		9.4		10.6	
2	SJR Near Mendota[1]																
3	SJR @ Sack Dam[1]																
4	SJR Near Dos Palos[1]																
5	Bear Creek Bert Crane Rd.																
6	Salt Slough @ Lander/Hwy 165[2]	1985--1994	1996-2002	14.2	3.4	10.1	2.1	10.1	2.3	12.2	2.3	15.8	2.5	17.3	2.6	20.0	3.2
7	Mud Slough (Downstr)[2]	1985--1999	1996-2002	14.6	2.4	10.1	2.3	10.3	2.7	12.1	2.3	15.8	2.8	17.9	3.2	21.2	3.9
8	SJR @ Stevinson[2]	1985--1993	1996-2002	14.7	3.2	9.9	2.1	9.8	2.2	12.1	2.4	16.2	2.9	17.6	3.1	20.3	3.2
9	SJR @ Fremont Ford[2]	1979--1994	1996-2002	13.8	2.6	9.6	2.3	10.0	2.6	12.3	2.1	15.6	2.7	16.9	2.7	20.3	3.3
10	SJR Upstream of Merced R.	2000--2000															
11	SJR Near Newman	1984--1988		13.0	1.4	9.2	2.5	10.8	1.0	13.6	3.2	15.6	1.6	17.0	4.6	16.0	2.5
12	SJR @ Crows Landing	2000--2000															
13	SJR @ Patterson[2]	1985--1994	1996-2002	14.5	2.5	10.2	2.2	10.5	2.2	12.2	1.6	15.8	2.4	17.8	2.8	20.9	3.1
14	SJR @ Maze[2]	1985--1994	1996-2002	14.5	2.3	10.4	2.0	10.6	2.1	11.9	1.7	15.1	2.4	16.9	3.0	20.3	3.4
15	SJR @ Airport Way/Vernalis[2]	1961--2000	1996-2002	12.7	2.0	9.4	1.7	9.7	1.7	11.1	1.7	13.6	2.1	15.7	2.1	18.5	2.2

B. Summer Conditions

Site Number	Site Name	USGS Period of Record	CVRWQCB Period of Record	Monthly Water Temperatures (deg C)									
				Jun		Jul		Aug		Sep		Oct	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant[1]			10.4		10.6		10.6		Sep		10.6	
2	SJR Near Mendota[1]									22.9		22.9	
3	SJR @ Sack Dam[1]			24.5		26.0		25.7		23.5		23.3	
4	SJR Near Dos Palos[1]												
5	Bear Creek Bert Crane Rd.												
6	Salt Slough @ Lander/Hwy 165[2]	1985--1994	1996-2002	22.8	2.9	24.6	1.9	24.4	2.0	22.3	2.6	17.8	2.5
7	Mud Slough (Downstr)[2]	1985--1999	1996-2002	24.1	3.3	26.0	2.2	25.0	2.4	23.8	2.5	18.9	2.6
8	SJR @ Stevinson[2]	1985--1993	1996-2002	24.0	3.6	26.0	2.3	25.5	2.2	23.1	2.3	18.4	2.5
9	SJR @ Fremont Ford[2]	1979--1994	1996-2002	23.5	3.0	24.9	2.2	24.6	2.2	22.4	2.2	17.6	2.4
10	SJR Upstream of Merced R.	2000--2000				27.5	0.7	25.5	1.4	23.0	2.8		
11	SJR Near Newman	1984--1988		24.0	1.1	24.8	1.8	24.2	0.9	20.8	1.7	17.5	2.8
12	SJR @ Crows Landing	2000--2000				26.0	1.4	23.8	0.4	22.0	2.1		
13	SJR @ Patterson[2]	1985--1994	1996-2002	23.2	2.7	24.6	1.7	24.8	2.2	22.5	2.3	18.6	2.1
14	SJR @ Maze[2]	1985--1994	1996-2002	23.2	2.5	24.5	1.9	24.6	1.9	22.5	2.1	18.6	2.3
15	SJR @ Airport Way/Vernalis[2]	1961--2000	1996-2002	21.0	2.3	23.5	2.0	23.3	1.9	20.9	1.9	17.2	2.1

1 Year 2001 Temp Data from SJRTEMP Model calibration report (JSA 2001). Note, no standard deviation is reported for a single year of data.

2 Temperature means for these sites were compiled from USGS and CVRWQCB data

Conversion Equations: F = 9/5(C+32) or C = 5/9(F-32)

6.6.3. San Joaquin River Temperature Model

The JSATEMP model was developed as a tool for evaluating flow releases for the Restoration Plan, as a component of the SJRiver Model (JSA 2001). The temperature component simulates hourly water temperature to estimate daily minimum and maximum water temperatures in the upper reaches of the San Joaquin River, above the major eastside tributary inputs (Reaches 1–4). Hourly meteorological data measured at the Fresno California Irrigation Management Information System (CIMIS) were used for the hourly heat transfer calculations. The water temperature calculations use an hourly time step, and the minimum and maximum temperatures in each river segment are saved at the end of each day. Jones and Stokes (2001) described the model's assumptions, development, and calibration to the years 2000-2001. Temperature monitoring sites are listed in Table 6-7.

Table 6-7. Temperature probe locations placed in the study area in 2000-01 for JSATEMP temperature model calibration.

Location	San Joaquin River Mile	Year 2000	Year 2001
North Fork Bridge	266.8	X	X
Donaghy Ranch (Rank Island)	259.9	▨	X
State Highway 41 Bridge	255.3	X	▨
CDFG Millburn Unit	248	▨	X
Santa Fe Railroad Bridge	245.1	X	X
Dickenson Avenue	240.7	▨	X
Skaggs Park	234.2	X	X
Emmert Ranch (Gravelly Ford)	228.2	X	X
Napa Avenue	222	X	X
River Mile 220	220	X	▨
Chowchilla Bifurcation Structure	216	X	X
San Mateo Avenue Bridge	212	X	X
Mendota Pool Release	204.8	X	X
Firebaugh Avenue 13 Bridge	195.2	X	X
Sack Dam	182	X	X
Turner Road Bridge	157	X	X

Note: Shaded boxes indicate no data collected for the indicated location and year.
Note: Temperature monitoring occurred during only selected time periods within each of the years.

October 2000 Water Temperature Monitoring. In the first data collection effort, hourly water temperatures were recorded from mid-September through October 2000 at 13 locations from Friant Dam to the Turner Road bridge, about 25 miles downstream of Sack Dam. Flows below Friant ranged from 150 cfs to 200 cfs, and at Gravelly Ford flows were around 100 cfs. Significant warming was evident by the time the water reaches the State Highway 41 Bridge (12 miles downstream of Friant Dam). In general, equilibrium temperature was reached by the time the river reached the Santa Fe Railroad Bridge (22 miles downstream of Friant), and temperatures were relatively constant at locations further downstream. Unfortunately, Friant Dam flow did not vary sufficiently during September 2000 to validate if flow affects Gravelly Ford water temperatures; Gravelly Ford flow was already near equilibrium temperature in September.

2001 Water Temperature Monitoring. In April 2001, thermographs were placed in the San Joaquin River, and left in place through early October 2001. Flows below Friant were maintained at an almost constant 200 cfs, except during a pulse flow from June 15 to 24, 2001. The pulse flow resulted in flows of 360 to 400 cfs, providing an excellent opportunity to calibrate the temperature model component. Contrary to anticipated results, these pulse flows had a relatively small effect on warming between Friant and State Route 41 (SR-41). Before the pulse flow release, at 200 cfs, water temperatures at SR-41 were warmed to 60–70% of the equilibrium temperatures. Water temperature warming dropped to about 40% of the equilibrium temperature during the pulse flow, and then rose to 70% of the equilibrium temperature within 3 days following the pulse flow.

JSATEMP Model Validation and Monitoring Results. Both historical and Year 2000–2001 data demonstrated that the JSATEMP model may be able to simulate both longitudinal and diurnal temperature fairly accurately (JSA 2001). Daily minimum and maximum temperatures for a limited range of Friant releases can also be simulated. The JSATEMP model results suggests that by mid-August a 250 cfs baseflow would provide approximately 14 miles of cool water (<68oF) habitat for over-summering salmonids from Friant dam to near the State Route 41 Bridge (RM 255). Given that the range of flows used for model calibration was very narrow, the temperatures predicted for higher flows may be less accurate. Additionally, the model currently assumes that Friant Dam release temperatures are relatively constant from month -to-month and year-to-year. The use of hatchery temperature data to represent temperatures at Friant Dam under either future or unimpaired flow conditions may be inaccurate, and an investigation of current operations and potential re-operation of Friant Dam will be required to better inform input temperatures to the model.

In summary, the JSATEMP model suggests that the dominant longitudinal temperature change in the upper San Joaquin River occurs from Friant Dam releases as they flow downstream toward Gravelly Ford. Below Gravelly Ford, the model shows that the instream temperatures are in equilibrium and diurnal temperature changes are controlled primarily by meteorology (ambient air temperatures, channel depth, and shading). This equilibrium zone will likely extend (un-modeled) downstream to the confluence with the major eastside tributaries (i.e., Merced, Tuolumne, and Stanislaus rivers) above Vernalis.

6.6.4. Implications for Aquatic Organisms

Temperature directly influences the habitat suitability for invertebrates and many fish species, with effects on life history timing, habitat suitability, growth rates, available DO, rates of infection and mortality from disease and toxic chemicals, and exposure to predators. As discussed in Chapter 7, temperatures have a dominant effect on the various life stages of many fish species. For salmonids, in addition to the need for cold water spawning habitat, warm temperatures can also have a significant effect on juvenile Chinook growth rates (Brett et al. 1982) and reduce the amount of suitable habitat for rearing (Lindsay et al. 1986). Beyond these well-known effects on salmonids, temperature also controls many other ecosystem components, such as invertebrate production and diversity (Rosenberg and Resh 1993).

The CVWRQCB Basin Plan (1998) contains narrative objectives that prohibit activities resulting in large (>9^{o}F or 5^{o}C) increases in water temperature for the protection of salmonids between April 1 through June 30 and September 1 through November 30 in all water year types. The current flow-regime of the river was established long before these objectives were codified and the distance of the Delta downstream of reservoirs is so large that the State Board considers reservoir releases to control water temperatures in the Delta an inefficient use (CVRWQCB 1998a). Nevertheless, water temperature is the physical factor with perhaps the greatest influence on anadromous salmonids, short of complete absence of water, and the model runs and temperature recorders show that the volume of water released from Friant Dam most directly influences water temperatures in Reach 1, with less to no effect downstream at moderate to low flows (<1,000 cfs).

In summary, historical measurements and reconstructed hydrographs of unimpaired flows for the River suggest longer periods of lower temperatures in the San Joaquin River above the Merced river confluence, possibly extending from early October into June under unimpaired flow conditions. Current temperature monitoring (post Friant Dam) and modeling for the San Joaquin River suggests the early summer and late fall temperature regime in the lower study reaches (Reaches 3–5) of the San Joaquin River frequently exceeds the temperature range recognized as suitable for salmonids, and poses a significant constraint for restoring anadromous salmonid populations.

6.7. SALINITY AND BORON

Along with temperature downstream of the Mendota Pool, salinity in the San Joaquin River basin is one of the largest water quality concerns, with the potential to influence the structure of biological communities, and to direct regional agricultural development. Salinity represents the accumulation of anions such as carbonates (CO_3), chlorides (Cl), and sulfates (SO_4), and cations such as potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na). Two general measures are used to assess salinity in water: electrical conductivity (EC) and total dissolved solids (TDS). EC measures the transmission of electricity between known electrode areas and path lengths (units µS/cm), and TDS is measured in mg/L by gravimetric analysis after drying (APHA 1998). TDS and EC are closely correlated; EC readings increase as salt levels increase. For the Lower San Joaquin River, from Landers Avenue to the Airport Way Bridge near Vernalis, TDS (in mg/L) to EC (in µS/cm) ratios range from 0.590 to 0.686 (SWRCB, 1987; 0.65 is typically used as the multiplier to convert from EC to TDS. The remainder of this section discusses salinity in terms of EC and TDS, with the exception of boron, which is discussed independently.

6.7.1. Historical Conditions

Inadequate drainage and salt accumulations were already concerns in the San Joaquin Valley at the turn of the century, and perhaps as far back as the 1880s (SJVDP 1990, as cited in CVRWQCB 2002b). Early irrigation practices intentionally over-irrigated fields to raise the local water table so that subsurface water would be available to crops during part of the dry summer season. However, water was usually applied well in excess of plant uptake and consequently some areas became waterlogged. Additionally, evapotranspiration of applied water resulted in salt build up in the soil and shallow groundwater table. By the late 1800s, salt accumulations and poor drainage had already adversely impacted agricultural productivity and some areas were removed from production (SWRCB, 1987).

Advances in pumping technology during the 1920s and 1930s led to increased groundwater pumping and accelerated agricultural production in the region. Groundwater withdrawals overdrafted the groundwater basin, lowering water table elevations; this overdraft temporarily alleviated the waterlogging problem and allowed salts to be leached below the crop root zone. In 1951, because of the continued groundwater overdraft and high regional demand for additional irrigation water supplies, the Delta Mendota Canal (DMC) began delivering surface water from northern California and the Delta to the northern San Joaquin River basin. Water delivered by the CVP essentially replaced and supplemented natural river flows that were diverted out of the San Joaquin River at Friant Dam, slowing groundwater overdraft, but exacerbating the basin’s salt buildup problems by applying water with higher TDS (CVRWQCB 2002b).

The majority of salt and boron loading into the river originates from lands on the west side of the San Joaquin River watershed. Soils on the west side of the valley are derived from rocks of marine origin in the Coast Range that are high in salts and boron. Soils on the east side of the valley are primarily derived from the igneous parent material of the Sierra Nevada; consequently, east side soils contain relatively low levels of salts and trace elements. The floodplain deposits consist of a relatively thin and more recent deposits that are mainly located in the valley trough (Kratzer 1985 as cited in CVRWQCB 2002a). Due to the rain shadow of the Coast Range, runoff to the San Joaquin River is dominated by eastside tributaries, thus keeping salt loadings historically relatively low. Under current conditions, water quality from all three eastside tributaries is very good, with EC values ranging from 50 to 100 µS/cm. Other constituents such as boron, chromium, lead, nickel, and zinc, are all reported below their respective detection limits (Chilcott et al. 2000). In the mainstem San Joaquin River, historical salinity conditions are much closer to those of the eastside tributaries, except during drought conditions.

6.7.2. Existing Conditions

Water quality data collected by the Central Valley Regional Water Quality Control Board over the past 15 years (CVRWQCB 2002) indicates that water quality objectives for salinity have been routinely exceeded throughout the San Joaquin River from the Mendota Pool to Vernalis (Figure 6-1). In contrast, the upper river (Study Reach 1) has very low salinity than the 120 miles below Mendota Pool (Study Reaches 3, 4, and 5). Delta waters represent over half of the total annual anthropogenic salt load to the Grassland area and long-term irrigation practices have contributed high concentrations of salts to Mud and Salt sloughs, and to the San Joaquin River in Study Reach 5 (Figure 6-1).

Agricultural drainage water collection and disposal, including return flows discharged to the San Joaquin River through Mud Slough and Salt Slough, have been identified as a major source of salinity. The Grassland area surrounding Mud Slough has been the focus of numerous assessments for salt, boron, and selenium. Since the implementation of the Grassland Bypass project in 1996, the majority of irrigation return flows from the Grassland area is now collected in a portion of the San Luis Drain, where it flows back to the San Joaquin River via Mud Slough. This remedial action has resulted in improved water quality in Salt Slough in terms of salinity in addition to other parameters, but has essentially shifted the problems slightly further downstream to Mud Slough. Results of ongoing water quality monitoring of the Mud and Salt Slough area are available through the Grassland Bypass Project web site: http://www-esd.lbl.gov/quinn/Grassland_Bypass/ grasslnd.html

In addition, water delivered to the Grasslands area has salinity concentrations similar to those monitored by the State Water Project's automated water quality stations, located at Check 13 and Check 21 (Figure 6-1) (data can be viewed at: http://wwwomwq.water.ca.gov/). Ongoing CVRWQCB monitoring indicates that while the Grassland area contributes approximately 6% of the total flow to Reach 5, it also generates 37% of the river's total salt load and 50% of the river's total boron load (CVRWQCB 1998b, 2002b).

The degree to which the lower portions of the San Joaquin River (Reaches 3-5) can assimilate salts, in the absence of low salinity water, is largely unknown. Impairment of the lower study reaches (Reaches 3 through 5) has prompted a TMDL development for the San Joaquin River (CVRWQCB 2002b) to determine

2) the major sources of salt loading to the lower San Joaquin River
3) the maximum amount of salt loading that may occur while still meeting water quality objectives
4) how to equitably allocate the available "assimilative" capacity among the identified sources.

Reaches 1 and 2 of the San Joaquin River study area generally meet the water quality goal of 150 µS/cm (CVRWQCB 2002a), as do the conductivity values of the Merced, Tuolumne, and Stanislaus Rivers.

At Friant Dam, winter and summer salinities are low. At Dos Palos (RM 180) near Sack Dam, however, instream conductivity and TDS exceed the CVRWQCB objectives for the San Joaquin River. It is important to recognize that the transition from high water quality to impaired water quality designation below Mendota Dam is due to the inputs of agricultural runoff and from water imported from the Delta, and not from water released from Friant Dam. The CVRWQCB has recommended a Basin Plan amendment intended to address salinity impairment in the lower San Joaquin River from Mendota Pool to Vernalis (Reaches 3, 4, and 5). EC and TDS data from USGS and CVRWQCB data sources are available (Table 6-8). The longest records maintained by the USGS are located at Vernalis (USGS 11303500), Crows Landing (USGS 11274550), and Patterson (USGS 11274570), which began reporting daily values in the 1950s and 1960s, and continue to the present day. Other long-term records are available at Friant (USGS 1125100), Fremont Ford. (USGS 11261500), Newman (USGS 11274000), and Maze Road (USGS 1130500). Recent records include Salt and Mud Sloughs (USGS 11261100 and 11262900), Stevinson (USGS 1126815), and a number of CVRWQCB sites (Table 6-8).

Since the lower San Joaquin River is heavily influenced by the Delta Mendota Canal and agricultural drainage water, separate boron WQOs were applied to the lower San Joaquin River upstream and downstream of the Merced River inflow (CVRWQCB 2002b). In the San Joaquin River from the mouth of the Merced River upstream to Sack Dam (Reaches 4 and 5), the current WQO for boron is 5.8 mg/L maximum, and a 2.0 mg/L monthly mean from March 15 through September 15. This WQO is higher than concentrations that affect sensitive crops and aquatic organisms, and it also exceeds levels that are recommended for protection of drinking water supplies. Consequently, the boron WQO was not approved by the USEPA. The Regional Board is currently reviewing the existing boron objectives for the lower San Joaquin River upstream of Vernalis as part of the Basin Plan amendment. The revised objectives for salinity (including boron), once adopted, will be established to protect the most sensitive beneficial uses of water in the lower San Joaquin River, including agricultural and municipal supply. Although the existing water quality objectives are directed at the most affected areas (Reaches 3, 4, and 5) of the San Joaquin River study area, it is possible that more stringent requirements will be applied in the future and these may affect water quality objectives in Reaches 1 and 2 as well.

6.7.3. Potential Implications for Riparian and Aquatic Resources

That salinity impacts fish species is well-known; salinity is one of the strongest physical factors structuring biological communities (Loomis 1954). Leland and Fend (1998) found that the invertebrate fauna of the nontidal portion of the lower San Joaquin River displayed a large-scale (basin-wide) pattern in community response to salinity (sulfate-bicarbonate type) when a standardized, stable substratum was sampled. Community structure, taxa richness, and EPT (Ephemeropterans, Plecopterans, and Trichopterans) richness all varied with TDS (55 to 1,700 mg/L) and distributions of many taxa indicated an optimal salinity was preferred. This salinity range is within the range shown in Table 6-8; this suggests that increased freshwater flows and decreases in salinity may contribute to large changes in aquatic community assemblages in the San Joaquin River, particularly between the upper (Reaches 1, 2) and lower Reaches (Reaches 3, 4 and 5) and between the mainstem Mud and Salt sloughs.

As part of the CVRWQCB's TMDL for salinity, a literature review was conducted to provide a scientific basis for setting salinity objectives (Davis 2000a and Davis 2000b as cited in CVRWQCB 2002b). The San Joaquin Valley Drainage Program identified 29 inorganic compounds in addition

Table 6-8. General water quality parameters for the San Joaquin River study area during typical winter and summer periods.

A. Winter

Site Number	Site Name	Agency	Period of Record[1]	Winter (November-May)											
				EC (uS/cm at 25°C)		TDS (mg/l)		Alkalinity (mg/L)		TSS (mg/l)		pH		DO (mg/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS	1951-1984	52	14	38	6					7.12	0.30		
2	SJR Near Mendota	USGS	1951-1984	324	229					85	52				
3	SJR @ Sack Dam	CVRWQCB													
4	SJR Near Dos Palos	USGS	1951-1959			141	112					7.46	0.36		
5	Bear Creek Bert Crane Rd.	CVRWQCB													
6	Salt Slough @ Lander/Hwy 165	USGS	1984-1994[2]	2413	662	1776	413	213	25	109	66	7.78	0.19	8.46	1.43
7	Mud Slough (Downstr)	USGS	1985-1999[3]	2874	1302	2128	359	396	57	131	126	7.96	0.23	9.30	1.47
8	SJR @ Stevinson	USGS	1985-2000[4]	675	559	395	109	4		60	54	7.87	0.29	10.20	1.79
9	SJR @ Fremont Ford	USGS	1955-1994	1512	867	1293	374			102	76	7.63	0.42	9.54	1.50
10	SJR Upstream of Merced R.	USGS	2000-2000												
11	SJR Near Newman	USGS	1951-1993	1259	605	749	286			83	52	7.82	0.24	9.31	0.86
12	SJR @ Crows Landing	USGS	1962-2000[5]	1145	503	747	305					7.96	0.29		
13	SJR @ Patterson	USGS	1962-2000[6]	1152	509	719	273	122	33	93	116	7.79	0.28	8.68	1.09
14	SJR @ Maze	USGS	1951-1994	744	378	438	224			98	99	7.65	0.27	8.93	0.99
15	SJR @ Airport Way/Vernalis	USGS	1950-2000	600	314	351	175	101	39	79	58	7.59	0.35	9.45	1.26

B. Summer

Site Number	Site Name	Agency	Period of Record[1]	Summer (June-October)											
				EC (uS/cm at 25°C)		TDS (mg/l)		Alkalinity (mg/L)		TSS		pH		DO (mg/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS	1951-1984	45	12	32	6					7.11	0.29		
2	SJR Near Mendota	USGS	1951-1984	401	220					155	84				
3	SJR @ Sack Dam	CVRWQCB													
4	SJR Near Dos Palos	USGS	1951-1959			292	133					7.49	0.37		
5	Bear Creek Bert Crane Rd.	CVRWQCB													
6	Salt Slough @ Lander/Hwy 165	USGS	1984-1994[2]	1600	458	836	54	107	115	199	54	7.81	0.19	6.81	1.11
7	Mud Slough (Downstr)	USGS	1985-1999[3]	2368	887	1830		176	212	125	87	8.08	0.29	9.89	4.01
8	SJR @ Stevinson	USGS	1985-2000[4]	882	672	320	98			99	141	8.03	0.38	9.18	2.68
9	SJR @ Fremont Ford	USGS	1955-1994	1204	587	1180	641			156	38	7.69	0.37	8.12	1.51
10	SJR Upstream of Merced R.	USGS	2000-2000	1744	679					72		8.30	0.22	10.37	3.08
11	SJR Near Newman	USGS	1951-1993	1078	382	666	208			155	84	7.87	0.24	7.72	0.98
12	SJR @ Crows Landing	USGS	1962-2000[5]	872	297	483	4			63	11	8.06	0.30	8.25	1.46
13	SJR @ Patterson	USGS	1962-2000[6]	1051	374	454	144	81	68	107	41	7.86	0.25	7.94	1.80
14	SJR @ Maze	USGS	1951-1994	907	344	569	169			153	112	7.76	0.37	8.28	2.64
15	SJR @ Airport Way/Vernalis	USGS	1950-2000	706	323	401	156	102	29	112	56	7.76	0.48	9.50	2.75

1 Period of record for entire site; actual periods may differ for each parameter.

2 Period of record for TDS: 1985-1986, Alkalinity: 1994-1994

3 Period of record for TDS: 1985-1986

4 Period of record for TDS: 1985-1986, Alkalinity: 1985-1985

5 Period of record for TDS: 1962-1963, TSS: 2000-2000, DO: 2000-2000

6 Period of record for Alkalinity: 1994-1994

to selenium and dissolved solids that are a concern for public health and maintenance of fish and aquatic life (Brown 1996). The most salt-sensitive beneficial uses are drinking water, irrigated agriculture, and industrial uses. Other beneficial uses, such as fish and aquatic life, waterfowl, poultry, and livestock uses, while impacted by increasing salinity levels, are somewhat more tolerant of small increases in salinity. For example, the Environmental Health Law under California Code Regulations (CCR) Title 22, Article 16, recommends a secondary maximum contaminant level (MCL) of 500 mg/L TDS or 900 µS/cm EC, with an upper limit of 1,000 mg/L TDS or 1,600 µS/cm EC. These levels are approached at Fremont Ford above Mud and Salt Slough, and the MCL is routinely exceeded within these two water bodies, downstream to the mouth of the Merced River (Table 6-8).

In contrast to chlorides and sulfates found in most salts, the most sensitive beneficial uses (agriculture, aquatic life, and municipal supplies) may be impacted by boron concentrations as low as 0.5 to 2.0 mg/L. With effects ranging from human cancer to leaf deformities in some irrigated crops, a concentration of 0.75 to 1.0 mg/L is one boron limit in aquatic systems (Davis 2000b as cited in CVRWQCB 2000b). For aquatic organisms, this level is based partly on laboratory and field studies on rainbow trout (Black, et al., 1993), which is a particularly boron-sensitive species. These levels are routinely exceeded in Salt and Mud sloughs, with periodic violations at downstream San Joaquin River sites too (Table 6-9).

Boron and salinity levels in soils and shallow groundwater could potentially limit the recruitment of riparian vegetation for much of the San Joaquin River study reaches (JSA 1998; Maas 1984 as cited in CVRWQCB 2000b). Boron and salinity may be limiting factors that are magnified by groundwater overdraft east of the river and the near absence of overbank flow over most of the historic floodplain. Although the salt tolerance for most riparian plant species (e.g., valley oak, Fremont cottonwood, narrow-leaf and black willow, etc.) is very low (Maas 1996, USDA-NRCS 2001), limited testing of representative soils within the former floodplain of the Upper San Joaquin River would better inform the potential success of riparian plant restoration in Reaches 3 through 5.

In summary, salinity in the San Joaquin River basin is a large influence on species diversity, and it represents a major limiting factor for restoration of aquatic resources in the lower study reaches (Reaches 3 through 5), with effects on invertebrates, fish, and riparian plant establishment (e.g., boron). Winter and summer salinity at Friant Dam is low, but in-stream conductivity and TDS rises above the CVRWQCB WQO for the San Joaquin River at Dos Palos (RM 180) near Sack Dam. It is likely that higher releases of low-salinity water from Friant Dam may produce changes in the aquatic and terrestrial communities along the river corridor. However, long term storage of groundwater laden with salt and boron has resulted in salt accumulation in the unconfined and semi-confined aquifers that underlie most of the west side of the San Joaquin Valley, and lands on the east side of the San Joaquin Valley directly adjacent to the river (CVRWQCB 2000b). At this time, the degree to which groundwater exchanges during irrigation season (May-October) will affect present and future salinity levels in the river is unknown.

6.8. DISSOLVED OXYGEN

Dissolved oxygen (DO) is a very important indicator of a water body’s ability to support aquatic invertebrates and fish. Oxygen enters surface waters through direct absorption from the atmosphere, with typical natural water concentrations between 7 to 12 mg/L (Horne and Goldman 1994). Small amounts of DO may be produced by aquatic plant and algal photosynthesis, but much of this oxygen is removed during “dark” respiration and bacterial decomposition of organic matter. The sources of dissolved oxygen from the atmosphere and from photosynthetic inputs are counterbalanced by consumptive metabolism (Wetzel 1975). Dissolved oxygen concentrations in water depend on several

Table 6-9. Selected Inorganic Water Quality Parameters in the San Joaquin River study area.

Site Number	Site Name	Period of Record[1]	Nitrate (mg/l as N and NO_3)		Ammonia (mg/l as N and NH_4)		Phosphorus (mg/l)		Boron (ug/l)		Selenium (ug/l)		Mercury (ug/g)[2]	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	1951-1984					0.00	0.00	38	53	1.0	0.0		
2	SJR Near Mendota	1951-1984												
3	SJR @ Sack Dam													
4	SJR Near Dos Palos	1951-1959							143	112				
5	Bear Creek Bert Crane Rd.													
6	Salt Slough @ Lander/Hwy 165[3,4,5]	1984-1994	5.9	4.0	0.2	0.7	0.11	0.04	1118	1011	4.7	6.9	0.15	
7	Mud Slough (Downstr)[4,5]	1985-1999	2.2	1.7	0.1	0.2	0.15	0.11	3466	1676	182.3	681.9	0.17	0.04
8	SJR @ Stevinson[3,4]	1985-2000	0.6	0.2	0.1	0.2	0.17	0.12	173	111	0.4	0.5	0.05	
9	SJR @ Fremont Ford[4]	1955-1994	3.2	2.9	0.1	0.1	0.13	0.06	593	447	2.1	3.6		
10	SJR Upstream of Merced R.	2000-2000			0.0	0.0	0.08	0.05						
11	SJR Near Newman	1951-1993	2.7	1.4	0.2	0.2	0.15	0.08	721	477	4.0	2.6		
12	SJR @ Crows Landing[4,6]	1962-2000	3.1	1.4	0.1	0.1	0.10	0.02	661	385				
13	SJR @ Patterson[3,4]	1962-2000	3.2	1.8	0.4	0.5	0.23	0.12	637	330	2.7	1.7	0.11	
14	SJR @ Maze[4]	1951-1994	2.9	1.8	0.3	0.3	0.19	0.10	345	199	1.5	1.0		
15	SJR @ Airport Way/Vernalis[4]	1950-2000	2.5	1.7	0.1	0.2	0.13	0.07	256	152	1.3	0.9	0.12	0.02

1 Period of record for entire site; actual periods may differ for each parameter.

2 Sediment mercury content from bottom samples, <63U, wet sieve.

3 Period of record for Mercury: 1992-1992.

4 Boron and selenium means for these sites were compiled from USGS and CVRWQCB data.

5 Period of record for Nitrate: 1985-1986.

6 Period of record for CVRWQCB Boron data: 1996-1997

factors, including temperature (i.e., colder water absorbs more oxygen), and the volume and velocity of water flowing in the water body (re-aeration), salinity, and the number of organisms using oxygen for respiration. This last factor (respiratory consumption) is, in turn, strongly influenced by the availability of limiting nutrients (nitrogen and phosphorus), generally derived from anthropogenic sources such as fertilizer.

6.8.1. Historical Conditions

Although DO concentrations in the San Joaquin River were not measured prior to the construction of Friant Dam, the San Joaquin River's historical equilibrium DO within the 10 to 25^{o}C temperature range is estimated to be on the order of 8–12 mg/L, with higher oxygen solubility at lower temperatures (APHA 1998). However, as agricultural development increased, the impact of large-scale applications of industrial fertilizers on primary productivity is unknown.

With the exception of the oxygen demand exerted by the accumulated peat soils found in the lower San Joaquin River and Delta, historical DO in the lower study reaches was likely close to the saturation conditions described above. With the exception of a higher gradient reach near the Merced River Confluence (Reach 5), historical reports of sluggish summertime flows and high temperatures were a result of low gradients (USGS 1899) and this may have inhibited re-aeration and resulted in historical DO lows similar to those found today. In contrast, the low organic and nutrient inputs to the Upper San Joaquin River were likely associated with historical DO levels on the order of 7 to 10 mg/L, which is suitable for most aquatic species.

6.8.2. Existing Conditions

In the last half century, large-scale changes in agricultural production, urbanization, and streamflow regulation have generally decreased DO concentrations in the San Joaquin River. The USGS gage at Vernalis (USGS 11303500) began measuring DO approximately monthly in 1966, with other stations collecting data for shorter periods. Most records span from 1985 to 1994. DO levels were also measured in grab samples in several locations along the San Joaquin River (Table 6-8). For the entire period of record at Vernalis, none of the monthly mean DO levels fall below CVRWQCB criteria for their beneficial uses. The gage at Vernalis appears to be stable from summer to winter (Table 6-8), and the generally good DO conditions in the lower San Joaquin River (at Vernalis) may be attributed to the large volume of tributary inputs from eastside rivers, relative to the San Joaquin River flows. However, minimum DO at Mud and Salt Sloughs (USGS 11261100 and 11262900) and in the San Joaquin River at Stevinson (USGS 11260815) are on the order of 4 to 5 mg/L, near or below the 5.0 mg/L criteria for warm water habitat, set by the CVRWQCB (1998). All sites shown in Table 6-8 below Mud and Salt sloughs exhibit a larger variability in DO during summer (June-October) than in winter (November-May), indicating excessive photosynthetic production from nutrient-stimulated algal and plant growth (Vollenweider 1974).

Although most DO data are generally not indicative of water quality impairment, low DO concentration has impaired the upstream end of the Stockton Deep Water Ship Channel since the 1970s, and a stakeholder-led effort has been developing a DO TMDL for the lower San Joaquin River within the Delta. In general, upstream nutrient sources and excessive algal productivity have been cited as the primary causes (Lehman and Ralston 2000). Numerous sources of this apparent eutrophication have been studied during TMDL development, indicating major contributions of subsurface drainage from Mud and Salt Sloughs, wastewater effluents, and urban runoff (Lee and Jones-Lee 2000; Stringfellow and Quinn 2002). DWR has in recent years installed a temporary rock barrier at the Head of Old River for the purpose of improving instream flows and dissolved oxygen concentrations within the lower San Joaquin River for the benefit of migrating fall-run adult Chinook salmon and other aquatic resources.

6.8.3. Potential Implications for Riparian and Aquatic Resources

Even small reductions in DO concentrations can have adverse effects on invertebrates and aquatic resources, particularly on rearing and migratory life stages of salmonids. While the greatest concern of the current TMDL process is within the lower river (Stockton Ship Channel), summer and autumn depressions in DO near the confluence of the San Joaquin River with Mud and Salt Sloughs (Reach 5) may continue to occur even with increases in instream flows in the San Joaquin River. Organics can be carried in sediment transported from the upper San Joaquin River under high flow regimes; whether these organics will exacerbate the current low DO conditions in the lower river, or be offset by flushing and nutrient reductions in the Delta and its backwater sloughs, remains unknown.

Low DO levels (< 5 mg/L) can cause physiological stress to Chinook salmon and impair development of other aquatic species; DO minimums in Reach 5 and further downstream (i.e., Vernalis, Stockton) can inhibit adult upstream migration (Hayes and Lee 1998; Hallock et al. 1970). In documenting passage delays and seasonal migration blockage of fall-run Chinook salmon in the lower San Joaquin River, Hallock et al. (1970) found that few adult fish migrated through water containing less than 5.0 mg/L DO, and the bulk of the salmon did not migrate until the DO concentration exceeded 5.0 mg/L. Hallock also noted that water temperatures in the lower river may have contributed to inhibiting adult salmon migration. Because seasonal highs in solar irradiance, algal growth, and water temperatures all occur at the same time as DO minimums, it is likely a combination of physical conditions – temperature and DO – are responsible for inhibiting upstream migration.

Daily fluctuations in DO are known to be associated with excessive pH fluctuations from algal productivity (Odum 1956; Vollenweider 1974). Even in portions of the San Joaquin River with suitable water column DO, the organic load may cause local DO depressions near the channel bottom and sediment-water interface. In addition to sediment, temperature, and other contaminants, many individual species of invertebrates (e.g., EPT) are sensitive to changes in DO (Rosenberg and Resh 1993), and low DO concentrations may alter the abundance and diversity of invertebrate and fish assemblages.

In summary, low DO in Reach 5 may approach levels that inhibit restoration of salmonids and other native fish resources, but the area of greatest concern is in the Stockton Deep Water Ship Channel. Changes in flows and sediment loads to the San Joaquin River may have effects on invertebrate and fish community assemblages in the near term. Increased instream flows may dilute nutrient inputs, lower respiratory metabolism of dissolved oxygen, and thus increase instream DO concentrations throughout the San Joaquin River. However, higher seasonal peak flows under consideration in the restoration plan may transport upstream organic sediments. This sediment would also likely carry additional nutrients from upstream to the DWSC and the lower San Joaquin River, and lead to further deterioration in DO at Stockton. This scenario would need to be evaluated within the context of the overall restoration plan. A limited amount of near-bottom DO measurements and site-specific sediment quality data (i.e., carbon and nitrogen content, sediment oxygen demand incubations) may have to be collected to characterize the potential changes in oxygen demand to the lower San Joaquin River (Reaches 3-5) that may occur under future flow regimes.

6.9. NUTRIENTS

High nutrient loads in past decades are associated with eutrophication of the lower San Joaquin River and Delta (Kratzer and Shelton 1998 as cited in Dubrovsky et al. 1998). Although water clarity in the Delta has improved in the past decade, it is coincident with improvements in wastewater treatment and the accidental introduction of many non-native filter-feeding shellfish (Jassby et. al. 2002). Nutrient enrichment of the lower study reaches has significantly affected aquatic resources. Diurnal fluctuations in pH and DO concentrations can occur in waters with enhanced plant growth caused by eutrophication. Problems occur in the early morning when algal and plant respiration causes low oxygen levels in the water column, causing mortality of invertebrates and fish, or causing long-term shifts in community structure. This section discusses ammonia, nitrate, and phosphates, because they are the primary nutrients required for aquatic life.

Ammonia. The EPA has established criteria for maximum ammonia concentrations in surface water, based on the potential threat to the health of aquatic organisms. These criteria vary with acidity and water temperature, which affect both the toxicity of ammonia and the form in which it occurs. In most natural surface waters, total ammonia concentrations greater than about 2 mg/L exceed the chronic exposure criteria for fish, with primary effects related to impaired gill function (Horne and Goldman 1994). In alkaline water at high temperature, the criteria can be exceeded by total ammonia concentrations less than 0.1 mg/L.

Nitrate. In natural waters, elevated concentrations of nitrate causes eutrophication, algal and plant growth, and subsequent water quality problems such as DO depletion (Horne and Goldman 1994). Nitrate contamination of groundwater and surface water is a major concern, especially in regions where large doses of agricultural fertilizers are applied. Other than its biostimulatory effects on plant life, nitrate by itself is generally not a health problem; when ingested by humans it is converted into nitrite by enteric bacteria. In humans lacking a key enzyme, however, nitrite can lead to “blue baby syndrome” (methemoglobinemia).

Phosphorus. Similar to nitrate, phosphorus is often a limiting nutrient in natural waters and contributes to eutrophication (Horne and Goldman 1994). Phosphorus as phosphates may be found in low levels in natural waters and in wastewaters. The principally bioavailable form includes several classes of phosphates: orthophosphates, condensed phosphates, and organically bound phosphates. These compounds are found in solution (by natural weathering or fertilizer application), in detritus, and in tissues of aquatic organisms (organic phosphates).

6.9.1. Historical Conditions

Prior to the construction of Friant Dam and other tributary impoundments along the San Joaquin River, nutrient conditions were not monitored, so information on these conditions is unavailable. Due to the lack of nutrient data from before the era of large-scale use of fertilizers and extensive agricultural development of the San Joaquin Valley, national and global background levels were reviewed. Fuhrer et al. (1999) suggest 2 mg/L nitrates as a typical background level for both groundwater and surface water, and ammonia and phosphate concentrations less than 0.1 mg/L. While higher nitrate levels are sometimes found, Horne and Goldman (1994) suggest typical surface water nitrate concentrations would be below 1 mg/L. Although particulate phosphate is associated with weathering of mineral deposits, dissolved orthophosphate is also typically low in the nation’s waters (Fuhrer et al. 1999). Granitic soils characteristic of the upper San Joaquin River basin generally yield low phosphate levels. As discussed below, changes in limiting nutrient status from nitrogen to phosphorus and back again are likely as sediment inputs, mineral geology and fertilizer inputs all change along the river corridor.

6.9.2. Existing Conditions

The major sources of nutrients in the San Joaquin River basin are dissolution of natural minerals from soil or geologic formations (e.g., phosphates, iron); fertilizer application (e.g., ammonia and organic nitrogen); effluent from sewage-treatment plants (e.g. nitrate and organic nitrogen); and atmospheric precipitation of nitrogen oxides. Organic nitrogen, ammonia, and organic phosphorus are all present in treated and untreated agricultural wastes and municipal effluents.

Prior to industrial production of ammonia, agricultural inputs of organic nitrogen sources were likely low. Following WWII, industrially produced ammonia largely replaced the use of manure and although experimental agricultural fertilization probably occurred in the early 20th century, between the 1950s and the 1980s, nitrogen fertilizer application rates increased from 114 to 745 million pounds per year nationwide (Mueller and Helsel 1996). Concentrations of nitrate in groundwater also increased, from less than 2 mg/L in the 1950s to about 5 mg/L in the 1980s. This increase, coupled with the construction of extensive tile drainage systems, has resulted in an overall increase in nitrates in the lower San Joaquin River.

Dissolved phosphates (PO_4^{2-}), ammonia (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) concentrations are presented for the period of record at the San Joaquin River water quality monitoring stations (Table 6-9). Phosphate and nitrate levels are greater than 2.5 mg/L at all monitoring stations downstream of Fremont Ford, which is much higher than typical background levels (Fuhrer et al. 1999). Ammonia concentrations are generally in excess of 0.1 mg/L in Reach 5, which may exert chronic stress on some aquatic organisms but does not exceed toxic acute thresholds. However, ammonia concentrations in agricultural drainages may approach acute levels (1-2 mg/L NH_4-N) along Mud and Salt Sloughs (Stringfellow and Quinn 2002). Kratzer and Shelton (1998) found that flow-adjusted ammonia concentrations have decreased during the 1980s at several sites, which is probably related to improved regulation of domestic and dairy wastes.

Nitrate levels are consistent with the widespread nitrate contamination of the region’s shallow groundwater, but do not exceed the 10 mg/L drinking water maximum contaminant level (MCL) criteria (Table 6-9). Kratzer and Shelton (1998) found that flow-adjusted nitrate concentrations in the lower San Joaquin River have increased steadily since 1950. Since 1970, this nitrate increase has been due primarily to increases in subsurface agricultural drainage. Although many groundwater wells exhibit nitrate concentrations that exceed the 10 mg/L drinking water MCL for nitrate in drinking water (Mueller and Helsel 1996), no concentrations approaching this level were found in the monitoring sites on the mainstem San Joaquin River (Table 6-9). Salt Slough, however, may approach or exceed these concentrations.

In earlier investigations of existing conditions, Dubrovsky et al. (1998) assessed nutrients and suspended sediment in surface water of the San Joaquin-Tulare basins using data from the U.S. Geological Survey’s National Water Information System and the U.S. Environmental Protection Agency’s STOrage and RETrieval database, over the period from 1972 to 1990. Comparisons of nutrient and suspended sediment concentrations were made in three environmental settings: the San Joaquin Valley-westside, the San Joaquin Valley-eastside, and the Sierra Nevada. Nitrate concentrations in the lower San Joaquin River are determined primarily by relatively concentrated inputs from west-side agricultural drainage, east-side wastewater treatment plants, and dairy runoff, with relatively dilute inputs from large east-side tributaries. Within the San Joaquin River watershed, there are large areas of riparian seasonal wetlands, some of which discharge high concentrations of nitrate to the San Joaquin River tributaries (Kratzer and Shelton 1998). Within Reach 5, Mud and Salt sloughs receive flow from subsurface drains underlying approximately 60,000 acres of agricultural land. Although the sloughs account for only about 10% of the streamflow in the San Joaquin River near Vernalis, the subsurface drainage is highly concentrated with nitrate (about 25 mg/L as N), and the sloughs contribute nearly one-half the total nitrate (Kratzer and Shelton 1998, as cited in Dubrovsky et al. 1998).

6.9.3. Potential Implications for Riparian and Aquatic Resources

Eutrophication of surface waters is the primary effect of excessive nutrient input. Moderate levels of ammonia (0.1 to 0.2 mg/L) in the lower study reaches (Reaches 3 through 5) may cause chronic stress to fish (Alabaster and Lloyd 1982). Phosphates are generally less of a concern for eutrophication, since phosphates generally do not migrate within groundwater far from the point of fertilizer application (Fuhrer et al. 1999). Algae and plant growth under eutrophic (high nutrient) conditions, along with their subsequent decomposition in the water column, lead to increased oxygen consumption and decreased DO concentrations, reduced light penetration, and reduced visibility. Reduced light penetration in water limits plant photosynthesis in deeper waters, and may, in combination with increased oxygen consumption (due to decomposition), lead to oxygen depletion at deeper levels. As discussed in Section 6.8, reduced DO levels from algal blooms and low visibility may render these areas unsuitable for some fish species (e.g., trout) and favor others (e.g., blackfish, sucker, carp, shad). Although daily DO fluctuations from excess nutrients are associated with excessive pH fluctuations (Odum 1956), whether the eutrophic conditions of the San Joaquin River vary pH enough to affect abundance or diversity of fish and invertebrate, is unknown. Acidity (pH) must vary significantly to cause additional nutrient releases (for example, a pH of 9.4 is required for the release of free ammonia).

In addition to the potential impairment of fish habitat from DO depletion and ammonia toxicity, increased turbidity and light absorption by algae may reduce water clarity substantially, and based upon turbidity increases, may interfere with fish foraging, which could lead to decreased growth rates (Section 6.12). Total suspended solids (TSS) (Table 6-8) are generally higher in summer than in winter for all stations reporting, suggesting a large TSS contribution by algae, which may consequently effect organic loading and sediment anoxia. Nutrient reductions are likely to substantially improve the water clarity of the San Joaquin River, along with sediment load reduction. Under current conditions, existing sediment loads and turbidity may be controlling algal blooms; improved light penetration from load reductions may allow increased algal and plant growth as light (rather than low DO levels), becomes the limiting factor in primary productivity in the San Joaquin River.

Riparian establishment may be limited by relationships established between soils and crop plants. Soils along the San Joaquin Valley floor have had historically low nutrient concentrations and have likely supported plants adapted to low nutrient conditions (i.e., oligotrophic plants). With the changes in agricultural practices in the past decades, riparian areas were both physically and chemically impacted by exposure to fertilizers, which can cause plant community shifts towards species adapted to higher nutrient levels (State of Washington 1992 as cited in Williamson et al. 1998). For this reason, nutrient requirements of desired plant species and continuing nutrient-laden water from agriculture may limit riparian re-establishment.

In summary, with the possible exception of higher groundwater exchange rates, nutrient loads in the San Joaquin River basin will not likely be improved without a reduction in the source of the nutrients. Given the economic incentives of fertilized and irrigated agriculture in the San Joaquin Valley, excessive nutrient conditions along the river will continue to be a significant water quality issue, potentially affecting restoration of fisheries and riparian resources along the lower reaches of the river.

6.10. TRACE ELEMENTS

Trace metals are generally multivalent cationic elements (heavy metals) that in minute quantities play an important role in cellular functions of living organisms. The primary elements of environmental concern are copper (Cu), zinc (Zn), silver (Ag), nickel (Ni), cadmium (Cd), chromium (Cr), lead (Pb), selenium (Se), mercury (Hg), and tin (Sn). Although some of these metals are biologically necessary in small quantities, at high concentrations nearly all of them cause serious harm, including mortality, birth defects, and behavioral and carcinogenic consequences. Of the trace elements discussed by Brown (1996), this section discusses only two: selenium and mercury. Boron is the subject of an ongoing TMDL development in the basin (CVRWQCB 2000b) and is discussed in Section 6.5. The particular focus on Se and Hg results from their interaction with the aquatic environment because Se and Hg can both be converted into methylated compounds by bacteria. In this methylated form, Se and Hg can "biomagnify" within the food chain; in other words, even very low ambient concentrations can become functionally larger due to fat solubility and can then produce large biological effects.

Mercury. Unlike selenium, no mercury levels are beneficial as a nutrient and even small amounts of mercury can cause neurological and reproductive harm. A few geologic sources of mercury ore (Cinnabar) exist in the region. But organic mercury enters the water as metallic mercury from past mining (primarily gold), from the burning of fuels or garbage, and from municipal and industrial discharges. Like selenium, mercury can be converted into methylated forms, which allows biomagnification up the food chain.

Selenium. Selenium, generally considered to be a micronutrient, is common to the soils of the western San Joaquin valley and has a toxic threshold very close to levels required for nutrition. Much of the selenium in soils is combined with sulfide minerals or with silver, copper, lead, and nickel minerals. During soil weathering, selenium combines with oxygen to form several substances, the most common of which are sodium selenite and sodium selenate. Plants easily take up selenate compounds from water and change them to organic selenium compounds such as selenomethionine. Some plants can build up selenium levels that are harmful to livestock that feed on these plants, potentially causing deformities and nervous system impairment.

6.10.1. Historical Conditions

Historical mercury conditions in this region were likely low because mercury-bearing ore deposits are generally not found in this region. Gold mining practices in many Sierra watersheds left a legacy of mercury contamination in the remaining tailings piles (Churchill 1999, Hunerlach et al. 1999) and in hydraulic mining alluvium; present-day mercury concentrations in the San Joaquin River study area (e.g., Bear Creek) are likely a result of these sources because historical concentrations were likely low.

Historical concentrations of trace elements in the San Joaquin River study area were likely similar to present conditions of water originating from the Sierra Nevada. The important exception was selenium runoff and groundwater flow from soils along the west side of the San Joaquin Valley that contain natural sources of selenium and boron. At a Regional Water Quality Control Board Staff Workshop on the San Joaquin River Selenium TMDL development (May 16, 2001), the following estimates of background concentrations of selenium were provided:

- Merced River = 0.2 µg/l
- San Joaquin River above Salt and Mud Sloughs = 0.5 µg/l
- Grassland wetlands = 1.0 µg/l

6.10.2. Existing Conditions

Mercury TMDL. The lower San Joaquin River (Reach 5) was added to the 303(d) list during the 2001 review period due to the mercury impairment. Evidence used to justify adding mercury to the 303(d) list was presented in Appendix B of the CVRWQCB's Draft Staff Report on Recommended Changes to California's Clean Water Act, Section 303(d) List, 27 September 2001. Mercury problems are evident region-wide, but only occur in Reach 5 of the study area because of historical mining in the Bear Creek watershed. This CVRWQCB report stated that trophic level 4 fish had an average mercury concentration of 0.45 ppm, exceeding the EPA criterion of 0.3 ppm. This concentration was an average for fish sampled in three locations in the San Joaquin River, including Landers Ave/Hwy165 downstream of the mouth of Bear Creek, a site between Crow's Landing and Las Palmas Roads, and a site near Vernalis.

Selenium TMDL. Selenium problems have a long history in the San Joaquin Valley. Due to the high salt, boron, and selenium concentrations in west side agricultural drainage identified in the early 1960s, an interim solution for salt and selenium accumulations was developed. The San Luis Drain project construction began in 1968 and halted in 1975. Funding limitations and environmental concerns ranging from disclosure of selenium-related bird mortalities in the Kesterson Reservoir, and concern for public health, prompted the Department of the Interior to develop an agreement with the Westlands Water District in 1985, calling for cessation of drainage flows to Kesterson Reservoir.

The CVRWQCB responded to the environmental problems at the Kesterson Wildlife Refuge with an amendment to the Basin Plan (CVRWQCB 1998) in which they established numerical water quality objectives for Selenium. The amendment was intended to protect sensitive beneficial uses from elevated levels of selenium in three identified areas within the San Joaquin River study area, including Salt and Mud sloughs and the San Joaquin River from Salt Slough to Vernalis. All three sites were added to the CVRWQCB 303 (d) list (Figure 6-1). The current Basin Plan (CVRWQCB 1998a) includes a water quality objective for selenium of 5 µg/l, based on a 4-day average of total recoverable selenium, and was instituted for Mud Slough and the San Joaquin River from Sack Dam to Vernalis. A 2 µg/l selenium water quality objective based on a monthly average of total recoverable selenium was instituted for Salt Slough and the Grassland channels. As stated in the TMDL for the lower San Joaquin River (CVRWQCB 2001b), water quality objectives were made more stringent than the selenium objective for other water bodies to offer added protection to the waterfowl using the wetlands. The compliance date for the San Joaquin River and Mud Slough is set for October 1, 2010 with earlier performance goals for the San Joaquin River of October 1, 2002 and 2005.

Selenium concentrations at selected sites along the San Joaquin River range between 1 to 5 µg/l (Table 6-9), which approach or exceed Basin Plan objectives set for Mud and Salt Sloughs. Mean selenium concentrations range widely for Mud and Salt Sloughs, however. Selenium is much higher for the Mud Slough monitoring site adjacent to the Grasslands Project Area (discussed below).

The limited amounts of data suggest that CVRWQCB water quality objectives for selenium are currently being exceeded for Mud Slough (Table 6-9) and downstream mainstem reaches to Vernalis (including Reach 5). The San Joaquin River at Stevinson station may be indicative of conditions upstream of Reach 5, in which selenium concentrations are one to two orders of magnitude lower than the San Joaquin River below Mud Slough. This difference in selenium concentrations will be useful when evaluating measures to reduce selenium input from Mud Slough.

Grasslands Project

The Grassland Bypass Project, initiated in 1995, utilizes a 28-mile segment of the San Luis Drain (SLD) to convey agricultural drainage water. This segment, known as the Grassland Bypass, conveys agricultural drainage waters from the Grasslands Subarea to the San Joaquin River via Mud Slough. This drainage had previously been contributing high concentrations of selenium to Salt Slough. Since September 1996, the implementation of the Grassland Bypass Project and the selenium TMDLs for Grassland Marshes and Salt Slough has dramatically improved selenium concentrations in Salt Slough. Water quality objectives are now being met for selenium and Salt Slough was removed from the 303(d) list for selenium during the 2001 review. Although Mud Slough and the San Joaquin River remain impaired due to selenium, long-term solutions to meet the selenium WQO by October 1, 2010 have been recommended by the CVRWQCB in their implementation section of the Basin Plan. Water quality monitoring results that document Salt Slough's water quality improvements since the implementation of the Grassland Bypass Project in 1996 are available http://www.esd.lbl.gov/quinn/Grassland_Bypass/grasslnd.html.

6.10.3. Potential Implications for Riparian and Aquatic Resources

The San Joaquin Valley Drainage Program identified selenium as one of 29 inorganic compounds that are a concern for public health and maintenance of fish and aquatic life (Brown 1996). Agricultural tile drainage has been shown to cause episodic toxicity to juvenile salmonids and striped bass (Saiki 1992), and high selenium concentrations from drain water have been linked to mortality and developmental abnormalities in fishes (Moyle and Cech 1988). Selenium dilution in the river may be expected with increased freshwater inputs from Friant Dam, but the major selenium accumulation in groundwater and increases in groundwater table elevation are legacies of past irrigation practices that increased surface flows may not be able to completely ameliorate. A long-term solution to the subsurface drainage problem has not been found for sustained agricultural crop production in western Fresno County. Nor is dilution of selenium by increased streamflows necessarily endorsed as the best approach to resolving impaired water quality. Furthermore, since only trace amounts of selenium cause reproductive harm in fish and birds, continued impairment of the lower portions of the San Joaquin River study area is likely to continue, posing a major limiting factor in any restoration plans.

In addition to the regional selenium contamination, mercury contamination of the lower watershed may represent another limiting factor in the restoration of the San Joaquin River. Methyl mercury bio-magnification in fish can cause death, reduced reproductive success, impaired growth and development, and behavioral abnormalities (Slotton 2000). Because methyl mercury is also a human neurotoxin, transfer to humans through consumption of fish from the Bay-Delta is a major health concern. Unintentional re-suspension of past mercury deposits in the channel bed, leading to increased uptake into the food chain, is a possible risk to anticipate in any restoration actions.

6.11. PESTICIDES AND HERBICIDES

Pesticides vary in their potential to affect water quality and aquatic resources. According to Brown (1998), many of the recently developed pesticides, such as the organophosphate compounds, are highly soluble in water and are relatively short-lived in the environment. In contrast, the previous generation of pesticides included organochlorine compounds such as DDT and toxaphene, which are non-polar and poorly soluble in water, and may persist in the environment for long periods. Non-polar compounds also allow bio-accumulation in animal tissues over time, posing a direct threat to aquatic resources and human health. Many of these chemicals were banned several decades ago, but the legacy of their use is still detected at levels considered a threat to water quality (Brown 1998).

A large number of pesticides have been detected by water quality sampling programs in the San Joaquin basin, including Aldrin, Carbaryl, Chlorpyrifos, Diazinon, Dieldrin, Diuron, Heptachlor, Lindane, Malathion, Metribuzin, and Trifluralin (Domagalski et al. 2000). Most problems occur in the lower study reaches (Reaches 3-5) where water quality is influenced by water imported from the Delta and by agricultural drainage. Reaches 1 and 2 have generally good water quality (Brown 1997). Domagalski's study (et al. 2000) and other multi-year studies (Brown 1997, Panshin et al. 1998) assessed a wide array of contaminants. The large and growing number of chemical pesticides found in the San Joaquin Valley is too large to encompass in this review. Furthermore, accurately quantifying risks that pesticides pose to aquatic resources is not easily validated; most studies rely on comparing contaminant levels (from biota or the environment) to literature values, regional or national statistics, or suitable reference sites. Because of the importance of DDT as a marker of past pesticide-use practices, this section discusses DDT along with two other pesticides (Diazinon and Chlorpyrifos) and two herbicides (Simazine and Metalachlor). These compounds were some of the most frequently detected compounds in the National Water Quality Assessment program studies (Dubrovsky et al. 1998).

Dichlorodiphenyltrichloroethane (DDT). DDT was the first chlorinated organic insecticide discovered (1873), but it was not until 1939 that the effectiveness of DDT as an insecticide was discovered. DDT earned wide publicity in the early 1970s environmental movement as a primary cause of declining avian populations. The chemical stability of DDT and its fat solubility contributed to its acute effects on wildlife (including egg shell thinning and deformities in birds) and its chronic, low-level toxicity in fish. DDT was eventually banned in the United States in 1973. Since 1998, DDT has also been regulated in Dicofol (now required to be less than 0.1 percent DDT).

Diazinon and Chlorpyrifos Pesticides. In winter, dormant-spray pesticides including diazinon and chlorpyrifos are applied to fruit orchards and alfalfa fields in the San Joaquin Basin and Delta islands (Kuilvila 1995, 2000). These pesticides are delivered to local water courses and the Delta by overland runoff. Diazinon is the common name of an organophosphorus (OP) insecticide used to control pest insects in soil, on ornamental plants, and on fruit and vegetable field crops. Chlorpyrifos is also an OP insecticide and is used to kill insect pests by disrupting their nervous system. OP pesticides were originally developed for their water solubility and ease of application. After they have been applied, they may be present in the soil, surface waters, and on the surface of the plants that are sprayed, and may be washed into surface waters by rain.

Simazine and Metalochlor Herbicides. In the late 1950s, Simazine was originally introduced and used as an aquatic herbicide to disrupt photosynthesis and control algae and submerged aquatic vegetation in lakes and ponds. Studies during the 1960s showed that this chemical was effective in controlling algae and certain species of aquatic plants with no apparent harm to fish (Mauck 1974). Metolachlor is a selective pre-emergence herbicide used on a number of crops. It can be lost from the soil through bio-degradation, photo-degradation, and volatilization. It is fairly mobile and under certain conditions, it can contaminate groundwater but it is mostly found in surface water.

6.11.1. Historical Conditions

Because the pesticides and herbicides discussed in this report have no natural origin, historically the San Joaquin River was free of these organic contaminants. Agricultural applications over the past 50 years have resulted in existing water quality conditions.

6.11.2. Existing Conditions

Although extraordinarily large amounts of data have been collected within the San Joaquin basin (Brown 1997, Dubrovsky et al. 1998, Gronberg and Burow *in press*, Panshin et al. 1998), only a limited amount of data available at the USGS website were analyzed in this report (Tables 6-10 and 6-11). The occurrence of pesticides and other toxic agents have been associated with land use activities that contribute to agricultural drainage and runoff in the lower reaches of the San Joaquin River study area (Reaches 3, 4, and 5). Although mean contaminant levels are low (Tables 6-10 and 6-11), it is likely these samples did not capture episodic contaminant exceedances during peak pesticide use and peak surface flow runoff into the San Joaquin River (Kuilvila 1995, 2000).

6.11.2.1. USGS NAWQA Toxicity Monitoring

The San Joaquin-Tulare study unit was among the first basins chosen for the USGS National Water Quality Assessment Program (NAWQA), and has recently focused considerable attention on pesticide

Table 6-10. Pesticides in water samples in the San Joaquin River study area.

Site Number	Site Name	Agency	Period of Record[1]	Winter (November-May) Diazinon (ug/l) Mean	Winter (November-May) Diazinon (ug/l) S.D.	Winter (November-May) Chlorpyrifos (ug/l) Mean	Winter (November-May) Chlorpyrifos (ug/l) S.D.	Summer (June-Oct) Diazinon (ug/l) Mean	Summer (June-Oct) Diazinon (ug/l) S.D.	Summer (June-Oct) Chlorpyrifos (ug/l) Mean	Summer (June-Oct) Chlorpyrifos (ug/l) S.D.
1	SJR Below Friant	USGS									
2	SJR Near Mendota	USGS									
3	SJR @ Sack Dam	CVRWQCB									
4	SJR Near Dos Palos	USGS									
5	Bear Creek Bert Crane Rd.	CVRWQCB									
6	Salt Slough @ Lander/Hwy 165	USGS	1993-1994	0.052	0.043	0.018	0.014	0.067	0.096	0.007	0.005
7	Mud Slough (Downstr)	USGS	1994-1999					0.013	0.001	0.010	0.008
8	SJR @ Stevinson	USGS	1994-2000	0.033	0.023	0.011	0.016	0.002	n.a.	0.004	n.a.
9	SJR @ Fremont Ford	USGS									
10	SJR Upstream of Merced R.	USGS									
11	SJR Near Newman	USGS									
12	SJR @ Crows Landing	USGS									
13	SJR @ Patterson	USGS	1994-2000	0.022	n.a.	0.007	n.a.	0.009	0.001	0.015	0.010
14	SJR @ Maze	USGS									
15	SJR @ Airport Way/Vernalis	USGS	1972-2000[2]	0.094	0.180	0.010	0.010	0.009	0.014	0.008	0.004

1 Period of record for monitoring of selected herbicides.

2 Period of record for monitoring Chlopyrifos: 1992-2000.

Table 6-11. Herbicides in water samples in the San Joaquin River study area.

Site Number	Site Name	Agency	Period of Record[1]	Winter (November-May)				Summer (June-Oct)			
				Simazine (ug/l)		Metolachlor (ug/l)		Simazine (ug/l)		Metolachlor (ug/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS									
2	SJR Near Mendota	USGS									
3	SJR @ Sack Dam	CVRWQCB									
4	SJR Near Dos Palos	USGS									
5	Bear Creek Bert Crane Rd.	CVRWQCB									
6	Salt Slough @ Lander/Hwy 165	USGS	1993-1994	0.048	0.025	0.010	0.009	0.028	0.022	0.016	0.015
7	Mud Slough (Downstr)	USGS	1994-1999					0.036	0.035	0.006	0.006
8	SJR @ Stevinson	USGS	1994-2000	0.119	0.083	0.006	0.005	0.043	n.a.	0.110	n.a.
9	SJR @ Fremont Ford	USGS									
10	SJR Upstream of Merced R.	USGS									
11	SJR Near Newman	USGS									
12	SJR @ Crows Landing	USGS									
13	SJR @ Patterson	USGS	1994-2000	0.163	n.a.	0.008	n.a.	0.038	0.004	0.109	0.051
14	SJR @ Maze	USGS									
15	SJR @ Airport Way/Vernalis	USGS	1992-2000	0.246	0.325	0.018	0.060	0.023	0.016	0.066	0.053

1 Period of record for monitoring of selected herbicides.

contamination in the San Joaquin basin (Dubrovsky et al. 1998; Panshin et al. 1998; Kratzer and Shelton 1998; Brown and May 2000). Generally, toxicity within the San Joaquin River has been attributed to pesticides from agricultural nonpoint sources, substantiated by the lack of detection of pesticide compounds in reference sites on the upper Kings River and Tuolumne River, situated above agricultural influences (Dubrovsky et al. 1998). In the NAWQA studies, available drinking water standards were not exceeded at San Joaquin River monitoring sites, but the concentrations of several pesticides exceeded the criteria for the protection of aquatic life. As mentioned previously, regional or national contamination levels are used to interpret San Joaquin River study results. Gilliom and Clifton (1990, from Brown 1998) reported that the San Joaquin River had some of the highest concentrations of organochlorine residues in bed sediments among the major rivers of the United States. Concentrations of organophosphate insecticides (i.e., Diazinon and Chlorpyrifos) in runoff are high, and highly variable during winter storms (Kratzer and Shelton1998). Long-banned organochlorine (e.g., DDT) concentrations detected in biota of the San Joaquin Valley streams appear to have declined from levels measured in the 1970s and 1980s (Dubrovsky et al. 1998), but still continue to be transported to streams by soil erosion of contaminated agricultural fields, resulting in contamination of suspended sediment, bed sediment, and aquatic organisms.

Reaches 1 and 2 of the San Joaquin River have not been identified as problem areas by the NAWQA studies, but pesticides have been detected in groundwater samples from domestic water supply wells. However, concentrations in groundwater supplies generally have not increased in the last decade (Dubrovsky et al. 1998). The extremely low levels of pesticides and herbicides, and ephemeral nature of their presence in surface waters, prompted the creation of the California Department of Pesticide Regulation within CalEPA, which tracks pesticide use. Data are available at the following web site: http://www.cdpr.ca.gov/dprdatabase.htm

6.11.2.2. Basin Plan Objectives and CVRWQCB Monitoring

For most pesticides, numerical water quality objectives for pesticides have not been adopted, but a number of narrative water quality objectives (e.g., no adverse effects) for pesticides and toxicity are listed in the Basin Plan (CVRWQCB 1998a). The EPA criteria and other guidelines are also extremely limited, since numerical targets based on the anti-degradation policy would not allow pesticide concentrations to exceed natural “background” levels (i.e., nondetectable levels or “zero”). For the San Joaquin River system, including the five reaches of this study area, the California SWRCB has set a goal of “zero toxicity” in surface water. This goal is intended to protect the beneficial uses of Recreation, Warm Freshwater Habitat, Cold Freshwater Habitat, and Municipal and Domestic Supply from potential pesticide impacts.

The most recent 303(d) list of impaired waterbodies presented by the CVRWQCB identifies Reaches 3, 4, and 5 of the San Joaquin River study area, Mud Slough, and Salt Slough as impaired due to pesticides and “unknown toxicity” (Figure 6-1). In addition to the CVRWQCB, the USGS and the State Department of Pesticide Regulation (DPR) are conducting cooperative synoptic and/or in-season sampling for pesticides, herbicides, and insecticides. The following stations are part of the ongoing studies: San Joaquin River at Vernalis (USGS 11303500), Maze (USGS 11290500), Patterson (USGS 11274570), Crows Landing (USGS 11274550), and Stevinson (USGS 11260815), Bear Creek at Bert Crane Rd. (CVRWQCB MER007), Salt Slough at Lander/Hwy 165 (USGS 11261100), Mud Slough (USGS11262900), and Los Banos Creek at Hwy 140 (CVRWQCB MER554). Results of these sampling efforts will help characterize the distribution of pesticides and other toxins within these impaired waterbodies. Annual reports discussing the results for the DPR-funded studies can be found at: http://www.cdpr.ca.gov/docs/empm/pubs/memos.htm.

Ongoing efforts to reduce and minimize the effects due to pesticides within the larger San Joaquin River area are coordinated through a recent draft workplan to develop a Diazinon and Chlorpyrifos TMDL for the Lower Sacramento River, Lower Feather River, Lower San Joaquin River (includes the San Joaquin River downstream of Mendota Dam to the Airport Way Bridge near Vernalis), and the main channels of the Sacramento–San Joaquin River Delta.

6.11.3. Potential Implications for Riparian and Aquatic Resources

Although modern pesticides are formulated for water solubility and low application levels, and although pesticides are detected ephemerally (Kuilvila 2000), a large number of older pesticides continue to be detected in the San Joaquin River (Panshin et al. 1998). The effects of pesticides on the restoration of riparian and aquatic resources include episodic toxicity and low level contamination of the San Joaquin River.

Pesticides and herbicides do not appear to alter invertebrate and fish species diversity in the NAWQA study areas (Brown 1998), but their synergistic effects with other environmental variables is largely unknown. For salmonids, chemical interference with olfactory functions (and therefore homing), and other chronic toxic effects, are potential problems due to pesticides and herbicides, and may limit restoration activities in Reaches 3-5 of the study area. Moore and Waring (1996) showed that the organophosphate pesticide diazinon had sublethal effects on the olfactory system of mature male Atlantic salmon. Reductions in the ability of mature salmon to detect and respond to reproductive odorants and pheromones may have long term implications for populations (Moore and Waring 1996). Pesticides at even low concentrations interfere with the production and activity of sex hormones in salmon, causing decreases in sperm production. (Moore and Waring 1996).

In summary, continued pesticide use may be a long term limiting factor for aquatic resources in the San Joaquin River. In terms of planned restoration activities, the combination of coarse-grained deposits and the relatively shallow depth to groundwater of the Valley's eastern side, increase the risk of transport of pesticides from irrigated areas (Domagalski and Dubrovsky, 1991, 1992). Continued toxicity episodes may occur. The greatest uncertainty with legacy deposits of DDT in sediments is the potential for sediment re-suspension and transport. DDT metabolites have been detected in bottom sediment samples in Reach 5 of the San Joaquin River (Dubrovsky et al. 1998), and could be remobilized at higher flows.

6.12. SUSPENDED SEDIMENT AND TURBIDITY

Very fine (colloidal) suspended matter such as clay, silt, organic matter, plankton and other microscopic organisms cause turbidity in water. Turbidity is an optical property (light scattering), which itself is not a major health concern, but high turbidity can interfere with temperature, DO, feeding habits, photosynthesis, and is associated with total metals loadings and sorption of contaminants from the water column (e.g., polar organics and cationic metal forms). Turbidity is closely related to total suspended solids (TSS). TSS and turbidity sources to the San Joaquin River include suspended sediment from tributary inflows, agricultural return flows, bank erosion, resuspension of local sediments from tidal mixing, high flows, wind-generated wave fetch, and summer algae production. Suspended sediment is discussed in Section 7.7.5.2 in relation to effects on fish species. This section emphasizes turbidity as a water quality parameter. For the purposes of this chapter, turbidity and suspended solids were estimated to have a 1:1 equivalence to turbidity (Montgomery 1985), where 1 mg/L TSS is approximately one nephelometric turbidity unit (1 NTU).

6.12.1. Historical Conditions

Although no historical measurements of suspended sediment and turbidity were found for this assessment, the San Joaquin River (and tributaries) probably historically carried relatively low suspended sediment loads due to the predominantly granitic geology of the upper basin. These conditions likely changed above Friant, as the parent geology shifted to decomposed granite and clays, producing relatively higher natural background suspended sediment and turbidity in the valley floor portion of the river below Friant (USGS, 1899). Perhaps the best description of the historical turbidity levels in the upper river are from Blake (1857 from Yoshiyama et al. 1996) who described the San Joaquin River in the vicinity of Millerton, in July, as “remarkably pure and clear, and very cold.” Suspended sediment concentrations were likely historically higher in west side tributaries to the San Joaquin River because of the finer-grained alluvial deposits of the Coast Ranges (Kratzer and Shelton 1998). However, other historical accounts suggest that the flood basins in Reaches 3-5 caused suspended sediments to deposit in the upper portion of the flood basin, longitudinally reducing turbidity in the downstream direction. This trend ended at the Merced River confluence.

6.12.2. Existing Conditions

The USGS currently collects suspended sediment data at Vernalis (USGS 11303500), which began reporting daily values in 1965. In addition, weekly and bi-weekly data were collected between 1985 and 1988 at Patterson (USGS 11274570), Fremont Ford (USGS 11261500), Stevinson (USGS 11260815), and near Mendota (USGS 11254000). Table 6-8 shows suspended sediment concentrations range between 60–100 mg/L in the winter and from 100–150 mg/L in the summer. Assuming a 1:1 correspondence between turbidity and TSS (Montgomery 1985), the range of TSS shown in Table 6-8 would vary from 60–100 NTU in winter and 100–150 in summer. Although the water transparency (Secchi depth) corresponding to these levels is low, we cannot accurately estimate transparency (light transmission) since its relationship between turbidity (light scattering) is non-linear. These grab sample data may suggest lower wintertime suspended sediment levels, perhaps reflecting decreases with increased rainfall and lower turbidity from eastside tributary inputs, but more likely reflect algal productivity in the river (Section 6.8). According to USGS Professional Paper 1587, nutrient and suspended sediment loads increased during wetter water year types, by increasing non-point source loading (Kratzer and Shelton 1998 as cited in Dubrovsky et al 1998) making these effects difficult to separate without targeted synoptic studies (e.g., nutrients, TSS, Chl-a). Also, TSS and turbidity levels are known to increase during storm events, perhaps as much as two to three orders of magnitude over an individual storm event. Mean suspended sediment concentrations are therefore misleading if data are not collected during storm events. Section 7.7 presents additional information regarding suspended sediment and turbidity.

6.12.3. Potential Implications for Riparian and Aquatic Resources

Suspended sediment and turbidity may be critical variables in restoration efforts in the San Joaquin River. In addition to its direct effects on primary production and fish, turbidity can cause decreases in the abundance of plants, zooplankton, and insect biomass, and reductions in herbivore, omnivore, and, consequently, predator classes of fish (Berkman and Rabeni, 1987 as cited in Henley et al. 2000).

At the base of the food web, high turbidity and TSS can limit algal productivity due to photo-inhibition, with indirect effects that propagate upwards (i.e., suppressed secondary production and reduced food availability for native fish assemblages). Lloyd et al. (1987) found that an increase in turbidity of only 5 NTU decreased primary production by 3–13 percent, and increases of 25 NTU decreased primary production up to 50 percent (Henley et al. 2000). High turbidity and fine sediment can cause dramatic shifts in invertebrate assemblages in rivers (Henley et al. 2000), and can impair the quality of spawning gravels used by salmonids (Tappel and Bjornn 1983).

In terms of its direct impacts on fish, excessive turbidity can reduce DO in the water column, and in extreme cases may cause a thickening of the gill epithelium and reduced respiratory function (Horkel and Pearson, 1976; Goldes et al., 1988; Waters, 1995; all as cited in Henley et al. 2000). Turbidity is also believed to reduce the visual efficiency of piscivorous and planktivorous fish in finding and capturing their prey (Henley et al. 2000). Turbidity works to reduce the reaction distance of a predator to its prey, greatly reducing the volume a fish can search in a given time: a 50 percent reduction in reaction distance reduces the volume searched by a factor of four (Confer and Blades 1975 as cited in Vinyard and O'Brien 1976). Higher turbidity may occasionally favor the survival of young fish by protecting them from predators (Bruton 1985, Van Oosten 1945) at the expense of reduced growth rates for sight feeding fish (Newcombe and MacDonald 1991, Newcombe and Jensen 1996).

In addition to the direct effects on fishes, indirect effects of high suspended sediment is related to contaminant transport. Regional gradients of total metal distributions in sediments and dissolved metals in the water column are generally reflective of parent geology and follow depositional trends and the transport of TSS (Brown, pers. comm. 2002). DO depressions are generally due to transport and settling of organic matter that sorbs on the sediment. Lastly, there may be a number of synergistic effects on aquatic resources impacted by pesticides and other toxins entering the river or stream sorbed onto the eroded material (Henley et al. 2000).

In summary, the current levels of turbidity in the San Joaquin River may inhibit feeding efficiency and may impair the quality of juvenile fish rearing habitat in the study reaches below Mendota Dam (Reaches 3-5). Algal productivity may contribute significant amounts of turbidity to the San Joaquin River, which will continue to inhibit food availability to higher focal fish species, overall measures of environmental quality, and habitat availability, regardless of the anticipated restoration measures. Because of these potential effects, even small decreases in sediment transport and turbidity from increased fresh water flows may lead to shifts in species density, biomass, and diversity throughout all trophic levels.

6.13. SUMMARY

Invertebrate and fish communities are responsive to water quality conditions and the effects are most critically related to physical parameters such as DO, temperature and salinity. A number of studies have demonstrated that fish and invertebrate assemblages structure themselves along water quality gradients (Brown 2000; Hughes and Gammon 1987; Saiki 1984), with subtler effects of pesticide gradients at low levels such as disruption of olfactory cues and hormonal effects on salmonids (Moore and Waring 1996). Despite intensified study and advances in our knowledge of the sources and distribution of water quality and contaminants, a number of parameters identified in this assessment may limit the ability to achieve long term restoration goals for the San Joaquin River.

Temperature. Water temperature modeling suggests that cold water habitat in the first few miles below Friant Dam can be improved by increased flow releases from Friant Dam. However, this effect only extends a short distance downstream during late spring and summer months. Historical measurements and reconstructed hydrographs of daily average flow suggest longer periods of lower temperatures in Reaches 1 and 2 of the San Joaquin River were historically available for salmonids and other native fish species. Additionally, the extensive artesian springs and shallow groundwater contributions may have provided local thermal refugia in Reaches 2-5. The early summer and late fall temperature regime in the lower study reaches (Reaches 3–5) of the San Joaquin River will remain a significant management issue for restoring anadromous salmonids, because the high ambient air temperatures, long river length, and loss of the spring snowmelt hydrograph make it difficult to provide suitable cold water temperatures in the downstream reaches (Table 6-12).

Salinity and Boron. Salinity has an enormous influences on aquatic community structure and species diversity and is potentially a major limiting factor for restoration of aquatic resources in the lower study reaches (Reaches 3–5), with effects on invertebrates, fish, and riparian plant establishment (Tables 6-8 and 6-9). Reaches 1 and 2 have relatively good water quality, but salinity increases in Reaches 3-5, and both conductivity and TDS increase above the CVRWQCB water quality objectives for the San Joaquin River at Dos Palos (RM 180) near Sack Dam. Increases in inputs of low salinity water from Friant Dam and decreases in the importation and irrigation of Delta water would reduce salinity in Reaches 3-5. However, modeling of “losing” and “gaining” reaches within the upper reaches of the river may be necessary to determine how much time would be required to reverse contributions from salinity accumulated and delivered in groundwater.

Dissolved oxygen. DO does not appear to be a critical water quality issue in the study area and it is likely that historical DO levels of the Upper San Joaquin River were on the order of 7-10 mg/L, similar to what is now typically measured in Reach 5 (Table 6-8). The primary exception to this generality is low DO problems in Mud Slough and Salt Slough. Farther downstream in Stockton, low DO levels from algal growth and nutrient contamination from the Delta Mendota Canal, Mud and Salt sloughs (Reach 5), and municipal effluent from Stockton may potentially delay fall-run salmon migration. Because of localized effects on benthic macro-invertebrates and its effects on migrating salmon, the nutrient causes of this DO condition represent a potentially important limiting factor for Reach 5.

Nutrients. High nutrient loads in the past decades continue to be associated with eutrophication of the lower San Joaquin River and Delta, with consequent effects on DO and the possibility of localized ammonia toxicity. Although phosphate and nitrate levels are higher than typical background concentrations (Table 6-9), it is unclear whether increased flows of low nutrient water would substantially reduce nutrient concentrations in the lower reaches. Nutrient dilution in the lower study reaches from future flow releases would be related to the magnitude and timing of the proposed reservoir releases, and adjacent groundwater exchanges. Modeling of “losing” and “gaining” reaches within Reaches 3-5 will have to be conducted to determine how much time would be required to reverse the groundwater buildup of nutrients in the basin.

Trace Elements. Mercury and selenium contamination are well-known problems in the lower San Joaquin River reaches (Table 6-9). Mercury is found primarily in the Bear Creek tributary of Reach 5 and is the most important trace element contaminant from a human health standpoint. Risks of sediment re-mobilization of historical mining deposits in the San Joaquin River need to be considered in restoration planning. The primary sources of selenium are from the Grasslands area and represent a major risk to larval fish species and birds. Although selenium is being addressed by a number of ongoing studies, changes in the groundwater relations of the river under future (higher) flow scenarios could be expected to reduce selenium concentrations in the river by dilution. As with other parameters (nutrients, salt, and boron), selenium impacts will be determined by reach-specific hydrology and concentrations identified in ongoing studies.

Pesticides and Herbicides. The most recent 303(d) list of impaired waterbodies presented by the CVRWQCB identifies Reaches 3, 4, and 5 of the San Joaquin River study area and Mud and Salt Slough as impaired due to pesticides and “unknown toxicity.” Pesticides and other toxicity have been associated with land use activities in these areas, and organophosphate insecticide concentrations (i.e., Diazinon, and Chlorpyrifos) in runoff to Reach 5 are elevated, and highly variable during winter storms. Reaches 1 and 2 or the San Joaquin River study have not been identified as problem areas by the NAWQA studies, but pesticides have been detected in groundwater samples from domestic water

Table 6-12. Summary of beneficial uses controlling water quality objectives, water quality impairments, and potential effects on aquatic resources and restoration planning for the San Joaquin River study area.

Reach	Study Reach	Beneficial Use Controlling Water Quality	303(D) Pollutant Limitation or Other WQO	Water Quality Parameters Likely Affecting Restoration of Aquatic Resources
1	Friant Dam to Gravelly Ford (RM 267-229)	Municipal water supply, cold water fish habitat.	EC<150 µmhos/cm	Late spring and early fall water temperature.
2	Gravelly Ford to Mendota Dam (RM 229-225)	Municipal water supply, cold water fish habitat.	EC<150 µmhos/cm	Late spring and early fall water temperature.
3	Mendota Dam to Sack Dam (RM 205-182)	Agriculture, warm water migratory game fish spawning habitat.	Boron , EC, Pesticides (Table 6-3)	Salinity and boron affecting riparian vegetation. Salinity and pesticides affecting invertebrate and fish species diversity. Possible effects of elevated turbidity.
4	Sack Dam To Bear Creek (RM 182-136)	Agriculture, warm water migratory game fish spawning habitat.	Boron, EC, Pesticides (Table 6-3)	Salinity and boron affecting riparian vegetation. Salinity and pesticides affecting invertebrate and fish species diversity. Possible effects of elevated turbidity.
5	Bear Creek To Merced River (RM 136-118)	Agriculture, warm water migratory game fish spawning habitat	Boron , EC, Pesticides (Table 6-3) Mercury, Selenium	Early fall water temperatures; salinity and boron affecting riparian vegetation, species diversity; TSS and DO extremes affecting invertebrates and fish; selenium affecting fish and avian species. Mercury, pesticides, and herbicides affecting invertebrate and fish species, avian species and human health.

supply wells. Long-banned organochlorine insecticides (e.g., DDT) continue to be transported to streams by soil erosion of contaminated agricultural fields, resulting in contamination of suspended sediment, bed sediment, and aquatic organisms (Table 6-10). Like mercury, risks of sediment re-mobilization of long buried sediment deposits containing DDT in Reaches 3-5 of the San Joaquin River need to be considered in restoration planning.

Suspended Sediments and Turbidity. Current levels of turbidity in the San Joaquin River may inhibit feeding efficiency and represent a major limiting factor for juvenile fish rearing in the study reaches below Mendota Dam (Reaches 3-5). In addition, the potential for direct impacts to the focal fish species (e.g., gill irritation), there are a number of subtler effects of suspended sediments related to contaminant transport and DO conditions.

6.13.1. Potential Water Quality Impacts under Restored Environmental Conditions

Water quality in the San Joaquin River is currently impaired by several parameters that will continue to impact fish and other aquatic and terrestrial resources for the foreseeable future. Recent intensified study and advances in our knowledge of the sources and distribution of water quality and contaminants have identified a number of parameters that may limit the ability to achieve long-term restoration goals for the San Joaquin River. A number of contaminants threaten fishes of the Central Valley (Saiki 1995). Reaches 1 and 2 generally have good water quality. The primary constraints to restoration are agricultural return flows in Reaches 3-5, Mud Slough, and Salt Slough, and the legacy of contaminants available for re-recruitment from surface flows and groundwater contributions. Despite these problems, significant progress has been made to ameliorate water quality contamination in the past decade and represents an enormous opportunity for restoration to contribute to improved water quality in the lower reaches of the San Joaquin River.

Several water quality parameters would likely be improved in Reaches 3-5 by higher streamflow releases from Friant Dam. However, dilution is not the best long-term solution to impaired water quality in the lower reaches. Instead, point-source and non-point source reduction are more viable long-term solutions. Identifying contaminant sources is the first step in the process of pollution control. The San Joaquin River was among the first watersheds selected for study under the USGS NAWQA program in the 1990s, and the second phases of this assessment are currently underway. The CVRWQCB has just initiated a Rotational Basin Monitoring Program to provide an expanded assessment of water quality conditions in five sub-watersheds. In addition to the WQOs set forth in the Basin Plan (CVRWQCB 1998a), ongoing and planned TMDL efforts are seeking to reduce and minimize the effects of nutrients (Stockton), salt and boron (Grasslands area-Reach 5), Mercury (Reach 5), selenium (Reaches 4 and 5) and pesticides (Reaches 3–5).

Although water quality conditions on the San Joaquin River relating to conservative ions, (e.g., salt and boron), and some nutrients are likely to improve under increased flow conditions, it is unclear how these and other potential restoration actions will impact many of the current TMDL programs and existing contaminant load estimates. This is most true of constituents with complex oxidation-reduction chemistry, and sediment/water/biota compartmentalization (e.g., pesticides, trace metals). A number of investigations could be planned to address uncertainties in DO, Hg contamination, salt accumulation in floodplain deposits, and improved temperature monitoring along the San Joaquin River. Perhaps the greatest risks to potential restoration actions within the San Joaquin River study reaches relate to uncertainties regarding remobilization of past deposits of organochlorine pesticides, i.e., DDT and mercury. The effects and implications of the water quality parameters on aquatic resources should be re-visited after a suite of recommended restoration actions is developed.

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CHAPTER 7. FISH RESOURCES

7.1. INTRODUCTION

Fish communities in the San Joaquin River basin have changed markedly in the last 150 years. Before Euro-American settlement, the river supported a distinctive native fish fauna that had evolved in relative isolation over a period of several million years. These native fish assemblages were adapted to widely fluctuating riverine conditions, ranging from large winter and spring floods to warm low summer flows. These environmental conditions resulted in a broad diversity of fish species that included both cold-water anadromous salmonids as well as cold and warm-water resident fish species.

As the land and water resources of the San Joaquin Valley were developed, riverine habitat conditions for native fish species deteriorated. The loss of habitat, combined with the introduction of non-native fish species, precipitated a decline in both abundance and distribution of native species and unique assemblages of these species. Current habitat conditions bear little resemblance to those under which native fish communities evolved, reflecting the effects of two general periods of significant human disturbance:

- early agricultural conversion of floodplains and valley-bottoms, and smaller-scale streamflow regulation (e.g., Mendota Dam, Sack Dam).
- more recent and significant flow regulation and diversion associated with the Central Valley Project (e.g., Friant Dam and the Delta-Mendota Canal) and large-scale aggregate mining in Reach 1.

Fish assemblages currently found in the San Joaquin River are the result of substantial changes to their physical environment, combined with more than a century of non-native fish and exotic invertebrate introductions. Areas where unique and highly endemic fish assemblages once occurred are now inhabited by assemblages composed primarily of introduced species. The primary environmental conditions that currently influence native fish species abundance and distribution (and frequently favor non-native species) include:

- dewatered stream reaches,
- highly altered flow regimes and substantial reductions in flow,
- substantial reductions in the frequency, magnitude, and duration of floodplain inundation,
- isolation of floodplains from the river channel by channelization and levee construction,
- changes to sediment supply and transport,
- habitat fragmentation by physical barriers,
- creation of false migration pathways by flow diversions,
- poor water quality.

Despite these conditions, many native fish species still persist in the basin, underscoring the potential for enhancing native aquatic communities in the San Joaquin River.

7.2. OBJECTIVES

Fish populations in the San Joaquin River and its tributaries are a central focus of restoration efforts. The objective of this chapter is to provide background information useful for developing appropriate restoration strategies for the San Joaquin River downstream of Friant Dam. Because of the large amount of information available, we have focused on the most up-to-date and pertinent information on fish and fish habitats in the San Joaquin River, with a particular focus on anadromous salmonid species. Native fish populations and their habitats are dependent on many of the fluvial geomorphic processes that govern river ecosystems, as well as interactions with the riparian and terrestrial communities. This chapter attempts to describe the linkages with other chapters, particularly hydrology (Chapter 2), geomorphology (Chapter 3), and vegetation communities (Chapter 8). This chapter includes the following:

- A description of historical and current fish assemblages occurring in the San Joaquin River, including their general habitat requirements, changes in distribution and abundance, and the primary reasons for changes in fish assemblages that have occurred;
- Summaries of the life histories and habitat requirements of native anadromous salmonids and selected native non-salmonid fish species;
- A description of current and existing conditions, and major changes that have occurred to components of fish habitat, including instream flows, fluvial processes and channel morphology, water quality, etc;
- A description of the non-native fish species currently present in the system, along with summaries of selected non-native fish species believed to strongly interact with native species; and,
- An evaluation of how native fish populations have responded to anthropogenic changes in riverine habitats.

7.3. STUDY AREA

The study area focuses on the San Joaquin River from Friant Dam downstream to the Merced River; however, historical and current fish assemblage distributions transcended these boundaries, and included not only the broader San Joaquin and Tulare basins, but also the Sacramento River basin and the Bay-Delta ecosystem as well. This factor complicates the task of describing fish species distributions, but allows use of a much larger amount of information about individual species' life histories and habitat requirements.

7.4. CENTRAL VALLEY FISH ASSEMBLAGES

7.4.1. Historical Distribution and Species Composition

Moyle (2002) has recently updated an earlier work (Moyle 1976) that describes the fish fauna of California and their ecology. The following summary draws heavily from Moyle's extensive research on Central Valley ichthyofauna.

The Central Valley forms a subprovince of the Sacramento-San Joaquin ichthyological province (Moyle 2002). The endemic fish fauna of the Central Valley appear to have evolved from a relatively limited number of ancestral species of complex origins. It appears that only a small number of species were able to invade the system from the interior before the rise of the present Sierra Nevada range, or perhaps only a small number of forms were able to survive the harsh climatic conditions during or after the Pleistocene (Moyle 1976). Fossil evidence indicates that the Sacramento-San Joaquin fish fauna was considerably more diverse in the early Pleistocene when conditions were wetter (Casteel 1978, cited in Moyle et al. 1982). The Central Valley subprovince has been an important center of fish speciation in California because of its large size, diverse habitats, and long isolation from other systems (10–17 million years [Minckley et al. 1986, as cited in Moyle 2002]). Many species within the Sacramento-San Joaquin province are endemic to the Central Valley, as shown in Table 7-1. Appendix B consists of summaries of the life histories and habitat requirements of most native and non-native fish species known to occur in the San Joaquin River.

Moyle (1976, 2002) has described the following four fish assemblages for the Central Valley:

- Rainbow trout assemblage,
- California roach assemblage,
- Pikeminnow-hardhead-sucker assemblage, and
- Deep-bodied fish assemblage.

These assemblages are naturally separated to some degree by elevation. The first three assemblages generally inhabit reaches flowing through high and mid-elevation mountains and foothills. The fourth assemblage previously occupied San Joaquin and Sacramento valley floor reaches, lakes, and floodplain habitats, but native fish species in this assemblage are now extinct (e.g., thicktail chub), extirpated (e.g., Sacramento perch), or are substantially reduced in abundance and distribution because of the drastic changes that have occurred in these ecosystems (Moyle 2002). The habitats once occupied by this assemblage are now inhabited primarily by non-native fish species. Table 7-1 lists the fish native to the San Joaquin River and the assemblages to which they belong. These assemblages are described in more detail below.

7.4.1.1. Rainbow Trout Assemblage

The higher gradient, upper reaches of the San Joaquin River (upstream of Reach 1) flow out of the Sierra Nevada Range and historically supported fish adapted to swift water velocities, high gradient habitats such as riffles, cold temperatures (<70°F), and high dissolved oxygen concentrations (Moyle 2002). The rainbow trout assemblage found in these reaches included rainbow trout, Sacramento sucker, speckled dace, riffle sculpin, and California roach. These species are adapted to living in coarse substrates with dense riparian vegetation that provides cover and shade, and habitats formed by instream large woody debris. Most of these species feed on aquatic and terrestrial invertebrates, although larger trout will prey opportunistically on other fish.

7.4.1.2. California Roach Assemblage

The California roach assemblage is adapted to the low dissolved oxygen concentrations and high temperatures (<86°F) that seasonally occur in intermittent lower-foothill (89 feet to 1,470 feet elevation) tributaries to the San Joaquin River (corresponding to tributary reaches in Reach 1). The California roach is the dominant species in this assemblage, although Sacramento suckers and some cyprinids occasionally spawn in intermittent streams during the winter and spring. It is also likely that Chinook salmon and steelhead occasionally spawned in the lower reaches of some intermittent streams (Maslin et al. 1997).

7.4.1.3. Pikeminnow-Hardhead-Sucker Assemblage

The pikeminnow-hardhead-sucker assemblage historically occupied the mainstem reaches of the San Joaquin River flowing through the lower foothills (corresponding to mainstem Reach 1). Habitats within these reaches range from deep, rocky pools to wide shallow riffles. Species within this assemblage were adapted to low flows and warm water temperatures in summer, infrequent large floods and cold water temperatures in winter, and high flows of long-duration during the spring snowmelt period. The primary species in this assemblage were Sacramento pikeminnow, Sacramento

Table 7-1. Fish species found in the San Joaquin River.

Common Name (Scientific Name)	Endemic (E)[1], Resident (R) or Migratory (M)	Status [2]	Current distribution [Reach No] (Historical distribution)[4]	Assemblage[3]	Source
NATIVE SPECIES					
Acipenseridae					
White sturgeon (*Acipenser transmontanus*)	M	Rare	[?] (1–5)	PHS, RT	Brown & Moyle 1993, Schaffter 1997, as cited in Moyle 2002.
Green sturgeon (*Acipenser medirostris*)	M	Rare	[?] (?)	PHS, RT	Moyle 2002
Catostomidae					
Sacramento sucker *(Catostomus occidentalis*)	R	Widespread w/ large numbers	[1,5] (1–5)	PHS, RT, CR	Saiki 1984, Brown & Moyle 1993, CDFG 2001, Moyle 2002
Centrarchidae					
Sacramento perch (*Archoplites interruptus*)	E, R	Extirpated	(1–5)	DB	Moyle et al. 1989
Cottidae					
Prickly sculpin (*Cottus asper*)	R	Widespread in moderate numbers	[1,3,5] (1-5)	PHS	Saiki 1984, Brown & Moyle 1993, Moyle 2002
Riffle sculpin (*Cottus gulosus*)	R	Uncommon	[1] (1-?)	PHS, RT	Brown & Moyle 1993
Cyprindae					
California roach *(Lavinia symmetricus.)*	E, R	Widespread w/ moderate numbers	[??] (1–5)	CR, RT, PHS	Moyle et al. 1989, Brown & Moyle 1993
Hardhead (*Mylopharodon conocephalus*)	E, R	Depleted and declining	[1] (1–5)	PHS	Brown & Moyle 1993, Saiki 1984, Moyle et al 1989, Mayden et al. 1991 as cited in Moyle 2002
Hitch (*Lavinia exilicauda exilicauda*)	E, R	Uncommon	[2,3,5] (1–5)	DB	Saiki 1984, Moyle 2002
Sacramento blackfish (*Orthodon microlepidotus*)	E, R	Widespread in moderate numbers	[3,5] (1–5)	DB	Brown & Moyle 1993, Saiki 1984

Table 7-1. cont.

Common Name (Scientific Name)	Endemic (E)[1], Resident (R) or Migratory (M)	Status [2]	Current distribution [Reach No] (Historical distribution)[4]	Assemblage[3]	Source
Sacramento pikeminnow (*Ptychocheilus grandis*)	E, R	Common	[1] (1–5)	PHS, CR	Saiki 1984, Brown & Moyle 1993
Speckled dace (*Rhinichthys osculus*)	R	Likely extirpated	[?] (1–5)	PHS, RT	Moyle 2002
Sacramento splittail (*Pogonichthys macrolepidotus*)	E,M	FT	[5] (1–5)	DB	Baxter 1998, Saiki 1984; Rutter 1908 as cited in Moyle 2002
Thicktail chub (*Gila crassicauda*)	E, R	Extinct	(1–5)	DB	Brown & Moyle 1993
Embiotocidae					
Tule perch (*Hysterocarpus traski traski*)	E, R	Declining	[1,3,5] (1–5)	PHS, DB	Brown & Moyle 1993, Saiki 1984, Moyle 2002
Gasterosteidae					
Threespine stickleback (*Gasterosteus aculeatus*)	R	Uncommon	[1] (1–5)	RT, PHS	Saiki 1984, Moyle 2002
Petromyzontidae					
Kern brook lamprey (*Lampetra hubbsi*)	R	Declining	[1?] (1–5)	RT, PHS	Brown and Moyle 1993
Pacific lamprey (*Lampetra tridentata*)	M	Widespread w/ moderate numbers	[?] (1–5)	PHS	Brown & Moyle 1993, Moyle 2002
River lamprey (*Lampetra ayresi*)	M	Possibly declining	[?] (?)	PHS	Moyle 2002
Western brook lamprey (*Lampetra richardsoni*)	R	Unknown	[?] (?)	PHS	Moyle 2002
Salmonidae					
Chinook salmon *(Oncorhynchus tshawytscha)*	M		[1] (1–5)	RT	California Department of Fish and Game 1991, Yoshyama et al. 1998, Moyle 2002
Fall run		Candidate FT			
Late fall run		CSC			
Spring		ST, FT			
Winter		SE, FE			
Rainbow trout *(Oncorhynchus mykiss)*	R	Common	[1] (1)	RT	Friant Water Users Authority 1992, Brown & Moyle 1993
Steelhead (*Oncorhynchus mykiss)*	M	Likely extirpated	(1–5)	RT, PHS	Brown & Moyle 1993, McEwan 2002

Table 7-1. cont.

Common Name (Scientific Name)	Endemic (E)[1], Resident (R) or Migratory (M)	Status [2]	Current distribution [Reach No] (Historical distribution)[4]	Assemblage[3]	Source
NON – NATIVE SPECIES					
Atherinidae					
Inland silverside (*Menidia beryllina*)	R		[3,4,5]	DB	Saiki 1984
Centrarchidae					
Black crappie (*Pomoxis nigromaculatus*)	R		[1,2,3,5]	DB	Saiki 1984
Bluegill sunfish (*Lepomis macrochirus*)	R		[1,2,3,5]	DB	Saiki 1984
Green sunfish (*Lepomis cyanellus*)	R		[1,2,3,5]	DB, CR	Saiki 1984
Largemouth bass (*Micropterus salmoides*)	R		[1,2,3,5]	DB	Saiki 1984
Pumpkinseed (*Lepomis gibbosus*)	R		[5]	DB	CDFG 2001, Moyle 2002
Redear sunfish (*Lepomis microlophus*)	R		[1,2,3,5]	DB	Saiki 1984
Smallmouth bass (*Micropterus dolomieu*)	R		[?]	DB, PHS	Saiki 1984, Moyle 2002
Spotted bass (*Micropterus punctulatus*)	R		[1–5?]	DB, PHS	Moyle 2002
Warmouth (*Lepomis gulosus*)	R		[1,2,3,5]	DB	Saiki 1984
White crappie (*Pomoxis annularis*)	R		[2,3,5]	DB	Saiki 1984
Clupeidae					
American shad (*Alosa sapidissima*)	M		[?]	DB	Moyle 2002
Threadfin shad (*Dorosoma petenense*)	R		[2,3,5]	DB	Saiki 1984
Cyprinidae					
Common carp (*Cyprinus carpio*)	R		[1,2,3,5]	DB, PHS	Saiki 1984
Fathead minnow (*Pimephales promelas*)	R		[2,3,5]	DB	Saiki 1984
Goldfish (*Carassius auratus*)	R		[1,2,3,5]	DB	Saiki 1984
Golden shiner (*Notemigonus crysoleucas*)	R		[1,2,3,5]	DB	Saiki 1984
Red shiner (*Cyprinella lutrensis*)	R		[3]	DB	Saiki 1984
Ictaluridae					

Table 7-1. cont.

Common Name (Scientific Name)	**Endemic (E)[1], Resident (R) or Migratory (M)**	**Status [2]**	**Current distribution [Reach No] (Historical distribution)[4]**	**Assemblage[3]**	**Source**
Black bullhead (*Ameiurus melas*)	R		[1,2,3,5]	DB	Saiki 1984
Brown bullhead (*Ameiurus nebulosus*)	R		[1,2,3,5]	DB	Saiki 1984
Channel catfish (*Ictalurus punctatus*)			[2,3,5]	DB	Saiki 1984
White catfish (*Ameiurus catus*)	R		[2,3,5]	DB	Saiki 1984
Percichthyidae					
Striped bass (*Morone saxatilis*)	M		[2,3,5]	DB	Saiki 1984
Percidae					
Bigscale logperch (*Percina macrolepida*)	R		[1,2,3,5]	DB	Saiki 1984
Poeciliidae					
Mosquitofish (*Gambusia affinis*)	R		[1,2,3,5]	DB	Saiki 1984

[1] E = Endemic to the Sacramento-San Joaquin Providence

[2] SE = Endangered under California State Law
ST = Threatened under California State Law
CSC = California Species of Special Concern
FE = Endangered under Federal Law
FT = Threatened under Federal Law

[3] based on Moyle 2002
RT = Rainbow Trout
CR = California Roach
PHS = Pikeminnow, Hardhead, Sucker
DB = Deep bodied fish

[4] Historical distribution is considered to be the late 1800's prior to introductions of non-native species
? indicates unknown

sucker, and hardhead. Tule perch, speckled dace, California roach, riffle sculpin, and rainbow trout were also occasionally found in this assemblage. Anadromous Chinook salmon, steelhead, and Pacific lamprey spawned in this zone, and rearing juvenile spring-run Chinook salmon, steelhead, and lamprey were part of the assemblage.

7.4.1.4. Deep-Bodied Fish Assemblage

The deep-bodied fish assemblage generally occupied the lower gradient, valley bottom reaches of the San Joaquin River where flows were generally slower and water temperatures were higher than upstream habitats. Some of the native species in this group, such as Sacramento perch, thicktail chub, and tule perch, were adapted to warm, shallow, low-velocity backwaters with thick aquatic vegetation, while others, such as hitch, blackfish, and splittail, were adapted to large, open, sluggish mainstem river channels. Large pikeminnows and suckers were also abundant in this zone, migrating into tributaries to spawn (Moyle 2002). Adult Chinook salmon and steelhead migrated through this zone to spawn further upstream, and their juveniles passed through this zone while migrating downstream to the ocean. Extended rearing by salmonids on large floodplains likely occurred when flows in late winter or spring were high enough to inundate the floodplain for several weeks. Species in this assemblage were particularly well-adapted to the once-abundant floodplain habitat found in the valley floor. Floodplains provided refuge from high flows, productive foraging habitat, and protection from larger predaceous fish that inhabited adjacent deep-water habitats (Moyle 2002, Sommer et al. 2001). Splittail, Sacramento blackfish, and possibly thicktail chub spawned in the inundated floodplains (Moyle 2002). Moyle suggests that the huge, shallow lakes in the San Joaquin Valley (e.g., Tulare, Buena Vista, Kern Lakes) that historically drained the Kern, Tulare, Kaweah, and Kings rivers were perhaps the most productive year-round habitat for this assemblage (Moyle 2002). These lakes supported large populations of Sacramento perch, thicktail chub, Sacramento blackfish, Sacramento pikeminnow, and Sacramento suckers. Indigenous tribes and early Euro-American settlers were sustained year-round by harvesting these abundant fish (Moyle 2002).

7.4.1.5. Historical Distribution and Abundance of Anadromous Salmonids

Salmon were an important part of the cultures of many indigenous tribes living in the Central Valley; tribes in this region attained some of the highest pre-European-settlement population densities in North America (Yoshiyama 1999). In the mid-1800s, particularly during the California Gold Rush, salmon gained the attention of early European settlers, and commercial harvest of salmon in the Sacramento and San Joaquin rivers soon became one of California’s major industries (Yoshiyama 1999). Excerpts from Yoshiyama et al. (1996) is provided in Appendix C, which details accounts of the historical distribution of Chinook salmon in the San Joaquin River watershed.

In the San Joaquin River, spring-run Chinook salmon historically spawned as far upstream as the present site of Mammoth Pool Reservoir (RM 322), where their upstream migration was historically blocked by a natural velocity barrier (P. Bartholomew, pers. comm., as cited in Yoshiyama et al. 1996). Fall-run Chinook salmon generally spawned lower in the watershed than spring-run Chinook salmon (CDFG 1957). The San Joaquin River historically supported large runs of spring-run Chinook salmon; CDFG (1990, as cited in Yoshiyama et al. 1996) suggested that this run was one of the largest Chinook salmon runs on any river on the Pacific Coast, with an annual escapement averaging 200,000 to 500,000 adult spawners (CDFG 1990, as cited Yoshiyama et al. 1996). Construction of Friant Dam began in 1939 and was completed in 1942, which blocked access to upstream habitat. Nevertheless, runs of 30,000 to 56,000 spring-run Chinook salmon were reported in the years after Friant Dam was constructed, with salmon holding in the pools and spawning in riffles downstream of the dam. Friant Dam began filling in 1944, and in the late 1940s began to divert increasing amounts of water into canals to support agriculture. Flows into the mainstem San Joaquin River were reduced to a point that river ran dry in the vicinity of Gravelly Ford. By 1950, the entire run of spring-run Chinook salmon was extirpated from the San Joaquin River (Fry 1961).

Although the San Joaquin River also supported a fall-run Chinook salmon run, they historically composed a smaller portion of the river's salmon runs (Moyle 2002). By the 1920s, reduced autumn flows in the mainstem San Joaquin River nearly eliminated the fall-run, although a small run did persist.

Steelhead are believed to have been historically abundant in the San Joaquin River, although little detailed information on their distribution and abundance is available (McEwan 2001). In large river systems where steelhead still occur, they are almost always distributed higher in a watershed than Chinook salmon (Voight and Gale 1998, as cited in McEwan 2001, Yoshiyama et al. 1996). Therefore, steelhead would likely have spawned at least as far upstream as the natural barrier located at the present-day site of Mammoth Pool (RM 322), and in the upper reaches of San Joaquin River tributaries.

7.4.2. Current Distribution and Species Composition

Anthropogenic activities have substantially changed aquatic habitats in the San Joaquin River (Table 7-2), and these habitat changes have altered the distribution and species composition of the native fish assemblages compared to historical conditions. Several factors have contributed to these changes, including flow regulation, levees, and colonization by non-native fish species. Of the 19 native fish species historically present in the San Joaquin River, 14 are now uncommon, rare, or extinct (Table 7-1), and an entire fish assemblage—the deep-bodied fish assemblage—has been largely replaced by warmwater fish assemblages composed of non-native fish species (Moyle 2002). Warmwater fish assemblages, composed of many non-native species such as black bass (*Micropterus* spp.) and sunfish (*Lepomis* spp.), appear better adapted to current, disturbed habitat conditions than native assemblages. However, habitat conditions in Reach 1 (slightly higher gradient, cooler water temperatures, and higher water velocities), seems to have restricted many introduced species from colonizing the upstream reach.

7.4.2.1. Rainbow Trout Assemblage

Distribution of the rainbow trout assemblage has increased in the Central Valley as a result of extensive introduction of hatchery trout in small mountain streams and lakes throughout the area. CDFG supplements rainbow trout populations in the San Joaquin River through its hatchery located near Lost Lake Park (RM 266). Interbreeding between native and hatchery rainbow trout stocks has likely reduced the genetic integrity of some native rainbow trout populations. Species composition within the assemblage has also changed as a result of brook and brown trout introductions. Interspecific competition with non-native brook and brown trout may have also reduced the abundance and distribution of native rainbow trout, sculpin, and dace (Moyle 2002). The cold, high-water-velocity conditions found in the reaches immediately below Friant Dam provides suitable habitat for the rainbow trout assemblage.

7.4.2.2. California Roach Assemblage

The California roach assemblage continues to be found in small, intermittent streams in the San Joaquin River, though its distribution is not well known. Green sunfish and mosquitofish appear to have largely replaced California roach in many tributaries (Moyle 2002), particularly in the upper San Joaquin River (corresponding to Reaches 1 and 2) where streams have been diverted and water temperatures have been altered.

Table 7-2. Major human activities affecting the San Joaquin River above the confluence with the Merced River prior to 1941

Year	Human Activity
1849	Gold Rush began
1860s	Agricultural colonies established
1870	Railroad constructed to Modesto
1870–1900	Nonnative fish introduced to California waters: smallmouth and largemouth bass, white catfish, brown bullhead, black bullhead channel catfish, carp, bluegill, green sunfish, white crappie, black crappie, striped bass, American shad
1871	Mendota Dam constructed
1872	Miller-Lux Canal constructed
1872	Railroad to Bakersfield
1880s	Artesian wells used for agriculture in San Joaquin Valley
1890s	Electric and natural gas pumps installed in the San Joaquin Valley
1892	Railroad constructed to Fresno
?	Sack Dam
After 1900	Nonnative fish introduced to California waters: readear sunfish, pumpkinseed, spotted bass, inland silversides, mosquitofish, golden shiner, spotted bass.
1910	5,000 electric or gas pumps on wells
1910	Bass Lake Reservoir
1915–1930	Local levee and flood control projects began
1916	Mendota Dam upgraded
1916–1920	Construction of James Bypass (Fresno Slough)
1917	Hunnington Lake Reservoir
1920	Kerckhoff Reservoir
1920-1930	Drains installed in more than 5,000 farms
1926	Florence Lake Reservoir
1930	23,500 electric or gas pumps on wells in the San Joaquin Valley
1941	Friant Dam and Millerton Lake Reservoir
1948	Friant-Kern Canal completed
1949	Temporary fish barrier erected above confluence with Merced River
1951	Delta-Mendota Canal completed
1989	Fish barrier re-erected above confluence with Merced River

7.4.2.3. Pikeminnow-Hardhead-Sucker Assemblage

The pikeminnow-hardhead-sucker assemblage is still present in the mainstem San Joaquin River downstream of Friant Dam; however, Chinook salmon and steelhead no longer spawn and rear in these reaches because flows downstream of Friant Dam are currently inadequate to support these species. Anthropogenic changes such as flow regulation, in-channel aggregate mining, channelization, agricultural land conversion, and levee construction have increased water temperatures and reduced water quality and habitat complexity, altering the distribution and species composition of the assemblage (Brown and Moyle 1992). The distribution of this assemblage has shifted upstream as a result of reduced instream flows and increased water temperatures, and tends to fluctuate based on flow and water temperature. Brown (2000) suggested that the downstream distribution of the pikeminnow-hardhead-sucker assemblage will continue to fluctuate with flow regime, extending further downstream during periods of high flows when the influence of cold water extends further downstream.

The native fishes of this assemblage are adapted to seasonal high flows and an extended period of cool water temperatures (Moyle 2002). Non-native fish species generally become abundant in the lower foothills (e.g., Reach 1) only where flow regimes have been stabilized and these seasonal fluctuations are largely reduced, such as downstream of Friant Dam. In general, smallmouth bass and green sunfish may be particularly abundant in zones occupied by the pikeminnow-hardhead-sucker assemblage; however, they rarely establish populations of any size where gradients are moderate to high and semi-undisturbed habitats remain (Moyle et al. 1982). The large pools, created by commercial aggregate mining in Reach 1, may provide the low-velocity, warmwater habitat that support the establishment of sizeable populations of non-native fish species in an area that would normally support the native fish of the pikemnnow-hardhead-sucker assemblage.

7.4.2.4. Deep-Bodied Fish Assemblage

The deep-bodied fish assemblage that once occupied aquatic habitats in the San Joaquin valley has been largely eliminated by (1) isolation of the channel from its floodplain by levee construction, (2) flow reductions and stabilization of flow regimes, (3) changes in channel morphology, including extensive channelization, and (4) poor water quality (Moyle 2002). The vast floodplains, huge shallow lakes, and wetlands that once covered the San Joaquin valley floor are greatly diminished, with most water now flowing through substantially modified channels and canals. The native fishes of this assemblage are extinct (thicktail chub), have been extirpated (e.g., Sacramento perch), or reduced to a few small populations. The current fish assemblage occupying valley-floor habitats is dominated by non-native species, including largemouth bass, white and black crappie, bluegill, redear sunfish, warmouth, threadfin shad, striped bass, bigscale logperch, red shiner, inland silverside, channel and white catfish, black and brown bullhead, common carp, and goldfish. These non-native fish often feed on non-native invertebrates such as *Corbicula* clams and crayfish, and use non-native aquatic vegetation as cover (Moyle 2002). As environmental conditions in the lower San Joaquin River continue to change, the species composition of this low-elevation fish assemblage will likely continue to change as well (Moyle 2002).

7.4.2.5. Changes in the Abundance and Distribution of Anadromous Salmonids

The historical abundance and distribution of anadromous salmonids is discussed in 7.4.1.5, and historical abundance of Chinook salmon is summarized in Appendix C. Anadromous salmonids have been extirpated from the mainstem San Joaquin River due principally to dewatering of stream channels. Construction of Mendota Dam in 1898, and a seasonal dam near Dos Palos (Sack Dam) in the early 1900s, created almost complete barriers to the upstream migration of fall-run Chinook salmon in the San Joaquin River (Warner 1991). By the early 1920s, flows in the mainstem San Joaquin River were reduced significantly by diversions at Mendota Dam (RM 205) and Sack Dam (RM 182). In general, fall-run Chinook salmon were greatly reduced in the mainstem San Joaquin River by the late 1920s due to commercial harvest and reduced fall flows from water diversions (Clark 1929, as cited in Yoshiyama et al. 1996). Runs of fall-run Chinook salmon are still present in the major tributaries to the lower San Joaquin River (Merced, Tuolumne, and Stanislaus rivers), supported in part by hatchery stock in the Merced River. The total average annual escapement (1950-2000) was an estimated 18,000 adult spawners. Since 1950, the fall-run in the San Joaquin basin has fluctuated widely, (see Figure 7-1), with a distinct periodicity that generally corresponds to periods of drought and wet conditions. During the last decade (1990-2000), escapements have ranged from 590 (1991) to 37,500 (2000). This periodicity was to some degree natural under unimpaired conditions, but has been exacerbated by the severity of streamflow regulation in the San Joaquin River and its tributaries during prolonged droughts (EA Engineering 1991). For example, following the drought of 1987-92, the total combined Chinook salmon run in the San Joaquin basin tributaries fell to 660, 590, and 1,370 in 1990–92, respectively. These population crashes aremay represent a major impediment to future restoration. Efforts are underway (e.g., VAMP) to coordinate water management among the downstream tributaries to the San Joaquin River to avoid the population crashes and encourage a more stable and robust population.

Spring-run Chinook salmon migrated upstream during higher flows fed by spring snowmelt runoff, so that Mendota and Sack Dams posed less of a barrier to migration. Consequently spring-run Chinook salmon remained relatively abundant in the mainstem San Joaquin River into the 1940s, when the construction and operation of Friant Dam began to take a toll on the spring run population by blocking access to upstream habitats and reducing flows downstream of the dam. These two effects were likely the largest factors contributing to the decline of Chinook salmon in the upper San Joaquin River (Brown and Moyle 1992). After closure of Friant Dam in November 1941, spring-run Chinook salmon and a few fall-run Chinook salmon continued to spawn below the Dam, including a run of 56,000 spring-run Chinook salmon observed in 1948 (Fry 1961). However, irrigation diversions increased in 1948 following completion of the Delta-Mendota Canal, and the juvenile salmonids resulting from the run in 1948 were stranded in the reach between Sack Dam and the mouth of the Merced River during their outmigration, as flow continuity was disrupted. By 1950, diversions at Friant Dam consistently eliminated surface water flow over a span of about 60 miles of river downstream of Sack Dam. The last real run of spring-run Chinook salmon in the upper San Joaquin River, consisting of only 36 individuals, was observed in 1950 (Warner 1991). Since the 1950's, the remaining Chinook salmon in the San Joaquin Basin consists only of fall-run Chinook salmon populations in the three tributaries to the lower San Joaquin River. Escapement data for these fall-run salmon populations is provided in Figure 7-1.

The Department of Fish and Game currently operates an artificial fish barrier on the San Joaquin River to direct fish into the Merced River, so as to prevent adult stranding in the upper San Joaquin River. Despite the barrier, fall-run Chinook salmon occasionally stray up the San Joaquin River, especially during wet years. Although data is limited, California Fish and Game (1991, as cited in Brown 1996) reported that 2,300 fall-run Chinook salmon of Merced River origin strayed up the San Joaquin River during 1988, 322 in 1989, and 280 in 1990. Each of these years was relatively dry; it is likely that more adult fall-run Chinook salmon would attempt to stray upstream during wet years. More detailed information on Chinook salmon distribution changes and population trends is provided in the species accounts contained in Appendix B.

Steelhead abundance and distribution in the San Joaquin River basin have been substantially reduced, and the native run is considered extinct by some researchers (Reynolds et al. 1990, as cited in

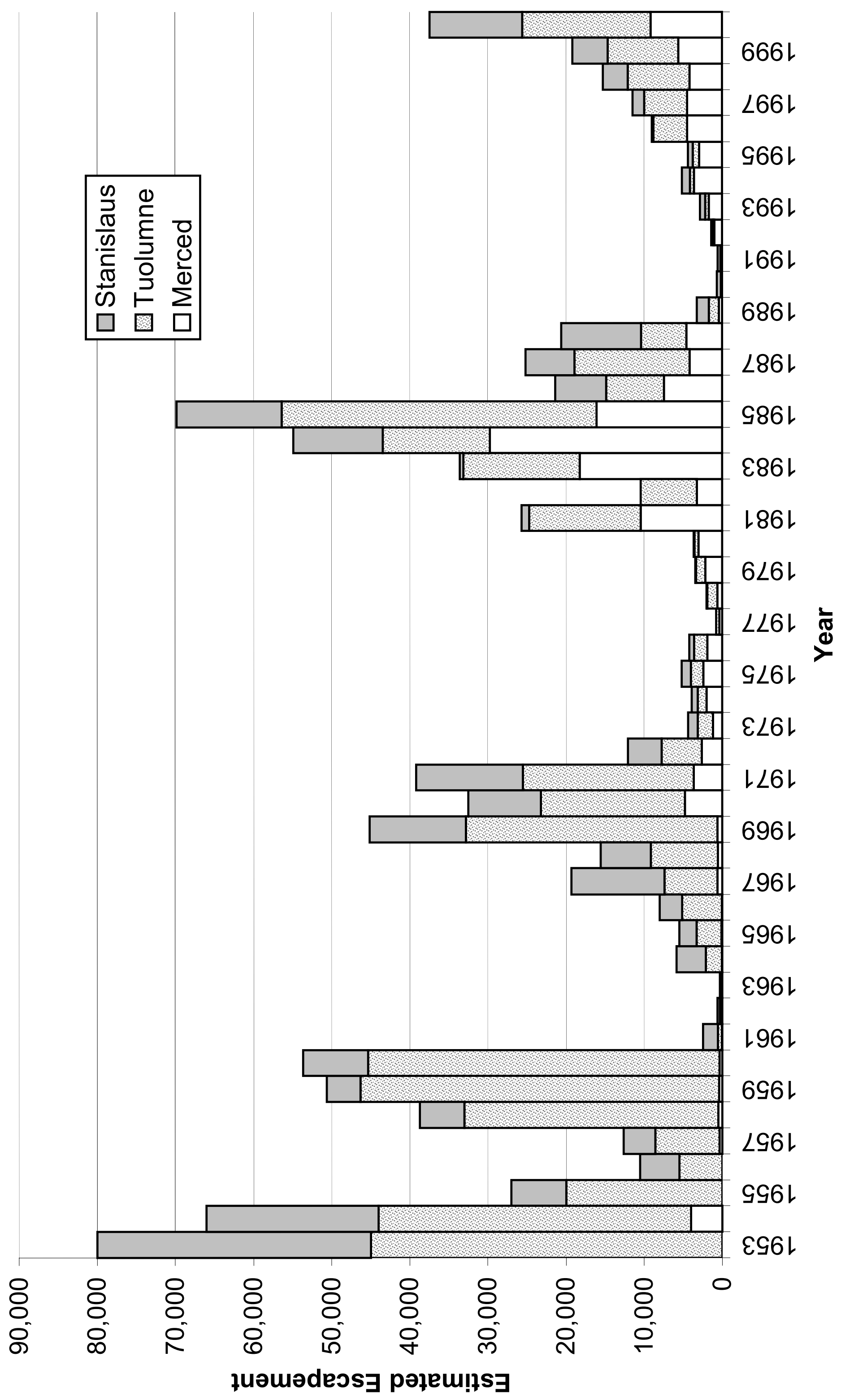


Figure 7-1. Fall-run Chinook salmon escapement into San Joaquin basin tributaries 1953 to 2000.

McEwan 2001). There is evidence of steelhead smolts in some lower San Joaquin River tributaries such as the Stanislaus River (McEwan 2001). Based on their review of factors contributing to steelhead declines in the Central Valley, McEwan and Jackson (1996) concluded that population declines were related to water development and flow management that resulted in habitat loss. Dams have blocked access to historical spawning and rearing habitat in upstream reaches, forcing steelhead to spawn and rear in lower river reaches where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001). More detailed information on steelhead distribution changes and population trends is provided in the species accounts contained in Appendix B.

7.5. SALMONID LIFE HISTORIES AND HABITAT REQUIREMENTS

7.5.1. Overview

Chinook salmon and steelhead are anadromous species that utilize freshwater rivers and tributaries for adult spawning, egg incubation, and early juvenile rearing. Juveniles migrate downstream after variable periods of rearing. Salmon and steelhead spend from 1 to 6 years in the ocean foraging in coastal and offshore habitats in the Pacific Ocean. Chinook salmon are semelparous (spawn once and die), and steelhead are iteroparous (capable of multiple spawning).

Chinook salmon and steelhead have genetically distinct runs differentiated by the timing of spawning migration, stage of sexual maturity when entering fresh water, timing of juvenile or smolt outmigration, and other characteristics (Moyle et al. 1989). Spring-run Chinook salmon adults migrate upstream in the spring during spring snowmelt floods, when the more sustained higher flows enable them to access upper reaches of a basin (Figure 7-2). During the summer, they reduce metabolic demands and become sexually mature while holding in deep pools, and then they spawn in the early fall. According to Healy (1991) juvenile spring-run Chinook salmon generally spend one or more years rearing in freshwater before migrating to the sea. Studies in the Sacramento River system have observed downstream movement of fry and subyearling smolts in addition to age 1+ smolts (Hill and Weber 1999). For the ocean phase of their life, spring-run Chinook salmon perform extensive offshore migrations, eventually returning to their natal river to spawn as two, three, four, and occasionally five year olds, (spring-run Chinook salmon are also referred to as “stream-type” Chinook salmon).

Fall (or “ocean-type”) Chinook salmon adults in the San Joaquin migrate upstream during the fall to return to their natal river a few days or weeks before spawning, which typically peaks in mid-November (Figure 7-3). Juveniles outmigrate to sea during their first year of life, typically within three months after their emergence from redds. Adult fall-run Chinook salmon in California streams spend most of their ocean life in coastal waters, before returning to their natal streams to spawn as two, three, four and five year olds.

Steelhead exhibit highly variable life history patterns throughout their range, but they are broadly categorized into winter- and summer-runs based on timing of upstream migration. Currently, only winter steelhead stocks are present in Central Valley streams (McEwan and Jackson 1996). They enter spawning streams in fall or winter, and they spawn soon after in winter or spring (Meehan and Bjornn 1991, Behnke 1992) (Figure 7-4). Adults may return to the ocean after spawning and return to freshwater to spawn in subsequent years. Juveniles remain in freshwater for 1 to 3 years before outmigrating to the ocean from April through June (Hopelain 1998, as cited in Moyle 2002).

The following section provides a general summary of salmonid life histories, with specific information on San Joaquin River populations where possible. Detailed habitat requirements and timing of specific life history events for Chinook salmon and steelhead, with a focus on San Joaquin River data, are provided in Appendix B.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Adults enter the rivers			▨	▨	▨								Geographic area: California rivers Enter estuaries March through May (Marcotte 1984). Source of data not stated.
Upstream Migration				▨	■▨	▨							Geographic area: San Joaquin River In San Joaquin River fish passed the Merced between mid-April and mid-June, and usually peaked there in the first half of May, and peaked at Mendota pool in early June (Hallock and Van Woert 1959). Source of data not stated
Upstream Migration					▨	▨	▨						Geographic area: San Joaquin River Fish ascend river during May, June, and the first part of July (CFGC 1921). Source of data is personal observation.
Upstream Migration			▨	▨	▨								Geographic area: San Joaquin River March to May in the San Joaquin River (Hatton and Clark 1942). Based on data from the Mendota weir.
Upstream Migration					▨	▨							Geographic area: Sacramento River Ascend rivers in May and June (Rutter 1908). Which rivers, and source of data not stated. Upstream migration has been observed to be bi-modal in the Sacramento River (Fisher, pers. comm., as cited in Marcotte 1984) with a portion of the run migrating to or near spawning areas while the remaining fish hold downstream (where in the river was not stated) and move up in the summer.
Upstream Migration			▨	▨	▨■	▨							Geographic area: Sacramento River basin, Deer and Mill Creeks Migrate up Deer and Mill Creeks from March through June (Vogel 1987a and b, as cited in Moyle et al. 1995). Source of data not stated In 1941 adults were trapped at a weir in Deer Creek from April to July 6 (Parker and Hanson 1944). Migration peaks in late May in Mill Creek. Migration into rivers earlier in southern tributaries and later in northern tributaries (Colleen Harvey, CFG, pers. comm.. 2002). Data based on personal observations in Mill Creek.
Upstream Migration		▨	▨	▨									Geographic area: Sacramento River basin, Butte Creek Entered Butte Creek in February through April (Yoshiyma et al. 1996). Source of data not stated.
Upstream Migration					▨	▨							Geographic area: Sacramento River basin, Feather River Enter Feather River in May or June (Yoshiyma et al. 1996). Hatchery influenced population. Source of data not stated.

Figure 7-2. Spring-run Chinook salmon life history.

LIFE STAGE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NOTES
Upstream Migration			▒	▒	▓	▓	▒						Geographic area: Sacramento River basin March through July, peaking in May–June (Fisher 1994). Source of data not stated.
Upstream Migration			▒	▒	▒	▒	▒	▒	▒				Jones and Stokes, Foundation Runs Report Geographic area: not stated Migrate to natal streams March through September (USFWS 1995). Source of data not stated.
Adult Holding				▒	▒	▒	▒						Geographic area: San Joaquin River River Congregate in large pools near Friant from May through mid-July (CFGC 1921), and then spawn in gorge upstream. Source of data is personal observation. Fish observed holding on May 23, 1942 in the pool directly below the Friant Dam (Clark 1942). No visits were made prior to this date. Fish were continued to be observed in subsequent visits in August and September in pools downstream of the dam, and directly below the dam. It appeared that fish moved as much as 10 miles downstream from holding pools to spawn.
Adult Holding				▒	▒	▒	▒						Geographic area: Sacramento River basin, Mill Creek Holding as early as late April and early May in Mill Creek. However, no observations conducted before late April, so fish could be holding earlier. Most fish holding by July. (Colleen Harvey, CFG, pers.comm. 2002). Based on walking and dive surveys. General comment: Many spring chinook migrate from holding pools to spawning areas further upstream in the watershed, while the rest remain to spawn in the tails of the holding pools (Moyle et al. 1995). No source or location of data stated.
Adult Holding					▒	▒	▒						Jones and Stokes Foundations Runs Report Geographic area: San Joaquin River Congregate in pools after upstream migration during May to early July (Yoshiyama et al. 1998).

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spawning								░	▓	▓			Geographic area: San Joaquin River The San Joaquin River below Friant dam was surveyed for one day in late August, late September, early October, and early November of 1942. The first spawning was observed on September 21, and large numbers of fish were spawning on all the riffles observed between Friant Dam and Lanes Bridge on November 4 (Clark 1942). Clark also reports that in detailed surveys prior to dam construction 417,000 ft^2 of spawning gravel were observed between Lanes Bridge and the Kerchoff Powerhouse. He reports that 36% of this area was eliminated by construction of the Friant Dam.
Spawning									░	░			Geographic area: San Joaquin River Spawning took place in September and early October near Friant (Hallock and Van Woert 1959). Source of data not stated.
Spawning								░	░	░			Geographic area: Sacramento River basin Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning								░	▓	░			Geographic area: Sacramento River basin Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning								░	▓	▓			Geographic area: Sacramento River basin, Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).
Spawning								░	░	░			Jones and Stokes Foundation Runs Report Geographic area: not stated Spawning August through October, depending on water temperatures (USFWS 1995). Source of data not stated.
Incubation													Embryos hatch after 5-6 month incubation. Alevins remain in gravel an additional 2-3 weeks (Moyle et al. 1995). No source or location of data stated.

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Emergence	░	░	░								░	░	Geographic area: Sacramento River basin Emergence November to March in the Sacramento River basin (Fisher 1994). Source of data not stated. Emergence in Butte Creek from November to March (Ward and Reynolds 2001). Based on outmigrant trapping of recently emerged fry.
Rearing	░	░	░	░	░	░	░	░	░	░	░	░	Geographic area: Sacramento River basin Rear 3 to 15 months in the Sacramento River basin (Fisher 1994). Source of data not stated. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. Some juveniles outmigrate after hatching, and others move downstream during the following fall as yearlings (C. Harvey, pers.comm., as cited in Moyle et al. 1995). Source of data not stated.
Fry Dispersal	░	▓	░	░	░	░							Geographic area: San Joaquin River Before construction of Friant Dam outmigration occurred during major seasonal runoff. Fish and Game fyke netting in 1939 and 1940 at Mossdale demonstrated a measurable seaward movement of fingerling salmon between January and mid-June, with a peak in February (Hallock and Van Woert 1959).
Fry Dispersal		░	░	▓	░	░							Geographic area: San Joaquin River After construction of Friant Dam outmigration it appeared that the elimination of flood flows altered migration patterns. In 1948 fyke trapping at Mendota there was a fairly steady downstream migration between February and June, but the peak was not reached until April. In 1949 peaks were recorded in early March and again in mid-May (Hallock and Van Woert 1959).

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fry Dispersal	▓	░	░								░	▓	Geographic area: Sacramento River basin Juveniles typically outmigrate during November through Jan. during the first high flows as subyearlings, though some stay as late as March (F.Fisher , pers. comm., as cited in USFWS 1994). Source of data not stated. Juveniles typically outmigrate as fry from Butte Creek between mid-November and mid-February, with a peak in December and January (Hill and Weber 1999, Ward and Reynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. In the Sacramento River most downstream movement takes place December to February as parr (Vogel and Marine 1991, as cited in USFWS 1994). Source of data not stated.
Spring Smolts (subyearling)			░	░	░	░							Geographic area: Sacramento River basin Some YOY remain in Butte Creek and outmigrate in late spring or early summer (Hill and Weber 1999, Ward and Reynolds 2001). Based on outmigrant trapping during 1999 and 2000. In the Sacramento River basin ocean entry during March to June (Fisher 1994). Source of data not stated
Fall Smolts (yearling)	░									░	░	░	Geographic area: Sacramento River basin Most yearlings outmigrate from Butte Creek in October to January (Hill and Weber 1999, Ward and Reynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Mill Creek some juveniles outmigrate during the following fall as yearlings (C. Harvey, pers.comm., as cited in Moyle et al. 1995). Source of data not stated.
Fall and Spring Smolts (yearling)	░	░	░	░							░	░	Geographic area: Sacramento River basin Ocean entry from November to April (Fisher 1994). Source of data not stated.
Spring Smolts (subyearling)				░	░	░							Jones and Stokes Foundation Runs Report Geographic area: not stated May rear in freshwater for 3 to 8 months, migrating to the ocean during spring (Raleigh 1986, Moyle 1976).

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fall Smolts (yearlings)										▨	▨	▨	Jones and Stokes Foundation Runs Report Geographic area: not stated Frequently rear over the summer and migrate to the ocean from October to December, after 12-14 months in freshwater (no source cited).
Juveniles enter the ocean					▨								Moyle et al. (1995) "presumes" that all fish have left the Sacramento basin by mid-may. No source of data stated.

▨	Span of Life History Activity
■	Peak of Life History Activity

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration									░	▓	▓	░	No data specific to San Joaquin basin fish on dates of arrival to the estuary was identified. Sonic tag studies conducted in 1964–1967 (Hallock et al. 1970) suggest a travel time from Prisoner's Point, in the Delta, to the Stanislaus River on the order of one month.
Spawning										░	▓	░	Carcass surveys in Merced, Tuolumne, and Stanislaus rivers are summarized in CDFG Central Valley Spawning Stock reports (various authors, titles, and dates; see references). More detailed data for the Tuolumne River is given in (TID/MID 1992, Appendix 3). Adults have occasionally been reported in the tributaries in late September or early January.
Incubation	░	░	░	░						░	░	░	inferred from appearance of newly emerged fry in seining studies in Tuolumne, Stanislaus, and San Joaquin Rivers, fyke net studies in the Tuolumne (TID/MID 1992, Appendices 12, 13)
Fry rearing	░	▓	▓░	░	░	░							Seining studies in Tuolumne, Stanislaus, and San Joaquin Rivers, Fyke net studies in the Tuolumne (TID/MID 1992, Appendices 12, 13)
Subyearling smolt outmigration			░	▓	▓	░							San Joaquin basin chinook tend to switch from "rearing fry" to "outmigrating smolts" very abruptly, and reach the ocean within a few days or weeks of beginning their outmigration (Baker and Morhardt 2001). Smoltification index data from Tuolumne River rotary screw trapping (TID/MID 1998a, 1998b, 2000)
Parr rearing				░	░	░	░	░	░	░			Inferred from yearling outmigration
Yearling smolt outmigration										░	░		Baker and Morhardt 2001.

░	Typical Span of Life History Activity
▓	Peak of Life History Activity

Figure 7-3. Fall-run Chinook salmon life history.

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Adult Migration	░	░	░	░	░	░						░	░	░	░	▒	▒	█	█	▒	░	░	░	░	Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░	Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration			▒																	▓					Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░																░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning	▒	▒	▒	▒	▒	▒																			Mills and Fisher 1994
Spawning	▓	▓	▓	▓	▓	▓	▓	▓															▓	▓	Peak spawning in California streams (McEwan 2001).
Spawning	▒	▒	▒	▒	▒	▒	▒	▒															▒	▒	Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea								▒	▒	▒	▒	▒	▒												Mills and Fisher 1994
Incubation	▒	▒	▒	▒	▒	▒	▒	▒	▒															▒	Reynolds et al. 1993
Emergence							▒	▒	▒	▒															Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).
Emergence						░	░	░	░	░	░	░	░	░	░	░	░								Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River

Figure 7-4. Winter-run Steelhead life history.

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Adult Migration	░	░	░	░	░	░						░	░	░	░	▒	▒	█	█	▒	░	░	░	░	Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░	Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration			▒																	▓					Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░																░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning	▒	▒	▒	▒	▒	▒																			Mills and Fisher 1994
Spawning	▓	▓	▓	▓	▓	▓	▓	▓															▓	▓	Peak spawning in California streams (McEwan 2001).
Spawning	▒	▒	▒	▒	▒	▒	▒	▒															▒	▒	Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea								▒	▒	▒	▒	▒	▒												Mills and Fisher 1994
Incubation	▒	▒	▒	▒	▒	▒	▒	▒	▒															▒	Reynolds et al. 1993
Emergence							▒	▒	▒	▒															Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).
Emergence						░	░	░	░	░	░	░	░	░	░	░	░								Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River

Figure 7-4. cont.

7.5.2. Upstream Migration

Adult salmon can navigate hundreds of mile of inland rivers to migrate from the ocean to their natal streams to spawn (although a small percentage may stray into other streams, especially during high water years). In the Sacramento system (the closest population of spring-run Chinook salmon to the San Joaquin River), adult spring-run Chinook salmon typically return to fresh water between March and May (Marcotte 1984). In the San Joaquin basin, fall-run Chinook salmon typically return between October and December (EA Engineering 1991a). Steelhead in the Sacramento River generally migrate to their natal streams in fall or winter (McEwan 2001).

To successfully navigate to their natal streams, adult Chinook salmon and steelhead require sufficient flow to provide adequate water depth in stream channels and to overcome flow-related barriers. Thompson (1972, as cited in Bjornn and Reiser 1991) is commonly cited for recommending water depths greater than 0.8 feet and water velocities less than 8 ft/s for successful upstream migration of adult fall and spring-run Chinook salmon. However, other factors, such as the length of stream and percent of the wetted cross section at a particular depth and velocity, need to be considered to determine if water depth and/or velocity pose a barrier.

In 1944 and 1947, The California Department of Fish and Game (CDFG 1955) observed from 5,000 to 6,000 spring-run Chinook salmon migrating up the San Joaquin River as far as Mendota Dam in a flow that was estimated to be 100 cfs in the reach between Sack Dam and the confluence with the Merced River. CDFG observed that “many of these fish have rubbed themselves raw going over the shallow sandbars” between Sack Dam and the confluence with the Merced River (a distance of approximately 50 miles). Such abrasions can increase the risk of mortality from disease for spring-run Chinook salmon, since they must hold in pools throughout the summer before spawning. CDFG also noted that the fish were highly susceptible to poaching and temperature effects in the 100 cfs flow. In contrast, CDFG (1955) noted that during the relatively wet years of 1945 and 1946, when “the flow which passed the sack dam was entirely adequate during the period of the spring migration,” an estimated 56,000 and 30,000 fish respectively, were counted at Mendota Dam. CDFG expressed concern that if spring-run Chinook salmon were required to migrate the entire 140 miles of the San Joaquin River to spawning areas at flows near 100 cfs, then very few adults would survive to spawn.

Adult Chinook salmon appear to be less capable of upstream migration through fish ladders, culverts, and waterfalls than steelhead (Nicholas and Hankin 1989a, Table 7-3), due in part to slower swimming speeds and inferior jumping ability (Reiser and Peacock 1985; Bell 1986, as cited in Bjornn and Reiser 1991). Cruising speeds that are used primarily for long-distance travel range up to 3.3 ft/s (Bjornn and Reiser 1991). Sustained speeds, which can be maintained for several minutes, range from 3.3 ft/s to 10.8 ft/s (Bjornn and Reiser 1991). Darting speeds, which can only be sustained for a few seconds, range from 10.8 ft/s to 22.3 ft/s (Bjornn and Reiser 1991). The maximum jumping height for Chinook salmon has been calculated to be approximately 7.9 feet (Bjornn and Reiser 1991).

Table 7-3. Migration speeds and requirements for Chinook salmon and steelhead. Based on Bjornn and Reiser (1991).

Migration Abilities	Chinook salmon	Steelhead
Cruising speeds (ft/s)	0–3.3	0–5
Sustained speeds (ft/s)	3.3–10.8	5–15
Darting speeds (ft/s)	10.8–22.3	14–27
Jumping Ability (ft)	7.9	17
Required Depth for Migration (ft)	>0.8	>0.6
Required Velocity for Migration (ft/s)	<8	<8

Steelhead are among the strongest swimming freshwater fishes. Steelhead have cruising speeds up to 5 ft/s; they can sustain swimming at speeds from 5 ft/s to 15 ft/s; and they can attain darting speeds from 14 ft/s to 27 ft/s (Bell 1973, as cited in Everest et al. 1985; Roelofs 1987). Steelhead have been observed making vertical leaps of up to 17 feet over falls (W. Trush pers. comm., as cited in Roelofs 1987). Thompson (1972, as cited in Bjornn and Reiser 1991) is commonly cited for recommending water depths greater than 0.6 feet and water velocities less than 8 ft/s for successful upstream migration of steelhead.

7.5.2.1. Temperatures during upstream migration

In general, Chinook salmon and steelhead appear capable of migrating upstream under a wide range of temperatures. Bell (1986) reported that salmon and steelhead migrate upstream in water temperatures that range from 37°F to 68^{o}F. Bell (1986) reports that temperatures ranging between 37°F and 55°F are suitable for upstream migration of spring-run Chinook salmon, and between 50 ^{o} and 66^{o}F for fall-run Chinook salmon. In a review of available literature, Marine (1992) reported a water temperature range of 43^{o}–57^{o}F as optimal for pre-spawning broodstock survival, maturation, and spawning for adult Chinook salmon.

In the San Joaquin River, spring-run Chinook salmon likely migrated during periods of relatively cold water temperatures because of high spring snowmelt runoff. Yoshiyama et al. (1996) quotes an 1853 observation of water temperature in late July that suggests unimpaired spring flows were cold. Writing of the San Joaquin River near Fort Miller in late July, 1853, Blake (1857) wrote:

> *The river was not at its highest stage at the time of our visit; but a large body of water was flowing in the channel, and it was evident that a considerable quantity of snow remained in the mountains at the sources of the river. A diurnal rise and fall of the water was constantly observed, and is, without a doubt, produced by the melting of the snow during the day. The water was remarkably pure and clear, and very cold; its temperature seldom rising above 64 ^{o} Fahrenheit while that of the air varied from 99^{o} to 104^{o} in the shade.*

Water temperatures of 64^{o}F in late July suggest that the spring snowmelt flood and recession produced suitably cold water temperatures in the Friant area during the expected period of spring-run Chinook salmon migration. However, there is little data to evaluate whether these adequate water temperatures continued throughout the study area.

The water temperature conditions that fall-run Chinook salmon likely encountered historically in the San Joaquin River are more difficult to conceptualize. Blake's observation of 64^{o} F water temperatures in late July 1853 suggest that water temperatures in the vicinity of Friant were similar to water temperatures to be expected in other, more northerly river systems that support fall-run Chinook salmon. However, there is no way to determine how quickly water temperatures warmed with increasing distance downstream of Friant Dam and, therefore, the water temperatures that fall-run Chinook salmon would have been exposed to in lower reaches. Fall-run Chinook salmon in the San Joaquin River historically migrated upstream during the late summer, when water temperatures would be expected to be at their warmest. Before their extirpation, the San Joaquin population of Chinook salmon represented the southernmost extent of Chinook salmon in North America, which also suggests that the San Joaquin population experienced the warmest climatological conditions. In 1875, the California Fisheries Commission (CFC) remarked upon the apparent high water temperatures that San Joaquin Chinook salmon were able to tolerate:

> *Large numbers pass up the San Joaquin River for the purpose of spawning in July and August, swimming for one hundred and fifty miles through the hottest valley in the State, where the temperature of the air at noon is rarely less than 80° F, and often as high as 105°F, and where the average temperature of the river at the bottom is 79°F and at the surface 80°F.*

There is also limited historical temperature data, collected between 1875 and 1877, that indicates fall-run Chinook salmon may have experienced relatively high water temperatures in the San Joaquin River. The data was collected at two sites: a railroad bridge crossing in Reach 1 (near the current location of the Highway 99 bridge); and a railroad bridge crossing near Mossdale near the current location of the Hwy 120 crossing at approximately RM 50 (below Vernalis). Average monthly water temperatures during August and September at these two sites ranged between 72ºF to 80.7ºF, with maximum temperatures in the range of 82ºF to 84ºF (CFC 1877, as cited in Yoshiyama et al. 1996). The California Fisheries Commission was so impressed by the unique temperature tolerances of the San Joaquin fall-run Chinook salmon that they suggested widely transplanting the species to rivers in the eastern and southern United States (CFC 1875, as cited in Yoshiyama et al. 1996). Yoshiyama et al. (1996) also suggest that San Joaquin fall-run Chinook salmon “possibly were distinctly adapted to the demanding environmental regime of the southern Central Valley”. Short-term or transient exposures to temperatures as high as 80.6ºF have been reported as tolerated by adult Chinook salmon (Piper et al. 1982, Boles 1988, as cited by Marine 1992). Unfortunately, both the spring and fall run Chinook salmon have been extirpated from the upper San Joaquin River, and it is not possible to determine if actual genetic or physiological differences did exist between upper San Joaquin River populations and more northerly populations. Another explanation for their noted ability to tolerate relatively high water temperatures during upstream migration may be the historical presence of artesian springs that are known to have occurred along the lower valley floor and perhaps within the river channel, that may have provided pockets of temperature refugia during upstream migration.

More recent studies of San Joaquin basin fall-run Chinook salmon suggest that water temperatures greater than 65°F may serve as a temperature barrier, either delaying or blocking the migration of adult salmon in San Joaquin River tributaries (Hallock et al. 1970). However, there is some question about the causal relationships posited by Hallock et al. Their four years of data indicated a noticeable delay between the time the first tagged fish migrated out of the Delta into the San Joaquin River and the onset of a steady run (13 days in 1964 and 1965, 6 days in 1966 and 1967). This delay was attributed to dissolved oxygen conditions in one year (1966), and to temperature conditions in the other three years. In the three years that temperature was cited as a causal factor affecting the run timing of spawning migration, temperatures were within a few degrees Fahrenheit of one another, and in two of the three years, no temperatures were recorded at the onset of migration. There may easily have been a combination of several factors affecting the run timing, rather than temperature alone.

McEwan and Jackson (1996) suggest that adult steelhead migrate in water temperatures ranging from 46ºF to 52ºF. Temperatures exceeding 70ºF are considered stressful (Lantz 1971, as cited in Beschta et al. 1987). Because steelhead historically migrated upstream in late-fall and winter months in the San Joaquin River, temperatures can generally be assumed to have been suitable.

7.5.3. Adult Holding

When adult spring-run Chinook salmon begin their migration to their natal streams, they are sexually immature, unable to spawn. After they arrive in their natal streams in the spring, they hold in deep pools through the summer, conserving energy until the fall when their gonads ripen and they spawn. In the Sacramento River system, adult spring-run Chinook salmon typically return to fresh water between March and May, where they hold between April and mid-July, and spawn from mid-July to September (Figure 7-2). While holding through the summer, spring-run adults minimize their activity, which is thought to lower metabolic rates and therefore conserve energy for eventual reproductive activities (NRC 1992; from Bell 1986).

To conserve energy while holding, spring-run Chinook salmon adults generally require deep pools with relatively slow water velocities. Deep pools help insulate the adults from potential solar and convectional heating of the surface water during warm summer months, and it helps them avoid predators so that they can remain relatively inactive. In addition to deep pools, instream cover (e.g., undercut banks, overhanging vegetation, boulders, large wood structure) also helps adult spring-run Chinook salmon to avoid predators. For spring-run Chinook salmon in the Sacramento River system, Marcotte (1984) reported that the suitability of holding pools declines at depths less than 8 feet. Airola and Marcotte (in prep., as cited in Marcotte 1984) found that spring-run Chinook salmon in the Deer and Antelope Creeks avoided pools less than about 6 feet. In the John Day River in Oregon, adults usually hold in pools deeper than 5 feet that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986).

To conserve energy, adult spring-run Chinook salmon holding in pools require relatively slow water velocities, so that they do not have to expend energy to maintain position. For spring-run Chinook salmon in the Sacramento River system, Marcotte reported that optimal water velocities in pools range from 0.5 ft/s to 1.2 ft/s.

Fall Chinook salmon and steelhead generally do not hold in pools for long periods of time (>1 week), but they may briefly use large resting pools during upstream migration.

7.5.3.1. Temperatures During Adult Holding

Water temperatures for adult Chinook salmon holding are reportedly optimal when less than 60.8ºF, and lethal when above 80.6ºF (Moyle et al. 1995). Moyle et al. (1995) reported that spring-run Chinook salmon in the Sacramento River typically hold in pools that have temperatures below 69.8 ºF to 77ºF.

7.5.3.2. Historical Distribution of Holding Habitat

Adult spring-run Chinook salmon held in pools above Friant Dam prior to its construction (CDFG 1921, as cited in Yoshiyama et al. 1996; Appendix C), and it is likely that they held in pools as far upstream as Mammoth Pool Reservoir (Yoshiyama et al. 1996). Hatton described “long, deep pools” in the canyon above Friant (1940, as cited in Yoshiyama et al. 1996). The amount of holding and spawning habitat available to spring-run Chinook salmon was reduced around 1920, when Kerckhoff Dam “blocked the spring-run salmon from their spawning areas upstream and seasonally dried up ~14 mi of stream, below the dam, where there were pools in which the fish would have held over the summer” (CDFG 1921, as cited in Yoshiyama et al. 1996). The completion of Friant Dam in 1941 further reduced the holding and spawning habitat available to spring-run Chinook salmon by completely blocking access to upstream areas. In July of 1942, Clark (1942) observed an estimated 5,000 adult spring-run Chinook salmon holding in two large pools directly downstream of

Friant Dam. He reported that the fish appeared to be in good condition, and that they held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 72ºF in July. Although some fish may have held in pools downstream of Lanes Bridge, Clark (1942) concluded that the abundant spawning he observed in September and October in riffles between Friant Dam and Lanes Bridge were from fish that held in the pools below the dam that had moved back downstream to spawn.

7.5.4. Spawning and Incubation

Upon arrival at the spawning grounds, adult female Chinook salmon dig shallow depressions or pits in suitably sized gravels, where they deposit eggs during the act of spawning, and then cover the fertilized eggs with additional gravel to protect the eggs. Over a period of one to several days, the female gradually enlarges the redd by digging additional pits in an upstream direction (Burner 1951, Healey 1991). By disturbing the gravel that surrounds the egg pocket, the female loosens the bed material and cleans some of the fine sediment from the gravel, thereby improving interstitial water flow. Females can remove from 2% to 15% of fine sediment smaller than 0.04 inches (<1 mm) during the redd building process, depending on the initial proportion of fines in the gravel (Kondolf 2000). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Defense of a constructed redd helps to prevent subsequent spawners from constructing redds in the vicinity of an egg pocket, which can scour the eggs and increase egg mortality. Adult Chinook salmon females generally defend their redd until they die, usually within 1–2 weeks of spawning.

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries 6.6 feet to 9.8 feet wide (Vronskiy 1972) to large mainstem rivers (Healey 1991). Chinook salmon generally prefer low-gradient (<3%) reaches for spawning and rearing, but will occasionally use higher-gradient areas (Kostow 1995). Spawning site (redd) locations are mostly controlled by hydraulic conditions dictated by streambed topography (Burner 1951). Chinook salmon are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). The water depths most often recorded over Chinook salmon redds range from 0.4 feet to 6.5 feet and velocities from 0.5 ft/s to 3.3 ft/s, although criteria may vary between races and stream basins. For example, fall-run Chinook salmon, because of their larger size, are generally able to spawn in deeper water with higher velocities, (Healey 1991) than spring-run Chinook salmon, which tend to dig comparatively smaller redds in finer gravels (Burner 1951). Similarly, four and five year old fish are generally larger than the average three year old fish, and can spawn in deeper, faster water with larger particle size gravels and cobbles.

Chinook salmon redds are typically located in riffles, where intra-gravel flow and dissolved oxygen are relatively high. Intra-gravel flow is an important function in constructed redds, because it delivers dissolved oxygen to incubating eggs and transports metabolic wastes from the egg pocket. Intra-gravel flow is influenced by size distribution of sediment particles that compose the channel bed (Platts et al. 1979). There are interstitial spaces between individual sediment particles that allow intra-gravel flow. When the interstitial spaces between spawning gravels are filled with fine sediments, then intra-gravel flow is generally reduced. Therefore, as the percentage of fine sediment in spawning gravels increases, the egg survival-to-emergence of Chinook salmon and steelhead generally decreases (Figure 7-5). In general, in substrate with greater than 13% fines (<2 mm), steelhead and Chinook salmon have less than 50% survival to emergence, though larger substrates also influence survival (Tappel and Bjornn 1983). D_{50} values (the median diameter of substrate particles found within a redd) for Chinook salmon have been found to range from 0.4 inches to 3.1 inches (10 mm to

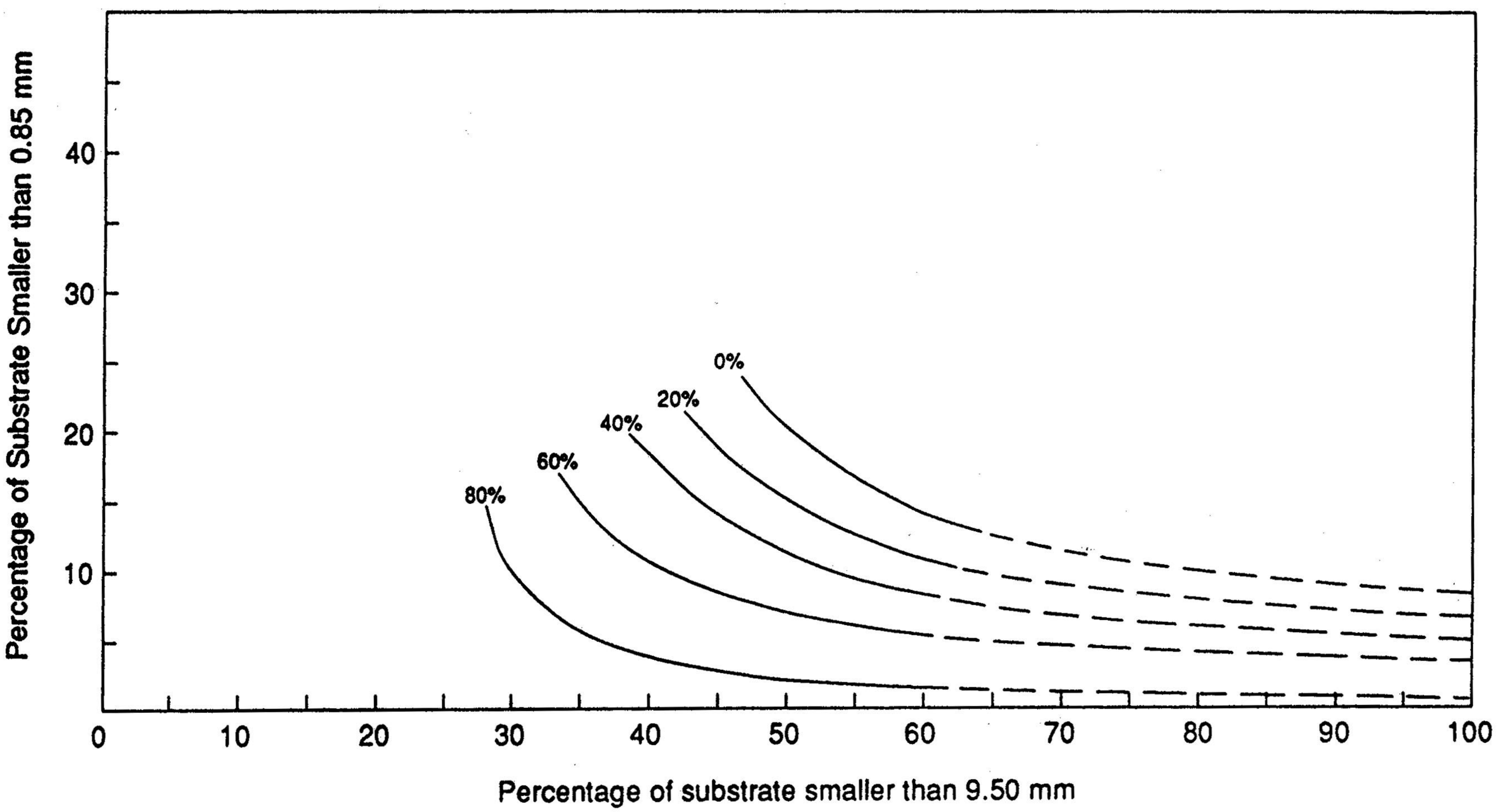


Figure 7-5. Relationship between fines (<0.085 mm) and survival to emergence. Data is from Tappel and Bjornn (1983).

80 mm) (Kondolf and Wolman 1993). Chinook salmon in the Central Valley have been observed to use spawning gravels with D_{50} values ranging from 1.2 inches to 2.6 inches (30 mm to 70 mm) (Van Woert and Smith, unpublished data 1962, as cited in Kondolf and Wolman 1993; and Kondolf and Wolman 1993).

Most steelhead spawn in the mainstem of small rivers and in tributaries. Steelhead may spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). Areas of the stream with water depths from about 0.5 feet to 4.5 feet and velocities from 2.0 ft/s to 3.8 ft/s are typically preferred for spawning by adult steelhead (Moyle et al. 1989, Barnhart 1991). Steelhead generally prefer smaller spawning gravels than Chinook salmon. D_{50} values for steelhead have been found to range from 0.4 inches (10 mm) (Cederholm and Salo 1979, as cited in Kondolf and Wolman 1993) to 1.8 inches (48 mm) (Orcutt et al. 1968, as cited in Kondolf and Wolman 1993). Detailed spawning habitat requirements for each salmonid species are provided in Appendix B.

7.5.4.1. Redd Size

The number of spawning salmonids that can be supported for a given area of spawning habitat is influenced by the size of individual redds; larger redds mean fewer spawning pairs that can be accommodated. If spawning habitat is insufficient for the number of spawners that have returned to a river, then the risk of redd superimposition generally increases. Redd superimposition has been found to be an important factor affecting Chinook salmon populations in the Tuolumne River (EA Engineering 1992a), because later arriving females dig redds on top of existing redds, causing substantial mortality of the previously deposited eggs (McNeil 1964, Hayes 1987).

Published accounts of Chinook salmon redd size vary considerably, based on fish size (larger fish create larger redds), river, and habitat conditions (e.g., higher water velocities and smaller gravels can both lead to larger redds). A literature review conducted by Healey (1991) found redd size ranging from 5 ft^2 to 484 ft^2. The large variability in reported redd size is also due to differing methods or objectives between studies. Burner (1951) suggests an area of 216 ft^2 is needed for each spawning pair, but his estimate includes not only the area needed for a redd, but also the area around the redd that is defended by the female salmon. Other researchers measure just the redd itself and arrive at much smaller values. But even when just measuring the redd, there are differences in methods. For example, the egg pocket area (sometimes called the mound) is almost always measured by researchers, but the pit and/or tailspill are not always included.

EA Engineering (1992) measured 354 fall-run Chinook salmon redds on the Tuolumne River in 1988 and 1989. For each redd, the length of the mound, length of the pit, and length of the tailspill were measured. In addition, the maximum width within the mound, water depth, and velocity were measured. Figure 7-6 illustrates of the distribution of redd size that result from these measurements. The total redd area, not including the area defended by spawning adults, had a mode of 55 ft^2. This area includes the redd pit, mound, and tailspill.

Before using redd size data from previous studies, it is therefore important to determine if the data are appropriate, both biologically (e.g., fish size) and methodologically, for the intended use. One of the primary uses of redd size data in the San Joaquin restoration project is to help asses the implications of the amount of spawning gravel on the population dynamics of re-established salmon runs. An individually-based spawning model is proposed to be used to determine the effect of gravel area on the number of eggs successfully deposited for different escapement sizes. The Tuolumne River data and data from other San Joaquin River tributaries will presumably be the most applicable

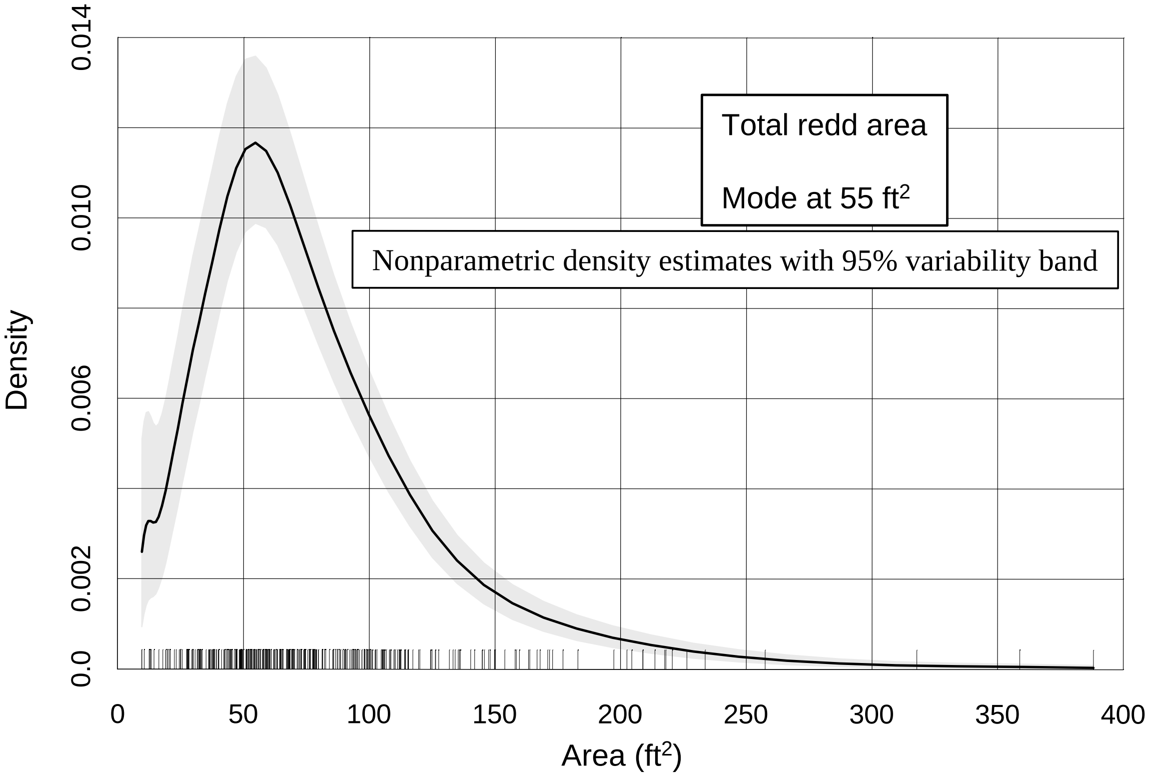


Figure 7-6. Chinook salmon redd size distributions based on total redd area, from Tuolumne River Data, 1988 and 1989, n=354.

to the restored San Joaquin mainstem. Because of the potential for redd superimposition and the direct relationship of superimposition to habitat availability and number of spawners that can be accommodated, the parent population selected for re-introducing Chinook salmon to the San Joaquin River also will be important. The parent population selected will influence average redd size, and will thus influence the amount of habitat that will need to sustain targeted population sizes.

The average size of a steelhead redd is smaller than that of a Chinook salmon redd (Reynolds et al. 1990). Reiser and White (1981, as cited in Bjornn and Reiser 1991) and Hunter (1973) estimated steelhead redd sizes from 47 ft^2 to 58 ft^2. Reynolds et al. (1990) indicated that redd sizes ranged from 22 ft^2 to 121 ft^2, averaging 56 ft^2.

7.5.4.2. Temperature During Incubation

Water temperatures during spawning and incubation are critical to successful reproduction and may be a primary evolutionary factor that has determined spawning timing (Heggberget 1988, as cited in Bjornn and Reiser 1991). Embryonic development time is a direct function of incubation temperatures, and the average incubation time can be predicted with approximately 97% accuracy or better with simple degree-day models (Myrick and Cech 2001).

Bell (1986) reports preferred spawning temperatures for spring-run and fall-run Chinook salmon of 42 °F to 57°F, and preferred (optimal) incubation temperatures of 41° F to 58°F. Temperatures above the preferred spawning range have been observed to increase the occurrence of abnormal fry, mortality, and lengthen the duration of the hatching period (Spence et al. 1996). The temperature at which incubating Chinook salmon eggs begin to experience significantly increased mortality is reported to range from a low of about 57°F (Healey 1979) to a high of 61°F (Olson and Foster 1957). The USFWS (1999, as cited in Myrick and Cech 2001) conducted egg thermal tolerance studies in the Sacramento River, and found that the mortality of fall-run Chinook salmon eggs held at temperatures ranging from 52°F to 56°F was not significant, but that mortality increased at temperatures ranging from 54°F to 60°F, and increased further at temperatures above 62°F.

Seymour (1956) found substantially higher mortality in groups incubated near 60°F (n=2, 22% and 35% respectively) than in groups incubated near 58°F (n=1, 2%) or 55°F (n=2, 2% and 5%). He found high mortality (n=2, 78%, 85%) in groups incubated near 62°F, and complete or near-complete mortality in groups incubated near 65°F (n=2). Seymour reproduces data from the Entiat hatchery which follow the same general pattern, although the Entiat data showed only 12.4% mortality near 60°F. Seymour also conducted experiments involving varying temperature regimes with eggs of several broodstocks, including a Sacramento River stock. These varying-temperature experiments are harder to interpret, but the results were broadly similar to the findings in the constant-temperature experiments.

Egg mortality at different temperatures varies with exposure duration (Donaldson 1955), dissolved oxygen concentrations present during the exposure (Eddy 1972), and developmental stage (Combs and Burrows 1957). The experimental results of Donaldson (1955) indicated that mortalities of 20% would be expected after an exposure of about 10 to 12 days at a temperature of 62°F, but 90% mortality would not be expected at this temperature even after 25 days. Donaldson (1955) found that an exposure of six days to 65°F was sufficient to kill nearly 50% of Chinook salmon eggs. At temperatures of 67°F, 90% mortality would be expected in about 10 days, according to Donaldson's experiments.

Preferred temperatures for steelhead egg incubation range from 48°F to 52°F (McEwan and Jackson 1996, FERC 1993). Temperature thresholds for steelhead spawning are provided in Table 2 of the Steelhead Summary in Appendix B, and incubation thresholds are provided in Table 3 of the Steelhead Summary in Appendix B.

7.5.4.3. Historical Spawning Distribution

Historically, spring-run Chinook salmon spawning in the San Joaquin River occurred from late August to October, with peak spawning occurring in September and October (Clark 1942, Figure 7-2). Fall-run Chinook salmon in the San Joaquin system typically spawned from October through December, with spawning activity peaking in early to mid-November (Figure 7-3). Spring Chinook salmon historically spawned as far upstream as the present site of Mammoth Pool Reservoir (RM 322), where they were blocked by a natural barrier (Yoshiyama et al. 1996). Spawning habitat in the upper San Joaquin River was historically considered to be the best of any river in the basin (Hatton 1940, as cited in Yoshiyama et al. 1996). Most spawning was concentrated between Lanes Bridge (RM 255) and the Kerchoff Powerhouse (RM 293) (Clark 1942). There is conflicting information on the areas with the most suitable and frequently used spawning habitat, but generally Clark (1942) and Hatton (1940, as cited in Yoshiyama et al. 1996) both report that highly suitable gravels were in the 10-mile reach from Lanes Bridge to the current site of the Friant Dam. The construction of the dam inundated and blocked access to about 16 miles of habitat that was historically used by spring-run Chinook salmon for spawning, representing an estimated 36% loss of the historic spawning habitat (Hatton 1940, as cited in Yoshiyama et al. 1996). Hatton (1940, as cited in Yoshiyama et al. 1996) noted that in the 1930s (before construction of Friant Dam) spawning habitat below the town of Friant appeared under-utilized, and based on spawning habitat alone he predicted that there would be no impact of the Friant Dam on spring-run Chinook salmon. Fall-run Chinook salmon spawning distribution is not as well documented, but it is likely that they spawned in Reach 1 between Gravelly Ford and Lanes Bridge (CDFG 1957, as cited in Cain 1997).

7.5.5. Juvenile Rearing

Following emergence, salmonid fry smaller than 2 inches (50 mm) occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris or large substrate (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry grow, they move into deeper and faster water further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Juvenile salmonids larger than 2 inches (50 mm) in the Sacramento-San Joaquin system also rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook salmon juveniles that reared on the Yolo Bypass than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. Bioenergetic modeling suggested that increased prey availability on the Yolo Bypass floodplain was sufficient to offset increased metabolic demands from higher water temperatures (9ºF higher than mainstem). Sommer et al. (2001) suggested that the well-drained topography may help reduce stranding risks when floodwaters recede. Considering the historical extent of floodplain inundation in the San Joaquin system, and the expanse of Tule marsh along the San Joaquin River prior to land development, it is possible that juvenile Chinook salmon, and possibly steelhead, reared on inundated floodplains in the San Joaquin River in Reaches 2 through 5. These downstream reaches were inundated for a good portion of the year for normal and wetter years, providing suitable water temperatures for juvenile rearing from January to at least June or July of most years, and perhaps extending into August of wetter years. As snowmelt runoff declined, and ambient temperatures increased, water temperatures in slow-moving sloughs and off channel areas probably increased rapidly. The extent to which juvenile salmonids would have used the extensive Tule marshes and sloughs historically found in Reaches 2, 3, 4, and 5, is unknown.

The length of time spent rearing in freshwater varies greatly among spring-run Chinook salmon juveniles. They may disperse downstream as fry soon after emerging from redds; they may migrate downstream as fingerlings early in their first summer; they may move downstream in the fall as flows increase; or they may overwinter in freshwater and emigrate the following year as yearlings (Healey 1991). In addition to rearing on inundated floodplains during winter, juvenile spring-run Chinook salmon that stay in the river over summer to rear take advantage of instream pools and runs in the mainstem channel. Fall-run Chinook salmon typically rear in freshwater for one to three months before outmigrating to the ocean, but some rear in the river through the summer and outmigrate the following fall.

Juvenile steelhead (parr) rear in freshwater at least one year before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead that rear in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period (e.g., 1 year) in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

7.5.5.1. Temperatures during juvenile rearing

Temperatures, in combination with food availability, have a significant effect on juvenile salmonid growth rates. On maximum daily rations, growth rates increase with temperature up to species-specific threshold temperatures, after which growth rates decline with further increases in temperature. Reduced rations can also result in reduced growth rates and influence how temperature affects growth rates; therefore, salmonid growth rates are a function of the synergistic effects of both temperature and food availability.

In addition to the effects of temperature on growth rates, high temperatures can cause direct mortality. Myrick and Cech (2001) suggest that the chronic upper lethal limit (based on prolonged exposure) for juvenile Central Valley Chinook salmon is approximately 77°F. Juvenile Chinook salmon can, however, withstand brief (acute) periods of higher temperatures up to 83.8°F when acclimated to 66.2°F (Cech and Myrick 1999). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments were conduced on steelhead reared at the Mokelumne River State Fish Hatchery from eggs collected at the Nimbus Fish Hatchery (American River). Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures that range from 62.6 °F to 68°F and a lethal critical thermal maximum of 80°F.

Defining appropriate temperature targets for juvenile salmonids is the focus of additional analysis being conducted to revise the quantitative objectives and develop restoration strategies for the San Joaquin River. The goal of this ongoing analysis is to define temperature targets warm enough that promote faster growth of juvenile salmonids so as to enhance their downstream survival, while avoiding the deleterious effects of temperatures that are too warm.

7.5.6. Smolt Outmigration

Juvenile salmonids undergo morphological, physiological, and behavioral changes as they emigrate from their natal rivers to the ocean. Prior to smoltification, the fish exhibit positive rheotaxis (Thorpe and Morgan 1978) and maintain their position against the stream current. Upon smoltification, fish are less prone to hold position against the current, and downstream movement is initiated. Morphologically, silvering in body color and a decrease in weight per unit length occur (Wedemeyer, et al. 1980), resulting in a more slender and streamlined fish. Some evidence exists for a threshold size that may be important in the timing of seaward migration (Folmar and Dickhoff, 1980). Physiologically, several changes occur during smoltification, including heightened hypo-osmotic regulatory capability that increases salinity tolerance and preference, an increase in endocrine activity, and an increase in gill Na^+-K^+ ATPase activity.

There are several potential mechanisms that may trigger the smoltification process. Larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989a, Beckman et al. 1998), and it appears that in some systems juveniles that do not reach a critical size threshold will not emigrate as smolts (Bradford et al. 2001). Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Bjornn and Reiser (1991) suggest that seaward migrations are regulated primarily by photoperiod, with streamflow, water temperature, and flows also playing important roles. The relative importance of each individual outmigration cue remains unclear (Bjornn 1971, Healey 1991).

In the mainstem San Joaquin River, outmigration trapping at Mossdale in 1939, 1940, and 1941 indicated that spring-run Chinook salmon smolts historically outmigrated from January until mid-June (Hatton and Clark 1942, Figure 7-2). In 1939 the peak of outmigration was in April (peak flow in early February), in 1940 the peak of outmigration was in late February (peak flows in March and April), and in 1941 the peak was in March (peak flow in March). Currently, most age 0+ outmigrants in Butte Creek (Sacramento River basin) move downstream at sizes of 1.2 inches to 4.3 inches (30 mm to 110 mm) (Hill and Weber 1999), while age 1+ outmigrants are generally larger than 5 inches (130 mm), and can reach 6 inches (152 mm) or more in Butte Creek (Hill and Weber 1999). In general, fall-run Chinook salmon fry (length <2 inches) and juveniles (length >2 inches) outmigrate from spawning areas between January and May, and likely later during wetter years.

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 6 inches to 8 inches (150 mm to 200 mm) (Meehan and Bjornn 1991). A length of 5.5 inches (140 mm) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). In the Sacramento River, steelhead generally emigrate as 2-year-old fish during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6 to 8 inches being typical for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Chinook salmon can undergo smoltification at temperatures that range from 42°F to 68°F (Zaugg and McLain 1972, Marine 1997, from Myrick and Cech 2001), but their saltwater survival is improved at lower temperatures. Marine (1997, from Myrick and Cech 2001) evaluated the smoltification patterns of juvenile Sacramento River fall-run Chinook salmon reared at low (55.4–60.8°F), moderate (62.8–68.0°F), and high (69.8–75.2°F) water temperatures. The high temperature regime appeared to impair the smoltification process compared to salmon reared at the low temperature regime. Salmon reared in the moderate temperature regime also displayed some alteration and variable impairment of smoltification patterns. Clarke et al. (1981) reported that Chinook salmon reared at 50°F survived immersion in saltwater better than fish reared at higher temperatures (59°F). Other studies (Clarke and Shelbourn 1985; Clarke et al. 1992, from Myrick and Cech 2001) indicate that Chinook salmon that complete juvenile and smolt phases in the 50–63.5°F range are optimally prepared for saltwater survival.

Studies by Baker et al. (1995) investigated the relationship between water temperature and the survival of hatchery reared fall-run Chinook salmon smolts migrating through the Delta. They observed an LT50 of 73.4±1.9°F. These modeling results were consistent with the results of several laboratory experiments reproduced in Houston (1982). These results are shown in Table 7-4. In Houston’s studies, temperatures ranging from 67.6°F to 74.8°F resulted in smolt losses of 10%; higher temperatures resulted in increasingly higher smolt losses, with up to 90% losses at temperatures ranging from 73.4°F to 79.3°F.

It appears that preferred or optimal rearing temperatures that contribute to higher growth rates are slightly higher than optimal temperatures for smoltification. Myrick and Cech (2001) conclude that “while temperatures in the 15–19°C (59–66°F) range lead to high juvenile growth rates, cooler temperatures are optimal for smoltification.” Optimal temperatures for smoltification appear to be in the range of 56–64°F in the studies cited above.

According to Myrick and Cech (2001), steelhead undergo smoltification in a very narrow temperature range, with optimal temperatures from 42.8 °F to 50°F. Similar to Chinook salmon, this temperature range is lower than temperatures preferred for rearing, and may reflect evolutionary adaptations to high spring snowmelt runoff that historically would have provided cold water temperatures throughout the San Joaquin River basin during the smolt outmigration period.

7.6. RESIDENT NATIVE FISH LIFE HISTORIES AND HABITAT REQUIREMENTS

Species within the Central Valley ichthyological subprovince evolved in a region where both extended droughts and massive floods were common, leading to special adaptations for surviving these environmental extremes (Moyle 2002). Adaptations to conditions found in California include long life spans and large body size, high fecundity, and well-developed dispersal capabilities (Moyle 2002). Longevity can ensure persistence of a population when conditions are unsuitable for spawning in some years, with the result that many populations may have one or more year classes missing, which may be associated with natural cycles of drought or flooding (Moyle et al 1982). Native fishes also tend to display strong differences in diet and habitat preferences between the juvenile

Table 7-4. Results of slow-heating smolt survival laboratory experiments by Houston (1982).

Acclimation temperature	*Temperatures resulting in loss*		
	10% loss	*50% loss*	*90% loss*
50°F (10°C)	73.2°F (22.9°C)		76.1°F (24.5°C)
50°F (10°C)	68.9°F (20.5°C)		74.3°F (23.5°C)
51.8°F (11°C)	73.4°F (23.0°C)	74.3°F (23.5°C)	74.8°F (23.8°C)
55.4°F (13°C)	67.1°F (19.5°C)		73.4°F (23.0°C)
64.4°F (18°C)	68.0°F (20.0°C)		74.3°F (23.5°C)
68°F (20°C)	74.8°F (23.8°C)	76.5°F (24.7°C)	76.6°F (24.8°C)
–	67.6°F (19.8°C)[1]	73.4°F (23.0°C)[1]	79.3°F (26.3°C)[1]

[1] Temperature values predicted by the Baker et al. 1995 analysis of Chinook salmon smolt outmigration data from the Delta.

and adult life stages; therefore, disturbances affecting one type of habitat or food resource are less likely to eliminate all members of a species' population (Moyle 2002). The purpose of this section is to describe the general life-history patterns of native fish in the San Joaquin River (Appendix D). Appendix B contains more detailed information on the life histories and habitat requirements of native fishes in the San Joaquin River.

The San Joaquin River corridor historically contained a large variety of aquatic habitats for fish, which led to the evolution of different life-history strategies for exploiting various habitats and food resources. Habitat diversity and fish community complexity generally increased in a downstream direction with the addition of lower-velocity and deeper habitats associated with the valley floor, including still backwaters, shallow tule beds, deep pools, and long stretches of slow-moving water (Moyle et al. 1982). Because natural habitats that support the rainbow trout assemblage are generally restricted to areas upstream of Friant Dam, the following discussion focuses primarily on the pikeminnow-hardhead-sucker and deep-bodied fish assemblages that occupied mainstem habitats within the study area.

Two large freshwater lakes (Tulare and Buena Vista lakes) historically inundated large portions of the valley floor, providing large areas of warm, shallow, extremely productive habitat for spawning and rearing fish. The fish fauna of these lakes were not studied before their destruction, but there was a small commercial fishery in the lakes for native cyprinids in the nineteenth century (Moyle 1976). Moyle believes that these lakes, as well as the backwaters, sloughs, and other slow-water habitats of the valley floor, were probably important habitat for Sacramento perch, thicktail chub, hitch, Sacramento splittail, and tule perch. Conditions in these valley-floor aquatic habitats fluctuated a great deal in association with natural flooding and drought. The adaptations to these fluctuations that are evident in native fish include tolerance to high turbidity, extremely high water temperatures, and high salinities and alkalinities (Moyle 2002). Moyle et al. (1982) point out that, although such fluctuating conditions might be expected to result in species that are relatively unspecialized to take advantage of a variety of foods and habitats, the native fish species are "remarkable for their distinct habitat preferences, feeding habits, and life-history strategies."

A range of feeding habits is found among the native resident fishes of the lower-elevation San Joaquin River. Sacramento blackfish are primarily suspension feeders on plankton (Sanderson and Cech 1992, 1995; as cited in Moyle 2002). Hitch are open-water plantivores that feed on filamentous algae and aquatic and terrestrial insects (M.S. thesis, University of California, Davis, unpubl. data 1996; as cited in Moyle 2002) in shallow sloughs or along shoreline areas of channels. Smaller fish that feed on benthic prey include prickly sculpin, tule perch, and juvenile splittail (Moyle 2002). Bottom-feeding omnivores include adult splittail, hardhead, and Sacramento sucker; the diet of these species is composed of detritus as well as small benthic invertebrates (Moyle 2002). Larger hardhead tend to feed on filamentous algae and other aquatic plants as well as larger invertebrates (Moyle 2002). Sacramento perch and Sacramento pikeminnow were formerly the dominant piscivorous fish in the San Joaquin River. Thicktail chub are believed to have fed on small fish and large aquatic invertebrates (Bond et al. 1988, as cited in Moyle 2002).

Native resident fish also display a variety of spawning behaviors. All of the native resident species spawn in the late winter or spring when water was historically abundant in the system (Moyle 1976). Many species grow to large sizes as adults and exhibit high fecundity, such as the cyprinids and Sacramento sucker. Several of the cyprinids (e.g., hitch, Sacramento pikeminnow, hardhead) and the Sacramento sucker make upstream migrations from lakes and low-elevation valley-bottom reaches into tributaries or swifter upstream reaches to spawn. Individual cyprinids in smaller streams may move only a short distance from pools to riffles or heads of pools to spawn (e.g., Sacramento pikeminnow, hardhead). The native cyprinids and the Sacramento sucker are broadcast spawners that do not build nests, defend spawning territories, or care for young. Some of these species spawn primarily over gravel in riffles (Sacramento pikeminnow, hardhead, Sacramento sucker). Other native fishes spawn in shallow-water habitats with dense aquatic vegetation (e.g., Sacramento blackfish, Sacramento perch). Sacramento splittail spawn on floodplains inundated by high flows in the spring, with eggs adhering to submerged vegetation and debris (Moyle 2002). Some species exhibit care of young through building of nests (e.g., threespine stickleback, Sacramento perch, prickly sculpin). Tule perch bear live young, often in shoreline areas with dense aquatic vegetation or overhanging riparian vegetation.

Larvae of many native fishes rear in shallow water habitats with dense cover that provides protection from predators. The once extensive floodplains and lakes of the San Joaquin Valley likely provided important spawning and rearing habitat for many native fishes. The loss of floodplain habitats and potential effects on native fish species are discussed in more detail in Section 7.7.3. Adults of some native fish species (e.g., hitch, tule perch, and Sacramento perch) prefer slow-moving reaches with dense aquatic vegetation. Native fishes that occupy larger, open-water reaches of the mainstem as adults include streamlined cyprinids such as Sacramento blackfish, Sacramento splittail, Sacramento pikeminnow, and hardhead (Moyle 1976).

Native resident fish display considerable dispersal capabilities. Superior dispersal capabilities allow fish to rapidly recolonize portions of a stream or basin where populations have been eliminated by natural or anthropogenic disturbances (Moyle 2002). The most common dispersal pattern is for adult fish to move upstream to spawn, which results in dispersal of young downstream throughout the system (Moyle et al. 1982). Several of the native cyprinids and the Sacramento sucker employ this life-history strategy.

7.6.1. Life Histories and Habitat Requirements of Selected Native Resident Fish

This section describes the life histories and habitat requirements of representative native resident fish. Appendix B includes additional species accounts for most native and non-native resident fish.

7.6.1.1. Sacramento pikeminnow

Pikeminnows are long-lived and thus well-equipped for persisting through periods of extended drought and low reproduction (Moyle 2002). Individuals may remain in a single home pool or small area for many years (Taft and Murphy 1950, as cited in Moyle 2002) or may undertake long migrations, particularly from March through May when they may migrate upstream to spawn (USBR 1983, as cited in Moyle 2002). Adult pikeminnows in large rivers or reservoirs usually move into tributaries to spawn, while fish in small or medium-sized streams usually move to the nearest riffle (Grant 1992, Taft and Murphy 1950, Mulligan 1975; all as cited in Moyle 2002). Spawning takes place over gravel in riffles or shallow flowing water at the tails of pools (Moyle 2002). Spawning movements occur during April and May (Grant 1992, Taft and Murphy 1950, Mulligan 1975; all as cited in Moyle 2002), but larvae have been found as late as July (Wang 1986, as cited in Moyle 2002).

Pikeminnows generally inhabit streams where summer water temperatures range from 64.4^{o}F to 82.4^{o}F and will seek temperatures in the upper part of this range in suitable habitat (Brown and Moyle 1993, Baltz et al. 1987, Dettman 1976; all as cited in Moyle 2002). A temperature of near 78.8^{o}F is the maximum preferred temperature and temperatures above 100.4^{o}F are lethal (Knight 1985, as cited in Moyle 2002). The species is most abundant where summer water temperatures exceed 68^{o}F for extended periods of time (Moyle et al. 1982). They are rarely found in water with salinities higher than 5 ppt (parts per thousand), but have been found in salinities as high as 8 ppt (Moyle 2002). Pikeminnows are opportunistic top predators. Juveniles feed primarily on aquatic insects. After reaching a length between 4 inches and 8 inches, they switch to feeding on fish and crayfish (Brown and Moyle 1996, Brown 1990, Taft and Murphy 1950, USBR 1983; all as cited in Moyle 2002). The diet of pikeminnows larger than 8 inches consists almost exclusively of fish and crayfish; however, large insects, frogs, and small mammals may also be eaten.

The Sacramento pikeminnow is still common in the Central Valley, although Moyle (2002) notes that they may be less abundant in low-elevation areas where they were once the dominant predator species. Moyle and Nichols (1973) noted that adult pikeminnows are generally scarce or absent in disturbed habitats where introduced fishes such as carp or centrarchids are present in large numbers, although juvenile pikeminnows may be numerous in the sloughs of the Delta where introduced fishes are common.

7.6.1.2. Hardhead

Hardhead are large cyprinids endemic to the Sacramento-San Joaquin drainage (Moyle 1976). In the Central Valley, the species occupies the relatively undisturbed reaches of larger low- to mid-elevation streams (Mayden et al. 1991, Moyle and Daniels 1982, both as cited in Moyle 2002) and the mainstem Sacramento River (Reeves 1964, as cited in Moyle 2002). They appear to have very restricted microhabitat preferences, being found “only in the sections of large, warm streams that contain deep, rock-bottomed pools” (Moyle et al. 1982). Juveniles are found in pools and shallower areas of these same stream reaches (Moyle et al. 1982). Deep (>2.5 feet) pools and runs with sand-gravel-boulder substrates, low turbidities, and low water velocities (0.7 ft/s to 1.3 ft/s) appear to be preferred (Mayden et al. 1991, Cooper 1983, Knight 1985, Moyle and Baltz 1985, Alley 1977; all as cited in Moyle 2002). The species belongs to the pikeminnow-hardhead-sucker assemblage, being always found in association with Sacramento pikeminnow, and often with Sacramento sucker (Moyle 2002).

Spawning by hardhead occurs primarily in April and May (Reeves 1964, Grant and Maslin 1997, both as cited in Moyle 2002), but may extend into August in some foothill streams (Wang 1986, as cited in Moyle 2002). Adult fish from larger rivers or reservoirs may undertake upstream spawning migrations into tributaries to spawn (Wales 1946, Moyle et al. 1995, both as cited in Moyle 2002). Others may move only a short distance from a home pool upstream or downstream to spawn (Grant and Maslin 1997, as cited in Moyle 2002). Although spawning activity has not been observed, hardhead are thought to spawn over gravel in riffles, runs, or the heads of pools (Moyle 2002). Little is known regarding their early life history; larval and post-larval fish likely remain along the edges of streams in dense cover and move into deeper habitats as they grow (Moyle 2002).

Hardhead most often occur in streams with temperatures over 68°F; they prefer relatively warm water temperatures, with optimal temperatures being 75.2° F to 82.4°F (Knight 1985, as cited in Moyle 2002). They are relatively intolerant of the low dissolved oxygen concentrations that occur at higher temperatures, which may be a factor influencing their distribution (Cech et al. 1990, as cited in Moyle 2002). Water velocity may act as a barrier to their movements because hardhead have relatively poor swimming ability at low temperatures (Myrick 1996, as cited in Moyle 2002).

Hardhead are omnivorous, feeding on benthic invertebrates and plant material, as well as drift (Alley 1977, both as cited in Moyle 2002). Juveniles feed on aquatic macroinvertebrates and small snails (Reeves 1964, as cited in Moyle 2002). Adults feed on large invertebrates (such as crayfish), and plants (primarily filamentous algae) (Moyle 1976).

Hardhead are usually absent where introduced species form a dominant portion of the fish community and in stream reaches that have been substantially altered by human disturbance (Baltz and Moyle 1993, as cited in Moyle 2002). Although historically widespread and abundant in the San Joaquin system (Reeves 1964, as cited in Moyle 2002), their current distribution indicates that populations have declined and that habitat fragmentation may be a factor affecting their long-term persistence (Moyle 2002). Habitat loss and predation by smallmouth bass and other non-native centrarchids appear to be the most important factors in the decline of hardhead populations.

7.6.1.3. Sacramento Sucker

The Sacramento sucker is endemic to the Sacramento-San Joaquin drainage and is currently a common and widely distributed species in central and northern California (Moyle 2002). They are an important member of the pikeminnow-hardhead-sucker assemblage. Sacramento suckers are now relatively uncommon in low-elevation reaches where they historically occurred, but their distribution has expanded in reservoirs and regulated streams (Moyle 2002). Sacramento suckers live in a variety of habitats, from cold, swift streams to warm sloughs and low-salinity areas of estuaries, but are most abundant in clear cool-water streams (Moyle and Nichols 1973, Brown and Moyle 1993, both as cited in Moyle 2002) and in lakes and reservoirs at elevations from 600 feet to 2,000 feet (Moyle 2002). Adult suckers are most numerous in larger streams and juveniles primarily inhabit tributaries or shallower reaches of large rivers inhabited by adults (Moyle 2002). Adults are generally absent from higher gradient, cool streams that lack large pools (Moyle et al. 1982). They are found both in association with native cyprinids as well as with non-native species (Moyle 2002).

Sacramento suckers in larger rivers or reservoirs often migrate into tributaries to spawn; these movements into spawning streams may begin as early as December (Moyle 2002). Spawning generally takes place over gravel riffles between late February and early June, with peak spawning in March and April (Villa 1985, Mulligan 1975, both as cited in Moyle 2002). Larvae tend to rear in shallow, warm, stream margin habitats over detritus substrate or among emergent vegetation (Moyle 2002). Juvenile suckers may move downstream into larger rivers or reservoirs after a period of rearing in the spawning tributary, or remain in shallow habitats with dense cover in streams with resident populations (Moyle 2002).

Suckers can live in streams with a wide range of water temperatures, from cool streams where temperatures are rarely above 59° F to 60.8°F, to streams where temperatures reach 84.2°F to 86°F (Cech et al. 1990, as cited in Moyle 2002). Their preferred temperature appears to be within the range of 68° F to 77°F (Knight 1985, as cited in Moyle 2002). Salinities exceeding 13 ppt may be tolerated by adult Sacramento suckers (Moyle 2002). Suckers generally feed on the bottom, with algae, detritus, and small invertebrates forming most of the diet.

Sacramento suckers are tremendously resilient to disturbance due to their longevity and ability to successfully seed an area with young in years following catastrophic population declines. Because of this, sucker populations may often be characterized by non-uniform age structures with strong and weak (or missing) year classes (Moyle 2002). It appears that reproductive success is highest in years when high flows increase the amount of available spawning habitat and increase the amount of flooded shallow habitat preferred as rearing habitat by larvae and small juvenile suckers (Moyle 2002).

7.6.1.4. Sacramento Perch

Sacramento perch are the only member of the centrarchid family native to streams west of the Rocky Mountains. In the San Joaquin Valley, Sacramento perch formerly occupied sloughs, slow-moving streams, and lakes at elevations below 328 feet and were an abundant member of the deep-bodied fish assemblage (Moyle 2002). They are associated with aquatic and emergent vegetation and other forms of underwater cover; however, they have also been found to be abundant in shallow, highly turbid reservoirs with no aquatic vegetation (Moyle 2002). The species is able to tolerate turbid water, high temperatures (preferred temperatures range from 77°F to 82.4°F), and high salinities and alkalinities (Moyle 2002).

Spawning habitat consists of shallow areas (8 inches to 20 inches deep) with dense growth of aquatic macrophytes or filamentous algae nearby. Rock piles and submerged roots or woody debris may also attract spawning fish (Moyle 2002). Spawning substrate ranges from clay and mud to rocks (Aceituno and Vanicek 1976; Mathews 1962, 1965; Murphy 1948a; all as cited in Moyle 2002). Spawning occurs from late March through early August; late May and early June are generally peak spawning times (Moyle 2002). Spawning occurs at temperatures from 64.4 °F to 84.2°F (P. Crain, University of California, unpubl. data 1998; as cited in Moyle 2002). Sacramento perch defend nests until larvae can swim well enough to leave the nests, but their eggs are still vulnerable to predation from schools of sunfish or large individual fish such as carp (Moyle et al. 2002). Larvae are planktonic for approximately 1 to 2 weeks before settling into aquatic vegetation or shallow water; during this time they are likely vulnerable to predation by many native and non-native fish species. Presence of aquatic vegetation appears essential for young-of-the-year Sacramento perch rearing in moderately clear water (Moyle 2002). Turbid water may afford similar cover. Very little is known regarding the early life history stages of Sacramento perch and whether physical or chemical factors may limit their survival (Moyle et al. 2002).

Young-of-the-year Sacramento perch “feed mostly on small crustacteans (amphipods, cladocerans, ostracods, and copepods) that are usually associated with the bottom or with aquatic plants” (Moyle 2002). As they grow, aquatic insect larvae and pupae, especially chironomids, become more important in the diet. Fish may be eaten by perch over 3.5 inches in length, as is observed in large lakes such as Pyramid Lake (Moyle 2002). In small lakes and ponds, chironomids and other aquatic macroinvertebrates continue to be important in the diet of large perch, with small crustaceans and fish of secondary importance.

Sacramento perch are currently extirpated from their historical range in the San Joaquin Valley, but persist in reservoirs where they have been introduced. Extant populations of Sacramento perch currently appear to be limited to habitats where non-native centrarchids are excluded by high alkalinities or lack of introductions. One exception is in Clear Lake, where a small population appears to persist despite the presence of six other non-native centrarchids. Black crappie and bluegill appear to be the species that most strongly compete with Sacramento perch for food and space (Moyle 2002).

7.6.1.5. Tule Perch

Tule perch are the only freshwater member of the surfperch family, and they are endemic to the Sacramento-San Joaquin drainage. They were historically distributed in most low-elevation streams in the Central Valley as part of the deep-bodied fish assemblage (Moyle 2002). Within the San Joaquin drainage, they currently occur mainly in the Stanislaus River, but are also found in the lower San Joaquin River, within the Delta, and in the lower Tuolumne River (Moyle 2002). They use a variety of valley-floor habitats from lakes and estuarine sloughs to clear streams (Moyle 2002). Within streams, they are associated with “beds of emergent aquatic plants, deep pools, and banks with complex cover, such as overhanging bushes, fallen trees, and undercutting” (Moyle 2002). The cover provided by large boulders along the edges of large deep pools (Moyle and Daniels 1982, Brown 2000, both as cited in Moyle 2002) or riprap may also be used (Moyle 2002).

Tule perch give birth to as many as 60 live young in low-velocity aquatic habitats or backwaters with aquatic vegetation or dense overhanging riparian vegetation (Moyle 2002). Young are born in May and June and may begin to form aggregations soon after (Moyle 2002). Tule perch are associated with cool waters and high dissolved oxygen concentrations; they are rarely found in streams that are warmer than 77^{o}F for extended periods of time, and generally prefer temperatures below 71.6^{o}F (Knight 1985, as cited in Moyle 2002). Tule perch tolerate high salinities and are found where salinities fluctuate annually from 0 to 19 ppt (Moyle 2002), and may occur in salinities as high as 30 ppt (R. Leidy, U. S. Environmental Protection Agency, pers. comm., as cited in Moyle 2002). Tule perch feed on small invertebrates associated with the benthos or aquatic vegetation, but may also feed on zooplankton in the water column (Moyle 2002).

This species has been extirpated from most of its habitat within the San Joaquin basin. The reasons for their disappearance appear to be poor water quality and contaminants (Moyle 2002). Isolated populations are extremely vulnerable to extinction from catastrophic disturbances. The species remains abundant in the regulated mainstem of the Sacramento River in areas with heavy cover or growth of aquatic plants (Moyle 2002).

7.6.1.6. Sacramento Splittail

The Sacramento splittail is endemic to the Sacramento-San Joaquin drainage, including the Sacramento-San Joaquin Delta, Suisun Bay, Suisun Marsh, and other portions of the Sacramento-San Joaquin estuary. The species’ original range included much of the San Joaquin Valley in the zone occupied by the deep-bodied fish assemblage. Sacramento splittail are a relatively long-lived cyprinid species found primarily in marshes, turbid sloughs and slow-moving river reaches. The species’ dependency on floodplains for spawning has made the species a key indicator for floodplain habitat quality and quantity.

Adult splittail tend to congregate and feed for two to three months before spawning in areas of inundated floodplain vegetation. Splittail spawn from February through June on floodplains inundated by spring high flows, with peak spawning in March and April. Splittail are broadcast spawners with adhesive eggs that attach to submerged vegetation and woody debris, which can make the eggs susceptible to dessication if water levels recede too quickly. After spawning, adults move into the lower Delta, where they remain until the fall rains begin. Larvae are believed to rear in the vicinity of the spawning grounds for up to two weeks (Wang 1986, as cited in Moyle 2000, Sommer et al. 1997) before moving into deeper water as they become stronger swimmers. Juvenile splittail rear in upstream areas for a few weeks to a year or more before moving to tidal fresh and brackish waters (Moyle et al. 2000). Juvenile splittail spend their first year of life in the lower Delta and lower reaches of streams. There is an increase in Sacramento splittail spawning habitat and access to spawning habitat during high flow years where floodplain inundation occurs. The Sutter and Yolo bypasses currently provide essential spawning and rearing habitat for splittail (Moyle et al. 2000). At least a month of bypass inundation appears to be needed for the development of a strong year-class (Sommer et al. 1997).

Splittail primarily inhabit fresh water, but are also found in water with salinities of 10 ppt to 18 ppt (Moyle et al. 1995). Not much is known about water quality tolerances of Sacramento splittail. Juvenile and adult splittail demonstrate optimal growth at 68^{o}F, and signs of physiological distress only above 84.2^{o}F (Cech and Young 1995 as cited in Winternitz and Wadsworth 1997). Splittail can survive very low dissolved oxygen concentrations (0.6 ppm to 1.2 ppm for young-of-the-year, juveniles, and subadults) (Young and Cech 1995, 1996).

Splittail forage benthically for invertebrates and detrital material (Daniels and Moyle 1983), and are thought to feed extensively on opossum shrimp (*Neomysis mercedis*) (Moyle et al. 1995). Inundated areas can provide abundant food sources and vegetated cover from predators (Sommer et al. 1997). Cladocerans have been documented as important prey of splittail (Stevens 1966). Feyrer and Matern (2000) found that splittail also consume *Potamocorbula amurensis*, the estuarine Asian clam found in San Pablo Bay through Suisun Bay, and most abundant in the Suisun Marsh region. Terrestrial invertebrate prey may also be important for splittail.

Sacramento splittail were listed as federally threatened in 1999. The loss of floodplain and large lake spawning habitat is believed to have been a major contributor to their decline in the San Joaquin basin (Moyle 2002). Moyle (2002) notes that splittail have “disappeared as permanent residents from portions of the Sacramento and San Joaquin Valleys because dams, diversions, channelization, and agricultural drainage have either eliminated or drastically altered much of the lowland habitat they once occupied or else made it inaccessible except during wet years.” Most splittail are currently found in the San Francisco Estuary, primarily in the Delta and Suisun Marsh (Moyle 2002). The Yolo Bypass appears to provide high quality spawning habitat for splittail during years when outflows are high during April and May when the species spawns.

7.6.1.7. Sacramento Blackfish

Sacramento blackfish are a cyprinid endemic to low-elevation reaches of the Sacramento and San Joaquin rivers and their tributaries; they are also native to Clear Lake and the Pajaro and Salinas rivers (Moyle 2002). They are one of the few native species of the deep-bodied fish assemblage that have persisted on the valley floor despite extreme changes to Central Valley habitats (Saiki 1984), although they may be less abundant in low-elevation habitats than historically (Moyle 2002).

Blackfish are most abundant in warm and usually turbid habitats of the Central Valley floor. Habitats used by blackfish include: oxbow lakes and sloughs in the Sacramento-San Joaquin Delta (Turner 1966, as cited in Moyle 2002); large, sluggish mainstem channels (Moyle 2002); and deep turbid pools with fine substrates of mud or clay in streams and rivers (Smith 1977, 1982, both as cited in Moyle 2002). They are believed to have been formerly abundant in the large Tulare and Buena Vista lakes of the San Joaquin Valley (Moyle 2002).

Observations of spawning are rare due to their preference for turbid habitats. Spawning in Clear Lake has been observed to take place in shallow areas with dense aquatic vegetation between April and July at temperatures of 53.6°F to 5.2°F (Moyle 2002). Larvae remain in shallow water, particularly where aquatic vegetation is present, but may also be found in open water (Wang 1986, as cited in Moyle 2002). Blackfish appear well-adapted for spawning in floodplain habitats of the valley floor.

The species is very tolerant of poor water quality (Brown and Moyle 1993). Adult blackfish are found where temperatures in the summer exceed 86°F and dissolved oxygen concentrations are low (Moyle 2002). Optimal temperatures appear to be from 71.6°F to 77°F (Smith 1977, 1982, Cech et al. 1979; all as cited in Moyle 2002). Upper lethal temperatures may be near 98.6°F (Knight 1985, as cited as Moyle 2002), suggesting that blackfish have adapted to survive through periods of drought and extreme low flows (Moyle 2002).

Blackfish are filter-feeding herbivores that feed primarily on plankton in suspension as adults (Monaco et al. 1981, Staley 1980, Murphy 1950, Cook et al. 1964, Johnson and Vinyard 1987, Sanderson and Cech 1992, 1995; all as cited in Moyle 2002). Juveniles feed on zooplankton and insects picked from the water column or substrate (Murphy 1950, Sanderson and Cech 1992, 1995, Cech and Linden 1987; all as cited in Moyle 2002). In lakes and ponds, blackfish may also feed off the bottom on soft material rich in organic matter and small invertebrates (Moyle 2002).

7.6.1.8. Hitch

Hitch are medium-sized cyprinids endemic to the Sacramento-San Joaquin basin that currently occur in scattered populations throughout the Central Valley in warm, low-elevation lakes, sloughs, and slow-moving reaches of streams (Moyle 2002). They may also be found in cool, sand-bottom streams (Brown and Moyle 1993, Leidy 1984, Moyle and Nichols 1973, Smith 1982; all as cited in Moyle 2002). Adults in lakes are usually pelagic (Moyle 2002). Hitch are omnivorous open water feeders on filamentous algae and aquatic and terrestrial insects (Moyle 2002).

Hitch spawn primarily in riffles of streams tributary to larger open-water habitats after flows increase following spring rains (Moyle 2002). Large spawning migrations from lakes may take place from March into June. Larvae and juvenile hitch rear in shallow areas with dense cover from aquatic or emergent vegetation or debris.

Hitch can tolerate the highest temperatures of any Central Valley native fish. They select temperatures from 80.6 °F to 82.4°F, and can withstand temperatures up to 100.4°F for short periods (Knight 1985, as cited in Moyle 2002). They have been found in water with salinities as high as 9 ppt (J. Smith, California State University, San Jose, pers. comm., as cited in Moyle 2002).

Hitch were formerly associated with the native deep-bodied fish assemblage, but are now most commonly found with non-native species that occupy low-elevation habitats (Moyle 2002). Sacramento blackfish, Sacramento sucker, and Sacramento pikeminnow may be found with hitch in less disturbed areas (Leidy 1984, Moyle and Nichols 1973, both as cited in Moyle 2002). Populations of hitch appear to be declining and increasingly isolated from one another (Moyle 2002). Some populations in the San Joaquin River appear to have been extirpated in recent years (Brown and Moyle 1993). Potential factors contributing to their decline include reductions in high spring flows for spawning, loss of summer rearing and holding habitat, increased pollution, and predation by non-native species (Moyle 2002).

7.7. CHANGES IN FISH HABITAT FROM HISTORICAL CONDITIONS

The San Joaquin River was historically an alluvial river downstream of the present-day Friant Dam, with several morphological transitions that often delineate the Reaches used in this report (i.e., Reaches 1-5). Within this broader alluvial river context, the gravel-bedded Reach 1 had several bedrock exposures that controlled gradient of the river, was often multiple-channeled, was low slope, and periodically migrated or avulsed during large floods. In downstream reaches (Reach 2 through 5), the river was sand-bedded, meandering, and in some reaches, multiple-channeled. Downstream reaches were also noted for their flood basins adjacent to the river (Reaches 3 through 5), which had extensive tule marsh and sloughs. Riparian vegetation varied between the reaches, with patchy riparian vegetation in Reach 1, more extensive but narrow riparian forests in Reaches 2 and 3, extensive tule marsh in Reach 3 through 5, and riparian levees in Reaches 3 through 5. Floodplains and flood basins were vast and were seasonally inundated to allow fish access to high quality ephemeral aquatic habitat. Portions of less-disturbed, lower elevation floodplain developed dense forest flora and was a highly productive interface between aquatic and terrestrial habitats. Our understanding of how certain fish species used floodplain and flood basin habitat is better known (e.g., threadfin shad, delta smelt); however, other resident fish are less understood (e.g., fry, juvenile, and smolting Chinook salmon).

Significant changes in physical (fluvial geomorphic) processes and streamflows in the San Joaquin River have resulted in large-scale alterations to the river channel and associated aquatic, riparian, and floodplain habitats. This section presents a conceptual model of how fluvial geomorphic processes and the natural flow regime created and maintained aquatic habitat and native fish populations, then summarizes the major hydrologic, geomorphic, and habitat changes that have occurred as a result of regulation from Friant Dam and land use impacts. This section finally assesses the potential effects of these changes on native fish species.

7.7.1. Hydrograph Components and Connectivity to Fish Life History and Habitat

Typical of Central Valley rivers and a semi-arid climate, the natural or “unimpaired” flow regime of the San Joaquin River historically provided large variation in the magnitude, timing, duration, and frequency of streamflows, both inter-annually and seasonally. Variability in streamflows provided conditions that partially helped sustain multiple salmonid life history trajectories, as well as life history phases of numerous resident native fish species. To understand the importance of streamflows to fish life history patterns, we evaluated key components of the natural flow regime, using historical and synthetic unimpaired streamflow data for the San Joaquin River at Friant (USGS STN# 11-251000) for the period of record 1896–1999. See Chapter 2 for a description of the analytical process used to develop this combination of measured and modeled daily average flow records. This data provides an approximate representation of streamflow conditions to which the native resident fish assemblages had adapted to best survive over the long-term.

We evaluated unimpaired hydrograph components, and the associated variability in magnitude, timing, duration, and frequency to determine a median or mean value, peak value, and/or minima and maxima representative of each water year class (see Chapter 2). We then related these hydrograph components to the distinct life history stages of anadromous salmonids (and other fish species). Unimpaired hydrograph components were then compared to regulated flow conditions, again using San Joaquin River at Friant (USGS STN # 11-251000) for the period 1950–2000. Five water year classes were developed for this analysis in Chapter 2, and the streamflow ranges expressed for each hydrograph component represent typical or median conditions ranging from Critically Dry to Extremely Wet water year conditions (these water year classes do not reflect any water year designations that may be used by USBR or DWR). The hydrograph component analysis in Chapter

2 identified five distinct components: Summer-Fall baseflows, Fall and Winter Floods, Winter Baseflows, Snowmelt Peak Flows, and Snowmelt Recession Limb. The following discussion includes Reach 1 and Reach 2 where the Friant gaging station reasonably reflects hydrology; however, Reaches 3 through 5 had inflows (e.g., Fresno Slough and tributaries) and extensive flood basins such that the Friant gaging station hydrology magnitude does not reflect actual conditions in those reaches, but the hydrograph component timing and patterns are very similar.

7.7.1.1. Summer-Fall Baseflows

Summer/fall baseflows represent minimum annual streamflow conditions, which typically commenced in the San Joaquin River with the cessation of the spring snowmelt hydrograph in July or early August and extended into October or November of most water years. Typical baseflows during this period ranged from approximately 200 to 600 cfs during normal and drier years and infrequently higher (600 to 800 cfs) early in summer during wetter water years when winter snow pack was high (Figure 7-7). Minimum flows during this period sometimes fell to 100 cfs and infrequently lower during extreme drought conditions. Flows generally decreased as the season progressed, allowing water temperatures to increase with increases in air temperatures. Spring Chinook salmon were present during this period, holding in deeper pools in Reach 1 and upstream reaches now blocked by Friant Dam (CDFG 1921; Hatton 1940, both as cited in Yoshiyama et al. 1996; Clark 1942), until ambient and water temperatures decreased to allow spawning activity to initiate. These moderate magnitude baseflows were historically supplemented in downstream reaches by artesian springs and shallow groundwater contributions (see Chapter 4), but the unimpaired accretion flows is unknown because the earliest downstream gaging station began in 1910, well after substantial diversions had begun upstream.

Under regulated conditions, summer and fall baseflows in Reach 1 is strictly controlled by Friant Dam releases, typically ranging from 50 cfs to 90 cfs in the winter months, and 150 cfs to 250 cfs in the summer months. The change in baseflows from historical conditions depends on the water year and season, but can be reduced to 10% or more of unimpaired values in winter months, and can be slightly increased during dry summers due to flow releases for riparian diversions. These baseflows in Reach 1 are quickly diverted and/or infiltrate into the shallow groundwater table, such that the river is typically dry in Reach 2. Friant Dam releases baseflows for riparian diverters and groundwater infiltration so that minimum instream flow at the last riparian diversion (approximately at Gravelly Ford, RM 229) is 5 cfs. Below Gravelly Ford (Reach 2), the channel is typically dry down to the Mendota Pool, where the Delta Mendota Canal (DMC) adds 300 cfs during the winter to Reach 3 and up to 600 cfs in the summer. This baseflow is conveyed downstream to Sack Dam, where it is diverted into the Arroyo Canal. The San Joaquin River is again dewatered downstream of Sack Dam (Reach 4), and agricultural return water begins to rewater the river in the downstream half of Reach 4B. Much more flow is contributed to Reach 5 by agricultural return flows from the Eastside Bypass and Bear Creek, then Salt and Mud Sloughs.

Historically, baseflows in all reaches supported native resident warm water species, and allowed free migration upstream and downstream. Warm water temperatures probably limited salmonid use of downstream reaches during the summer baseflow periods, with the possible exception of cold-water refugia that may have occurred under unimpaired groundwater conditions (local artesian springs and groundwater seeps). Fall baseflows were important migration periods for adult fall-run Chinook salmon, and the moderate baseflows provided adequate hydraulic and depth conditions for adult fish passage (Figure 7-7). Historical references described fish migrating through Reaches 3 through 5 at flows as low as 100 cfs, but the observer noted extensive damage to the fishes bellies from abrasion while swimming across sand bars (CDFG 1955). Present day conditions for all native

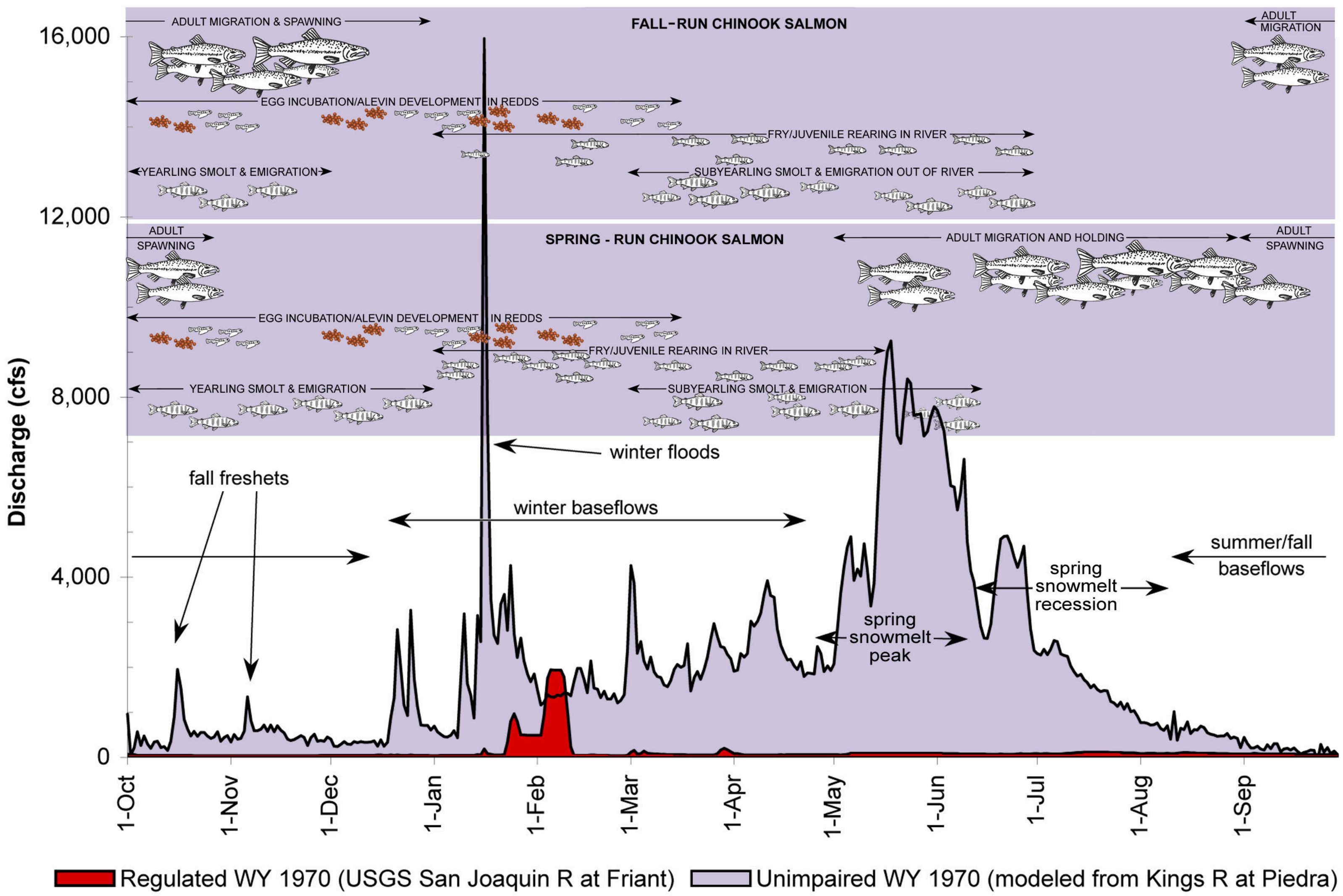


Figure 7-7. Annual unimpaired hydrograph of the San Joaquin River at Friant (reconstructed based on data from Kings River at Piedra USGS #11-222000) and regulated flows at Friant (USGS #11-251000) for WY 1970 (approximately average water year conditions), showing typical hydrograph components and the important life history stages of fall-run Chinook salmon.

species are only favorable for migration and rearing in Reaches 1, 3, and 5, since Reaches 2 and 4 are nearly always dry. During the summer months, Reach 1 is the only reach that would have suitable water temperatures to support juvenile salmonids (with moderate flow releases from Friant Dam). Holding habitat for adult spring-run Chinook salmon would be reduced due to lower water depths and higher water temperatures (shorter length of river with suitable temperatures). Juvenile rearing habitat would probably be reduced slightly in all years but the driest due to reduced baseflows and higher water temperatures. Lower baseflows also reduces access to lateral habitats, and increases vulnerability to predation, and can impact macroinvertebrate food production (Everest et al. 1985). Restoring salmonid populations would require continuous flows through all reaches of at least 100 cfs during the periods of adult migration, and potentially more for juvenile salmonids depending on their outmigration timing (to provide suitable water temperatures).

7.7.1.2. Fall and Winter Floods

Between October and late December, early seasonal storms provided relatively low magnitude, short duration freshets in the San Joaquin River (Figure 7-7). These unimpaired flows ranged from approximately 1,000 cfs to 2,500 cfs (median values), and generally increased in magnitude as the winter storms intensified and soils in the watershed became saturated. Fall storms may have contributed to triggering upstream migration of fall-run Chinook salmon, and perhaps allowed late spawning adult spring-run Chinook salmon to migrate further upstream to additional spawning areas. Historical fall baseflows probably provided adequate flow magnitude to allow adult salmonid passage through all reaches, but the freshets may have had some effect of concentrating the specific timing of larger groups of fish migrating up the river. Since these freshets were a function of individual rainstorms, they are absent from many unimpaired annual hydrographs, generally reflecting local weather patterns for those years (Appendix A). The fall freshets may have also played a role in the reducing inter-breeding of fall-run Chinook salmon and spring-run Chinook salmon. Spring-run tended to spawn in September and October (generally prior to the freshets), and the fall freshets may have provided later spawners the ability to migrate upstream further if necessary. Additionally, if the fall freshets did provide a migratory cue for fall-run Chinook salmon (debatable), they would have arrived at the spawning areas after the spring-run had already spawned, reducing the possibility of inter-breeding.

Under regulated conditions, runoff from fall freshets is captured by Millerton Lake and thus natural fall storm hydrographs are virtually absent in the lower San Joaquin River. The exception is during years following Extremely Wet water years, in which flows up to approximately 1,000 cfs are released from Friant Dam to evacuate flood storage space prior to the onset of winter. This situation occurred in 1983, 1984, 1999, and 2000. It is debatable whether adult fall-run Chinook salmon on the San Joaquin River historically required fall freshets to allow migration, so we do not fully understand the full ecological significance of losing these fall freshets. The impacts of losing the fall freshet on spring-run and fall-run Chinook salmon interbreeding is probably minor compared to the potential impact of Friant Dam forcing both to spawn in the same reach. Elimination of fall freshets under the regulated flow regime may have additional ecological consequences that we are currently unaware of, and should be considered in Restoration Study development.

Typically occurring between mid-December and April, winter floods were generated by rainfall or rain-on-snow storm events (Figure 7-7). These floods were usually the largest over the period of record as larger magnitude, short duration rain-on-snow events generally occurred in late December through January. Smaller magnitude rainfall-only events produced moderate magnitude floods through April, but the magnitude of these storms generally tapered off as winter progressed and precipitation fell primarily as snowfall. Unimpaired median winter floods ranged between 4,000 and

28,000 cfs depending on water year type. Annual instantaneous flood magnitudes from the pre-dam period of record commonly ranged from 10,000 to 30,000 cfs, with several floods exceeding 50,000. The peak hourly inflow into Millerton Reservoir during the 1997 flood was 95,000 cfs (ACOE, 1999). These historic high flows would occur during the time that salmonid eggs were incubating in gravels in Reach 1 and upstream reaches, and bed scour during larger floods certainly caused some mortality to the incubating eggs. Furthermore, emerging fry are not well suited to survive high velocities immediately after hatching and emerging from the gravels, such that there was probably fry mortality caused by these floods. However, the diversity of the pre-dam channel distributed spawners over many locations of the channel (including side-channels), and this distribution of spawning location ensured that a catastrophic loss of the cohort during a large flood would not occur. Likewise, the complex channel morphology and accessible floodplains mitigated water velocities during these large floods, providing velocity refugia to fry.

Under regulated conditions, most winter floods are either captured entirely by Millerton Reservoir or severely attenuated before passing downstream. However, the relatively small storage capacity of Millerton Reservoir (520,500 ac-ft) compared to the average annual inflow (1,801,000 ac-ft) still allows flows in the range of 5,000 to 16,000 cfs to be released under flood control conditions from Friant Dam. Most winters, however, have relatively small magnitude flood peaks, well below 1,000 cfs. The reduction in high flows has many significant geomorphic impacts to channel morphology, which is described in more detail in Chapter 3. Common impacts to fish habitat by the severe reduction in high flow regime includes buildup of fine sediment (sand) in spawning areas (Reach 1), virtual cessation of lateral channel migration and avulsion in all reaches, riparian encroachment in reaches with perennial flows that has confined the low flow channel and simplified channel morphology, local imbalances in the sediment budget, and reduction in the magnitude, frequency, and duration of bedload transport events in Reach 1. These geomorphic processes were responsible for creating and maintaining suitable salmonid habitat, as well as aquatic and terrestrial habitats for other species. These flood events likely partially distributed juveniles into downstream reaches and onto floodplains where flood magnitudes were attenuated and inundated floodplain habitat was available for rearing. Reduced winter floods have greatly decreased the magnitude, duration and frequency of floodplain inundation, thus decreasing available overwinter habitat for juvenile salmonids and other native fishes.

7.7.1.3. Winter Baseflows

In the unimpaired hydrograph, winter baseflows were low to moderate flows between individual winter storm events that generally occurred between December and April (Figure 7-7). Winter baseflows were maintained by the receding limbs of individual storm hydrographs and shallow groundwater discharge, and generally increased in magnitude throughout the winter as soil moisture content increased, shallow groundwater tables rose, and soils became saturated. Flow conditions during winter months were highly variable, and wetter years generally exhibited higher baseflow magnitudes. Unimpaired median winter baseflows ranged between 300 cfs to 900 cfs depending on water year class and sequence of storm events, and occasionally reached as high as 1,700 cfs during wetter water years.

Regulated winter baseflows have been significantly reduced in most water years, and are now strictly Friant Dam releases between 50 cfs to 100 cfs. Winter baseflows have been reduced by up to 95% in Reach 1, and 100% in Reach 2 and Reach 4. These baseflows vary between 50 cfs and 100 cfs through the winter, and do not tend to exceed 200 cfs except during wetter water years when flood releases from Friant Dam are necessary. These infrequent flood control releases generally range between 1,000 cfs and 3,000 cfs, and usually are less than 8,000 cfs per Army Corps of Engineers

(ACOE) requirements (see Chapter 5). The reduced winter baseflows impact salmonid adult migration (particularly winter-run steelhead) through Reaches 2 and 4, as well as greatly reducing juvenile rearing habitat in all reaches. The most significant impacts of reduced winter baseflows would likely be reduced access to off-channel habitat and floodplain rearing for fry and juvenile salmonids, and creation of favorable conditions for non-native fish that predate on salmonids and other native fish.

7.7.1.4. Snowmelt Peak Flows

Snowmelt floods were generally smaller in magnitude, but longer in duration, than winter floods, and generally began in April, peaked in June–July, then receded into late-July and August of wetter years (Figure 7-7). Prior to construction of Friant Dam, the spring snowmelt flood hydrograph component was the largest contributor to the total annual water yield, with sustained flows ranging from 5,000 cfs to 19,000 cfs (median values) depending on the water year, with occasional peaks in excess of 25,000 cfs. Many snowmelt floods had multiple peaks, responding to cycles of hotter ambient air temperatures. These unimpaired snowmelt floods likely transported gravels and cobbles in Reach 1 and upstream reaches, increased turbidity, probably kept water temperatures reasonably low in downstream reaches, and inundated extensive areas of floodplain in the lower reaches of the San Joaquin River at a time when cottonwood and willows were distributing seed. This latter process was important in causing natural regeneration of these species on an infrequent basis when the peak flow was large enough and recession limb were gradual enough for a successful recruitment year. Additionally, fall-run Chinook salmon, steelhead, and likely spring-run Chinook salmon juveniles and smolts outmigrated during the spring snowmelt flood, which likely provided adequate water temperatures for outmigration, overbank flows for juvenile rearing on floodplains and side channels, and moderate turbidity to increase outmigration success (Figure 7-7). Adult spring-run Chinook salmon also migrated into Reach 1 and upstream reaches during the snowmelt floods.

Similar to winter floods, most spring snowmelt floods are captured or attenuated by Millerton Reservoir. Most years have no snowmelt runoff release from Friant Dam, except during wetter years when the flood storage space is encroached and flood control releases are invoked. These flood control releases usually range between 2,000 and 5,000 cfs, but can be as high as 8,000 cfs. Normal and drier water years receive only summer baseflow releases. The loss of snowmelt floods in the mid 1940's ultimately led to the extirpation of the remaining spring-run Chinook salmon. The near loss of the spring snowlmelt floods would have severely impacted the ability of fall-run Chinook salmon smolts from outmigrating (had fall-run still been in the river at that time). The loss of the spring snowmelt hydrograph has also greatly reduced riparian recruitment on floodplains and encouraged riparian encroachment along the low flow channel, which has simplified channel morphology and aquatic habitats. These snowmelt floods and subsequent gradual increases in water temperatures that accompanied the snowmelt recession likely encouraged smolting of juvenile fall-run Chinook salmon, and may have also provided cues for migrating towards the Delta. These floods also distributed juveniles onto floodplains where flood magnitudes were attenuated and inundated floodplain habitat was available for rearing. The near elimination of snowmelt floods has greatly decreased the magnitude, duration and frequency of floodplain inundation, thus decreasing available springtime rearing habitat for juvenile salmonids and other native fishes. Remediating the loss of the snowmelt floods and the geomorphic and ecological functions that it provided will be a significant challenge for future restoration of the San Joaquin River.

7.7.1.5. Snowmelt Recession Limb

The snowmelt recession limb connects the snowmelt floods to the summer baseflows (Figure 7-7). During wetter years, the snowmelt recession extended into July and August in wetter years, but generally ended in June in drier water year types (Appendix A). The timing, magnitude, and duration of the snowmelt recession depended on the water year type, with larger, longer, and later recessions occurring during wetter years than drier years. The snowmelt recession provided many of the same ecological functions as the snowmelt peak floods, but was usually geomorphically less significant than the snowmelt peak floods. Sand transport in downstream reaches certainly occurred, and some channel migration or bank calving may have occurred, but gravel transport in Reach 1 and upstream reaches was probably minimal. Fall-run Chinook salmon smolt outmigration and spring-run Chinook salmon adult immigration occurred during this period, with migration ending as flows decreased and water temperatures increased. The snowmelt recession generally maintained extensive floodplain inundation rearing, particularly important for juvenile and smolting salmonids slowly migrating from spawning grounds through the lower river and into the Delta. Later (and larger) recession limbs extended the duration of lower river and Delta rearing, before water temperatures increased and smolts exited to the ocean. Additionally, the snowmelt recession rate was important factor in whether riparian seedlings survived to establishment phase (discussed more in Chapter 8).

As with the snowmelt flood hydrograph component, the recession has also been eliminated in most water years. In those infrequent years with flood control releases during the historic snowmelt recession, Friant Dam releases are operated such that once the flood control space is achieved, releases to the river are abruptly dropped to summer baseflows. These sudden drops in flow can occur over 1-2 days, which is much faster than the historical recession rates. The loss of the snowmelt recession component has similar ecological impacts as the loss of the snowmelt flood component. Elimination of the snowmelt recession reduced access to complex habitat for emigrating salmonids, likely resulting in decreased growth rates and increased exposure to predation. The steep recession caused by Friant Dam operations at the end of infrequent flood control releases also reduces the survival of cottonwood and willow seedlings that may have initiated during the snowmelt peak (flood control releases). The root system on a seedling on a high surface cannot grow its taproot fast enough to keep up with the rapidly declining capillary fringe, and the seedling dies. The exception is for seedlings that establish along the low flow channel. Because their roots are already at the summer baseflow water table, they survive and often cause riparian encroachment.

7.7.1.6. Hydrograph Component Considerations for Non-Native Species

Changes in seasonal flow patterns may reduce the abundance and distribution of native resident fish species and promote the persistence of non-native fish species. Streams in the western United States may be quickly invaded by non-native fishes when they are dammed and natural fluctuations in seasonal flow patterns are reduced (Moyle 1976, Minckley and Meffe 1987; both as cited in Moyle and Light 1996). Moyle and Light (1996) suggest that established native fish communities can maintain their integrity despite continued invasions by non-native fish where highly fluctuating natural conditions exist, with non-native fish persisting only where habitats have been highly disturbed by human activities (Moyle and Light 1996). Increasing flows in the fall and winter to improve spawning and rearing habitat for Chinook salmon and other anadromous fish does not provide the spring flows needed by resident fish for spawning and rearing (Moyle et al. 1998). Moyle (2002) attributes the decline of hitch in the San Joaquin River at least partially to loss of spring spawning flows. Sacramento splittail are another native cyprinid that spawned on floodplains inundated by spring high flows (Moyle 2002). To improve conditions in Putah Creek (a tributary to Yolo Bypass in the Sacramento Valley) for native resident fish, Moyle et al. (1998) proposed increasing flows in February and March to favor the spawning and rearing of native resident fishes in that stream, and to provide pulse flows every three to five years to reduce numbers of non-native species that are not adapted to high flow events.

7.7.2. Fluvial Processes, Channel Form, and Aquatic Habitat

Contemporary understanding of river ecosystems now recognizes that the underlying hydrology (water) and geology (sediment, techtonics) are the primary governing variables of these systems; how water, sediment, vegetation and human influences interact together (fluvial processes) define the resulting channel form (Figure 7-8). Correspondingly, the resulting channel form defines aquatic and terrestrial habitat within the river corridor, which influences the biota that humans are usually interested in managing. Figure 7-8 can be put in a hierarchical perspective: SUPPLY ➔ PROCESSES ➔ FORM ➔ HABITAT ➔ BIOTA. Changes to the input variables (SUPPLY) in this conceptual system usually cascades down to the biota, but this cascading effect is usually not adequately considered before the change is imposed on the system (e.g., how will Friant Dam impact aquatic habitat downstream of the dam). The primary natural components of the SUPPLY tier are water and sediment, with some influence by large wood. The primary natural components of the PROCESSES tier are sediment transport, sediment deposition, channel migration, channel avulsion, nutrient exchange, and surface water-groundwater exchange. Sediment transport and deposition form alluvial features, including alternate bars and floodplain surfaces. In turn, these channel and floodplain features provide the physical location and suitable conditions that define habitat for aquatic organisms, including native fish species. Channel morphology is thus a critical linkage between physical riverine processes and the native biota that use the river corridor.

Alternating bars are considered basic units of alluvial rivers (Dietrich 1987), and this conceptual framework is also useful in describing links between alluvial river form and aquatic habitat (Trush et al. 2000). Each alternate bar is composed of an aggradational lobe (point bar) and scour hole (pool) connected by a riffle (Figure 7-9). A variable flow regime caused spatial and temporal differences in sediment transport, scour, and deposition on alternate bar features to create morphologic and hydraulic complexity, which in turn produces diverse, high quality aquatic habitat (Figure 7-9), including:

- adult holding habitat in pools;
- preferred hydraulic conditions and substrates for spawning in riffles and pool tails;
- high quality egg incubation environment in permeable, frequently mobilized spawning gravels;
- winter and spring rearing habitat in cobble substrates along slack-water bar surfaces, and in shallow backwater zones behind point bars;
- fry and juvenile velocity refugia and ephemeral rearing habitat on inundated bar and floodplain surfaces during high flows;
- abundant primary and secondary (food) production areas on the surface of gravels and cobbles, on woody debris, and on floodplains (terrestrial invertebrates);
- large organic debris and nutrient input (logs, root-wad, leaf litter, salmon carcasses) that provides structural diversity as well as a primary source of nutrients for lower trophic levels.

A dynamic alternating bar morphology is only one indicator of a properly functioning alluvial channel. Floodplains, terrace complexes, and side channel networks are also key morphological indicators. These depositional features may not be the direct consequence of alternate bar formation, but all are interdependent to varying degrees. As the channel migrates (over a time span of years to decades), large wood is contributed into the channel, cobbles and gravels are deposited on the inside of the bend in the gravel bedded reaches, sand bars are deposited on the inside bend in the sand-bedded reaches, and fine sediment is deposited on developing floodplains at the backside of alternate bars (Figure 7-10). Riparian vegetation initiates on these new floodplain surfaces, and as it matures and the channel eventually migrates again, this mature riparian vegetation is again contributed to the river.

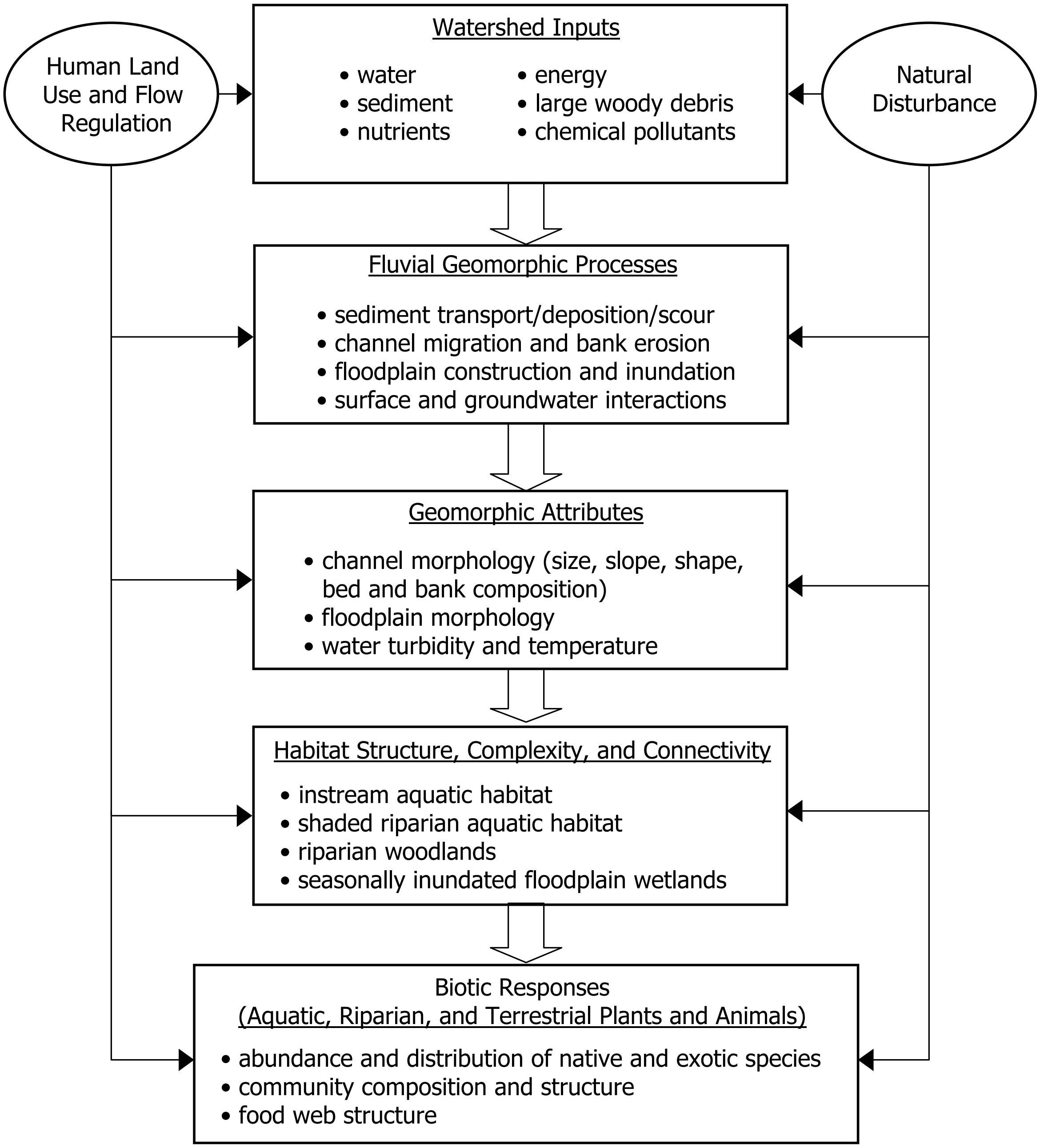


Figure 7-8. A simplified conceptual model of the physical and ecological linkages in alluvial river-floodplain systems.

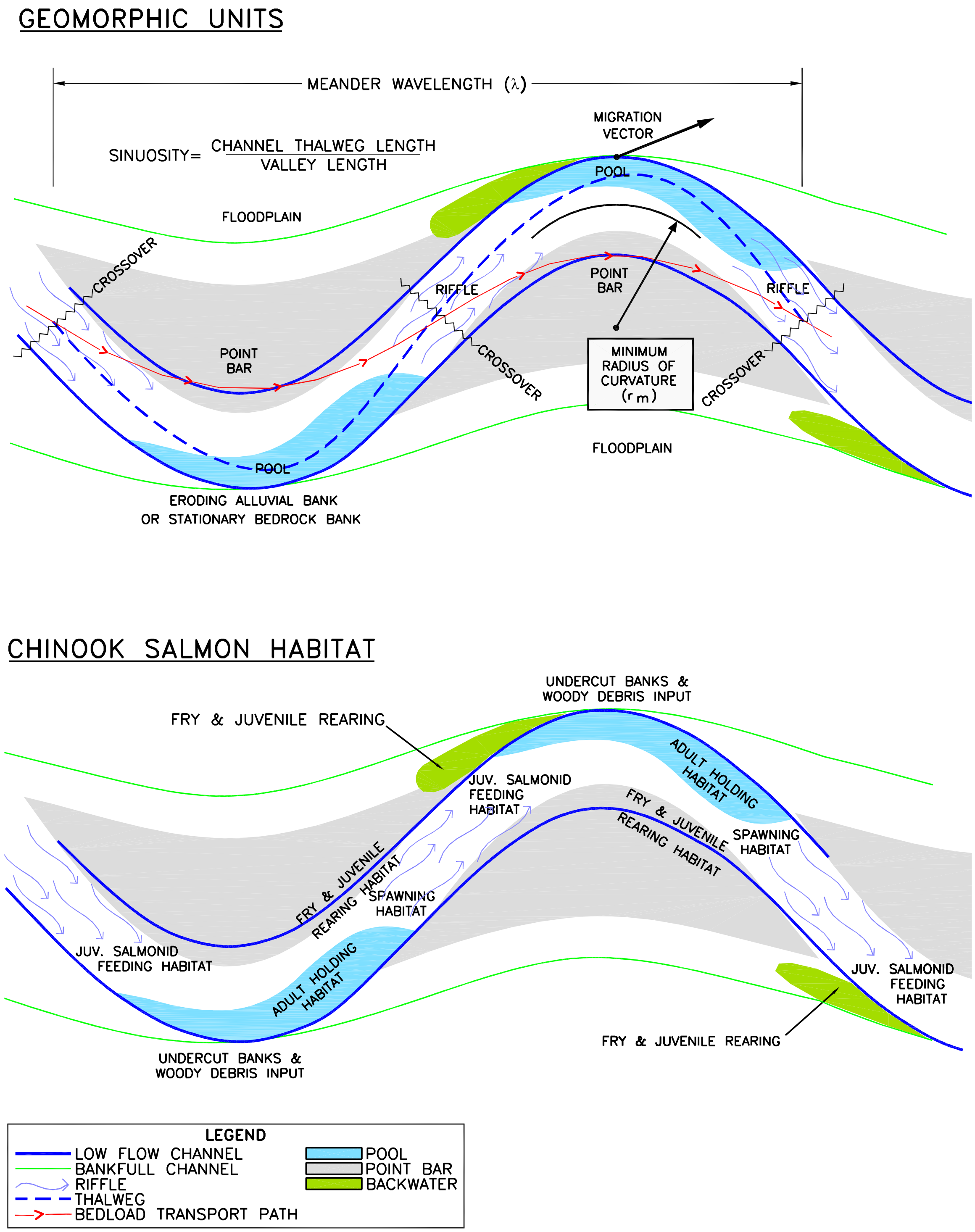
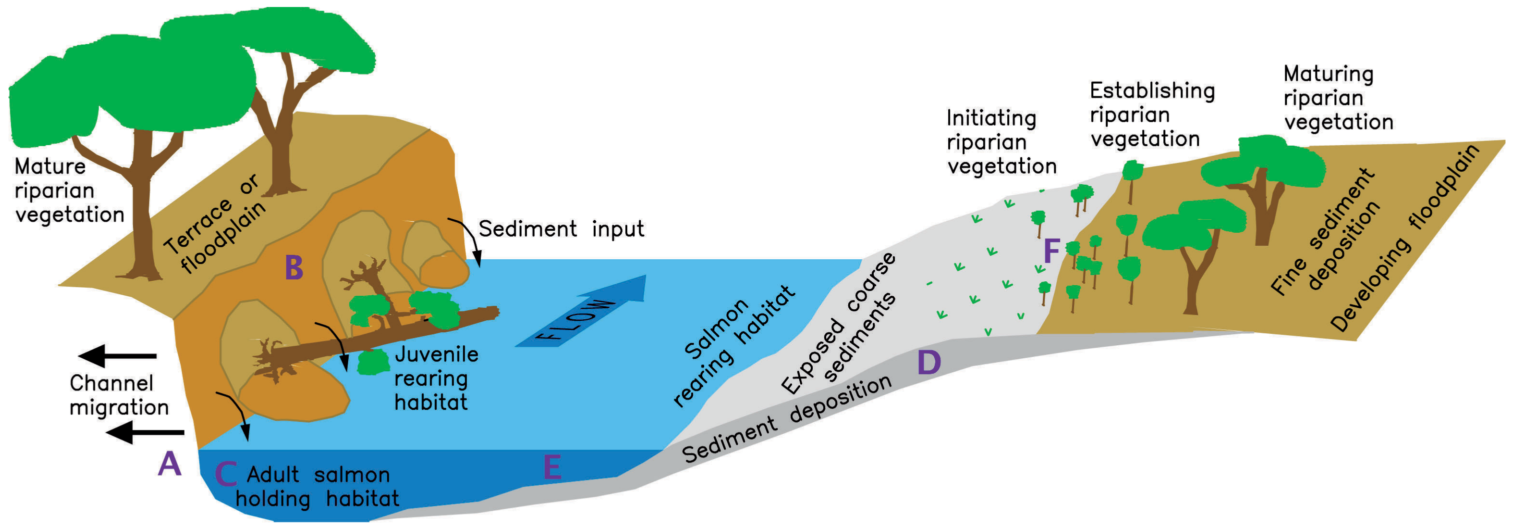


Figure 7-9. Idealized alternate bar morphology (modified from Dietrich 1987), showing conceptual relationships between alternate bar features and Chinook salmon habitat (modified from Trush et al. 2000).



Conceptual linkages between channel migration and fish habitat. (A) A channel with adequate space to migrate erodes the channel bank on the outside of the meander bend during high flows, (B) encouraging mature riparian trees to topple into the channel. (C) The pool along with large wood on the outside of the bend provide structural complexity for good fish habitat. As bank erosion continues, the pool "migrates" laterally and downstream, but high quality habitat is maintained. (D) On the inside of the bend high flows scour and redeposit sediments (gravel in Reach 1, sand in downstream reaches), forming a shallow bar on the inside of the bend. (E) In Reach 1, this area provides slow-water rearing conditions for fry and juvenile chinook salmon, as well as habitat for aquatic insects (fish food), amphibians and reptiles. (F) Progressively higher up the gravel bar surface, receding water levels during the spring snowmelt allow riparian seedlings to establish. Newly established woody riparian seedlings are sporadically scoured out, but those established high enough on the bank become mature to eventually topple into the channel as the river migrates back across the valley (A). Large floods create scour channels on upper bar surfaces and inundate floodplains, providing juvenile salmon rearing habitat during higher flows.

Figure 7-10. Idealized channel migration process, showing relationship between migration and salmonid habitat contributions by migration.

This idealistic description of alluvial channel dynamics and morphology is much more complex in a natural riverine setting. The San Joaquin River has several reaches (e.g., Reach 1, Reach 4, and portions of other reaches) with multiple split channels, side channels, or sloughs. In Reach 1, these split channels and side channels were likely very important spawning areas, as well as fry and juvenile rearing habitat. Figure 7-11 shows an example of this relatively complex channel morphology in Reach 1 (RM 258.5) in 1938. A larger-scale alternate bar encompasses the entire figure (does not have a dashed box around it), while smaller-scale alternate bars in split channels nested within this larger feature. Riparian vegetation, while evident in the 1938 photograph, does not dominate channel morphology due to frequent high flows, sediment transport, and lateral channel movement. As discussed in Chapter 8, removal of the high flow disturbance regime often results in the riparian vegetation establishing and maturing along the low flow channel (riparian encroachment), which has a net result of simplifying channel morphology and reducing habitat quantity, quality, and diversity. The 1938 photograph attempts to illustrate the habitat benefits of the historic channel morphology and historic hydrologic regime: baseflows provide adequate spawning and rearing habitat, but as flows increase during storm events or snowmelt runoff, flows spill into side channels, high flow scour channels, and floodplains to provide additional habitat and/or high water velocity refugia.

In reaches downstream of that shown in Figure 7-11, the river loses confinement from the bluffs and terraces in Reach 1, and enters the valley floor of the Central Valley. As described in Chapter 3 and Chapter 8, the valley floor over the study reach was an extensive flood basin that frequently had prolonged inundation, particularly in during the spring snowmelt runoff period. Numerous sloughs, oxbows, and high flow scour channels in these downstream reaches (in addition to the flood basins and tule marshes) likely provided enormous amounts of salmonid rearing habitat during winter and spring months. These inundated flood basins and tule marshes provided substantial habitat for other native resident fish species, including threadfin shad and others. Due to the limited amount of historical temperature data available in these downstream reaches, it is unknown how late into the spring and summer that water temperatures would have been low enough to support salmonids, although there may have been local artesian springs and groundwater seeps that may have provided local refugia.

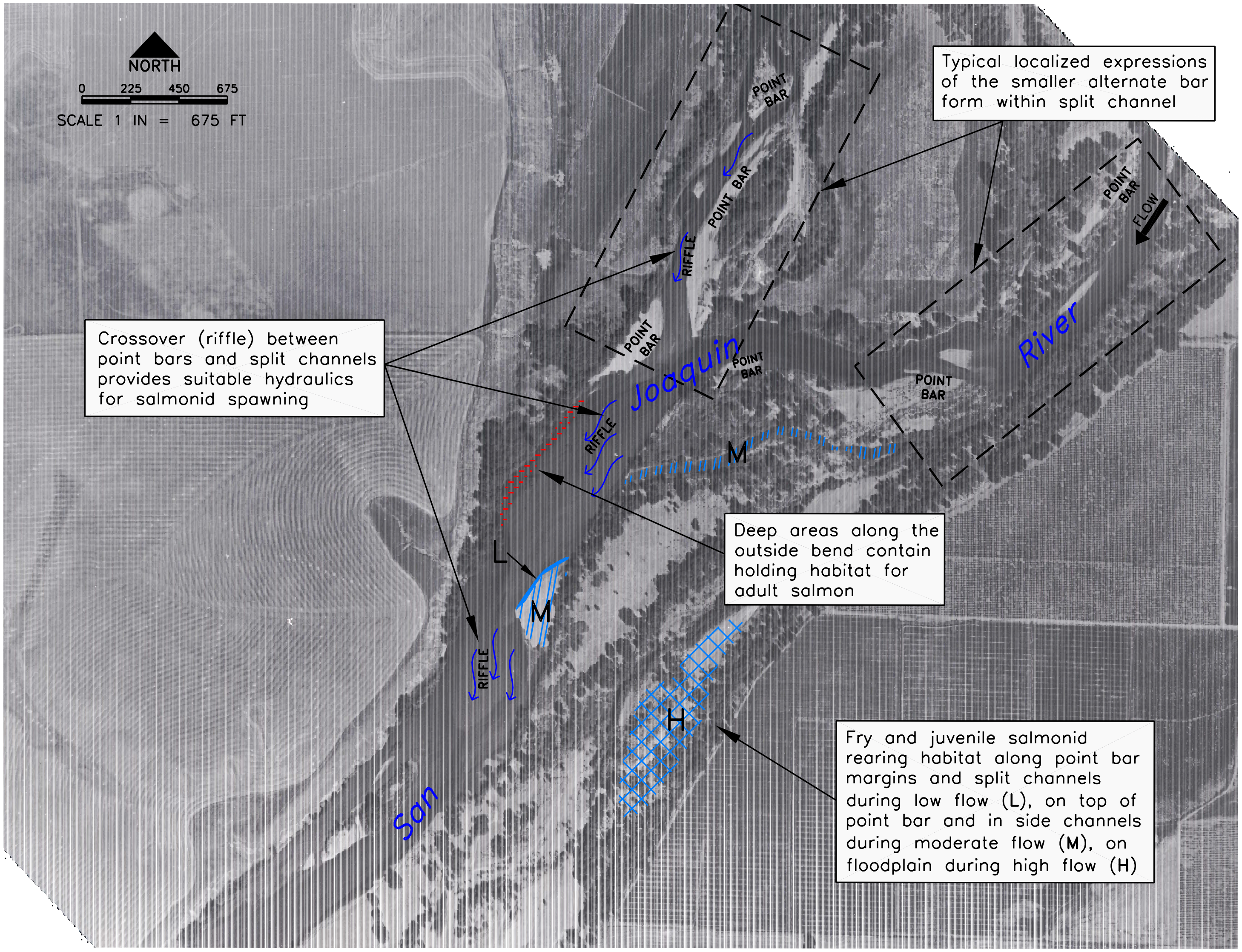
This historical channel morphology, and the habitat provided by it, was radically changed with the arrival of Euro-Americans in the late 1700's, culminating in the river conditions of the present. The frequency and distribution of habitat types and micro-habitat features have changed substantially compared to historical conditions. A reach-by-reach description of channel and floodplain changes, and the potential impacts to different life stages of anadromous salmonids as well as native fish species is provided below.

7.7.3. Changes in Fluvial Processes and Channel Morphology

The historical descriptions of fluvial processes and channel morphology contained in Chapter 3 and summarized above have been severely altered by Euro-American activities, which have had corresponding impacts to fish habitat and life history. There is very little site-specific information available on the San Joaquin River to describe these changes; therefore, our description below relies heavily on observations of impacts on tributaries to the San Joaquin River where one would expect the impacts to be similar.

7.7.3.1. Channel Morphology

There have been many changes to channel morphology over the study reach, with the most pronounced as follows:



Typical localized expressions of the smaller alternate bar form within split channel

Crossover (riffle) between point bars and split channels provides suitable hydraulics for salmonid spawning

Deep areas along the outside bend contain holding habitat for adult salmon

Fry and juvenile salmonid rearing habitat along point bar margins and split channels during low flow (L), on top of point bar and in side channels during moderate flow (**M**), on floodplain during high flow (H)

Figure 7-11. 1938 aerial photograph of the San Joaquin River in Reach 1 (RM 258.5) showing diverse alluvial features of the historic San Joaquin River channel that provided different habitat components for Chinook salmon. Similar channel form-habitat linkages exist for other native fishes, but are not shown on this figure.

- Reach 1: Pits from instream gravel mining, loss of exposed gravel bars and floodplains from "off-channel" gravel mining, riparian encroachment, probable accumulation of fine sediment in the channel, and probable small amount of channel incision
- Reach 2-4: Agricultural encroachment has reclaimed floodplains, levees confine the river during high flows and reduce inundated floodplain, and riparian encroachment (except in Reach 2).
- Reach 5: Project levees confine the river during high flows

Implications of gravel mining pits on salmonids in Reach 1 include impacts to coarse sediment routing, direct loss of spawning and rearing habitat, and predation. As has been demonstrated on the Tuolumne River, these pits provide habitat conducive to fish species that prey on juvenile salmonids, such as largemouth, smallmouth, and red eye bass (EA Engineering, 1991b). Gravel pits have also converted what was historically lotic habitat, to lentic habitat that may provide habitat for Sacramento pikeminnow. Direct loss of spawning habitat by gravel mining, combined with blocked access to upstream spawning areas and loss of upstream gravel supply by Friant Dam, has likely greatly reduced the historical quantity of spawning habitat on the San Joaquin River. Rearing habitat was also significantly reduced by the direct loss of habitat from gravel mining, as well as loss of floodplain access, loss of side channels, and reduced flows. Pools used for spring-run Chinook salmon holding over the summer downstream of Friant Dam still remain; however, field observations may suggest that they may have partially filled in with sand and gravel as a result of the reduced flow regime after Friant Dam was completed, although there is no quantitative data to evaluate this. There has been additional field reconnaissance to evaluate the quantity and suitability of potential holding pools in Reach 1 as part of the restoration strategies, but the results have not been summarized to date.

Habitat conditions for salmonids in Reaches 2 through 5 have been substantially modified by levee/dike construction, agricultural encroachment, and water diversions. These have reduced the quantity of floodplain habitat, as well reduced main channel complexity and off-channel habitat in these reaches. Because these reaches are sand bedded, the primary impact to salmonids has been a decrease in the amount of complex rearing, refuge, and foraging habitat for juvenile salmonids during the winter and early spring months. Floodplain habitat in these downstream reaches of the San Joaquin River was historically extensive and vegetated with tule marsh, with narrower bands of willow, cottonwood, box elder, and Oregon ash along the channel margins and flood basin margins (see Chapter 8 for more description). Much of this floodplain habitat has been isolated from the river by dikes and levees, and that remaining floodplain habitat is rarely inundated under current hydrologic conditions. Under current conditions, juvenile anadromous salmonids produced in Reach 1 would be forced to rear in the main channel, and based on recent research of juvenile growth rates on inundated floodplains (Sommer et al. 2001), growth rates in the main channel may be less than historically occurred on inundated floodplains, with increased predation mortality and increased vulnerability to displacement by high flows. Developing a strategy for juvenile rearing and growth will be an important component of the restoration strategies developed as part of the Restoration Study.

Habitat conditions for native warm water fish have likewise been negatively impacted in Reach 2 through 5. Shallow floodplain and lake habitats historically present on the San Joaquin Valley floor provided warm, productive shallow-water habitat with dense vegetative cover for spawning and rearing of native fish. Floodplain and off-channel habitat in Reaches 4 and 5 would have provided substantial areas of vegetated floodplain habitat used by Sacramento splittail, Sacramento perch, and Sacramento blackfish for spawning, rearing, and overwintering. Fry and juvenile fish dispersed in these habitats would have been less vulnerable to predation by larger fish that reside in deeper, main-channel habitats. These shallow-water habitats have been substantially reduced in area from historical conditions. Loss of these shallow vegetated habitats, combined with the introduction of numerous non-native predaceous fish have likely worked in combination to reduce the abundance and distribution of several native fish species, particularly Sacramento splittail. Other species that likely used floodplains for spawning, including Sacramento blackfish and Sacramento suckers, appear to be doing well, although they may not be as abundant as they formerly were on the valley floor (Moyle 2002). Deeper oxbow lakes and off-channel pools in floodplains may have provided oversummering habitat and areas where fish might persist during periods of extended drought; the loss of these oxbows may also have affected native fish populations.

7.7.3.2. Sediment Supply and Spawning Gravels

Sediment is supplied to rivers as a result of erosional processes in headwater streams and tributaries. In addition to erosion/transport processes, the bed and banks of alluvial rivers also supply the channel with sediment. In concept, an alluvial channel morphology is maintained in a "dynamic quasi-equilibrium" by transporting its sediment load downstream at a rate approximately equal to the sediment supply (Lane 1955). This process maintains the channel in a generally constant form over time, despite the continual routing of sediment through the system. Sediment moving through the system is intermittently stored in depositional features such as gravel and cobble point bars in Reach 1, sandy point bars in Reaches 2 through 5, or on floodplains and terraces in all reaches. These sediment deposits become sorted by particle size and provide an additional level of complexity and habitat for aquatic organisms. The most obvious example is salmonid spawning gravels.

As described in Chapter 3, Friant Dam has eliminated sediment supply from the upper watershed, and combined with the modified flow regime and land used downstream of Friant Dam, varying degrees of sediment budget imbalance has occurred in downstream reaches. These local imbalances have caused local aggradation (sedimentation) and degradation (incision) over the reaches, which can have significant consequences for the channel morphology within the study reaches. The current paradigm of dam impacts to sediment supply downstream of the dams is that periodic high flow releases from the dam transports sediment stored in the bed, and because the sediment supply from the upper watershed is blocked, channel degradation occurs downstream of the dam (Collier et al., 1996). Instream gravel mining would exacerbate this sediment deficit. However, the low slope in Reach 1 probably resulted in very low coarse sediment transport rates, and combined with intermittent bedrock control in the upper portions of Reach 1, the amount of channel degradation has probably been fairly modest. Cain (1997) reports 1939-1996 thalweg elevations increasing at two cross sections by approximately 3 feet, with thalweg elevations at the remaining six cross sections lowering between 5 feet to 18 feet due to a combination of dam impacts and gravel mining. Typically, if unreplenished from upstream sources, alluvial features (bars and riffles) slowly diminish, causing channel widening and bed degradation. Smaller particle clasts, such as spawning gravels, are more readily mobilized, and spawning gravel storage in reaches below Friant Dam may have gradually been reduced over time. The combination of reduced sediment storage and blocked supply has likely reduced the amount of suitable spawning gravel and habitat in Reaches 1 and 2 relative to historical conditions.

Clark (1942) conducted detailed surveys of the San Joaquin River for available spawning gravel, though it is not clear what criteria were used to determine suitability. An estimated 417,000 ft^2 of suitable spawning gravel was found in 26 miles of channel between Lanes Bridge (RM 255) and the Kerchoff Powerhouse (14 miles upstream of Friant Dam), where most spawning was historically observed (Table 7-5). Friant Dam inundated 36% of this spawning gravel estimate, leaving about 266,800 ft^2 of suitable spawning gravel in the channel in the reach between Lanes Bridge and Friant Dam. In 1943, an estimate of 1,000,000 ft^2 of suitable spawning gravel at 350 cfs was made in the reach between Gravelly Ford and Friant Dam (38 miles of channel) (Fry and Hughes 1958, as cited in Cain 1997). In 1957 Ehlers (R. Ehlers, pers. comm., as cited in Cain 1997) estimated over twice as much (2,600,000 ft^2) of suitable spawning gravel occurred in the same reach, only 70% of which (1,820,000 ft^2) was useable for spawning. By the late 1950s, CDFG (1957) was concerned that heavy silt and sand deposited by gravel mining operations was damaging the last of the available suitable spawning habitat, which at that time they believed was confined to the 13 miles below Friant Dam (Reach 1 upstream of Lanes Bridge).

Several recent estimates of spawning gravel quantity have been made. Cain (1997) estimated a total of 303,000 ft^2 of spawning gravel between Gravelly Ford and Friant Dam (Table 7-5). Most riffles in this reach were described as having suitable gravels, and Cain (1997) attributed the decline of spawning gravel in this reach to effects of Friant Dam, gravel mining operations, and riparian vegetation encroachment.

In summer and fall of 2000, Jones and Stokes Associates (JSA) and Entrix conducted surveys of potential spawning gravel in the upper San Joaquin River. Areas considered suitable were delineated, recorded on aerial photos, and transferred to a GIS. These surveys estimated 773,000 ft^2 of spawning habitat for salmon and steelhead available between Friant Dam (RM 267) and Skaggs Bridge (RM 234), of which 408,000 ft^2 contained less than 40% fines based on ocular estimates (Table 7-4).

In spring 2002, a second survey was conducted to map suitable spawning gravel in the reach from the RM 267 (Friant Dam) to RM 243 (Highway 99). Spawning habitat suitability was based on the depth, velocity, and substrate requirements for Chinook salmon and steelhead, as described in detail in Appendix B. Thirty-nine riffles were observed in the 12 miles of river between Lanes Bridge and Friant Dam, and an additional 26 riffles were observed in the 12 miles of river between Highway 99 and Lanes Bridge. Many riffles were composed of two or more sub-patches, often varying in substrate quality and hydraulic suitability. Over 357,000 ft^2 of suitable spawning gravel was delineated between Highway 99 Bridge and Friant Dam, of which approximately 281,400 ft^2 of suitable spawning gravel occurred between Lanes Bridge and Friant Dam (Table 7-5). Riffles were typically small (average = 5,500 ft^2) and infrequent. Many riffles were adjacent to suitable rearing habitat, particularly upstream of Lanes Bridge, but very few riffles were adjacent to suitable holding habitat. Substrate was generally well-rounded, with low embededdness, and low fines. There appeared to be a high proportion of coarse sand (>0.08 inches) upstream of Lanes Bridge, and a higher proportion of fine sand (<0.08 inches) downstream of Lanes Bridge. Table 7-5 summarizes spawning gravel quantity estimates from Friant Dam to Gravelly Ford as reported both historically and currently.

Table 7-5. Summary of anadromous salmonid spawning habitat estimates on the upper San Joaquin River.

Source	**Date of survey**	**Extent of survey**	**Estimate 1 (ft^2)**	**Estimate 2 (ft^2)**
Clark (1942)	1942	Lanes Bridge (RM 255.2) to Kirkhoff Powerhouse (281.5)	417,000	266,800[a]
Fry and Hughes (1958)	1943	Gravelly Ford (RM 229) to Friant Dam (267.5)	1,000,000[b]	none
R. Ehlers, pers. comm., in Cain (1997)	1957	Gravelly Ford (RM 229) to Friant Dam (267.5)	2,600,000	1,820,000[c]
Cain (1997)	1996	Gravelly Ford (RM 229) to Friant Dam (267.5)	303,000	none
Jones and Stokes Assoc./Entrix, this document	2001	Friant Dam to Skaggs Bridge	773,000 [d]	408,000[d,e]
Stillwater Sciences, this document	2002	Friant Dam to Highway 99 Bridge	357,000[f]	281,400[a,f]

[a] spawning habitat between Lanes Bridge and Friant Dam (RM 267.5)

[b] estimated at 350 cfs, so incorporated hydraulic suitability

[c] 70% of 2,600,000 ft^2 was suitable, presumable criteria was quality (limit of fines in gravel)

[d] included gravel beyond the baseflow channel (e.g., on point bars, etc.), probable over-estimate

[e] based on portion of spawning gravel with less than 40% fines (ocular estimate)

[f] incorporated hydraulic suitability at potential spawning baseflows

Between Friant Dam and Lanes Bridge (12 miles of channel), historical estimates of spawning gravel quantity of 266,800 ft^2 (Clark 1942) are mostly comparable to current estimates of 281,400 ft^2 (based on recent surveys, and assuming use of similar suitability criteria). Looking at a more expanded reach between Friant Dam and Gravelly Ford (38 miles of channel), historical estimates of 1,000,000 ft^2 and 1,820,000 ft^2 (Ehlers 1957, Fry and Hughes 1958, both as cited in Cain 1997) are significantly greater than current estimates of 303,000 ft^2 (Cain 1997). The various spawning gravel surveys are somewhat difficult to compare due to differing (or unknown) suitability criteria and methods, so a conclusion cannot be confidently made to the degree of spawning habitat loss. Simple review of historical photographs and obvious effects of gravel mining impacts dictates that some significant loss of suitable spawning habitat has occurred. Further, infiltration of fine sediment from gravel mining and other fine sediment sources downstream of Friant Dam, as well as high water temperatures during the fall in downstream portions of Reach 1 may reduce the incubation success of salmonid eggs. However, the impact of reduced spawning gravel quantity and quality on future salmon populations has not been quantified, and can only be properly evaluated in relation to other potential limiting factors.

7.7.3.3. Channel Migration and Avulsion

Channel migration and avulsion are typically considered undesirable because migration can damage human structures (bridges, etc.), cause property loss on the eroding bank, and reduce agricultural production. However, as described above, channel migration and avulsion was a critical process for salmonid habitat, as well as for riparian regeneration and large wood debris recruitment into the channel. The steady conversion of land for agricultural production, and correlated levees and dikes, has channelized the river channel. Agricultural conversion has directly reduced the amount of floodplains, and levees and dikes have further isolated historic floodplains from the channel. Additionally, bank protection along channel margins and reduced flow regime has stabilized the channel, reduced bank erosion, reduced lateral migration, and greatly reduced the processes that create complex side channels and high flow scour channels.

Impacts of these activities to fish habitat has been significant. Undercut banks, riparian vegetation, and recruitment of large woody debris have all been reduced or eliminated as a consequence of channel stabilization, and the corresponding habitat benefits realized by these processes have been largely eliminated. Reduced channel migration has eliminated off-channel habitats, reduced complex side channels, and reduced instream habitat complexity for native fish species. The loss of undercut banks and large woody debris reduces cover and velocity refuge for salmonids, increasing exposure to predation and high flows. The loss of riparian vegetation recruitment may contribute to increased stream temperatures, and reduced complexity during the now rare periods of floodplain inundation. Overall, reduced channel migration has contributed to conditions in which future salmonids produced in the river would be forced to rear in a simplified channel, possibly reducing growth rates and increasing exposure to predation.

7.7.4. Habitat Connectivity

7.7.4.1. Physical Barriers

Physical structures and environmental conditions can reduce habitat connectivity and migratory access between habitats. Upstream and downstream movement past physical structures such as dams or weirs requires depth and velocity conditions conducive to unimpeded passage. If structures are not designed to provide passage, fish ladders or other modifications may be necessary to provide conditions that attract migrating fish and enable them to pass successfully. Signicifant structures in the study area that are impediments to both upstream and downstream fish movement are illustrated in Figure 7-12, and include:

- a weir located just upstream of the confluence with the Merced River (RM 118) to direct migrating adult salmonid into the Merced River and prevent them from entering the San Joaquin River, which has been operated by the California Department of Fish and Game since 1950;
- a drop structure on the Eastside Bypass near its confluence with the San Joaquin River (RM 138);
- a drop structure on the Mariposa Bypass near its confluence with the San Joaquin River (RM 147.6);
- culverts with slide gates on the San Joaquin River at the confluence at the Sand Slough Control Structure (RM 168);
- a drop structure at the upper end of the Eastside Bypass near its confluence with the San Joaquin River (RM 168);
- Sack Dam, a diversion dam for the Arroyo Canal (RM 182);
- Mendota Dam, delivery point of the Delta-Mendota Canal and diversion point for several irrigation canals and pumps (RM 205);
- radial gates and control structure on the Chowchilla Bifurcation Structure on the San Joaquin River and Chowchilla Bypass (RM 216);
- at least one earthen diversion dam just downstream of Gravelly Ford (RM 227);
- culverts on the San Joaquin River between the gravel-mining ponds (RM 253);
- Friant Dam, primary storage dam on the San Joaquin River and upper limit of potential salmonid migration (RM 267.5).

Fish ladders are on Mendota Dam and Sack Dam; however, the fish ladder on Mendota Dam would require substantial modification for it to function properly. The fish ladder at Sack Dam is in good condition, and would only require placement of flashboards and other minor modification for it to function well. The other impediments listed above would require substantial modification to provide adequate fish passage.

In addition to physical barriers such as dams and gates, other environmental conditions such as high water temperature or salinity, or low instream flows (discussed below), may impede or eliminate access. For example, in 1994, the Central Valley Regional Water Quality Control Board (CVRWQCB) classified the San Joaquin River Deep Water Ship Channel (DWSC) near Stockton, as Clean Water Act 303(d) impaired because dissolved oxygen (DO) concentrations routinely fell below the water quality objective in the fall (CVRWQCB 1998). Low dissolved oxygen concentrations in the DWSC may cause delays in the onset of upstream migration until later in the fall when DO concentrations improve. The 303(d) listing requires that a total maximum daily load (TMDL) be developed to control the loads/conditions that cause violations of the DO Water Quality Objective. Adult salmon migrating upstream from the Delta may also encounter near-lethal stream temperatures that would delay migration until temperatures decline.

7.7.4.2. Flow Continuity

In the San Joaquin River, a variety of structures and channel modifications disrupt flow continuity under current conditions. Flow continuity refers to the need for unbroken depth and velocity conditions that enable species movement between channel types and between reaches. Poor flow continuity and dewatered channels, particularly in Reaches 2 and 4, inhibits fish passage between Reaches 1 and 5. Reaches 2 and 4 are typically dry, restricting fish migration through these reaches and access to upstream or downstream habitats. Friant Dam releases flows for downstream riparian diversions, and releases enough flow such that a minimum flows of at least 5 cfs flows past the last riparian diversion (near Gravelly Ford, top of Reach 2). The lower part of Reach 2 (Mendota Pool) and Reach 3 receive water year-round from the Delta Mendota Canal (DMC). Water released from Mendota Dam maintains flow through Reach 3. There is no base-flow requirement below Sack Dam at the bottom of Reach 3, however, leaving Reach 4 dry much of the time. Irrigation return flows and stormwater runoff do not compensate for the water lost to irrigation (Hazel et al. 1976 *in* Saiki 1984, Friant Water Users Authority 1992). Flow in Reach 5, dominated by DMC releases much of the year, is maintained by storm and agricultural runoff from Bear Creek, Salt Slough, and Mud Slough.

7.7.4.3. False Migration Pathways

False migration pathways lead fish away from the life history trajectory (pathway) that would otherwise allow it to survive, grow, and complete its life cycle. Fish may be passively diverted into false pathways or, when attracted by flow conditions, may actively move into a false pathway. Canals divert juvenile migratory fish and others along false pathways, removing individuals from the population (Figure 7-12). Mendota and Sack Dams play an important role in diverting water for irrigation. The San Joaquin River also has an extensive system of bypasses that divert and carry water around the mainstem San Joaquin River channel. Bypasses lead fish away from their required habitat and expose them to higher water temperatures, low dissolved oxygen concentrations, high dissolved salts, and high risks of predation. The Chowchilla Bypass is the primary bypass on the San Joaquin River and diverts floodflows from the San Joaquin River at Gravelly Ford (Reach 2). Other potential false pathways created by the bypass and levee system are Salt Slough, Mud Slough, Bear Creek, Ash Slough, Berenda Slough, Dry Creek, Fresno River, Lone Willow Slough, Mariposa Bypass, East Side Bypass, Arroyo Canal, Main Canal, other canals, and Little Dry Creek (Figure 7-12). Gravel-mining ponds in Reach 1 may also be minor false pathways that can confuse downstream and upstream migrating fish and delay migration.

In addition to false pathways between Friant Dam and Hills Ferry, water diversions and pumping facilities in the Lower San Joaquin River and Delta modify natural currents and direction of flows through migration pathways in this area. These diversion structures are discussed in Chapter 12.

7.7.4.4. Effects of Loss of Habitat Connectivity on Native Fish

The loss of habitat connectivity has likely had the greatest single impact on anadromous salmonids in the San Joaquin River. Chinook salmon and steelhead are currently blocked from migrating into the upper reaches of the San Joaquin River where they historically spawned and reared. Although they are not complete barriers at all flows, Mendota Dam and Sack Dam are major barriers to both upstream and downstream movement of fish. Adult fall-run Chinook salmon migrating up the San Joaquin River historically arrived at Mendota Dam and Sack Dam during low flows in late summer, when they formed nearly complete barriers to migration. Adult spring-run Chinook salmon migrated upstream during high spring flows when Sack Dam was dismantled and Mendota Dam had better passage conditions]. The construction of Friant Dam in 1941 prevented salmon from accessing historical holding, spawning, and rearing habitat upstream of RM 267.

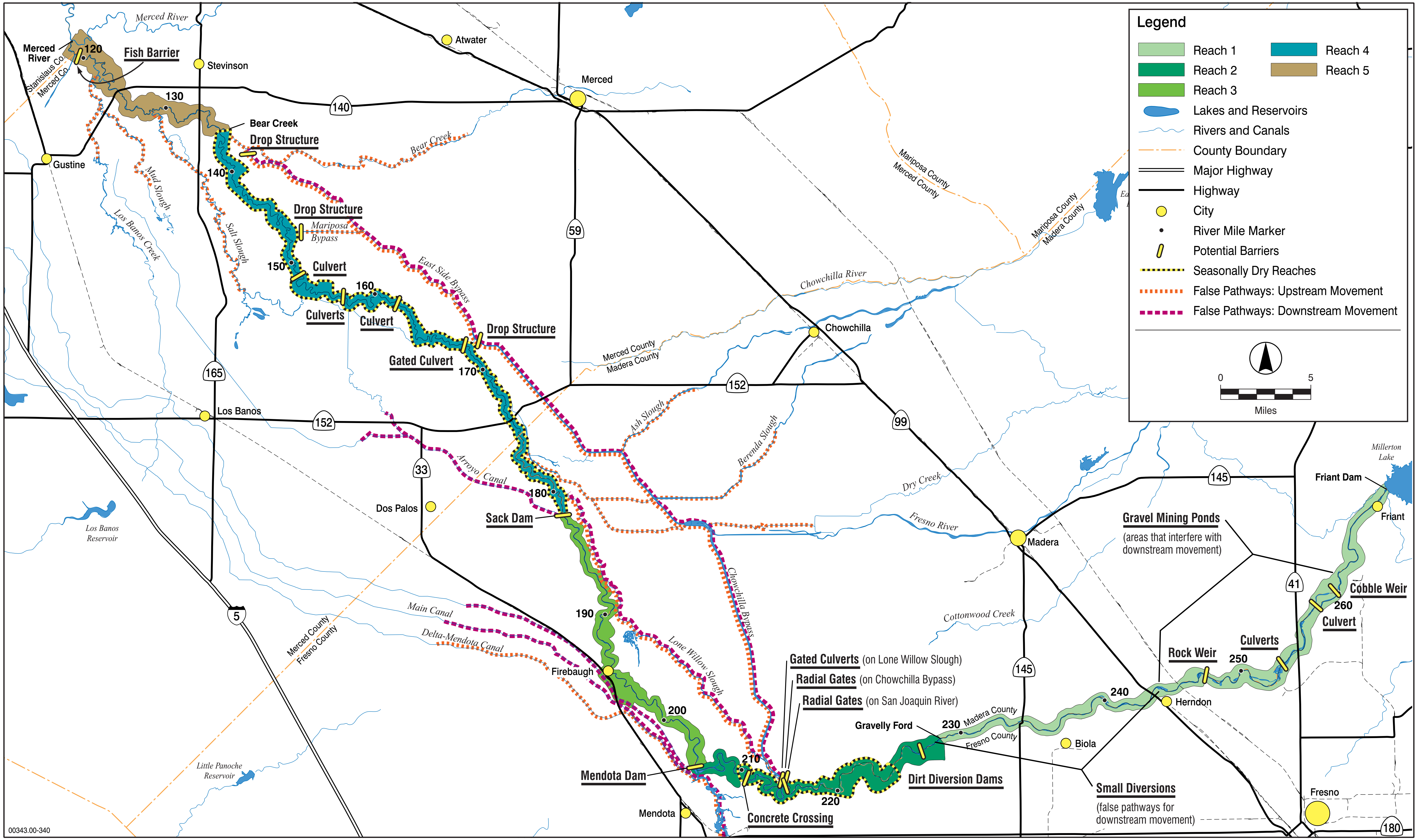


Figure 7-12. Potential and probable salmonid migration barriers along the San Joaquin River study reaches.

In most years, Reaches 2 and 4 are dry (Jones & Stokes Associates 1998), restricting migration through these reaches and access to upstream or downstream habitats. For example, a record run of 56,000 spring-run Chinook salmon was observed in 1948, after closure of the dam (Fry 1961). However, the fry from the record run were stranded in a dry reach below Sack Dam during their outmigration due to increased water diversion to meet demands in the lower valley during that year. In 1950 the last run of spring-run Chinook salmon was observed, by which time increased diversions from Friant Dam consistently eliminated flows in about 60 miles of river below Sack Dam (Yoshiyama et al. 1998), eliminating habitat connectivity for anadromous salmonids between their spawning grounds and the Delta.

False pathways lead fish away from the life history trajectory (pathway) that would otherwise allow it to survive, grow, and complete its life cycle. False pathways affect both upstream and downstream fish movement. During upstream movement, flow may attract fish into drains and bypasses that do not provide habitat because spawning substrate or cover, food availability, water temperatures, dissolved oxygen concentrations, salinity, and other environmental conditions are unsuitable. If upstream habitat exists, such as in a bypass that reconnects to the main river, barriers may block or delay upstream movement, and potentially result in mortality.

Canals generally do not provide habitat that can sustain populations of most fish species, and frequently end in an irrigated agricultural field. Bypasses may not provide environmental conditions that support movement to downstream habitat, especially if flow entering the bypass is interrupted and fish are stranded. Fish may also be adversely affected by increased vulnerability to predation or poaching. Appropriately designed fish screens and timing of barrier and diversion operations can minimize movement of downstream-migrating fish into bypasses, canals, and other diversions.

Currently unscreened canals could divert juvenile anadromous salmonids, lamprey, and other fish into habitats and agricultural fields where they would not survive, removing individuals from the population (Figure 7-12). The San Joaquin River also has an extensive system of bypasses that divert and carry water around the mainstem San Joaquin River channel. Bypasses lead fish away from suitable habitat and expose them to higher water temperatures, low dissolved oxygen concentrations, high dissolved salts, and areas where large non-native predaceous fish may be more common. Gravel-mining ponds in Reach 1 may also delay fish during upstream and downstream migration because they lack the strong directional flow that would be found in natural stream reaches. The individual impacts of the numerous unscreened water diversions, false pathways, and canals, on juvenile and adult salmonids will be evaluated during the development of restoration strategies.

Modifications to natural flow directions and flow reversals in the Delta that result from potentially alter migration. Outmigrating juvenile salmonids follow the direction of flow, and upon encountering reverse flows may reverse direction, delaying migration and increasing potential mortality. Effects of changes in Delta dynamics on native fish are discussed in Section 7.7.9.

Habitat connectivity for resident native fish has been reduced by physical barriers, reaches with poor water quality, the presence of predator fish populations, or other factors. Habitat fragmentation may isolate subpopulations and increase potential for their extirpation during catastrophic natural or anthropogenic disturbances, reduce genetic exchange between subpopulations, and reduce the potential for long-term persistence for species in the Central Valley as a whole. Tule perch have been extirpated from most of their native range within the San Joaquin basin and exist only as isolated populations that are extremely vulnerable to extinction from natural or anthropogenic disturbances (Moyle 2002). Water quality may affect their ability to persist in some areas of the valley (Moyle 2002). Hitch populations in the San Joaquin basin also appear to be increasingly isolated from each other (Moyle 2002).

Many native cyprinids and Sacramento suckers make upstream spawning migrations within their home stream or from larger reaches or lakes and reservoirs into tributaries to spawn. The juveniles of these species may require a period of rearing in these habitats to avoid predation that might occur in the habitats occupied by the larger adults. Barriers to resident fish movements may result in spawning in habitats where substantial predation on fry and juvenile fish may occur.

7.7.5. Water Quality

The historical water quality of the San Joaquin River likely provided suitable conditions for native fish, including anadromous salmonid populations. Cold, clear snowmelt runoff flowing from the granitic upper-basins of the southern Sierra Nevada provided optimal conditions for freshwater life-history stages of salmonids in the upper San Joaquin River, and for invertebrate production, the primary food resource for salmonids. The abundant cold water in the upper San Joaquin River also had high (saturated) dissolved oxygen concentrations, low salinity, and neutral pH levels. Suspended sediment and turbidity levels were low, even during high runoff events, due to the predominantly granitic geology in the upper San Joaquin River basin. Historically, warm water temperatures occurred in the lower San Joaquin River in the summer, influenced by low summer baseflows and high ambient air temperatures.

As reported in Chapter 6, water quality in the San Joaquin River has changed dramatically in many locations. While relatively good water quality probably still exists upstream of Millerton Reservoir, and water quality is generally quite good in Reach 1 below Friant Dam, water temperatures downstream of Friant Dam are severely degraded by numerous factors. For example, temperature stratification in Millerton Reservoir maintains fairly constant year-round instream release temperatures between 50°F to 60°F, but the decreased flow rates in most seasons has subsequently allowed more rapid increases in water temperature in Reaches 1 and 2.

7.7.5.1. Temperature

Water temperature has a direct influence on fish populations. Virtually all-biological and ecological processes are affected by ambient water temperature (Spence et al. 1996). Not only does temperature directly influence life history timing, habitat suitability, and the survival of individual fish in certain circumstances, but the indirect (and cumulative) effects of water temperature as manifested by reduced growth rates, altered life history timing, increased rates of infection, metabolic stress, and mortality from disease, increased DO, and toxic chemicals, and increased exposure to predators better adapted to warm water temperatures, all influence the production of juvenile salmonids. Incredibly, despite the central importance of water temperature to salmonids, much less research has been devoted to this subject than many other parameters or life-history stages (Myrick and Cech 2001) in the Central Valley.

In the San Joaquin River basin, low water temperatures are rarely a concern because of the extremely low frequency of periods of extreme cold in areas used by salmonids. However, warm water temperatures (exceeding 70^{o}F) are an important management concern. Hot summer ambient temperatures combined with low summer baseflows result in elevated summer and fall water temperatures in reaches 2 to 5.

The temperature of water released from Friant Dam is controlled by two outlets delivering water to the Friant fish hatchery. Minimum annual temperatures recorded at the hatchery in winter months range between 45°F and 50°F from January through March. Hatchery water temperatures increase during the spring from about 50°F to 55°F by the end of June. Summer hatchery temperature remains below 60°F, with the maximum daily temperatures often recorded at the end of September.

Water temperatures below Friant Dam increase rapidly during hot summer months. In general, mean monthly temperatures under the current flow regime remain suitable for salmonids and other temperature-sensitive fish species (<65°F) from November to April in most years, with temperatures rising above 68°F from May through October. Note that these mean monthly values do not reflect daily or monthly maxima at these sites, which can be much higher with resulting fish kills in the absence of cold water pools or other refugia for fish. Table 6-6 shows a compilation of the daily temperature record at Vernalis with mean temperature, and the maximum and minimum temperatures recorded at this station for the entire period of record (1961–2000). The maximum temperatures recorded at Vernalis above 68°F occurred in the period between April 1 and November 1, with daily maxima occasionally approaching 85°F).

7.7.5.2. Suspended Sediment and Turbidity

In most streams, there are periods when the water is relatively turbid and contains variable amounts of suspended sediment, and other periods when water is relatively clear. Turbidity and total suspended solids (TSS) are closely related. Turbidity is an optical property (light scattering), and is not a major health concern by itself. But high turbidity can interfere with temperature, DO, photosynthesis, the feeding habits of aquatic species, and is associated with total metals loadings and sorption of contaminants from the water column. TSS and turbidity sources to the San Joaquin River include suspended sediment from storm-generated tributary inflows, agricultural return flows, bank erosion, resuspension of sediments during high flows, and summer algae production.The effects of suspended sediment and turbidity on fish and aquatic life have been fairly well documented (e.g., Newcombe and MacDonald, 1991).

Historical data on suspended sediment and turbidity levels are not available for the San Joaquin River prior to 1960. It is probable that the San Joaquin River (and tributaries) historically carried relatively low suspended sediment loads and generally had low turbidity levels due to the predominantly granitic geology of the upper basin as well as relatively low rates of primary productivity (algae growth). Perhaps the best description of the historical turbidity levels in the upper river is from Blake (1857 quoted in Yoshiyama et al. 1996) who described the San Joaquin River in the vicinity of Millerton, in July, as “remarkably pure and clear, and very cold.”

The USGS gauge at Vernalis (USGS STN # 11-303500) provided daily average suspended sediment data from 1960 to 1996. Although our research was not exhaustive, we found no other sites upstream of Vernalis with suspended sediment or turbidity data. Data from the Kings River and Cosumnes River were also evaluated. The San Joaquin River at Vernalis data were plotted as daily average suspended sediment concentrations over the water years where suspended sediment was measured. These graphs indicate that daily average suspended sediment concentrations exceeded a lower threshold of 84 mg/L in all years (1960–96), exceeded 200 mg/L in 27 out of 36 years, and exceeded 500 mg/L in 9 out of 36 years. Many of these concentrations were chronic (long-duration exposure times). On average, for the period of record, daily average suspended sediment concentrations exceeded 100 mg/L during 95 days out of every year. By comparison, daily average suspended sediment data for the Cosumnes River at Michigan Bar (USGS STN # 11-335000; 1962–1970) exceeded 100 mg/L on average during only 10 days per year. Sedi-graphs for the Cosumnes also appear much flashier, indicating that suspended sediment loads are more closely associated with short-duration storm events as opposed to chronic exposure periods that are potentially much more harmful to fish. Chapter 6 provides additional information on the available historical and current suspended sediment conditions in the San Joaquin River.

Newcombe and MacDonald (1991) developed a concentration-duration response model to assess the environmental effects caused by chronic exposure to elevated concentrations of suspended sediment.

Their data review summarized effects of suspended sediment concentration and exposure duration on Chinook salmon, including gill hyperplasia and poor condition of fry at 1.5 mg/L to 2.0 mg/L (60 day exposure duration), reduction in growth rates in the range of 6 mg/L to 84 mg/L (60 to 14 day exposure duration), and 50% mortality of smolts at 488 mg/L (4 day exposure duration). Numerous additional studies have been conducted that document the effects on rainbow trout as well as other salmonid species, but are not presented here.

Newcombe and Jensen (1996) provide a synthesis of literature describing fish responses to suspended sediment in streams and rivers. Their research describes suspended sediment concentrations and exposure durations (sediment doses) that achieve a range of effects from no effect, behavioral effects, sublethal effects (including short-term reductions in feeding success), and lethal/paralethal effects (including direct mortality, reduced growth, reduced fish density, delayed hatching, habitat damage, etc.). They develop quantitative metrics (dose-response equations) that allow researchers and managers to document the sediment concentration and duration of exposure, and use these data to infer the most probable severity of impact to aquatic resources. Applying the above Vernalis data to the Newcombe and Jensen model (1996) shows that the long-term daily average suspended sediment concentrations of 100 mg/L for an average of 95 days/year would result in a 9 or 10 (out of 14) on the scale of severity of ill effects for juvenile salmonids, corresponding to lethal and paralethal effects (0% to 20% mortality, reduced growth rates, habitat damage, etc.).

7.7.5.3. Salinity and Trace Elements

Historically the San Joaquin River likely had good water quality and low concentrations of salinity and trace elements. Current measurement of these constituents from the lower San Joaquin River eastside tributaries indicate trace elements are all below their reported detection limits, and with salinity EC values ranging from 50 µmhos/cm to 100 µmhos/cm. These conditions are probably similar to historical San Joaquin River conditions.

The San Joaquin-Tulare Basin was selected as one of the first 20 National Water Quality Assessment Program (NAQWA) study units, based primarily on data indicating elevated concentrations of salinity and trace elements (Brown 1996). Salinity and trace element concentrations in the San Joaquin River basin are a primary water quality concern, potentially influencing several beneficial uses in the basin, including agriculture, municipal supplies, and aquatic resources. Salinity results from accumulation of anions (e.g., carbonates, chlorides, sulfates) and cations (e.g., potassium, magnesium, calcium, sodium), and is derived from irrigation of west-side soils that are high in salts and boron, and from imported irrigation water from the Delta via the Delta-Mendota canal. Salinity and boron are discussed in Section 6.7. Trace elements of concern include copper (Cu), zinc (Zn), silver (Ag), nickel (Ni), cadmium (Cd), chromium (Cr), lead (Pb), selenium (Se), mercury (Hg), and tin (Sn). Although some of these metals are biologically necessary in small quantities; at high concentrations, nearly all of them cause serious harm, including direct mortality, birth defects and behavioral and carcinogenic consequences. Selenium and mercury are discussed in Section 6.10.

Available data suggest that water quality objectives for salinity set by the Central Valley Regional Water Quality Control Board (CVRWQCB) are routinely exceeded (CVRWQCB 2002) in lower study reaches (Reaches 3 to 5), Mud and Salt Sloughs, and the lower San Joaquin River to Vernalis (see Figure 6-1).

Much of the focus on trace elements as a water quality concern has been toward selenium, particularly in the lower San Joaquin River reaches, Mud Slough, and Salt Slough. Historically, concentrations of trace elements in the study area were likely similar to present-day water quality in streams flowing from the foothills of the Sierra’s, i.e, generally low in trace element concentrations. Problems generally become significant in the lower reaches (Reaches 3 to 5), along the valley floor.

Selenium concentrations have been demonstrated in fish and food-chain organisms exposed to agricultural drain water, and numerous studies have focused on the selenium problem, particularly in the Kesterson National Wildlife Refuge (NWR). But studies have also recognized 29 inorganic compounds in addition to selenium and salinity as a concern for public health and aquatic resources, and 21 trace elements have been detected in tissues of biota in the NAQWA San Joaquin-Tulare study unit (Brown 1996; also see Section 6.10.3).

Selenium and mercury are of particular concern because of their ability to convert to methylated compounds, which then accumulate in tissues and can become toxic. Presently, Reaches 3 to 5 are listed as impaired for selenium by the CVRWQCB 303d list, and the limited amount of data available suggest that water quality objectives for selenium are still being exceeded for Mud and Salt Sloughs and Reaches 3 to 5. Mercury problems seem to be islolated to Bear Creek and Reach 5 of the study area, due to historic mining in that drainage. Other trace element constituents were not detected in high enough concentrations to warrant concern to human and aquatic resources. The continued impairment of these reaches due to mercury and selenium will definitely be an important factor in attempts to restore native fish populations, particularly for migratory species.

7.7.5.4. Effects of Changes in Water Quality on Native Fish

Increased temperatures in the San Joaquin River would be most likely to have an effect on juvenile salmonid rearing during the summer, adult upstream migration during the spring and summer, adult spring-run Chinook salmon holding during the summer, and on salmonid egg incubation during the fall. Low flow releases from Friant Dam during the summer and fall lead to rapid increases in stream temperatures in Reach 1, and further increases in Reaches 2 to 5. The amount of time for adult salmonids to migrate from the Delta to upstream spawning locations would have a strong influence on the effect of temperatures on adults in the lower reaches of the San Joaquin River, but is not known. Migration times will be evaluated during the development of a restoration strategy. Current water temperatures would likely be suitable for holding and rearing only in the upper portion of Reach 1. Increased water temperatures have also increased the distribution of non-natives upstream, potentially increasing predation risk for juvenile salmonids. During the development of restoration strategies instream flows will be modeled to evaluate potential effects of temperature on summer juvenile rearing, and adult spring-run Chinook salmon holding habitat.

Incubating salmon eggs may be exposed to lethal temperatures during the fall (Myrick and Cech 2001). Spring-run Chinook salmon are particularly susceptible because they spawn in the early fall when water temperatures are still high, (Vogel and Marine 1991, Myrick and Cech 2001). Fall-run Chinook salmon eggs are less likely to encounter water temperatures above 57°F, except during the start of the spawning period. Increases in temperature during egg-incubation can cause direct mortality, and even slight increases in temperature can decrease incubation period, and alter emergence timing. During the development of restoration strategies water temperatures will be modeled to evaluate potential lethal thresholds and alterations to emergence timing.

Although data are limited, it appears that suspended sediment has increased in the San Joaquin River. Increased sediment can contribute to the decline of fish populations through several mechanisms, including clogging spawning gravel (Chapman 1988), impacting feeding ability and growth rates (Newcombe and MacDonald 1991, Newcombe and Jensen 1996), and simplifying habitat by filling in pools and low gradient reaches (Frissel, 1992). Particulate materials can also physically abrade fish respiratory structures, fill gravel interstices used as habitat by juveniles, and affect light transmission that disrupts primary and secondary production (Spence et al. 1996). On the other hand, some moderate level of increased turbidity may improve juvenile salmonid survival by reducing predation during emigration.

Moderate and higher levels of suspended sediment (125 mg/L to 275 mg/L) and turbidities (25 to 50 NTU's) can interfere with feeding patterns of newly emerged fry and juveniles, resulting in reduced growth rates (Bjornn and Reiser 1991). Other reports indicate that juvenile salmonids avoided chronically turbid streams carrying high suspended sediment loads (Sigler et al 1984; Lloyd 1987; both from Spence et al. 1996). Adult salmonids appear to be less effected by high concentrations of suspended sediment (Bjornn and Reiser 1991), but have been documented to cease migrating when turbidity is high (Cordone and Kelley 1961; from Bjornn and Reiser 1991), potentially delaying migration. Short-term increases in turbidity may have occurred historically coincident with the spring snowmelt runoff, rainfall events, and with season juvenile and smolt emigration. Results of studies conducted elsewhere within the Central Valley have shown a pattern of juvenile salmonid emigration coincident with short-term increases in turbidity. Management programs on the Tuolumne River have recommended high flow releases to temporarily increase turbidity under the assumption that reduced water clarity during smolt outmigration would reduce predation on juvenile salmon (EA Engineering 1991b). It is likely that short-term increases in turbidity would have occurred naturally on the San Joaquin River.

Salinity is one of the strongest physical factors structuring biological communities, and may represent a critical limiting factor inhibiting restoration of native fish fauna and salmonid populations in the San Joaquin River. In addition to triggering behavioral cues that may directly influence broad distribution patterns of different fish species, and further disrupt the structure of fish assemblages, chronic exposure to higher concentrations of some salinity constituents (e.g., sodium chloride) is lethal to Chinook salmon and striped bass (Moyle and Cech 1988, Saiki et al. 1992), and causes reduced growth rates at lower concentrations (Saiki et al. 1992). Bio-accumulation of several trace elements also resulted from exposure to undiluted agricultural drainwater (Saiki et al. 1992). Salinity can also affect the diversity and distribution of macroinvertebrate species, potentially altering the availability of food resources for fish (Brown 1996).

Chinook salmon and steelhead inhabiting the lower reaches of the San Joaquin River are likely to suffer from synergistic effects of temperature, suspended sediment, salinity, other water quality and environmental parameters, such as DO levels, presence of pesticides, trace elements, disease, food availability, and predators. For example, increased water temperatures may lower resistance to disease, and decrease predator avoidance ability. During the development of restoration strategies suitable holding, spawning, and rearing will be evaluated while considering the combined effects with other water quality parameters, instream flows, and environmental conditions.

Declines in water quality may be contributing to the decline of some native resident fish. Although many native resident species are adapted to withstand high temperatures, low dissolved oxygen, and high salinities, many non-native species can withstand even higher temperatures, lower dissolved oxygen concentrations, and levels of contaminants not tolerated by native species. Moyle (2002) notes that tule perch may have disappeared from most of its habitat within the San Joaquin basin due to water quality and contaminants. Contaminants may also be contributing to the decline of hitch in the basin (Moyle 2002).

7.7.6. Introduced Species

7.7.6.1. Overview

Many non-native fish species appear better adapted than native species to the aquatic habitat and water quality conditions currently present in the San Joaquin River basin (Brown 2000, Moyle 2002). Interspecific interactions between native and non-native fish, including competition, predation, and hybridization may influence the abundance and distribution of native fish and alter fish assemblages. Table 7-1 lists non-native fish species that are currently found in the San Joaquin River basin. Changes in channel morphology may have increased habitat for non-native species. Gravel mining, for example, has created large areas characterized by low water velocities, warm water temperatures (>75°F), and dense aquatic vegetation. These areas provide high-quality habitat for largemouth bass and many other non-native warmwater species. Non-native fish species that are successful in the San Joaquin River generally have long reproductive seasons that result in populations that are very resilient to the effects of environmental disturbances. In contrast, native species with restricted reproductive seasons may lose entire year-classes as a result of short-term environmental disturbances such as floods or droughts. Moyle (2002) noted that native fish species may be more likely to persist in aquatic habitats that still resemble conditions under which they evolved, while non-native fish may quickly colonize more disturbed habitat.

Streams in the western United States may be quickly invaded by non-native fishes when they are dammed and natural fluctuations in seasonal flow patterns are reduced (Moyle 1976, Minckley and Meffe 1987; both as cited in Moyle and Light 1996). Moyle and Light (1996) suggest that established native fish communities can maintain their integrity despite continued invasions by non-native fish where highly fluctuating natural conditions exist, with non-native fish persisting only where habitats have been highly disturbed by human activities (Moyle and Light 1976). In the Sacramento-San Joaquin Delta, CDFG (1987) reports that the abundance of introduced centrarchids is correlated primarily with the dead-end slough channel type and secondarily with the intermediate conductivities and water transparencies typical of these habitats. They were also reported to be abundant in oxbows, channels behind berm islands, and small embayments where calm water and riparian or aquatic vegetation was common.

7.7.6.2. Competition for Food and Space

Competition may result in reduced growth and survival of native fish species, and may increase the likelihood that their populations are affected by other anthropogenic or natural disturbances. Elimination of a species solely through competition for a resource is rare, however (Moyle 2002). Some non-native fish species have habitat requirements that overlap with those of native species; these species may be more aggressive and territorial than native species and result in their exclusion from certain habitats. Many of the non-native species, such as green sunfish, also tolerate extremely high water temperatures and appear better able to persist in water with low dissolved oxygen, high turbidity, and contaminants than native fishes.

7.7.6.3. Predation

Native resident fish populations have likely been substantially impacted by the addition of non-native piscivores. Non-native fish species in the San Joaquin River and Delta that feed primarily on fish include largemouth bass, smallmouth bass, green sunfish, warmouth, black crappie, and striped bass. Largemouth bass have been at least partially blamed for the elimination of native species through predation (Minckley 1973, as cited in Moyle 1976). Many introduced piscivorous species, such as redeye bass, are opportunistic feeders, focusing on a prey species when they become sufficiently abundant. Due to their small size and weaker swimming abilities, larval and early life-stages of fish are particularly vulnerable to predation. Anadromous salmonids may be vulnerable to predation by non-native fish species during their outmigration, when they must pass through low-elevation reaches and the Sacramento-San Joaquin Delta and Estuary.

7.7.6.4. Potential Effects of Introduced Species on Selected Native Fish

Native fish species that may have been particularly affected by introductions of non-native fish in the San Joaquin River include Sacramento perch, Chinook salmon, hardhead, California roach, and hitch. Potential effects of non-native species on some of these species are described below.

7.7.6.5. Chinook salmon

Juvenile anadromous salmonids may be vulnerable to predation during the fry and juvenile stages and during their outmigration to the ocean. Before the introduction of non-native fish, the only fishes that would have preyed on the salmon were Sacramento pikeminnow, Sacramento perch, and rainbow trout (including juvenile steelhead). Sculpins may also feed on salmon eggs and fry, but predation by this species is not believed to result in substantial mortality. Due to the preference of salmonids for cool, well-oxygenated water, fry and juvenile rearing generally takes place in stream reaches with temperatures that are less suitable for non-native predaceous species such as black bass. Predation may be most important during outmigration, when juvenile and smolt Chinook salmon and steelhead must pass downstream through reaches occupied historically by Sacramento pikeminnow and Sacramento perch, and currently occupied by many additional piscivorous species now abundant in these areas, including largemouth and smallmouth bass, black crappie, warmouth, and striped bass. In addition, redeye bass, which prefer clear, warm streams and more lotic habitats than many other bass species, may also be abundant in the San Joaquin River, and may prey on juvenile Chinook salmon. Because juvenile salmonids become an abundant prey for a relatively short period of time, it is possible for predaceous fish to switch to feeding on them as a preferred prey and to take large numbers of them. Piscivorous fish seem to be able to substantially reduce the numbers of salmon smolts emigrating to the ocean when smolt numbers are inadequate to have a swamping effect on the predators. Mainstem habitats used as migration corridors by juvenile salmon in the San Joaquin basin have been altered by channelization, which reduces the availability of shallow-water habitats that could have offered refuge from predation, and by instream gravel mining, which has provided high-quality habitat for piscivorous species such as largemouth bass. Striped bass are likely the most important predators of salmon in the Delta.

Many juveniles of non-native species utilize similar food resources as juvenile salmonids, but because production appears to be high in the lower San Joaquin River, competition for food is not likely as significant an effect on salmonids as other interactions.

7.7.6.6. Sacramento perch

There are three primary hypotheses offered to explain the extirpation of Sacramento perch from most of their native habitat in California’s Central Valley: (1) habitat degradation, (2) embryo predation by introduced fish species, and (3) interspecific competition with introduced fish species for food and space (Moyle 2002). It is likely that a combination of all three factors has been responsible for the species’ decline. Black crappie and bluegill appear to be the species that most strongly compete with Sacramento perch (Moyle 2002). Extant populations of Sacramento perch in California currently appear to be limited to habitats where non-native centrarchids are excluded by high alkalinities or lack of introductions. One exception is in Clear Lake, where a small population appears to persist despite the presence of six other non-native centrarchids.

Moyle et al. (2002) have discussed the following potential difficulties of re-introducing Sacramento perch into Central Valley stream habitats where non-native fish species have become established. Black crappie and bluegill are likely important competitors with Sacramento perch for food (primarily benthic invertebrates). Bluegill and green sunfish have been observed to dominate Sacramento perch; displacement of Sacramento perch from preferred cover may increase their vulnerability to predation by piscivorous species. Early life-history stages of Sacramento perch may be particularly vulnerable to predation by introduced species. Although Sacramento perch defend their nests until larvae disperse, their eggs are still vulnerable to predation from schools of sunfish such as bluegill or from large fish such as carp. Larvae are planktonic for approximately 1 to 2 weeks before settling into aquatic vegetation or shallow water; during this time they are likely vulnerable to predation by many native and non-native fish species.

7.7.6.7. Hardhead

Hardhead and smallmouth bass may occupy similar stream reaches and habitats and both feed on introduced crayfish, which may also result in competition between the two species for food and space (Brown and Moyle 1993). Hardhead populations typically decline where smallmouth bass are present (Brown and Moyle 1993). Moyle (2002) notes that predation by smallmouth bass and other centrarchid basses may be an important factor contributing to the decline of hardhead populations. Brown and Moyle (1993, as cited in Moyle 2002) reported that hardhead disappeared in the upper Kings River following the establishment of smallmouth bass in that stream.

7.7.6.8. Other Species

California roach may be particularly vulnerable to predation by green sunfish in small and intermittent streams in the San Joaquin drainage; they appear to have been extirpated from many of these streams since 1970 (Moyle 2002). Moyle (2002) lists predation by non-native species as one factor potentially contributing to the decline of hitch populations in the San Joaquin River. Other native species appear to persist despite the introduction of non-native species, including Sacramento sucker, Sacramento pikeminnow, and blackfish. Tule perch appear less affected by predation by non-native species, which may be a result of their live-bearing reproductive strategy (Moyle 2002).

7.7.7. Life Histories and Habitat Requirements of Selected Non-Native Species and Their Potential Effects on Native Fish Species

Moyle and Light (1996) suggested that invasions of piscivorous fish are most likely to alter native fish assemblages, while omnivores and detritivores are the least likely to do so. Native fish may be maladapted to recognizing non-native piscivores and their predatory behavior (Moyle and Light 1996). Non-native omnivorous and detritivorous fish are less likely to alter fish communities because they exploit a food resource that is not often limiting in aquatic systems (Moyle and Light 1996); however, these species may still have the capacity to alter ecosystem functions (Power 1990, as cited in Moyle and Light 1996). Certain non-native species in the San Joaquin River basin are believed to be stronger interactors than others. Introduced centrarchids (basses, sunfish) have the potential to more strongly influence the abundance and populations of native fish species in the San Joaquin River. Information on these species may be crucial for developing restoration strategies that discourage persistence of these species and promote native fish or assemblages with a higher number of native species. For this reason, we have included more detail on specific centrarchid species believed to have strong influences on native fish populations.

7.7.7.1. Largemouth Bass

7.7.7.1.1. Life history and habitat requirements

Largemouth bass are a large non-native centrarchid that is widely distributed in the Central Valley. In their native range, lacustrine habitats are preferred by largemouth bass (Emig 1966, Scott and

Crossman 1973, both as cited by Stuber et al. 1982); however, the species can also be abundant in streams. Optimal riverine habitat for largemouth bass consists of large, slow-moving rivers or pools with fine-grained (sand or mud) substrates, some aquatic vegetation, and relatively clear water (Trautman 1957, Larimore and Smith 1963, Scott and Crossman 1973, all as cited in Stuber et al. 1982). Streams suitable for bass are generally low gradient and have a high percentage of pool and backwater habitat (Stuber et al. 1982). Moyle (2002) notes that largemouth bass in low elevation streams of the Central Valley occur primarily in disturbed areas where there are large, permanent pools with heavy growths of aquatic plants and 2 to 5 other introduced species (Moyle and Nichols 1973, Brown and Moyle 1993, Moyle and Daniels 1982; all as cited in Moyle 2002).

Streams used by largemouth bass often contain many other species (Fajen 1975), including bluegill, redear sunfish, black and brown bullheads, golden shiners, threadfin shad, and mosquitofish (Moyle 2002). Bain et al. (1991) group largemouth bass into a guild of fish using depositional shoreline microhabitats which are described as having deep water, slow current, fine substrate, and cover. Moyle (1976) describes their usual habitat as warm, quiet waters with low turbidities and beds of aquatic plants.

Optimal velocities are generally under $\leq$0.2 ft/s and velocities >0.34 ft/s are avoided by the species (Hardin and Bovee 1978, as cited in Stuber et al. 1982). Current velocities of over 0.66 ft/s are believed to be unsuitable (Hardin and Bovee 1978, as cited in Stuber et al. 1982). A broad range of depths is used by adult largemouth bass, which may be due to the fact that they have few predators of their own once they reach adult size. Because of their preference for areas that support aquatic vegetation (used as cover for sit-and-wait feeding and also used as cover by the smaller fish that are the bass preferred prey), it is possible that depths less than about 20 feet that support submergent vegetation are more suitable as adult bass habitat.

Spawning begins in March or April when water temperatures reach 59 ^{o}F to 60.8^{o}F (Weaver and Ziebell 1976, Emig 1966, Miller and Kramer 1971; all as cited in Moyle 2002) and may continue through June in water temperatures up to 75.2^{o}F (Moyle 2002). Males build nests in a wide variety of substrates including sand, mud, cobble, and vegetation, but gravel seems to be preferred (Newell 1960, Robinson 1961, Mraz 1964). Silty substrates are unsuitable, however (Robinson 1961, as cited in Stuber et al. 1982). Male bass do not feed during spawning or during the 2 to 4 week period after hatching while they guard their fry. After being abandoned by the male, fry form schools in shallow habitats where risk of predation is lower; flooded terrestrial vegetation may provide high quality for fry and juvenile bass (Aggus and Elliot 1975, as cited in Stuber et al. 1982).

Largemouth bass tolerate extreme water quality conditions, including temperatures of 96.8 ^{o}F to 98.6^{o}F with dissolved oxygen concentrations as low as 1 mg/l (Coutant 1975, Smale and Rabeni 1995, both as cited in Moyle 2002). Water temperatures optimum for largemouth bass growth range from 77 ^{o}F to 86^{o}F (Coutant 1975, as cited in Moyle 2002). Very little growth of largemouth bass occurs at temperatures below 59^{o}F (Mohler 1966, as cited in Stuber et al. 1982) or above 96.8^{o}F (Carlander 1977, as cited in Stuber et al. 1982).

7.7.7.1.2. Potential effects on native fish

Adult largemouth bass feed on a variety of prey, including fish, crayfish, and amphibians and are capable of changing foraging behavior based on prey availability, habitat type, experience, and size (Schindler et al. 1997, as cited in Moyle 2002). They may become completely piscivorous by the time they attain lengths of 3.1 inches to 3.9 inches (Keast 1970, Clady 1974, Kramer and Smith 1962; all as cited in Werner et al. 1977). Their ability to forage on a wide variety of prey under many conditions, and their broad environmental tolerances allow largemouth bass to play the role of a keystone predator in many aquatic environments (Moyle 2002). These fish may cause changes throughout the aquatic ecosystem, primarily through changing abundances of their preferred prey. In the large, low-elevation reaches of the valley floor, native cyprinids do not persist where populations of largemouth bass are present, even with continual colonization from upstream areas (Moyle 2002). Largemouth bass in the Delta appear to be expanding with an increase in the exotic aquatic weed *Egeria densa*, which provides cover for bass and their prey (Moyle 2002). There are deep pools in the Tuolumne River (a tributary to the San Joaquin River) created by instream gravel mining where adult largemouth bass are found in large numbers. Stomach sampling efforts conducted in these habitats have shown that these fish may take a substantial number of juvenile Chinook salmon during their outmigration (EA Engineering 1992b). This type of predation is expected to be most important during years when smolt production is low because of the short amount of time that smolts are exposed to the predators, and the fact that predator populations are not likely to respond to changes in smolt abundance from year to year.

7.7.7.2. Smallmouth Bass

7.7.7.2.1. Life history and habitat requirements

Smallmouth bass are a large non-native centrarchid now found in most of the larger streams and reservoirs in the Central Valley (Moyle 2002). In the San Joaquin River basin, they are most abundant in the mainstem and larger tributaries at elevations between 328 feet and 3281 feet (Moyle 2002). Smallmouth bass occur in large clear-water lakes (Coble 1975) and in streams of moderate gradient with riffle-pool morphology, relatively low turbidity, and rocky substrates (Hubbs and Bailey 1938, Reynolds 1965, Coble 1975, Lee et al. 1980, Todd and Rabeni 1989). Optimal stream reaches for adult smallmouth contain large pools, slow runs, eddies, or backwaters with abundant cover (e.g., boulders, rock ledges, undercut banks, and Large Woody debris (LWD)) and prey (especially small fish and crayfish) and cobble-boulder substrates. In streams, larger adult smallmouth bass have been described variously as pool guild members (Schlosser 1982), run or pool inhabitants (Leonard and Orth 1988), and habitat generalists (Bain et al. 1988, Lobb and Orth 1991). The biology of the smallmouth bass is quite similar to that of the largemouth bass; however, the smallmouth bass shows a somewhat greater preference for cooler streams with areas of swifter current and adult smallmouth bass may be less piscivorous than largemouth bass where crayfish are abundant (McGinnis 1984). Restricted home ranges have been observed for smallmouth bass in both lakes and streams (Larimore 1952, Gerking 1953, Fraser 1955, Funk 1957, Latta 1963, Munther 1970, White 1970; all as cited in Coble 1975).

Male smallmouth bass build nests near instream cover primarily on rubble, gravel, or sand substrates (Moyle 2002). In California, spawning occurs from May through July when water temperatures reach 55.4 ^{o}F to 60.8^{o}F (Moyle 2002). Nests are built at depths ranging from 1.6 feet to 16.4 feet, but are generally situated at depths of about 3 feet (Moyle 2002). Males guard the young fry for 1–4 weeks until fry disperse into shallow water habitats (Moyle 2002). Predation mortality is very high during the fry stage. High flows may disrupt nesting and reduce reproductive success in streams through displacement of eggs and fry by flow or through disruption of spawning behavior by low temperatures (Graham and Orth 1986, Lukas and Orth 1995, both as cited in Moyle 2002). Water velocities 0.26 ft/s over the nest may displace fry as they emerge from the nests and may result in high mortality (Simonson and Swanson 1990, as cited in Moyle 2002).

Most smallmouth bass in California are found in areas where summer temperatures are in the range of 69.8 ^{o}F to 71.6^{o}F; the species rarely establishes populations in areas where temperatures do not exceed 66.2^{o}F for extended periods (Moyle 2002). Optimal growth of smallmouth bass in the laboratory occurs at temperatures of about 79 ^{o}F to 84^{o}F (Rowan 1962, Peek 1965, Horning and Pearson 1973; all as cited in Coble 1975). More often, smallmouth bass are reported as occupying temperatures of

68 °F to 78.8°F in summer (Coble 1975, Coutant 1975, as cited in Bevelhimer 1996). Selection of cooler temperatures may reflect prey abundance or availability (Armour 1993). Similar to largemouth bass, juveniles will select areas with water temperatures that are warmer than those selected by adults, which would be beneficial for rearing in shallow water where small prey are abundant, but larger cannibalistic adult bass are not (Coble 1975). Temperatures below about 50°F result in pronounced cover-seeking behavior (Beeman 1924, Hubbs and Bailey 1938, Webster 1954; all as cited in Coble 1975).

Juvenile smallmouth bass feed primarily on insects and other small invertebrates until they reach total lengths of 1.2 inches to 2.0 inches, when larger prey such as fish and crayfish become more important (Moyle 2002). However, these prey do not tend to dominate the diet until the young bass reach lengths of 3.9 inches to 5.9 inches (Moyle 2002). Adult smallmouth in California prey primarily on crayfish, which are also an introduced species in many areas (Moyle 2002). Smallmouth bass may become piscivorous at sizes as small as 1.6 inches to 2.0 inches in length (Tester 1932, Lachner 1950, Webster 1954, all as cited in Coble 1975). All sizes may exhibit cannibalism (Moyle 2002). In a study conducted by Probst et al. (1984), adult smallmouth bass over 10.0 inches fed about equally on crayfish and cyprinids less than about 3.9 inches long (mean length of fish eaten was 3.2 inches). Larger adults also fed on larger fish, but did not ignore smaller prey fish.

7.7.7.2.2. Potential effects on native fish

Smallmouth bass often coexist with native fishes in the streams of the Central Valley, but this may depend on smallmouth bass population densities remaining low (Moyle 2002). Moyle (2002) notes that this may be because they feed primarily on crayfish, which are also introduced to the system. Hardhead populations tend to decline when smallmouth bass are present, perhaps because they also feed on crayfish (Brown and Moyle 1993). The maintenance of natural flow regimes may keep smallmouth bass numbers to levels at which they can coexist with native fish species. Moyle (2002) states that “Where flows are reduced, water temperatures may be warmer early in the season, favoring smallmouth bass spawning. During drought years, even in natural streams, smallmouth bass often show an increase in numbers for similar reasons. In ‘normal’ or wet years, however, native fishes typically spawn a couple of months before smallmouth bass can spawn. It is possible that the large numbers of young-of-year pikeminnows that develop in shallows may reduce the success of bass spawning by preying on bass fry.” Smallmouth bass residing in pools created by instream gravel mining in the Tuolumne River were found to prey on outmigrating Chinook salmon, but were less abundant than largemouth bass in these habitats (EA Engineering 1992b).

7.7.7.3. Green Sunfish

7.7.7.3.1. Life history and habitat requirements

Green sunfish are found throughout California in small, warm streams, ponds, and lakes (Moyle 2002). In the Central Valley, they are most abundant in intermittent streams that have warm, turbid, muddy-bottom pools with beds of aquatic vegetation (Moyle and Nichols 1973). They appear to be less common where there are more than three or four other species already present in the fish community (Moyle 1976). In streams that are extremely disturbed or polluted, they may be the only fish species present. Moyle (2002) notes that riprap may be used as cover by green sunfish. They have extremely well-developed dispersal and colonizing abilities and are often the first species to colonize stream reaches that have been dry (Moyle 2002). Under historical conditions, such streams in the Central Valley would have supported California roach, which would persist in pools through long periods of drought (Moyle 2002).

Green sunfish in California spawn when water temperatures reach 66.2°F. At this time, males congregate in shallow (1.6 inches to 19.7 inches deep) water and build nests. Fine gravel substrates near overhanging riparian vegetation or other cover is preferred as nest sites (Moyle 2002). Larvae settle in or near vegetation soon after hatching; heavy mortality from predation occurs during this early life history stage (Moyle 2002). Green sunfish are uniquely suited for colonizing new habitat and persisting in disturbed habitats; they can reproduce at a length of 2.0 inches to 2.8 inches, and typically reach sexual maturity at the beginning of their third year (Moyle 2002). Wang (1986, as cited in Moyle 2002) notes that they can spawn in water with dissolved oxygen concentrations too low for other fish to spawn in. Spawning may be heaviest in May and June, but can continue into July and August (Moyle 2002).

Adult green sunfish feed on invertebrates and small fish, feeding opportunistically on a wider range of items than most other sunfish species (Moyle 2002). Both green sunfish and the closely related warmouth are known to prey as adults on small fishes and crayfish.

7.7.7.3.2. Potential effects on native fish

Green sunfish are highly aggressive and territorial. Moyle and Nichols (1974) believe that the green sunfish, because of its ability to colonize warm intermittent tributaries and its predaceous diet, has probably been responsible for the elimination of the California roach in parts of the San Joaquin Valley. Smith (1982, as cited in Moyle 2002) reports that whenever green sunfish invade a small stream or pool of a larger stream, small native fishes tend to disappear. California roach and other small cyprinids and threespine stickleback may be especially vulnerable to competition and predation by this species (Smith 1982, as cited in Moyle 2002). Green sunfish rarely reach a size large enough to be significant predators of juvenile salmon, primarily because salmon would normally be found in the same habitats as green sunfish only during outmigration to the ocean.

7.7.7.4. Bluegill

7.7.7.4.1. Life history and habitat requirements

Bluegill are distributed throughout California and the Central Valley and are one of the most abundant fishes in the state (Moyle 2002). Moyle (2002) notes that they do best in “warm, shallow lakes, reservoirs, ponds, streams, and sloughs at low elevations” and that they are “often associated with rooted aquatic vegetation...and with bottoms of silt, sand, or gravel.” Bluegill prefer relatively shallow water with depths usually less than 16.4 feet (Moyle 2002). They may be common in streams with warm summer temperatures that have deep pools with aquatic vegetation or other cover (Moyle and Nichols 1973, Brown 2000; both as cited in Moyle 2002).

Spawning begins when temperature reach 64.4°F to 69.8°F and can continue into September (Moyle 2002). Nests are built in gravel, sand, or mud substrate where there are twigs or dead leaves (Moyle 2002). Bluegill have high fecundity; from 2,000 to 18,000 young are produced for each nest (Emig 1966, as cited by Moyle 2002). Bluegill fry in streams tend to enter the water column after the period of male guarding is over and settle into backwaters (Marchetti 1998, Rockriver 1998; both as cited by Moyle 2002). As with other sunfish, predation mortality is high during this stage. After guarding the fry for about a week, males begin another breeding cycle (Moyle 2002).

Bluegill tolerate a very wide range of water temperatures, from lows of 35.6°F to 41°F in winter to as high as 104°F to 105.8°F in the summer for short periods (Houston 1982, as cited by Moyle 2002). Optimal temperatures appear to be nearer to 80.6°F to 89.6°F (Houston 1982). Salinities up to 5 ppt are tolerated in the San Francisco Estuary (Moyle 2002). Dissolved oxygen concentrations less than 1 ppm may be tolerated as well (Moyle 2002). The food of bluegills includes many types of organisms from aquatic insects to plankton, snails, small fish, fish eggs, and crayfish (Moyle 2002).

7.7.7.4.2. Potential effects on native fish

Because of their abundance and high reproductive rates, bluegills may have strong influences on native fish populations in low elevation streams of the Central Valley, primarily through eating their eggs and young and by competing for food with native fish (Moyle 2002). Laboratory studies conducted by Marchetti (1999, as cited in Moyle 2002) suggest that they may have been a major factor contributing to the decline of Sacramento perch.

7.7.7.5. Redeye Bass

7.7.7.5.1. Life History and Habitat Requirements

Redeye bass are locally abundant in foothill portions of the South Fork Stanislaus River and the Cosumnes River, where they have displaced most other fish. This species is adapted for living in small, clear, upland streams with warm water 79°F to 82°F (26°C to 28°C). They prefer pools, undercut banks, and pocket water. Their small size, aggressive behavior, and generalized habitat and feeding requirements presumably allow them to dominate the foothill streams where they have been introduced. Because they are easily confused with smallmouth bass, with which they are known to hybridize (Pipas and Bulow 1998), it is likely that redey bass are more widespread than is currently known in the Stanislaus River and other San Joaquin basin streams.

Redeye bass are voracious predators that feed opportunistically on insects, fish, crayfish, salamanders, and other prey. Redeye bass tend to feed at night, after emerging from daytime cover, and take prey from the surface, in the water column, and on the bottom. It is believed that they have considerable ability to displace native fishes, presumably by predation on juveniles. Spawning takes place in small tributary streams or at the head of pools in larger streams, where males construct and guard nests in gravel beds. Spawning occurs in late spring when water temperatures rise to 60–70°F (16-21°C). Fecundity is high for such a small fish, but growth rates are known to grow very slowly in streams.

7.7.7.5.2. Potential effects on native fish

Their establishment in the Cosumnes and Stanislaus Rivers indicates that redeye bass are capable of invading San Joaquin basin foothill streams and displacing native fishes. Moyle (2002) believes redeye bass are likely to spread to other streams and reservoirs and are highly likely to become a major problem for conservation of native species. Creation of holding pools or other types of spring and fall Chinook salmon habitat may improve habitat conditions for redeye bass. Due to their small size, however, redeye bass presumably cannot use spawning gravels suitable for salmonids. Turbidity may preclude this species from using certain areas of the mainstem San Joaquin River, regardless of habitat availability. Redeye bass, if established in the San Joaquin River, could become important predators of native fishes. Juvenile fish would be the most likely prey items, due to the small size of this species.

7.7.8. Food Webs

After spawning, adult Chinook salmon carcasses remain in the stream corridor to decompose, and are an important food and nutrient source within a watershed (Cederholm et al. 1999). Decomposing salmon carcasses are recognized as a source of marine-derived nutrients that play an important role in the ecology of Pacific Northwest streams (Gresh et al. 2000). On the Olympic Peninsula in Washington, 22 different animal species were observed feeding on salmon carcasses (Cederholm et al. 1999). Carcass nutrients can affect the productivity of algal and macroinvertebrate communities that are food sources for juvenile salmonids. And decomposing salmon carcasses have been shown be vital to the growth of juvenile salmonids (Bilby et al 1998; Bilby et al. 1996, as cited in Gresh et al 2000).

The relatively low abundance of salmon and steelhead has significantly reduced this important nutrient source in the Central Valley, and throughout the Pacific Northwest. The study by Gresh (et al. 2000) estimated that the annual biomass of salmon entering Pacific Northwest streams (California, Oregon, Washington, Idaho) was historically on the order of 352 million pounds, and has been reduced to only approximately 26 million pounds, a reduction of over 93%. Channelization and removal of large woody debris can also decrease the retention of salmon carcasses and reduce nutrient input.

Inundated floodplains that support riparian vegetation and wetlands are also a primary source of nutrients that propagate through the ecosystem. Floodplain habitats produce small invertebrates with short life cycles such as chironomids and cladocerans. Native species adapted to using these flooded areas for feeding include juvenile salmonids, cyprinids, and suckers. The frequency and magnitude of floodplain inundation required to sustain high levels of macroinvertebrate production is being evaluated as part of the effort to develop restoration strategies.

Benthic macroinvertebrates and algal communities are poorly documented in the San Joaquin River, so the effects of disturbances on community structure and function are not fully understood (Brown 1996). However, it is fairly certain that modifications to habitat and introduction of three species of crayfish and other introduced biota have undoubtedly had impacts to the native macroinvertebrate and algal communities (Brown 1996).

Gravel substrates and riffles in Reach 1 provide productive habitat for benthic invertebrates. Increased fine sediment from gravel mining operations may reduce invertebrate production by filling in interstitial spaces between substrate particles (Chutter 1968, Bourassa and Morin 1995). Aquatic invertebrate sampling in pool and riffle habitat throughout Reach 1 is being conducted to aid in the developing restoration strategies. The unstable sand substrates and extreme flow variability in upper Reach 2 and Reach 4 are not likely to support high invertebrate densities. Sand substrates found in Reaches 2 through 5 are likely to have low taxa richness species diversity and primarily support specialized chironomids, small annelids, microturbellarians, and introduced *Corbicula* clams. Poor water quality in Reach 5 may also be limiting aquatic production in this reach.

7.7.9. Bay-Delta Conditions

7.7.9.1. Overview

Salmonids produced in the upper San Joaquin River must migrate through the lower San Joaquin River and the Bay-Delta to the sea. The lower San Joaquin River below Reach 5 provides similar physical habitat and water quality conditions as found in Reach 5; however tributaries including the Merced, Tuolumne, and Stanislaus rivers increase flows. The historical Delta consisted of low-lying islands and marshes that flooded during high spring flows. The current Delta consists of islands generally below sea level that are surrounded by levees to keep out water. In addition, federal and state pumping plants near Tracy send water from the Delta to various parts of the State utilizing a network of upstream and downstream storage reservoirs and aqueducts. Water to be exported from the Delta generally originates from excess runoff, flood control of upstream reservoirs, or planned release from upstream reservoirs. Within the central and southern Delta, the diversion facilities have a large effect on channel net flow direction and magnitude, including Old and Middle rivers, the Grant Line Canal, and the San Joaquin River.

In addition to the large export facilities, water is removed from Delta channels by approximately 2,500 pumps, siphons, and floodgates to irrigate agricultural lands surrounding and within the Delta. Because the elevation of island land surfaces is below the channel surface elevation, approximately half of the diversions are siphons (with the remainder divided evenly between pumps and floodgates) and most of the return drains require pumping over levees into channels (CDWR 2000). Almost all Delta agricultural diversions are rated to less than 250 cfs (Cook and Buffaloe 1998). The latest CDFG data indicates that less than a tenth of the 2,500 floodgates, siphons and pumps are screened (Raquel et al. 2002).

7.7.9.2. Effects on Native Fish

Delta flow patterns affect adult migration to upstream spawning areas and tributaries as well as juvenile outmigration to the sea. River discharge is an important migration cue for adult salmonids attempting to enter their natal streams to spawn, and increases in discharge may improve water quality and habitat conditions in the Bay/Delta – particularly dissolved oxygen in the Stockton Deep Water Ship Channel – allowing adult salmon to successfully migrate through the Delta.

Discharge is also a key factor for smolts outmigrating to sea from their spawning and rearing areas. Direct losses of salmonids occur from a variety of mortality agents within the Delta, primarily at the Central Valley Project (CVP) and State Water Project (SWP) pumps near Tracy as a result of entrainment into pumping facilities, from predation in pump forebays, predation within the Delta, and from fish salvage operations at the pumping facilities. Recognizing the importance of reducing mortality caused by SWP and CVP exports in the South Delta, the Vernalis Adaptive Management Program (VAMP) was developed to investigate Chinook salmon smolt survival during outmigration through the Delta in April and May, in response to alterations in San Joaquin River flows at Vernalis (USGS STN# 11-303500) and SWP and CVP exports. As part of the VAMP program, in years when spring flow in the San Joaquin River is less than 7,000 cfs, a temporary barrier is placed at the Head of Old River (HORB) to prevent outmigrating San Joaquin Basin salmon from migrating directly down the Old River channel toward the pumps.

The VAMP program has collected smolt survival data for two years (2000 and 2001) and has also included earlier survival estimates from the 1990’s in their annual technical reports (SJRGA 2002). Survival indices and absolute survival rates are based on releases of Chinook salmon smolts marked with coded wire tags at Durham Ferry (RM 67) and Mossdale (RM 60), marked salmon releases at Jersey Point (RM 10), and the relative proportion of salmon recaptured at Antioch (RM 5) and Chipps Island (RM 0). Key study conclusions indicate:

- The relative proportions of salmon released and recaptured during 2001 (target flow 4,450 cfs and 1,500 cfs exports) did not differ significantly from the relative proportions released during 2000 (target flow 5,700 cfs and 2,250 cfs exports);
- Approximately 65% of the unmarked salmon migrating past Mossdale in 2001 migrated during the VAMP period, and were therefore protected by increased San Joaquin River flow and the HORB barrier;
- Absolute survival rates of marked, hatchery Chinook salmon smolts for the 2001 VAMP experiments ranged from 14% to 34% for the Durham Ferry releases, and 11% to 31% for the Mossdale releases. These survival rates were not significantly different from those recorded during the 2000 VAMP experiments. Chipps Island recaptures showed higher absolute survival rates than did Antioch recaptures, possibly attributed to the marked salmon not being equally distributed or vulnerable to the trawls throughout the 24-hour period;
- The variability inherent in conducting salmon smolt survival studies in the lower San Joaquin River and Delta makes it difficult to detect statistically significant differences in salmon survival between VAMP flow and export conditions; no conclusions on the relative roles of San Joaquin River flow and SWP/CVP exports on juvenile Chinook salmon smolt survival can be made with these two years of data;

In addition to mortality resulting from the SWP/CVP export facilities, abundance and survival of salmonids are influenced by an interconnected complex of Delta environmental factors, including food and habitat availability and quality, water quality, and distribution of predators and conditions affecting susceptibility to predation. All of these factors are also affected to some degree by Delta hydrodynamics (Bennett and Moyle 1996). At present, salmonid mortality relating to these factors is not being evaluated quantitatively, except as they contribute to survival during the VAMP studies.

7.8. IMPLICATIONS FOR FISHERY RESTORATION

This chapter distills a large body of knowledge about the fish resources of the San Joaquin River and its tributaries, including information about historical and current fish abundance, distribution, and habitat. The summary information provided in this chapter describes:

1) the life history timing and habitat requirements for numerous fish species native to the San Joaquin River;
2) historical and existing conditions of both habitat and fish populations; and,
3) hydrologic and geomorphic linkages to fish habitat and life history.

Though this chapter focuses on anadromous salmonids (fall-run and spring-run Chinook salmon, and winter-run steelhead), it also includes descriptions of native resident fish, as well as non-native fish species that may influence efforts to restore native fish populations. This chapter is accompanied by Appendix B, which provides brief summaries of the life history and habitat requirements for 45 fish species. Rather than summarize the information presented in this chapter, this section identifies key issues that will need to be considered in the development of restoration strategies in order to achieve fishery components of the Mutual Goals statement (see Chapter 1).

Experience from other river systems that are regulated by large dams demonstrate that it is possible to restore and maintain some measure of ecosystem functioning and, by extension, fish populations. The resilience of rivers and fish populations in these other regulated systems promotes optimism for restoring, in some measure, the San Joaquin River and its associated fish resources.

As with other regulated river systems, there are a number of general challenges to restoration of the San Joaquin River. For example, while it seems feasible to “scale down” a river to be in balance with a reduced, regulated flow regime so as to restore some level of ecosystem function, it is unclear how to achieve this balance specifically for a given river. Another general challenge involves compensating for some of the inherent effects of dams, such as the trapping of sediment from upper watershed areas. In addition to these general challenges to restoring the San Joaquin River and its fish resources, there are a number of additional challenges specific to the San Joaquin River based upon local conditions in the river channel and surrounding area.

This section briefly describes some of the reasons for optimism that the fish resources of the San Joaquin River can be restored successfully, then it describes some of the unique challenges to achieving this restoration. By identifying the challenges to restoring the fish resources of the San Joaquin River, this section helps to lay the groundwork for the development of general restoration strategies for the San Joaquin River.

This summary of opportunities and challenges to restoration focuses on anadromous salmonids because: (1) they are the focus of numerous other restoration efforts in the Central Valley due to their sport, commercial, and intrinsic value; and, (2) as anadromous species, salmonids use the entire river corridor within the San Joaquin River Restoration Study planning area, so improving conditions for anadromous salmonids will likely benefit native resident fish that use only a portion of the San Joaquin River channel (Moyle, pers. comm.).

7.8.1. Restoring Fish Resources in the San Joaquin River

There are a number of reasons to be encouraged that efforts to restore the fish resources of the mainstem San Joaquin River will be successful. Adult escapements of fall-run Chinook salmon on the San Joaquin River tributaries have been strong recently, and though it is too soon to tell if these higher escapements are the combined result of fishing restrictions and restoration efforts, there is optimism that restoration is contributing to the rebounding fish population. There are several physical and biological factors (e.g., habitat conditions) and social and human factors (e.g., recent collaboration between environmental and agricultural interests) in the San Joaquin Basin that will contribute to the successful restoration of San Joaquin River fish resources.

7.8.1.1. Resiliency of San Joaquin River Fall-Run Chinook salmon

Each of the major tributaries to the San Joaquin River (e.g., the Merced, Tuolumne, and Stanislaus Rivers) is regulated by a large water-supply dam that has blocked access to upstream salmonid habitat and degraded downstream habitat conditions through flow regulation and sediment trapping. The San Joaquin River tributaries have also been disturbed by extensive gold (dredger) mining, which left windrows of tailings on floodplains, and commercial aggregate mining, which left large instream and floodplain mining pits that pose a hazard to salmonid migration. Despite such extensive human disturbances to the river channel and nearby floodplains, each of the major San Joaquin River tributaries maintains a population of fall-run Chinook salmon, testifying to the resiliency of Chinook salmon. Fall-run populations in the San Joaquin River tributaries have experienced dangerous population crashes in some years, but the populations have been able to rebound quickly. For example, escapement on the Tuolumne River in the early 1990s was as low as 100 adults; however, recent returns have been consistently between 10,000 and 20,000 adults.

The fact that Chinook salmon populations persist on San Joaquin River tributaries in the face of significant human disturbance stimulates confidence that populations of salmonids can be restored successfully on the mainstem San Joaquin River.

7.8.1.2. Fish Habitat Remains on the San Joaquin River

The different habitat components required by different life history stages of salmonids are generally available in the mainstem San Joaquin River, although it is not yet clear if the extent and quality of existing habitat is sufficient to support long-term population needs. For example, there are still holding pools below Friant Dam suitable for adult spring-run Chinook salmon; moderate quantities of salmonid spawning habitat still remain in Reach 1A; and the river channel in Reach 1 seems capable of providing instream rearing habitat for juvenile salmonids in certain months. Even if the amount and quality of existing habitat is inadequate to achieve the objectives set forth in the Mutual Goals statement, the amount and quality of existing habitat seem sufficient to at least *initiate* the process of restoring salmonid populations.

7.8.1.3. Expanded Knowledge of Fishery and Restoration Science

There are numerous restoration activities on other Central Valley tributaries, including each of the three lower San Joaquin River tributaries, targeted at improving salmonid habitat conditions and populations. The wealth of experience gained in restoring these other river systems can be applied to the restoration of the San Joaquin River, such that restoration activities for the mainstem San Joaquin River benefit from the lessons learned in other river systems. The restoration of salmonid populations in the San Joaquin River also presents a unique opportunity for testing restoration concepts and approaches that can make significant contributions to both restoration and fishery science. For example, the selection of parent stock for salmonid species will provide unique opportunities for examining concepts and hypotheses related to fish phenotype. The San Joaquin River can become a prominent location for learning for both the scientific and resource management communities.

7.8.1.4. Complementary Restoration Programs and Efforts

As described in Chapter 12, there are many other restoration efforts underway in the lower San Joaquin Valley that will complement efforts to restore the anadromous salmonid fishery in the study area. First, CALFED has made significant investments in river restoration and preservation in the lower San Joaquin River (e.g., San Joaquin River Wildlife Refuge). Secondly, there are several current and proposed activities for increasing smolt survival in the lower San Joaquin River and Delta, including reoperation of the State and Federal pumps at Tracy and flow management during the smolt outmigration period (e.g., the Vernalis Adaptive Management Program). These downstream restoration efforts will likely benefit future San Joaquin River salmonid production by enhancing smolt survival. Similarly, current efforts to improve water quality in the lower San Joaquin River (described in Chapter 6) will likely provide benefits to future salmonids produced in the mainstem San Joaquin River.

7.8.1.5. Friant Dam Infrastructure Capabilities

Friant Dam has a capacity for managed flow releases up to 16,000 cfs, which provides future management flexibility for releasing flows to restore fluvial geomorphic processes and riverine habitat (once downstream flood management issues are resolved) without costly and time-consuming retrofitting of the dam. In contrast, some dams on other river systems (e.g., Whiskeytown Dam on Clear Creek) do not have the current outlet capacity to support managed flow releases for restoring fluvial geomorphic processes. The outlet infrastructure of Friant Dam also provides the opportunity for hypolimnial cold water releases to the river, which make it possible to restore cold-water fishes, including those that require cold water temperatures year-round (e.g., spring-run Chinook salmon, winter-run steelhead). These opportunities will allow managed releases from Friant Dam to occur without requiring costly and lengthy retrofitting to the dam (as has been required on Shasta Dam and others).

7.8.1.6. Increasing Public Support and Participation in River and Fishery Restoration

There is growing public awareness and support for restoring river habitats and fish populations, as evidenced by: public approval of recent restoration bonds (Proposition 204) and parks bonds (Proposition 13); recent funding and support for the CALFED Bay-Delta Program; and the development of the San Joaquin River Parkway. More active public participation in restoration efforts have accompanied this growing public awareness. For example, landowners and local interests played a significant role in the development of the Merced River Corridor Restoration Plan (Stillwater Sciences 2002). Local stakeholders have also played a significant role in developing and implementing numerous restoration projects funded by the CALFED Bay-Delta Program. More active local participation allows restoration planning and implementation to benefit from local experience and expertise.

7.8.1.7. Salmonids Can Co-Exist With Agriculture and Urban Land Uses

Recent restoration experience on other San Joaquin River tributaries have demonstrated that enhancing riverine habitat and salmonid populations can be compatible with continued economic uses of land and water resources, thereby avoiding the contentious and counter-productive polarization of the issue into fish/wildlife vs. people. Furthermore, numerous partnerships have been developed on other tributaries between funding agencies, regulatory agencies, local agencies, landowners, restoration groups and environmental groups to develop mutually beneficial solutions to common problems. Cooperative conservation and floodway easement programs facilitated by the Natural Resources Conservation Service (NRCS) is a prime example of where floodway conveyance is improved, riparian habitat is improved, fee title and riparian water rights are retained by the owner, and fair compensation is provided to the landowner. These success stories can be transferred to upper San Joaquin River restoration efforts.

7.8.2. Challenges to Restoring the Fish Resources of the San Joaquin River

There are a number of significant challenges to restoring the fish resources of a river that has been de-watered in several reaches for over half a century. There are several general challenges common to San Joaquin River tributaries, such as understanding, and planning for, how downstream biological effects will affect the population dynamics of restored San Joaquin River salmonid populations. For example, the southern Sacramento-San Joaquin River Delta has been called a “black hole” for juvenile salmon because it harbors several significant sources of mortality (e.g., entrainment in Delta pumps; water quality; predation by non-native fish species, etc.). The design of restoration actions in the San Joaquin River, such as pulse flows to stimulate juvenile outmigration, will need to consider downstream conditions, such as the timing of Vernalis Adaptive Management Plan (VAMP) flows. Similarly, periods of low dissolved oxygen have been documented in the Stockton Ship Channel and have been hypothesized to be a barrier to the upstream migration of adult salmon. Actions applied in the mainstem San Joaquin River that are designed to stimulate the upstream migration of fall-run Chinook salmon, such as the release of fall attraction/passage flows, will need to consider the implications of low DO conditions downstream and its potential effects upon the success of San Joaquin River restoration actions.

In addition to these general challenges, there are challenges to the restoration of fish resources that are grounded in the unique conditions of the mainstem San Joaquin River. Several of these more specific challenges are described below.

7.8.2.1. Restoring an Extirpated Species

Unlike the other San Joaquin River tributaries, salmonids were extirpated from the mainstem San Joaquin River by 1950. Consequently, a restored salmonid population will require using a parent stock from some other tributary. Parent stock for fall-run Chinook salmon will likely come from one of the San Joaquin River tributaries. However, there are no significant populations of spring-run Chinook salmon or steelhead in the San Joaquin basin. As a result, parent stock for these species will likely come from Sacramento River tributaries.

One consequence of salmonids being extirpated from the mainstem San Joaquin River is that restoration planning will not have the benefit of examining how a local population uses the existing habitat, to see the unique adaptations a local stock makes to local conditions. Restoration strategies will have to be grounded in historical accounts, general scientific understanding of salmonid ecology, and conceptual approaches appropriate to the life history of the selected phenotype.

7.8.2.2. Supporting two Chinook salmon Populations

It will be a challenge to support two populations of Chinook salmon in the mainstem San Joaquin River. Hatton (1940, as cited in Yoshiyama et al. 1996) estimated that the completion of Friant Dam blocked access to approximately 36% of the salmonid spawning habitat that was available historically. As a result, spring-run Chinook salmon holding, spawning, and rearing have been concentrated downstream of Friant Dam. Early Euro-American development of San Joaquin River water resources (e.g., Sack Dam) greatly reduced the fall-run fishery (Hatton, 1940, Clark 1929, as cited in Yoshiyama et al. 1996), so that the adult spring-run Chinook salmon displaced by the closure of Friant Dam likely encountered little competition for the spawning habitat downstream of the dam. However, the restoration strategies will need to contemplate supporting two salmon populations with substantially less spawning habitat than was available historically to support the spring-run population and a meager fall-run fishery.

7.8.2.3. Competition and/or Hybridization of Fall-Run and Spring-Run Chinook salmon

Fall-run and spring-run Chinook salmon can occupy and use similar habitats. In rivers that support both fall-run and spring-run Chinook salmon populations, spawning is generally segregated spatially. Fall-run tend to use downstream riffles and spring-run spawn in upstream riffles that are closer to the pools where they hold over the summer (typically found higher in a drainage basin). Despite this general segregation of spawning between the two species, there is still the potential for overlap, which is exacerbated by dams that block access to upstream spawning habitat historically used by spring-run Chinook salmon, forcing them to spawn lower in the drainage.

When fall-run and spring-run Chinook salmon use the same spawning riffles, the risk of redd superimposition and genetic hybridization increase. Fall-run generally spawn later in the season than spring-run, so if they use the same spawning riffles, they can dig their redds atop existing spring-run redds (superimposition), thereby scouring the spring-run eggs and increasing the risk of egg mortality. There can also be a temporal overlap in fall-run and spring-run spawning so that individuals of the two different species are using the same spawning riffles at the same time. In such a scenario, individual fall-run and spring-run Chinook salmon may spawn together, thereby leading to genetic hybridization.

Friant Dam eliminates access to a substantial amount of historical spawning habitat used by spring-run Chinook salmon, concentrating them downstream. Consequently, fall-run and spring-run Chinook salmon may use the same spawning riffles in Reach 1. The restoration strategies will need to assess the risk of both redd superimposition and genetic hybridization and develop approaches for segregating, both spatially and temporally, fall-run and spring-run Chinook salmon spawning as a means of preventing or reducing the threat of redd superimposition and hybridization.

7.8.2.4. Carrying Capacity of Existing Habitat

Though the mainstem San Joaquin River contains most of the habitat components required by the different life history stages of salmonids, it is not clear if there is adequate habitat of sufficient quality to support target populations of salmonids. For example, there are two large pools immediately downstream of Friant Dam that will likely provide holding habitat for spring-run Chinook salmon. However, the capacity of the pools is unknown. If the existing pool habitat is insufficient to support the number of adult spring-run Chinook salmon required for a self-sustaining population, then additional holding habitat may be required to satisfy salmonid population targets. The restoration strategies, and the revision of the quantitative objectives, will require developing a better understanding of the capacity of existing habitat components for salmonids.

7.8.2.5. Geomorphic Limitations for Dynamic Channel Morphology in Gravel-Bedded Reach

The stream gradient in the gravel-bedded reach of the mainstem San Joaquin River is one-half to one-third as steep as the gravel-bedded reaches of the San Joaquin River tributaries (e.g., Merced, Tuolumne, and Stanislaus Rivers). The gentler slope of the mainstem San Joaquin River gravel-bedded reach generally limits the amount of salmonid habitat available, both directly and indirectly. There are areas of Reach 1 with suitable spawning gravels, but the relatively gradual slope of the channel reduces water velocities below those generally preferred by adult salmonids, thereby rendering those gravel-bedded reaches unavailable as spawning habitat. Also, the relatively gentle slope of Reach 1, combined with flow regulation through the operation of Friant Dam, may deprive the reach of sufficient energy to drive the fluvial geomorphic processes (e.g., bedload routing, channel migration, etc.) that may be necessary for maintaining habitats. In other river systems with steeper slopes, it has been possible to scale down the channel morphology and particle size to better match the post-dam flow regime while still achieving important fluvial geomorphic thresholds, thereby restoring fluvial geomorphic processes. However, it will likely be more difficult to restore fluvial geomorphic processes in the gravel-bedded reach of the mainstem San Joaquin River through channel alterations, because it is more difficult to alter channel slope conditions to create desired channel morphology (e.g., spawning riffles). Attempts to change reachwide slope have been attempted in smaller streams, but it is considerably more difficult to alter the slope of a river as large as the San Joaquin River. The restoration strategies will have to account for the low slope of Reach 1, especially since it has significant implications for attempting to restore the frequency of fluvial processes and the maintenance of aquatic habitat.

7.8.2.6. Balancing Juvenile Salmonid Growth and Smolt Outmigration

Water temperature modeling of the mainstem San Joaquin River suggests that water temperatures in certain spring months may get too warm in the lower sand-bedded reaches of the study area for juvenile salmonid outmigrants (assuming average meteorological conditions). To prevent juvenile mortality, it will be important to move them out of the study reach before water temperatures become harmful or lethal. However, the survival of juvenile salmonids is correlated positively with size; larger juveniles have higher survival rates. Moving juvenile salmonid outmigrants out of the study area sooner to avoid high water temperatures will compress the window of opportunity for promoting juvenile growth. It will be a challenge to provide rearing opportunities that promote juvenile growth fast enough to enhance the downstream survival of outmigrants that are moved out of the study area to avoid high water temperatures in the spring.

7.8.2.7. Poaching

Adult salmonids may be vulnerable to poaching in the mainstem San Joaquin River, especially because adult salmon will be holding and spawning in reaches of the river that support both recreational and subsistence fishing. Spring-run Chinook salmon will be especially vulnerable to poaching because they tend to group in high densities; they have long exposure time to poaching opportunities during their holding phase (all summer); and much of the San Joaquin River channel in Reach 1 has public access.

7.8.2.8. Water Quality

Poor water quality in Reaches 3-5 will likely affect fishery restoration efforts for both anadromous salmonids and certain native warm-water resident species. While release of Delta-Mendota Canal water into Reach 3 provides perennial flow over the entire reach, this water is much more saline than water released from Friant Dam (and it may cause imprinting problems on anadromous salmonid smolts outmigrating through the reach). Application of this saline water to naturally saline soils on the west side of the San Joaquin Valley increases the concentration of salts in agricultural return flows in Reach 5, further impairing water quality. Other contaminants are contributed by these agricultural return flows into Reach 5, and are discussed in more detail in Chapter 6. Flows released from Friant

Dam to meet fishery and other ecological objectives may also provide incidental benefits to water quality by reducing concentrations of salts and other contaminants. However, until expanding efforts to reduce source contributions begins to reverse contaminant loading rates, water quality in Reach 5 (and downstream reaches) will continue to be an issue to consider for fishery restoration efforts.

7.8.2.9. Mendota Dam and Pool

Mendota Dam and Pool functions as a manifold system where imported water from the Delta Mendota Canal (and periodic flows from the San Joaquin River and Fresno Slough) is distributed to several large canals, as well as numerous pumps adjacent to the pool. Some of the diversions have a capacity of up to 1,500 cfs, and experience on Sacramento River has shown that diversions of this size can entrain large numbers of juvenile salmonids. Screening these large diversions to meet entrance velocity criteria can be difficult and expensive. Therefore, routing adult and juvenile fish through Mendota Pool poses a significant challenge to salmonid restoration efforts.

7.8.2.10. Competition and Predation by Non-Native Fishes

Because of the introduction of non-native fish species, it is infeasible to restore native fish assemblages that occurred in the San Joaquin River historically. While it may be possible to control the abundance of, and contain the spread of, certain non-native fish species, it is very difficult to eradicate them. Therefore, the target fish assemblage for the San Joaquin River will be a mix of both native and non-native species. Determining the mix of native and non-native fish species that will be part of the target assemblage will require additional analysis. For example, it will be important to understand:

- inter-specific competition and predation between native and non-native fish species;
- how non-native fish species that inhabit the mainstem San Joaquin River have capitalized on current habitat conditions; and,
- which non-native fish species are more susceptible to control/eradication efforts.

Such analysis will support an assessment of which native and non-native species can co-exist and, therefore, which species will be part of the target assemblage. On the Tuolumne River and other Central Valley rivers, predation on salmonid juveniles by non-native fish species can be a significant factor limiting production from the basin. Since Chinook salmon are a focus of restoration efforts, it will be important to identify which non-native fish species pose a significant predation risk to juvenile salmonids. The restoration strategies will need to explore actions that simultaneously inhibit non-native species while supporting the restoration of native species.

7.8.2.11. Availability of Habitat to Support a Steelhead Population

It is likely that the watershed upstream of Friant Dam historically provided most of the habitat to satisfy steelhead life history needs on the San Joaquin River. Cold water habitats are needed for juvenile over-summering, which can still be provided by cold-water releases from Friant Dam in Reach 1, but steelhead tend to spawn and rear in smaller tributary streams rather than larger mainstem channels. Friant Dam has blocked access to many of these traditional headwater streams, and steelhead restoration opportunities may be limited to Reach 1 of the mainstem San Joaquin River, Cottonwood Creek, and Little Dry Creek. The restoration strategies will need to assess if sufficient steelhead habitat can be restored in Reach 1 to support a self-sustaining population of steelhead. Also, steelhead can prey upon juvenile salmon, so the restoration strategies will also need to consider balancing a restored steelhead population with restored Chinook salmon populations.

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CHAPTER 8. VEGETATION

8.1. INTRODUCTION

Species composition and distribution of plant communities are determined by local environmental factors: soils, surface water hydrology, fluvial geomorphology, groundwater hydrology, climate, slope, aspect, herbivores, pests, and others. Hydrology and fluvial geomorphology are environmental factors that heavily influence wetland and riparian vegetation along the San Joaquin River. Hydrology and fluvial geomorphology influence not only the species composition in the corridor, but also the location and extent of each species. Compared to other major river systems draining into the Central Valley, the San Joaquin River upstream from its confluence with the Merced River is unusual in several respects. Under natural conditions, it had a later and more moderate peak flow (dominated by snowmelt rather than rainfall). Other lowland Central Valley river systems, such as the Sacramento River, formed extensive natural levees or berms where their sediment-laden waters overflowed the banks in the valley and these berms supported extensive riparian and oak communities. The lower reaches of the San Joaquin River carried less sediment than other Central Valley rivers, and consequently the natural levees characteristic of these other Central Valley rivers were not as tall and wide. Historically, extensive flood basins and low sediment loads in downstream reaches between Mendota and the Merced confluence resulted in vast tule marshes with a narrow band of woody riparian vegetation along the margins of the San Joaquin River. Vast riparian forests historically did not appear to occur in these reaches because of the low sediment supply and prolonged inundation during the snowmelt runoff period.

Further upstream, denser riparian forests did occur along the San Joaquin River floodway in reaches with greater sediment supply (Reach 2), although the width was still not extensive (usually less than 2,000 ft. In the gravel-bedded Reach 1, the channel morphology encouraged riparian vegetation along the channel margins, high flow scour channels, and side channels. The lateral extent of riparian vegetation was confined by bluffs, making the forested zone less extensive than on other large rivers draining into the San Joaquin Valley. Rivers entering the valley on broad alluvial fans, such as the Kings River and Kaweah River, were flanked by extensive oak woodlands, in addition to having broad riparian zones along the major channels.

This chapter will focus on the riparian zone, a corridor flanking the river in which potential natural vegetation is influenced by the river-related factors such as elevated soil moisture or periodic flooding, and as a result, is distinct from the vegetation of adjacent zones that are not influenced by the river. Along the study reach of the San Joaquin River, the most characteristic riparian zone vegetation is typically dominated by trees such as willows and cottonwoods. However, the riparian zone also includes areas dominated by non-woody hydrophytic vegetation, and these areas may also be referred to as tule marshes or wetlands. In the discussions that follow, there is no attempt to discriminate between riparian communities that may or may not meet state or federal regulatory definitions of wetland.

Riparian and wetland vegetation strongly influenced the biota that used the San Joaquin River corridor on a permanent and/or seasonal basis. Sediment and nutrients were exchanged and cycled during frequent overbank flows (e.g., distributing salmon carcasses, recruiting terrestrial insects into the flowing water). The overbank flows also recharged shallow groundwater tables and deposited nutrients and fine sediments, resulting in floodplains being some of the most productive areas in the Central Valley. Deposition of conifers from the upper watershed, combined with contribution of large riparian trees into the San Joaquin River by channel migration and/or avulsion, provided large wood structure to the river, contributing to the complex aquatic habitat framework typically provided by a dynamic channel morphology. The importance of overbank flows, sediment loads, and large woody riparian vegetation again highlight the interconnectedness of the river ecosystem components in the San Joaquin River (See Figure 2-1).

Historical vegetation in the San Joaquin River corridor can be broadly categorized by the larger scaled geomorphic differences between the reaches. In upper sand bedded (Reach 2A) and lower gravel bedded reaches (Reach 1), the canopy species within the riparian corridor consisted of a patchy band of cottonwoods, willows, and valley oaks on floodplain and terrace surfaces between the confining bluffs. In downstream reaches (downstream of Mendota), river morphology was quite different. Floodplains (higher geomorphic surfaces inundated every 1-2 years [Leopold et al, 1964]), gave way to large flood basins (low lying areas adjacent to the river channel) dominated by tule marsh on both sides of the river, often many miles wide. Riparian canopy species (cottonwood, willow, valley oak) were limited to relatively narrow bands (typically less than 1,000 feet wide based on 1914 maps) of mineral soil berms deposited along channels that dissected the vast tule marsh.

The value of these expansive tule marshes to waterfowl is obvious; flocks numbering in the millions lived in or migrated through the San Joaquin Valley. The riparian forests were important to many bird species, including herons, egrets, ospreys, yellow-billed cuckoo, and many other species. Land management--beginning with grazing and agricultural clearing, followed by dramatic changes to fluvial geomorphic processes, surface water hydrology, and shallow groundwater hydrology--directly reduced the amount of vegetation along the San Joaquin River corridor. Reduction in riparian vegetation cascades down to the biota supported by the riparian vegetation, extirpating many animal species, and greatly reducing populations of other species.

This chapter describes historic vegetation along the San Joaquin River corridor, describes the evolution of riparian vegetation characteristics from historic to current conditions, discusses land use changes that caused the evolution in vegetation, and presents conceptual models linking riparian vegetation regeneration to surface water hydrology and fluvial geomorphology.

8.2. OBJECTIVES

The objectives of the Vegetation Communities chapter are to:

- Describe and evaluate stream dependent (riparian and wetland) vegetation conditions, life history, and distribution.
- Compare changes in riparian vegetation species and distribution over time as a result of human influences.
- Analyze and summarize changes in physical conditions and their effect on the recruitment, maintenance, and succession of riparian vegetation.
- Analyze life history and distribution of key riparian vegetation species and develop conceptual models that relate these species to pre- and post-Friant Dam annual hydrographs, and pre- and post-Friant Dam geomorphic processes.

It was originally intended for the Background Report to also evaluate whether certain sequences of water years facilitate recruitment classes of riparian vegetation by analyzing cores taken from established riparian trees; however, this task was not conducted, and therefore should be considered in future riparian evaluations.

8.3. STUDY AREA

The study area for the Vegetation Communities chapter encompasses the San Joaquin River from Friant Dam downstream to the confluence with the Merced River. For characterization of the historic pre-Gold Rush conditions, the study area's lateral limits encompass the floodplains and flood basins of unimpaired river conditions. This broad study area is defined to describe the historical vegetation conditions, and for planning and analyzing future restoration activities.

This chapter also includes a historical riparian vegetation coverage analysis using historical aerial photographs; this analysis defined a narrower study area width. While the narrower study area width significantly underestimates historic and existing riparian and wetland vegetation, the analysis provides a useful illustration of recent changes in riparian and wetland vegetation along the present river corridor. Aerial photographs from 1938 were used as the oldest mapping base. By 1938, much of the riparian vegetation had been cleared and wetlands drained, which was one reason why a narrower study area was used. A set of rules was devised by JSA (1998) to ensure that riparian habitat associated with the mainstem and adjacent land uses was included despite the complexity of conditions in the study area. The rules devised are as follows:

- When no levee, escarpment, or clear and discrete outer boundary of riparian vegetation was present, but riparian vegetation extended more or less continuously from the mainstem to adjacent sloughs or side channels, the boundary was set at 2,000 feet from the center line of the main channel of the San Joaquin River (e.g., portions of Reach 5). When a clear escarpment or levee that confined the river was present, the boundary was set at 1,000 feet beyond the escarpment or levee (e.g., the upper portion of Reach 1 and most of Reaches 3 and 4).
- When no levee or escarpment was present, but the outer boundary of riparian vegetation associated with the mainstem was clear, the boundary was set at 1,000 feet beyond the outer limit of the riparian vegetation (e.g., portions of Reaches 1 and 2).
- When no levee, escarpment, or clear, discrete outer boundary of riparian vegetation was present, but riparian vegetation extended more or less continuously from the mainstem to adjacent sloughs or side channels, the boundary was set at 2,000 feet from the center line of the main channel of the San Joaquin River (e.g., portions of Reach 5).

Figure 8-1 and 8-2 illustrate the application of the above four guidelines.

8.4. INFORMATION SOURCES

Qualitative and quantitative information sources were used in this chapter. Historical anecdotal information (explorer journals, hand-drawn maps, etc.) was used to describe historical conditions in a qualitative way. Aerial photographs, detailed maps, and ground surveys provided quantitative information for comparing changes in vegetation coverage.

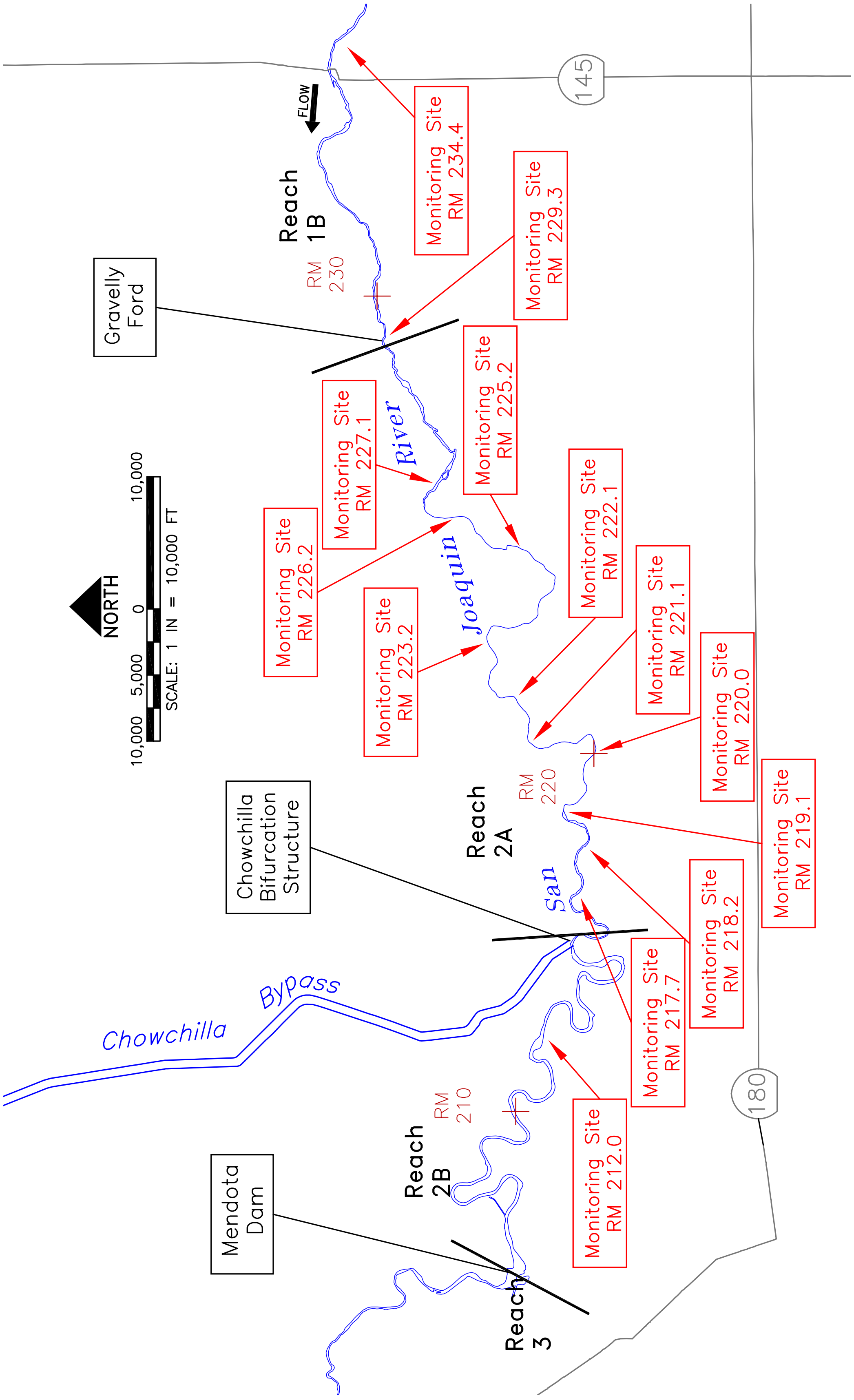


Figure 8-1. Location of 1999-2001 San Joaquin River Riparian Habitat Restoration Program Pilot Project study sites.

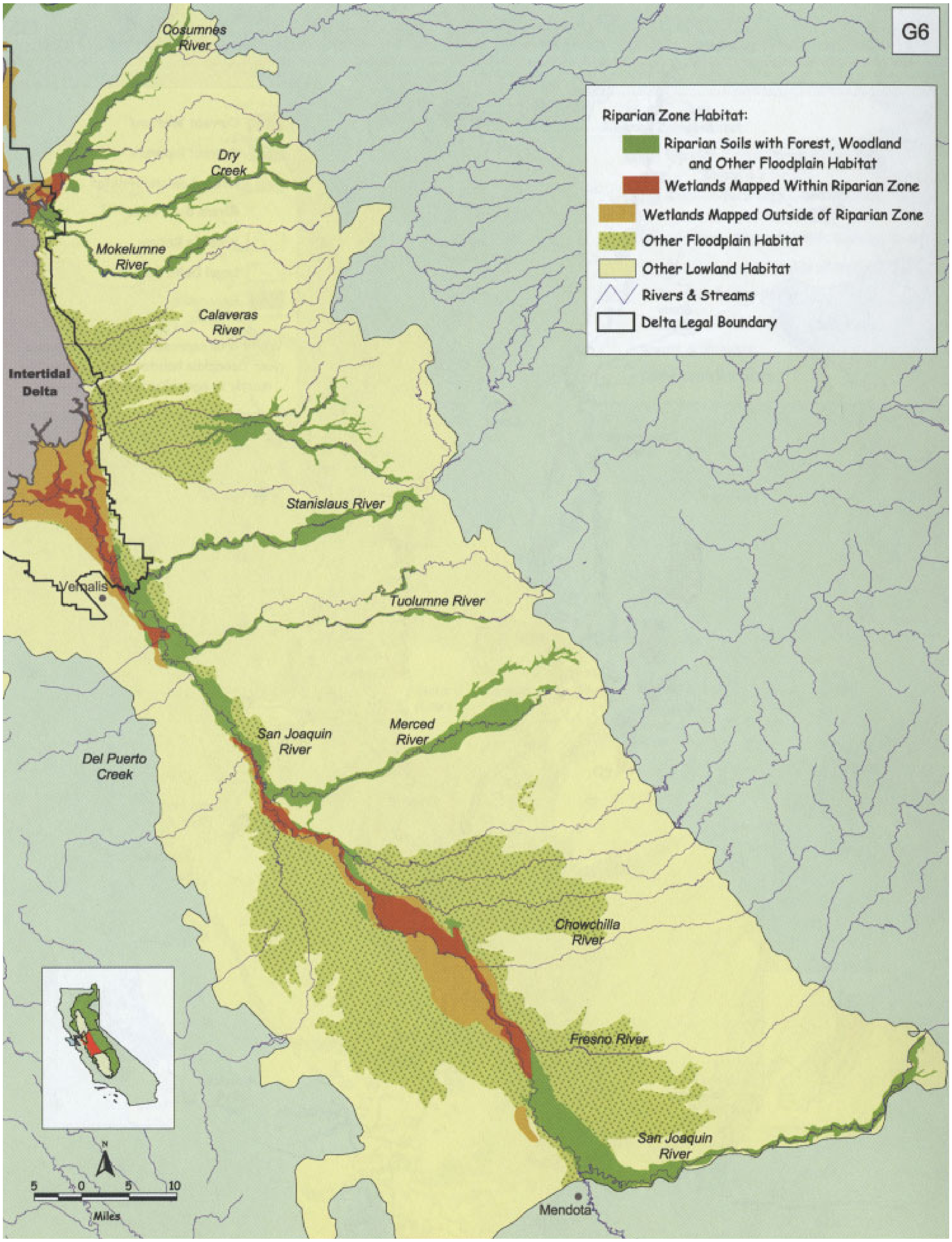


Figure 8-2. San Joaquin Valley historical river floodplain ecosystem (from The Bay Institute, 1998).

8.4.1. Historical and Existing Vegetation Conditions' Sources

Historical descriptions from early explorers were used to develop a general description of Central Valley vegetation prior to European settlement. Recent book compilations of historical sources and descriptions of the San Joaquin Valley were also used. The primary sources are listed below; complete references are cited at the end of this chapter:

- Edwin Katibah (1984): A brief history of riparian forests in the Central Valley of California.
- John Thompson (1957): The settlement geography of the Sacramento-San Joaquin Delta.
- Hubert Bancroft (1884): The history of California.
- William Brewer (1949): Up and down California.
- Phyllis Fox (1987a and 1987b): Excerpts of early explorer descriptions of the San Joaquin Valley.
- George Derby (1852): Map of Tulare Lake and San Joaquin River.
- John Nugen (1953): Topographic sketch of the Tulare Valley.
- William Hall (1886): Topographical and irrigation map of the San Joaquin Valley.
- US Government Land Office (1855): Plat maps along the San Joaquin River.
- Jones and Stokes Associates, Inc. (1998). Analysis of historical riparian habitat conditions along the San Joaquin River.
- Jones and Stokes (2000) and SAIC (2002): 2000 and 2001 results of San Joaquin Riparian Restoration Program Pilot Project.
- Moise and Hendrickson (2002): 1998 riparian habitat mapping and 2000 vegetation transects on the San Joaquin River.

These sources--coupled with the descriptions of later investigators who used soil survey data, remnant vegetation, and additional historical accounts as tools to reconstruct earlier vegetation-- form the basis for discussing pre-1937 vegetation conditions in Section 8.6.1. There are historical ground photos available that would help illustrate historical vegetation along the San Joaquin River; however, due to time constraints, the Background Report relied more on gathering historical maps and aerial photographs rather than ground photos. Another source that was not used, but would provide some additional information on historical riparian vegetation, is the field books of William Hammond Hall (e.g., Hall, 1880 for the Kings River). The 1913–1914 California Debris Commission (CDC) survey maps (ACOE 1917), which encompass the area from Herndon downstream to the confluence with the Merced River, are another useful source; however, these maps clearly reflect that effects on the riparian environment from relatively extensive land use changes had already occurred.

8.4.2. Vegetation Mapping Sources

Post-1937 vegetation was mapped using air photos taken in 1937, 1957, 1978, 1993 and 1998; and using topographic maps or orthophotoquads created at various dates. These maps and photos are described more fully under methods (Sections 8.5.1 and 8.5.2). Two studies published in 1998 formed the basis for much of this analysis. They are the historical air photo analyses of the study region performed by JSA (1998) and the evaluation of physical processes and riparian habitat potential of the San Joaquin River prepared by JSA and MEI (1998).

Present day vegetation is described in Moise and Hendrickson (2002), which is based on interpretation of detailed rectified air photos taken in 1998 and on extensive field transects conducted in by the California Department of Water Resources (DWR) in 2000. Monitoring data from two sets of transects, which were designed to document the vegetation responses to the 1999 pilot project flows (JSA and MEI 2000, JSA and MEI 2002), provide additional recent background information.

8.5. VEGETATION MAPPING METHODS

8.5.1. Photographic Materials

Historical aerial photographs were used to identify land cover signatures. The aerial photographs used were taken at approximately 20-year intervals starting at 1937. Photographs were taken within 1 to 4 years of 1937, 1957, 1978, 1993, and 1998.

Extensive research was conducted to locate historical aerial photographs at government agencies, libraries, and universities. Although many sources for aerial photographs of the San Joaquin River Basin were found, in most cases, complete coverage of the entire study area was unavailable for a particular year (Table 8-1). Differences in photograph scale and quality affected the data's quality. False-color infrared photographs are ideal for identifying vegetation types, but photographs using this technology were not available. In some instances (1937, Fresno County; 1957, Merced County) institutions were unable to lend photographs, and high-quality photocopies of the photographs were used. Although considered adequate for this project, the 1978 aerial photographs were the least suitable because of their scale; differences between riparian forest types are somewhat unreliable and should be interpreted with caution. When sufficient overlap existed between photographs, stereo pairs were examined using a Lietz MS-27 3X-magnifying stereoscope. A 6X-magnifying hand lens was also used to identify vegetation signatures.

For 1937, 1957, and 1978, aerial photographs for the entire study area could not be obtained. Missing portions were “filled in” using photographs taken no more than 4 years before or after the pertinent year. The 1957 photographs were supplemented with 1961 photographs for the reach from Mendota Dam to State Route (SR) 152 (RM 175-RM 205; Table 8-1). The 1978 photographs were supplemented with 1980 photographs for the reach from Biola to Friant Dam (RM 237-RM 267; Table 8-1). Throughout this report, the year that provided most of the photographs is used to indicate the time in the analysis. For example, although photographs from both 1978 and 1980 were used to represent the third period, this period is designated 1978.

In some cases, aerial photographs did not cover the entire study area width. Photographs always included the riparian corridor but did not always include adjacent areas. These areas, which were almost exclusively agricultural or grassland, were assigned a “no data” label on the maps.

Table 8-1. Aerial photographs used for historical vegetation mapping.

Period	Date	Scale	B/W or Color	Flown for	Contact for Originals	Prints/ Photocopies/ digital	River Miles	Description
1937	9/9/1938	1:10,000 (1"=833')	B/W	ACOE	ACOE, Sacramento, CA	prints	267–243	Friant Dam to Herndon (Hwy 99)
	10/6/1937	1:7,920 (1"=660')	B/W	USDA	California State University, Fresno, Map Library, Fresno, CA	photocopies	243–175	Herndon (Hwy 99) to Merced/Fresno county line (near Hwy 152)
	7-10/1937	1:7,920 (1"=660')	B/W	USDA	Central California Irrigation District, Los Banos, CA	prints	205–136	Mendota Dam to upstream of confluence with Bear Creek
	7-8/1938	1:7,920 (1"=660')	B/W	USDA	National Archives, Washington, D.C.	prints	175–118	Merced/Fresno county line (near Hwy 152) to confluence with Merced River
1957	8/31/1957	1:12,000 (1"=1000')	B/W	USDA	Department of Water Resources, Fresno, CA	prints	267–205	Friant Dam to upstream of Mendota Dam
	7/1961	1:7,920 (1"=660')	B/W	USDA	California State University, Fresno, Map Library, Fresno, CA	photocopies	205–175	Mendota Dam to Merced/Fresno county line (Hwy 152)
	4&5/1957	1:7,920 (1"=660')	B/W	USDA	Merced Community College, Merced, CA	photocopies	175–118 (89% of area)	Merced/Fresno county line (Hwy 152) to confluence with Merced River
	8/31/1957	1:63,360 (1"=1 mile)	B/W	USDA	USBR, Fresno, CA	prints	175–118 (11% of area)	Merced/Fresno county line (Hwy 152) to confluence with Merced River
1978	3/8/1980	1:12,000 (1"=1000')	B/W	USDA	Department of Water Resources, Sacramento, CA	prints	267–237	Friant Dam to Biola
	12/6/1978	1:24,000 (1"=2000')	B/W	ACOE	ACOE, Sacramento, CA	prints	237–118	Biola to confluence with Merced River
1993	5/23/1993	1:6000 (1"=500')	Color	USBR	USBR, Sacramento, CA	prints	267–118	Friant Dam to confluence with Merced River
2000	9/2/1998	1:4,000 (1"= 333')	Color	USBR	USBR, Fresno, CA	digital	267-229	Friant Dam to Gravelly Ford
2000	7/30/1998	1:4,000 (1"= 333')	B/W	ACOE	ACOE, Sacramento, CA	digital	229-118	Gravelly Ford to confluence with Merced River

8.5.2. Topographic Base Maps

Riparian vegetation and land use types were transferred by hand to rectified base maps. Four types of rectified base maps were used: black-and-white photocopies of 1920s USGS topographic maps (scale = 1:31,680; surveyed: 1915–1922); current USGS 7.5-minute topographic quadrangle maps (scale = 1:24,000; surveyed: 1956–1965, updated 1964–1987); 1976–1978 USGS "orthophoto quads" (rectified composites of aerial photographs; scale = 1:24,000); and rectified 1998 aerial photographs (scale = 1:4,000). The four types of maps offer different advantages. The 1920s topographic maps clearly show that the channel planform more closely resembles 1937 conditions than do the current topographic maps; the orthophoto quads clearly represent vegetation from 1976 to 1978; and the current topographic maps show elevation and, in some cases, urban and industrial development through the 1980s.

The 1920s maps were used for mapping the 1937 habitat and land use types. The orthophoto quads were used for mapping the 1978 habitat and land use types from the Mendota Dam quadrangle (RM 218.5) to the Merced River. USGS does not have orthophoto quads for the area east of the Mendota Dam quadrangle, so that area was mapped on current topographic maps. With the exception of the orthophoto mapping of the Gustine and Stevenson quadrangle areas (downstream from RM 140) for 1993, the 1957 and 1993 habitat types were mapped on current topographic maps. The lower reach of the study area for 1993 was mapped on orthophoto quads for 2 reasons: l) to increase consistency with the 1978 maps, and 2) because an accurate representation of streams is more important than elevation.

8.5.3. Methods for Historical Aerial Photograph Interpretation

Historical vegetation communities were mapped onto rectified base maps using historical aerial photographs taken from 1937 to 1993. The historical conditions were also compared to existing conditions, mapped in 2000 by DWR onto 1998 digital aerial photographs (Moise and Hendrickson 2002). The methods used for mapping existing conditions are described in the "Existing Conditions" section below. The maps were digitized and "built" into ARC/INFO polygon coverages. ARC/INFO (Version 8) software was used to analyze the spatial data, and Arcview 3.2 software was used to create maps.

8.5.3.1. Mapping Precision

Riparian vegetation types were mapped using a minimum mapping unit of 5 acres, and adjacent land uses were mapped using a minimum mapping unit of 20 acres. Linear features were mapped with a minimum width of 75 feet on the 1920s topographic maps, and with a minimum width of 50 feet on the current topographic maps. When widths on the 1920s maps were from 75 to 250 feet and many adjacent features were also narrow and linear, the features were mapped as a line with the width indicated; this line was later expanded to a polygon with the appropriate width. On the current topographic maps, this mapping method was sometimes used for narrow linear features (50 to 150 feet wide). The locations of vegetation polygons were generally more precisely mapped on the orthophoto quads than on the topographic maps because vegetation boundaries were visible on the orthophoto quads but were generally invisible on the topographic maps. Polygon location was more accurately mapped on the current topographic maps than on the 1920s maps because the 1920s maps were at a larger scale.

8.5.3.2. Mapping Accuracy

When identifying the appropriate category for a riparian vegetation polygon, the level of accuracy depended on the aerial photographs' scale, resolution, and type (color or black and white). The accuracy was highest for the 1993 color aerial photographs (scale = 1:6,000) and lowest for the 1980 black-and-white photographs (scale = 1:12,000). For 1957, two small areas (6.5 river miles, or 4% of the study area) were mapped from index composite photographic sheets at a scale of 1:63,360 (1" = 1 mile) because no coverage for these areas could be located. Acreage estimates were not seriously affected by this lower accuracy because the areas were small. On October 29, 1997, some "ground truth" data were collected for the 1993 vegetation-type identification. The ground truth effort consisted of visiting mapped areas between Mendota and Firebaugh to verify aerial photograph signatures using the 1993 aerial photographs.

Because mapping precision and accuracy depended on a number of unknown and variable relationships between the created maps and aerial photographs of varying quality and scale, and because ground truth data of historical vegetation could not be collected, confidence intervals could not be quantified for acreages obtained from the vegetation maps. Therefore, for changes in acreages between years, approximate statistical significance levels could not be calculated.

8.5.3.3. Digital Data Management and Quality-Control Procedure

Hand-drawn maps were digitized using AutoCAD Version 12 software. The root mean square digitizing error was less than 14.7 feet. The digitized lines and vegetation attributes were exported to ARC/INFO Version 7.1 software and built into separate polygon coverages for each map. A uniform study area boundary was drawn (see Section 8.3) on a set of 7.5-minute quadrangle maps and digitized, and all riparian habitat and land use data were clipped at this boundary.

8.5.3.4. Data Analysis and Interpretation

Habitat and land use maps were intersected with the study reaches in ARC/INFO, and acreages of habitat and land use were calculated by subreach. For each subreach, an interpretation was developed of how riparian habitat types changed over time, as a function of known changes in land use and hydrology. As in most historical analyses, exact and unambiguous causes of observed historical changes could not always be assigned. However, factors that are likely to change historical vegetation patterns could be identified.

8.5.4. Development of Historical and Present-day Toposequences

Toposequences for five reaches along the San Joaquin River were developed using a combination of data sources. The toposequences are conceptual cross-sections of the riparian corridor, which illustrate the relationships of different riparian plant assemblages with river channel/valley floor topography, and which show the relationships' changes over time (pre-1770, 1937 and 1998). A vertically exaggerated cross section was drawn using the 1914 CDC maps to illustrate the main channel, side channels, and overflow basins. These 1914 CDC cross-sections provided the base on which the pre-1770 vegetation toposequences were drawn. The vertical axis is exaggerated to better illustrate the relationship of the plant assemblages to topography. Land use changes were already evident on the 1914 maps and these may have had localized effects on the river morphology. Pre-1770 conditions are assumed to be unimpaired, as this was the approximate date when European influence began in the San Joaquin Valley. An idealized riparian vegetation assemblage was depicted for the pre-1770 cross sections; however, for the 1937 and 1998 cross sections, we used air photos and contemporary topographic maps to develop the toposequences and to update the topography, which reflected changes such as leveled fields, gravel mine pits, and other changes in the active channel. Within the different assemblages, the plant species are selected representative dominant species known from the area, based on historical documents and present day distribution. Although a considerable amount of data supports these toposequences, some of the information is recognized as speculative, especially data on herbaceous cover of upland and riparian habitats that were affected by widespread livestock grazing in the late 18th and early 19th centuries. In addition, climatic changes from the pre-1770 period to present, as well as long series of wet or dry years, have also possibly induced changes to the riparian vegetation. However, the dramatic change in flow regime, sediment regime, and land use and the associated effect on riparian vegetation is assumed to overwhelm any climatically induced changes to riparian vegetation.

8.5.5. Classification Used to Map Historical Vegetation

Riparian vegetation and land use types were mapped as a part of this project; two vegetation mapping classification systems have been used in this document (Table 8-2). The first was used in mapping the historical vegetation from air photos (JSA 1998). The second, more detailed classification system is used in defining existing vegetation conditions (Moise and Hendrickson 2002). The more detailed classification was allowed through greater resolution in the air photos and the extensive on-the-ground vegetation sampling that accompanied the mapping. A one-to-one correspondence between the classification systems does not exist (Table 8-2) but considerable overlap does occur. Vegetation types are adapted from Holland’s (1986) *Preliminary Descriptions of the Terrestrial Vegetation of California*. JSA’s classification system is hierarchical (Table 8-2), and can be correlated to the classification used by Moise and Hendrickson (2002). For riparian scrub and forest, a low-density modifier was used when the shrub or tree cover was below 30% for the polygon. Characteristics of the vegetation/land cover types used in the air photo interpretation and historical vegetation analysis (JSA 1998) are described below. Section 8.5.6 describes the system used by DWR to map and classify present-day vegetation (Moise and Hendrickson 2002).

8.5.5.1. Open Water

“Open water” is characterized by unvegetated permanent, or semi permanent ponded or flowing, water. Open water may be the result of constructed impoundments or naturally occurring water bodies. The open water mapping category also may include small areas of riparian scrub or herbaceous riparian vegetation that were too small to map as separate polygons.

8.5.5.2. Riverwash

“Riverwash” consists of alluvial sands and gravel associated with the active channel of the San Joaquin River. Generally, riverwash areas exist as sand and gravel point bars within the floodplain of the river. The acreage of riverwash should not be interpreted as a precise estimate because riverwash acreage is partially a function of the flow at the time that the aerial photograph was taken.

8.5.5.3. Great Valley Cottonwood Riparian Forest

“Great Valley cottonwood riparian forest” is a multilayered riparian forest found on the active low floodplain of the San Joaquin River. Older and decadent stands of Great Valley cottonwood riparian forest also exist in areas that were formerly active floodplains, but are now on functional terraces because of the reduction in high flow regime following completion of Friant Dam and associated diversion canals.

Pristine Great Valley cottonwood riparian forests have three somewhat distinct vertical layers: overstory, midstory, and understory. Winter deciduous trees that are adapted to frequent flooding dominate the overstory. Common dominant trees in the overstory include Fremont cottonwood (*Populus fremontii*) and Goodding's black willow (*Salix gooddingii*). California wild grape (*Vitis californica*) is a conspicuous vine found growing within the canopy of this forest. The midstory is often dominated by shade-tolerant shrubs and trees, such as Oregon ash (*Fraxinus latifolia*) or California box elder (*Acer negundo* ssp. *californica*). Other shrubby species of willow (*Salix* spp.) may also be present within the midstory. The understory typically is dominated by native grasses and forbs, such as creeping wildrye (*Leymus triticoides*), nettle (*Urtica* sp.), and Barbara sedge (*Carex barbarae*). Great Valley cottonwood riparian forest intergrades with Great Valley willow scrub at lower elevations near the active channel, and with mixed riparian forest on higher floodplain positions.

Table 8-2. Comparison of classification systems for historical and existing vegetation and land use.

Historical Vegetation Classification (JSA 1998)			**Existing Vegetation Classification (Moise and Hendrickson 2002)**
Category[1]	**Subcategory**	**Vegetation type**	**Category**
Open water			Open water
Riverwash			Riverwash
Riparian vegetation	Riparian forest	Great Valley cottonwood riparian forest	Cottonwood riparian forest
			Willow riparian forest
		Great valley mixed riparian forest	Mixed riparian forest
			Exotic trees
		Great Valley valley oak riparian forest	Valley oak riparian forest
	Riparian scrub		Willow scrub
			Riparian scrub (nonwillow)
			Elderberry savanna
			Giant reed
	Herbaceous riparian and marsh		Wetland
			Alkali sink
			Grassland and herbaceous riparian [2]
Open space	Grassland and pasture		Grassland and herbaceous riparian [2]
	Agricultural field		Agricultural field
	Orchard and vineyard		
Disturbed land	Disturbed land-other		Disturbed
	Former aggregate mining		
Urban and industrial	Aggregate mining		
	Other industrial		
	Urban/residential		Urban

Notes:

[1] Corresponding mapping categories are shown in the same horizontal box

[2] Herbaceous riparian in JSA (1998) is included in Grassland and herbaceous riparian in Moise and Hendrickson (2002).

8.5.5.4. Great Valley Mixed Riparian Forest

“Great Valley mixed riparian forest” is a multilayered winter-deciduous forest generally found on the intermediate terrace of the floodplain of the San Joaquin River. Under pristine conditions, this vegetation type experiences less physical disturbance from flood flows than does the cottonwood riparian forest. However, following the construction of Friant Dam and the resulting attenuation of flood flows, sites that typically would support cottonwood riparian forest now exhibit structure and species composition of the mixed riparian forest.

Species dominance in mixed riparian forest depends on site conditions, such as availability of groundwater and frequency of flooding. Typical dominant trees in the overstory include Fremont cottonwood, box elder, Goodding’s black willow, Oregon ash, and western sycamore (*Platanus racemosa*). Immediately along the water’s edge, white alder (*Alnus rhombifolia*) occurs in the upper portion of the study area. Common shrubs include red willow (*Salix laevigata*), arroyo willow (*Salix lasiolepis*), and buttonbush (*Cephalanthus occidentalis*). The understory of mixed riparian forest is similar to that of Great Valley cottonwood riparian forest.

Great Valley mixed riparian forest intergrades with Great Valley valley oak riparian forest at sites higher on the floodplain, and with Great Valley cottonwood riparian forest and Great Valley willow scrub on sites closer to the active channel.

8.5.5.5. Great Valley Valley Oak Riparian Forest

“Great Valley valley oak riparian forest” is a tree-dominated habitat with an open-to-closed canopy. This forest type is found on the higher portions of the floodplain and is therefore exposed to less flood-related disturbance than other riparian vegetation types in the study area. Dense stands of this vegetation type were not observed in aerial photographs of the study area; however, woodland-like stands of this type were observed upstream of Herndon.

Valley oak is the dominant tree in this vegetation type; California sycamore, Oregon ash, and Fremont cottonwood are present in small numbers. Common understory species in this vegetation type include creeping wild rye, California wild rose (*Rosa californica*), Himalaya blackberry (*Rubus procerus*), and California blackberry (*R. ursinus*).

Great Valley valley oak riparian forest intergrades with mixed riparian forest closer to the active channel, and with grassland habitats on higher terraces of the San Joaquin River.

8.5.5.6. Great Valley Willow Scrub

“Great Valley willow scrub” is a dense assemblage of willow shrubs often found within the active floodplain of the river. Sites with willow scrub are subject to more frequent scouring flows than are sites supporting riparian forests. Willow scrub often occupies stable sand and gravel point bars immediately above the active channel. Often, riparian scrubs are successional to riparian forest and persist only in the presence of frequent disturbance.

Dominant shrubs in Great Valley willow scrub include sandbar willow (*Salix exigua*), arroyo willow, and red willow. Occasional emergent Fremont cottonwood may also be present in Great Valley willow riparian scrub.

Initially, mapping was intended to include buttonbush scrub, elderberry savanna, and exotic vegetation (giant reed and tamarisk); however, following a review of the project’s aerial photographs, mapping of these vegetation types was determined infeasible. Buttonbush scrub is present in the study area; however, patches of this vegetation type occur primarily as small, linear features along the water's edge or as small areas of scrub within back-swamps and could not be identified on available aerial photographs. Without false-color infrared aerial photographs, separation of the signatures of buttonbush scrub and Great Valley willow scrub was extremely difficult. Buttonbush scrub in the study area could not be mapped without extensive on-the-ground mapping.

Elderberry savanna has not been reported along the San Joaquin River within the study area (Natural Diversity Data Base 1997) and was not discernible, even on the oldest aerial photographs (1937 and 1938). However, recent field work by DWR and the San Joaquin River Riparian Pilot Project did find small patches of the elderberry savanna type in the study area. Based on site conditions where this vegetation type does occur (i.e., silty, sandy soils on high floodplains along the American and Sacramento Rivers and along the San Joaquin River at Caswell State Park), extensive areas of this vegetation type would have likely occurred historically along the San Joaquin River study area, particularly in Reach 1B and Reach 2 where silty, sandy, well-drained floodplain and terrace soils would have occurred.

Exotic vegetation (giant reed and tamarisk) is present along the San Joaquin River in the study area; however, patches were too small (i.e., less than 5 acres) to be accurately mapped using the historical aerial photographs.

8.5.5.7. Herbaceous Riparian Vegetation and Marsh

"Herbaceous riparian vegetation and marsh" cover types includes two distinct components: a terrestrial component composed of annual and perennial herbaceous vegetation found on mesic sites within the floodplain of the river; and an aquatic component (tule and cattail marsh) dominated by emergent wetland vegetation. Characteristic herbaceous riparian species in the study area include Bermuda grass (*Cynodon dactylon*), sunflower (*Helianthus* spp.), cocklebur (*Xanthium strumarium*), goosefoot (*Chenopodium* spp.), and beggar's tick (*Bidens frondosa*). Characteristic marsh species include bulrushes (*Scirpus* spp.) and cattails (*Typha* spp.).

8.5.5.8. Grassland and Pasture

"Grassland and pasture" is an herb- and grass- dominated vegetation type that is typically dominated by annual species. Generally, sites with grassland or pasture are well drained and flood only occasionally under present-day hydrologic conditions. Most areas of grassland or pasture are above the frequently flooded zone of the San Joaquin River. The grassland and pasture vegetation type is composed of an assemblage of nonnative annual and perennial grasses, and occasional nonnative and native forbs.

8.5.5.9. Orchard and Vineyard

"Orchards and vineyards" are agricultural areas planted in vines or trees and used for the production of stone fruits, nuts, raisins, and table grapes.

8.5.5.10. Disturbed Land—Other

Land in the "disturbed land–other" cover type is land that has experienced some level of disturbance unrelated to agricultural cultivation or aggregate extraction. Common examples of the "disturbed land–other" category include areas used by off-highway vehicles and sites where rubble or fill has been deposited.

8.5.5.11. Disturbed Land–Former Aggregate Mining (Inactive)

The "disturbed land–former aggregate mine" cover type was mapped in areas that were formerly aggregate mines but now exist as dry or unvegetated open pits. Where former aggregate mines were vegetated or had standing open water, other cover types took precedence in the mapping; the category of formerly mined areas is, therefore, underestimated.

8.5.5.12. Aggregate Mining—Active

"Active aggregate mines" were mapped in areas of active aggregate extraction. Open water areas within active aggregate mining operations were mapped as open water, which is described above.

8.5.5.13. Other Industrial

The "other industrial" cover type was used for farm compounds and outbuildings not associated with aggregate mining.

8.5.5.14. Urban/Residential

The "urban/residential" cover type indicates areas developed for urban and residential land uses.

8.5.6. Classification Used to Map Present-Day Vegetation

DWR staff mapped existing riparian vegetation in the study area onto rectified 1998 aerial photographs and field verified these maps in the summer and fall of 2000. Detailed mapping methods are described in Moise and Hendrickson (2002). The aerial photographs for Reach 1 were in color and taken on September 2, 1998. The photographs for the remainder of the study area were taken on July 30, 1998, and were black and white. The summer of 1998 was relatively wet, which may have resulted in higher cover of wetlands than in a typical year. In addition, the 1998 aerial photographs were taken following the largest flood in the study area since the completion of Friant Dam. This flood, which occurred in January 1997, caused some minor shifts in the planform of the river.

Vegetation was mapped onto photo prints at a scale of 1:4,000 (1" = 333') with a minimum mapping unit of 0.3 acres or smaller. Woody vegetation units bordering herbaceous areas were extended to include a "zone of influence" of one-half canopy width. Woody vegetation was mapped as low density or moderate to high density. Low-density vegetation had an absolute canopy cover of less than 50%. Individual plants outside a stand were ignored if their distance to the stand exceeded two canopy widths.

Woody vegetation types were given a structural classification according to Hink and Ohmart (1984) (Table 8-3).

Table 8-3. Hink and Ohmart (1984) structural classification system for describing canopy height and understory.

Class	Description
1	Canopy height 40 feet or greater, dense understory
2	Canopy height 40 feet or greater, sparse understory
3	Canopy height 15–40 feet, dense understory
4	Canopy height 15–40 feet high, sparse understory
5	Canopy height less than 15 feet, dense understory
6	Canopy height less than 15 feet, sparse understory

Several important, invasive, exotic plants was mapped and generated as a separate GIS theme. The exotic plant species included in the GIS layer are scarlet wisteria (*Sesbania punicea*), giant reed (*Arundo donax*), eucalyptus (*Eucalyptus* sp.), tree-of-heaven (*Ailanthus altissima*), pampas grass (*Cortaderia* sp.), and edible fig (*Ficus carica*). A number of other invasive exotic species occur in the study area, but their occurrence was not systematically mapped. These species include Himalayan blackberry (*Rubus discolor*), white mulberry (*Morus alba*), castor bean (*Ricinus communis*), Lombardy poplar (*Populus nigra* var. *italiana*), and tamarisk (*Tamarix pentandra*) (Moise and Hendrickson 2002).

8.5.7. Present-day Vegetation Transect Methods

Section 8.6.3 (Existing Vegetation Composition) describes species composition, structure, and to the extent possible, the dynamics of vegetation under existing conditions along the San Joaquin River. Three recent data sets provided information for this description: a survey of riparian vegetation along the San Joaquin River by the DWR (Moise and Hendrickson 2002), and monitoring data from two sets of transects designed to document the response of vegetation to 1999 pilot project flows (JSA 2000, JSA and MEI 2002). These data sets and their use in this report are described below.

8.5.7.1. DWR vegetation transects

During July through October 2000, DWR staff collected data on the species composition and structure of vegetation along 125 transects located in 41 different mile-long segments of the river from Reach 1 to Reach 5 (Moise and Hendrickson 2002). These transects were subjectively located to represent the range of vegetation structure and species composition. They ranged in length from 11 to 428 meters, and passed through one or more of the vegetation polygons mapped in the GIS layer. The number of transects passing through each vegetation type and their combined lengths are summarized by reach (Table 8-4).

Three sets of data were collected along each transect: (1) herbaceous plant cover, (2) tree and shrub cover, and (3) tree diameter at breast height (DBH). The cover of each herbaceous species was recorded in 0.25 m^2 plots (0.71 m by 0.355 m) located every 5 m along the transect. Cover was visually estimated and recorded in the following cover classes, expressed as proportion of plot area: << 1%; <1 %; 1–5 %; 5–25 %; 25–50 %; 50–75 %; and 75–100%. Tree and shrub cover was recorded along the transect tape by measuring the length of tape covered by the vertical projection of the tree and shrub crowns of each species. DBH and species name were recorded for all stems >5 cm DBH, within 3 m of the transect tape. Thus, the tape served as the centerline for a 6-m-wide plot, in which tree diameters were recorded.

Descriptions of vegetation types were based on this DWR transect data. From the complete set of transect data in Appendix 1 of Moise and Hendrickson (2002), the absolute and relative cover were calculated for woody (trees and shrubs) and herbaceous plants, within each sampled vegetation type. Absolute cover is the percentage of woody and herbaceous plants relative to plot area or transect length; relative cover is the percentage of woody and herbaceous plants relative to the total cover of all plant species combined. For each tree-dominated vegetation type, the distribution of stem diameters was tabulated based on data in Appendices 1, 3, and 4 of Moise and Hendrickson (2002). Gradients along the river (from Reaches 1–2 to Reaches 4–5) are described where the data are adequate and indicate a gradient in the species composition or structure of a vegetation type. Because transect location was subjective, and the number of transects in a vegetation type varied among reaches and was often small, this data set did not provide a consistent basis for describing differences among reaches in the structure and composition of vegetation types. Therefore, transect data generally were not summarized by reach.

Table 8-4. Distribution of Moise and Hendrickson (2002) transects by vegetation type and river reach. "Total length" is the length of all transects that pass through a certain vegetation type, and "# of transects" is the total number of transects that pass through a certain vegetation type.

Vegetation Type	**Reach 1**		**Reach 2**		**Reach 3**		**Reach 4**		**Reach 5**		**Total**	
	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects
Agriculture	-	-	-	-	-	-	-	-	-	-	-	-
Cottonwood riparian forest	1,209	17	488	11	854	20	73	2	239	4	2,864	54
Disturbed	257	4	-	-	-	-	-	-	-	-	257	4
Elderberry	-	-	10	1	-	-	-	-	-	-	-	-
Exotic Tree	-	-	-	-	-	-	-	-	-	-	-	-
Giant Reed	61	2	-	-	-	-	-	-	-	-	61	2
Herbaceous	108	5	408	5	144	3	939	12	608	13	2,207	38
Mixed riparian forest	956	17	-	-	-	-	160	1	-	-	1,115	18
Riparian Scrub	36	2	248	6	-	-	226	4	11	1	521	13
Riverwash[a]	260	7	117	3	-	-	-	-	-	-	377	10
Valley Oak riparian forest	187	3					125	2	103	2	415	7
Wetland	47	2	23	1	45	3	123	3	158	5	396	14
Willow riparian forest	772	15	411	16	69	3	1,022	18	923	14	3,197	66
Willow Scrub	631	18	377	5	105	4	38	1	130	4	1,281	32

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

8.5.7.2. 1999-2001 Pilot Project

Additional sets of transects were established for monitoring the vegetation response in Reaches 1B, 2A, and 2B to pilot flow releases from Friant Dam in the 1999, 2000, and 2001 pilot project. In the 1999 pilot project, the goal of the flow releases from Friant Dam were to establish riparian vegetation on upper sand bar surfaces, primarily in Reach 2. Monitoring focused on evaluating whether managed flow releases promoted riparian tree growth along those subreaches that had very limited riparian vegetation due to long periods of dewatered conditions in the river, and at what locations vegetation established. In 2000, the goal of the pilot project flow release was primarily to maintain vegetation that had initiated during the previous years' pilot project release. In 2001, the goal of the pilot project flow releases was primarily vegetation maintenance and evaluation of hydrologic routing and shallow groundwater characteristics. The primary objectives of the monitoring was to evaluate vegetation at the beginning and end of the growing season, to determine the response of vegetation to augmented flows released into the San Joaquin River during the summer and fall of 1999-2001 (JSA and MEI, 2002a), and to evaluate and calibrate hydraulic and flow routing models. When widespread establishment of seedlings occurred in response to the flows, monitoring transects were installed to document their distribution, abundance, and subsequent growth and survival.

The first set of transects was established during September 1–5, 1999 (FWUA and NRDC 2002). These transects were resurveyed in November 1999 and April 2000. During 2000, additional permanently marked transects were established, for a total of 13 sites and 24 transects between River Miles 212 and 234.4 (Figure 8-1) (JSA and MEI 2002). Monitoring methods were also greatly revised in 2000 in order to better quantify vegetation changes. Transects were perpendicular to the channel and of varied length. They were monitored in 1999, 2000, and 2001 (JSA and MEI 2002, SAIC 2002). Transects were divided into 1-meter intervals, and data were recorded for all stems of woody species emerging from the ground surface within 1-meter of the transect line. Thus, each transect was treated as a series of 1-meter by 2-meter plots. At each study site, the following data was collected:

- Cross section geometry
- Water surface elevation in the channel
- Shallow groundwater surface elevation at one or more locations on each cross section
- Presence of riparian vegetation, plant numbers, plant size (size class), species, and cover class.

The presence of all species of vegetation was listed, and the cover of all species was documented at the cross sections; woody riparian vegetation was further quantified by documenting the numbers and species of all plants. Woody riparian plants were classified into three size classes: less than 1.5 meters tall; greater than or equal to 1.5 meters tall, but with stem less than 10 centimeters; and stem greater than 10 centimeters at breast height. Cover was characterized in six cover classes, ranging from zero to 100 percent cover, as well as an open water classification. At each site where permanently marked transects were located, the 2000 and 2001 densities of each woody riparian species were compared within the size classes, in order to evaluate establishment, growth, and mortality. This monitoring was conducted in the summers of 1999 (JSA, 2000), 2000 (JSA and MEI, 2002), and 2001 (SAIC, 2002).

Hydrology was monitored with a variety of techniques. Streamflow was estimated at the Gravelly Ford gaging station, discharge measurements were made at the Gravelly Ford gaging station, and spot discharge measurements were made at various locations in Reach 2 to evaluate gains and losses. Water surface elevations at cross sections were manually observed from staff gages, and shallow groundwater elevations were monitored by hand measurements in alluvial groundwater wells and instream and floodplain piezometers through 2002; pressure transducers and continuous water stage recorders monitored shallow groundwater elevations thereafter.

8.6. HISTORICAL AND EXISTING CONDITIONS

This section begins with a description of the likely conditions of the San Joaquin Valley from the early 1800s until the 1930s. Changes initiated by the Spanish/Mexican settlement began in Southern California in the late 1700s, and reached the San Joaquin River study reach during the early 1800s. Prior to the 1770s, Native American populations were sparse and their impact was comparatively modest. The tempo and magnitude of change increased dramatically in the years following 1848, when the Gold Rush began. Later subsections discuss the land use changes that can be measured after 1937, when the first known complete set of air photographs was flown. This analysis evaluates and compares habitat conditions in 1937, 1957, 1978, and 1993, and 2000, when relatively complete photographs of adequate resolution were available and quantitative estimates of habitat area could be made. This section concludes with a detailed description of present day conditions, including descriptions of plant communities present. Present-day conditions are based on air photo interpretation done using rectified air photos flown in 1998, supported by extensive vegetation field work conducted in 2000 by DWR and the restoration program.

8.6.1. Conditions Prior to 1937

Prior to the early 1800s, human impacts on the riparian systems in the San Joaquin Valley were limited to Native American activities (fishing, hunting, gathering, burning of grassland and marsh habitats to promote wildlife and desired food plant species). Early explorers and surveyors characterized the San Joaquin Valley outside of the riparian and marsh areas as a treeless plain, with extensive areas of grassland and alkaline soils, and very hot temperatures during summer. The historical written descriptions of pristine (pre-1800) vegetation along the San Joaquin River above the confluence with the Merced River are anecdotal, and refer mostly to extensive areas of tule marsh, especially along the axis of the San Joaquin Valley, with locally prevalent groves of riparian forest, the latter generally along stream and slough channel margins. The overall extent of riparian vegetation and wetlands was expansive (Figure 8-2). The general character of the historical riparian vegetation has been assumed to be similar to existing remnant patches of well-developed riparian vegetation, although the validity of this assumption has not received critical evaluation.

The impact of livestock grazing by the Spanish and Mexican ranchers began in the early 1800s following Lieutenant Gabriel Moraga’s initial explorations of the San Joaquin River area, after the Mission San Juan Bautista was founded in 1797 (Rose 2000). Grazing by cattle, sheep, and other livestock introduced by the Spanish and then by Mexican ranchers is believed to have created profound changes in the landscape during the early 1800s. Grazing led to reductions in the dominance of palatable plant species, including native perennial and annual grasses; the introduction of livestock also led to the explosive spread and dominance of exotic annual grasses and forbs throughout the valley. Landscapes formerly dominated by native perennial and annual grasses and forbs were overrun with these exotic species, which were pre-adapted to the climate and had evolved with domestic livestock. The introduced livestock undoubtedly had effects on riparian vegetation through trampling, browsing, and spreading of exotic plant species, as well as causing bank erosion and water quality degradation during low flow periods.

By the 1830s, American and French Canadians entered the San Joaquin Valley and hunted beavers, mink, and river otter (Preston, 1981), leading to the near eradication of these species. Beavers had substantial effects on riparian zones. Their dams impound water and create shallow flooded areas, affecting vegetation, hydrology, and movement of fish and wildlife. Beavers' felling and removal of trees for food and construction led to profound changes in the local vegetation. The ecological effects of beaver eradication have not been specifically documented for the San Joaquin Valley, but are likely to have been significant.

After the Gold Rush began, human settlement in the San Joaquin Valley developed rapidly, and encouraged activities such as timber cutting (for steamship fuel and for construction), upstream gold mining, agriculture, water diversions, and water development. These activities initiated dramatic changes in the riparian corridor (Figure 8-3).

The general picture of the valley floor is riparian forest and scrub vegetation along the main river channels, especially on elevated surfaces of fine sediment deposited along the channel margins during flood overflow events (when water leaving the channel would drop sediment as it spread over the land). These localized zones of woody riparian vegetation were flanked by extensive tule marshes that formed where overflow waters spread over the nearly flat flood basin. The outer limit of the tule marshes was flanked by saltbush or grassland (prairie) communities; the tule marsh limits approximately coincided with the boundaries of the natural flood basin (Fox 1987a). These marshes would sometimes dry up in the late summer or fall, and extensive areas would sometimes burn under these conditions, according to accounts of early travelers. An 1850 reconnaissance map of Tulare Valley by Derby (1852) implies that the dominant vegetation was tule marsh in Reach 2 and 3 (Figure 8-4). Derby's map on the San Joaquin River does not include Reaches 4 and 5, and the mapping shown on the San Joaquin River should be treated with caution because of the large scale of the map, and that the map was prepared for the Tulare Lake basin rather than the San Joaquin River basin. This small-scale map does not illustrate woody riparian vegetation along the San Joaquin River (although it is shown on the Kings River and others draining into Tulare Lake), suggesting that under unimpaired conditions, the zone of woody riparian vegetation and associated oak woodland was narrow compared to that of other large rivers draining into the Central Valley. This is possibly because of the confining bluffs along most of Reach 1, extending from Friant Dam to the valley floor. These bluffs limit the potential area where riparian and oak woodland can grow. In contrast, the Kings River and Kaweah River enter the valley on extensive alluvial fans formed by flood deposits from migrating major and minor channels. These fans offer extensive areas with conditions suitable for extensive riparian forest and oak woodlands. An additional map by Nugen (1853) corroborates Derby's map with regard to the extensive tules in the Tulare Lake Basin and in Fresno Slough. Nugen's larger-scale map also shows a band of woody riparian vegetation along Reaches 1 and 2 (Figure 8-5), but does not show the lower reaches of the river. Nugen's map also shows extensive plains beyond the riparian and tule marsh boundaries. This map corroborates numerous descriptions by early explorers of the treeless nature of the plains away from the banks of the San Joaquin River. For example, Brewer (1949) describes the plains on the west side of the San Joaquin River:

> *"From a nearby hill yesterday we could look over an area of at least two hundred square miles and not see a tree as far as the river, where, ten miles off, there is a fringe of timber along the stream"*

Carson (1950) (as summarized in Fox 1987b) describes Reach 3 through 5 in the 1846-1852 era as follows:

> *The Mariposa, Chowchilla, and Fresno Rivers may be classed with the Calaveras, being running streams during the rainy season and spring only. These streams do not enter directly into the San Joaquin, but their united waters form the immense tule marsh between the bend of the San Joaquin [assumed to be at Mendota] and the mouth of the Merced; the water thus collected enters in the San Joaquin at many different points during high water"*

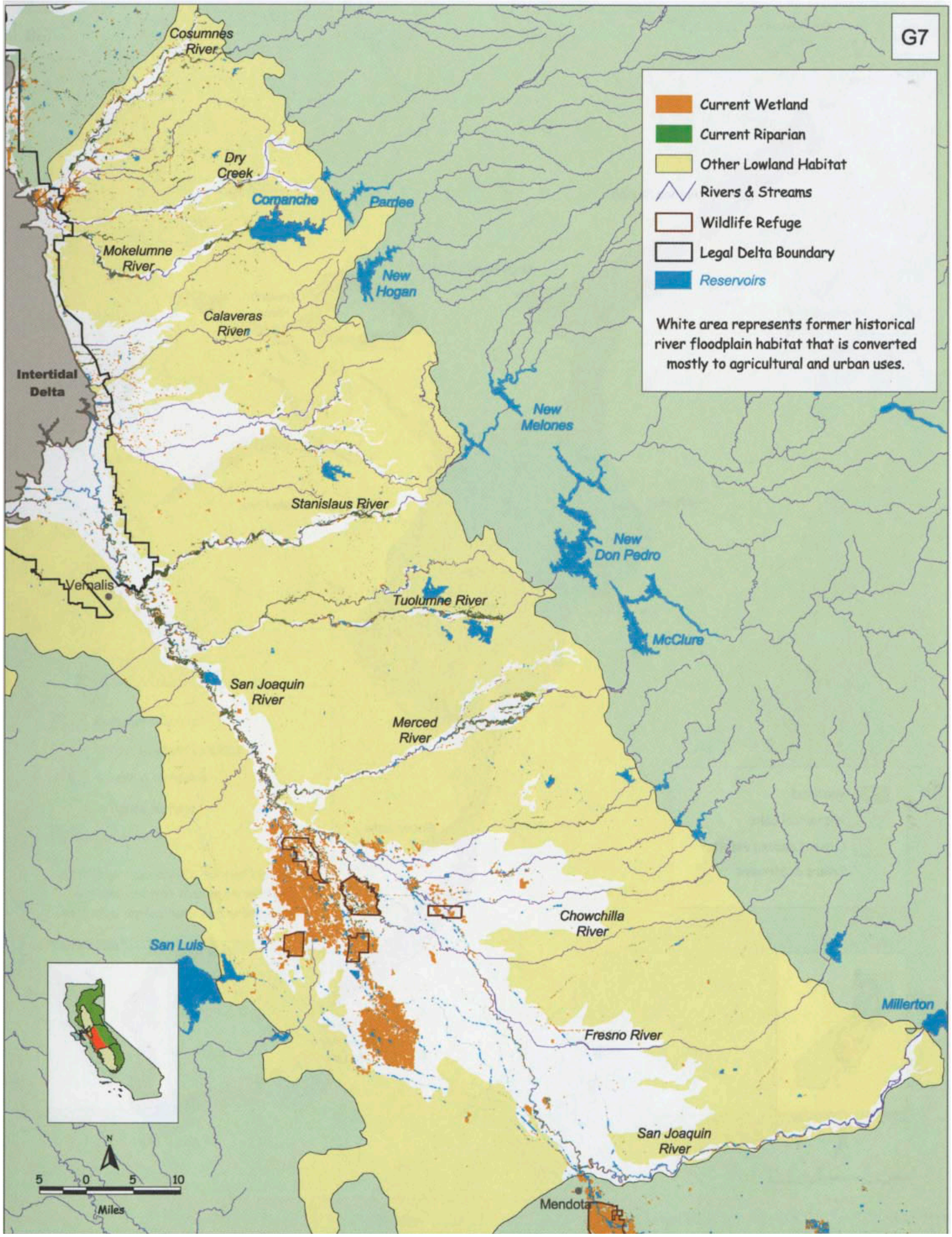


Figure 8-3. San Joaquin Valley current river floodplain ecosystem (from The Bay Institute, 1998).

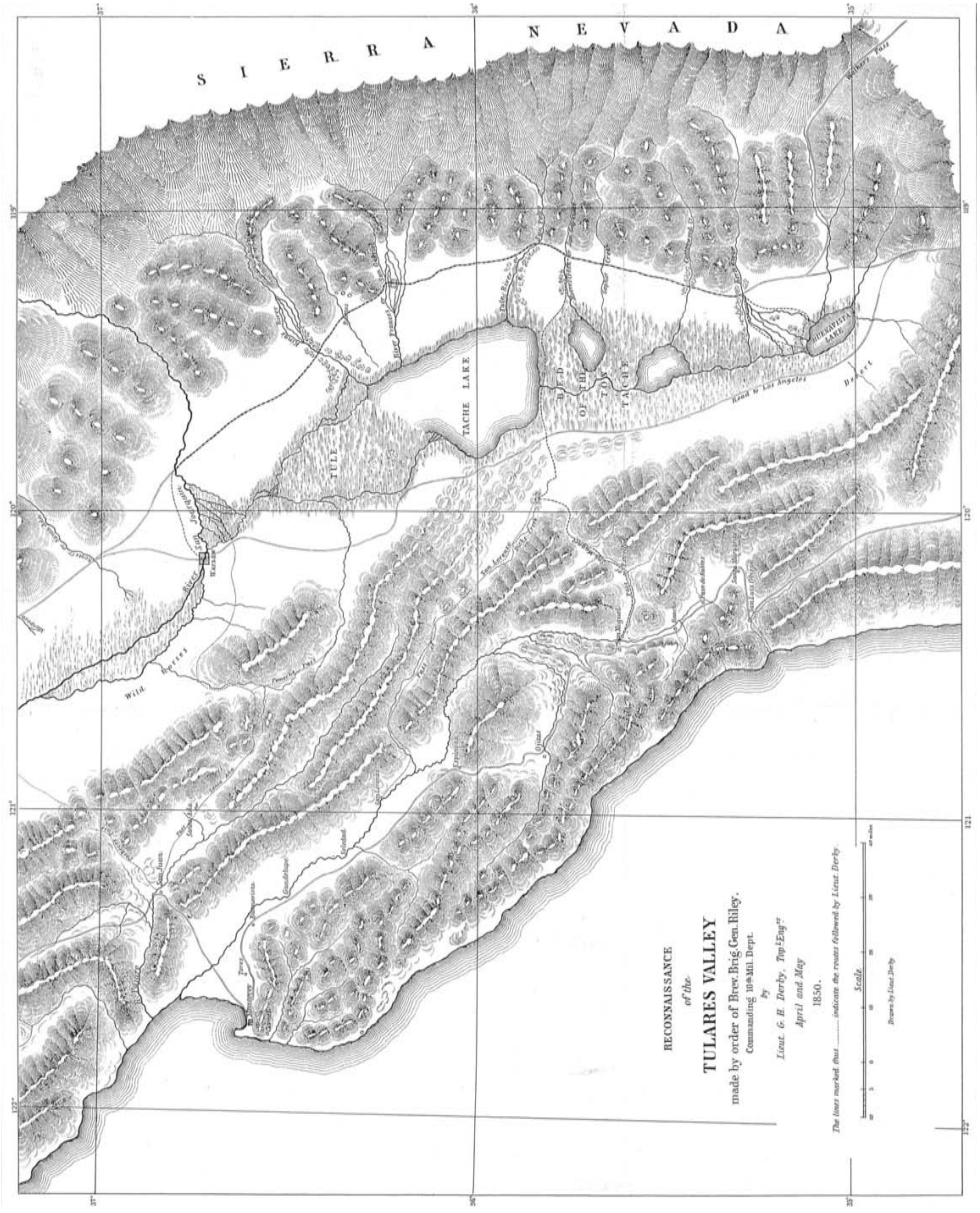


Figure 8-4. Reconnaissance map of the Tulare Valley, showing extensive tule marshes along the San Joaquin River, sloughs diverging from Reach 2 of the San Joaquin River into Fresno Slough, and no mapped woody riparian vegetation along the San Joaquin River (from Derby 1850).

Figure 8-5. Topographical sketch of the Tulare Valley, showing tule marshes, sloughs diverging from Reach 2 of the San Joaquin River into Fresno Slough, and a thin band of woody riparian vegetation along Reach 1 and 2 of the San Joaquin River.

The Moraga expedition of 1806 (as summarized in Fox 1987b) describes the San Joaquin River near Santa Rita (Reach 4):

> *"There are also great tule swamps in all this region and much black willow along the stream. On all sides [of two stream beds] tremendous tule swamps present themselves, which can be very miry in wet years"*

Finally, the Fremont expedition in 1844 (as excerpted in Fox 1987b, and TBI 1998) describes the San Joaquin River in April moving upstream from the Merced River confluence (Reach 5):

> *"Here the country appears very flat; oak trees have entirely disappeared, and are replaced by a large willow nearly equal in size [probably black willow]… The river was deep, and nearly on a level with the surrounding country; its banks raised like a levee, and fringed with willows… After having traveled fifteen miles along the river we made an early halt under the shade of sycamore trees…Late in the afternoon we discovered timber, which was found to be in groves of oak-trees on a dry arroyo… Riding on through the timber… we found abundant water in small ponds… bordered with bog-rushes (Juncus effusus) and tall rush (Scirpus lacustris) twelve feet high, and surrounded near the margin with willow-trees in bloom; among them one which resembled Salix myricoides. The oak of the groves was the same already mentioned, with small leaves, in form like those of the white oak, and forming, with the evergreen oak, the characteristic trees of the valley:*

The large valley oak woodlands typical in the Sacramento Valley and terraces of rivers exiting the Sierra Nevada foothills did not appear to exist in the San Joaquin Valley plains in Reaches 2 through 5. Fremont's narrative suggests that the oaks occurred on tributaries and sloughs (e.g., Bear Creek, which joins the San Joaquin River about 15 miles upstream from the Merced confluence), but were not extensive along the San Joaquin River channel. It is also possible that the trees were on a high flow channel or slough between anastomosing channels of the San Joaquin River approaching the Merced confluence. Additionally, review of 1855 Government Land Office plat maps did not indicate that valley oaks were along the river. The U.S. Meander Lines surveyed by the Government Land Office typically use larger trees (valley oak and cottonwood) for "witness" trees; review of these maps in Reaches 2 through 5 show that all witness trees are willows, not valley oak or cottonwoods.

From several sources, Fox (1987a) postulated the extent of tule marsh and its relationship with saltbush and prairie communities on the valley floor (Figure 8-6). This map was compiled from sources that used varying lines of evidence (such as existing vegetation, soils, topography, patches of remnant vegetation, hydrology, climate, ecological requirements of the dominant plant species, and historical information). For the San Joaquin River drainage, this map closely resembles that of Kuchler (1977) that portrays potential natural vegetation not appreciably disturbed by humans.

The historical river floodplain ecosystem map (Figure 8-2) was based principally on mapped soils and geologic information (e.g., quaternary stream deposits) coupled with historical information. Figure 8-2 was a collaborative effort between TBI (1998) and Fox (personal communication 2002), thus supercedes Figure 8-2. Figure 8-2 identifies the area that could have been occupied by riparian woodland and forest sometime during the last 10,000 years (TBI 1998). This riparian vegetation estimate exceeds the amount that would likely have been present, at any one time, during that period.

Thompson (1961) described the major streams of the Sacramento Valley as bordered by well-developed riparian forests and woodlands, occurring on the coarse alluvium of natural levees and river terrace deposits. Sub-irrigation, fertile alluvial loam soils, and relative freedom from surface

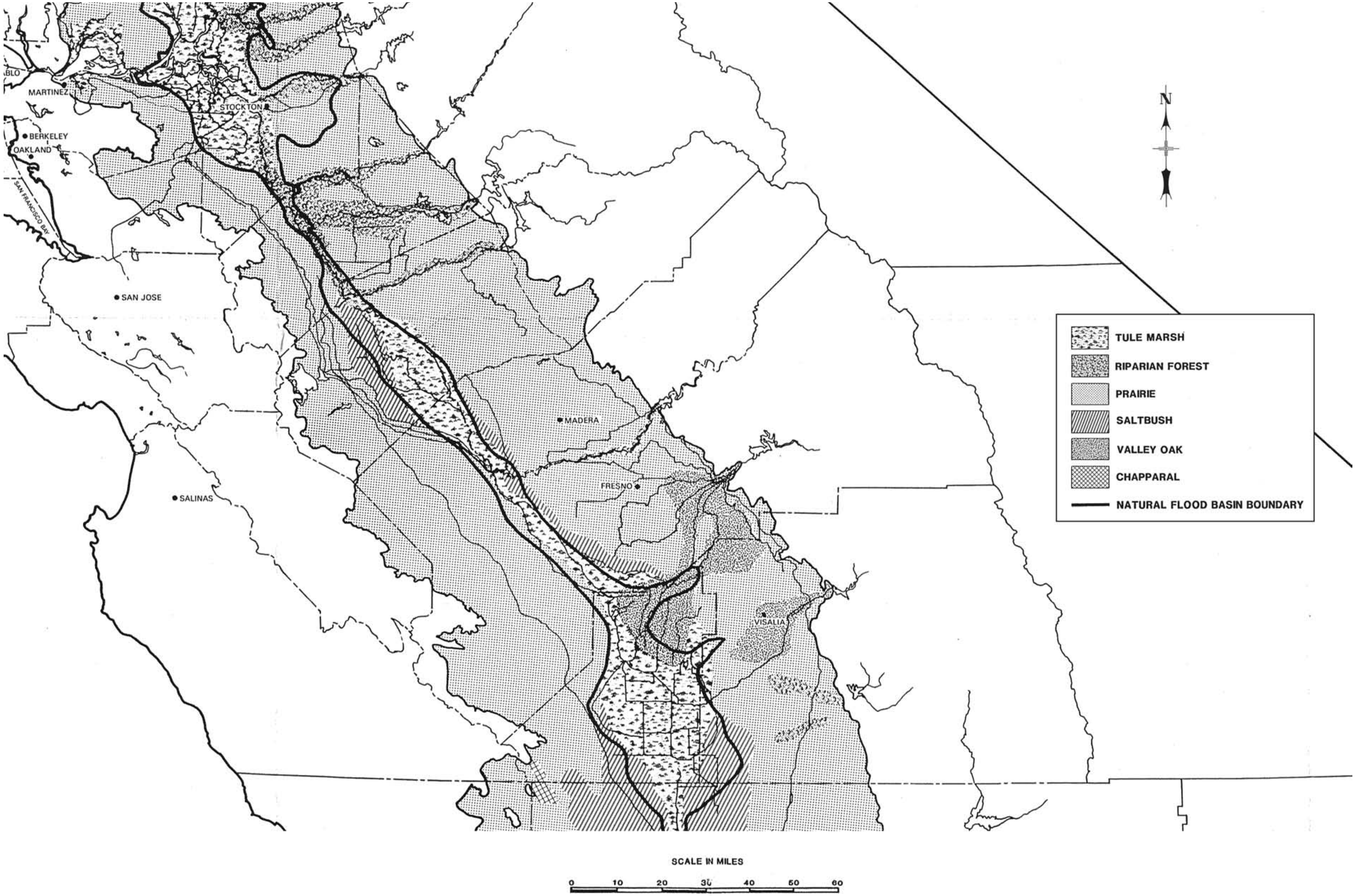


Figure 8-6. Natural vegetation and flood basins of the California Central Valley, based on compilations of maps by Kuchler (1977), Roberts et al. (1977), and DWP (1931).

waterlogging and fire were major factors contributing to their presence (Thompson 1961). Thompson correlated remnant riparian patches with historical evidence contained in diary accounts of early Central Valley explorers to conclude that the remnant patches did indeed reflect the historical conditions.

By applying Thompson's assumptions to the San Joaquin River, it can be deduced that the low and high floodplains in Reach 1 were probably vegetated by a winter deciduous broad-leafed riparian forest characterized by Fremont cottonwood, several species of willow, sycamore, box elder, Oregon ash, valley oak, buttonwillow, wild grape, California blackberry, and clematis. This assumption was validated by recent field observations and limited historical references. Photos from 1911, remnant vegetation, and accounts from old-timers suggest that sycamore and cottonwood were extensive along the lower portions of Reach 1 and the upper portions of Reach 2 (Cain 1997; Cain, personal communication, 2002). Nelson et al. (1918) described native vegetation occurring on Hanford series soils (the only recently deposited alluvial soil mapped along the San Joaquin River at that time) as including a moderate to heavy growth of willows, native vines, and cottonwoods that added considerable cost to land clearing for agricultural conversion.

The California Debris Commission Map of the San Joaquin River from Herndon to the Merced River (ACOE 1917) shows extensive areas of brush in the riparian zone, which likely represent willow vegetation associations; however, whether cottonwood was a significant component in this vegetation is unclear. Assuming the California Debris Commission maps represent unimpaired conditions needs to be done with caution, because extensive cattle grazing and fuel wood harvesting had been occurring for over 50 years prior to creation of the California Debris Commission maps, and agricultural manipulation of the river corridor was rapidly occurring (as suggested by numerous diversion canals shown on the maps).

While valley oak was not a dominant tree in the active floodplain, it probably was the dominant tree of young terraces and fans in Reach 1. Other less water-dependent riparian trees, shrubs, or vines, (including sycamore, Oregon ash, box elder, blue elderberry, blackberry, poison oak, grape, clematis, and wild rose) probably also were present. Remnants of dense rose and grape thickets are still evident today in Reaches 2, 3, and 4. Hall (1880) wrote a description of the vegetation along the Kings River (which contains similar recently deposited alluvial soils but is less arid than the San Joaquin River in Fresno County):

> *"thick growth of valuable timber composed principally of oak, with some cottonwood and willows, which latter are found immediately along the riverbanks, while the former extends out on the plains for several miles each side of the river. The soil within the timber belt is rich and productive upon compare. This extensive belt of woodland forms one of the most prominent and anomalous features upon the face of the country."*

In contrast to the broad and unconfined alluvial fan geomorphology along the Kings River, which supported wide expanses of oak woodland flanking the riparian forest where it flowed out of the mountains into the valley, the equivalent portion (Reach 1) of the San Joaquin River was limited to a much narrower zone of woodland and forest due to topography and soils. From Friant Dam downstream to near Gravelly Ford (Reach 1), the San Joaquin River is deeply incised below a Pleistocene-age terrace composed of paleo-alluvial fan sediments (Janda 1965). In this reach, the San Joaquin River floodplain is confined by bluffs to a relatively narrow-steep-sided valley, typically less than one mile in width (from data in Cain, 1997). Outside of the valley bottom, the arid habitat is unsuitable for woodland growth and probably supported grassland vegetation. The early explorer maps are consistent with this description (Figure 8-5).

In the reach below Firebaugh (Reach 3), the floodplain contained a narrow band of coarser riparian soils that form a complex association with finer riparian soils associated with the historical tule marshes. The mapping of riparian soils was limited mostly to the recently deposited alluvial soils occurring next to the river, even though the same soils may also occur away from the river but are separated by basin clays or clay loams. Minor areas of clay loam, however, were included in the riparian soil category if they occurred between a major slough (e.g., Pick Anderson Slough) and the San Joaquin River. The vegetation in the river reach below Firebaugh probably was a complex of cottonwood, willows, buttonwillow, and tules, with the taller woody species being localized and limited to the coarse-textured soils of higher ground, natural levees, or around the margins of oxbow lakes. Hall's *Topographic and Irrigation Map of the San Joaquin Valley* (1886) mapped swamp and overflowed lands up to 6 miles wide in this area (see Figure 4-6). Government Land Office plat surveys (circa 1855) map the areas as "overflowed willow swamp or tule swamp." A local newspaper, the *San Joaquin Democrat*, reported tules as far as the eye could see in an article from the 1860s (McKown, personal communication). The picture emerging from these different accounts is one of bands of woody riparian vegetation in a sea of tules.

Katibah (1984) emphasizes the relative scarcity of natural levees along the San Joaquin River after it reaches the valley floor (Reaches 4-5), a result of low natural sediment loads, compared with the extensive natural levees of other systems such as the Sacramento. The modest development of natural levees along portions of the San Joaquin River traversing the Valley bottom would have limited the habitat that could have been occupied by woody riparian vegetation. Prolonged inundation by floodwaters would have precluded growth of riparian forest in the flood basins. Fremont's accounts (described above) describing "levee-like banks fringed with willows" are not inconsistent with Katibah's because the scale of the levee-like banks are small compared to other lowland Central Valley rivers. Other systems such as the Sacramento River are characterized by well-developed natural levees created by flood deposited sediments. These natural levees, which ranged from 5-20 feet above the elevation of the surrounding flood basins and averaged 3 miles in breadth along the Sacramento River (Thompson 1961, in Katibah 1984) tended to contain the seasonal floodwaters during drier years and provided habitat for riparian and oak forest. The naturally low sediment loads along the San Joaquin River are attributed to relatively low-energy peak flows (Katibah 1984) and to significant inputs of essentially sediment free water (groundwater, overflow water from the Kings River, and San Joaquin River water that has deposited most of its sediment load by the end of Reach 2 and 3). With regard to the portion of the river between Fresno Slough (Mendota) and the confluence with the Merced River, Katibah (1984) states:

> *With no natural levees to contain its waters, the San Joaquin River spread out over the flat valley floor*

Quantitative studies of the historical riparian habitat in the San Joaquin River Basin have generally been based on anecdotal accounts of early travelers, historical maps, or historical and contemporary soil maps. Dawdy (1989) quotes several travelers' logs from the 18th and 19th centuries in which the lower San Joaquin River Basin is described as having extensive fields of tules with scattered willows in the river bed and "some nice groves of willows" at the confluence of the Merced and San Joaquin Rivers. Dawdy (1989) also points out that estimates of the extent of pristine riparian vegetation in the San Joaquin River Basin vary widely, from as little as a conservatively estimated 187,500 acres (Katibah 1984) to as much as 298,000 acres (Fox 1987b, in Dawdy 1989). More recent estimates in TBI (1998) based on soil surveys of the San Joaquin River Basin from Friant to the Delta resulted in an estimate of approximately 286,000 acres of potential riparian vegetation (329,000 acres of riparian soils minus 43,000 acres of wetlands within riparian zone). No quantitative estimates of potential riparian habitat were made for the study area (Friant to Merced River), but qualitative review of Figure 8-2 suggests that slightly greater than ½ of the 286,000 acres was within the study area. Fox (personal communication 2002), collaborated on this effort, which supersedes her 1987 estimates of the extent of riparian and wetland vegetation. Kuchler (1977) published a map of “potential natural” vegetation in California at a scale of 1:1,000,000. Kuchler’s mapping of the study area conforms to an 1886 map by Hall that shows “swamp and overflowed” lands (mainly tule marsh) along the river north (downstream) of Mendota and “bottom lands” (woody riparian habitat) between Friant and Gravelly Ford (see Figure 4-6).

During and after the Gold Rush, the intensity of human disturbances along the San Joaquin River and other Central Valley systems increased dramatically. Placer gold mining, dredge mining, flood control activities and diversions, and agricultural encroachment all had substantial effects on the river systems (Fox 1987a; Roberts et al. 1977; Warner 1985). Logging for fencing, construction lumber, and steamship fuel, also affected riparian zones, which were the only source of wood on the floor of the valley. Early steamships periodically traveled up river from Stockton to points within the study reaches, including near the Merced River confluence, Firebaugh, Salt Slough, Fresno Slough, Herndon; and occasionally a steamship made it as far upstream as the present day location of Rank Island (RM 260, approximately seven miles downstream of Friant Dam). Although some steamboats were designed to use coal as fuel, they were periodically forced to use trees such as ash or willow from the riverbanks, leading to the deforestation of streamside vegetation. Early accounts cited in Rose (2000) relate the difficulty and time-consuming nature of obtaining wood to fire the boilers while traveling upriver.

Agricultural colonies were established in the San Joaquin Valley in the 1860s, with settlers pooling resources to establish irrigation projects. The hydrology of the San Joaquin River began to be affected by a system of canals and diversions to supply irrigation water and by high water bypasses that reduced the flood potential along the mainstem river (JSA and MEI 1998). In the 1870s, Mendota Dam was established and a major canal was constructed to irrigate the west side of the valley. Artesian wells were constructed throughout the valley in the 1880s and the use of electric and natural gas pumps spread during the 1890s as water tables declined. By the 1870s, railroad service had reached Modesto and Bakersfield (north and south of the study area, respectively, and by 1892, it had reached Fresno, greatly facilitating commerce and export of agricultural products and demise of riverboats.

By 1913 to 1914, the California Debris Commission (ACOE 1917) prepared a series of survey maps that encompassed the area from Herndon (RM 243) downstream to the confluence with the Merced River. The maps document extensive development of canals and other land use changes in the immediate vicinity of the river, affecting the riparian zone. During this time, dams, diversions and canals continued to be developed or improved, and the number of wells in the valley increased dramatically. Reclamation of wetland and riparian areas to agricultural lands became extensive. All of these factors directly or indirectly affected the vegetation and hydrology of the valley.

These historical references lead to the following conceptual model of historical conditions:

- Reach 1 and potentially portions of Reach 2 consisted of bands of woody riparian vegetation (alders, willows, cottonwoods, sycamore, and valley oak) along the floodway of the San Joaquin River corridor, typically in discontinuous patches along high flow scour channels and side channels closer to the groundwater table. Valley oak occurred on terraces primarily in Reach 1.
- Reaches 2 through 5 consisted of bands of woody riparian vegetation (in places perhaps exclusively black willow) along the margins of the San Joaquin River channels and sloughs,

with extensive tule marshes in the flood basins beyond the narrow (typically less than 2,000 feet wide) riparian bands. In these reaches, woody riparian vegetation probably also grew on higher ground along the margins of sloughs, oxbow lakes, and minor natural levees along abandoned channels.

This general conceptual model is discussed in more detail for the five reaches in the following section.

8.6.2. Historical Trends 1937–Present

In the mid-1940s, Friant Dam and associated diversion canals became operational and population growth and development continued in the region. The Delta-Mendota Canal became operational in the early 1950s, bringing water from the Delta back into the San Joaquin River at Mendota Dam. To provide estimates of the changes in riparian vegetation over this period, JSA (1998) mapped vegetation/land cover from 1937 aerial photographs (Figure 8-7); they also mapped vegetation/land cover for 1957, 1978, and 1993. A 1998 air photo was used by DWR to develop the most recent vegetation/land cover map (Figure 8-8) (Moise and Hendrickson, 2002). The 1937 and 1998 vegetation/land cover maps use different classifications; Table 8-2 illustrates these differences and attempts to correlate the classifications to make the two maps more comparable. To reduce differences in mapping methods and classification systems used by JSA (1998) for 1937–1993, and by DWR for 1998 (Moise and Hendrickson 2002), habitat types and land use categories were combined into broad categories for use in the following analysis.

Areas of riparian habitats and land use types within the study corridor width described in Section 8.3 dramatically changed between 1937 and 1998 (Tables 8-5 to 8-13; Figures 8-9 to 8-17). Changes in riparian features such as sloughs that extend further away from the main channel are not reflected in this analysis.

Acreage figures given in Moise and Hendrickson (2002) covered a larger study area than that covered by JSA (1998); reach boundaries were also slightly different. Even when broad habitat categories are compared for 1993 and 2000 over the same areas, differences in mapping methodology between JSA and DWR become apparent.

One difference in mapping methods was that DWR mapped riparian forest polygons including a “zone of influence” of one-half canopy width, while JSA used a “smoothed-out” canopy outline to determine the boundary of riparian forest. This may have resulted in a higher riparian forest area estimate from the DWR data than from the JSA data.

A second major difference in mapping methods was the minimum mapping units used in the two studies. JSA (1998) used a 5-acre minimum mapping unit for riparian habitats and wetlands, and a 20-acre minimum mapping unit for other cover types; this was appropriate for their unrectified low-resolution historical aerial photographs. DWR used a 0.3-acre minimum mapping unit, which was appropriate for their high-resolution rectified aerial photographs. In areas where many small polygons occur, such as riparian and wetland habitat in Reach 5, this minimum mapping unit difference would result in higher estimates from DWR data than from JSA data.

The distribution of habitat types in the 53,400-acre vegetation study area changed dramatically between 1937 and 1998 (Table 8-5, Figure 8-9), reflecting large changes in land use and physical and biological processes. The degree of change varied substantially between reaches due to differences in hydrology, geomorphology and land use. The 1937 habitat types in Table 8-5 do not imply pristine conditions; habitat types had already been drastically changed by 1937.

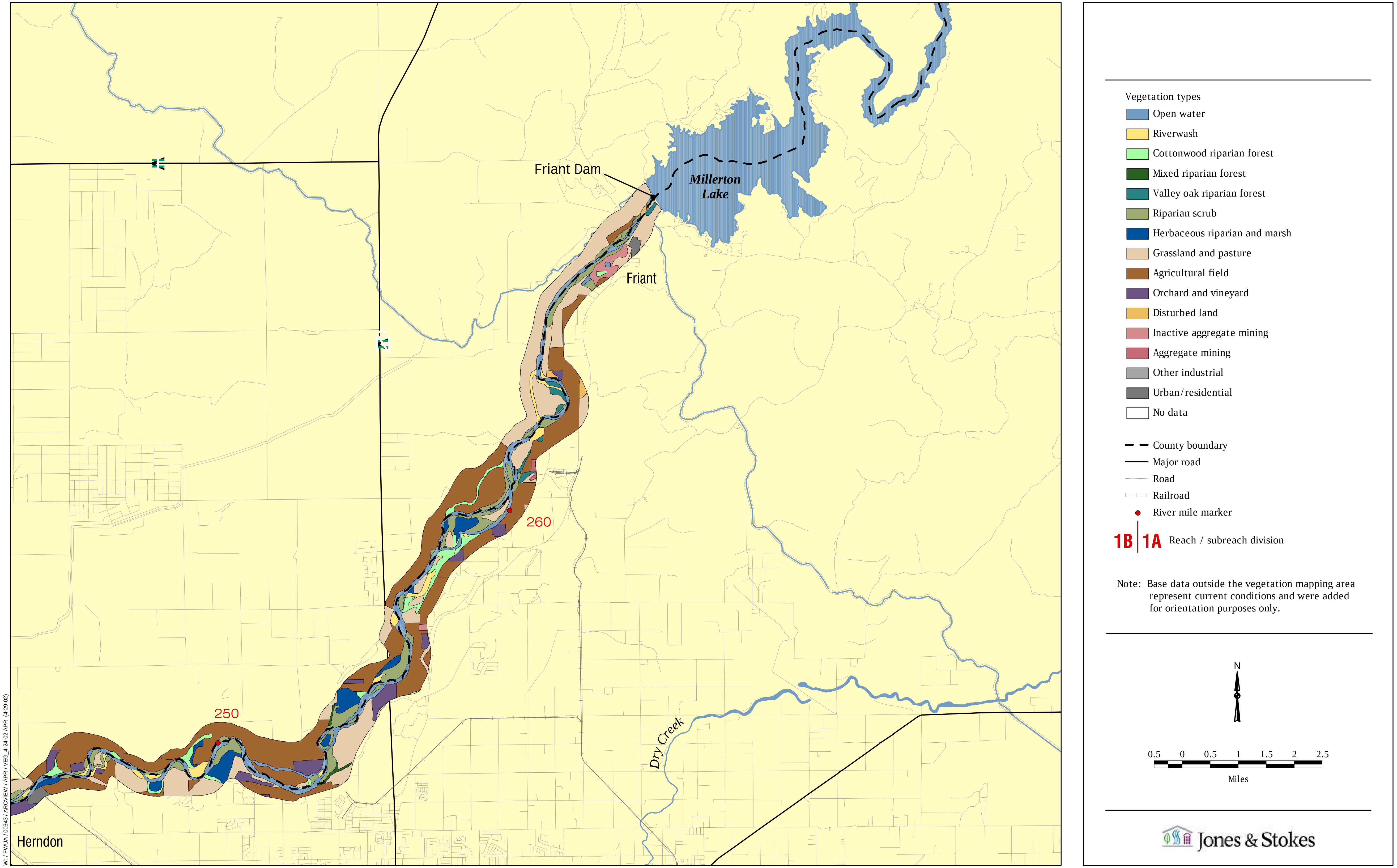


Figure 8-7. Vegetation types along the San Joaquin River in 1937 (JSA 1998a).

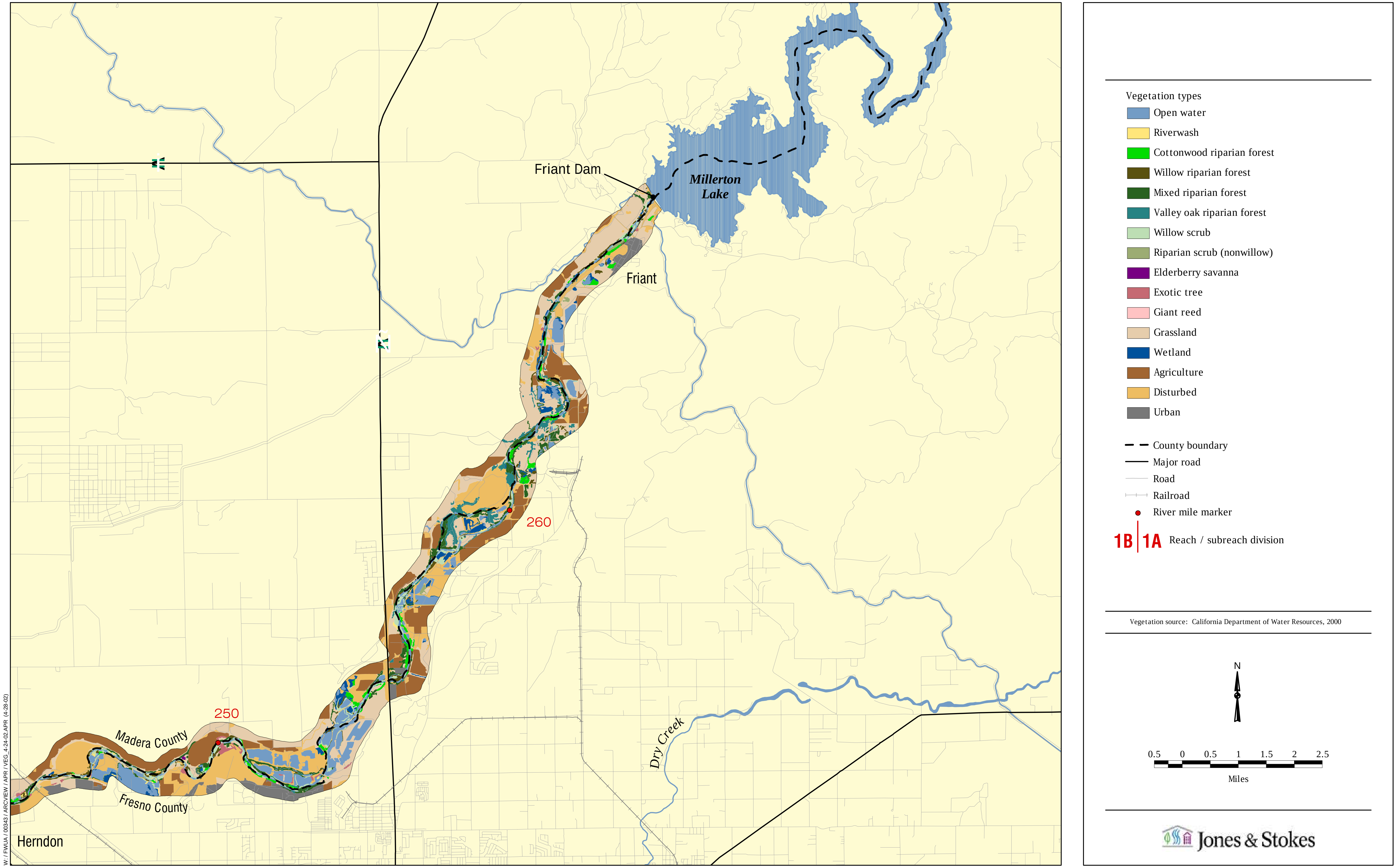


Figure 8-8. Vegetation types along the San Joaquin River in 1998 (Moise and Hendrickson 2002).

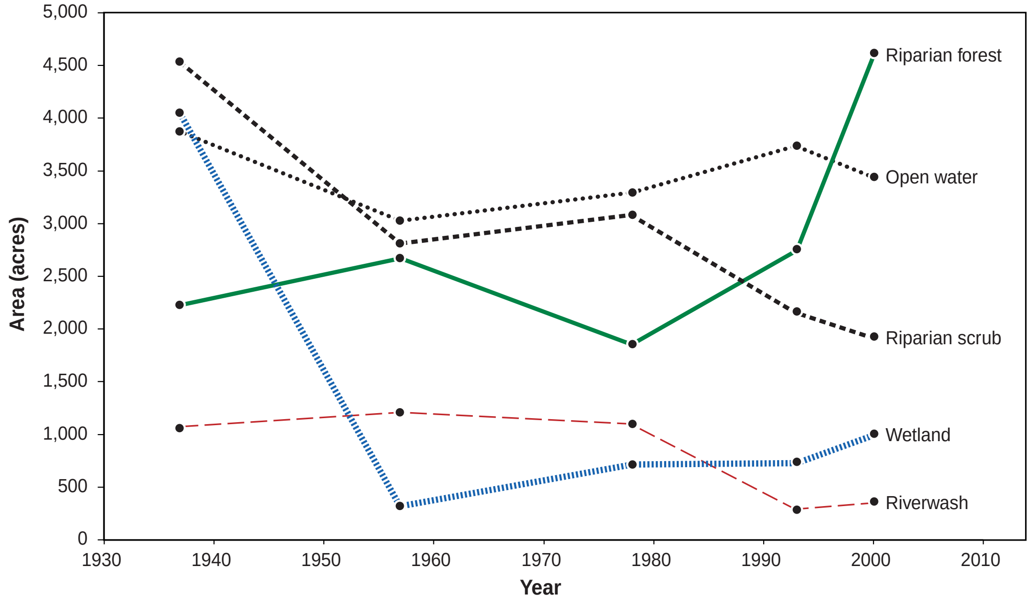


Figure 8-9. Change in vegetation area from 1937-1998 over entire study area (all reaches, Friant Dam to Merced River confluence). Data plotted as 2000 data were mapped on 1998 air photos.

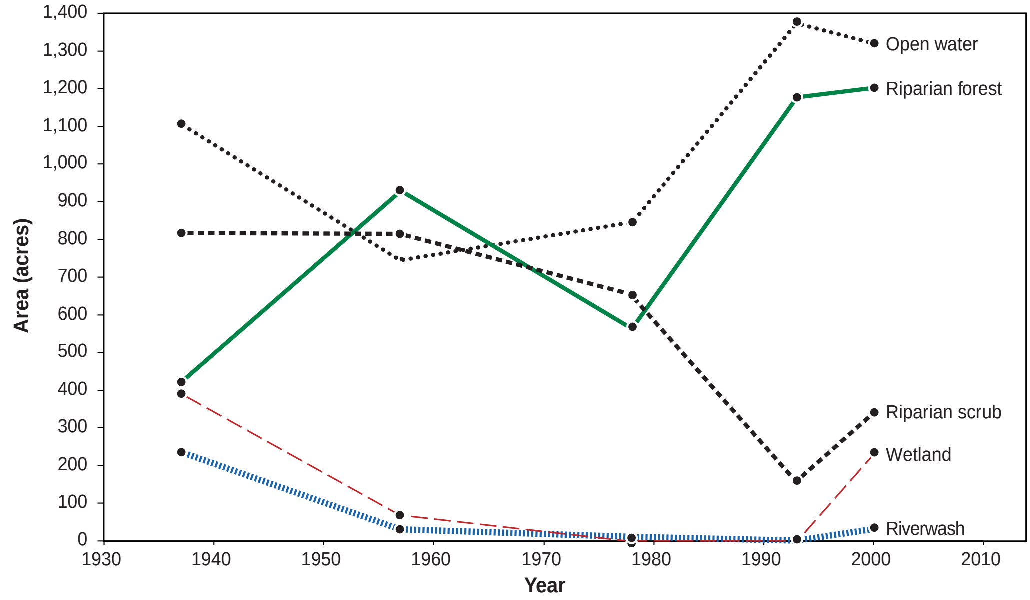


Figure 8-10. Change in vegetation area from 1937-1998 over Reach 1A (Friant Dam to Herndon). Data plotted as 2000 data were mapped on 1998 air photos.

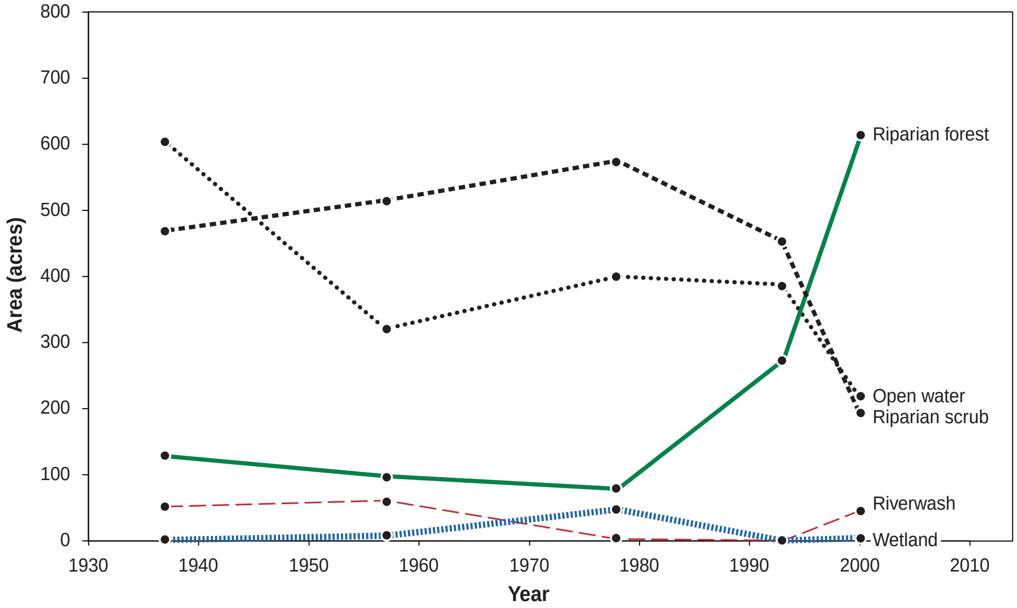


Figure 8-11. Change in vegetation area from 1937-1998 over Reach 1B (Herndon to Gravelly Ford). Data plotted as 2000 data were mapped on 1998 air photos.

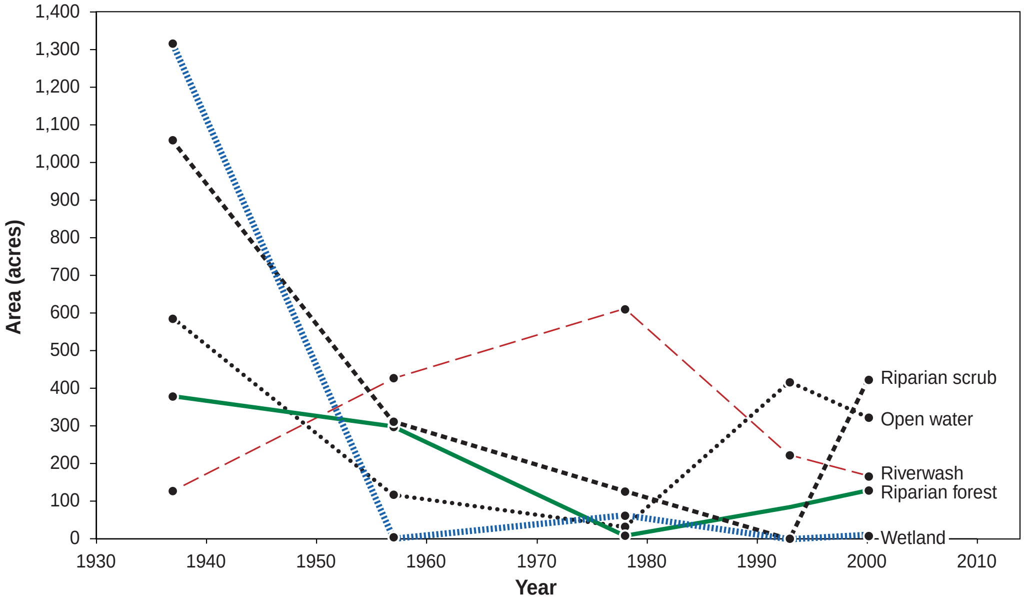


Figure 8-12. Change in vegetation area from 1937-1998 over Reach 2A (Gravelly Ford to Chowchilla Bifurcation Structure). Data plotted as 2000 data were mapped on 1998 air photos.

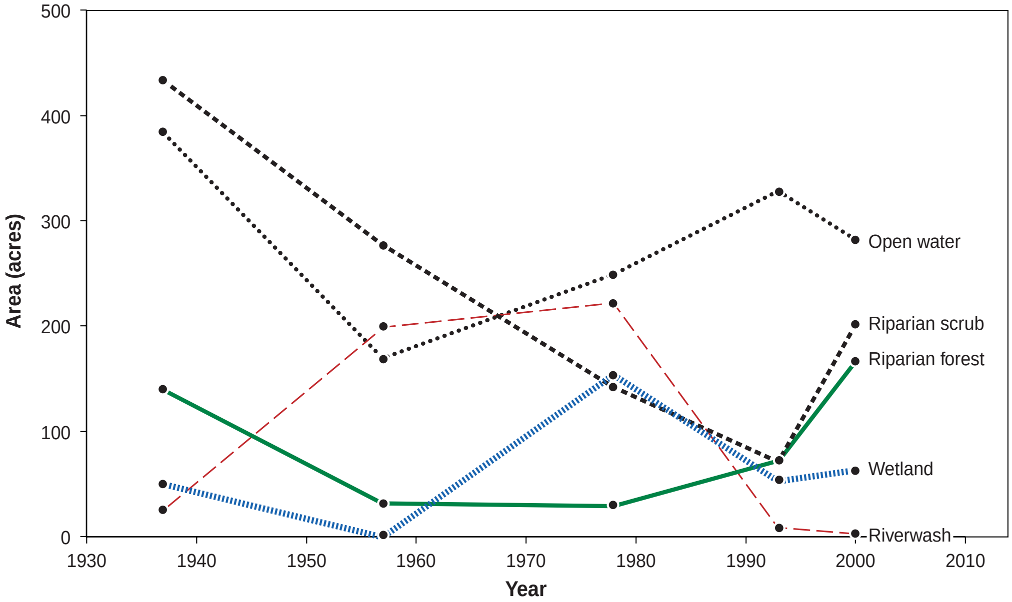


Figure 8-13. Change in vegetation area from 1937-1998 over Reach 2B (Chowchilla Bifurcation Structure to Mendota Dam). Data plotted as 2000 data were mapped on 1998 air photos.

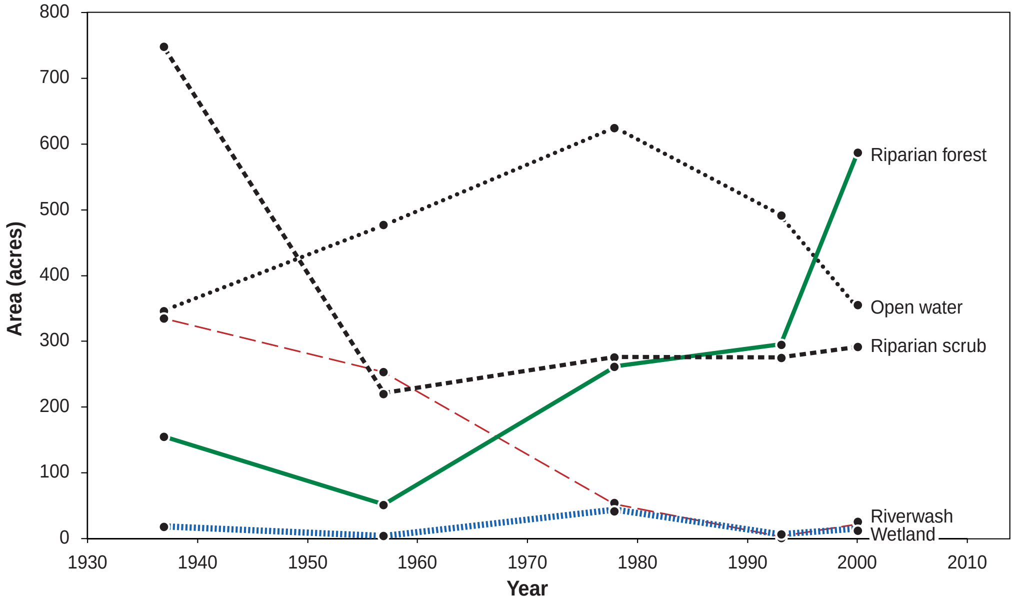


Figure 8-14. Change in vegetation area from 1937-1998 over Reach 3 (Mendota Dam to Sack Dam). Data plotted as 2000 data were mapped on 1998 air photos.

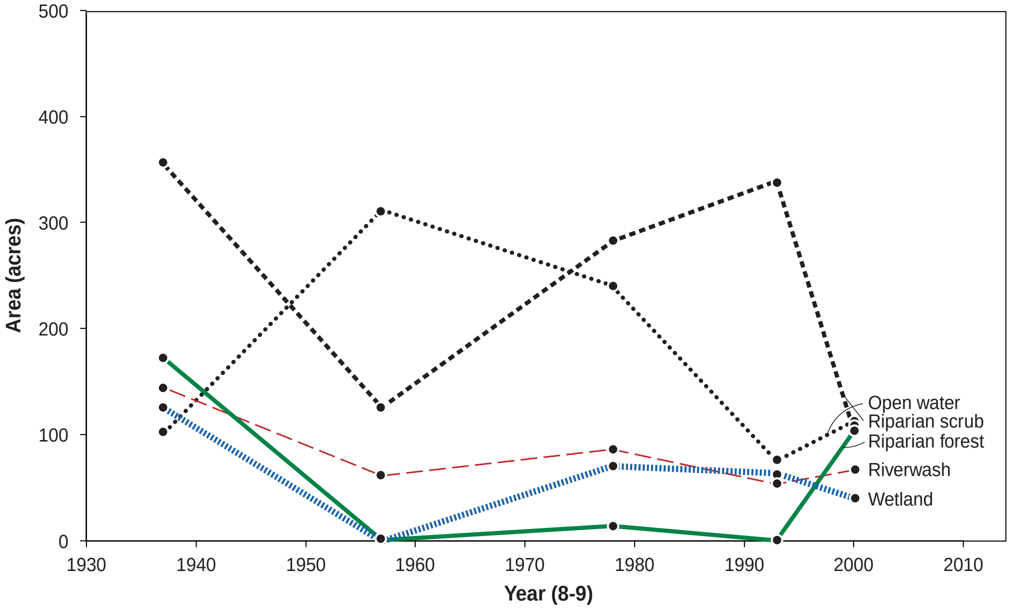


Figure 8-15. Change in vegetation area from 1937-1998 over Reach 4A (Sack Dam to Sand Slough Control Structure). Data plotted as 2000 data were mapped on 1998 air photos.

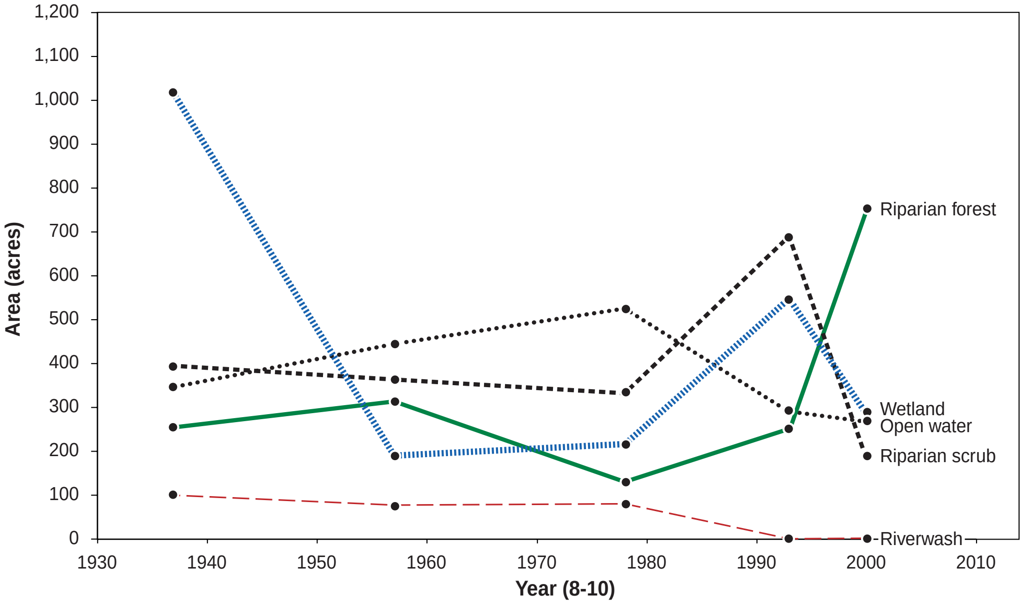


Figure 8-16. Change in vegetation area from 1937-1998 over Reach 4B (Sand Slough Control Structure to Bear Creek confluence). Data plotted as 2000 data were mapped on 1998 air photos.

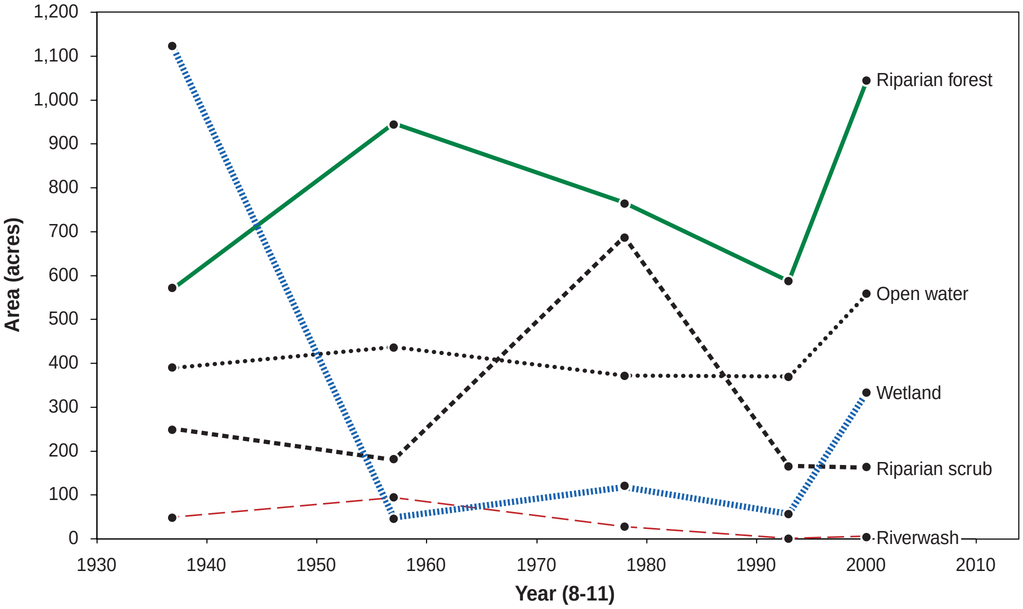


Figure 8-17. Change in vegetation area from 1937-1998 over Reach 5 (Bear Creek confluence to Merced River confluence). Data plotted as 2000 data were mapped on 1998 air photos.

Table 8-5. Area (acres) of habitat types in the study area over time (Friant Dam to Merced River).

	Year				
Class	**1937**	**1957**	**1978**	**1993**	**1998**
Open water	3,880	3,030	3,300	3,740	3,450
Riverwash[a]	1,080	1,210	1,100	300	350
Riparian forest	2,232	2,680	1,860	2,750	4,610
Riparian scrub	4,540	2,820	3,090	2,160	1,920
Wetland	4,055	320	720	730	1,000
Grassland	19,344	14,380	11,480	12,140	10,670
Agriculture	17,691	27,340	28,840	26,720	25,380
Urban and disturbed	562	1,630	2,840	2,990	6,030
No data	30	0	200	1,880	0
Total	53,413	53,410	53,410	53,410	53,410

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Between 1937 and 1957, wetland area decreased from 4,060 to 320 acres (a 92% reduction) over the entire study area (Table 8-5, Figure 8-9). Riparian scrub area also declined by 38% during this period, but riparian forest slightly increased. Large declines in riparian, and especially marsh habitat, were likely caused by 1) conversion of these lands to agricultural fields, and 2) changes in hydrology resulting from Friant Dam operations. Hydrologic changes likely affected vegetation maturation and succession processes; for example, reduced flood disturbance allowed mature vegetation to withstand scouring of sand and gravel bars. On riverwash areas, reduced flood disturbance and scouring allowed vegetation development, leading to riparian scrub, and maturation of vegetation from riparian scrub to riparian forest (JSA 1998).

Between 1957 and 1998, the area mapped as riverwash decreased, probably a result of encroachment by riparian vegetation. Wetland area increased, in part due to wetland management and restoration in the San Luis National Wildlife Refuge Complex and State Wildlife Management Areas. As vegetation matured, riparian scrub area decreased and riparian forest area increased.

However, between 1993 and 1998, the riparian forest area increased from 2,750 to 4,610 acres, which is more than can be accounted for by maturation of riparian scrub area (Figure 8-9). The apparent sharp increase in riparian forest area may be due to differences in mapping methods between DWR and JSA. Using a "zone of influence" rather than a "smoothed-out" canopy, plus using a minimum mapping unit of 0.3 acre instead of 5 acres, caused the riparian forest estimates mapped for 1998 to be higher than would be expected based on the methods used for 1993. In addition, the 1993 analysis followed a 6-year drought, whereas the 1998 analysis was based on 1998 air photos and data taken after 4 consecutive wet years (although it is not known what effect these antecedent dry and wet years had on the mapping results).

Another notable difference between 1993 and 1998 land cover is the increase in urban and disturbed lands. This category includes existing and former aggregate mines, other industrial lands, urban and residential areas, and waste places (unused, previously disturbed, barren or weedy land). Comparison of 1998 (upon which the 1998 mapping was performed) and 1993 photographs shows an increase in the area affected by aggregate mining and by urbanization. Since 1998, a further increase in the area affected by aggregate mining has occurred (Moise and Hendrickson 2002). Regardless of the differences in data from JSA and DWR, urban and mining areas increased, and agricultural and grassland area decreased.

Because of the hydrologic and geomorphic differences in the study reaches, an analysis of riparian habitat and land use changes by reach is more meaningful than an analysis of these changes for the study area as a whole. In each of the reaches below, the overall changes in riparian acreages between 1937 and 1998 are tabulated and discussed. In addition, a representative 2 to 4 mile-long section of the San Joaquin River was prepared for each of the five reaches, using the 1855 Government Land Office plat maps, the 1914 CDC maps (ACOE, 1917), the 1937 aerial photographs, and the 1998 aerial photographs. Unfortunately, the 1937 aerial photographs were unavailable in Reaches 4 and 5, and the 1914 CDC mapping effort did not extend into the upper portion of Reach 1. For each representative reach, we developed a conceptual cross section showing riparian and channel morphology evolution for each of the mapping/photo series. This cross section is based on the 1914 cross section surveys conducted by the ACOE, but the riparian vegetation and topography further from the channel is inferred from anecdotal sources rather than quantitative sources. Figure 8-18 shows the location of these example sites.

8.6.3. Historical and Present Conditions by Reach

8.6.3.1 Reach 1

8.6.3.1.1. Historical overview

Prior to 1770, broad, infrequently flooded terraces (>2 year flood recurrence) supported valley oak, interior live oak, walnut, elderberry and sycamore, with an understory of native grasses, herbs and shrubs. The active channels were flanked by a cottonwood-willow community that included white alder and Oregon ash. Point bars and channel margins were occupied by the willows and alders with the remaining species generally concentrated on slightly higher terraces. Abandoned channels, oxbows, and overflow channels supported a variety of communities depending upon the depth to

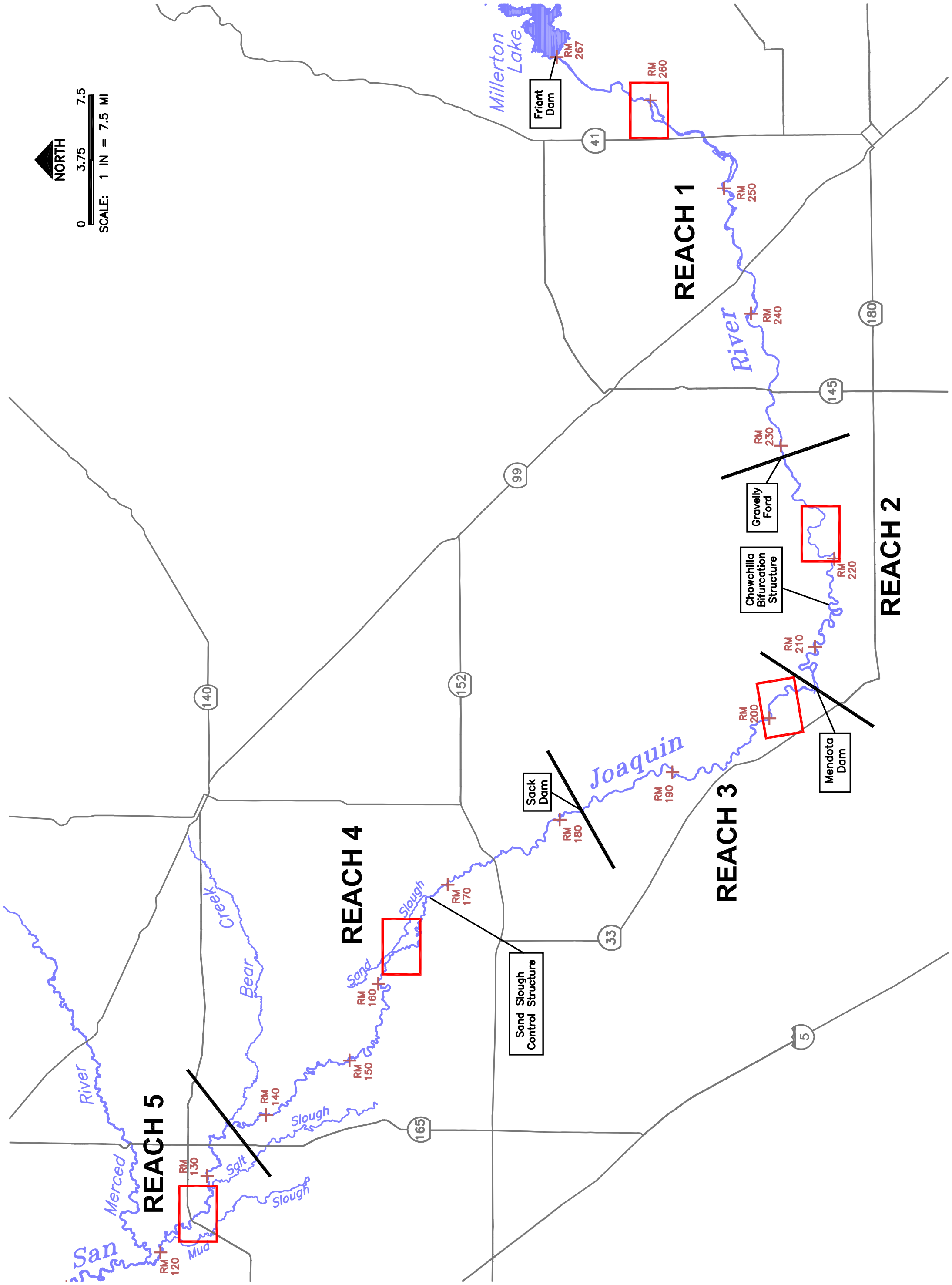


Figure 8-18. Location of historical planform evolution example reaches.

water, intervals between flooding and time since last flood. Backwaters provided permanently flooded or saturated (swampy) habitat with low flow and supported buttonwillow, tules, and cattails.

To illustrate some of the planform changes that have occurred, historical maps and air photos were compared for a portion of Reach 1A at River Mile 259, roughly 3 miles upstream from the Highway 41 crossing (Figure 8-19). Additionally, a conceptual cross section with topography and vegetation is provided based on historical maps and explorer accounts (Figure 8-20). The cross section shows hypothesized pristine conditions, in comparison to conditions apparent in 1937 and 1998, based on interpretations of aerial photographs and topographic maps (see Section 8.5.4 for a description of the methodology).

By 1937, clearing for agriculture or livestock grazing affected most of the accessible terraces that had previously supported valley oak woodland, resulting in a dramatic reduction in that habitat type. Some of this had been cut over much earlier. William Hammond Hall’s early survey notes show that there were numerous oak stumps in Reach 1 providing evidence that Reach 1 once had significant oak woodlands that had been cut over by the time of his surveys in the 1870s. In 1998, the active channels are flanked by a declining cottonwood-willow community with an understory dominated by exotic upland species. White alder survives at the fringe of the cottonwood-willow community, where slope changes mark the former bankfull channel (1.5 to 2.2-year return interval under unregulated conditions).

Note the changes in shape and location of the active channels between 1937 and 1998. Following completion of Friant Dam, steady year-round flows and the lack of scouring flood flows have allowed narrow-leaf willow and white alder, which tend to form dense monotypic stands, to encroach on the active channels. This encroachment led to changes in the cross-sectional morphology of the channels by trapping sediment during infrequent higher flows, followed by cycles of additional plant growth and additional sediment deposition. The aggrading riparian berms, armored by the dense mats of willow stems and white alder roots, eventually create a more or less trapezoidal or rectangular cross section (Pelzman 1973; McBain and Trush 1997). This process, which has been documented on highly regulated streams throughout the western United States, “locks” the channel into place, reducing sinuosity, lateral channel migration, and habitat diversity. Compared to the sloping cross-section characteristic of unregulated conditions, the modified cross-section creates a simpler, more uniform aquatic habitat, which reduces salmonid spawning and rearing habitat. Additional discussion of riparian encroachment is in Section 8.7.6.

8.6.3.1.2. Current conditions.

Subreach Reach 1A presently supports nearly continuous riparian vegetation, except where the channel has been disrupted by instream aggregate removal or captured off-channel aggregate pits. The attenuation of peak inflows by the reservoir, and the reduction in the frequency and duration of channel-scouring flood flows below Friant Dam, have created more stable conditions in the active channel. Where the active channel was formerly dominated by riverwash deposits on large point bars and mid-channel islands, the reduced flow regime has promoted occupation of the bars and shoreline by alder, buttonwillow, willow, and ash (Figure 8-20). Continuous open water, created by a relatively uniform summer base flow and numerous instream mining ponds (Figure 8-19), appears to be the primary factor preventing greater encroachment of woody vegetation within the active channel (JSA and MEI 1998). These mining ponds are permanently flooded by the shallow groundwater table, and are bordered by narrow-leaf willow. Without mechanical filling, these pits will be long-term features because Friant Dam flow and sediment regimes would require centuries to naturally fill the pits.

Long-term removal of sand and gravel in the channel and floodplain, combined with loss of the

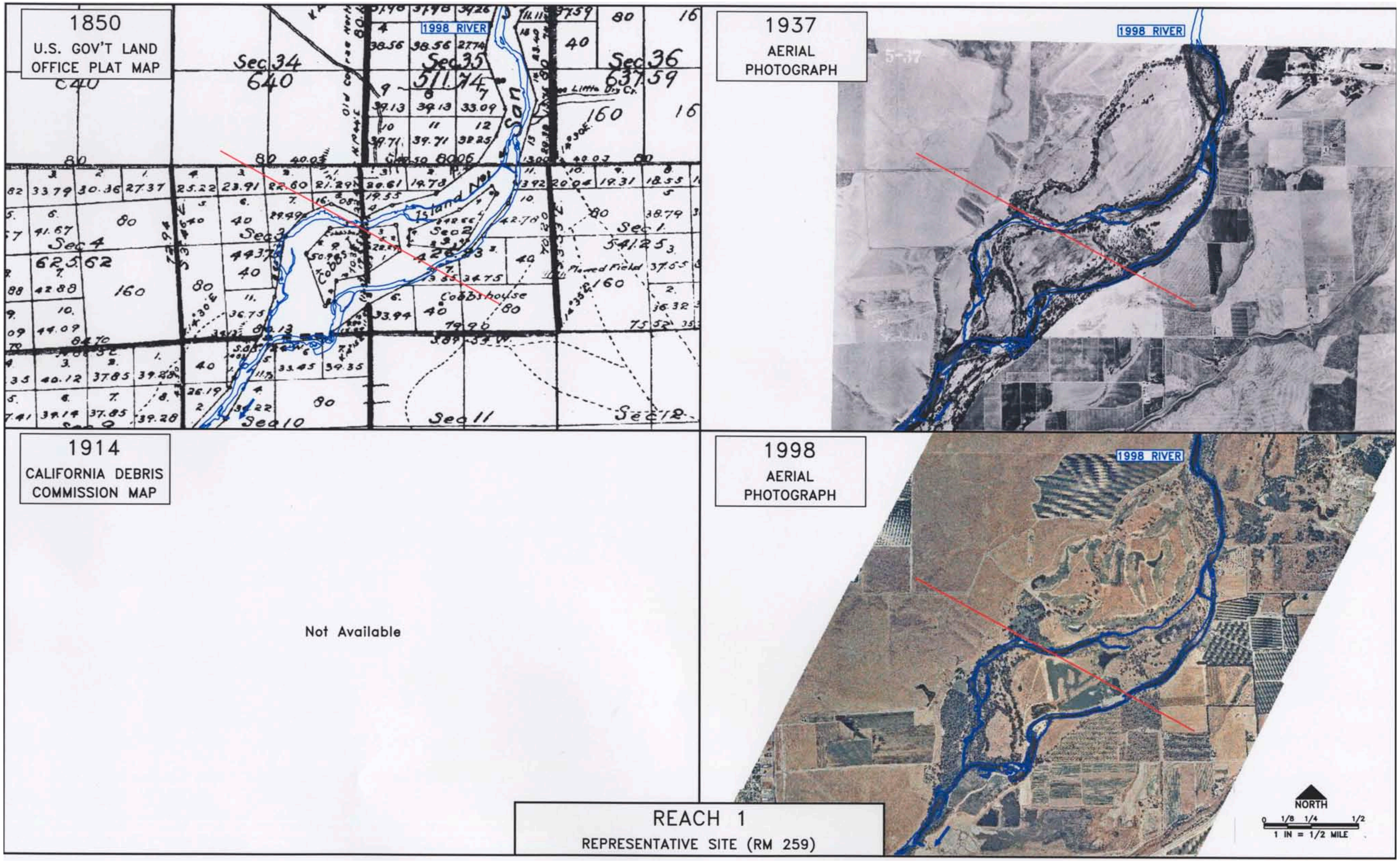


Figure 8-19. Example planform evolution in Reach 1 (RM 259), showing 1855 plat map, 1937 air photo, and 1998 air photo.

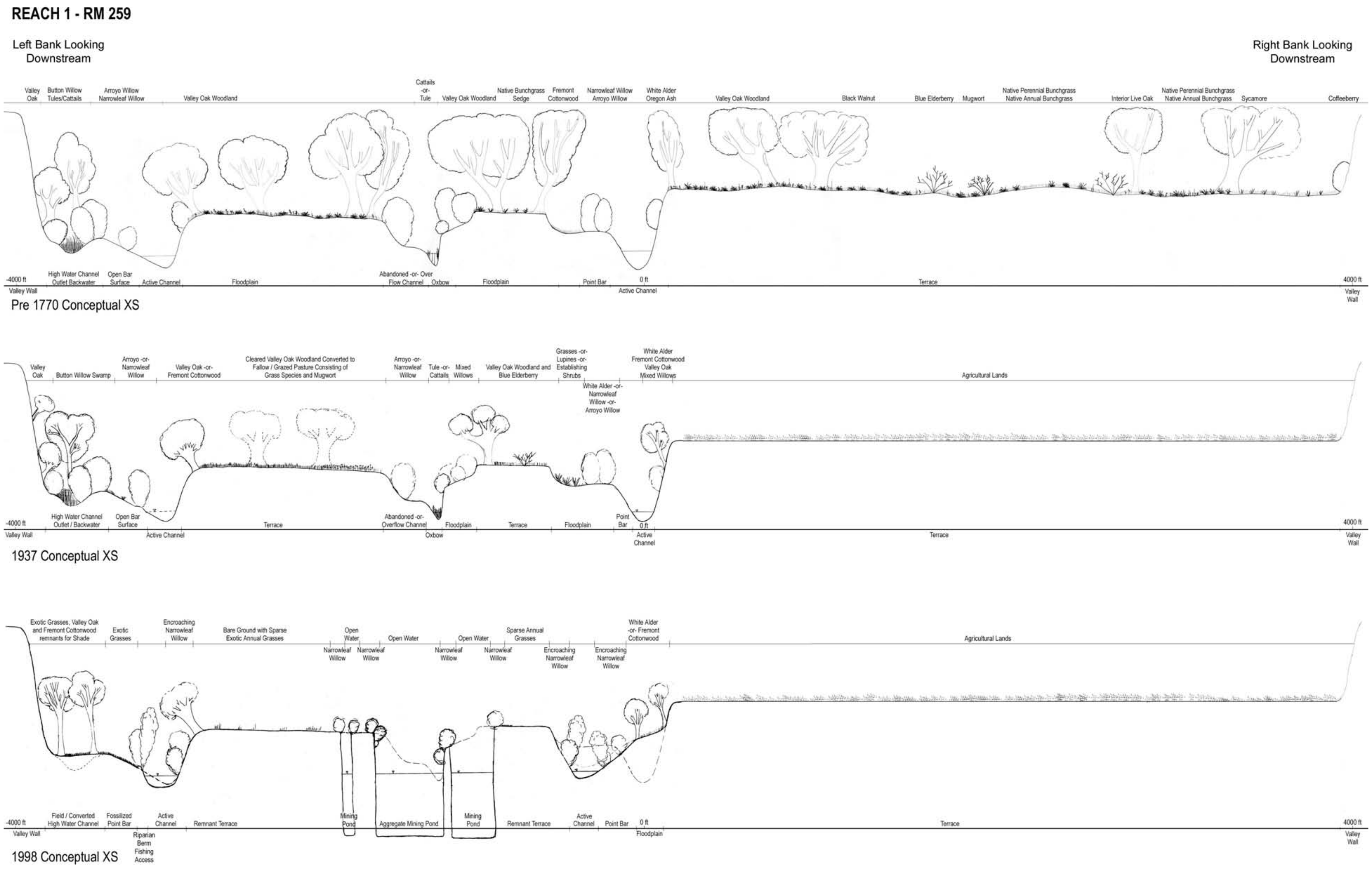


Figure 8-20. Conceptual cross section in Reach 1 (RM 259), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

upstream sediment supply, has caused local degradation of the channel thalweg in Reach 1. Channel incision and pit capture generally increase the cross sectional area of the channel; greater discharge is therefore needed to reach bankfull stage and inundate the adjacent floodplains where riparian vegetation is commonly found (JSA and MEI 1998).

In Reach 1B, mature vegetation on the backside of many point bars and on low floodplains is scarce; this may represent the lasting effect of the Corps' of Engineers extensive removal of riparian vegetation for floodway clearing, performed in 1968 through 1970 between Gravelly Ford and Highway 41 (JSA 1998). Remnant valley oaks are present on some of the higher terraces. Previously cleared terraces and the understory of the cottonwood and oak stands are dominated by exotic annual grasses. Riparian encroachment has occurred over most of Reach 1, with narrow-leaf willow and white alder dominating the canopy in the riparian berms.

8.6.3.1.3. Quantitative changes in vegetation documented between 1937 and 1998.

In Reach 1A, wetlands, riverwash, and riparian forest decreased in area from 1937 to 1957, as the result of development and an increase in upstream diversion (JSA 1998). Between 1957 and 1993, wetlands and riverwash further declined (Table 8-6 and Figure 8-10). In the 1960s and 1970s, riparian forest and riparian scrub declined in area, probably as a result of aggregate mining and urban development around Fresno (JSA 1998). In the following period, riparian scrub declined in area and riparian forest increased, probably as scrub habitat succeeded to forest habitat. Between 1993 and 1998, riparian scrub area increases, possibly the result of new habitat created by the January 1997 flood and subsequent high flows in 1998 (Moise and Hendrickson 2002). Wetland area also increased, possibly in response to the wet conditions in 1998 when the aerial photography for the 1998 mapping was taken (Moise and Hendrickson 2002).

Table 8-6. Area (in acres) of habitat types in Reach 1A (Friant Dam to Herndon).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	1,109	747	847	1,376	1,322
Riverwash[a]	239	32	12	2	33
Riparian forest	423	932	566	1,178	1,203
Riparian scrub	819	816	656	161	342
Wetland	394	69	0	0	233
Grassland	2,699	2,108	2,044	3,276	2,582
Agriculture	4,277	4,754	4,143	2,238	1,915
Urban and disturbed	300	803	1,929	2,029	2,629
No data	0	0	64	0	0
Total	10,261	10,261	10,261	10,261	10,261

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

In Reach 1B, after an initial decline in riparian forest and increase in riparian scrub, trends reverse after 1978 (Table 8-7, Figure 8-11). These trends may reflect the influence of encroachment first by scrub and then by forest on the low floodplain and channel. This process is also reflected in a decline in riverwash and open water area. A reduction in the incidence of clearing and snagging of vegetation from the floodway after the 1970s may also be reflected in the increase in the combined acreage of riparian scrub and forest (Table 8-7).

Table 8-7. Area (in acres) of habitat types in Reach 1B (Herndon to Gravelly Ford).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	606	322	401	389	220
Riverwash[a]	53	62	4	0	47
Riparian forest	129	98	79	274	614
Riparian scrub	470	516	576	455	196
Wetland	0	9	48	0	5
Grassland	481	290	218	396	300
Agriculture	3,146	3,467	3,466	3,347	3,167
Urban and disturbed	45	164	137	68	381
No data	0	0	0	0	0
Total	4,929	4,929	4,929	4,929	4,929

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1937 photo and 1998 photo to estimate changes in riparian width (Figure 8-19). There remains considerable remnant vegetation on the 1998 photo that is not reflective of being supported by the present flow/sediment regime, so width estimates from the 1998 photo are assumed to be the riparian width supported by the present flow/sediment regime (primarily the band of riparian encroachment. Because the 1937 riparian is a combination of valley oak patches, bands of cottonwood, and open bars, the 1937 to 1998 riparian widths in Reach 1 is not reasonably comparable. Given this caveat, the 1937 riparian widths range from 1,200 feet to 4,000 ft (includes approximately 250 feet width of river channel open water), and the 1998 riparian widths ranged from 80 feet to 300 feet (excludes the river channel width).

8.6.3.2. Reach 2

8.6.3.2.1. Historical overview

To illustrate some of the planform changes that have occurred, historical maps and air photos are compared for a portion of Reach 2 at River Mile 223, above the Mendota Pool between Gravelly Ford and the Chowchilla Bypass (Figure 8-21). A conceptual cross section with topography and vegetation is provided based on historical maps and explorer accounts (Figure 8-22). These maps, photos, and cross section document that the main channel is bounded by natural levees, known as rimlands, which were vegetated by a diverse forest likely dominated by Fremont cottonwood, black willow, and narrow-leaf willow. Broad, undulating floodplain deposits, abandoned oxbow channels, and high flow scour channels flanked the forested rimlands along the meandering channel. Wet channel features on the floodplain are vegetated by hydrophytes such as cattails and tules, with willows established along some of the channel margins. Except for these low channel features, the floodplain is shown as being dominated by native upland species (including perennial grasses and annual and perennial forbs). The reconstruction of the herbaceous upland vegetation in Figure 8-22 is somewhat speculative because vegetation changed rapidly with the introduction of livestock grazing and exotic plant species by the first Spanish and Mexican settlers; pristine conditions were not well-documented prior to land conversion.

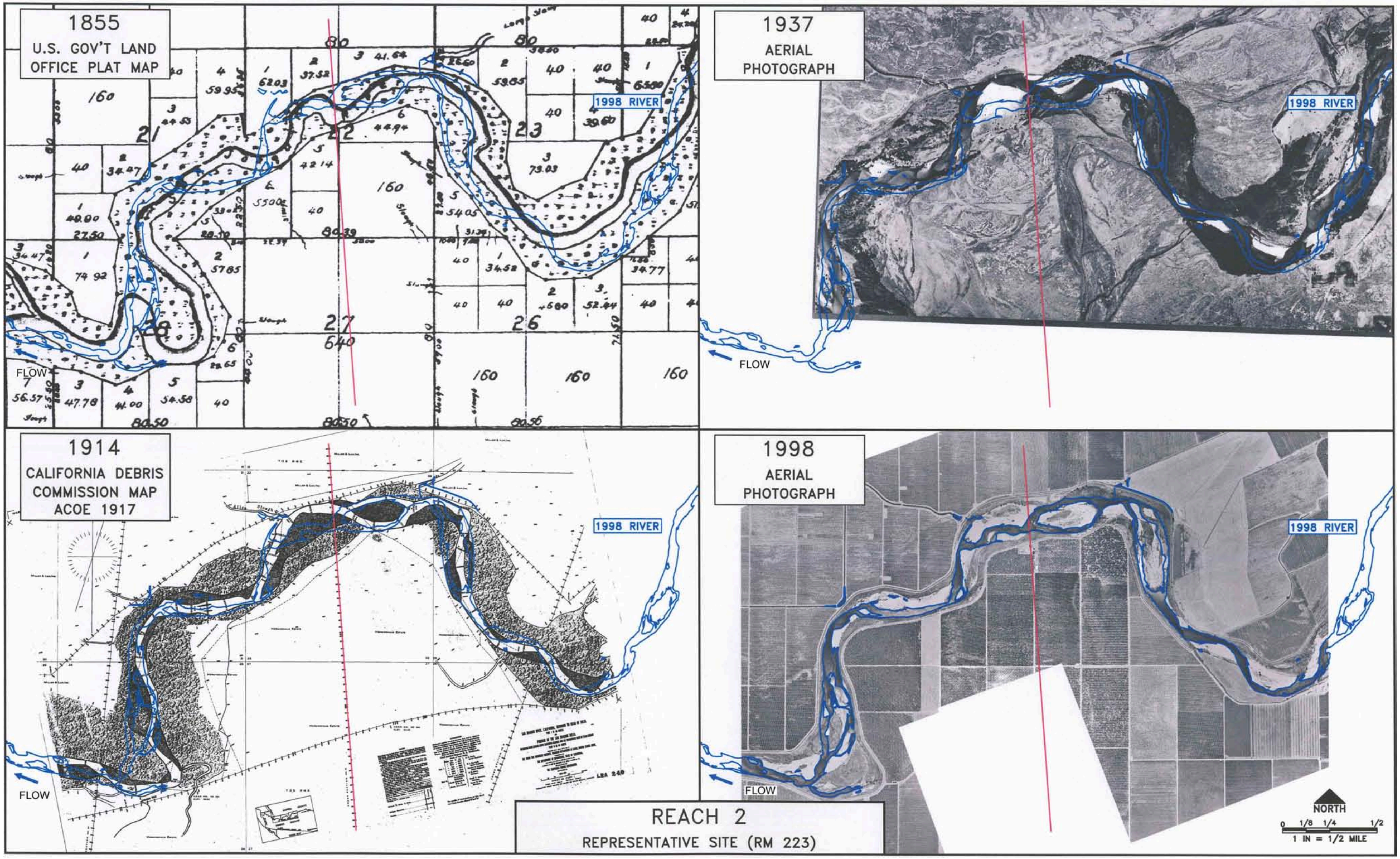


Figure 8-21. Example planform evolution in Reach 2 (RM 223), showing 1855 plat map, 1914 CDC map, 1937 air photo, and 1998 air photo.

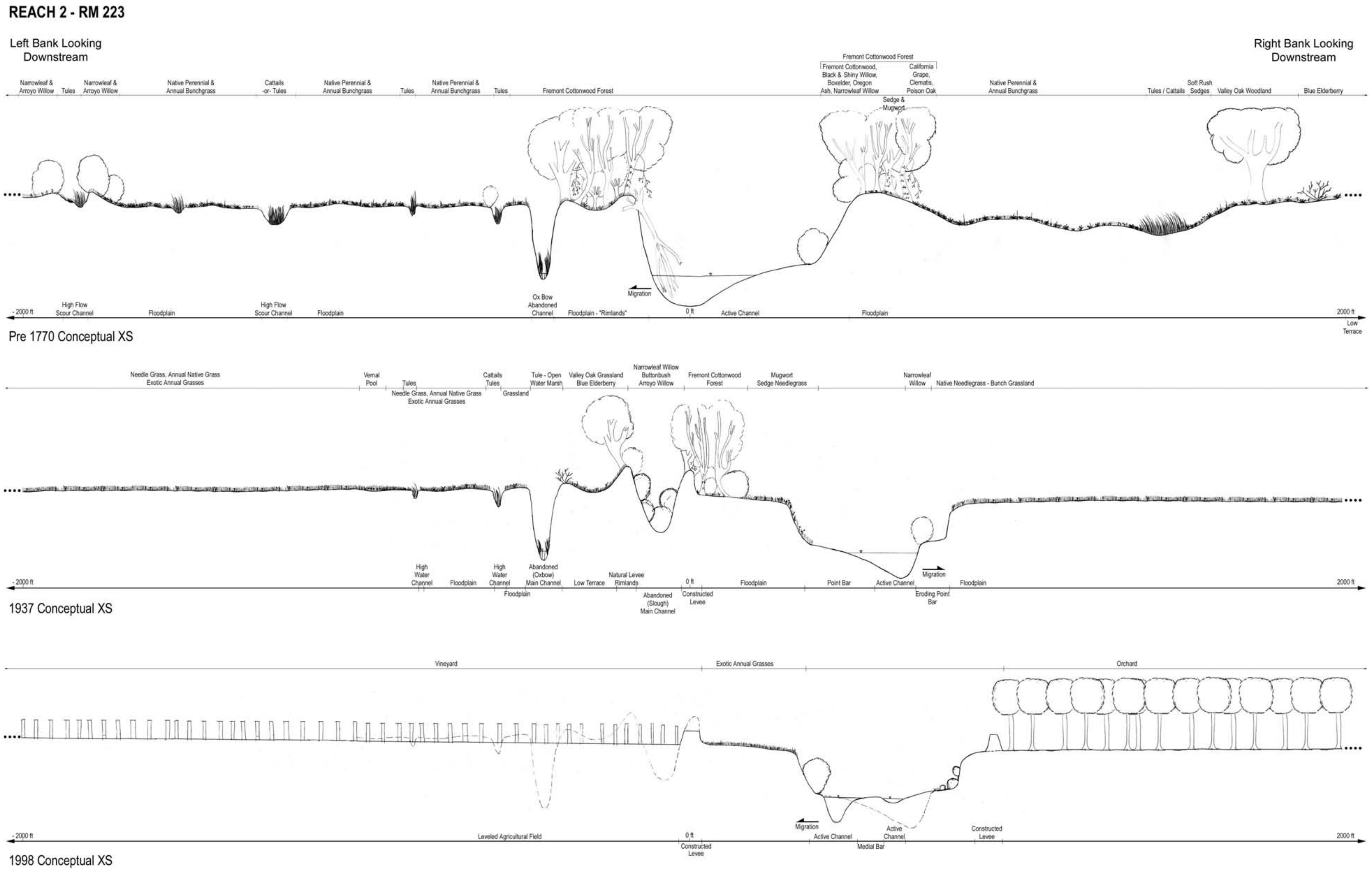


Figure 8-22. Conceptual cross section in Reach 2 (RM 223), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

Higher terraces remote from the main channel were likely primarily grasslands, with sporadic groups of valley oaks and blue elderberry savanna (Figure 8-22). Some of the upland area adjacent to the riparian zone may have supported alkali flat and mima mound habitat with saltbush scrub transitioning to grassland, as suggested by present-day habitat remnants. Early explorers (e.g., Brewer 1949) describe the highlands adjacent to the San Joaquin River as plains devoid of trees, so groups of trees were likely associated with some of the sloughs diverging from the San Joaquin River (e.g., Lone Willow Slough, sloughs connecting the San Joaquin River to Fresno Slough shown in Figure 8-5). By 1937, the floodplains had been heavily modified by previous agricultural grading and the aerial photograph shows grasslands dominated by native and exotic grasslands used for livestock grazing. The main channel has migrated to the right and the former channel has become a slough filled with willows and buttonbush. Remnants of the riparian forest shown on the 1914 CDC maps remain in the 1937 photographs, and channel migration has been minor over all sequences. By 1998, the main channel has not developed woody riparian vegetation except along its margins where narrow-leaf willow established. The lowered groundwater table, coupled with minimal or absent surface water flows, account for the general lack of riparian vegetation in the 1998 photograph.

8.6.3.2.2. Current conditions.

By 1998, agricultural grading has virtually eliminated the floodplain and former rimlands, and the remaining riparian zone is confined between levees and flanked by vineyards and orchards. Within the levees, the terraces are vegetated by exotic grasses and weeds, and the riparian forest is represented only by growth of narrow-leaf willows at the margins of the channel and on formerly active sandbars. Riparian vegetation in the upper 10 miles of this reach (Reach 2A) is sparse or absent because the river is usually dry and the shallow groundwater is overdrafted (see Chapter 4). However, there is an expanse of elderberry savanna on the left side near the Chowchilla Bifurcation Structure at the junction of Reaches 2A and 2B.

The lower few miles of Reach 2B support narrow, patchy, but nearly continuous vegetation where backwater forms upstream of Mendota Pool. The vegetation in Reach 2B may be supported by a shallower groundwater aquifer supplemented by Mendota Pool. In most years, the channel is essentially dry most of the year from Gravelly Ford to Mendota Pool, except under flood release conditions, when up to 2,000 cfs is passed downstream of the Chowchilla Canal bypass inlet (JSA and MEI 1998). USBR uses 5 cfs as a minimum flow to fulfill the requirement that there be at least 5 cfs flowing past every legal diversion point (State of California v. Rank). The last legal diversion is just upstream of the Gravelly Ford gaging station. When there are no flood releases and there is no localized rain runoff, the flow at Gravelly Ford is typically in the 0 to 20 cfs range. This flow does not extend far downstream from Gravelly Ford because of the porous bed substrate and high rate of percolation. Occasional higher flows at Gravelly Ford under these conditions result from upstream return flows or unused water right releases. The USBR compiles the mean daily flows each month in a spreadsheet that shows the Friant releases, Cottonwood and Dry Creek inflows, flows in lower Reach 1 at two gaging stations, and the flow at the Gravelly Ford gaging station.

8.6.3.2.3. Quantitative changes in vegetation documented between 1937 and 1998.

Reach 2A exhibited a large decline in wetland, riparian scrub, and riparian forest over most of the study area between 1937 and 1998 (Table 8-8 and Figure 8-12). These declines reflect the functional drought conditions prevalent in this reach after the completion of Friant Dam (JSA 1998). From 1978 to 1998, riparian forest area slightly increased, perhaps as the result of succession from riparian scrub to riparian forest. Riparian scrub was shown to increase dramatically from 1993 to 1998, perhaps in response to high flows in 1997 and 1998, and the 1999 and 2000 pilot flows. The open water acreages in 1993 and 1998 in Reach 2 were higher than typical since the photos were taken when there was a non-typical surplus water release occurring.

Table 8-8. Area (in acres) of habitat types in Reach 2A (Gravelly Ford to the Chowchilla Bifurcation Structure).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	590	119	32	418	327
Riverwash[a]	130	429	613	225	170
Riparian forest	380	300	10	86	130
Riparian scrub	1,061	313	128	0	424
Wetland	1,321	2	64	0	11
Grassland	2,380	1,931	344	800	491
Agriculture	430	3,199	4,970	3,427	4,554
Urban and disturbed	0	0	0	0	184
No data	0	0	132	1,336	0
Total	6,293	6,293	6,293	6,293	6,293

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

The pattern of Reach 2B is similar to that of Reach 2A, except that the riparian forest and scrub area are somewhat greater as a proportion of the total area (Table 8-9, Figure 8-13). Reach 2B also shows a higher and fluctuating area of wetland. These differences are attributable mainly to the influence of the backwater of the Mendota Pool, which causes the downstream portion of this reach to be wetter.

Table 8-9. Area (in acres) of habitat types in Reach 2B (Chowchilla Bifurcation Structure to Mendota Dam).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	385	170	250	329	284
Riverwash[a]	26	200	223	9	3
Riparian forest	140	32	29	73	167
Riparian scrub	434	278	143	71	203
Wetland	50	0	154	53	64
Grassland	1,112	554	1,403	342	226
Agriculture	1,104	2,019	1,048	2,373	2,047
Urban and disturbed	0	0	3	4	259
No data	0	0	0	0	0
Total	3,253	3,253	3,253	3,253	3,253

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 2 (Figure 8-21). In contrast to Reach 1, little remains of the vegetation observed on the 1914 maps and 1937 aerial photographs. The 1914 riparian widths range from 850 feet to 2,000 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranged from 0 feet to 250 feet (excluding exposed bars and wetted river channel).

8.6.3.3. Reach 3

8.6.3.3.1. Historical overview

Planform changes using historical maps and air photos are again provided for a portion of Reach 3 at River Mile 202, downstream of Mendota Pool (Figure 8-23). A conceptual cross section with topography and vegetation is again provided based on historical maps and explorer accounts (Figure 8-24). These show hypothesized conditions prior to 1770, in comparison to conditions apparent in 1937 and 1998 based on interpretations of aerial photographs and topographic maps. The pre-1770 condition shows a narrow active channel bounded by an elevated floodplain, which is itself flanked by extensive lower-elevation floodplain and flood basin features. On the natural levees along the river margins, the dominant overstory woody riparian plant is uncertain. The cross section illustrates the dominant canopy species as Fremont cottonwood on the portions nearest to the river, with some valley oak woodland on terraces farther from the river (outside the tule marsh dominated flood basin). This is based on review of the 1914 CDC maps and 1937 aerial photographs. However, historical explorer accounts do not mention these species (while noting willows). Additionally, the US Government Land Office plat maps (1855) show willow witness trees, but no other species. Therefore, these conceptual cross sections may need further refinement.

The flood basins and overflow channels, subject to annual overflows and deposition of sand and silt, are vegetated by freshwater marsh with tules and cattails. Slightly elevated areas between overflow channels and basins support a cover of buttonbush, and shrubby willows. By 1937, the overflow channels and flood basins had been drained and filled and were used as pasture or for annual crops such as small grains (Figure 8-24). Levees, irrigation canals, and general thinning of riparian vegetation are evident on the rimlands, which were used for livestock grazing. A high water channel on the left side of the active channel assumes some of the function of the now- absent overflow channels and flood basins.

8.6.3.3.2. Current conditions.

By 1998, virtually all of the floodplain and rimlands have been agriculturally graded and leveled. Riparian vegetation is confined to the active channel, and is supported by delta water introduced to the river at Mendota Dam. Floodwaters are regulated by upstream structures, with most flows diverted out of the San Joaquin River into the Chowchilla Bypass.

Nearly continuous riparian vegetation of various widths and cover types occurs on at least one side of the channel within this reach. Continuous open water, created by a relatively uniform irrigation season base flow of imported Delta water, appears to be the primary factor preventing further encroachment of woody vegetation within the active channel (JSA and MEI 1998). Urban development at Firebaugh, local levees, agricultural encroachment, and irrigation canals that flank the river have further limited the natural vegetation that formerly grew there (JSA and MEI 1998).

8.6.3.3.3. Quantitative changes in vegetation documented between 1937 and 1998.

In Reach 3, riparian forest, riparian scrub, and grassland areas again decreased from 1937 to 1957 (Table 8-10, Figure 8-14). In that same period, the agriculture and urban areas greatly increased. After 1957, riparian scrub area remained relatively constant, while the riparian forest area increased. This increase coincides with a decrease in riverwash area, indicating encroachment of riparian vegetation on sand bars, at least up to 1993 (JSA 1998). The steep increase in riparian forest area between 1993 and 1998 coincides with a decrease in open water and may be attributable to increasing tree growth over the channel and/or a different mapping method.

Table 8-10. Area (in acres) of habitat types in Reach 3 (Mendota Dam to Sack Dam).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	349	478	626	495	355
Riverwash[a]	335	254	53	4	22
Riparian forest	156	53	263	296	588
Riparian scrub	750	222	277	276	292
Wetland	19	4	45	7	16
Grassland	1,597	112	150	186	174
Agriculture	4,763	6,409	6,057	5,978	5,361
Urban and disturbed	206	643	704	816	1,367
No data	0	0	0	118	0
Total	8,175	8,175	8,175	8,175	8,175

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 3 (Figure 8-23). The 1914 maps illustrate riparian vegetation between already constructed canals that confine the river corridor, so the riparian width estimates from the 1914 maps probably under predict unimpaired riparian widths. The 1937 aerial photographs show that clearing of the remaining riparian vegetation between the canals is underway. As in Reach 2, little remains of the vegetation observed on the 1914 maps and 1937 aerial photographs. The 1914 riparian widths range from 750 feet to 1,700 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranged from 20 feet to 250 feet (excluding exposed bars and wetted river channel).

8.6.3.4. Reach 4

8.6.3.4.1. Historical overview

Planform changes using historical maps and air photos were evaluated for a portion of Reach 4 at River Mile 163, downstream of Mendota Pool (Figure 8-25). This site is located in Reach 4B, downstream of the Sand Slough Control Structure. Unfortunately, a copy of the 1937 aerial photograph could not be obtained. A conceptual cross section with topography and vegetation is again provided based on historical maps and explorer accounts (Figure 8-26).

The pre-1770 condition is likely a well-developed cottonwood-willow riparian forest which bounds the active channel on natural levees. Again, the conceptual model of cottonwood being a dominant canopy species along the river edge is subject to some additional discussion. The natural levees are produced by deposition of sediments by floodwaters as they overflow the main channel and deposit sediment along the rough channel edges caused by the vegetation. These natural levees likely decreased in size and height moving downstream between Reaches 3 and 5 as the sediment load decreased due to cumulative deposition on the levees. A variety of active and abandoned side channels and sloughs mark floodplains and flood basins away from the rimlands on the right hand

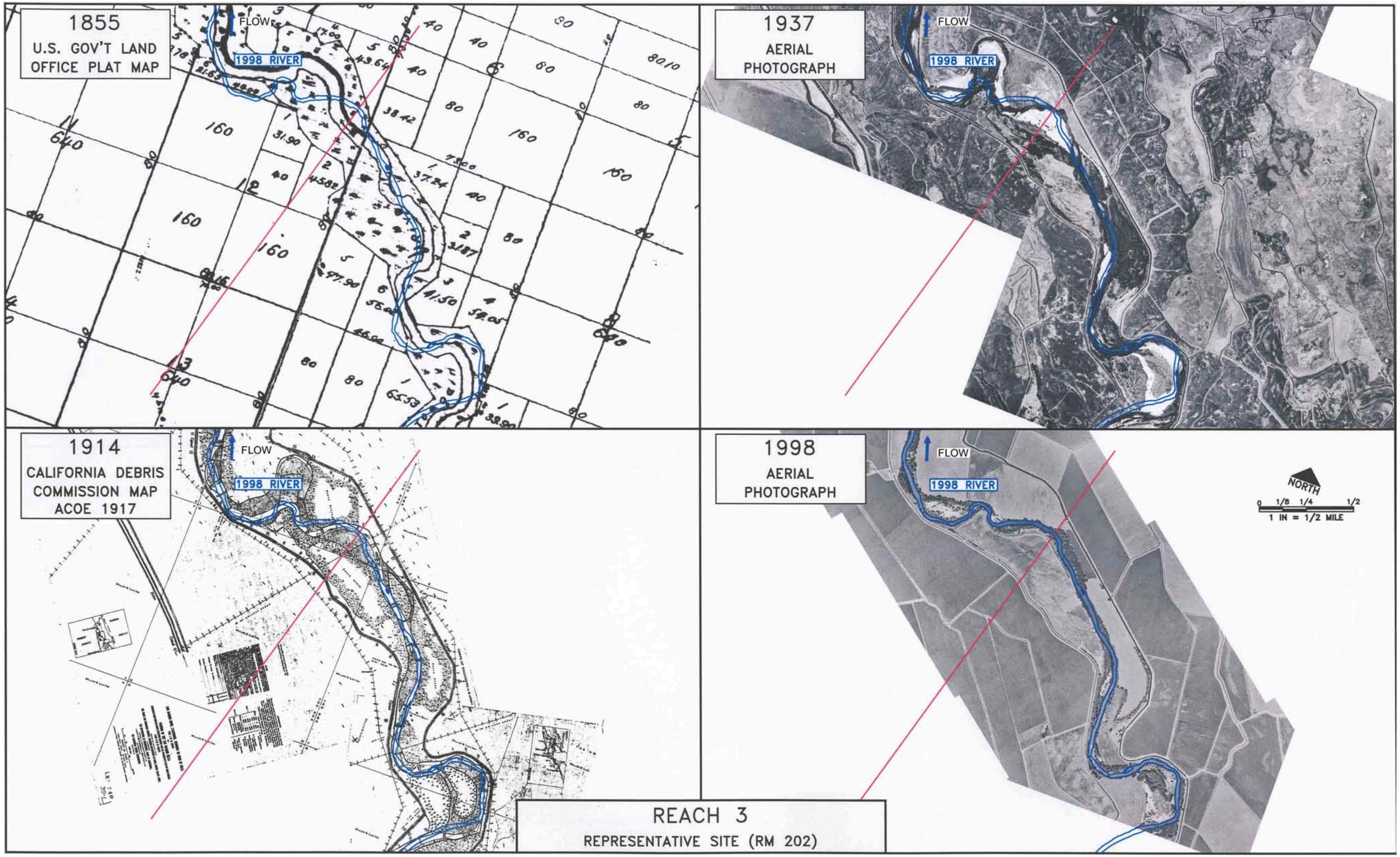


Figure 8-23. Example planform evolution in Reach 3 (RM 202), showing 1855 plat map, 1914 CDC map, 1937 air photo, and 1998 air photo.

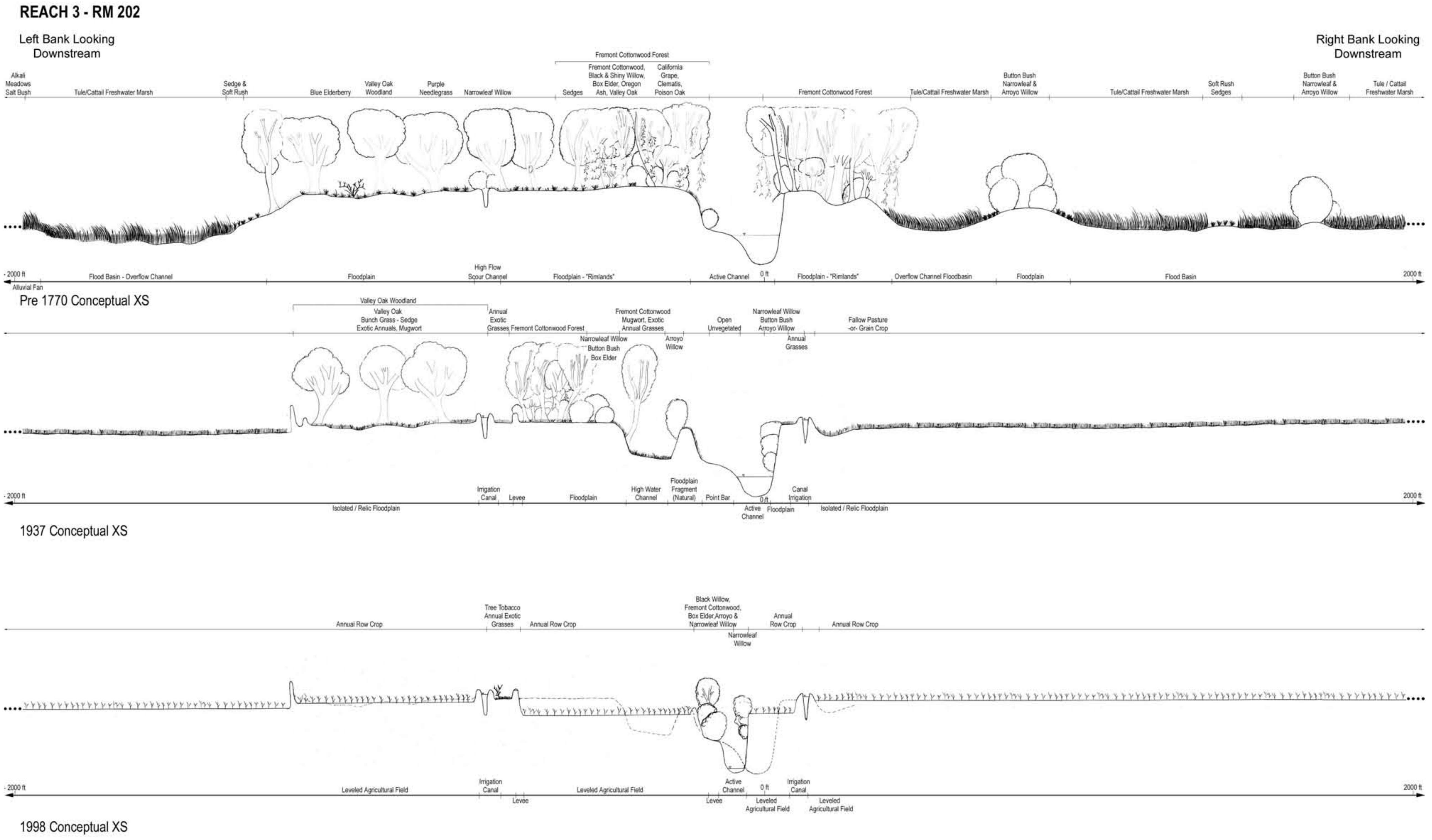


Figure 8-24. Conceptual cross section in Reach 3 (RM 202), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

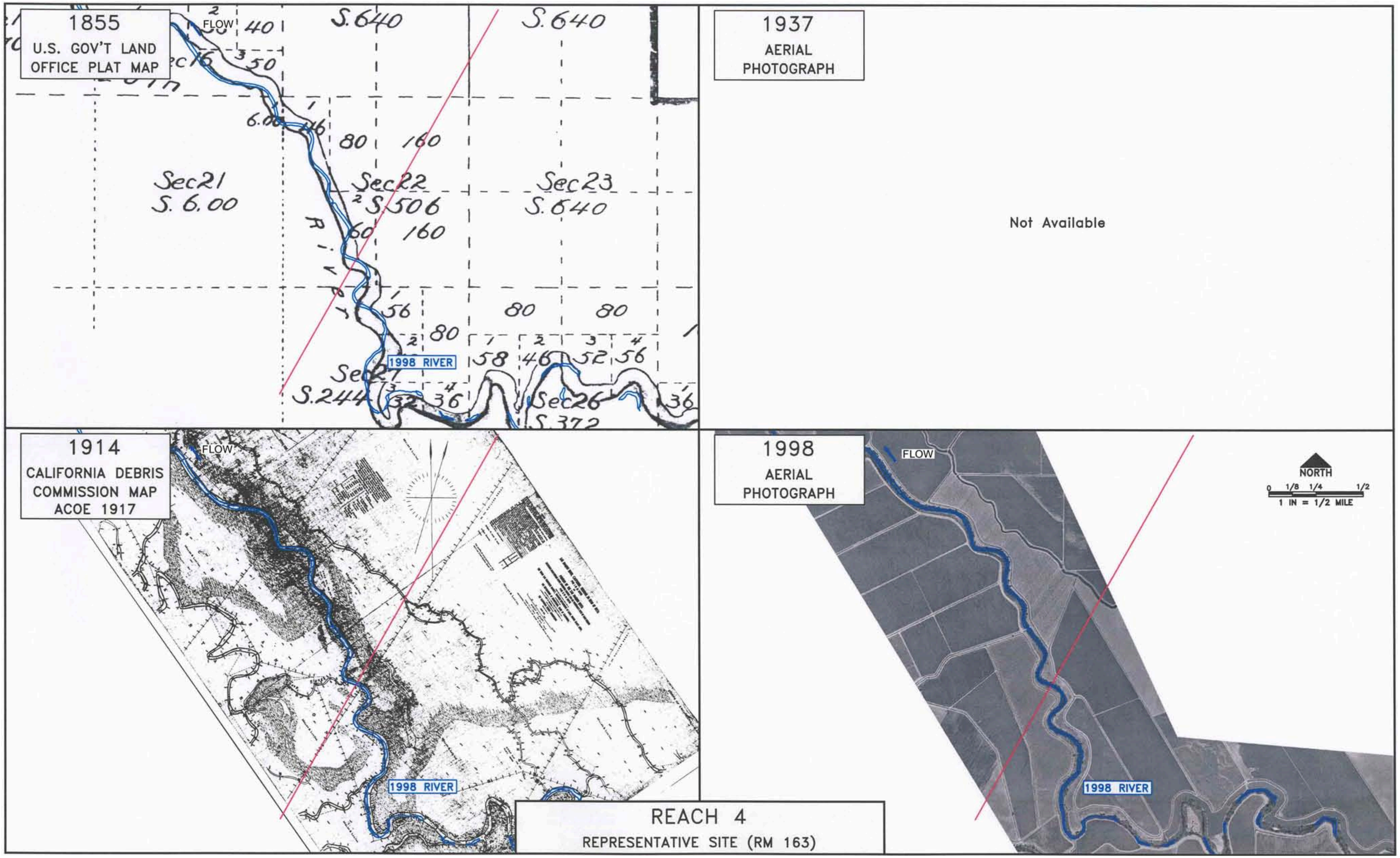


Figure 8-25. Example planform evolution in Reach 4 (RM 163), showing 1855 plat map, 1914 CDC map, and 1998 air photo.

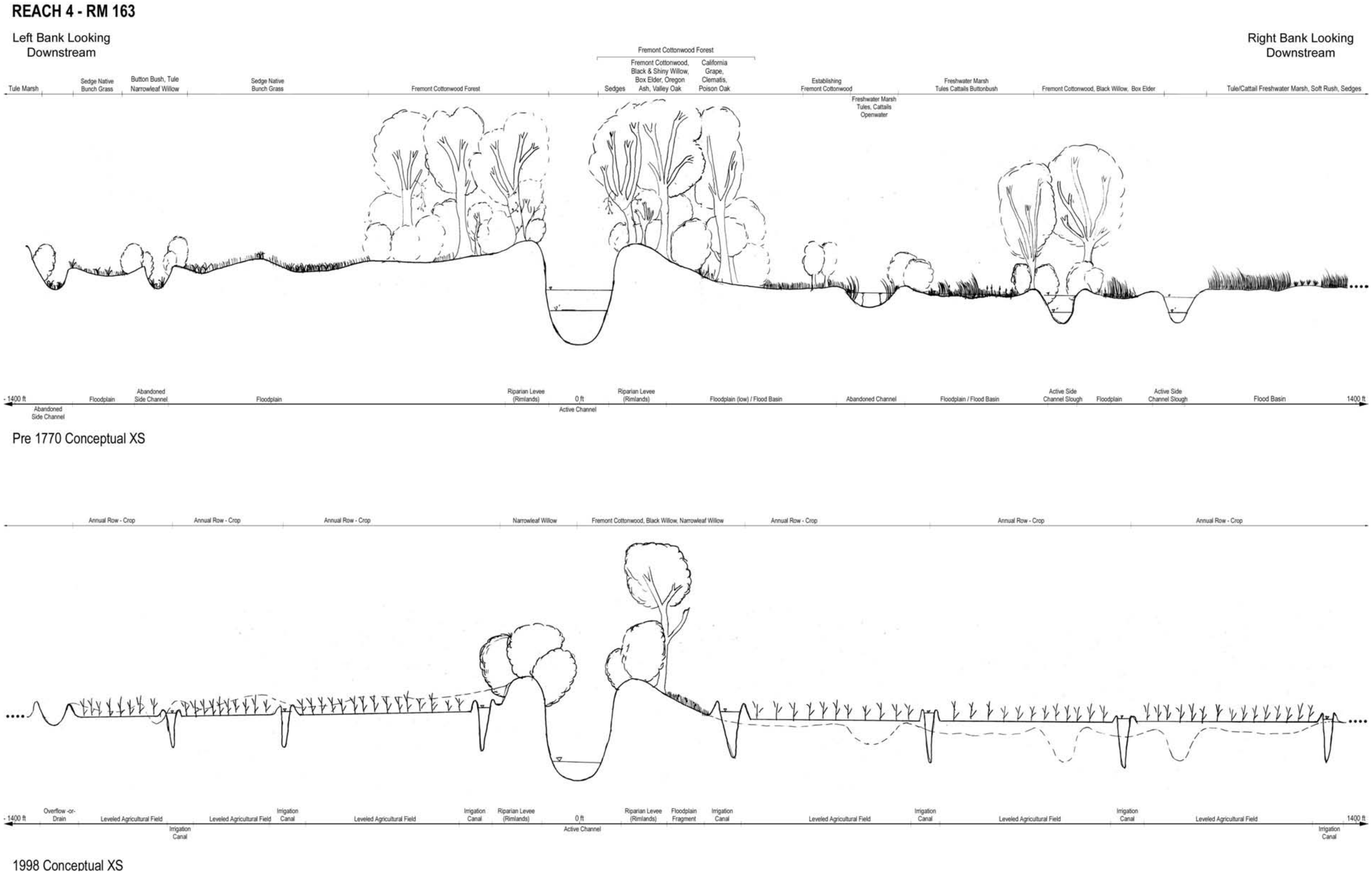


Figure 8-26. Conceptual cross section in Reach 4 (RM 163), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

side of the channel. These low areas were seasonally inundated and supported freshwater marsh, with riparian forest developing next to active side channels and sloughs. Low areas associated with active or abandoned side channels intersect the water table and allow wetland vegetation to develop.

By 1998, the floodplains on both sides of the river have been graded and converted into irrigated agriculture. The riparian forest is narrow and botanically simpler, and is confined to the remnant vegetation of the rimland on both sides of the river. The formerly extensive overflow habitat has been drained and converted to agriculture.

8.6.3.4.2. Current conditions.

Reach 4A (located upstream of the representative reach illustrated in Figure 8-25) is only sparsely vegetated, with a very thin band of vegetation along the channel margin (or none at all). Sporadic narrow strands or patches of mostly willow scrub occur, as do small “potholes” with marsh vegetation (JSA and MEI 1998). For most of the year, Reach 4A is dry. Survival of established (mature) riparian vegetation does not appear to be affected by the intermittent flow regime because groundwater is shallow along this reach. Full-canopied riparian scrub and forest occur in small to large stands, and ponds rimmed by small areas of marsh vegetation are present within the channel (JSA and MEI 1998).

In-channel vegetation is supported by flows and/or moisture from: 1) leakage or spillage at Sack Dam, 2) from shallow groundwater, 3) from field drain water, and possibly 4) from seepage from the canals that border the river. Field drain water is pooled in this section of the San Joaquin River with small berms and/or is run downstream to a small pool where it is recirculated by being pumped out for irrigation. These pools help maintain riparian vegetation, albeit, mostly within the channel outside of the wetted area. The in-channel vegetation increases the hydraulic roughness and increases sediment deposition, thereby affecting channel flow capacity. Historically, this subreach of the river had multiple channels in the overbank areas. Winter and spring high flows that were historically conveyed by the river and its sloughs are now conveyed in the Eastside Bypass system (JSA and MEI 1998).

Primary factors in the reduced acreage of riparian-associated habitats include reduced hydrology impacts (lower spring baseflow and lower bankfull discharge frequency and duration), levee and ditch construction that isolated backwater ponds and sloughs, and draining of large marsh areas. A very low rate of recolonization of riparian vegetation on overbank areas, attributable to agricultural encroachment, infrequently inundated floodplains and secondary sloughs. Possibly higher concentrations of surface salinity could be contributed to an overall gradual loss of woody cover. Continuing land uses, primarily intensive agriculture and managed wetlands, also prevent reestablishment of riparian habitat on otherwise moist lowland surfaces, and in remnant basins and swales (JSA and MEI 1998).

Reach 4B also historically contained multiple channels, with the flows being divided between the meandering mainstem and multiple sloughs distributed throughout the expansive overbank area as illustrated above in the toposequence for this reach (Figure 8-25). Local levees and channel plugs now separate the sloughs from flow in the river. Under existing conditions, flows no longer are allowed to enter Reach 4B; therefore, inundation of the channel margins to encourage natural riparian regeneration no longer occurs (all flows are routed to the Eastside Bypass via the Sand Slough Control Structure).

Reach 4B upstream of the Mariposa Bypass supports a nearly unbroken, dense, but narrow corridor of willow scrub or young mixed riparian vegetation on most of the reach, with occasional large gaps in the canopy. Lack of surface flow in Reach 4B above the Mariposa Bypass outlet, coupled with agricultural return flows downstream of the Mariposa Bypass outlet; levee and ditch construction that isolated or filled backwater ponds and sloughs, and drainage of large marsh areas appear to be the primary factors causing reduced acreage of riparian-associated habitats. A very low rate of recolonization of riparian vegetation on overbank areas, attributable to infrequent inundation of floodplains and secondary sloughs, clayey soils, and possible higher concentrations of surface water salinity, contribute to an overall gradual loss of woody cover.

8.6.3.4.3. Quantitative changes in vegetation documented between 1937 and 1998.

An initial decline in Reach 4B riparian scrub, riparian forest, and wetland area in the period from 1937 to 1957 was followed by an increase in these cover types after 1957 (Table 8-11, Figure 8-15). From 1993 to 1998, riparian forest increased in area, while riparian scrub declined, probably as the result of successional development from scrub to forest. However, the decline in riparian scrub is greater than the increase in riparian forest, suggesting additional loss of scrub. Grassland and open water were shown to increase in this period. These differences may be the result of clearing vegetation or flooding of scrub that encroached on the channel below Sack Dam.

Table 8-11. Area (in acres) of habitat types in Reach 4A (Sack Dam to Sand Slough Control Structure).

	Year				
Class	**1937**	**1957**	**1978**	**1993**	**1998**
Open water	102	312	241	76	113
Riverwash[a]	146	62	87	54	68
Riparian forest	174	1	15	0	104
Riparian scrub	357	126	283	340	109
Wetland	127	0	71	65	41
Grassland	1,447	199	5	50	201
Agriculture	1,358	3,010	3,009	3,126	2,702
Urban and disturbed	0	0	0	0	372
No data	0	0	0	0	0
Total	3,710	3,710	3,710	3,710	3,710

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Wetland area in Reach 4B declined in the period from 1937 to 1957, while the area in agriculture increased (Table 8-12, Figure 8-16). The area of riverwash, riparian forest, and scrub remained relatively constant from 1937 to 1978. From 1978 to 1993, wetland, riparian scrub, and riparian forest area increased, probably because of habitat restoration on the San Luis National Wildlife Refuge Complex. Subsequently, riparian scrub area declined while riparian forest area increased, probably at least in part as the result of succession.

Table 8-12. Area (in acres) of habitat types in Reach 4B (Sand Slough Control Structure to Bear Creek).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	348	446	526	292	269
Riverwash[a]	101	79	81	0	3
Riparian forest	256	314	132	253	756
Riparian scrub	396	364	334	692	190
Wetland	1,019	191	218	549	290
Grassland	5,592	4,368	3,287	2,342	2,730
Agriculture	1,361	3,303	4,484	4,840	4,189
Urban and disturbed	10	17	22	21	658
No data	0	0	0	95	0
Total	9,084	9,084	9,084	9,084	9,084

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 4 (Figure 8-25). The 1914 maps illustrate a narrow band of riparian vegetation along the river channel, with tule marsh beyond the band of riparian vegetation. Estimates of riparian width from the 1914 maps do not include the tule marsh width. Again, little remains of the vegetation observed on the 1914 maps. The 1914 riparian widths ranges from 50 feet to 1,000 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranges from 0 feet to 50 feet (excluding exposed bars and wetted river channel). The outer boundaries of the tule marsh on the 1914 are not clearly delineated, but the width of the tule marsh is at least 10,000 feet wide on Figure 8-25 (including the river channel, sloughs, and riparian bands).

8.6.3.5. Reach 5

8.6.3.5.1. Historical overview

Planform changes were evaluated using historical maps and air photos for a portion of Reach 5 at River Mile 126, near where Highway 140 crosses the river (Figure 8-27). Again, the 1937 aerial photograph for this sequence was unavailable. A conceptual cross section with topography and vegetation is again provided based on historical maps and explorer accounts (Figure 8-28).

Prior to the 1770s, environmental conditions were likely characterized by a dynamic system of well-developed and diverse willow-dominated riparian forest on natural levees, which bounded the main channel; riparian vegetation in different stages developed on secondary channels. Abandoned channels and lower portions of the floodplain were vegetated with freshwater marsh (primarily tules). Oxbow lakes formed on cutoff meanders, which supported freshwater marsh, bounded by buttonbush, black willow, and narrow-leaf willow. On the right bank of the river, the floodplain abruptly grades into higher ground based on the 1914 topography. This higher ground is likely a portion of the Merced River delta, where valley oaks would begin to occupy areas closer to the river. Native upland bunchgrasses would have also been on this surface. The floodplain was very broad on the left bank of the river.

By 1998, the flood basin on left bank of the river was modified for agriculture and the channel features were partially filled in. This historical flood basin now lacks native riparian vegetation or the wetland vegetation that historically existed there. A road has been developed on the river's left bank and no riparian vegetation is present on the side of the road opposite the river. Cottonwood trees still grow on the right side of the river, with occasional valley oaks and exotic annual grasses on the higher right bank surface. Narrow-leaf willow is present around the former oxbow lake.

8.6.3.5.2. Current conditions.

In Reach 5, the San Joaquin River is surrounded by large expanses of upland grassland with numerous inclusions of woody riparian vegetation within the floodplain. The floodplain and basin are generally disassociated from the mainstem river due to project levees, and remnant tree groves are concentrated on the margins of mostly dry secondary channels and depressions, or in old oxbows. Along the mainstem San Joaquin River, a relatively uniform pattern of patchy riparian canopy hugs the channel banks as large individual trees or clumps (primarily valley oaks or black willow) with a mostly grassland or brush understory. Visual examination of the 1938 aerial photographs by JSA (JSA and MEI 1998) showed a similar patchy pattern of vegetation, but total woody cover was greater, with a higher proportion of mixed riparian vegetation relative to scrub. Large expanses of herbaceous riparian vegetation and marsh clustered along the river and sloughs. None of these features are now present (JSA and MEI 1998).

The frequency of overland flow beyond the natural channel banks is likely greater in this reach than in those described previously, because Reach 5 is located downstream of the Mariposa Bypass, and collects flows from the Eastside Bypass and Bear Creek. However, inundation of the floodplain is still less frequent than occurred before construction of Friant Dam. Comparison of cross sections shows that the channel has both widened and deepened in the area where a significant portion of the flood flows from the Eastside Bypass are discharged back into the mainstem San Joaquin River (JSA and MEI 1998)

8.6.3.5.3. Quantitative changes in vegetation documented between 1937 and 1998.

Wetland area decreased from 1,124 to 50 acres (96%) in Reach 5 from 1937 to 1957 (Table 8-13, Figure 8-17). Most of this area was drained and converted to grassland and pasture, and a part of this area was converted to riparian forest. Lack of periodic floods encouraged establishment of riparian vegetation on the old natural levees that are abundant in this area. In 1978, riparian forest decreased over 1957 levels, perhaps as a result of temporarily lower flows caused by the drought in the 1970s. After 1978, the area of riparian scrub decreased, then increased by 1998 (perhaps as a result of the four wet years prior to 1998).

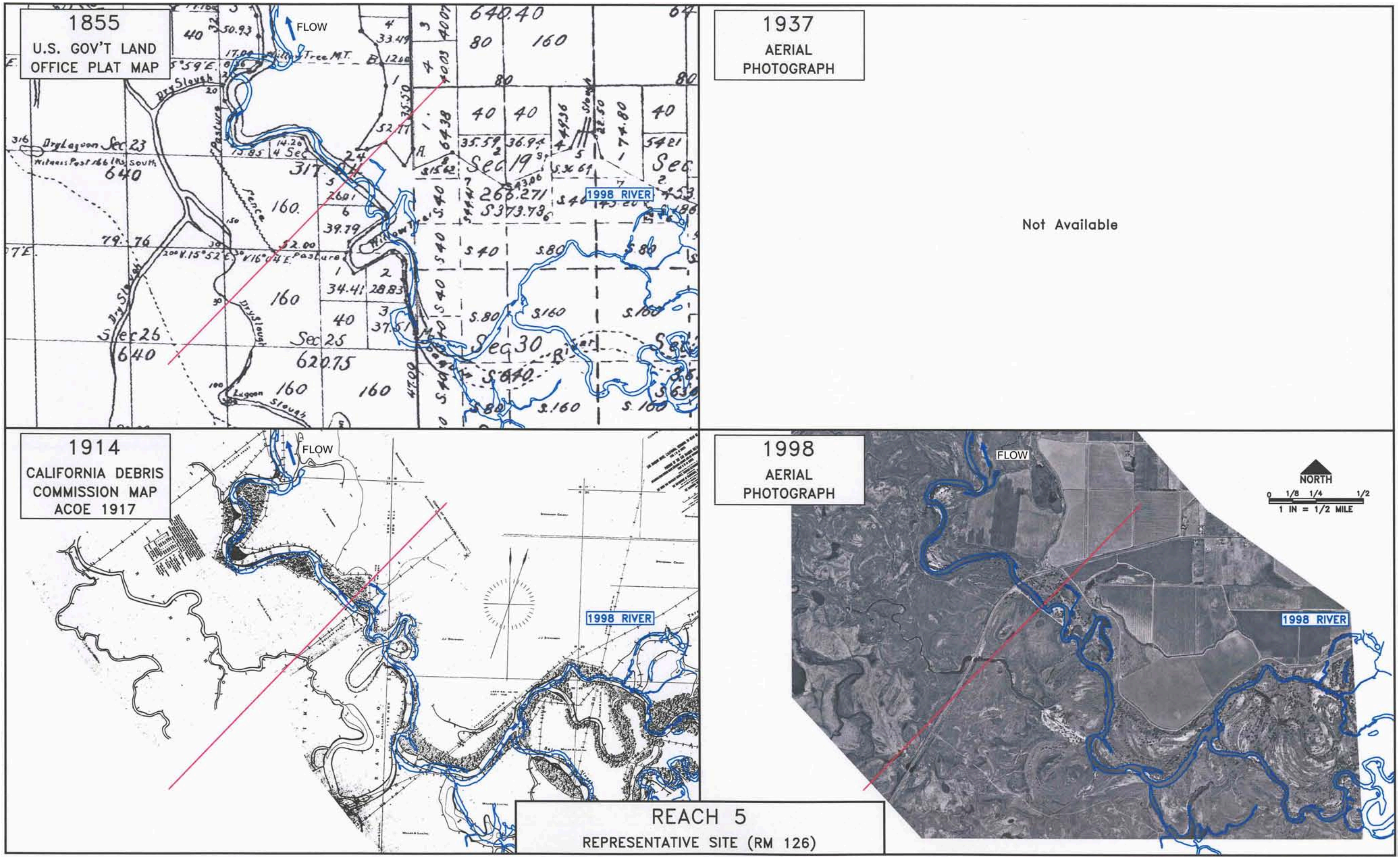
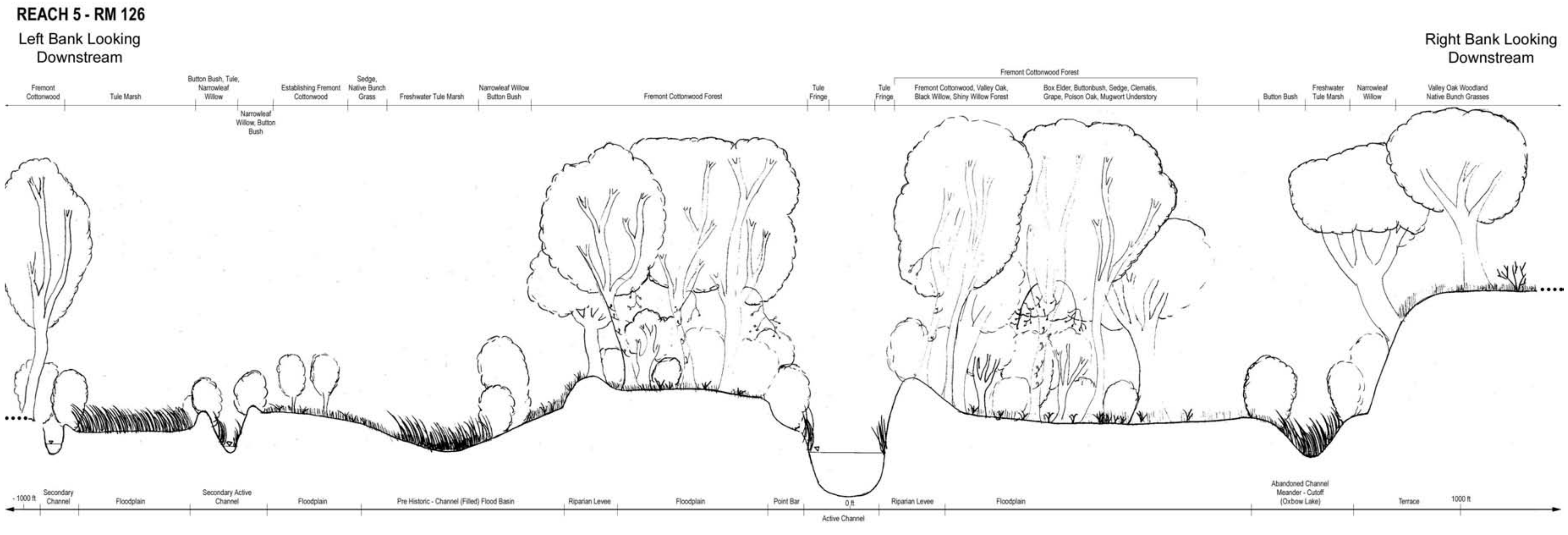
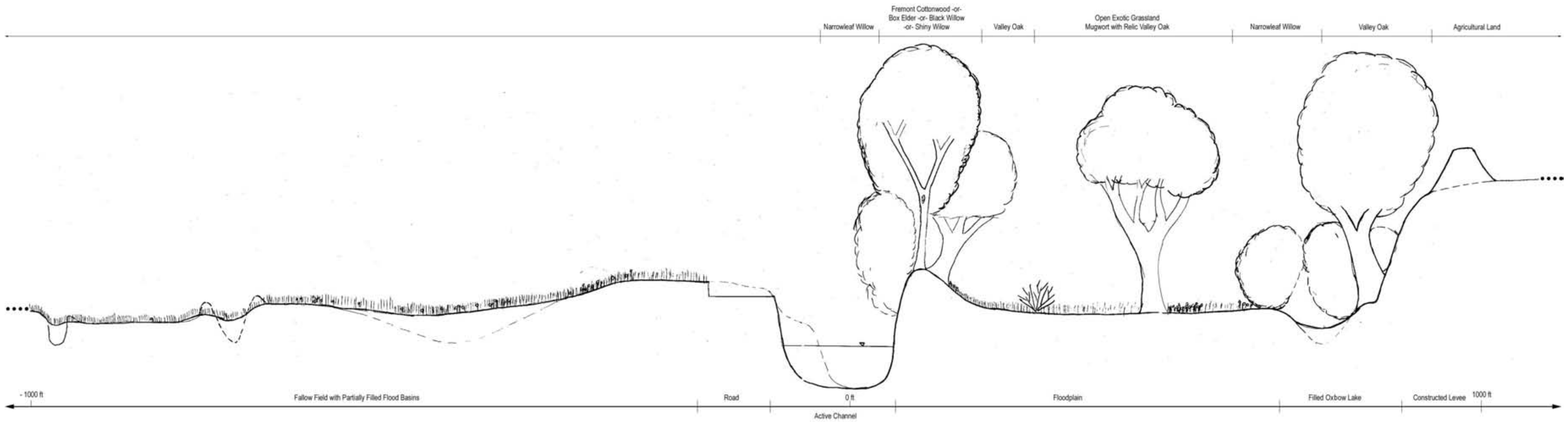


Figure 8-27. Example planform evolution in Reach 5 (RM 126), showing 1855 plat map, 1914 CDC map, and 1998 air photo.



Pre 1770 Conceptual XS



1998 Conceptual XS

Figure 8-28. Conceptual cross section in Reach 5 (RM 126), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

Table 8-13. Area (in acres) of habitat types in Reach 5 (Bear Creek to Merced River).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	391	438	373	371	559
Riverwash[a]	51	95	29	2	7
Riparian forest	573	948	768	588	1,047
Riparian scrub	253	181	689	168	163
Wetland	1,124	50	118	57	336
Grassland	4,036	4,815	4,025	4,751	3,969
Agriculture	1,251	1,181	1,662	1,387	1,445
Urban and disturbed	0	0	43	55	182
No data	0	0	0	329	0
Total	7,709	7,709	7,709	7,709	7,709

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Wetland and riparian areas in Reach 5 apparently increased between 1993 and 1998. During that period, riparian forest area increased by 459 acres. However, much of this apparent increase is likely due to the different minimum mapping units used. Within Reach 5, wetlands are often seasonal swales and vernal pools, and riparian trees occur in many small and narrow patches. Most of these patches were not mapped for 1993 because JSA used a 5-acre minimum mapping unit (JSA 1998); instead, these patches were included in the surrounding grassland. DWR's 0.3 acre minimum mapping unit (Moise and Hendrickson 2002) allowed many of these small habitat patches to be included in the acreage totals. For example, in 1998, 110 acres of Reach 5's riparian habitat were in patches smaller than 1 acre, and thus would not have counted as riparian habitat in 1993.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 5 (Figure 8-27). As with Reach 4, the 1914 maps illustrate a narrow band of riparian vegetation along the river channel, but the tule marsh beyond the band of riparian vegetation is not identified on the 1914 maps (although it most likely occurred there). Estimates of riparian width from the 1914 maps do not include this assumed tule marsh width. As opposed to Reaches 2, 3, and 4, it appears that some of the historic vegetation observed on the 1914 maps still remains as shown on the 1998 aerial photograph. The 1914 riparian widths ranges from 100 feet to 750 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranges from 50 feet to approximately 150 feet (excluding exposed bars and wetted river channel). If the 1998 riparian vegetation, wetland areas, sloughs, and river channels are included, the width is up to 5,300 feet.

8.6.4. Existing Vegetation Composition

This section describes the present-day vegetation in the study area. In contrast to the preceding descriptions, which are based primarily upon interpretation of historical to recent aerial photographs, the descriptions in this section are based upon a combination of on-the-ground vegetation sampling and interpretation of recent air photos. The area and distribution of vegetation by type are based on DWR studies during 2000 (Figure 8-8, Table 8-14) (Moise and Hendrickson 2002). Although extirpation of the area's native riparian plant species has not been documented, certain plant community types have been dramatically reduced, such as formerly extensive backwater sloughs or swamps dominated by buttonbush (see Table 8-16). This species apparently thrives and is sometimes dominant in backwaters where still, poorly oxygenated water stands throughout the year (Conard et al. 1977), but these habitats have been almost entirely destroyed by development making button bush swamp forest one of the rarest and most endangered vegetation types in the state (Holstein 1984). Comparing documented and hypothetical historical conditions, losses of higher terrace and floodplain riparian forests and valley oak woodlands have been severe; these areas, as well as the historic wetlands, have been extensively converted to agricultural land. Tule and buttonwillow swamps that occupied overflow channels, sloughs, and flood basins are other areas that experienced severe losses. In addition, the areal extent and diversity of cottonwood and willow forest have been greatly reduced, along with reductions in diversity of native understory species. Valley oak and sycamore, which tend to establish on the higher terraces and natural levees in the riparian zone after very infrequent major flood events, reproduce poorly under current conditions (under a modified flood regime and land use conversion).

Most of the woody plants are native; however, woody exotics such as blue gum (*Eucalyptus globulus*), giant reed, and Himalayan blackberry are widespread and abundant in the study reaches, and others are increasing in importance (see below in Section 8.6.4.11). In all transects, of the 25 woody species having one percent or more relative cover, 19 (76%) are native (Table 8-16). The proportion of native herbaceous (non-woody) species is considerably lower, however. Only 25 of the 48 herbaceous species (52%), comprising one percent cover of any of the vegetation transects, are native (Table 8-17).

Inspection of Table 8-14 leads to the following general observations:

- Almost half of the study area (25,400 acres) consists of agricultural lands (agricultural fields, orchards, and vineyards). The second largest category of cover type is grasslands (10,700 acres), which includes herbaceous riparian habitat.
- The study area supports approximately 4,200 acres of riparian forest.
- The largest area of valley oak riparian forest (265 acres) is in Reach 1A; it also has the greatest cover of invasive exotic species (58 acres). The relative proportion of willow riparian forest, dominated by black willow, becomes greater in downstream reaches.
- Riparian scrub is found on approximately 1,900 acres in the study area. In Reaches 1A, 1B, 3, and 4B willow scrub is the dominant riparian scrub type, but in Reaches 2A, 2B, and 4A the non-willow riparian scrub types dominate. In Reach 5 both scrub types are about equally abundant. Elderberry savanna, a scrub type that was not previously mapped along the San Joaquin River (Moise and Hendrickson 2002), was found on 63 acres in Reach 2B and was also mapped in small patches in Reaches 1A and 2A.
- Most of the 991 acres of wetland mapped in the study area was mapped in Reaches 1A, 4b, and 5. This includes 5 acres of alkali sink habitat, a rare vegetation community, mapped in Reach 5.

Below are descriptions of the species composition and canopy structure of most vegetation types along the San Joaquin River. These descriptions are based on data collected during the recent field surveys by DWR (Moise and Hendrickson 2002). Overall, they document forests with tree layers composed of small to medium-sized trees. The forests are dominated by relatively few species and have sparse covers of understory vegetation. In the sections that follow, descriptions of communities dominated by woody plants precede descriptions of communities dominated by herbaceous plants. In the descriptions that follow, the term “absolute cover” refers to the percentage of the ground surface that lies under the canopy of a species or vegetation type whereas “relative cover” refers to the proportion of the total vegetative cover contributed by a given species.

Table 8-14. Area of vegetation types (in acres) in 1998.

Category	Vegetation type	**Reach**								
		1A	**1B**	**2A**	**2B**	**3**	**4A**	**4B**	**5**	**Total**
Open water	Open water	1,322	220	327	284	355	113	269	559	3,447
Riverwash[a]	Riverwash	33	47	170	3	22	68	3	7	354
Riparian forest	Cottonwood riparian forest	167	79	31	48	441	16	32	41	855
	Cottonwood riparian forest, low density	27	114	41	1	23	4	4	0	213
	Willow riparian forest	205	119	43	112	116	65	508	590	1,759
	Willow riparian forest, low density	28	0	4	6	8	14	118	308	557
	Mixed riparian forest	400	260	0	0	0	6	0	32	697
	Mixed riparian forest, low density	56	19	2	0	0	0	0	17	94
	Valley oak riparian forest	265	0	0	0	0	0	23	46	335
Riparian scrub	Willow scrub	216	113	76	38	190	38	119	73	864
	Willow scrub, low density	74	32	124	15	41	10	13	10	318
	Riparian scrub (nonwillow)	47	48	216	87	61	61	58	81	658
	Elderberry savanna	2	0	3	63	0	0	0	0	68
Invasive Exotics	Exotic tree	55	22	9	0	0	0	0	12	99
	Giant reed	3	4	6	0	0	0	0	0	13
Wetland	Wetland	233	5	11	64	16	41	290	336	991
Other	Grassland	2,582	300	491	226	174	201	2,730	3,969	10,672
	Agriculture	1,915	3,167	4,554	2,047	5,361	2,702	4,189	1,445	25,380
	Disturbed	2,244	381	184	259	743	372	658	182	5,024
	Urban	385	0	0	0	623	0	0	0	1,008
Total		10,261	4,929	6,293	3,253	8,175	3,710	9,084	7,709	53,413

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Table 8-15. Absolute cover of woody and herbaceous plants in vegetation along the San Joaquin River based on data in Appendix 1 of Moise and Hendrickson (2002).

Vegetation Type	Transect No.	Transect Length (m)[a]	Woody Cover (% of transect length covered)[b]	Herbaceous Cover (% of transect length covered)[c]
Cottonwood Riparian Forest	54	2,864	60	45
Disturbed	4	257	33	47
Grassland	38	2,207	1	67
Mixed Riparian Forest	18	1,115	72	40
Riparian Scrub	13	521	17	72
Riverwash[d]	10	377	26	26
Valley Oak Riparian Forest	7	415	61	65
Wetland	14	396	36	82
Willow Riparian Forest	66	3,197	50	50
Willow Scrub	32	1,281	41	43

Notes:

[a] Transect length is the combined length of transects within the vegetation type.

[b] Woody cover is the total cover of trees and shrubs.

[c] Herbaceous cover is the total cover of herbaceous plants.

[d] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Table 8-16. Relative cover of woody plants in vegetation along the San Joaquin River based on data in Appendix 1 of Moise and Hendrickson (2002).

	Vegetation Type: [a]	CORF	DIST	GRAS	MXRF	RPSC	RVWS	VORF	WETL	WLRF	WLSC
	Transect Number:	54	4	38	18	13	10	7	14	66	32
	Transect Length (m): [b]	2,864	257	2,207	1,115	521	377	415	396	3,197	1,281
Scientific Name [c]	**Common Name**	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Acer negundo	box elder										1
Alnus rhombifolia	alder	< 1			3						
Baccharis salicifolia	mule fat	< 1			1						< 1
Cephalanthus occidentalis	button bush	4			13		5		4	7	4
Eucalyptus globulus	blue gum	1	15			12					
Ficus carica	fig										
Fraxinus latifolia	Oregon ash	3			15	11	80			2	
Juglans californica* var. *hindsii	N. California Black Walnut				1						
Morus alba	white mulberry				1					< 1	
Nicotiana glauca	tree tobacco				1	13					
Platanus racemosa	sycamore				11	15					3
Populus fremontii	Fremont cottonwood	33	41		4		7	< 1	4	4	< 1
Quercus lobata	valley oak	1	1		11			61		1	
Quercus wislizenii	interior live oak									2	
Rosa californica	California rose	2			1	12				3	
Rubus discolor	Himalayan blackberry				3					1	2
Rubus ursinus	California blackberry	4			7					1	
Salix exigua	sandbar willow	2	12		13	12	7	< 1	11	7	69
Salix Gooddingii	Goodding's black willow	42	30	100		17	2	38	81	68	12
Salix laevigata	red willow	1						1		1	

Table 8-16, Continued.

Scientific Name [c]	Common Name	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Salix lasiolepis	arroyo willow	4			1					< 1	
Salix lucida	shining willow									< 1	1
Sambucus mexicana	elderberry				1	7				1	< 1
Sesbania punicea	scarlet wisteria				1					1	2
Vitis californica	California wild grape				< 1						

Notes:

[a] Vegetation types are CORF = Cottonwood riparian forest, DIST = Disturbed vegetation, GRAS = grassland, MXRP = mixed riparian forest, RPSC = riparian scrub, RVWS = riverwash, VORF = valley oak riparian forest, WETL = wetland, WLRF = willow riparian forest, and WLSC = willow riparian scrub.

[b] Transect length is the combined length of transects within the vegetation type.

[c] Scientific names of native species are in bold

Table 8-17. Relative cover of herbaceous plants in vegetation along the San Joaquin River.

Scientific Name [c]	**Vegetation Type: 3**	CORF	DIST	GRAS	MXRF	RPSC	RVWS	VORF	WETL	WLRF	WLSC
	Transect Number:	54	4	38	18	13	10	7	14	66	32
	Transect Length (m): 4	2,864	257	2,207	1,115	521	377	415	396	3,197	1,281
	Common Name	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Ambrosia psilostachya	western ragweed	1		1		2	4				1
Anthemis cotula	dog- fennel			2				1			2
Anthriscus caucalis	bur-chevil		4		4						1
Artemisia douglasiana	Mugwort	10	6	1	10	24		5	9	11	14
Atriplex triangularis	spearscale	3				1					
Baccharis douglassii	coyote bush				2					1	
Brassica nigra	black mustard	1	3	3		9	3	1	2	2	5
Bromus diandrus	ripgut brome	18	54	7	26	2	4			4	6
Bromus hordeaceous	soft chess brome	1	4	1	2		4			2	
Bromus madritensis	fox-tail chess	1				1	4				12
Centaurea solstitialis	yellow star thistle		< 1	4	1	1		2	2	3	
Chenopodium berlandieri	pitseed goosefoot								9		
Conium maculatum	poison hemlock				4					2	
Conyza canadensis	horseweed	1	< 1	6				2		3	
Cynodon dactylon	Bermuda grass	16	1	1	30	2	12	14		11	3
Distichlis spicata	salt grass			4	2	9			1	5	2
Epilobium brachycarpum	willow herb	4	< 1	2	1	2	3	2	5		
Eremocarpus setigerus	doveweed		2				4				
Erodium botrys	broadleaf filaree		4	1			8				
Erodium cicutarium	red-stemmed filaree		< 1	9							
Euthamnia occidentalis	western goldenrod	3		1	2				25	4	4

Table 8-17., continued.

Scientific Name [c]	**Common Name**	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Frankenia salina	alkali heath			2	2						
Gnapthalium purpureum	purple cudweed						4				
Grindelia camporum	gum plant			4		4					
Hordeum marinum	Mediterranean barley			6							
Melilotus alba	white sweetclover							1	1	5	1
Helianthus annuus	sunflower	1		2		2		2	3	1	
Hemizonia pungens	spikeweed			2		4		1			
Heterotheca grandiflora	telegraph weed		1	2	< 1						3
Heterotheca oregona	Oregon goldenaster						2				
Juncus mexicanus	Mexican rush			1		5			4		2
Lactuca serriola	prickly lettuce	3	1	3		2		6		4	
Leerzia oryzoides	rice cutgrass	1			1		3				1
Lepidium dictyotum	alkali pepper grass						4				
Leymus triticoides	creeping wildrye	3		3	2	6		5	2	2	6
Lolium perenne	perennial ryegrass			1				7			
Lotus purshianus	Spanish clover	2	6	3		2	3			1	3
Malvella leprosa	alkali mallow	1			4				1		
Marsilia vestita	hairy pepperwort						3				
Polypogon monspeliensis	annual beard grass	1			1		1	3			
Polygonum lapathifolium	pale smartweed								13		
Silybum marinum	blessed milk thistle							2	1	2	
Solanum sp.	nightshade species					2					
Sorghum halpense	Johnson grass					2					
Stellaria media	common chickweed						8				
Urtica dioica	nettle				1	2				2	

Table 8-17., continued.

Scientific Name [c]	**Common Name**	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Vulpia myuros	rat-tail fescue	7	11	7	3		13			4	17
Xanthium strumarium	cocklebur					3		2	2	2	1

Notes:

[a] Vegetation types are CORF = Cottonwood riparian forest, DIST = Disturbed vegetation, GRAS = grassland, MXRP = mixed riparian forest, RPSC = riparian scrub, RVWS = riverwash, VORF = valley oak riparian forest, WETL = wetland, WLRF = willow riparian forest, and WLSC = willow riparian scrub.

[b] Transect length is the combined length of transects within the vegetation type.

[c] Scientific names of native species are in bold.

8.6.4.1. Cottonwood Riparian Forest

The cottonwood riparian forests occur along all reaches of the San Joaquin River (Table 8-14). Important characteristics of the cottonwood riparian forest include:

- The cottonwood riparian forest canopy of trees and shrubs covers 60% of the ground area, 44% with a single layer of trees or shrubs, and 16% with both a tree canopy and an understory of shrubs and suppressed saplings (Table 8-15)
- 42% of cottonwood riparian forests have canopies 15 to 40 feet high, and 57% have canopies more than 40 feet high (Figure 8-29). Trees are typically less than 40 cm (16 inches) dbh and only 5 per hectare (about 2 per acre) are greater than 60 cm (2 feet) dbh (Figure 8-30).
- The dominant tree species are Goodding's black willow and Fremont cottonwood.
- Shrub species have moderately low covers in cottonwood forests (Table 8-16), but the herbaceous layer covers 45% of the transect length (Table 8-15).

8.6.4.2. Mixed Riparian Forest

Mixed riparian forests occur along reaches 1, 4B, and 5 (Table 8-14) but more than 90% of the mixed riparian forest is along Reach 1, where it is the dominant forest type. Important characteristics of the mixed riparian forest include:

- The trees and shrubs canopy covers 72% of the area (Table 8-15), 45% with a single layer of trees or shrubs, and 27% with both a tree canopy and an understory of shrubs and suppressed saplings.
- More than half of the mixed riparian forests canopy is greater than 40 feet high, and the remainder canopies are 15 to 40 feet high (Figure 8-29).
- Trees are typically less than 20 cm (8 inches) dbh; only 8 per hectare (about 3 per acre) are larger than 40 cm (1.3 feet) dbh (Figure 8-30).
- The most abundant tree species are Oregon ash and Goodding's black willow (Table 8-16). Important shrub species include buttonbush, sandbar willow, and California blackberry.
- The herbaceous layer of the mixed riparian forest covers 40% (Table 8-15), with primary species being exotic grasses; Bermuda grass, and ripgut brome. Mugwort, with 10% relative cover, was the only native species with more than 2% relative cover in the herbaceous layer.

8.6.4.3. Valley Oak Riparian Forest

Valley oak riparian forests occur along reaches 1, 4B, and 5 (Table 8- 14) but 80% of this forest is along Reach 1. Important characteristics of the valley oak riparian forest include:

- The valley oak canopy and shrubs covers 61% of the area (Table 8-15), 53% with a single layer of trees or shrubs, and 8% with both a tree canopy and an understory of shrubs and suppressed saplings.
- More than 90% of valley oak riparian forests have canopies greater than 40 feet high, (Figure 8-29).
- Trees are typically 20 to 40 cm (8 to 16 inches) dbh, and only 4 per hectare (about 1½ per acre) are larger than 60 cm (2 feet) dbh (Figure 8-30).
- Valley oak and Goodding's black willow are the dominant tree species.

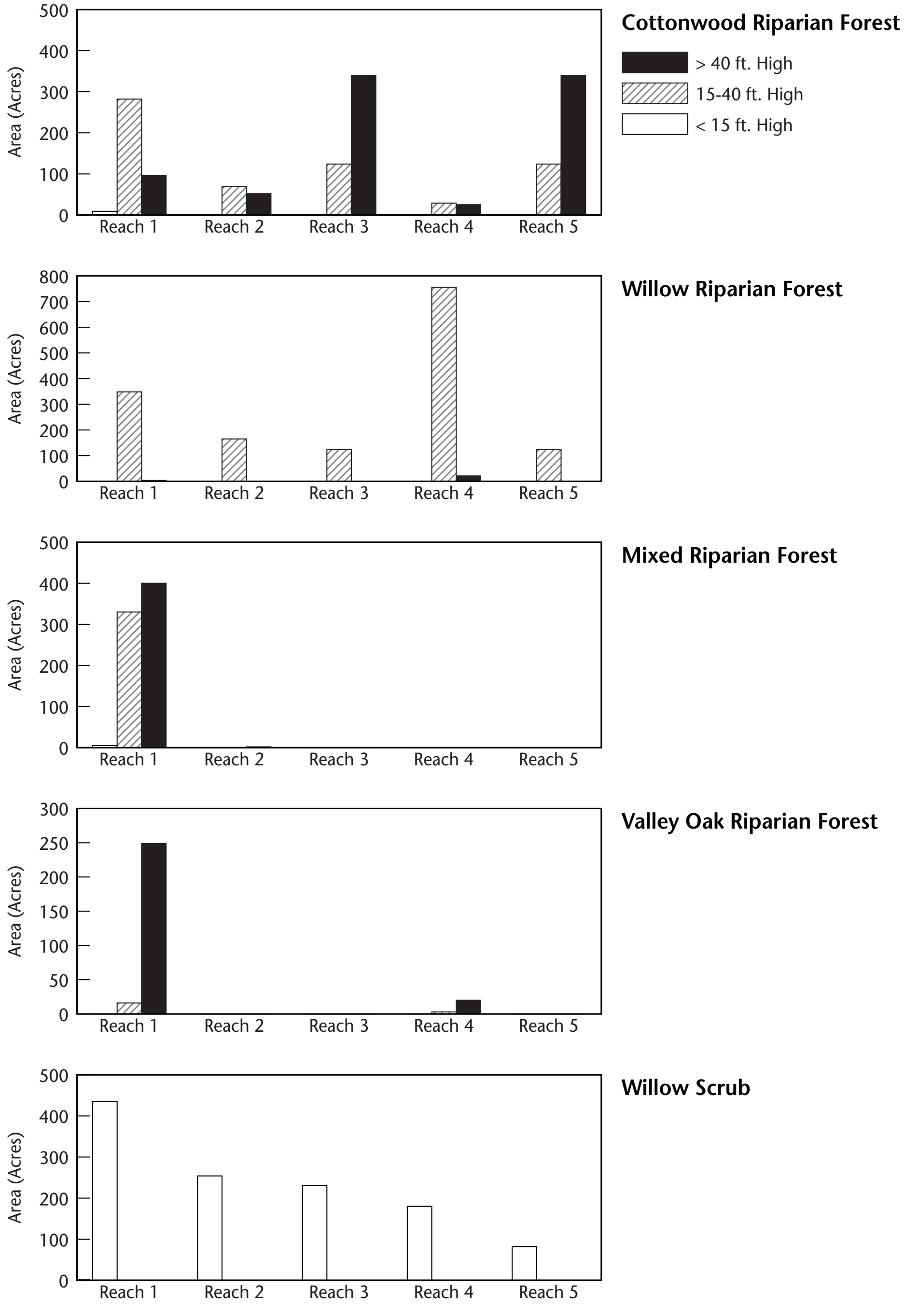
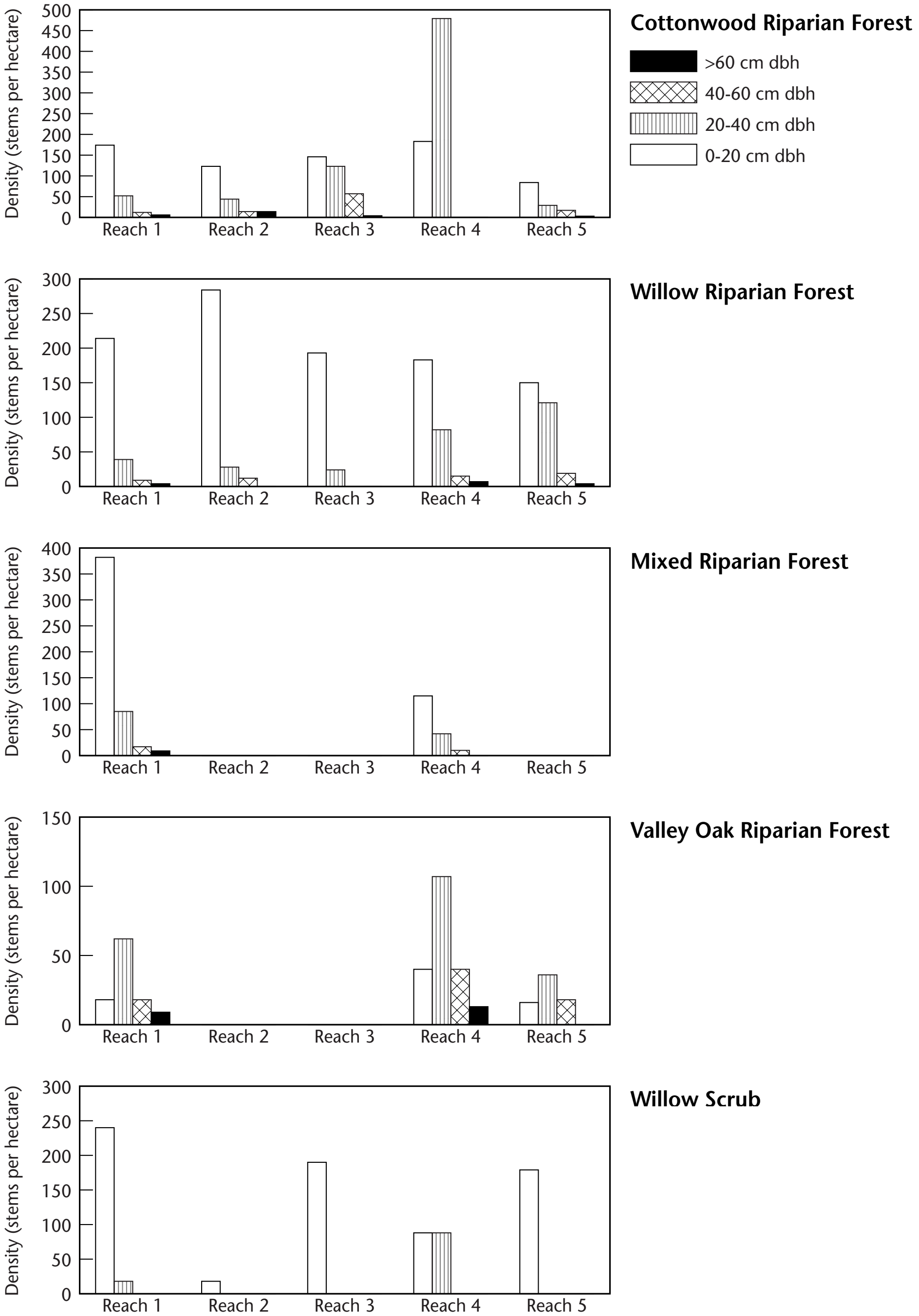


Figure 8-29. Histogram of canopy height and associated acreages of existing vegetation in Reaches 1-5.



Cottonwood Riparian Forest

Willow Riparian Forest

Mixed Riparian Forest

Valley Oak Riparian Forest

Willow Scrub

Figure 8-30. Histogram of stem diameters and associated plant densities of existing vegetation in Reaches 1-5.

- The herbaceous layer covers 65% of the transect length and is dominated by exotic species (Table 8-15 and Table 8-17). The most abundant exotic species are ripgut brome, Bermuda grass, perennial ryegrass, and prickly lettuce. Mugwort and creeping wildrye are the only abundant native species, with 5% relative cover each.

8.6.4.4. Willow Riparian Forest

Willow riparian forests occur along all reaches (Table 8-14). Important characteristics of the willow riparian forest include:

- Willow riparian forest tree and shrub canopy covers 50% of the area (Table 8-15).
- Most (98%) of willow riparian forests canopies are 15 to 40 feet high (Figure 8-29).
- Trees are typically less than 20 cm (8 inches) dbh, with only 14 per hectare (about 6 per acre) larger than 40 cm (1.3 feet) dbh (Figure 8-30). The dominant tree species is Goodding's black willow (Table 8-16). The herbaceous layer covers 50% of the transect length (Table 8-15).
- The dominant herbaceous species are Bermuda grass, and to a lesser degree, native species including mugwort and salt grass (Table 8-17).

8.6.4.5. Willow Scrub

Willow scrub occurs along all reaches (Table 8-14), and important characteristics of the willow riparian forest include:

- Trees and shrubs cover 41% of the willow scrub area (Table 8-15), 37% with a single layer of trees or shrubs, and 4% with both a tree canopy and an understory of shrubs and suppressed saplings.
- The canopy is less than 15 feet high, and stems are less than 20 cm (8 inches) dbh (Figures 8-29 and 8-30). The dominant species are sandbar willow and Goodding's black willow (Table 8-16).
- Several invasive exotics (giant reed, Himalayan blackberry, and scarlet wisteria) are more abundant in willow scrub than in other riparian forests, and have a combined relative cover of 10% (Table 8-16).
- Willow scrub area's herbaceous layer covers 43% of transect length (Table 8-15). Within it, the most abundant species are the exotic species rattail fescue and foxtail chess, and the most abundant native species being mugwort. Creeping wildrye, black mustard, and western goldenrod are also common, though less abundant (Table 8-17).

8.6.4.6. Disturbed Vegetation

Disturbed vegetation is associated with roads, canals, levees and aggregate pits. Although it exists along all five reaches, more than half the area of disturbed vegetation is along Reach 1 (Table 8-14). There it occupies more land than all types of riparian forest and scrub combined.

8.6.4.7. Grassland

Grassland vegetation occupies more area within the study area than any other native vegetation type (Table 8-14). The grassland category is internally variable and ranges from upland grasslands to herbaceous riparian vegetation, and grasslands that include or intergrade with the seasonal wetlands category. Overall, the five most abundant species are three exotic grasses (ripbut brome, foxtail fescue, and Mediterranean barley) and two herbs, the exotic red-stemmed filaree and the native horseweed (Table 8-17).

Grassland vegetation displays a shift in species composition from upstream to downstream reaches. Along Reaches 1 and 2, the dominant species are foxtail fescue, ripgut brome, and spike weed, all characteristic of upland grasslands. Along Reaches 4 and 5, the dominant species are creeping wildrye, salt grass, and alkali heath, which indicate wetter and more saline conditions.

8.6.4.8. Riparian Scrub

Riparian scrub is distributed throughout all reaches of the San Joaquin River (Table 8-14). On average, woody plants cover 21% of the area within riparian scrub; herbaceous plants cover 72% (Table 8-15). Several co-dominant woody species account for most of the tree and shrub cover (Table 8-16), and their abundance varies substantially among reaches. Similarly, of herbaceous species only mugwort and black mustard are abundant in all reaches.

Herbaceous species' abundance changes from upstream to downstream reaches. In Reaches 1 and 2, the most abundant species are mugwort, cocklebur, black mustard, spikeweed, and ripgut brome. In contrast, the most abundant species along Reaches 4 and 5 are mugwort, salt grass, black mustard, creeping wildrye, and Mexican rush. Except for black mustard, these are native perennial species. This change in species composition represents a change in growth form because mugwort, salt grass, creeping wildrye, and Mexican rush are all perennials with stems that spread along or below the ground. Greater soil moisture and changing soil types, including increased salinity and finer soil textures in the downstream areas, may be factors strongly influencing species composition.

8.6.4.9. Riverwash

Riverwash occurs along the length of the study reach (Table 8-14), but was sampled only along Reaches 1 and 2. As previously stated, The acreage of riverwash should not be interpreted as a precise estimate because riverwash acreage is partially a function of the flow at the time that the aerial photograph was taken. Woody and herbaceous plant cover is low (Table 8-15). Oregon ash is abundant in riverwash along Reach 1. Numerous herbaceous species occur within riverwash areas; however, most are relatively uncommon. The most abundant species are foxtail fescue, Bermuda grass, red-stemmed filaree, and willow herb (Table 8-17). Also abundant are lupines that grow on sandbar areas categorized as riverwash.

8.6.4.10. Wetland

Wetlands habitats range from seasonally saturated or inundated to persistently inundated; the type of vegetation reflects the duration of saturation or inundation. Wetland vegetation occurs along all reaches (Table 8-14). Wetland habitat has a low cover of woody plants, composed mostly of tree saplings, and a relatively high cover of herbaceous plants (Table 8-15). Goodding's black willow is the dominant woody plant (Table 8-16). The most abundant herbaceous species are western goldenrod and pale smartweed (Table 8-17). The species composition is indicative of seasonally saturated wetlands, rather than of persistently flooded wetlands or marshes that are typically dominated by bulrushes, cattails, and rushes. There are fringes of rush (*Juncus* sp.) along many areas of the river banks.

8.6.4.11. Invasive Exotic Plants

Exotic species are a major component of most, if not all, remaining natural habitats within the San Joaquin Valley, including habitats in the study reach. Some of these species are problematic invasive species that dominate areas to the exclusion of other plants, and expansion of their range and local abundance can cause substantial ecological change. In the understory, non-native species such as Himalayan blackberry are dominant components; however, the canopy vegetation is dominated by native trees and shrubs, except in localized areas where giant reed or eucalyptus dominate (Moise and Hendrickson 2002).

Invasive exotic species in California are well summarized in Randall and Hoshovsky (2000); thus not discussed in great detail here. Plant invasions alter ecosystem function and tend to reduce diversity of native species (Randall and Hoshovsky 2000). Invasive species may interfere with the regeneration of native dominants, reduce the cover and diversity of native species, form dense monotypic stands, alter resource availability, or change the disturbance regime. As a consequence, controlling invasive exotic plants is perhaps the most urgent task facing managers of natural habitats.

Controlling an invasive exotic plant before it becomes well-established is important. Once a species has become widespread and abundant, mechanical and/or chemical removal can be prohibitively expensive, and after an invasive species is removed, it frequently re-invades. Furthermore, removal of the invasive species is not guaranteed to remove the invasive impacts. Locally extirpated native species may require re-introduction to the site.

Several invasive exotics are already widespread and abundant in the study area. They cover 99 acres in nearly monospecific stands (Table 8-14) and are a minor component of most vegetation types. These species are particularly abundant and widely distributed along Reach 1. High levels of disturbance may have aided their spread in Reach 1, as suggested by their distribution relative to aggregate pits.

These species may interfere with the success of restoration actions, particularly when a restoration action (such as a dispersal flow or channel modification) creates an opportunity for the dispersal and establishment of the invasive species. Therefore, in developing restoration strategies, the biology of the individual species and the techniques available to control their spread must be considered (Table 8-18).

Table 8-18. Prevalent perennial invasive exotic species along the San Joaquin River.

Species	Description
Eucalyptus *(Eucalyptus globulus)* *CalEPPC List* *A-1*	Blue gum is a large, long-lived, Australian tree reaching more than 150 feet in height. It can form dense stands with little understory vegetation and a thick, flammable litter layer. When cut or damaged by fire, it sprouts new stems and blue gum seedlings establish readily on burned or otherwise disturbed sites (Boyd 2000). Because it is a valued landscape tree, biocontrol of blue gum is not an option, and burning is ineffective. However, repeated cutting of stems and application of herbicides are both successful techniques for eradicating blue gum (Boyd 2000). Blue gum and other naturalized eucalyptus species were widespread on the river in Reaches 1, 2, and 5. Nearly 85 acres were recorded in Reach 1A and 32 acres in Reach 1B ; Reaches 2 and 5 had 7 and 12.3 acres, respectively (Moise and Hendrickson 2002).
Giant Reed *(Arundo donax)* *CalEPPC List* *A-1*	Widespread in tropical regions, giant reed is a perennial grass whose stems (culms) are 10-30 feet in height, and whose below-ground stems reach depths of several feet. It forms dense stands that can expand to occupy much of the riparian zone. These stands have low value as wildlife habitat and provide little instream shade (Dudley 2000). Though rapidly growing and long-lived, giant reed does not appear to produce seed and establish seedlings in North America (Dudley 2000). Expansion of existing stands is entirely a result of vegetative reproduction. Successful extirpation of giant reed depends on herbicide application, as no biocontrol agents are available, burning is ineffective, and mechanical eradication is extremely difficult (Dudley 2000). This species is most prevalent along reaches 1A, 1B, and 2, where 16.4, 7.0, and 17.5 acres acres were mapped, respectively. Small amounts were present on all other reaches except Reach 4 (Moise and Hendrickson 2002).
Scarlet Wisteria *(Sesbania punicea)* *CalEPPC List* *Red Alert*	Scarlet wisteria is a South American shrub or small tree reaching 10 feet in height. It is grows rapidly, and its seeds are both readily dispersed and persistent. The pods containing the seeds may float for up to a week, and if not abraded the seed remain dormant, perhaps for years (Hunter, unpublished data). Scarlet wisteria can form dense stands excluding other species, and its populations are rapidly increasing. The species was not even included in the most recent flora for California (Hickman 1993) yet is now widespread and abundant in Reach 1A, along the lower American River, and elsewhere. Because it has become a problematic invasive plant only recently, the effectiveness of control strategies is still being evaluated. Scarlet wisteria was found mainly on Reach 1A extending downstream to river mile 242 in Reach 1B. It forms dense colonies on disturbed areas and on sand and gravel bars where it displaces the native willow scrub (Moise and Hendrickson 2002).
Tree-of-Heaven (*Ailanthus altissima*) *CalEPPC List* *A-2*	Tree-of-heaven is a clonal tree from China. Its individual stems are short-lived and seedling establishment may be relatively uncommon in California. However, it repeatedly produces new stems from it roots, forming persistent thickets of considerable area (Hunter 2000). Because of its production of root sprouts, cutting and burning are relatively ineffective in removing established tree-of- heaven thickets. Application of herbicide to frilled stems is probably the most effective means of removing tree-of-heaven (Hunter 2000). Tree of heaven was found on reaches 1 and 2, with almost 3 acres recorded in reach 1A (Moise and Hendrickson 2002).

Table 8-18., continued.

Species	Description
Himalayan blackberry (*Rubus discolor = R. procerus*) *CalEPPC List A-1*	Himalayan blackberry, native to western Europe, forms large impenetrable clumps and is widespread along the river, especially along channelized banks. It grows vigorously and according to Moise and Hendrickson (2002) "appears to have usurped the niche of its native relative, the California blackberry (*Rubus ursinus*)." It is a prolific seeder and the seeds are readily dispersed by mammals, birds, and water (Hoshovsky, 2000). It also reproduces vegetatively. Due to difficulty in distinguishing it from the native blackberry without relatively close examination, only one occurrence of this species was mapped (in Reach 1A) by Moise and Hendrickson (2002). However, they do state that most of the blackberry along the river appears to be Himalayan blackberry.
Parrot's Feather (*Myriophyllum aquaticum*) *CalEPPC List B*	Parrot's feather is a stout emergent aquatic perennial that forms dense mats of intertwined brownish stems (rhizomes) in water (Godfrey, 2000). Whorled feather-like leaves (four to six at a node) make the emergent stems resemble bright green bottlebrushes. These may extend as much as eight inches above the water surface. This aquatic weed was not documented in the DWR vegetation surveys, which focused on the wetland and upland vegetation, but was observed during recent field visits in Reach 1 (Orr, personal communication 2002).

Notes: CalEPPC = California Exotic Pest Plant Council. Exotic Pest Plant of Greatest Ecological Concern in California, October 1999. List A-1—Most Invasive Wildland Pest Plants—Widespread in California; List A-2-- Most Invasive Wildland Pest Plants—Regional distribution in California; List B—Wildland Plants of Lesser Invasiveness; Red Alert: Pest plants with the potential to spread explosively; infestations currently small and localized.

8.6.5. Summary of results from San Joaquin River Riparian Habitat Restoration Program 1999-2001 Pilot Project

As discussed in Section 8.5.7.2, monitoring goals varied between the 1999-2001 pilot projects. In the 1999 pilot project, the goal of the flow releases from Friant Dam were to establish riparian vegetation on upper sand bar surfaces, primarily in Reach 2. Monitoring focused on evaluating whether managed flow releases promoted riparian tree growth along those subreaches that had very limited riparian vegetation due to long periods of dewatered conditions in the river, and at what locations vegetation established. In 2000, the goal of the pilot project flow release was primarily to maintain vegetation that had initiated during the previous years' pilot project release. In 2001, the goal of the pilot project flow releases was primarily vegetation maintenance and evaluation of hydrologic routing and shallow groundwater characteristics. Monitoring methods for the 1999-2001 pilot project are provided in Section 8.5.7.2. A brief summary of results is presented that focus on the 2001 monitoring season, as some of the more interesting observations were made during this monitoring season. Readers are directed to FWUA and NRDC (2002), SAIC (2002), and JSA and MEI (2002a and 2002b), for more details on monitoring methods and results of 1999, 2000, and 2001 pilot projects.

8.6.5.1. Hydrology Results

Flows were released from Friant Dam during the summers of 1999-2001 for the respective pilot projects (Table 8-19).

Table 8-19. Summary of hydrology during 1999-2001 releases for pilot projects.

Water Year	Dates of pilot project flows	Date of peak Friant Dam release	Peak release from Friant Dam (cfs)	Peak flow at Gravelly Ford (RM 227.5) (cfs)	Peak flow at Chowchilla Bifurcation Structure (RM 216.1) (cfs)
1999	July 3 – Oct 6	June 4-6	813[1]	550[1]	434[1]
2000	June 5-June 21	June 18	2,590	1,760	Not reported
2001	June 1-June 25	June 17-23	400[1]	181[1]	0[3]
2001	Aug 27-Sept 9	Sept 5-7	880[1]	640	0[4]

[1] Daily average flow, steady flow so roughly equal to instantaneous peak

[2] Daily average flow, short duration flow so less than instantaneous peak

[3] Flow extended downstream to at least RM 223.2 (SAIC 2002)

[4] Flow extended downstream to at least RM 217.7 (SAIC 2002)

Because the one of the primary objectives of the 2001 pilot projects was hydrologic routing and groundwater response, the following discussion focuses on results from the 2001 monitoring effort. In 2001, two pulse flows were released from Friant Dam (Figure 8-31): 1) a flow of 200 to 250 cfs between June 1 to June 24, with a short peak flow of approximately 400 cfs, 2) a shorter peak flow of 880 cfs between August 27 and September 9. The flow averaged approximately 40 cfs at Gravelly Ford between the two pulses, but flows approached zero during short periods of time (Figure 8-31). A two-day lag time occurred between Friant Dam and Gravelly Ford (approximately 39 river miles). Highlights from the hydrologic monitoring include:

- There was a strong relationship between the river flows and shallow groundwater table within the floodway and the transition between floodway and agricultural lands. Monitoring wells were not installed at any significant distance beyond the floodway margins, so the relationship between river flows and regional shallow groundwater elevations cannot be quantified. The severe depletion in the regional shallow groundwater aquifer (see Chapter 4) suggests that the groundwater flow gradient away from the river is strong, re-filling the depleted shallow groundwater aquifer. However, no data have been collected as part of the pilot project to confirm or reject this assumed gradient.
- Prior to the release, the river was dry downstream of Gravelly Ford (RM 227.5). The limit of flowing water in the river extended five miles downstream to RM 223.2 during the June pulse flow (peak release = 400 cfs). The September pulse flow (peak release = 880 cfs) extended farther downstream, with flowing water ending between the RM 217.7 and the RM 212.0 sites. Therefore, surface flows did not necessarily reach the downstream-most transects.
- In-river water surface elevations increased between 1 and 3 feet during the pulse releases.
- Corresponding shallow groundwater fluctuations depended on location. At sites upstream of Gravelly Ford, the June pulse increased shallow groundwater elevations by 1 to 2 feet, while the September pulse increased elevations by 2 to 3 feet (Figure 8-32). Shallow groundwater elevations naturally tapered off after the peak streamflow occurred, within one month after the pulse. This plateau occurred because flow is perennial upstream of Gravelly Ford (i.e., the river supports the local shallow groundwater table).

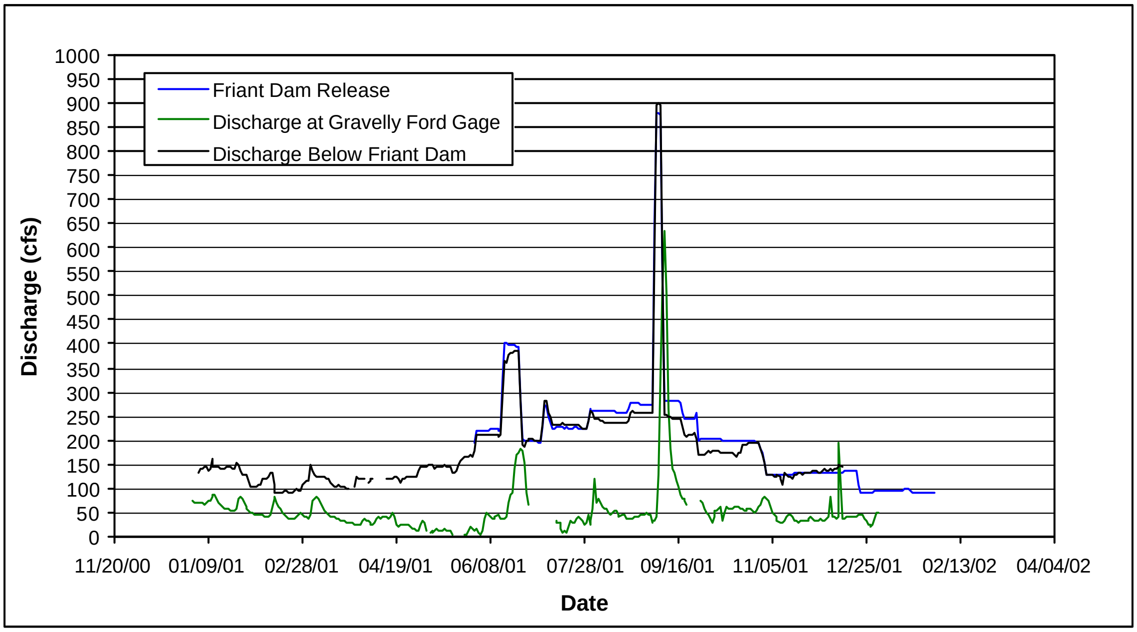


Figure 8-31. Friant Dam Release (May to September 2001) and San Joaquin River discharge below Friant Dam and at the Gravelly Ford Gage (January to December 2001).

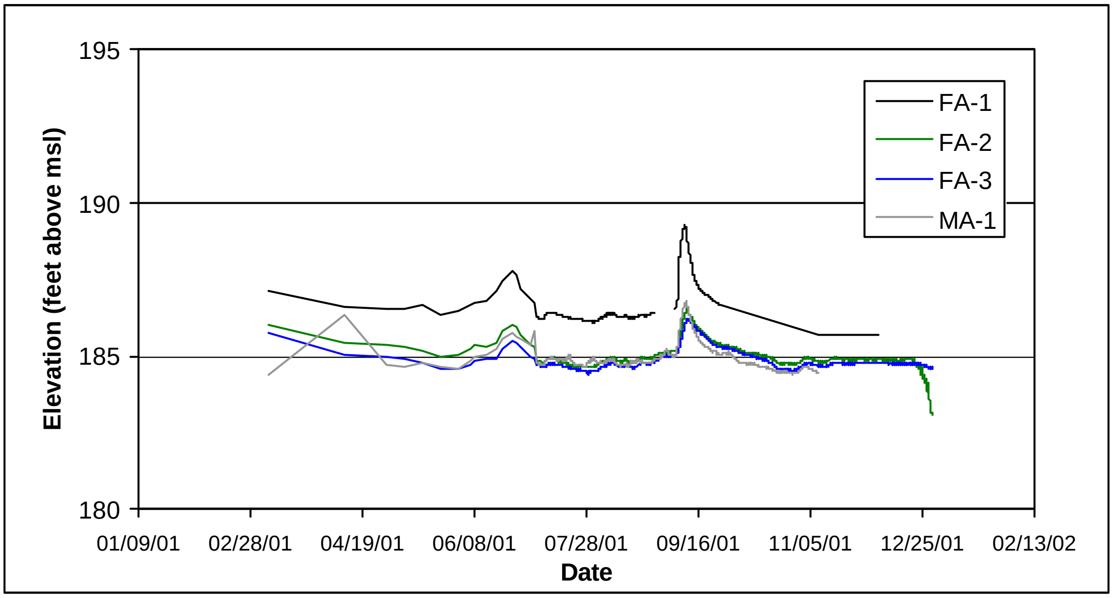


Figure 8-32. Summer 2001 Groundwater elevation trends from four alluvial wells at the RM 229.3 (Lake Avenue) study site (upstream of Gravelly Ford). Cross section thalweg elevation is 181.66 ft.

- Downstream of Gravelly Ford, sites do not normally have river flows except during Pilot Project pulse flows and flood control releases. The groundwater response to the Pilot Project flows was different compared to the upstream study site with its perennial flows. Due to groundwater overdraft (see Chapter 4), groundwater elevations are far below the thalweg of the San Joaquin River downstream of Gravelly Ford. Therefore, when streamflows are released, the shallow groundwater aquifer rapidly fills up (up to 15 feet) as it is recharged (Figure 8-33 and 8-34). This likely results in significant flow attenuation and flow loss until this shallow groundwater "hole" is filled. The peak flow at Gravelly Ford (RM 227.5) during the September pulse was approximately 630 cfs, but flow ended between RM 217.7 and 212.0, such that 630 cfs was "lost" to this hole in 11 to 16 river miles (Figure 8-31).
- The shallow groundwater response to the June 2001 pulse was strong downstream to the RM 222.1 site, but the response was very small at the RM 220.0 site (Figure 8-34). Recalling that the surface flow during the June 2001 pulse ended at approximately RM 223, the small groundwater response observed at RM 220.0 suggests that the longitudinal groundwater response ended at approximately RM 220.
- Local influences on shallow groundwater elevations at the RM 222.1 site (Figure 8-33) are not apparent at the other sites during the Pilot Project flows (Figure 8-32). Shallow groundwater elevations rose in response to the June and September pulse flows, but there are other rises in the shallow groundwater table in November, December, and January that are not related to instream releases (Figure 8-33). Perhaps the groundwater elevation increases are due to cessation of local groundwater pumps, and/or irrigation with surface water that recharges the shallow groundwater aquifer. Regardless, in Reach 2, shallow groundwater monitoring results illustrate that shallow groundwater elevations fluctuate greatly through the year.

8.6.5.2. Vegetation Results

Similar to monitoring of the 2000 pilot project, vegetation monitoring during 2001 occurred before the pulse flows (June 2001) and after the pulse flows (November 2001). Vegetation analysis was complicated to an unknown degree by herbicide spraying in the channel, although extensive amounts of vegetation appeared to be killed by the spraying. Highlights from the vegetation monitoring include:

- The number of plants decreased 50% from 2000 to 2001; of the approximately 6,000 seedlings of the 2000 cohort, almost all of them appeared dead by the June 2001 monitoring cycle. Hydrologic conditions were favorable for seedling establishment and survival in 2000, because perennial flows occurred at all monitoring sites throughout the summer (JSA and MEI, 2002b). Conditions in 2001 were unfavorable even with the pulse flow releases, because downstream sites were dry most of the year and the two downstream-most sites were dry even through the 2001 pulse flows. Stress or mortality from lack of water in the root zone is one of several mortality agents. Others include herbivory, herbicide spraying, bed scour, and prolonged inundation.
- Of the 1,892 plants sampled before the June 2001 pulse release, 95% of the plants (1,774 individuals) were narrow leaf willow (*S. exigua*) or Goodding's black willow (*S. gooddingii*). Fremont cottonwood (*Populus fremontii*) made up less than 1% of the plants (12 individuals), Oregon ash (*Fraxinus latifolia*) made up 1.3% of the plants (25 individuals), and western sycamore (*Platanus racemosa*) made up less than 1% of the plants (3 individuals). Box elder was not observed in the sampling transects.

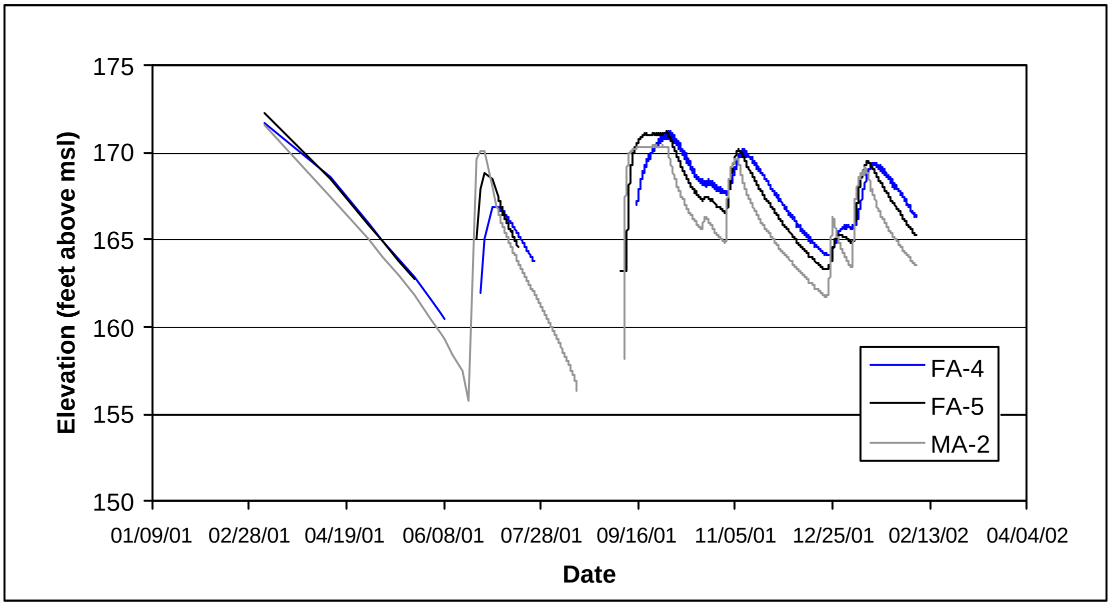


Figure 8-33. Summer 2001 Groundwater elevation trends from three alluvial wells at the RM 222.1 study site (downstream of Gravelly Ford). Cross section thalweg elevation is 171.33 ft.

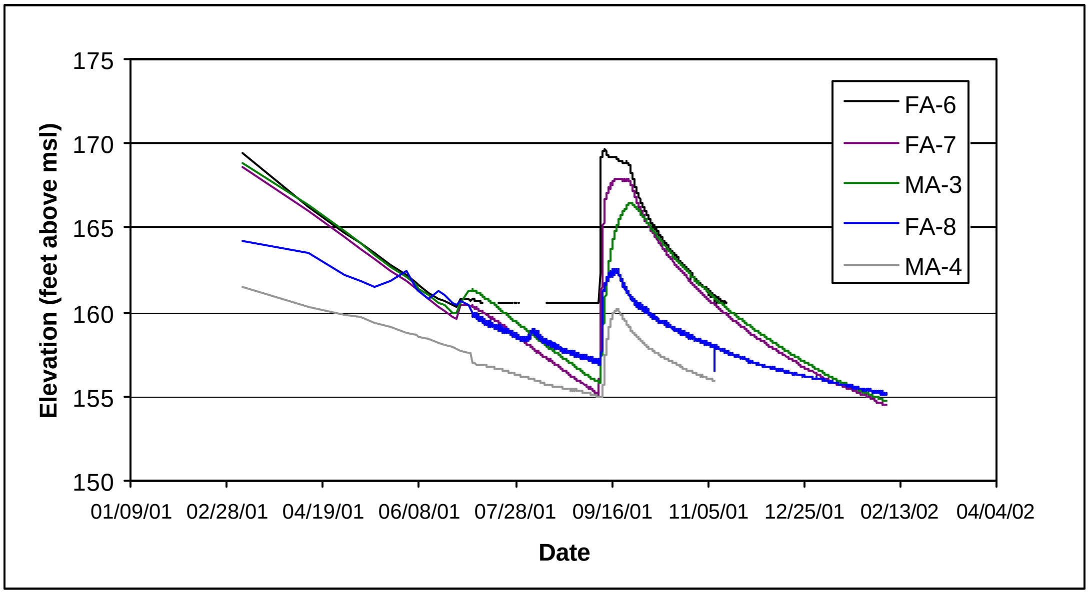


Figure 8-34. Summer 2001 Groundwater elevation trends from five alluvial wells at the RM 220.0, RM 218.2, and RM 217.7 study sites (downstream of Gravelly Ford). Cross section thalweg elevations are 168.83 ft (FA-6, FA-7, MA-3), 163.66 ft (FA-8), and 161.60 ft (MA-4).

- The November 2001 monitoring counted 1,450 plants, a decrease of 23%. The percentages of remaining plant species were similar to the June 2001 monitoring survey, with over 95% (1,379 individuals) of the plants being narrow leaf willow and Goodding's black willow.
- Most plant individuals (59%) were class 1 seedlings or saplings (less than 1.5 meters tall). The balance (40%) were size class 2 (greater than 1.5 meters tall but less than 10 centimeters dbh). However, these size distributions do not imply that the plants are failing to reach maturity because most of the plants were narrow-leaf willow, which do not generally grow larger than size class 2.
- Some longitudinal trends in abundance of certain species were observed. Oregon ash and buttonwillow were documented almost exclusively (95%) at monitoring sites upstream of Gravelly Ford. Approximately 60% of the Fremont cottonwood plants were also observed upstream of Gravelly Ford. Downstream, the most common species were sandbar and black willows.

8.6.5.3. Summary

The pilot projects' results suggest that selected woody riparian species can survive when shallow groundwater elevations are far below the thalweg of the river channel (e.g., 15 feet or more at some sites for short durations. However, only certain species can survive these extreme conditions and diversity is limited. While not a stated conclusion of the pilot project reports, restoring a perennial and seasonally variable flow regime will likely improve riparian plant establishment on both lower elevation surfaces and higher channel surfaces, and will likely encourage greater species diversity beyond narrow leaf willow and Goodding's black willow.

Since 2000, willow saplings' dynamics have varied at the monitoring sites (Table 8-20). From 2000 to 2001, the density of sandbar willow stems less than 1.5 m high decreased substantially along all monitoring transects. This density decrease was accompanied by a density increase of larger stems (those greater than 1.5 m high) at only two sites, indicating that substantial willow mortality had occurred, with little recruitment into larger size classes (with the caveat that narrow-leaf willow rarely grows to the largest size class). For Goodding's black willow, changes have been more varied (Table 8-20). Additional seedling and sapling recruitment (size class 1) of Goodding's black willow occurred at four of the 12 monitored sites. At two sites, mortality of all saplings was complete, but at several other sites, a decrease in density of stems less than 1.5 m high was accompanied by an increase in stems greater than 1.5 m high; these findings suggest successful willow growth to larger sizes. Perhaps the success to larger size classes was a result of the location of the plants with respect to the surface water location. However, the density differences between monitoring sites did not correspond to differences in groundwater elevations.

Table 8-20. Density of willow saplings along Pilot Project transects in 2000 and 2001.

Study Site Location	**Year**	***Salix Gooddingii***				***Salix exigua***	
		Size Class 1[a] (plants/HA)	**Size Class 2[b] (plants/HA)**	**Size Class 3[c] (plants/HA)**		**Size Class 1[a] (plants/HA)**	**Size Class 2[b] (plants/HA)**
RM 234.4	2000		186	159		2,800	783
	2001	NS	NS	NS		NS	NS
RM 229.3	2000	28	14	0		1,028	222
	2001	413	124	14		83	41

Table 8-20., Continued

Study Site Location	**Year**	***Salix Gooddingii***				***Salix exigua***	
		Size Class 1[a] (plants/HA)	**Size Class 2[b] (plants/HA)**	**Size Class 3[c] (plants/HA)**		**Size Class 1[a] (plants/HA)**	**Size Class 2[b] (plants/HA)**
RM 227.1	2000	342	291	6		2,203	382
	2001	265	416	0		265	170
RM 226.2	2000	15	0	0		3,701	67
	2001	345	427	0		480	157
RM 225.2	2000	86	60	0		3,395	224
	2001	466	255	0		86	186
RM 223.2	2000	85	7	0		285	48
	2001	24	24	0		132	31
RM 222.1	2000	795	164	0		2,428	369
	2001	833	89	0		592	434
RM 221.1	2000	36	879	0		490	907
	2001	79	0	0		50	22
RM 220.0	2000	61	142	0		411	27
	2001	0	0	0		32	7
RM 219.1	2000	137	258	5		212	5
	2001	0	0	0		35	0
RM 218.2	2000	55	1,930	86		1,633	94
	2001	164	232	0		138	0
RM 217.7	2000	36	0	0		276	182
	2001	0	0	0		216	205
RM 212.0	2000	96	507	139		149	32
	2001	64	149	0		21	16

[a] SC1 = Size class 1, stems less than 1.5 m high.

[b] SC2 = Size class 2, stems greater than 1.5 m high, with a diameter less than 10 cm.

[c] SC3 = Size class 3, diameter greater than 10 cm.

Another key observation of the pilot project is that surface flow losses to infiltration can be severe in Reaches 1B, 2A, and 2B. These reaches of the San Joaquin River are locations where groundwater overdraft has been severe (see Chapter 4). Results suggest that surface flow losses (and likely some evapotranspiration losses) to infiltration can be very severe (over 600 cfs “lost” to infiltration in 10 miles of river as the groundwater “hole” is filled). Once the initial groundwater recharge occurs with surface flows, the steady-state seepage loss rate is approximately 100 cfs in Reach 2A based on 1999 synoptic flow measurements. Recharging the shallow groundwater aquifer could require a substantial flow from the river, and the recharge effects could be hampered by shallow groundwater pumping nearby based on the response of shallow groundwater tables shown in Figure 8-33. Pumping could impair flow restoration and continuity efforts through this reach.

The pilot projects documented the germination and establishment of riparian vegetation, and described shallow groundwater hydrology, in the most-difficult-to-restore reaches of the San Joaquin River. Monitoring should be continued in these reaches, and expanded to other priority reaches where riparian establishment is desired.

8.7. RIPARIAN VEGETATION LIFE HISTORY AND CONCEPTUAL MODELS

Hydrology and fluvial geomorphology play a central role in determining the ecology of woody riparian vegetation (e.g., Hupp and Osterkamp 1985, Mahoney and Rood 1998, Scott et al. 1999, Bradley and Smith 1986, Shafroth et al. 1998, Shafroth et al. 2000). Critical plant life-history stages respond to varying flow regimes; these responses determine the elevational and lateral distribution and extent of riparian plant species. Seed dispersal, germination, establishment, vegetative growth, and survival are all mediated by flow-related events. Thus, the timing, magnitude, duration, and frequency of flows affect the elevational distribution, extent, and community structure of riparian vegetation. The following sections describe a combination of conceptual models illustrated in the riparian scientific literature, as well as unpublished conceptual riparian models developed for the Central Valley.

Developing conceptual models requires an understanding of key life-history stages, timing, and strategies of each riparian species. Individual riparian plant species typically have four life-cycle stages: initiation, establishment, maturity, and senescence (Figure 8-35). For convenience in conceptual modeling, these stages are defined as follows:

- *Initiation* begins after a seed lands on exposed, moist substrate and germinates; this stage continues through the first growing season.
- *Establishment* begins after the first growing season and continues until the plant has enough resources to begin sexual reproduction.
- *Maturity* begins when a plant first flowers and produces seeds.
- *Senescence* follows maturity, when seed production and reproductive capacity eventually decline.

The structure of riparian stands is a result of hydrologic, climatic, and fluvial processes interacting with the life history of individual species. Primary causes of plant mortality include seedling desiccation, seedling scour, lateral erosion, density dependent mortality (shading), herbivory, disease, and infestation (Figure 8-35). Over time, these processes influence mortality rates at each life stage, resulting in variable and dynamic riparian stands. For example, a particular year may exhibit high seedling mortality associated with a scouring high flow, while later, more moderate floods may encourage seedling survival on certain bank surfaces.

The following sections summarize some of the linkages between hydrology, fluvial geomorphology, and key life history components of woody riparian vegetation. We focus on the linkages of spring-seeding woody riparian species (willows and cottonwoods) because they were historically the dominant woody riparian species in the study area, more is known about their life history needs, and they are ecologically desirable species to restore.

8.7.1. Dispersal and establishment of key riparian species

For this discussion, dispersal phenology is defined as the seasonal timing of seed dispersal for a given species. Understanding a species' dispersal phenology is critical when linking to hydrologic and geomorphic processes, because the seed dispersal period often defines the window of time when favorable environmental conditions are needed to generate a successful cohort of new plants. This is especially true of willows and cottonwoods because the seeds have a very short period of viability (a few days) and need to land in open habitat with sufficient soil moisture for establishment immediately after they disperse or establishment will not occur.

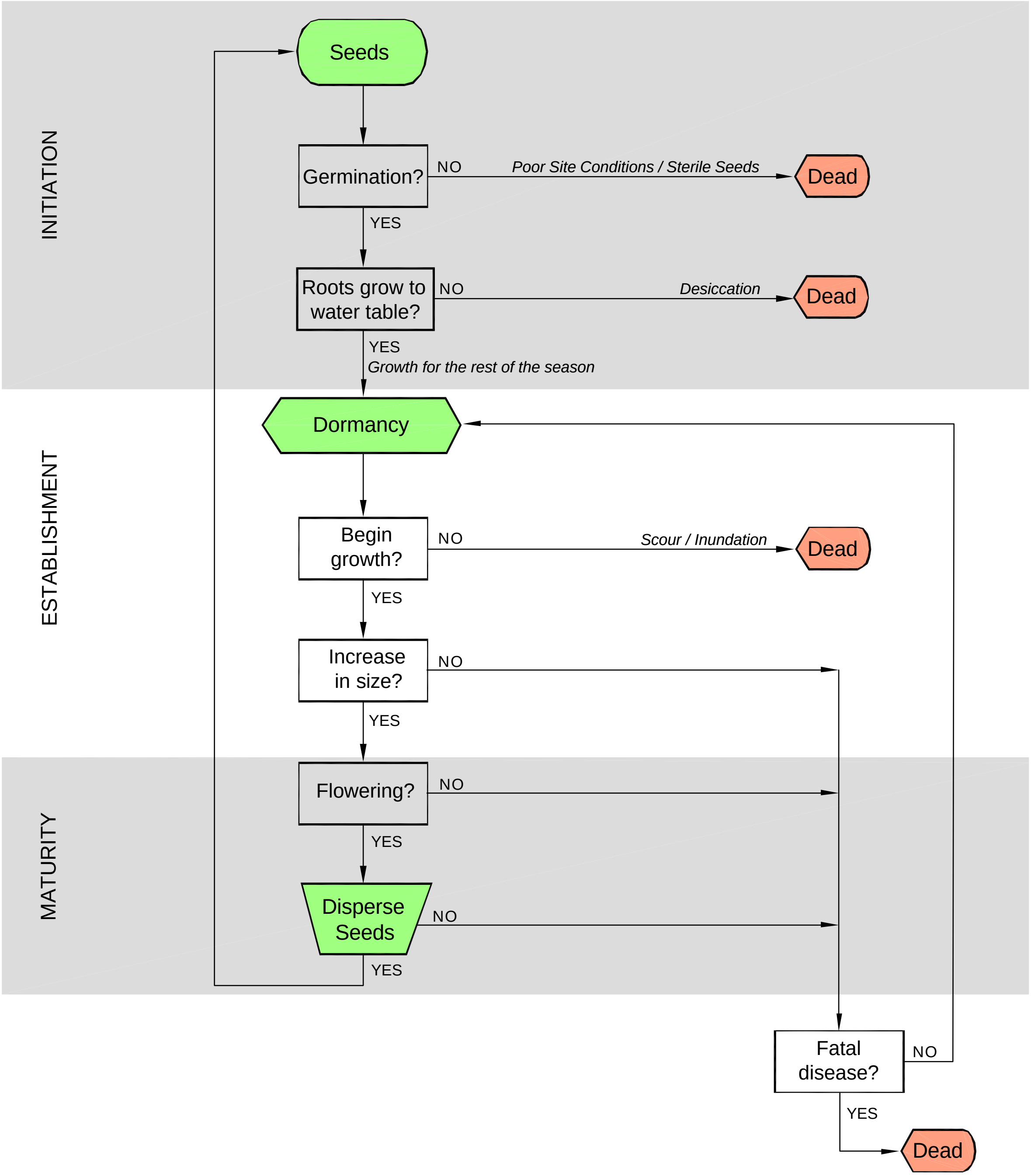


Figure 8-35. Generalized woody riparian plant life cycle, showing life stage and mortality agents that affect life stages.

Peak seed dispersal periods of riparian species vary considerably from species to species and may also vary from year to year with variation in annual climatic conditions (Wolfe and Associates 1999). Data on seed dispersal timing can be useful for managing target (i.e., desired) species. For example, to increase the success of natural regeneration of a target species such as Fremont cottonwood or black willow, flow releases can be developed to coincide with seed dispersal times to increase the success of natural regeneration of those species. Conversely, to discourage regeneration of exotic species, flow releases could be managed to avoid exotic species' seed dispersal times.

Two studies have documented seed maturation and dispersal phenology for Fremont cottonwood and several willow species along the San Joaquin River. The first study was conducted from June 6 through September 24, 1999 (Wolfe and Associates 1999), and the second was conducted from April 2 through June 26, 2002 (Stillwater Sciences, unpublished data). Additional field observations on the Tuolumne River were recorded in the fall of 1996 through the spring of 1998 (McBain and Trush, 2000) and on the San Joaquin River in the spring of 1998 (EA Engineering, 1999). Although some variation in phenology is expected among years and sites, the data from these studies can be used to establish general patterns of peak seed dispersal for the species studied.

Species in the willow family disperse seed in the spring and summer. Arroyo willow is the first of the local species to release seed, generally from mid-February through late March; with peak dispersal in the first half of March (Figure 8-36). Fremont cottonwood is the next species to disperse seed; typically during April and May, with a peak in late April through early May (Figure 8-36). Goodding's black willow, red willow, and narrow-leaf willow all generally disperse seed towards the end of or subsequent to the cottonwood dispersal period. Although the limited data show narrow-leaf willow to have the longest and latest seed dispersal period, extending into mid-August (Figure 8-36), there is some evidence from the 1999 Pilot Project that longer seed viability of Goodding's black willow may extend its potential germination period into the early fall. In contrast to the willows and cottonwoods, some of the other common riparian hardwood species exhibit seed dispersal in the fall (Figure 8-36). Box elder, for example, generally releases seed from mid-September through October with a peak in mid-October. White alder typically releases seed during October, with a peak in mid-October. Valley oak also disperses seeds (acorns) in the fall.

The seed dispersal phenology data collected in the spring and summer of 2002 by Stillwater Sciences (unpublished data) indicate that much variation in seed dispersal timing can occur among individuals both within and between sites (Figures 8-37 through 8-39). Cottonwoods observed at the Lost Lake site (RM 265) and Highway 140/165 site (RM 133) tended to exhibit synchronous seed dispersal with a peak during the last week of April (Figure 8-37). The length of the seed dispersal window was approximately one month at the Highway 140/165 site and two months at the Lost Lake site. A "middle" site at Firebaugh (RM 194) experienced the longest period of seed dispersal, with seed dispersal occurring from early April until the study terminated in late June. This extended seed dispersal period resulted from several different patterns among individual trees, with some trees peaking early, some later, while others had multiple or extended peaks.

In addition to variation in seed dispersal timing, there was also much variation in seed production among sites and among individual trees. At the downstream site (Highway 140/165), relatively few seeds were produced (<40 open catkins per tree at peak release), but at the Lost Lake site, trees produced many seeds (>100 open catkins per tree at peak release). The Firebaugh site trees exhibited the most variability; four of the ten observation trees produced many seeds, while the other six produced few seeds.

The 2002 data indicate that Goodding's black willow is the next species after cottonwood to start dispersing seed, beginning in early to mid-May and peaking in late June or later (Figure 8-38). The 2002 study ended before the peak seed dispersal occurred for this species. Sandbar willow began

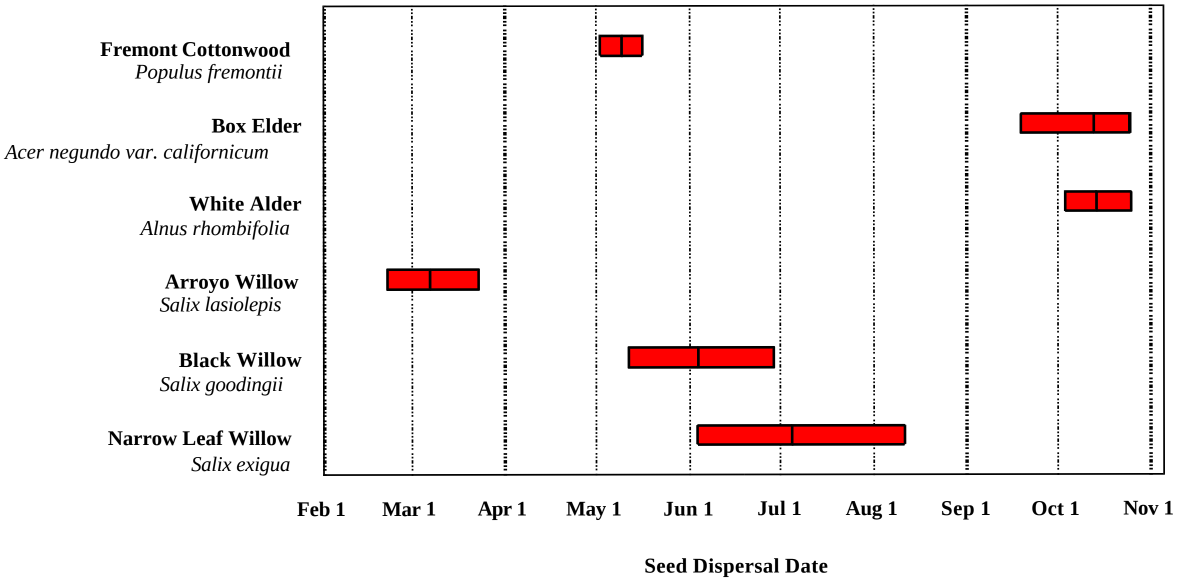


Figure 8-36. Generalized woody riparian vegetation seed dispersal periods for six common species, from EA Engineering (1999).

dispersing seed around the first of June in 2002, with seed dispersal strongly increasing by the end of June (Figure 8-39). The primary difference in the 2002 seed dispersal between the two willow species was that black willow began releasing seed 2 to 3 weeks earlier than sandbar willow. There may also have been differences in the duration and termination of seed release in 2002, but data collection stopped before any such pattern could be documented. Observations during the 1999 Pilot Study, which documented establishment of black willow seedlings after September releases, suggest either an extended period of seed viability or of dispersal for this species. The latter seems plausible given the site-to-site and individual-to-individual variation in phenology observed in this and other riparian species (Figure 8-37). Given the copious seed production of individual trees, even a few late dispersing individuals could account for this observation.

The 1999 study, which began in June and ran through September, documented a similar pattern for the three willow species studied (narrowleaf, black, and red willow), with seed dispersal generally beginning in early June and 90% or more of all seeds dispersed by late June or early July (Wolfe and Associates 1999). Differences in the timing of seed dispersal initiation among the three species may have been missed since the study was not started until June 6.

8.7.2. Establishment conceptual model: spring seed dispersal species

For successful recruitment, Fremont cottonwood (*Populus fremontii*) and willows (*Salix* spp.) are particularly dependent on specific hydrologic events during and immediately following their seed release periods. Establishment and survival of these early successional species are important for new patches of riparian vegetation, which facilitates the establishment of other species. Within new patches of willows and cottonwood, other tree species such as box elder and Oregon ash, often become established concurrently or at a later date, which initiates succession towards mixed riparian forest and understory. In this riparian system, the later-successional species, including box elder, Oregon ash, western sycamore, and valley oak, are more tolerant of shade than are cottonwood and willows; the establishment of late-successional species is less dependent upon specific hydrologic events.

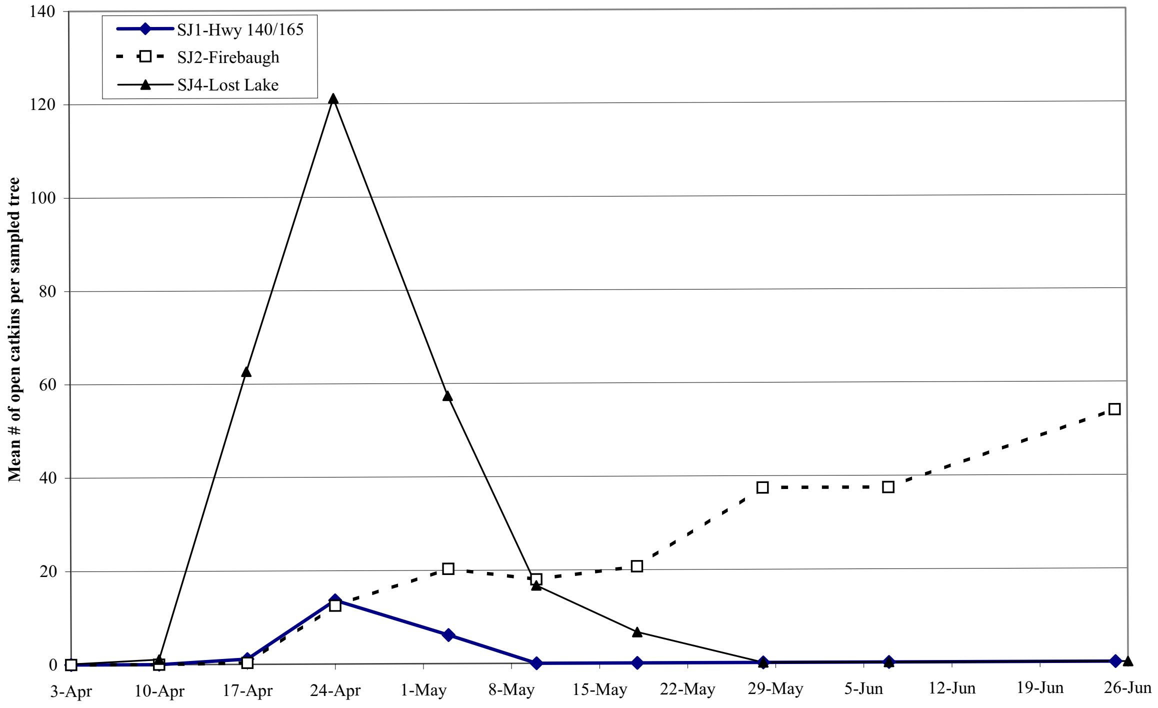


Figure 8-37. Spring and summer 2002 phenology data for Fremont cottonwood at three sites in the San Joaquin River study reach.

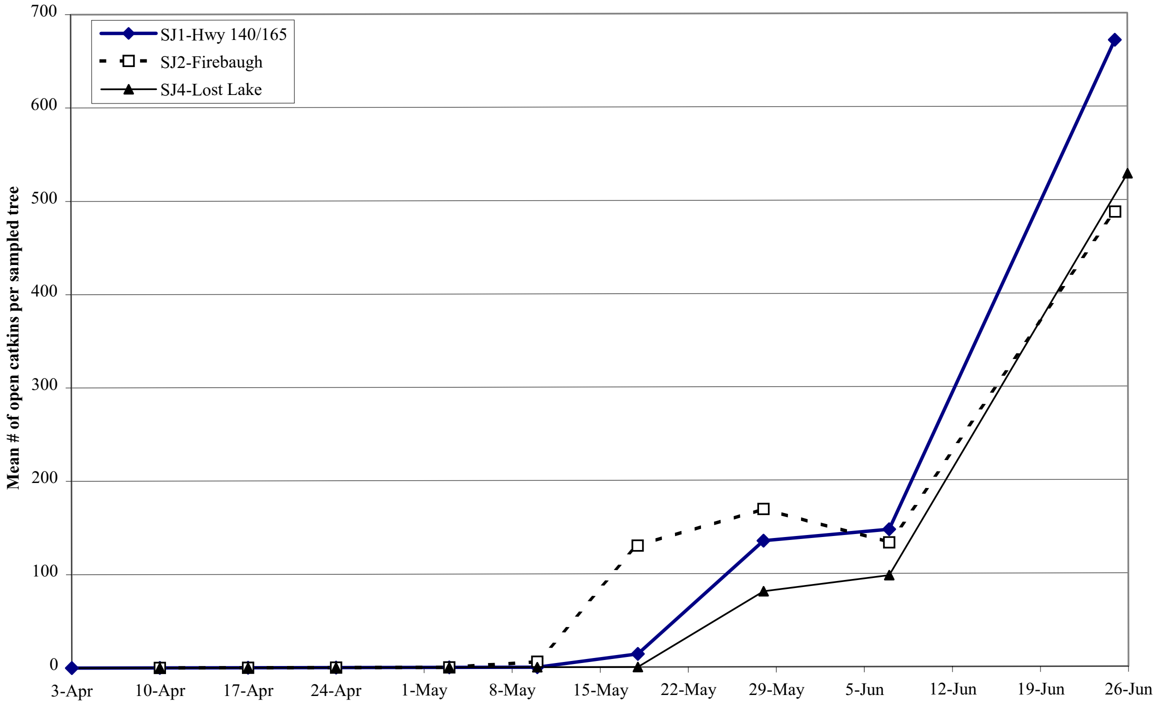


Figure 8-38. Spring and summer 2002 phenology data for black willow at three sites in the San Joaquin River study reach.

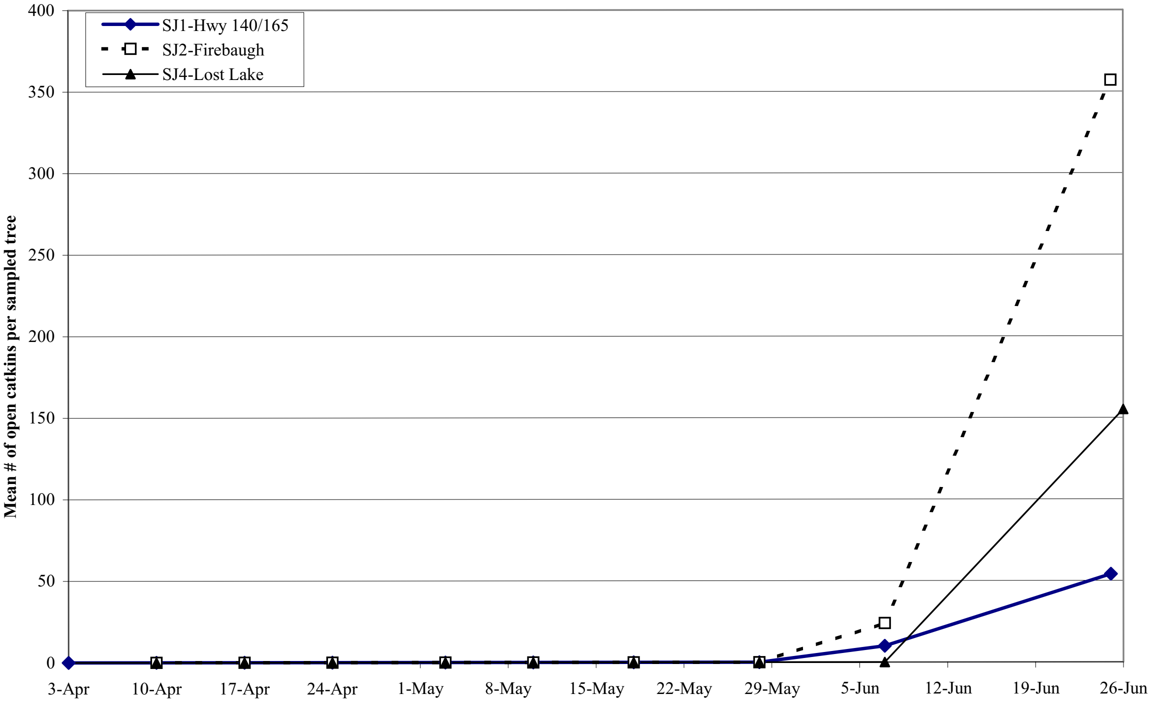


Figure 8-39. Spring and summer 2002 phenology data for narrow-leaf willow at three sites in the San Joaquin River study reach.

Cottonwood and willows dominate early successional vegetation along the San Joaquin River, as they do along many western rivers. These shade-intolerant species produce very small and short-lived seed. As described above, each of these species has a different period of seed dispersal during the spring or early summer. Consequently, successful recruitment of these species, and thus also the establishment of new patches of cottonwood-willow forest, depends upon suitable river flows coinciding with the period of seed dispersal. These flows must deliver seed to appropriate surfaces and maintain a moist substrate while germination and initial stages of establishment occur. The snowmelt hydrograph, which is characterized by a prolonged period of moderate flows in the spring and early summer months, provides suitable conditions for recruitment of these species (Figure 8-40). Even under unimpaired hydrologic conditions, suitable recruitment conditions did not occur every year, but at irregular intervals, depending on the species, the stream, and the water year. Recruitment of cottonwoods typically occurred during wetter water years.

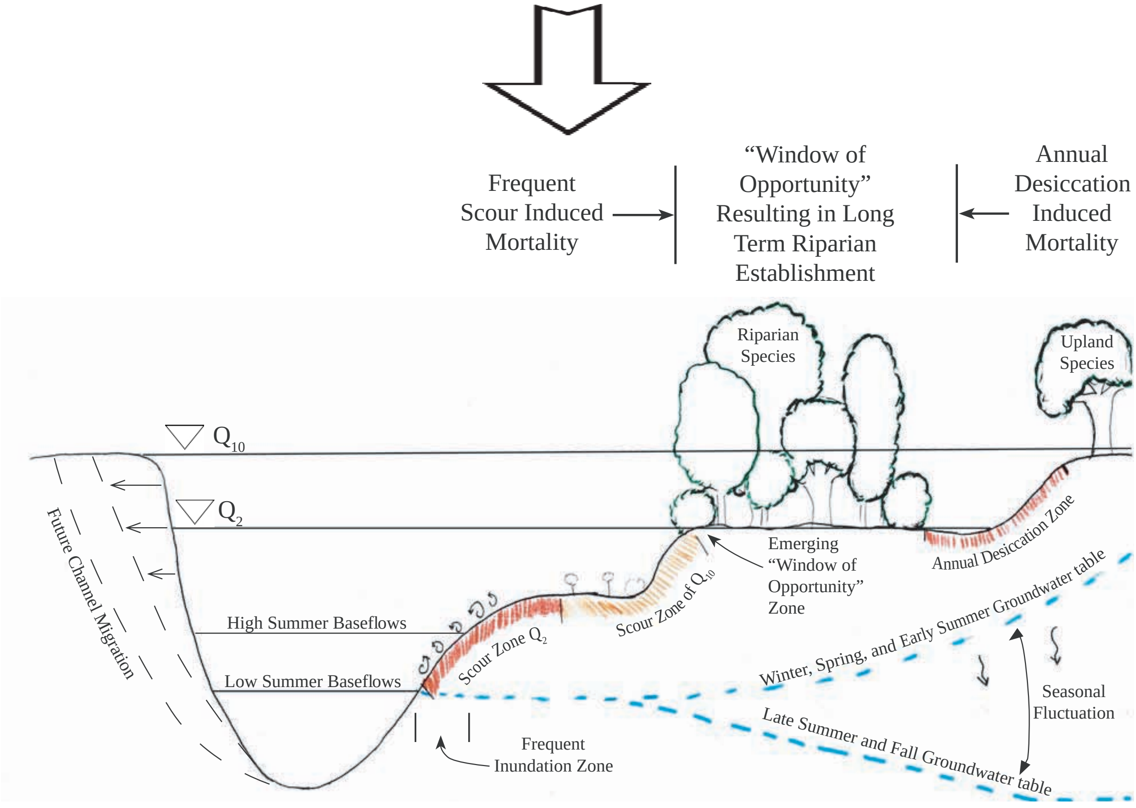
Establishment of cottonwood is a higher restoration priority than establishment of willows because Fremont cottonwood is typically less successful than willows at regenerating under highly regulated conditions. Since the completion of Friant Dam, flow modifications have constrained cottonwood regeneration, and the frequencies of early season flows required for cottonwood seed dispersal and germination have been severely reduced. Therefore, successful cottonwood regeneration along the San Joaquin River has been correspondingly reduced. Willows, in particular narrow-leaf willows, disperse their seeds later in the season and over a longer time period, resulting in greater opportunities for regeneration. Narrow-leaf willow also aggressively propagates from root sprouts, much more so than cottonwood.

INITIATION AND ESTABLISHMENT PROCESS

Early Seeding Plant Box Recruitment Model		Fall Seedling Plant Rafting Recruitment Model	
Species:	Cottonwood and Willows	Species:	Alder, Ash, Sycamore, Valley Oak
Time of Seed Dispersal:	Spring / Summer	Time of Seed Dispersal:	Fall (seeds) / Winter (cones/catkins)

MORTALITY PROCESS

	Scour	Desiccation	Inundation
Process:	Winter storms, snowmelt peaks mobilizing and/or scouring bed surface	Rapid decline of receding limb of snowmelt hydrograph, low summer baseflows after germination	Prolonged receding limb of snowmelt hydrograph, high summer baseflows during seed dispersal / rafting period



- The 2 year flood (Q_2) removes seedlings
- The 10^{+} year flood (Q_{10}) removes small trees / shrubs, maintaining channel width

(ADAPTED FROM KONDOLF AND WILCOCK 1996)

Figure 8-40. Spring seeding woody riparian life history conceptual model (cottonwood and willow species).

Seeds of Fremont cottonwood and willow are commonly dispersed through the air or by floating on water, and large numbers of seeds wash onto shorelines and bars as water levels recede. Prior to and/or during seed dispersal, large flows tend to create seed beds as herbaceous plants are scoured away and/or fine sediment is deposited (Figure 8-40). Following this seed bed preparation, the river stage during the dispersal period must be sufficiently high to distribute seeds to a surface “safe” from scouring by subsequent flows, but low enough to prevent desiccation of seedlings once the river recedes. Mahoney and Rood (1998) suggest that this intermediate bank zone lies between 2 and 7 feet above the late summer, low-flow stage in many western rivers. However, these elevations vary between river systems, and successful recruitment appears to occur at higher elevations along larger rivers.

Asexual reproduction of cottonwoods and willows needs to be considered in the conceptual model as well. Both willows and cottonwoods are well known for their facility to develop roots and resprout from fragments ranging from portions of stems to whole downed trees. This capacity for resprouting is routinely taken advantage of in restoration projects and erosion control projects in which cuttings are directly planted into moist soil (e.g., “pole cuttings”) or bundles of cuttings (“wattling”) are placed in moist soils along banks or shores in a system to control erosion. With both methods, a high percentage of the cuttings “take” and develop into new plants, provided that soil moisture conditions are satisfactory. Recent experience on the Cosumnes River showed significant post-flood establishment of cottonwoods both from seed and from living plant material, such as branch fragments, deposited in the flood. Subsequent monitoring by Tu (Tu 2000; Swenson, et al. in press) showed that cottonwoods established from cuttings grew taller and survived better than cottonwoods grown from seed. There was extensive mortality of cottonwood seedlings from desiccation during the first season of growth. No seedlings of willows were found at this site during the study, however, there was extensive regeneration of willows from branch fragments (Tu 2000). Establishment from plant fragments represents an important complement to establishment from seed after major floods in which living plant material is broken loose and carried downstream and may be the dominant mode of reproduction at some sites in some years.

Roberts (personal communication 2002) has documented extensive clonal patches of cottonwood in Utah that have resulted from suckering or root-sprouting. He hypothesizes that initiation of these patches is stimulated by a major flooding event that exposes and perhaps damages portions of the root system. He believes that this mode of reproduction is especially important in mountain streams systems with narrow-leaved cottonwood, and possibly less important in valley bottoms with Fremont cottonwood. It may also be important on regulated streams in which the flooding regime required to stimulate recruitment from seeds no longer exists.

A moist substrate must be maintained for approximately a week after seed dispersal flows, to allow seeds to germinate (Scott et al. 2000). After germination, river stage must decline gradually so that seedlings root growth can follow the declining capillary fringe and allow the seedling to establish. If river stage declines too quickly following germination, seedlings could die from desiccation (Figure 8-40). To supply seedlings with adequate water as their roots grow toward the water table, the decline in river stage should not exceed 1 to 1.5 inches per day (Mahoney and Rood 1998, Shafroth et al. 1998, Scott et al. 2000). This decline in river stage guideline assumes a soil substrate that is coarse, such as sand or a sandy loam.

Soil properties also influence seedling recruitment. Soil texture greatly affects the water holding capacity of the soil; coarser-textured soils with a higher porosity require a slower decline in river stage because their soil water drains so rapidly. Along the San Joaquin River, textures generally become finer downstream. Saline or alkaline soils also become more common in lower reaches

(U.S. Soil Conservation Service 1962a, 1962b; 1971; 1990; JSA 1998). Although soil textures are primarily sands to sandy loams, many of San Joaquin soils exhibit considerable variability, and within soil mapping units, inclusions of several different soils are common (U.S. Soil Conservation Service 1962a, 1962b; 1971; 1990).

Historically, flows suitable for cottonwood and willow establishment did not occur in most years. In numerous river environments in the western U.S., historical records and tree aging studies indicate that the combination of factors leading to a large-scale recruitment event typically occurs once every 5 to 10 years (Mahoney and Rood 1998, Scott et al. 1997, Stromberg et al. 1991). In an area with little channel movement, Scott et al. (1997) determined that recruitment of mature cottonwoods on the upper Missouri River was most likely on surfaces inundated by floods with a recurrence interval of more than 9 years. Hughes (1994) wrote that long-term cottonwood establishment was associated with even longer flood return intervals (30 to 50 years) along some non-meandering rivers.

Beyond providing suitable conditions for establishment, flows must be sufficient to maintain existing riparian vegetation year-round. Cottonwoods and willows are very susceptible to drought stress. In California, dry summer conditions limit these and other riparian tree species to areas with readily available shallow groundwater. Therefore, flows following seedling establishment must be sufficient to maintain the elevation of the riparian groundwater surface within 10 to 20 feet of the ground surface elevation over the long term (JSA and MEI 2002b).

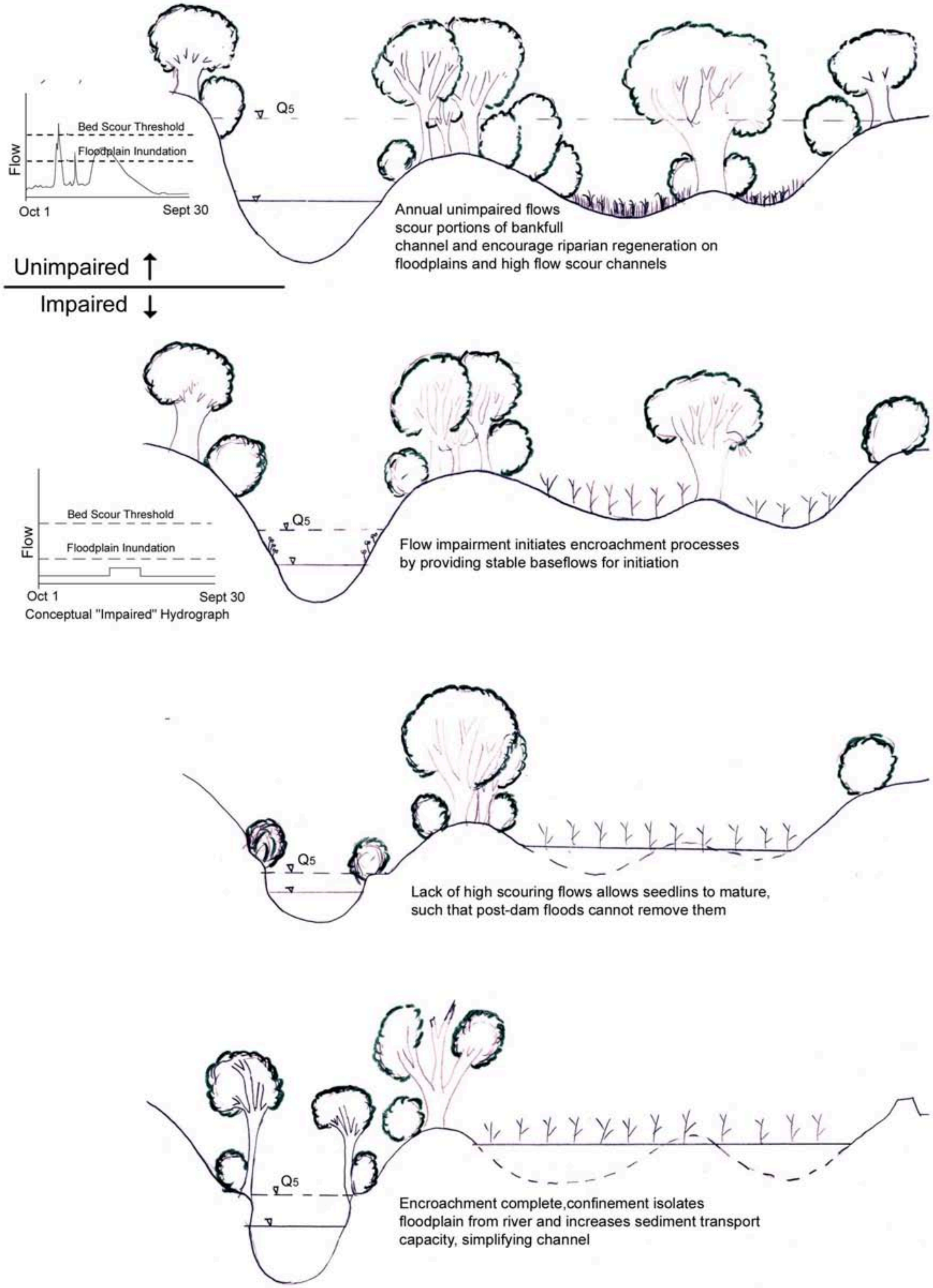
8.7.3. Establishment conceptual model: fall seed dispersal species

The establishment of late season seed dispersers, such as Oregon ash and white alder, has received less attention than the willows and cottonwood. A conceptual model of late season seed dispersers begins with seeds dispersing during the fall and winter months (Figure 8-41). Seeds deposited in water accumulate along debris lines and germinate in the moist substratum during the following spring. Once seeds germinate, the hydrologic factors required for survival to maturity are the same as those needed for spring seeding species (i.e., need to avoid mortality from desiccation, scour, toppling). As surface water levels recede to baseflow conditions, seedlings whose root growth cannot keep pace with the receding ground water levels die. Additional mortality from summer drought may occur later in the season. Surviving seedlings, approximately 6 months old at the end of the summer, are then subject to mortality during flood flows causing bed scour. Thus, for established seedlings to survive their first winter, a relatively dry year after initial establishment, or a chance event such as channel migration away from the seedlings, is generally required for the established seedlings to survive their first winter. As the surviving seedlings continue to grow a deeper and more extensive root system, the risk of drought and scour-induced mortality diminishes.

The establishment of valley oak and western sycamore, which are also fall seed dispersers, may follow a similar pattern. However, because they generally grow on geomorphic surfaces that are either higher and/or farther from the active channel (e.g., terraces), valley oak and sycamore establishment likely depends on a combination of less frequent events. These species may not be as dependent on fluvial processes and surface-water hydrology as the aforementioned species, but more dependent on soil characteristics and rainfall patterns prior to and during the establishment years.

8.7.4. Window of opportunity conceptual models: riparian establishment and maturity

Riparian vegetation establishment and growth to maturity requires a combination of factors to occur (Figure 8-35). Under unimpaired conditions, the San Joaquin River's streamflow hydrology was characterized by pronounced snowmelt runoff and winter storm periods, although the magnitude



Annual unimpaired flows scour portions of bankfull channel and encourage riparian regeneration on floodplains and high flow scour channels

Flow impairment initiates encroachment processes by providing stable baseflows for initiation

Lack of high scouring flows allows seedlins to mature, such that post-dam floods cannot remove them

Encroachment complete,confinement isolates floodplain from river and increases sediment transport capacity, simplifying channel

Figure 8-41. Fall seeding woody riparian life history conceptual model (alder, ash, valley oak, and other species).

varied from year-to-year. Some years provided favorable conditions for initiation of one or more riparian species, but a rapidly declining hydrograph limb after initiation frequently caused death by desiccation. In other years, hydrologic conditions were adequate for establishment, but a moderate scouring flow during the following winter removed established seedlings along the low flow channel margin (Figure 8-42). Larger floods would scour a wider band of established seedlings. Integrating these establishment requirements with scour and desiccation mortality results in a conceptual "window of opportunity", where riparian vegetation may avoid scour and desiccation mortality, thus reaching maturity (Figure 8-42). On the San Joaquin River under historical conditions, this window of opportunity varied between reaches, due to differences in fluvial geomorphology and hydrology (see Figures 8-19 through 8-28). The windows of opportunity in the downstream reaches (Reaches 3 through 5) likely operated only on a narrow elevational band on the natural levees bordering the primary channel margins. Compared to downstream reaches 4 and 5, upstream reaches (Reaches 1, 2, and portions of 3) likely had wider bands of woody riparian vegetation associated with moderate size floodplains, side channels, and scour channels. However, confining bluffs and terraces well above the presumed groundwater elevation would have limited the width of potential riparian zone to less than 1 mile in Reach 1.

The window of opportunity was likely much greater in most reaches during unimpaired conditions, because hydrologic conditions were more favorable to most species, and because floodplain surfaces were less disturbed by agricultural and other human land uses. Also, the unimpaired shallow groundwater surface elevation was likely much closer to potential initiation surfaces (see Chapter 4) than at present conditions; thus, the desiccation zone shown on Figure 8-42 was likely much less pronounced. However, in Reach 1 and Reach 3, riparian forest has actually increased (Tables 8-6, 8-7, and 8-10), likely due to riparian encroachment (see Section 8.7.6 below).

8.7.5. Conceptual relationship between riparian vegetation and channel form and processes.

The abundance and composition of riparian habitats varied among reaches, due to differences in channel processes, channel form, and soils. First, substrate varied greatly in the study area, with cobble, gravel, and sand in Reach 1; sands and silts in Reaches 2 and 3; and silts and clayey soils in Reaches 4 and 5.

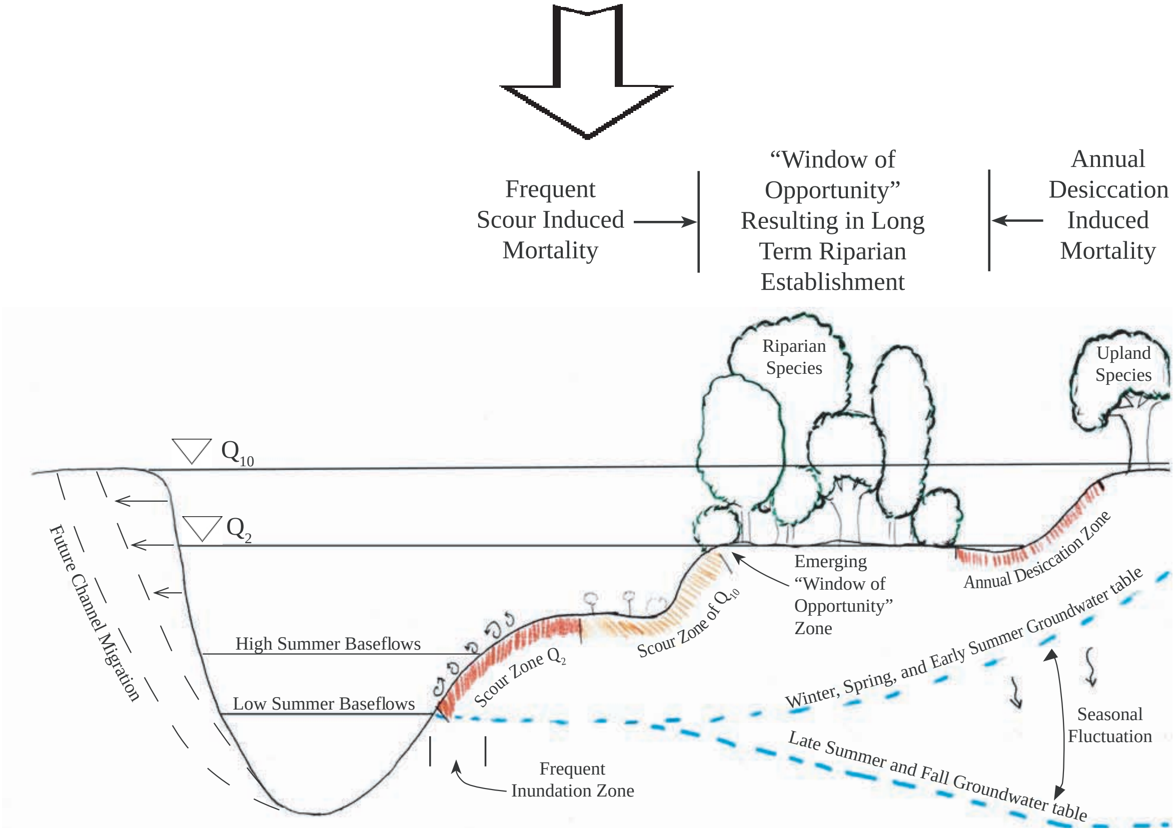
Second, under unimpaired conditions, sediment supply decreased in the downstream direction as it was deposited as bars, floodplains, and riparian levees. Moderate volumes of sediment were delivered from the Sierra Nevada to Reach 1 (primarily cobbles, gravel, and coarse sand). As sediment-laden water flowed down through the reaches, sediment settled out, such that sediment supplies in Reaches 3, 4, and 5 were extremely low. This longitudinal trend in sediment supply determined a longitudinal gradient in channel morphology (Figure 8-43). The supply of cobbles, gravels, and sand in Reach 1 resulted in a semi-braided channel morphology, with sporadic floodplains, many side-channels, many high flow scour channels on floodplains, and minor levees along the primary channels. Downstream, the channel became more sinuous, with oxbow lakes, larger floodplains, and more pronounced levees along the primary channel. Further downstream in Reaches 3, 4, and 5, the combination of low sediment supply and grade control by the Merced River delta caused a meandering channel morphology with multiple channels. The reduced sediment supply prevented extensive floodplains, with levees along the primary channel becoming the primary depositional feature (Figure 8-43). Vast tule marshes existed beyond these levees, extending up to three miles beyond the primary river channel.

INITIATION AND ESTABLISHMENT PROCESS

Early Seeding Plant Box Recruitment Model		Fall Seedling Plant Rafting Recruitment Model	
Species:	Cottonwood and Willows	Species:	Alder, Ash, Sycamore, Valley Oak
Time of Seed Dispersal:	Spring / Summer	Time of Seed Dispersal:	Fall (seeds) / Winter (cones/catkins)

MORTALITY PROCESS

	Scour	Desiccation	Inundation
Process:	Winter storms, snowmelt peaks mobilizing and/or scouring bed surface	Rapid decline of receding limb of snowmelt hydrograph, low summer baseflows after germination	Prolonged receding limb of snowmelt hydrograph, high summer baseflows during seed dispersal / rafting period



- The 2 year flood (Q_2) removes seedlings
- The 10^+ year flood (Q_{10}) removes small trees / shrubs, maintaining channel width

(Adapted from Kondolf and Wilcock 1996)

Figure 8-42. Conceptual model of "window of opportunity" (Kondolf and Wilcock 1996) that results in long-term riparian vegetation morphology in dynamic alluvial rivers.

This longitudinal trend in channel morphology caused longitudinal trends in riparian vegetation species and morphology. Upstream reaches contained a wide variety of species, including numerous willow species, Fremont cottonwood, sycamore, valley oak, and white alder. In downstream reaches, the canopies of these species began to taper off. As discussed in Section 8.6.1, the amount of valley oak and cottonwood present in downstream reaches under unimpaired conditions is uncertain. Figure 8-43 illustrates valley oak and cottonwood on the riparian levees along primary channels; however, we believe willow species (primarily black willow) dominated the canopy. Additionally, white alders ended at the gravel-bed to sand-bed transition (the approximate boundary between Reaches 1 and 2), to be replaced by box elder. White alders prefer coarser substrate (cobbles to coarse sands), while box elder prefers finer substrates found in sand-bedded reaches.

Unimpaired hydrograph components interacted with geomorphic surfaces in ways that influenced riparian initiation and establishment. For example, channel migration caused by moderate and extreme winter floods caused delivery of mature riparian vegetation to the San Joaquin River (large woody debris). Channel migration also assisted in building point bars and floodplains on the insides of migrating bends, thus creating new seedbeds for riparian germination and establishment (Table 8-21). Table 8-21 summarizes these and other important inter-relationships between unimpaired hydrology, geomorphic features, and riparian vegetation.

8.7.6. Conceptual model of riparian encroachment due to flow regulation

The 1914 CDC maps (ACOE 1917) and the 1937 aerial photographs document that under pre-Friant Dam flow and sediment regime, riparian vegetation along the primary channels did not grow along the low water edge, but was separated from the low water edge by exposed gravel or sand bars (see Figures 8-19, 8-21, 8-23, 8-25, and 8-27). This occurred because the window of opportunity for vegetation was controlled by bed scour during winter storms and spring snowmelt.

Once upstream dams and diversions reduced the magnitude of high flows, bed scour decreased, which allowed plant establishment closer and closer to the low flow channel. As seedlings establish and mature along the low flow water surface, the reduced magnitude, duration, and frequency of floods no longer scoured the seedlings, allowing them to mature (Figure 8-44). Flow and sediment regulation has continued such that the contemporary flow regime can no longer remove mature vegetation.

As the riparian vegetation establishes and matures along the low flow channel, fine sediments deposit amongst the vegetation during those infrequent flows that are capable of suspending fine sediments. Over time, this trend of fine sediment deposition along the low flow channel creates new levees called riparian berms. Riparian berms and the process creating them are very common on regulated rivers in the western US, and have been studied by Pelzman (1973), McBain and Trush (1997), and others. This encroachment process sometimes increases riparian cover compared to unimpaired conditions. However, the combination of riparian berms and a reduced flow regime confines the river and disconnects the river from its historic floodplain. The confinement increases shear stress during infrequent moderate flows, resulting in simplified channel morphology and its associated aquatic habitat (McBain and Trush 1997).

8.8. SUMMARY

The changes in riparian and wetland vegetation in the San Joaquin Valley have been dramatic. The following sections summarize the changes in vegetation communities, followed by a summary of vegetation restoration opportunities and constraints. Conceptual models that may help guide future vegetation restoration efforts are not summarized in this section; we refer the reader to Section 8.7 for this information.

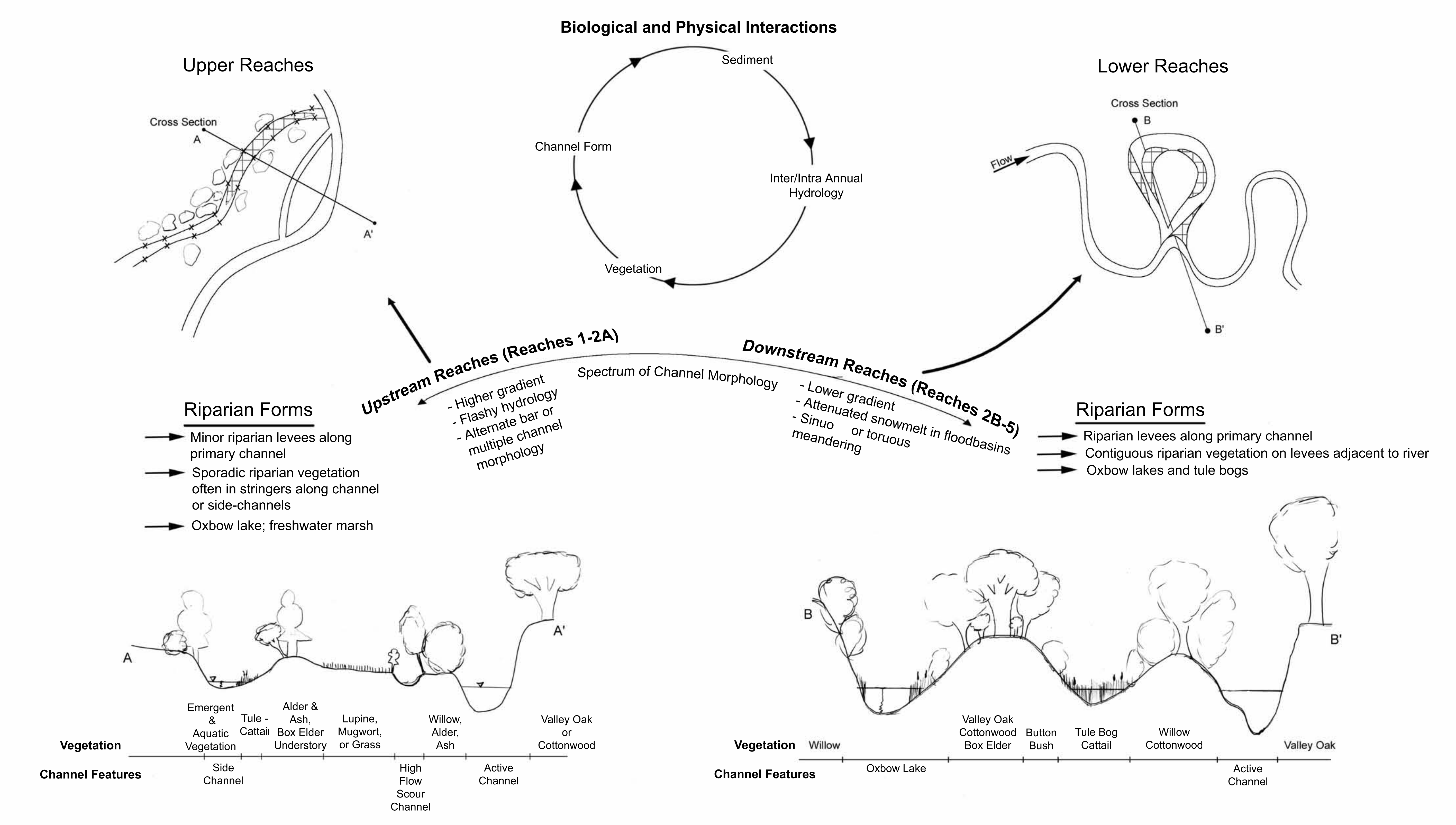


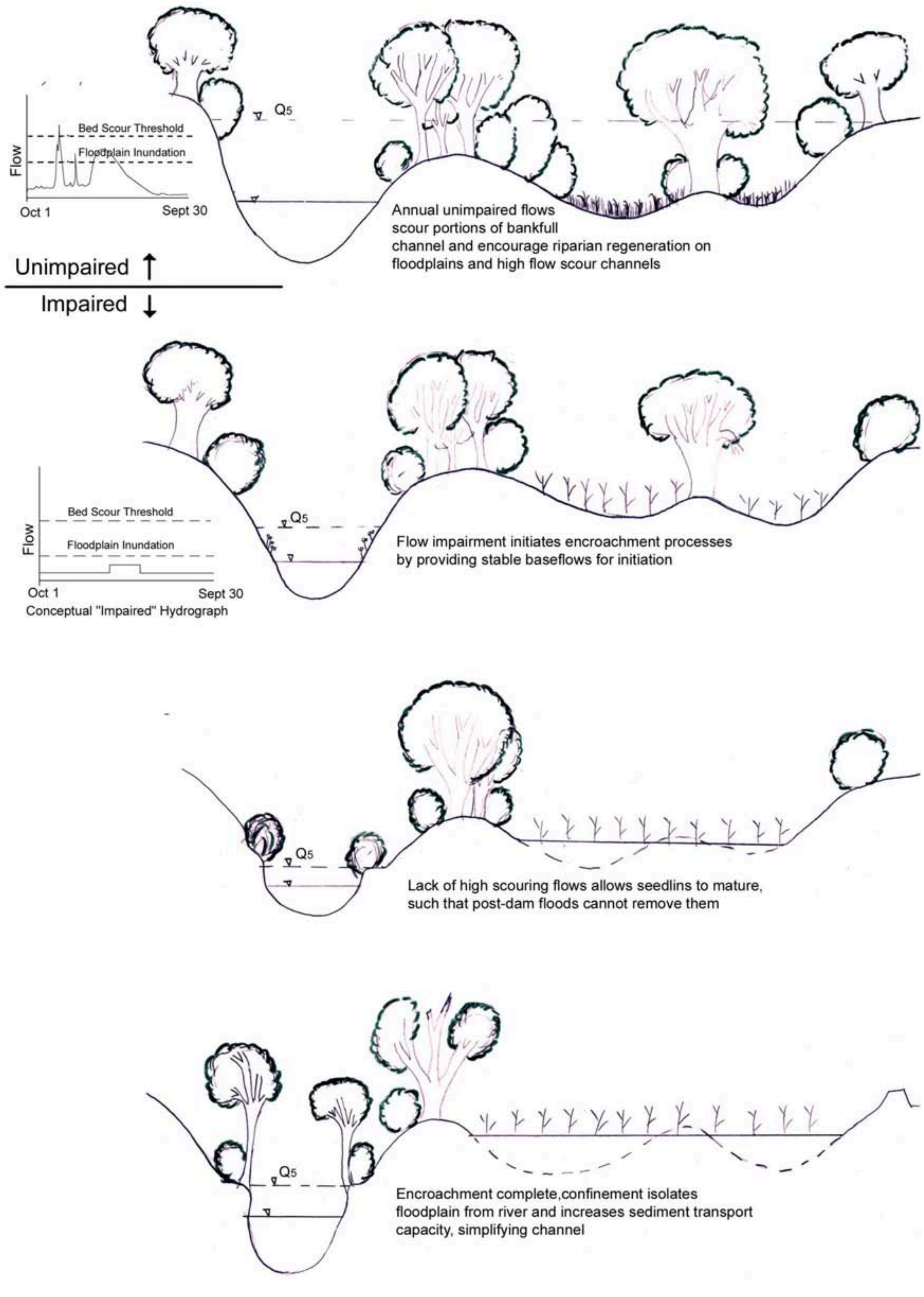
Figure 8-43. Conceptual model of riparian establishment and species composition relationships with channel form and processes in different reaches of the San Joaquin River study area.

Table 8-21. Matrix of interactive effects of individual hydrograph components and fluvial geomorphology on woody riparian vegetation.

Geomorphic Feature ⇨ **Hydrograph Component ⇩**	**Point Bar**	**Floodplains**	**Terraces**	**Outside of Meander bends**	**Oxbows**
Winter/spring baseflow	Promote inundation mortality of seedlings Prevent germination by inundating the active channel margins	Maintains or recharges ground water, promoting late season growth and maximum growth after plants break dormancy	Maintains or recharges shallow groundwater aquifer, facilitating maximum growth in establishing, mature, and senescent vegetation	Maintains or recharges shallow groundwater aquifer	Maintains or recharges shallow groundwater aquifer, sustaining off channel wetlands
Winter Floods	Significantly mobilize channel bed, scouring previous years seedlings	Builds and adds nutrients to floodplain by fine sediment and organics deposition Promotes inundation mortality in physiologically sensitive plant species. Deposits seeds, establishes short term seed bank waiting for suitable germination conditions	Deposits seeds, establishing a short term seed bank for future suitable germination conditions	Channel migrates against the outside of the bend, causing limited mortality to mature and senescent vegetation, introducing large woody debris	Overbank flow can refill sloughs and oxbows, potentially introducing additional plant species
Extreme winter floods **(during normal or above normal water years)**	Move and reorganize in-channel woody debris Realign channel by jumping channel or cutting off sharp meander bends creating wetlands	Scour or topple mature and senescent vegetation, creates new seed beds Mobilize wood jams Fine sediment deposition promotes root suffocation of certain species	Builds and add nutrients to terrace by fine sediment and organics deposition Promotes inundation mortality in physiologically sensitive plant species. Fine sediment deposition promotes root suffocation of certain species	Channel migrates against the outside of the bend, causing limited mortality to mature and senescent vegetation, introducing large woody debris	Oxbow may be recaptured by the channel and the wetland reoccupied by the main channel Fine sediment and organics deposition creates greater topographic variation and increases nutrient availability

Table 8-21, Continued.

Geomorphic Feature ⇨ **Hydrograph Component ⇩**	**Point Bar**	**Floodplains**	**Terraces**	**Outside of Meander bends**	**Oxbows**
Snowmelt peak	Prevent germination by inundation of point bar Scour establishing seedlings Promote inundation related mortality	Encourages seed germination by providing high soil moisture Discourages germination near the active channel by inundation	Encourages seed germination by providing high soil moisture	Channel migrates against the outside of the bend, causing limited mortality to mature and senescent vegetation, introducing large woody debris	Surface and groundwater recharges, creating the specialized environmental conditions required by ephemeral herbaceous plant species.
Snowmelt recession	Prevent plant germination by inundation	Facilitates seed germination over a wide elevation range Drops in river stage causes desiccation mortality to plants that had germinated earlier in the spring	Drops in river stage causes desiccation mortality to plants that had germinated earlier in the spring	Recharges ground water promoting maximum growth after breaking dormancy	Surface and groundwater recharges, creating the specialized environmental conditions required by ephemeral herbaceous plant species. Water table draw down causes desiccation related mortality
Summer baseflows	Plant germination on point bar occurs late in the growing season, reducing initiation and encouraging scour during the next years flow regime Sustains herbaceous perennials along the summer baseflow water surface elevation	Desiccate seedling germinated through the late winter and spring	Low water tables stresses plants, leading to desiccation related mortality Sustains herbaceous perennials surviving along the summer baseflow water surface elevation	Desiccate seedlings that germinated through the late winter and spring	In below normal water years, some portions could dry up, causing widespread mortality to aquatic and emergent vegetation



Annual unimpaired flows scour portions of bankfull channel and encourage riparian regeneration on floodplains and high flow scour channels

Flow impairment initiates encroachment processes by providing stable baseflows for initiation

Lack of high scouring flows allows seedlins to mature, such that post-dam floods cannot remove them

Encroachment complete,confinement isolates floodplain from river and increases sediment transport capacity, simplifying channel

Figure 8-44. Conceptual model of riparian encroachment due to flow and sediment regulation.

8.8.1. Evolution from historical conditions

In the late 1700s and early 1800s, the original Spanish explorers of the San Joaquin Valley found a landscape populated by Native Americans who subsisted by hunting, fishing, and gathering wild plant foods. The Native Americans were known to use fire in upland ecosystems to increase the yield of certain food plants and to improve conditions for game. They fished for salmon and other species in the river, and hunted waterfowl in the marshes. The spread of domestic livestock by the Spanish and Mexican settlers, coupled with the spread of exotic plant species from the Mediterranean, led to dramatic changes in vegetation species composition, especially in the valley's extensive grasslands. By the 1830s, American and French Canadians entered the San Joaquin Valley and hunted beavers, mink, and river otter (Preston 1981), leading to the near eradication of these species. With the onset of the Gold Rush, the tempo, intensity, and magnitude of human effects on the hydrology and vegetation of the San Joaquin River increased rapidly, especially when compared to the background effects of land use by Native American harvesting and periodic burning of vegetation, and later Spanish and Mexican cattle ranching. Thereafter, human population and land uses increased along the river, and its resources were directly and indirectly affected by activities including logging in the riparian zone, agricultural conversion, instream mining, flow and sediment regulation, and irrigation and flood control.

These activities, most of which continue today, resulted in a drastic depletion of wetland habitat, such as tule marshes on the floodplain of the San Joaquin River. Significant reductions of riparian forest habitat also continue along the river and sloughs. Estimates of historic wetland and riparian vegetation (including vast tule marshes) are not quantified specifically for the study area, but estimates of changes for the entire San Joaquin Valley could be as high as a 95% reduction (TBI 1998). The comparison between 1937 and 1993 (JSA 1998b) showed a slight increase in riparian forest (potentially from riparian encroachment), and an approximate 50% decrease in riparian scrub (Figure 8-9). The changes in certain habitat types shown on Figure 8-9, particularly wetland, open water, and riparian scrub, is likely underestimated because the width used to perform the inventory (1,000 ft beyond escarpment or levee) is probably much narrower than the pre-1850 extent of the floodway.

Current activities affecting the river include continued agricultural development (such as drainage, irrigation, and flood control projects), in-channel aggregate mining, accelerating urban development, and the initiation of habitat restoration activities. The greatest historical change in habitat between 1937 and 1957 occurred when Friant Dam, Friant-Madera Canal, Friant-Kern Canal, and the Delta-Mendota Canal were completed, dramatically affecting the hydrology of the San Joaquin River. The reduced flow regimes caused Reaches 2A, 2B, and 4A to be dry most of the year, and caused the upper portion of Reach 4B to now be dry in all years. In these reaches, areas of wetland, riparian scrub, and riparian forest declined dramatically between 1937 and 1957. Releases from Friant Dam maintained continuous flow year-round in Reach 1, and releases of Delta water from Mendota Dam provide continuous flow in Reach 3. Riparian vegetation in these reaches encroached onto the river's sand and gravel bars. Operation of Friant Dam reduced the frequency of moderate and high flows, which historically scoured the channel and deposited new sand and gravel bars, which would restart the successional cycle of riparian vegetation. Without these scouring flows, vegetation in Reaches 1A, 1B, and 3 developed from sand and gravel bar (riverwash) vegetation to riparian scrub and then to riparian forest. Agricultural return water in Reaches 4B and 5 maintained some riparian vegetation in these areas, although water quality is reduced and riparian forest species coverage and diversity is limited.

Conversion of native vegetation types to agriculture, aggregate mining, and urban development has also strongly affected the San Joaquin River's wetlands and riparian habitat. Agricultural lands reached their maximum extent in 1957 for Reaches 1A, 1B, 3, and 5; 1978 for Reach 2A; and 1993 in Reaches 2B, 4A, and 4B. Urban and aggregate extraction lands are now at their maximum historical extent, and will likely continue to increase in the future. The most dramatic increase in urban development occurs in Reaches 1A (Fresno); smaller increases have occurred in Reach 3 (Firebaugh). Most aggregate mining occurred in Reaches 1A and 1B, with some smaller scale sand extraction in Reach 2A. Some of the aggregate extraction has converted riparian habitat to deep open water ponds. Further expansion of aggregate mining is limited by resource availability and several operations are in the process of closing down extraction sites as they are mined-out.

The change in hydrologic and geomorphic processes from unimpaired conditions creates some opportunities and constraints to future riparian and wetland restoration efforts. First, prolonged inundation and limited sediment supply for floodplain development under historical conditions in Reach 4 and Reach 5, and to a lesser degree Reach 3, created a condition of extensive low-lying tule marshes, and riparian vegetation (predominately black willow) was confined to narrow (few hundred feet wide) sediment berms that were higher elevation and drained. The dramatic change in topography and inundation patterns in this reach would make restoration of functional tule marshes more difficult to accomplish, but because future hydrology will likely not have prolonged periods of inundation (months), there is opportunity to restore larger-scale riparian (cottonwood-willow) forests that did not historically occur in those reaches. An additional change from historical conditions has been the increase in white alder and box elder in Reach 1 as part of the riparian encroachment process, and the reduction in dominance of cottonwood. Cottonwood regeneration and survival is closely tied to the historical disturbance regime (channel changes resulting from flood events) and the snowmelt hydrograph, whereas white alder and box elder are more susceptible to scour mortality (they are shallow rooting plants). The reduction in high flow regime has reduced cottonwood recruitment and extent, and allowed white alder and box elder to become the dominant canopy species in Reach 1 as part of the riparian encroachment band along the low flow channel. A significant challenge to future restoration in Reach 1 will be to reduce the encroachment of white alder and box elder, and encourage cottonwood recruitment on floodplains, side channels, and high flow scour channels.

As is the case with most Central Valley rivers, the spread of perennial invasive exotic species is affecting substantial areas of riparian habitat along the river, especially in the understory. These exotic species can spread extensively without additional human intervention to remove them. These invasive exotic species reduce the biological diversity in the riparian zone. While a native species, narrow-leaf willow also presents a problem to regulated rivers due to its invasive nature. Removal of the disturbance regime by flow and sediment regulation, combined with reduced variability of flows, encourages narrow-leaf willow to encroach along the low flow channel and cause riparian encroachment. This riparian encroachment process can also reduce plant diversity in the riparian zone.

Recently developed conceptual models suggest conditions necessary to establish key riparian tree species. More effort is spent on strategies applicable to willows and cottonwoods, which release their short-lived seeds in spring or early summer, and less effort on species such as white alder, ash, oak, and sycamore that release their seeds during the late summer or fall. These conceptual models are based on historic flood and flow conditions, and we acknowledge that these historic conditions cannot be re-created today. However, using these conceptual models, key conditions can be simulated and/or recreated by managing flow releases, managing sediment supply, reconfiguring flood plains, and artificial propagation of riparian vegetation.

8.8.2. Opportunities and Constraints

The San Joaquin River presents many opportunities for restoring native terrestrial habitat, but it also introduces important constraints. Opportunities can be categorized as to whether they primarily involve hydrologic, geomorphic, or other management approaches (such as vegetation manipulation). Although these approaches are discussed separately, in practice a combination of approaches would normally be employed for successful restoration.

8.8.2.1. Opportunities

Improving seasonal instream flows that encourage riparian initiation and establishment presents a significant hydrologic opportunity to improve vegetation conditions along the study reach. Flow releases to initiate natural regeneration of riparian vegetation would be needed with approximately a 10-yr recurrence (Scott, personal communication 2000); however, the yearly flow regime must be sufficient to maintain summer groundwater tables shallow enough to support the survival of established plants (i.e., no more than about 10 feet below the ground surface). Flood flows would also help develop new seed beds by fine sediment deposition and/or scouring herbaceous plants. Flood flows would also assist scouring out plants that are initiating too close to the low flow channel (thus, discouraging riparian encroachment). Establishment flows would be released as peak flows during the seed dispersal period of desirable plant species, then the flows would need to decline slowly to allow seedling establishment. This approach has been applied more to spring seeding species (willow and cottonwood) rather than fall seeding species, but once seed germination has occurred, the ramp down guidelines should be applicable for all species. Under regulated conditions, peak flows during the dispersal periods of riparian tree species are abruptly ended to conserve water, and the ramp-down rate is too steep to prevent desiccation of new seedlings. Gradually ramping down flows allows seedling roots to keep up with the capillary fringe of a declining water table. The summer low flow groundwater table needs to be near the ground surface to allow survival of riparian plants.

Geomorphic opportunities to improve riparian restoration are those that modify the shape of the channel and floodplain to benefit native vegetation regeneration. Geomorphic approaches include mechanically lowering floodplain surfaces, removing bank armoring to re-establish later channel migration and floodplain creation, and constructing microtopography on floodplain surfaces that are closer to the groundwater table. Measures that enlarge the active floodplain, by setting back or breaching levees, also fit in this category. Restoring the river’s access to abandoned side channels, oxbows, or backwaters is another approach. Dredging the entrance to such abandoned features, or connecting such features by another means to another water source, may be required.

Vegetation management opportunities include removing existing exotic and/or invasive vegetation to artificially reset the succession cycle, planting native vegetation, and improving grazing management. Artificial plantings could use a variety of planting methods, including container stock, pole cuttings, seeds, and other horticultural methods. Irrigation, using either a drip system or flooding, is usually involved. Modification of the grazing regime may require modifying seasonal grazing frequency and intensity of cattle or other livestock in riparian areas. Managed livestock grazing could potentially be used to reduce undesirable plant species.

Additional riparian vegetation opportunities include:

1. The modest flood control storage in upstream dams still allows flood flows to occur downstream of Friant Dam (e.g., 1995, 1997, 1998) and from the Kings River via Fresno Slough. These floods could be reasonably re-operated (primarily the receding limb of the hydrograph) to better enable natural riparian regeneration to occur during those high flow years.

2. While the land-base to conduct riparian and wetland restoration is small, key areas do exist. There are many opportunities in Reach 1 to coordinate with the San Joaquin River Parkway and Conservation Trust to improve riparian vegetation on their lands, and the large number of aggregate pits provides substantial opportunities for revising reclamation plans and improving wetland conditions. Much of Reach 4B and 5 is owned by the State of California and the US Fish and Wildlife Service, and is relatively undisturbed wetland and floodplain habitat. However, project levees presently isolate many of these areas from the river.
3. Low-lying lands subject to frequent flooding are often of marginal agricultural value, but of great value as potential riparian restoration areas. A variety of mechanisms exist to make it financially feasible for a willing landowner to retire the land from cultivation and allow restoration activities to take place. Land management agreements, tax incentives, conservation easements, and mitigation banks for wetlands or endangered and threatened species are examples of mechanisms that may have economic benefit to the landowner. Fee title and conservation easement purchases from willing sellers has been an approach applied to tributaries of the lower San Joaquin River that may be mutually beneficial to both restoration efforts and the landowner and represent an opportunity in the study area. Following are two examples:
    - Certain reaches have low-lying agricultural fields with a shallow groundwater table protected by levees or dikes (e.g., Reach 2B and Reach 4). These shallow groundwater conditions would provide an opportunity for riparian restoration efforts in areas outside the current levees or dikes, such that they could be reconnected to the river and revegetated if the levees or dikes were set back further with the agreement of the landowner.
    - Certain reaches have low-lying agricultural fields protected by small berms (e.g., Reach 3). The vulnerability of these surfaces to inundation and the low cost required to re-connect them to the river (removing or breaching small berms) results in these types of areas being a favorable opportunity for riparian restoration with the agreement of the landowner.
4. Examples of improved grazing management in the western US has shown that continued livestock grazing can co-exist with riparian restoration if done properly. This may include adjustments in the season or duration of grazing, changes in stocking rates, or exclusion of cattle from riparian areas, depending upon management objectives. For example, livestock grazing could to be managed to avoid adverse impacts to seedling establishment or to reduce exotic grasses and enhance tree and shrub establishment. This approach depends upon the cooperation of the landowners and a planning assistance and financial incentives are available from a variety of sources as indicated above.
5. Increased releases of San Joaquin River water from Friant Dam to the Merced River confluence would improve water quality through all reaches, and reduce the salinity concentrations in Reaches 3 through 5. The degree if water quality improvement depends on a number of factors, and is not evaluated in this report.
6. Irrigation in downstream reaches (Reaches 3 through 5) is primarily provided by surface water supplied by the Delta Mendota Canal rather than by groundwater pumping, thus the elevation of the shallow groundwater table in downstream reaches on the west side of the San Joaquin Valley is near the channel bed elevation of the San Joaquin River. This is in contrast with Reach 1B and Reach 2, where the shallow groundwater table can be from 0 to 15 feet deep (or deeper, see Chapter 4). The shallow groundwater table in these downstream

reaches provides an opportunity for riparian restoration because riparian vegetation initiated further away from the river can utilize the shallow groundwater table for establishment and maturity. The depleted groundwater table in Reach 2 is a constraint for riparian establishment and maintenance, as instream flows will need to assume a greater role in vegetative success by directly providing water to the plants, or indirectly via subsurface recharge of the shallow groundwater table.

7. If perennial flows were restored to all reaches, the San Joaquin River flows would tend to maintain the shallow groundwater table within the floodway (see Section 8.6.4). This increase in the shallow groundwater table elevation may be enough that artificial riparian vegetation propagation could focus on using willow and cottonwood cuttings, thus avoiding the need for container stock and irrigation. This approach could drastically reduce the cost and infrastructure needed for artificial propagation.
8. The infrastructure on the San Joaquin River may also provide some restoration opportunities for controlling how flows are routed through the reaches. Chowchilla Bifurcation Structure, Mendota Pool, Sack Dam, Sand Slough Control Structure, Reach 4B headgates, and Mariposa Bifurcation Structure could be used to better control flow magnitude in certain reaches to improve riparian regeneration.
9. As discussed in Chapter 10, opportunities for riparian restoration may be greater on adjacent lands that are prone to flooding, and those lands that typically grow annual or row crops. The value of the land, as well as the cost to restore, is typically lower than lands with more infrastructure and investment (e.g., vineyards and orchards).

8.8.2.2. Constraints

The primary constraint to vegetation restoration is the reduced flow and sediment regime induced by cumulative dams and diversions. Another primary constraint is the lack of a land base upon which riparian vegetation restoration could occur. Additional constraints to vegetation restoration along the San Joaquin River are many, and may include invasive species effects, reduced flood control capacity due to increased hydraulic roughness from increased vegetation, conflicting land uses or infrastructure, regulatory obstacles, insufficient funding, and institutional and political obstacles. The following constraints may need to be addressed to restore riparian vegetation and wetlands. Although numerous, many of the following constraints can be avoided by implementing appropriate techniques designed to avoid or reduce these constraints.

1. The depleted groundwater table in Reach 2 constrains natural riparian regeneration because the depth to the summer groundwater table under existing conditions can exceed 15 feet, which is greater than the rooting depth of many woody riparian species.
2. The reduction in the groundwater table elevation in all reaches, combined with the loss of artesian springs and reduction of flows from the Kings River, has reduced the ability of the San Joaquin River to support seasonal and perennial wetlands in Reaches 3-5.
3. Invasive native and exotic species may benefit from disturbance caused by restoration actions, and may out-compete desired native species.
4. Water quality limitations, especially high salinity, may constrain restoration on some sites in Reaches 4 and 5. In the absence of improved water quality, restoration planning would need to emphasize native salt tolerant species. Even if water quality were improved by increased Friant Dam releases, residual salts in the soils and channel sediments may continue to impair riparian regeneration for some time.

5. Herbivore browsing may cause plant mortality, especially those plants that are installed in a restoration project. In Reach 1, the dramatic increase in aggregate pits has likely increased beaver populations to the point where they may have a significant impact on revegetation efforts. Additionally, creating riparian floodway corridors may increase deer browsing. Livestock grazing would be another possible constraint.
6. Increasing vegetation in the channel or floodplain may increase flood stage by increasing hydraulic roughness. Agencies responsible for maintaining conveyance within the flood control system are currently required to remove or spray vegetation that may reduce conveyance. Increasing floodway conveyance with setback levees and/or modification of the channel geometry would be a means to offset hydraulic conveyance impacts of additional riparian vegetation, and reduce the need for spraying to maintain hydraulic capacity.
7. Upstream dams trap all size classes of sediment, including the finer sands and silts that create and maintain floodplains. The remaining fine sediment supply downstream of Friant Dam is derived from the sandy loam soils along the San Joaquin River channel margins with contributions from tributaries such as Little Dry Creek and Cottonwood Creek, and the amount, frequency, and duration of silt deposition on floodplains is greatly reduced, making limited silt supply a constraint to floodplain and riparian restoration.
8. As discussed in Chapter 10, riparian restoration may conflict with existing land use. Because riparian restoration efforts would have a very small land base under existing conditions, significant improvement in vegetation along the study reach will require cooperative agreements with private landowners.
9. As discussed in Chapter 11, riparian restoration efforts may be considered by the local communities as incompatible with existing land use and the local economy. While this perception may be correct under certain circumstances, much progress has been made on the lower portions of the San Joaquin River tributaries in developing means to increase riparian vegetation that are mutually beneficial to the river corridor and local landowners.
10. Artificial riparian revegetation can be costly (e.g., up to $16,000/acre); wetland restoration is even more so. Funding commensurate with the scale of desired restoration needs to be secured for the entire duration of the restoration project. Additionally, due to the scale of riparian restoration needs within the study area, methods of reducing the unit-cost of riparian and wetland restoration need to be developed.
11. Fires periodically occur in the existing riparian areas, and often burn both younger maturing plants, as well as older mature and senescent plants. These fires are caused by a combination of factors, and may represent a future constraint to riparian restoration.

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CHAPTER 9. SPECIAL-STATUS PLANTS AND WILDLIFE

9.1. INTRODUCTION

The Mutual Goals Statement (see Chapter 1) directs the scope of the San Joaquin River Restoration Study to consider restoration of the entire ecosystem, including plants, wildlife, and other native fish species as well as anadromous salmonids. The purpose of this chapter is to describe the life histories and habitat requirements of special-status plants and wildlife along the San Joaquin River corridor, with the exception of special-status fish species, which are discussed in Chapter 7.

This chapter also provides an overview of the special-status plant and wildlife species that could be affected by future restoration efforts. The degradation and elimination of natural habitat in the floodplain of the San Joaquin River and adjacent upland areas has contributed to a decline in population size for many fish, wildlife, and plant species. In particular, species that depend on wetlands and riparian habitats have declined, and several species that depend on grassland have also declined (Moore et al. 1990, Williams et al. 1997). State and federal resource agencies have listed a number of species as threatened or endangered, while other species are of concern and may become listed in the future. These species are of significance to the Restoration Study because restoration actions should benefit many of these species and result in an increase of their habitat. Restoration efforts could potentially contribute to the recovery of some of these species, or could reduce the necessity of future listing of species of concern. However, restoration actions could potentially also adversely affect listed species. Some potentially adverse impacts will be short-lived, such as those associated with physical modification of the river channel, while others could persist as a result of long-term changes to habitat.

Several species that historically occurred within the San Joaquin River basin that are now extirpated from the study area are included in this report because restoration of the historical habitat of these species along the San Joaquin River could potentially contribute to their reintroduction to the area. Examples include the California red-legged frog, a federally threatened species that occurs in wetlands and aquatic habitats; the least Bell’s vireo, a state- and federally endangered bird that breeds in riparian habitats; and the fulvous whistling duck, a federal candidate for listing, which used to breed in the San Joaquin Valley.

Describing the life histories and habitat requirements of these species is an important step in developing the Restoration Study. This understanding will allow the Restoration Study to target actions that would benefit numerous native plant and animal species. For example, a healthy floodplain with riparian vegetation in Reach 5 may improve habitat connectivity and provide migratory corridors between areas of the San Joaquin National Wildlife Refuge. Restoring specific hydrograph components and associated physical processes, such as the historical spring snowmelt flood, may benefit many other native fish species (in addition to salmonids).

9.2. OBJECTIVES

The objectives of this chapter are to:

- identify threatened and endangered species and other species of concern that may be adversely impacted or benefited by a restoration program on the San Joaquin River;
- summarize life history and habitat requirements of each special-status species as well as its historical and existing abundance and distribution; and
- provide a brief statement how restoration activities may affect these species of concern.

The number of species that are threatened, endangered, sensitive, and/or extirpated from the study area is substantial, and providing detailed descriptions of each species and speculating on anticipated responses of each species to the myriad of potential restoration actions is beyond the scope of this chapter. The following sections provide an introductory description of the species and their distribution. For conciseness, the anticipated responses of each species to potential restoration actions is illustrated in three matrices in Section 9.6.

9.3. STUDY AREA

The study area encompasses the San Joaquin River from Friant Dam to the confluence with the Merced River, and includes the riparian corridor and adjacent upland habitats. The width of the study area would vary based on this definition, ranging from as low as 1,000 feet in Reach 1 to several miles in downstream reaches. Thus, the study area includes the area that will be directly affected by the Restoration Study, as well as upland habitats that also may be used by species associated with the San Joaquin River corridor during part of their life cycle or for some life-history needs.

9.4. DATA SOURCES

Information was gathered and reviewed to develop lists of and describe special-status plant and wildlife species that are known to exist, could potentially exist, or historically existed in the study area. Several data sources were reviewed to develop these lists, including records from CDFG's California Natural Diversity Data Base (CNDDB 2002), published and unpublished literature, and reconnaissance-level field surveys conducted for this and other projects along the San Joaquin River (e.g., Riparian Habitat Restoration Program, Rank Island channel repair, Milburn Unit restoration project). The following USGS quadrangles encompass the study area (within about 2 miles of the San Joaquin River and bypass systems) and were searched in the CNDDB: Biola, Bliss Ranch, Broadview Farms, Delta Ranch, Firebaugh, Firebaugh Northeast, Fresno North, Friant, Gravelly Ford, Gregg, Gustine, Herndon, Ingomar, Jamesan, Lanes Bridge, Little Table Mountain, Madera, Mendota Dam, Millerton Lake West, Newman, Ocalis, Poso Farm, San Luis Ranch, Sandy Mush, Santa Rita Bridge, Stevinson, Tranquility, and Turner Ranch. These quadrangles provided adequate coverage of the study area.

Focused field surveys and habitat assessments for special-status species have not been conducted in the project area for the specific purpose of this chapter, although pilot studies have collected useful information (Newman et al. 2001; PRBO unpublished data 2002; Wolfe and Assoc. unpublished data 2000 and 2001; and Kucera et al. 2001 for Reach 2). This chapter is based on information available from the existing data sources described above. Comprehensive reach-specific data for most species that could occur along or adjacent to the San Joaquin River are lacking. Previous analyses of special-status species occurrences in the study area have been conducted in the West Bear Creek area (JSA et al. 2000, JSA 2001a), which includes portions of Reaches 5 and 4B, and Reach 2A (JSA 2001b). Therefore, the data available for these reaches is generally more comprehensive than for other locations in the project area. The West Bear Creek area includes all or portions of the West Bear Creek (formerly the West Gallo Property), San Luis, Kesterson, Frietas, and Arena Plains units of the San Luis National Wildlife Refuge (NWR); and Great Valley Grasslands State Park. Available information on species occurrence in the vicinity of the San Joaquin River is summarized below for each species, but it should be noted that species could occur in areas where they have not been documented, as long as suitable habitat is available.

9.5. SPECIAL-STATUS SPECIES

For the purpose of this document, special-status species are plants and animals that are legally protected under the federal Endangered Species Act (ESA), California Endangered Species Act (CESA) or other state regulations, and species that are considered sufficiently rare by the scientific community to warrant conservation concern.

Special-status plants and animals are species in the following categories:

- species listed, proposed for listing, or candidates for possible future listing as threatened or endangered under the federal ESA (50 CFR 17.12 [listed plants], 50 CFR 17.11 [listed animals], various notices in the Federal Register [proposed species], and 64 FR 57534, October 25, 1999 [candidate species]);
- species listed or proposed for listing by the State of California as threatened or endangered under the CESA (14 CCR 670.5);
- plants designated as rare under the California Native Plant Protection act (California Fish and Game Code, Section 1900 et seq.);
- plants considered by the California Native Plant Society (CNPS) to be “rare, threatened, or endangered in California” (Lists 1B and 2 in CNPS 2001);
- animals considered species of special concern by California Department of Fish and Game (CDFG) (Remsen 1978 [birds], Williams 1986 [mammals], and Jennings and Hayes 1994 [amphibians and reptiles]);
- animals fully protected in California (California Fish and Game Code, Section 3511 [birds], 4700 [mammals], and 5050 [amphibians and reptiles]);
- birds of prey, their nests, and eggs (California Fish and Game Code, Section 3503.5);
- bald and golden eagles (Bald Eagle Protection Act of 1940); and
- birds designated as sensitive species under California Forest Practice Rules by the California Department of Forestry and Fire Protection (14 CCR 898.2(d)).

9.5.1. Federally-Listed and State-Listed Plants

This section describes the special-status plant species that occur or have the potential to occur in the project area. A total of 28 special-status plant species were identified as having the potential to occur in the project area (Table 9-1). Ten of these 28 species have been reported to occur in the project area. The remainder of these 28 species is not known to occur in the project area, but they occur, or occurred historically, in the vicinity of the project area, and the project area contains potential habitat for these species. The potential for occurrence of these species was classified as low, moderate, or high (Table 9-1). This classification was based primarily on the availability of suitable habitat in the project area, and the proximity of the project area to documented occurrences of the species.

The legal status, California distribution, habitat requirements, and potential for occurrence of special-status plants are summarized in Table 9-1. Each of the species is briefly described below.

9.5.1.1. Succulent (Fleshy) Owl’s Clover (*Castilleja campestris* ssp. *succulenta*)

Succulent owl’s-clover is listed as threatened by the US Fish and Wildlife Service (USFWS) and as endangered by the State of California (CDFG 2000). The California Native Plant Society has placed it on List 1B (CNPS 2001). Its discontinuous distribution extends along the base of the Sierra Nevada

Table 9-1. Special-status plant species with potential to occur in the study area.

Common and Scientific Names	Status[1] Federal/State/CNPS	California Distribution	Habitat Requirements	Occurrence in Study Area[2]
Alkali milk-vetch *Astragalus tener* var. *tener*	--/--/1B	Central Valley and eastern San Francisco Bay Area	Alkaline wetlands, vernal pools, and adobe clay valley and foothill grasslands and playas	Documented in study area
Heartscale *Atriplex cordulata*	--/--/1B	West edge of the Central Valley	Alkali grasslands, alkali meadows, alkali scrub	Documented in study area
Crownscale *Atriplex coronata* var. *coronata*	--/--/1B	Central Valley, eastern south inner coast range	Alkaline chenopod scrub, valley and foothill grassland, and vernal pools	Moderate potential
Brittlescale *Atriplex depressa*	--/--/1B	Central Valley and Tulare Basin	Chenopod scrub, playas, valley and foothill grassland on alkaline or clay soils	Documented in study area
San Joaquin spearscale *Atriplex joaquiniana*	--/--/1B	West edge of Central Valley from Glenn County to Tulare County	Alkali meadows, alkali grasslands, saltbush scrub	Moderate potential
Lesser saltscale *Atriplex minuscula*	--/--/1B	Southern San Joaquin Valley	Adjacent to alkali sinks and alkaline vernal pools on sandy soils	Documented in study area
Vernal pool smallscale *Atriplex persistens*	--/--/1B	Scattered locations throughout the Central Valley from Glenn, Merced, Stanislaus, and Tulare counties	Vernal pools on alkaline soils	Documented in study area
Subtle orache *Atriplex subtilis*	--/--/1B	Known from fewer than 20 occurrences including locations in Fresno, King, Madera, and Merced counties	Valley and foothill grassland	High potential; documented in several USGS quads adjacent to study area
Lost Hills crownscale *Atriplex vallicola*	--/--/1B	Lost Hills, vicinity of McKittrick in Kern County, scattered locations in Fresno and Merced counties	Alkali sink, alkaline vernal pool, saltbush scrub	Low potential
Succulent (Fleshy) owl's-clover *Castilleja campestris* ssp. *succulenta*	T/CE/1B	Southern Sierra Nevada foothills, eastern San Joaquin Valley, Fresno, Madera, Merced, Mariposa, San Joaquin, and Stanislaus counties	Vernal pools	Moderate potential; occurs near Friant
Hoover's spurge *Chamaesyce hooveri*	T/--/1B	Central Valley from Butte County to Tulare County	Vernal pools	Moderate potential
Hispid bird's-beak *Cordylanthus mollis* ssp. *hispidus*	--/--/1B	Scattered locations in San Joaquin Valley from Solano County to Kern County	Meadows, grasslands, and playas on alkaline soils	Documented in study area

Table 9-1, Cont'd

	Status[1]			
Common and Scientific Names	**Federal/State/CNPS**	**California Distribution**	**Habitat Requirements**	**Occurrence in Study Area[2]**
Palmate-bracted bird's-beak *Cordylanthus palmatus*	E/CE/1B	Glenn, Colusa, Yolo, Alameda, Madera, and Fresno counties	Chenopod scrub, alkaline grasslands	Moderate potential; known to occur near the study area at the Alkali Sink Ecological Reserve and Mendota Wildlife Management Area
Recurved larkspur *Delphinium recurvatum*	--/--/1B	San Joaquin Valley and central valley of the South Coast Ranges, Contra Costa County to Kern County	Subalkaline soils in annual grassland, saltbush scrub, cismontane woodland, and vernal pools	Moderate potential
Four-angled spikerush *Eleocharis quadrangulata*	--/--/2	Central Valley	Freshwater marshes, lake and pond margins	Moderate potential; known to occur near study area
Round-leaved filaree *Erodium macrophyllum*	--/--/2	Lassen to San Diego counties	Cismontane woodland, clay soils in valley and foothill grassland	Low potential
Delta button-celery *Eryngium racemosum*	--/CE/1B	San Joaquin River delta and floodplains	Seasonally-inundated depressions along floodplains	Documented in study area
Spiny-sepaled button celery *Eryngium spinosepalum*	--/--/1B	Southern and eastern San Joaquin Valley	Valley and foothill grassland, and vernal pools	Moderate potential; known to occur near study area
Munz's tidy-tips *Layia munzii*	--/--/1B	Western San Joaquin Valley and interior foothills valleys from Fresno County to San Luis Obispo County	Chenopod scrub, grasslands, flats and hillsides in alkaline clay soils	Low potential
Madera linanthus *Linanthus serrulatus*	--/--/1B	Fresno, Kern, Madera, Mariposa, and Tulare counties	Cismontane woodland, lower montane coniferous forest	Low potential
Prostrate navarretia *Navarretia prostrata*	--/--/1B	Merced County	Valley and foothill grassland on alkaline soils; vernal pools and other mesic habitats	Moderate potential
Colusa grass *Neostapfia colusana*	T/CE/1B	Merced, Solano, Stanislaus, and Yolo counties	Vernal pools	Moderate potential; known to occur near study area
San Joaquin Valley Orcutt grass *Orcuttia inaequalis*	T/CE/1B	Eastern part of the San Joaquin Valley from Tulare to Merced County	Vernal pools	Moderate potential; occurs near Friant
Hairy Orcutt grass *Orcuttia pilosa*	E/CE/1B	Scattered locations along east edge of the Central Valley and adjacent foothills, from Tehama County to Merced County	Vernal pools	Moderate potential

Table 9-1, Cont'd

	Status[1]			
Common and Scientific Names	**Federal/State/CNPS**	**California Distribution**	**Habitat Requirements**	**Occurrence in Study Area**[2]
Slender-leaved pondweed *Potamogeton filiformis*	--/--/2	Central Sierra Nevada, San Joaquin Valley, San Francisco Bay Area, and Modoc Plateau	Shallow freshwater marshes	Documented in study area
Hartweg's golden sunburst *Pseudobahia bahiifolia*	E/CE/1B	Eastern side of Sacramento and San Joaquin Valleys and adjacent foothills; historically as far north as Yuba County	Predominantly on northern slopes of rocky, bare or grassy areas along rolling hills, and adjacent to vernal pools and streams	Moderate potential
Sanford's arrowhead *Sagittaria sanfordii*	--/--/1B	Scattered locations in Central Valley and Coast Range	Freshwater marshes, sloughs, canals, and other slow-moving water habitats	Documented in study area
Wright's trichocoronis *Trichocoronis wrightii* var. *wrightii*	--/--/2	Central Valley and south coast	Alkaline meadows, marshes and swamps, riparian forests, and vernal pools	Documented in study area

[1] Status :

Federal
E = listed as endangered under the federal Endangered Species Act
T = listed as threatened under the federal Endangered Species Act
-- = no status

State
CE = listed as endangered under the California Endangered Species Act
-- = no status

California Native Plant Society (CNPS)
1B = List 1B species: rare, threatened, or endangered in California and elsewhere
2 = List 2 species: rare, threatened, or endangered in California, but more common elsewhere

[2] See the text for specific information regarding the location and timing of documented occurrences.

foothills through northern Fresno, western Madera, eastern Merced, southeastern San Joaquin, and Stanislaus counties (CDFG 2000). Thirty-two of the 35 extant populations occur on privately owned land. Succulent owl's-clover occurs in a few vernal pools on Big Table Mountain near Friant in Fresno County on land owned by CDFG and the Bureau of Land Management (BLM). It also occurs in a vernal pool complex in Madera County owned by CalTrans. One population occurs on land owned by the U.S. Bureau of Reclamation (USBR) near the Madera Equalization Reservoir in Madera County. Seven privately owned populations occur on the Flying M Ranch in Merced County, portions over which The Nature Conservancy (TNC) has a conservation easement. Two small occurrences were found in 1997 at the old Castle Air Force Base in Merced County (CDFG 2000).

Conversion of habitat to agriculture, urbanization, proposed gravel and aggregate mining, land fills, flood control, highway expansion, disking of vernal pools, competition from non-native weeds, and inappropriate grazing practices have all been cited as threats to succulent owl's clover. The type-locality of the species near Ryer in Merced County has been destroyed (CDFG 2000).

Succulent owl's-clover is a succulent, hemiparasitic (partly parasitic) annual herb in the figwort family (Scrophulariaceae). It has brittle narrow leaves and heads of bright yellow flowers. This species grows in drying vernal pools in valley grassland areas of the San Joaquin Valley (CDFG 2000).

This species has been recorded in the Fresno North, Friant, Lanes Bridge, and Millerton Lake West study area quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.1.2. Hoover's Spurge (*Chamaesyce hooveri*)

Hoover's spurge is listed as threatened under the ESA. It is endemic to vernal pool complexes in the Central Valley. Its historical distribution is not well documented, but presumably it was more common than at present among the vernal pools of the eastern Sacramento and San Joaquin Valleys. This species has been found in 11 pools on the Sacramento NWR in the Sacramento Valley. Hoover's spurge is a small, prostrate, annual herb of the spurge family (Euphorbiaceae) that forms mats from a few inches to a few feet across (Federal Register [149]:41700-41708, August 5, 1993). Hoover's spurge occurs in relatively large, deep vernal pools among the rolling hills, remnant alluvial fans, and depositional stream terraces at the base of the Sierra Nevada foothills. It tends to occur where competition from other species has been reduced by prolonged inundation. Hoover's spurge blooms in July (Skinner and Pavlik 1994).

Hoover's spurge is not known to occur in the study area but it occurs in the region and suitable habitat for this species is present. It has been documented in the Turner Ranch quadrangle (CNDDB 2002). Restoration actions that restore or modify vernal pools could affect this species.

9.5.1.3. Palmate-bracted Bird's-beak (*Cordylanthus palmatus*)

Palmate-bracted bird's-beak is listed as endangered under the ESA and CESA. In 1985, there were only 2 known occurrences of palmate-bracted bird's-beak in the state. As a result of intensive survey efforts and additional introductions, palmate-bracted bird's-beak is now known to occur in 7 populations: 4 in the Sacramento Valley, 1 in the Livermore Valley, and 2 in the San Joaquin Valley (USFWS 1998).

Cordylanthus species are hemiparasitic annuals, meaning that they manufacture their own food but obtain water and nutrients from the roots of other plants. Saltgrass is the most likely host plant for palmate-bracted bird's-beak. The combination of hemiparasitism, salt excretion, and a deep root system allows palmate-bracted bird's-beak to grow during the hot, dry months after most other annuals have died (Coats et al. 1993). This species is restricted to seasonally flooded, saline-alkali soils in lowland plains and basins at elevations of less than 150 meters (500 feet). Within these areas, palmate-bracted bird's-beak grows primarily along the edges of channels and drainages, with a few individuals scattered in seasonally wet depressions, alkali scalds, and grassy areas (USFWS 1998).

The occurrence of palmate-bracted bird's-beak has been recorded at the Alkali Sink Ecological Reserve and Mendota National Wildlife Refuge, approximately 6 kilometers (km) (4 miles) south of Reach 2A. It has been documented in the Firebaugh Northeast, Poso Farm, and Tranquility quadrangles (CNDDB 2002). Restoration actions that influence seasonally flooded areas along the river corridor could affect this species.

9.5.1.4. Delta Button-celery (*Eryngium racemosum*)

Delta button-celery is listed as endangered under CESA. Delta button-celery's historical distribution includes Calaveras, Merced, Stanislaus, and San Joaquin counties. Of the approximately 20 occurrences recorded in the CNDDB, most have been extirpated, including all occurrences in San Joaquin County and most in Stanislaus County. Most extant occurrences are found in Merced County along the San Joaquin River.

Delta button-celery is an herbaceous perennial in the carrot family (Apiaceae). It grows 10–50 cm tall and occurs at elevations of 15–75 feet. Delta button-celery occurs on clay soils on sparsely vegetated margins of seasonally flooded plains and swales. Suitable habitat is supported by periodic flooding, which maintains seasonal wetland hydrology and reduces competition through scouring (CDFG 1998). The flowering period of Delta button-celery is July to October.

Delta button-celery is known from at least 4 occurrences along the San Joaquin River in the West Bear Creek Unit (CNDDB 2001), and from several locations in seasonal wetlands in the flood basin of the San Joaquin River in the Great Valley Grasslands State (CNDDB 2001, Hoopes et al. 1996). It frequently occurs in association with the mat-forming lippia. More individuals than are recorded in the CNDDB have been observed outside the levees of the West Bear Creek Unit after the 1997 and 1998 flood events. In areas of suitable habitat, these populations were still present in 1999 (D. Woolington, pers. comm., as cited in JSA et al. 2000).

Several occurrences reported by Hoopes et al. (1996) in vernal pools outside the floodplain in the West Bear Creek area were visited during field surveys in 2000 but were not relocated (JSA et al. 2000). The species has been documented in the Gustine, San Luis Ranch, Sandy Mush, Stevinson, and Turner Ranch quadrangles (CNDDB 2002). Restoration actions that restore floodplain inundation could benefit this species.

9.5.1.5. Colusa Grass (*Neostapfia colusana*)

Colusa grass is listed as threatened under ESA and as endangered under CESA. Colusa grass is endemic to the Sacramento and San Joaquin valleys. The species' historical distribution included Merced, Stanislaus, Solano, and Colusa counties. Forty populations are currently known from Merced, Stanislaus, and Solano counties; none remain in Colusa County (CDFG 1992).

Colusa grass is an annual belonging to the grass family (Poaceae) and grows 10–30 centimeters (cm) tall. It occurs in large or deep vernal pools on clay substrates (CNDDB 1998). The flowering period for Colusa grass is May–July.

Colusa grass currently exists within one vernal pool on the Arena Plains Unit of the San Luis NWR, and on privately owned vernal pools located approximately 3 miles east of the Arena Plains Unit (JSA et al. 2000). It has the potential to occur in the study area because suitable habitat is present in the study area. It has been documented in the Sandy Mush and Turner Ranch quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.1.6. San Joaquin Valley Orcutt Grass (*Orcuttia inaequalis*)

San Joaquin Valley Orcutt grass is listed as threatened under ESA and endangered under CESA. This grass is the only Orcutt grass restricted to the San Joaquin Valley. San Joaquin Valley Orcutt grass was once common along the eastern margin of the valley in Stanislaus, Merced, Fresno, Madera, and Tulare counties. Most of the remaining occurrences of San Joaquin Valley Orcutt grass are concentrated in 2 small areas in eastern Merced County. The species occurs in 2 vernal pools that are partially on land owned by BLM and partially on private land on Big Table Mountain near Friant in Fresno County. San Joaquin Valley Orcutt grass also occurs in a vernal pool complex in Madera County that was acquired by the California Department of Transportation (CalTrans) in 1995 for mitigation purposes. Just before acquisition by CalTrans, the pools were disked, which resulted in an invasion by upland plants. Nonetheless, the pools still support rare species. In 1997, a small population of San Joaquin Valley Orcutt grass was discovered in a vernal pool on CDFG’s Stone Corral Ecological Reserve in Tulare County. Three occurrences of the species on the Flying M Ranch in Merced County are protected through conservation easement agreements with TNC. Twenty-two of the approximately 25 extant occurrences are privately owned. The overall trend for this species is one of decline (CDFG 1999).

San Joaquin Valley Orcutt grass is a small, grayish-green, sticky, aromatic, tufted annual of the grass family (Poaceae) that occurs in vernal pools. The plant has several stems 2–6 inches tall, terminating in a spike-like inflorescence (58 Federal Register [149]:41700-41708, August 5, 1993). The blooming period for this species is from May though September (Skinner and Pavlik 1994).

San Joaquin Valley Orcutt grass occurs near Friant, and suitable habitat for this species is present on clay soils on hillsides far above the river. It has been documented in the Fresno North, Friant, and Lanes Bridge quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.1.7. Hairy Orcutt Grass (*Orcuttia pilosa*)

Hairy Orcutt grass is listed as endangered by both the USFWS and the state of California (CDFG 2000). The California Native Plant Society has placed it on List 1B (CNPS 2001). The historical range includes the eastern margins of Sacramento and San Joaquin valleys from Tehama County south to Stanislaus County and through Merced and Madera Counties. Only 24 of 34 historically known populations still exist (USFWS 2002). Conversion of vernal pool habitat to irrigated agriculture or to urban uses has been the primary factor leading to decline in this species (USFWS 2002). Of the 24 native, extant populations and 1 translocated population, only 12 populations are considered stable (USFWS 2002). CDFG (2000) reported that several extant occurrences are damaged or declining, and at least 11 occurrences contain less than 1,000 individuals. Occurrences with such small numbers of individuals are particularly susceptible to decline over time and ultimate extirpation.

Hairy Orcutt grass is a yellow-green, aromatic, tufted, annual in the grass family (Poaceae) (CDFG 2000). It inhabits vernal pools in rolling topography on remnant alluvial fans and stream terraces. Hairy Orcutt grass can tolerate some grazing, but ecologically appropriate livestock numbers, timing, and intensity are unknown (CDFG 2000). However, as long as the land remains in dry pasture, moderate grazing regimes appear to have little impact on Orcutt grasses (USFWS 2002).

This species has been recorded in the Gregg, Herndon, Lanes Bridge and Madera quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.1.8. Hartweg's Golden Sunburst (*Pseudobahia bahiifolia*)

Hartweg's golden sunburst, also known as Hartweg's pseudobahia, is listed as endangered under ESA and CESA. Hartweg's golden sunburst is endemic to the Central Valley. Historically, the species' range may have extended from Yuba County south to Fresno County, approximately 200 miles, but it was only abundant in a few locations. Today, only 16 extant occurrences are known, which are concentrated in the Friant region of Fresno and Madera counties and the La Grange region in Stanislaus County (CDFG 1992; 57 FR [230]:56549-56555, November 30, 1992). Twelve populations remain in Stanislaus County, 2 in Madera County, and 2 in Fresno County (CDFG 1999). Of the 16 extant occurrences of Hartweg's golden sunburst, 11 are very small and contained fewer than 200 plants in 1990. Part of one population in Fresno County occurs on land owned by the U.S. Bureau of Reclamation, and another part of the same population is protected by a conservation easement with the Nature Conservancy. All other populations are on privately owned land. The overall trend for species is one of decline (CDFG 1999).

Hartweg's golden sunburst is a slender, woolly annual in the sunflower family (Asteraceae). It has 1 or a few stems 2–6 inches tall, with mostly narrow, undivided leaves, and yellow ray flowers. Hartweg's golden sunburst occurs on the grassy slopes of valley and foothill grasslands and at the margins of blue-oak woodland, primarily on shallow, well-drained, fine-textured and gravelly soils of the Amador and Rocklin series (57 FR [230]:56549-56555, November 30, 1992). Hartweg's golden sunburst typically occurs on the north- or northeast-facing slopes of mima mounds, which are often associated with vernal pools, with the highest densities on upper slopes having minimal grass cover (CDFG 1999). Hartweg's golden sunburst blooms in March and April (Skinner and Pavlik 1994).

Hartweg's golden sunburst occurs near Friant. It has been documented in the Millerton Lake West and Friant quadrangles (CNDDB 2002). Restoration actions that influence grasslands and vernal pools could affect this species.

9.5.2. Other Special-status Plants

9.5.2.1. Alkali Milk-Vetch (*Astragalus tener* var. *tener*)

The California Native Plant Society has placed alkali milk-vetch on List 1B (CNPS 2001). The historical distribution of alkali milk-vetch includes the southern Sacramento Valley, northern San Joaquin Valley, and the eastern San Francisco Bay Area. This species is believed extirpated from all historical occurrences except for those in Merced and Yolo counties.

Alkali milk-vetch is an annual herb of the legume family (Fabaceae) that grows 4–30 cm tall (Hickman 1993). This species is associated with the clay soils of alkaline flats and meadows, valley and foothill grasslands, and alkaline vernal pools. The flowering period of alkali milk-vetch is March–June (Skinner and Pavlik 1994).

Four occurrences of this plant have been reported from the Great Valley Grasslands State Park in the West Bear Creek area of the San Luis NWR (Hoopes et al. 1996). It has been documented in the Gustine, San Luis, and Stevinson quadrangles (CNDDB 2002). Restoration actions that influence alkaline wetlands and grasslands could affect this species.

9.5.2.2. Heartscale (*Atriplex cordulata*)

Heartscale has been placed on List 1B by CNPS (CNPS 2001). It is endemic to alkali desert scrub and grassland habitats of Alameda, Butte, Fresno, Glenn, King, Kern, Madera, Merced, Solano, and Tulare counties. There are more than 35 known occurrences of heartscale, with populations ranging from 10 to 3,500 individuals (CNDDB 1998).

Heartscale is an annual herb of the goosefoot family (Chenopodiaceae) that grows 10–50 cm (4–20 inches) tall (Hickman 1993). This species lives in moderately alkaline or saline soil in chenopod scrub, desert scrub, or sandy grassland habitats (Skinner and Pavlik 1994). Heartscale blooms from May to October (Skinner and Pavlik 1994).

Heartscale has been reported to occur in the study area in the Great Valley Grasslands State Park, and also occurs elsewhere in the region (CNDDB 2001). It has been documented in numerous quadrangles of the project area (CNDDB 2002). Restoration actions that influence alkaline or saline scrub or grassland could affect this species.

9.5.2.3. Crownscale (*Atriplex coronata* var. *coronata*)

Crownscale has been placed on List 1B by CNPS (CNPS 2001). It is known from the Central Valley and southeastern inner coast range, including Alameda, Contra Costa, Stanislaus, Merced, Fresno, Kings, Kern, Monterey and San Luis Obispo counties (Skinner and Pavlik 1994).

Crownscale is an annual herb of the goosefoot family (Chenopdiaceae) and is similar to heartscale (Hickman 1993). It occurs on alkaline soils in chenopod scrub, grassland, and vernal pools. The flowering period is from April to October. Crownscale is known to occur in the region and habitat is present in West Bear Creek area (JSA et al. 2000). Restoration actions that affect alkaline uplands and vernal pools could affect this species.

9.5.2.4. Brittlescale (*Atriplex depressa*)

Brittlescale has been placed on List 1B by CNPS (CNPS 2001). It is known to occur in Alameda, Contra Costa, Colusa, Fresno, Glenn, Kern, Madeira, Merced, Solano, Tulare, and Yolo counties. It is believed to be extirpated from Stanislaus County (Skinner and Pavlik 1994).

Brittlescale is an annual herb from the goosefoot family (Chenopodiaceae). The species is found in chenopod scrub, playas, and valley-foothill grassland habitats on clay or alkaline soils (Skinner and Pavlik 1994). One occurrence of brittlescale has been reported from the Great Valley Grasslands State Park in the West Bear Creek area (Hoopes et al. 1996). It has been documented in the Bliss Ranch, Jamesan, Sandy Mush, Stevinson, and Tranquility quadrangles (CNDDB 2002). Restoration actions that influence alkaline uplands and wetlands could affect this species.

9.5.2.5. San Joaquin Spearscale (*Atriplex joaquiniana*)

San Joaquin spearscale has been placed on List 1B by CNPS (CNPS 2001). It is known from Alameda, Contra Costa, Colusa, Glenn, Merced, Napa, Sacramento, San Benito, Solano, and Yolo counties. It is believed to be extirpated from Santa Clara, San Joaquin, and Tulare counties (Skinner and Pavlik 1994).

San Joaquin spearscale is an annual herb of the goosefoot family (Chenopodiaceae). This species grows to 10–100 cm in height (Hickman 1993). San Joaquin spearscale grows on sites with low vegetative cover in alkali desert scrub, chenopod scrub, seasonal alkali meadows, and grassland habitats on alkaline soils. The flowering period of San Joaquin saltbush is April–September (Skinner and Pavlik 1994).

San Joaquin spearscale has been reported from the region and suitable habitat is present in the West Bear Creek area (JSA et al. 2000). It has been documented in the Gustine quadrangle (CNDDB 2002). Restoration actions that influence alkaline uplands could affect this species.

9.5.2.6. Lesser Saltscale (*Atriplex minuscula*)

Lesser saltscale has been placed on List 1B by CNPS (CNPS 2001). It is known to have occurred historically in the southern San Joaquin Valley (Hickman 1993). Its distribution extended through Fresno, Kern, Madera, Merced, and Tulare counties (Skinner and Pavlik 1994). The species is now known to occur only in Merced, Kern, Fresno, and Butte counties (CNDDB 1998).

Lesser saltscale is an annual herb of the goosefoot family (Chenopodiaceae) (Hickman 1993). The species has many upright reddish stems that grow up to 40 cm (16 inches) tall, and egg-shaped leaves. Lesser saltscale occurs in alkaline soils of chenopod scrub, playa, and grassland habitats (Skinner and Pavlik 1994). The flowering period of lesser saltscale is May–October (Skinner and Pavlik 1994).

Two occurrences of lesser saltscale have been reported from the Great Valley Grasslands State Park (Hoopes et al. 1996) and from occurrences in the Freitas Unit (Woolington, pers. comm., as cited in JSA et al. 2000) in the West Bear Creek area. It has been documented in the Bliss Ranch, Jamesan, Mendota Dam, Poso Farm, and Sandy Mush quadrangles (CNDDB 2002). Restoration actions that influence alkaline uplands and wetlands could affect this species.

9.5.2.7. Vernal Pool Smallscale (*Atriplex persistens*)

Vernal pool smallscale has been placed on List 1B by CNPS (CNPS 2001). It is distributed throughout portions of Glenn, Merced, Solano, Stanislaus, and Tulare counties (CNDDB 1999, Skinner and Pavlik 1994).

Vernal pool saltbush is an annual herb of the goosefoot family (Chenopodiaceae). This species is found in chenopod scrub and vernal pool communities. The flowering period of vernal pool saltbush blooms is July–September (Skinner and Pavlik 1994).

This species has been reported from in the West Bear Creek Unit of the San Luis NWR (CNDDB 1999). It has been documented in the Gustine, San Luis Ranch, Sandy Mush and Stevinson quadrangles (CNDDB 2002). Restoration actions that influence alkaline scrub and vernal pools could affect this species.

9.5.2.8. Subtle Orache (*Atriplex subtilis*)

Subtle orache has been placed on List 1B species by CNPS (CNPS 2001). It is confined to south-central California, mostly in Tulare, Fresno, Kern, and Kings counties (Stutz and Chu 1997). Subtle orache is a short-statured, fine-textured, diploid annual (Stutz and Chu 1997) found in valley and foothill grasslands (CNPS 2001). The blooming period is from June to October.

This species has been recorded in the Bliss Ranch, Jamesan, Sandy Mush, and Santa Rita Bridge quadrangles (CNDDB 2002). Restoration actions that influence grasslands could affect this species.

9.5.2.9. Lost Hills Crownscale (*Atriplex vallicola*)

Lost Hills crownscale has been placed on List 1B species by CNPS (CNPS 2001). A dicot in the family Chenopodiaceae, this annual herb is endemic to California (Lum 1975 and Walker 1992, both as cited in CalFlora 2002). Historical locations for Lost Hills crownscale include Fresno, Kern, and

San Luis Obispo counties. Only two large centers of concentration remain today. Other historically-known occurrences and much suitable valley-floor habitat have been destroyed by conversion to agriculture (Cypher 2002).

Walker (1992, as cited in CalFlora 2002) describes the Lost Hills crownscale as occurring in alkaline soil under vernally-flooded conditions in vernal-pool habitats. USFWS (1997, as cited in CalFlora 2002) reported that the species usually occurs in wetlands, but is also occasionally found in non-wetlands. Lost Hills crownscale has been reported at elevations between 0 and 1,000 feet (Lum 1975 and Walker 1992, both as cited in CalFlora 2002).

The two main remaining populations occur in the Kern-Kings county boundary near the community of Lost Hills, and on the Carrizo Plain in San Luis Obispo County (Cypher 2002). Much smaller populations are known from the Kerman Ecological Reserve in Fresno County, the Lokern-McKittrick area of Kern County, and southwestern Merced County (Cypher 2002). CNDDB has records of this species in the Firebaugh, Jamesan, Mendota Dam, and Tranquility quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.2.10. Hispid Bird’s-beak (*Cordylanthus mollis* ssp. *hispidus*)

Hispid bird’s-beak has been placed on List 1B by CNPS (CNPS 2001). Historically, Hispid bird’s-beak has been distributed in California’s central and southern Central Valley, including Alameda, Merced, Placer, Kern, and Solano counties (Hickman 1993, Skinner and Pavlik 1994). Although this species is believed to be extirpated from most of the San Joaquin Valley, it is known from approximately 30 occurrences within its range (CNDDB 1999, Skinner and Pavlik 1994).

Hispid bird’s-beak is a hemiparasitic annual herb of the figwort family (Scrophulariaceae) that grows 10–40 cm tall (Hickman 1993). This species grows in playas, alkaline meadows, saline marshes, and flats. The flowering period of Hispid bird’s-beak is June–September (Skinner and Pavlik 1994). Hispid bird’s-beak has been observed in the West Bear Creek area in the San Luis and Kesterson units of the San Luis NWR (Woolington, pers. comm., as cited in JSA et al. 2000). It has been documented in the Gustine, Ingomar, San Luis Ranch, and Delta Ranch quadrangles (CNDDB 2002). Restoration actions that influence alkaline uplands and wetlands could affect this species.

9.5.2.11. Recurved Larkspur (*Delphinium recurvatum*)

Recurved larkspur has been placed on List 1B by CNPS (CNPS 2001). It is widely distributed throughout elevations of 30–600 meters in California’s Central Valley (Hickman 1993). The species is known from over 60 recorded populations from Alameda, Contra Costa, Colusa, Fresno, Glenn, Kern, Kings, Merced, Monterey, San Benito, San Luis Obispo, Solano, and Tulare counties.

Recurved larkspur, a member of the buttercup family (Ranunculaceae), is a perennial herb that grows 18–85 centimeters tall (Hickman 1993). This species grows in seasonal alkali wetlands of chenopod scrub, grassland, and montane woodland communities, typically on valley bottoms on heavy clay alkali soils (JSA 1988). Recurved larkspur is usually found along sloughs or above vernal pools, directly adjacent to soils that are moist at least one time during the year (M. Wolfe, pers. comm.). Recurved larkspur blooms from March through May (Skinner and Pavlik 1994).

Recurved larkspur has not been reported from the West Bear Creek area, although suitable habitat is present. It has been documented in the Jamesan quadrangle (CNDDB 2002). Restoration actions that influence alkaline uplands and wetlands could affect this species.

9.5.2.12. Four-angled Spikerush (*Eleocharis quadrangulata*)

Four-angled spikerush has been placed on List 2 by CNPS (CNPS 2001). It is distributed throughout the Central Valley, below 455-meter (1,500-foot) elevation (Hickman 1993). There are 9 known occurrences of this species, in Butte, Shasta, and Tehama Counties. Two historical occurrences have been recorded in Merced County. Four-angled spikerush is a perennial herb of the sedge family (Cyperaceae) that grows 50–100 cm (20–39 inches) tall (Hickman 1993). This species is found in freshwater marshes and lake and pond margins of valley and foothill grasslands and woodlands (Hickman 1993, CNDDB 2001, Skinner and Pavlik 1994). The flowering period of four-angled spikerush is July–September (Skinner and Pavlik 1994).

The occurrence of four-angled spikerush has been reported from the region, and there is suitable habitat in the West Bear Creek area (JSA et al. 2000). It has been documented in the Gustine, Ingomar, and Stevinson quadrangles (CNDDB 2002). Restoration actions that influence wetlands could affect this species.

9.5.2.13. Round-leaved filaree (*Erodium macrophyllum*)

Round-leaved filaree has been placed on List 2 by CNPS (CNPS 2001). It is known to occur in Alameda, Butte, Contra Costa, Colusa, Fresno, Glenn, King, Kern, Lake, Lassen, Los Angeles, Merced, Monterey, Napa, Riverside, Santa Barbara, San Benito, Santa Cruz Island, San Diego, San Joaquin, San Luis Obispo, San Mateo, Solano, Stanislaus, Tehama, Ventura, and Yolo counties. It is believed to be extirpated from Alameda County (CNPS 2001).

Round-leaved filaree, a dicot in the family Geraniaceae, is an annual herb that is native to California (Hrusa 2001, as cited in the CalFlora 2002). The species is found in cismontane woodland areas and valley and foothill grassland habitats on clay soils (CNPS 2001). The flowering period of the round-leaved filaree is March to May (CNPS 2001).

Round-leaved filaree has not been recorded in the study area quadrangles (CNDDB 2002). If it occurs in the study area, restoration actions that influence upland habitats could affect this species.

9.5.2.14. Spiny-sepaled button celery (*Eryngium spinosepalum*)

Spiny-sepaled button-celery has been placed on List 1B by CNPS (CNPS 2001). It is known to occur in Fresno, Madera, Stanislaus, Tulare, and Tuolumne counties.

Spiny-sepaled button-celery, a dicot in the family Apiaceae, is an herb that is endemic to California (Lum 1975, Walker 1992 as cited in CalFlora 2002). The species is found in valley and foothill grassland habitats and vernal pools (CNPS 2001). The flowering period of spiny-sepaled button-celery is April to May (CNPS 2001).

Spiny-sepaled button-celery has been recorded in the Little Table Mountain quadrangles (CNDDB 2002). Restoration actions that influence grassland and vernal pools could affect this species.

9.5.2.15. Munz's tidy-tips (*Layia munzii*)

Munz's tidy-tips has been placed on List 1B species by CNPS (CNPS 2001). Historically, the species was widespread in the western San Joaquin Valley and inner Coast Ranges from Fresno south (Williams et al 1998). Conversion of low-lying areas in Fresno County may have destroyed populations of Munz's tidy-tips (Williams et al. 1998).

Munz's tidy-tips is an annual that grows on alkaline clay in low-lying areas and on hillsides in grasslands, valley saltbush scrub, and valley sink scrub (Williams et al 1998). Historical and current sites ranged from 150 to 2,600 feet (45 to 800 meters) in elevation (CDFG 1995, Lewis 1997).

In Fresno County, the species was collected near Firebaugh, Little Panoche Creek, Mendota, the town of San Joaquin, and Wheatville (Williams et al 1998). CNDDB has records of this species in the Firebaugh and Tranquility quadrangles (CNDDB 2002). Restoration actions that influence grasslands and scrub could affect this species.

9.5.2.16. Madera linanthus (*Linanthus serrulatus*)

Madera linanthus has been placed on List 1B species by CNPS (CNPS 2001). It is endemic to California (Lum 1975 and Walker 1992, both as cited in CalFlora 2002). It is known to occur in Fresno, Kern, Madera, Mariposa, and Tulare counties.

Madera linanthus, a dicot in the family Polemoniaceae, is an annual herb that is found in cismontane woodland and lower montane coniferous forest. It has been reported at elevations between 1,000 and 4,000 feet (Lum 1975, Walker 1992, both as cited in CalFlora 2002). The species blooms from April to May.

Madera linanthus has been documented in the Friant, Madera, and Millerton Lake West quadrangles (CNDDB 2002). Restoration actions that influence upland woodlands and forests could affect this species.

9.5.2.17. Prostrate navarretia (*Navarretia prostrata*)

Prostrate navarretia has been placed on List 1B by CNPS (CNPS 2001). It is known to occur in Alameda, Los Angeles, Merced, Monterey, Orange, Riverside, San Bernardino, and San Diego counties. It is believed to be extirpated from Alameda County (CNPS 2001).

Prostrate navarretia, a dicot in the family Polemoniaceae, is an annual herb that is endemic to California (Lum 1975, Walker 1992, as cited in the CalFlora 2002). The species is found in coastal scrub areas, valley and foothill grassland habitats on alkaline soils, vernal pools, and other mesic habitats (CNPS 2001). The flowering period of prostrate navarretia is April to June (CNPS 2001).

Prostrate navarretia has not been recorded in the study area (CNDDB 2002). If it occurs in the study area, restoration actions that influence grasslands and wetlands could affect this species.

9.5.2.18. Slender-leaved Pondweed *(Potamogeton filiformis*)

Slender-leaved pondweed has been placed on List 2 by CNPS (CNPS 2001). It is an aquatic macrophyte that in California occurs only from the vicinity of the study area to Mono County; this species is also known to occur in Arizona, Nevada, and Oregon (Skinner and Pavlik 1994).

This species is found in marshes and open water habitat. Slender-leaved pondweed occurs in the study area along Reach 2A and in the West Bear Creek area. Four occurrences of this plant in the Great Valley Grasslands State Park have been reported by Hoopes et al. (1996). It is likely to occur in the West Bear Creek area because there is suitable habitat (JSA et al. 2000). It has been documented in the Ingomar quadrangle (CNDDB 2002). Restoration actions that influence open, marshy habitat could affect this species.

9.5.2.19. Sanford's Arrowhead (*Sagittaria sanfordii*)

Sanford's arrowhead has been placed on List 1B by CNPS (CNPS 2001). It is distributed throughout the northern part of the north coast, Central Valley, and northern part of the south coast of California (Hickman 1993). Of its original range, this species is believed to be extirpated from Orange and Ventura counties and mostly extirpated from the Central Valley (Skinner and Pavlik 1994). There are approximately 50 known occurrences of Sanford's arrowhead.

Sanford's arrowhead is a rhizomatous emergent perennial herb of the waterplantain family (Alismataceae). This species grows in freshwater marshes, ponds, and ditches and various other shallow freshwater habitats (Hickman 1993, Skinner and Pavlik 1994). It flowers from May through August (Skinner and Pavlik 1994).

One occurrence of Sanford's arrowhead has been reported along Reach 2A, although it has not been observed since 1948 (CNDDB 2001). There is suitable habitat for the species in the West Bear Creek area (JSA et al. 2000). It has been documented in the Delta Ranch, Firebaugh, Fresno North, Jamesan, Mendota Dam, Tranquility, and Turner Ranch quadrangles (CNDDB 2002). Restoration actions that influence freshwater lentic habitats could affect this species.

9.5.2.20. Wright's Trichocoronis (*Trichocoronis wrightii* var. *wrightii*)

Wright's trichocoronis has been placed on List 2 by CNPS (CNPS 2001). It is known from Riverside and Merced counties and is presumed extirpated from San Joaquin, Colusa, and Sutter counties. Although rare in California, this species is more common in Texas.

Wright's trichocoronis is an annual herb of the sunflower family (Asteraceae). It grows in meadows, freshwater marshes, riparian forests, and vernal pools and occurs on alkaline soils (Skinner and Pavlik 1994). The flowering period of Wright's trichocoronis is May–September (Skinner and Pavlik 1994).

Wright's trichocoronis has been reported from one population in the Great Valley Grasslands State Park (Hoopes et al. 1996). It has been documented in the San Luis Ranch quadrangle (CNDDB 2002). Restoration actions that influence riparian forest or wetlands could affect this species.

9.5.3. Federally-listed and State-listed Wildlife

The following sections describe the special-status wildlife species that occur or have the potential to occur in the project area. A total of 57 special-status wildlife species were identified as having the potential to occur in the project area (Table 9-2). Forty-four of these 57 species have been reported to occur in the project area. The remainder of these species is not known to occur in the project area, but they occur in the vicinity of the project area or occurred there historically, and the project area contains potential habitat for these species. The potential for occurrence of these species was classified as low, moderate, or high (see Table 9-2). This classification was based primarily on the availability of suitable habitat in the project area, and the proximity of the project area to documented occurrences of the species.

The legal status, California distribution, habitat requirements, and potential for occurrence of special-status wildlife are summarized in Table 9-2. Each species is briefly described below.

9.5.3.1. Conservancy fairy shrimp (*Branchinecta conservatio*)

The Conservancy fairy shrimp is a federally endangered species that is endemic to California's Central Valley grassland vernal pools. The species has an elevation range of between 16 and 476 feet. The population distribution is limited within this range to Vina Plains in Butte County, the

Table 9-2. Special-status wildlife species with potential to occur in the study area.

Common and Scientific Names	Status[1] Federal	State	California Distribution	Habitat Requirements	Occurrence in Study Area[2]
INVERTEBRATES					
Conservancy fairy shrimp *Branchinecta conservatio*	E	--	Disjunct occurrences in Solano, Merced, Butte, and Glenn counties	Large, deep vernal pools in annual grasslands	Documented in study area
Longhorn fairy shrimp *Branchinecta longiantenna*	E	--	Eastern margin of central Coast Ranges from Contra Costa County to San Luis Obispo County	Small, clear to moderately turbid, clay- or grass-bottomed pools, or pools in sandstone rock outcrops	Documented in study area
Vernal pool fairy shrimp *Branchinecta lynchi*	T	--	Central Valley, central and south Coast Range from Shasta County to Santa Barbara County; isolated populations also in Riverside County	Vernal pools; also found in sandstone rock outcrop pools	Documented in study area
Vernal pool tadpole shrimp *Lepidurus packardi*	E	--	Shasta County to Merced County	Vernal pools and ephemeral stock ponds	Documented in study area
Valley elderberry longhorn beetle *Desmocerus californicus dimorphus*	T	--	Streamside habitats in Central Valley	Riparian habitats with elderberry shrubs (elderberries are the host plant)	Documented in study area
AMPHIBIANS					
California tiger salamander *Ambystoma californiense* (= *A. tigrinum c.*)	C	SSC	Central Valley, including Sierra Nevada foothills and coastal region from Butte County south to Santa Barbara County	Small ponds, lakes, or vernal pools in grasslands and oak woodlands for larvae; rodent burrows, rock crevices, or fallen logs for cover and summer dormancy for adults	Documented in study area
Western spadefoot *Scaphiopus hammondii*	--	SSC	Sierra Nevada foothills, Central Valley, Coast Ranges, coastal counties in southern California	Seasonal wetlands, such as vernal pools, in annual grasslands and oak woodlands	Documented in study area
California red-legged frog *Rana aurora draytoni*	T	SSC	Coast and coastal mountain ranges of California from Humboldt County to San Diego County; Sierra Nevada mid-elevations from Butte County to Madera County; historically occurred on floor of Central Valley	Permanent and semipermanent aquatic habitats, such as creeks and coldwater ponds with emergent and submergent vegetation and riparian species along edges; may aestivate in rodent burrows or cracks during dry periods	Low potential; species has been extirpated from area
REPTILES					
Western pond turtle *Clemmys marmorata*	--	SSC	Found throughout California, west of the Sierra-Cascade crest; absent from most desert regions	Ponds, marshes, rivers, streams, and irrigation canals with muddy or rocky bottoms and with watercress, cattails, water lilies, or other aquatic vegetation, in woodlands, grasslands, and open forests	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
REPTILES, Cont'd					
Blunt-nosed leopard lizard *Gambelia*(= *Crotaphytus*) *silus*	E	E, FP	San Joaquin Valley from Stanislaus County through Kern County and along eastern edges of San Luis Obispo and San Benito counties	Open habitats with scattered low bushes on alkali flats, canyon floors, plains, washes, and arroyos; substrates may range from sandy or gravelly soils to hardpan	High potential; documented near study area (near Mendota Pool)
California horned lizard *Phrynosoma coronatum frontale*	--	SSC	Sacramento Valley, including foothills, south to southern California; Coast Ranges south of Sonoma County	Grasslands, brushlands, woodlands, and open coniferous forests with sandy or loose soil	Documented in study area
Silvery legless lizard *Anniella pulchra pulchra*	--	SSC	Along Coast, Transverse, and Peninsular ranges from Contra Costa County to San Diego County, with spotty occurrences in San Joaquin Valley	Habitats with loose soil for burrowing, or thick duff or leaf litter (often forages in leaf litter at plant bases); may be found on beaches, sandy washes, and in woodland, chaparral, and riparian areas	Documented in study area
San Joaquin whipsnake (= coachwhip) *Masticophis flagellum ruddocki*	--	SSC	From Colusa County in Sacramento Valley south to the Grapevine in San Joaquin Valley and west into inner Coast Ranges; an isolated population occurs at Sutter Buttes	Open, dry, vegetative associations with little or no tree cover, such as valley grassland and saltbush scrub associations; often occurs in association with mammal burrows	Low potential
Giant garter snake *Thamnophis gigas*	T	T	Central Valley from Fresno north to Gridley/ Sutter Buttes area; has been extirpated from areas south of Fresno	Sloughs, canals, and other small waterways where there is a prey base of small fish and amphibians; requires grassy banks and emergent vegetation for basking, and areas of high ground protected from flooding during winter	Documented in study area
BIRDS					
American white pelican (nesting colony) *Pelecanus erythrorhynchos*	--	SSC	Historically, nested at large lakes throughout California; the only breeding colonies in the state occur at lower Klamath National Wildlife Refuge, Siskiyou County, and at Clear Lake, Modoc County; winters along California coast from southern Sonoma County to San Diego County; inland, occurs at Salton Sea, in Delta region, and in Central Valley	Freshwater lakes with islands for breeding; inhabits river sloughs, freshwater marshes, salt ponds, and coastal bays during the rest of the year	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
BIRDS, Cont'd					
Double-crested cormorant (rookery site) *Phalacrocorax auritus*	--	SSC	Winters along entire California coast and inland over Coast Range into Central Valley from Tehama County to Fresno County; a permanent resident along the coast from Monterey County to San Diego County, along Colorado River, in Imperial, Riverside, Kern, and Kings counties; also nests in Central Valley	Rocky coastlines, beaches, inland ponds, and lakes; needs open water for foraging; nests in riparian forests or on protected islands, usually in snags	Documented in study area
Western least bittern (nesting) *Ixobrychus exilis hesperis*	--	SSC	Permanent resident along Colorado River and Salton Sea and in isolated areas in Imperial, San Diego, and Los Angeles counties; summers at Tulare Lake and parts of Fresno, Merced, Madera, Siskiyou, and Modoc counties; also summers in marshlands of Yolo, Sutter, Colusa, Glenn, and Butte counties	Marshes and pond edges, where tules and rushes provide cover; nests are built low in tules over water	Documented in study area
Great blue heron (nesting colonies) *Ardea herodias*	--	CDF	Fairly common throughout most of California year-round in shallow estuaries and fresh and saline emergent wetlands. Few rookeries have been found in southern California but many are scattered throughout the Central Valley	Usually nest in colonies in the tops of secluded large snags or live trees, usually among the tallest trees available; require fish-bearing water	Documented in study area
Great egret (nesting colonies) *Ardea alba*	--	CDF	Humboldt, Bolinas, and San Francisco bays and the large streams, lakes, and rivers of the Central Valley. Winters throughout the Central Valley, Suisun Marsh, and San Francisco Bay Area	Require groves of trees that are suitable for nesting and roosting, relatively isolated from human activities, and near aquatic foraging areas	Documented in study area
White-faced ibis (rookery site) *Plegadis chihi*	--	SSC	Both resident and winter populations on Salton Sea and in isolated areas in Imperial, San Diego, Ventura, and Fresno counties; breeds at Honey Lake, Lassen County, at Mendota Wildlife Management Area, Fresno County, and near Woodland, Yolo County; winters in Merced County and along the Sacramento River in Colusa, Glenn, Butte, Sutter, and Yolo counties	Prefers freshwater marshes with tules, cattails, and rushes, but may nest in trees and forage in flooded agricultural fields, especially flooded rice fields	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
BIRDS, Cont'd					
Fulvous whistling duck (nesting) *Dendrocygna bicolor*	--	SSC	Formerly nested in San Joaquin Valley; currently nests in only a few locations in Imperial Valley	Prefers freshwater marshes for nesting and roosting; forages in marshes and in nearby open ponds and flooded fields	Low potential; species has been extirpated from area. Historically a common breeding species in wetlands near Los Banos; has not been reported as a breeding species in San Joaquin Valley since early 1960s
Osprey (nesting sites) *Pandion haliaetus*	--	SSC, CDF	Nests along the north coast from Marin County to Del Norte County, east through Klamath and Cascade ranges, and in upper Sacramento Valley; important inland breeding populations at Shasta Lake, Eagle Lake, and Lake Almanor; small numbers elsewhere south through Sierra Nevada; winters along the coast from San Mateo County to San Diego County	Nests in snags, trees, or utility poles near the ocean, large lakes, or rivers with abundant fish populations	Documented in study area
White-tailed kite (nesting) *Elanus leucurus*	--	FP	Coastal and valley lowlands west of the Sierra Nevada	Rarely found away from agricultural areas; nest near the top of dense oak or other tree stands; forage in wetlands and grasslands	Documented in study area
Bald eagle *Haliaeetus leucocephalus*	T (PD)	E, FP, CDF	Nests in Siskiyou, Modoc, Trinity, Shasta, Lassen, Plumas, Butte, Tehama, Lake, and Mendocino counties and in Lake Tahoe Basin; reintroduced into central coast; winter range includes the rest of California, except southeastern deserts, very high altitudes in Sierra Nevada, and east of Sierra Nevada south of Mono County	In western North America, nests and roosts in coniferous forests within 1 mile of a lake, reservoir, stream, or the ocean	Documented in study area
Northern harrier (nesting) *Circus cyaneus*	--	SSC	Throughout lowland California; has been recorded in fall at high elevations	Grasslands, meadows, marshes, and seasonal and agricultural wetlands	Documented in study area
Golden eagle *Aquila chrysaetos*	--	SSC, FP, CDF	Foothills and mountains throughout California; uncommon non-breeding visitor to lowlands such as Central Valley	Nests on cliffs and escarpments or in tall trees overlooking open country; forages in annual grasslands, chaparral, and oak woodlands with plentiful medium and large mammals	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
BIRDS, Cont'd					
Merlin (wintering) *Falco columbarius*	--	SSC	Does not nest in California; rare but widespread winter visitor to Central Valley and coastal areas	Forages along coastline in open grasslands, savannas, and woodlands; often forages near lakes and other wetlands	Documented in study area
American peregrine falcon *Falco peregrinus anatum*	--	E, FP, CDF	Permanent resident along north and south Coast Ranges; may summer in Cascade and Klamath Ranges and through Sierra Nevada to Madera County; winters in Central Valley south through Transverse and Peninsular ranges and plains east of Cascade Range	Nests and roosts on protected ledges of high cliffs, usually adjacent to lakes, rivers, or marshes that support large prey populations	Documented in study area
Prairie falcon (nesting) *Falco mexicanus*	--	SSC	Permanent resident in south Coast, Transverse, Peninsular, and northern Cascade ranges, the southeastern deserts, Inyo-White Mountains, foothills surrounding Central Valley, and in Sierra Nevada in Modoc, Lassen, and Plumas counties; winters in Central Valley, along the coast from Santa Barbara County to San Diego County, and in Marin, Sonoma, Humboldt, Del Norte, and Inyo counties	Nests on cliffs or escarpments, usually overlooking dry, open terrain or uplands; forages in open upland habitat	Documented in study area
Sharp-shinned hawk (nesting) *Accipiter striatus*	--	SSC	Permanent resident in Sierra Nevada, Cascade, Klamath, and North Coast ranges at middle elevations and along the coast in Marin, San Francisco, San Mateo, Santa Cruz, and Monterey counties; winters over the rest of the state except at very high elevations	Nests in dense-canopy ponderosa pine or mixed-conifer forest, and riparian habitats; forages in woodland and scrub	Documented in study area
Cooper's hawk (nesting) *Accipiter cooperii*	--	SSC	Throughout California except high altitudes in Sierra Nevada; winters in Central Valley, southeastern desert regions, and plains east of Cascade Range	Nests in a wide variety of habitat types, from riparian woodlands and grey pine-oak woodlands to mixed-conifer forests; forages on open water and in riparian vegetation	Documented in study area
Swainson's hawk *Buteo swainsoni*	--	T	Lower Sacramento and San Joaquin Valleys, Klamath Basin, and Butte Valley; highest nesting densities occur near Davis and Woodland, Yolo County	Nests in oaks or cottonwoods in or near riparian habitats; forages in grasslands, irrigated pastures, and grainfields	Documented in study area

Table 9-2, Cont'd.

	Status[1]				
Common and Scientific Names	**Federal**	**State**	**California Distribution**	**Habitat Requirements**	**Occurrence in Study Area[2]**
BIRDS, Cont'd					
Ferruginous hawk (wintering) *Buteo regalis*	--	SSC	Does not nest in California; winter visitor along the coast from Sonoma County to San Diego County, eastward to Sierra Nevada foothills and southeastern deserts, Inyo-White Mountains, plains east of Cascade Range, and Siskiyou County	Open terrain on plains and in foothills where ground squirrels and other prey are available	Documented in study area
Yellow rail *Coturnicops noveboracensis*	--	SSC	Historical records of nests in Mono County east of Sierra Nevada and Marin County on the coast; winters on the coast from Humboldt County to Orange County, and in Merced and Riverside counties	Freshwater marshes, brackish marshes, coastal salt marshes, and grassy meadows	Low potential
Greater sandhill crane *Grus canadensis tabida*	--	T, FP	Breeds in Siskiyou, Modoc, Lassen, Plumas, and Sierra counties; winters in Central Valley, southern Imperial County, Lake Havasu National Wildlife Refuge, and Colorado River Indian Reserve	Summers in open terrain near shallow lakes or freshwater marshes; winters on plains and in valleys near bodies of fresh water	Documented in study area
Western snowy plover (inland population) *Charadrius alexandrinus nivosus*	--	SSC	Nests at inland lakes throughout northeastern, central, and southern California; occasionally nests in Central Valley	Nests at alkaline or brackish inland lakes; forages on sandy shorelines	Documented in study area
Mountain plover *Charadrius montanus*	PT	SSC	Does not breed in California; in winter, found in Central Valley south of Yuba County, along the coast in parts of San Luis Obispo, Santa Barbara, Ventura, and San Diego counties, and in parts of Imperial, Riverside, Kern, and Los Angeles counties	Open plains or rolling hills with short grasses or very sparse vegetation; nearby bodies of water are not needed; may occupy newly plowed or sprouting grainfields	Documented in study area
Long-billed curlew (nesting) *Numenius americanus*	--	SSC	Nests in northeastern California in Modoc, Siskiyou, and Lassen counties; winters along the coast and in interior valleys west of Sierra Nevada	Nests in high-elevation grasslands adjacent to lakes or marshes; during migration and in winter, frequents coastal beaches, mudflats, interior grasslands, and agricultural fields	Documented in study area
Black tern (nesting colony) *Chlidonias niger*	--	SSC	Spring and summer resident of Central Valley, Salton Sea, and northeastern California where suitable emergent wetlands occur	Freshwater wetlands, lakes, ponds, moist grasslands, and agricultural fields; feeds mainly on fish and invertebrates while hovering over water	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
BIRDS, Cont'd					
Western yellow-billed cuckoo *Coccyzus americanus occidentalis*	C	E	Nests along upper Sacramento River, lower Feather River, south fork of Kern River, and Amargosa, Santa Ana, and Colorado Rivers; migratory range includes Central Valley	Wide, dense riparian forests with a thick understory of willows for nesting; sites with a dominant cottonwood overstory are preferred for foraging	Low potential
Western burrowing owl *Athene cunicularia*	--	SSC	Lowlands throughout California, including the Central Valley, northeastern plateau, southeastern deserts, and coastal areas; rare along south coast	Uses rodent burrows in sparse grassland, desert, and agricultural habitats	Documented in study area
Long-eared owl (nesting) *Asio otus*	--	SSC	Permanent resident east of Cascade Range from Placer County north to Oregon border, east of Sierra Nevada from Alpine County to Inyo County; scattered breeding populations along the coast, Sierra Nevada foothills, and in southeastern California; winters throughout Central Valley and southeastern California	Nests in abandoned crow, hawk, or magpie nests, usually in dense riparian stands of willows, cottonwoods, live oaks, or conifers	Documented in study area
Short-eared owl (nesting) *Asio flammeus*	--	SSC	Permanent resident along the coast from Del Norte County to Monterey County (although very rare in summer north of San Francisco Bay), in Sierra Nevada north of Nevada County, in plains east of Cascades, and in Mono County; winters primarily in Central Valley	Freshwater and salt marshes, lowland meadows, and irrigated alfalfa fields; needs dense tules or tall grass for nesting and daytime roosts	Documented in study area
Willow flycatcher *Empidonax traillii*	--	E	Summer range includes a narrow strip along the eastern Sierra Nevada from Shasta County to Kern County, another strip along the western Sierra Nevada from El Dorado County to Madera County; widespread in migration	Riparian areas and large, wet meadows with abundant willows for breeding; usually found in riparian habitats during migration	Documented in study area (migrating)
California horned lark *Eremophila alpestris actia*	--	SSC	Throughout much of California; less common in mountainous areas of the north coast and absent from coniferous and chaparral habitats	Open habitats, usually where large trees and shrubs are absent; prefers grasslands and deserts	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
BIRDS, Cont'd					
Bank swallow *Riparia riparia*	--	T	The state's largest remaining breeding populations are along the Sacramento River from Tehama County to Sacramento County, along the Feather and lower American rivers and Cache Creek, and in the Owens Valley; nesting areas also include the plains east of the Cascade Range south through Lassen County, northern Siskiyou County, and small populations near the coast from San Francisco County to Monterey County	Nests in bluffs or banks, usually adjacent to water, where the soil consists of sand or sandy loam to allow digging	Documented in study area
Loggerhead shrike *Lanius ludovicianus*	--	SSC	Resident and winter visitor in lowlands and foothills throughout California; rare on coastal slope north to Mendocino County, occurring only in winter	Open habitats with scattered shrubs, trees, posts, fences, utility lines, or other perches	Documented in study area
Least Bell's vireo *Vireo bellii pusillus*	E	E	Historically occurred in central and southern California; small populations remain in Riverside, San Diego, Orange, Los Angeles, Ventura, Santa Barbara, southern Inyo, and southern San Bernardino counties	Riparian thickets; nests along margins of bushes and forages low to ground	Low potential; species has been extirpated from area
California yellow warbler (nesting) *Dendroica petechia brewsteri*	--	SSC	Small permanent populations in San Diego and Santa Barbara counties; largest California breeding populations are in San Bernardino and Kern counties; spring and fall migrant in Central Valley	Nests in riparian trees dominated by willows, cottonwoods, sycamores, or alders, or in mature chaparral; may also use oaks, conifers, and urban areas near streams; during migration, uses woodland, forest, and scrub	Documented in study area
Tricolored blackbird (nesting colony) *Agelaius tricolor*	--	SSC	Permanent resident in Central Valley from Butte County to Kern County; breeds at scattered coastal locations from Marin County south to San Diego County and at scattered locations in Lake, Sonoma, and Solano counties; rare nester in Siskiyou, Modoc, and Lassen counties	Nests in dense colonies in emergent marsh vegetation, such as tules and cattails, or upland sites with blackberries, nettles, thistles, and grainfields; habitat must be large enough to support 50 pairs; probably requires water at or near nesting colony	Documented in study area

Table 9-2, Cont'd.

Common and Scientific Names	Status[1]		California Distribution	Habitat Requirements	Occurrence in Study Area[2]
	Federal	State			
MAMMALS					
Pale Townsend's (= western) big-eared bat *Corynorhinus townsendii pallescens*	--	SSC	Klamath Mountains, Cascades, Sierra Nevada, Central Valley, Transverse and Peninsular ranges, Great Basin, and Mojave and Sonora deserts	Uses a wide variety of habitats; gleans insects from brush or trees and feeds along habitat edges. Roosts in caves, tunnels, mines, trees, and buildings.	Low potential
Pacific Townsend's (=western) big-eared bat *Corynorhinus townsendii townsendii*	--	SSC	Coastal regions from Del Norte County south to Santa Barbara County	Uses a wide variety of habitats; gleans insects from brush or trees and feeds along habitat edges. Roosts in caves, tunnels, mines, trees, and buildings.	Low potential
Riparian brush rabbit *Sylvilagus bachmani riparius*	E	E	Limited to San Joaquin County at Caswell State Park near confluence of Stanislaus and San Joaquin Rivers; historically ranged from Stanislaus County to the Delta	Dense thickets of brush associated with riparian or chaparral habitats	Low potential; not documented near study area
San Joaquin (Nelson's) antelope ground squirrel *Ammospermophilus nelsoni*	--	T	Western side of San Joaquin Valley from southern Merced County south to Kern and Tulare counties; also found on Carrizo Plain in San Luis Obispo County and Cuyama Valley in San Luis Obispo and Santa Barbara counties	Arid grasslands with loamy soils and moderate shrub cover of *Atriplex* and other shrub species	Low potential; not documented near study area
Fresno kangaroo rat *Dipodomys nitratoides exilis*	E	E	Fresno County only	Found at 200-foot to 300-foot elevations in alkali-sink habitats	Moderate potential; captured at Alkali Sink Ecological Reserve and Wildlife Management Area near the study area
San Joaquin Valley (Riparian) woodrat *Neotoma fuscipes riparia*	E	SSC	Known only from an area along the San Joaquin, Stanislaus, and Tuolumne rivers in Stanislaus and San Joaquin counties; only verified extant population is restricted to Caswell Memorial State Park on the Stanislaus River; historically occurred in northern San Joaquin Valley	Riparian forest where trees and brush are available for cover and nesting	Low potential; not documented near study area
San Joaquin kit fox *Vulpes macrotis mutica*	E	T	Principally occurs in San Joaquin Valley and adjacent open foothills to the west; recent records show presence in 17 counties, extending from Kern County north to Contra Costa County	Saltbush scrub, grasslands, oak savannas, and freshwater scrub	Documented in study area

Table 9-2, Cont'd.

FOOTNOTES

[1] Legal Status:

Federal status
E = listed as endangered under the federal Endangered Species Act
T = listed as threatened under the federal Endangered Species Act
PE = proposed for federal listing as endangered under the federal Endangered Species Act
PT = proposed for federal listing as threatened under the federal Endangered Species Act
C = candidate species; species for which the U.S. Fish and Wildlife Service has on file sufficient information on biological vulnerability and threat(s) to support issuance of a proposed rule to list
PD = proposed for delisting
-- = no status

State status
E = listed as endangered under the California Endangered Species Act
T = listed as threatened under the California Endangered Species Act
SSC = species of special concern in California
FP = fully protected under the California Fish and Game Code
CDF = listed as "sensitive" by the California Department of Forestry and Fire Protection
-- = no status

[2] See the text for specific information regarding the location and timing of documented occurrences.

Jepson Prairie Reserve in Solano County, the Sacramento Wildlife Refuge in Glenn County, Haystack Mountain in Merced County (Eng et al. 1990), and in the San Luis NWR complex (USFWS file data). There is also 1 unconfirmed population from Ventura County on Matau Flat Road.

The Conservancy fairy shrimp is found in large, clay-bottomed vernal pools. Average depth of occupied ponds is approximately 7.8 inches. Specimens have been collected from poorly vegetated, turbid pools from November to early April (Eng et al. 1990). Copulation occurs shortly before the pools dry up and the eggs are either dropped to the pool bottom or remain in the brood sac until the female dies and then sinks to the bottom of the pool. These eggs can withstand heat, cold, and prolonged desiccation and are often referred to as "resting" or "summer" eggs. When the pool is re-watered within the current season, or several seasons later, some, but not all, of the eggs may hatch (USFWS 1994). Fairy shrimp develop quickly after hatching. According to Donald (1983, as cited in USFWS 1994), the egg bank in the soil of a vernal pool could be comprised of eggs from several years of breeding. This species achieves sexual maturity at a mean age of 37 days, reproduces at a mean age of 46 days, and has a mean life span of approximately 114 days (Helm 1998).

This species has been documented at the San Luis, Kesterson, and Arena Plains units of the San Luis NWR complex (USFWS file data) but would not be expected elsewhere in the study area because suitable vernal pool habitat is lacking.

This species was reported from one vernal pool at Great Valley Grasslands State Park (Hoopes et al. 1996); however, the tabular data did not correspond with the published map. Subsequent examination by a Jones & Stokes invertebrate biologist of the specimens collected during the Hoopes et al. (1996) study (1996) did not confirm the identity of the Conservancy fairy shrimp at Great Valley Grasslands State Park. The species has been documented in the Gustine, San Luis Ranch, Stevinson, and Turner Ranch quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.3.2. Longhorn Fairy Shrimp (*Branchinecta longiantennae*)

Longhorn fairy shrimp are federally endangered. This species is known from 8 disjunct populations along the eastern margin of the central Coast Range from Alameda and Contra Costa counties south to Carrizo Plain in San Luis Obispo County (USFWS 1994). This species also was identified at the Kesterson Unit of San Luis NWR.

Longhorn fairy shrimp inhabit clear to turbid, grass-bottomed vernal pools in grasslands and clear-water pools in sandstone depressions (USFWS 1994). They have been observed from late December until late April in grassland pools characterized by low conductivity, total dissolved solids, and alkalinity (USFWS 1994). This species achieves sexual maturity at a mean age of 22 days, reproduces at a mean age of 43 days, and has a mean life span of approximately 114 days (Helm 1998).

Presence of this species at Kesterson suggests that they might be found elsewhere in vernal pools of the San Luis NWR complex (JSA et al. 2000), but would not be expected elsewhere in the study area because suitable vernal pool habitat is lacking. The species has been documented in the Gustine, Ingomar, San Luis Ranch, and Stevinson quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.3.3. Vernal pool fairy shrimp (*Branchinecta lynchi*)

The vernal pool fairy shrimp is listed as threatened under ESA. It is found from Shasta County in the north, throughout the Central Valley, and west to the central Coast Ranges. Southern populations occur on the Santa Rosa Plateau and near Rancho, California in Riverside County (Eng et al.1990).

The vernal pool fairy shrimp is endemic to small, shallow wetlands in California (Helm 1998). It is found in grassland vernal pools, rock outcrops, and roadside ditches from December through early May. This species achieves sexual maturity at a mean age of 18 days, reproduces at a mean age of 40 days, and has a mean life span of approximately 91 days (Helm 1998).

The vernal pool fairy shrimp has been documented at the West Bear Creek, San Luis, Kesterson, and Arena Plains units of the San Luis NWR complex (USFWS file data, as cited in JSA et al. 2000), but would not be expected elsewhere in the study area because suitable vernal pool habitat is lacking. This species was documented at 11 of 71 surveyed vernal pools in the West Bear Creek Unit (JSA et al. 2000). It has been documented in the Gustine, Lanes Bridge, Little Table Mountain, San Luis Ranch, Sandy Mush, Stevinson, Turner Ranch, Friant, and Gregg quadrangles (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.3.4. Vernal Pool Tadpole Shrimp (*Lepidurus packardi*)

The vernal pool tadpole shrimp is listed as endangered under ESA. The vernal pool tadpole shrimp is found scattered throughout the Central Valley from the Millville and Stillwater Plains in Shasta County south to Merced County (Helm 1998).

The vernal pool tadpole shrimp is found in stockponds and vernal pools. The eggs are deposited on vegetation and other objects on the bottom of the pool. These eggs can withstand heat, cold, and prolonged desiccation and will wait out the summer months as diapaused eggs in pool sediment (USFWS 1994). When the pool is re-watered in the fall and winter of subsequent seasons, some, but not all, of the eggs may hatch. This species achieves sexual maturity at a mean age of 38 days, reproduces at a mean age of 54 days, and has a mean life span of approximately 144 days (Helm 1998). Specimens have been collected from winter through spring (Helm 1998).

This species has been documented at the West Bear Creek, San Luis, Kesterson, and Arena Plains units of the San Luis NWR complex (JSA et al. 2000), but would not be expected elsewhere in the study area because suitable vernal pool habitat is lacking.. It was documented at 41 of 71 surveyed vernal pools at the West Bear Creek Unit and at 34 vernal pools at Great Valley Grasslands State Park (JSA et al. 2000). It has been documented in the Gustine, Ingomar, San Luis Ranch, Stevinson, and Turner Ranch quadrangles (CNDDB 2002). This species could occur in other locations of the study area that support suitable habitat. Restoration actions that influence vernal pools could affect this species.

9.5.3.5. Valley Elderberry Longhorn Beetle (*Desmocercus californicus dimorphus*)

The valley elderberry longhorn beetle is listed as threatened under ESA. The valley elderberry longhorn beetle is found in scattered populations throughout its historical distribution. The valley elderberry longhorn beetle was historically distributed throughout the Central Valley from Redding (Shasta County) to Bakersfield (Kern County) (Arnold et al. 1994). The species' range includes most of the California Central Valley north to Trinity County, south to San Diego County, and east to San Bernardino County (Barr 1991). Occurrences have been recorded in Merced, Stanislaus, and San Joaquin counties (CDFG 1997). These beetles are dependent on elderberry plants (*Sambucus* spp.), which occur within riparian forests of the Central Valley or occasionally in separate patches or as individuals in non-forested habitat types.

Eggs are laid in crevices in elderberry bark and hatch in about 10 days. Larvae bore into the pith of elderberry roots, branches, and trunks to create an opening in the stem within which they pupate for one or two years before they emerge as adults. Larvae feed on tree pith, while adults eat the foliage and possibly the flowers of the plants. After metamorphosing into an adult, the beetle chews a circular exit hole through which it emerges (Barr 1991). Current information on the habitat of the beetle indicates that it is found only with its host plant, the elderberry.

A population of valley elderberry longhorn beetles was reported in a stand of elderberry shrubs at RM 245 (Reach 1A) of the San Joaquin River (Thelander 1994). Numerous host plants were also identified in surveys conducted east of Mendota near the Chowchilla Canal, several of which had holes in the trunk that may have been made by exiting beetle larvae (Kucera et al. 2001). The species has been documented in the Lanes Bridge and Herndon quadrangles (CNDDB 2002). This species could occur in other locations of the study area that support suitable habitat. Restoration actions that influence riparian scrub could affect this species.

9.5.3.6. California Red-legged Frog (*Rana aurora draytonii*)

The California red-legged frog is a federally threatened taxon and is considered a species of special concern by CDFG. This species is one of two subspecies of the red-legged frog (*Rana aurora*) that occur along the Pacific Coast. The species occurs west of the Sierra-Cascade crest and along the Coast Ranges for the length of the state of California (Stebbins 1985). The California subspecies (*Rana aurora draytonii*) historically ranged from the vicinity of Point Reyes National Seashore (Marin County) along the coast and from the vicinity of Redding (Shasta County) inland, south to northwestern Baja California. There are no known extant populations of this subspecies in California's Central Valley (Jennings and Hayes 1994). According to Jennings and Hayes (1994), there are several old records for the California red-legged frog from western Stanislaus County and western Tuolumne County.

A highly aquatic species invariably associated with water, the California red-legged frog inhabits still or slow water in streams, marshes, ponds, reservoirs, and canals (Stebbins 1951). Like all frogs, tadpoles are herbivorous and switch to carnivory after metamorphosis (Zeiner et al. 1988). The California red-legged frog preys on terrestrial and aquatic insects, crustaceans and mollusks, and sometimes small fish and tadpoles as well. Preferred riparian habitat consists of deep, still pools surrounded by dense stands of cattails and overhanging vegetation such as willow. On occasion, individuals may be found in less optimal habitat. California red-legged frogs utilize small mammal burrows and moist leaf litter up to 85 feet (26 m) from water in dense riparian vegetation for aestivation. Permanent, deep pools are required for reproduction and larval development (Zeiner et al. 1988). Rain or moist conditions may be necessary for dispersal.

The California red-legged frog, once considered a culinary delicacy, was harvested to the brink of extinction in the late 1800s. Some remaining populations are highly restricted and consist of small numbers of individuals (Jennings et al. 1992). Human activities that result in habitat destruction and the introduction of exotic competitors and predators have a negative effect on populations (Moyle 1973). This species has been historically recorded from the Newman quadrangle by CNDDB, although it is now extirpated from the San Joaquin Valley (CNDDB 2002).

9.5.3.7. Blunt-nosed Leopard Lizard (*Gambelia silus*)

The blunt-nosed leopard lizard is listed as endangered under ESA and CESA, and as a fully protected species under the California Fish and Game Code. The blunt-nosed leopard lizard was historically found throughout the San Joaquin Valley and adjacent foothills from San Joaquin County to eastern San Luis Obispo County (CDFG 1992). Blunt-nosed leopard lizard habitat was reduced from 228,000 acres to 158,000 acres between 1976 and 1980 (CDFG 1992). The species currently occupies isolated and scattered areas of undeveloped habitat on the San Joaquin Valley floor and in the eastern foothills of the Coast Ranges (CDFG 1992).

Blunt-nosed leopard lizards are found in sparsely vegetated plains, alkali flats, grasslands, low foothills, canyon floors, and large washes (CDFG 1988). They inhabit areas with sandy soils and scattered vegetation and are usually absent from thickly vegetated habitats (CDFG 1992). The mating season for the blunt-nosed leopard lizard is from late April through May (Zeiner et al. 1988). Breeding females can be identified by the orange or reddish spots on their sides (CDFG 1992). Blunt-nosed leopard lizards feed on a variety of insects, as well as on other small lizards, and have been known to be cannibalistic (Zeiner et al. 1988).

There are several records of this species occurring near Mendota Pool. Restoration actions that influence open upland habitats may affect this species.

9.5.3.8. Giant Garter Snake (*Thamnophis couchi gigas*)

The giant garter snake is listed as threatened under ESA and CESA. According to Fitch (1940, as cited in USFWS 1993), the historical range of the giant garter snake extended from the vicinity of Sacramento and Contra Costa counties south to Buena Vista Lake, near Bakersfield in Kern County. The lack of records prior to 1970 makes it difficult to precisely establish the species' former range; however, the records coincide with the historical distribution of large flood basins, freshwater marshes, and tributary streams in the Central Valley (USFWS 1993).

The giant garter snake was apparently extirpated from the southernmost portion of its range by the 1940s to 1950s due to loss of wetlands to agriculture and other land uses (Hansen and Brode 1980, as cited in USFWS 1993). As recently as the 1970s, the species was found from near Burrell, Fresno County (Hansen and Brode 1980, as cited in USFWS 1993) north to the vicinity of Chico, Butte County (Rossman and Stewart 1987, as cited in USFWS 1993). According to Fisher et al. (1994), the giant garter snake currently is found from Butte Creek near Gridley, 19 km (12 mi) south of Chico in Butte County south to the Mendota Wildlife Area, 16 km (10 mi) west of Fresno, implying that they could still be distributed in general vicinity of the study area. However, according to Hansen (1988, as cited in USFWS 1993), the species is distributed in portions of the rice production zones of Sacramento, Sutter, Butte, Colusa, and Glenn counties; along the western border of the Yolo Bypass in Yolo County; and along the eastern edge of the Sacramento-San Joaquin River delta from the Laguna Creek-Elk Grove region of central Sacramento County south to the Stockton area of San Joaquin County.

The giant garter snake is the largest member of its genus and one of the most aquatic of the garter snakes, feeding on small fish, tadpoles, and frogs (Fisher et al. 1994). It frequents areas of permanent freshwater, particularly sloughs and marshes overgrown with tules, willows, and weeds (Hansen and Brode 1980), and is rarely seen more than a few feet from water. It requires terrestrial burrows or crevices that do not flood for winter hibernation. Hibernation occurs from late October to mid- or late March, in the abandoned burrows of small mammals located above prevailing flood elevations (Fisher et al. 1994). Breeding occurs in March and April (Hansen and Hansen 1990, as cited in USFWS 1993). Females give birth to live young from July through September, with litter size varying between 10 and 46 young (Fisher et al. 1994).

The CNDDB lists records for this species for San Joaquin and Merced counties; no records were found for Stanislaus County (CDFG 1997). According to CNDDB records (as cited in USFWS 1993), there have been no records of observations from Burrell, Fresno County, north to Stockton, San Joaquin County since 1980. This subspecies has been observed at the San Luis, Kesterson, and West Bear Creek units of the San Luis NWR (Woolington, pers. comm., as cited in JSA et al. 2000). It has also been documented in the Mendota Wildlife Area (Newman et al. 2001), and south of the study area in Fresno Slough. Restoration actions that influence wetlands could affect this species.

9.5.3.9. Bald Eagle (Haliaeetus leucocephalus)

The bald eagle is listed as threatened under ESA (but has been proposed for delisting), as endangered under CESA, as fully protected under the California Fish and Game Code, and as sensitive by the California Department of Forestry and Fire Protection. The bald eagle is also protected under the federal Bald and Golden Eagle Protection Act. Historically, the bald eagle nested throughout California; however, the current breeding distribution is restricted primarily to the mountainous habitats in the northern quarter of the state, in the northern Sierra Nevada, Cascades, and northern Coast Ranges (CDFG 1992). Bald eagles winter at lakes, reservoirs, and along major river systems throughout most of central and northern California and in a few southern California localities.

By 1972, there were only 26 known active bald eagle territories in California. Currently, approximately 100 pairs of bald eagles nest in the state. Nesting remains primarily restricted to the northern part of the state, with concentrations of birds at Shasta Lake, Claire Engle Lake, Eagle Lake, and Lake Almanor, and on the Pit River between Lake Britton and Shasta Lake. Additionally, 3 pairs of bald eagles are known to nest on the floor of the Central Valley in Shasta and Tehama counties. Another pair of bald eagles is known to nest at Eastman Lake (Chowchilla River) in Madera County. The species appears to be increasing in most portions of the state (CDFG 1992).

Bald eagle nesting territories in California are found primarily in ponderosa pine and mixed conifer forests. Bald eagle nest sites are always associated with a lake, river, or other large water body and are usually within 1 mile of water. Nests are usually constructed in a tree that provides an unobstructed view of the water body and that is almost always the dominant or codominant tree in the surrounding stand. Snags and dead-topped live trees are important habitat components in a bald eagle nesting territory, providing perch and roost sites. Bald eagles winter along rivers, lakes, or reservoirs that support adequate fish or water bird prey and have mature trees or large snags available for perch sites. Bald eagles often roost communally during winter, typically in mature trees or snags with open branching structures that are isolated from human disturbance.

Bald eagles are annual winter residents within the San Luis NWR complex, with sightings at the West Bear Creek Unit in 1995 and 1999 (JSA et al. 2000). Large numbers of bald eagles overwinter at Lake Millerton each year, and a few have been observed foraging along the river near Rank Island (M. Wolfe, pers. obs.). Restoration actions that influence fish, the bald eagle's prey, in the San Joaquin River, or that influence nesting or roosting trees near the river, could affect this species.

9.5.3.10. American Peregrine Falcon (*Falco peregrinus anatum*)

American peregrine falcons are listed as endangered under the CESA, designated a sensitive species by the California Department of Forestry and Fire Protection, and fully protected under the California Fish and Game Code. This species was nearly driven to extinction in the 1970s by DDT use and PCB poisoning. Current recovery efforts are directed at controlling pesticides and protecting breeding sites (CDFG 1992). If successful, these efforts will increase population sizes, thereby reducing vulnerability to stochastic environmental factors. The breeding population is stable and increasing, with population increases occurring in some parts of the state, but little or no improvement occurring in others (Cade 1988, CDFG 1992). The USFWS delisted the species in 1999. It historically bred over most of North America, from the tree line south to Baja California. It is now absent from large areas except where it has been successfully reintroduced. This species has reoccupied most of its historical breeding range in California, including the Channel Islands, the Coast and Cascade ranges, and the Sierra Nevada Range. Peregrines inhabit all counties in the state at various times of the year (Gertsch et al. 1994).

Peregrine falcons usually breed near water bodies in open areas with cliffs and canyons. While breeding pairs tend to remain near their breeding territories throughout the year, immature and non-breeding individuals range over large distances, including Oregon and Mexico. During winter, the California peregrine population increases in areas where prey is abundant (Gertsch et al. 1994). Peregrines feed almost exclusively on other birds, usually pigeons, songbirds, shorebirds, and waterfowl, which they kill in mid-air with blows from their talons. Nesting sites are typically on ledges of large cliff faces, but some pairs are now nesting on city buildings and bridges. Nesting and wintering habitats are varied, including wetlands, woodlands, and other forested habitats, cities, agricultural lands, and coastal habitats (Gertsch et al. 1994).

Although this taxon has been documented in the West Bear Creek area (JSA et al. 2000), the CNDDB lists no records of this species in the study area quadrangles (CNDDB 2002). Restoration actions that influence wetlands and other areas where their prey is concentration could affect this taxon.

9.5.3.11. Swainson’s Hawk (*Buteo swainsoni*)

Swainson’s hawks are listed as threatened under CESA. The Swainson’s hawk’s breeding range extends from southwestern Canada to northern Mexico (Godfrey 1986, Semenchuk 1992, Howell and Webb 1995, Smith 1996, England et al. 1997). Nearly all North American populations of Swainson’s hawks winter in South America and Mexico; however, some small populations regularly winter in the United States in southern Florida (Stevenson and Anderson 1994) and in the San Francisco Bay Delta (Yee et al. 1991, Herzog 1996).

Throughout its range, the Swainson’s hawk nests almost exclusively in only a few species of trees (Schlorff and Bloom 1983). A survey of nesting birds in California during 1979 revealed that Swainson’s hawks nested almost exclusively in large, sparsely vegetated flatlands characterized by valleys, plateaus, broad flood plains, and large expanses of desert (Bloom 1980). In a study of movements and habitat use, it was found that single trees or riparian areas were used most often for nesting (Estep 1989). Swainson’s hawks forage in many crops, and Schmutz (1987) found that the species is more abundant in areas of moderate cultivation than in either grassland or areas of extensive cultivation. Alfalfa is routinely used by foraging Swainson’s hawks (Estep 1989, Woodbridge 1991), but the ability of the hawk to use cultivated lands for foraging is a complex interaction of crop phenology and cultural practices (Schmutz 1987, Estep 1989, Woodbridge 1991). Orchards and vineyards, in general, are not suitable foraging habitat for Swainson’s hawks because of the dense woody cover, and rice is unsuitable most of the season because it is flooded (Estep 1989).

Swainson’s hawks can be observed throughout the San Luis NWR complex from early spring until late summer (JSA et al. 2000). Nests have been documented in riparian habitats at the West Bear Creek Unit and at Great Valley Grasslands State Park (JSA et al. 2000). The floodplain of the West Bear Creek Unit is an important staging area for fall migrants, with flocks up to 70 individuals being documented (San Luis NWR file data, as cited in JSA et al. 2000). Swainson’s hawks were frequently observed in the vicinity of the Chowchilla Canal on the San Joaquin River east of Mendota, typically within 1 mile (1.6 km) upstream of the diversion dams (Kucera et al. 2001). Nesting territories in the Mendota Pool area have been observed since 1979 by CDFG (R. Schlorff, pers. comm., as cited in Kucera et al. 2001), and three Swainson’s hawks were observed soaring above the river approximately 0.20 miles upstream from the Gravelly Ford Gauging Station near river milepost 227.7 (Newman et al. 2001). The species has been reported in numerous quadrangles in the project area by (CNDDB 2002). Restoration actions that influence riparian trees, adjacent grasslands, or adjacent alfalfa fields may affect this species.

9.5.3.12. Greater Sandhill Crane (*Grus canadensis tabida*)

Greater sandhill cranes are listed as threatened under CESA and are fully protected under California Fish and Game Code Section 3511. Historically, greater sandhill cranes nested in eastern Siskiyou County, northeastern Shasta County, and at Honey Lake in Lassen County (California Department of Fish and Game 1992). In a study of crane reproduction in 1988, nesting populations were found in Lassen (75 pairs), Modoc (165 pairs), Plumas (7 pairs), Shasta (1 pair), Sierra (1 pair), and Siskiyou (27 pairs) counties (Littlefield 1989, Littlefield et al. 1994, California Department of Fish and Game 1997, Pacific Flyway Council 1997). Lesser sandhill cranes *(G. c. canadensis*) breed in Siberia, Alaska, and northern Canada (Johnsgard 1983). Both subspecies winter in the Central Valley. During winter, they feed on grasses, forbs, waste grains, small mammals, amphibians, snakes, and invertebrates (Zeiner et al. 1990). They feed in pastures, flooded grain fields, and seasonal wetlands. The Grasslands Ecological Area, specifically the Merced NWR and Arena Plains Unit, is the primary wintering area for the majority (over 12,000) of the Pacific Flyway's lesser sandhill crane population.

USFWS has conducted sandhill crane surveys within the West and East Bear Creek units of the San Luis NWR since 1994. The highest counts for lesser sandhill cranes (2,500) were within the West Bear Creek Unit native uplands in 1995 (JSA et al. 2000). The highest counts for greater Sandhill cranes (37) were along the San Joaquin River in October 1997 (JSA et al. 2000). San Luis NWR personnel reported that sandhill crane populations appear to be doing well at the refuge complex (JSA et al. 2000). Sandhill cranes have been observed in Reach 2 over several years (M. Wolfe, pers. obs.). Restoration actions that influence wetlands and grasslands may affect this species.

9.5.3.13. Western Snowy Plover (*Charadrius alexandrinus nivosus*)

The western snowy plover is designated as a species of special concern by CDFG, and designated a migratory non-game bird of management concern by USFWS. There are two distinct populations of western snowy plover: coastal and inland. The inland population is the one that occurs in the Central Valley; the coastal population, listed as threatened under the ESA, is restricted to the coastline.

The western snowy plover's current distribution in California is along the coast from Oregon to Mexico and near lakes in the drier interior portions of California. In 1980, the adult population was estimated at 3,408 individuals; by 1989 it was estimated at 3,031. The largest coastal breeding population of this species is found around the San Francisco Bay; the largest inland breeding populations are found around Owens Lake (Inyo County) and Alkali Lake (Modoc County) (Small 1994).

The inland populations nest around the shores of alkali lakes and along dikes of saltponds (Grinnell and Miller 1944). There are nesting sites scattered along the coast from the Oregon border to San Diego County, as well as along many inland lakes and saltponds and on the Channel Islands (Remsen 1978). Western snowy plovers nest from April to August. Nests are built by digging a depression in the sand and lining it with shells and other debris (Zeiner et al. 1990). Western snowy plovers feed on arthropods in the dry sands of the upper beach, rarely foraging in the wet sand, and primarily on brine flies around saltponds and alkali lakes (Cogswell 1977).

The western snowy plover has been documented to occur at the Kesterson Unit of the San Luis NWR. It probably also occurs at the San Luis and Arena Plains units (San Luis NWR file data, as cited in JSA et al. 2000). Restoration actions that influence sandy beaches and shorelines could affect this taxon.

9.5.3.14. Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*)

Western yellow-billed cuckoos are a candidate species for federal listing and are listed as endangered by the state of California. The cuckoo ranges across most of the U.S. and northern Mexico, and winters in South America. The western subspecies of the yellow-billed cuckoo historically nested from British Columbia south to Mexico and was known to breed in all regions of California except the central and northern Sierra Nevada, the Great Basin, and the Colorado Desert. The western yellow-billed cuckoo's population has been severely reduced by loss of riparian habitats. Grazing, cutting of streamside vegetation, and water diversion projects have also impacted habitat for this species. In addition, pesticide use has resulted in eggshell thinning and reproductive failure (Laymon and Halterman 1987). Now, the western yellow-billed cuckoo has been extirpated as a nesting species from most of the state and the current distribution of the western subspecies is limited to scattered locations in California and along the Colorado River.

The species was observed in 1916 on the Tuolumne River near Modesto; this nesting population is currently presumed to be extirpated (CDFG 1997). In the late 1960s, a few yellow-billed cuckoos were regularly observed near the confluence of the Tuolumne and San Joaquin rivers, but this area was subsequently subject to intensive logging and no cuckoos have been observed in recent years (H. Reeve, pers. comm., 1998). Reeve (1988) considers the yellow-billed cuckoo to be a rare migratory species during the spring in Stanislaus County. No summer occurrences have been recorded.

This species forages primarily on grasshoppers, cicadas, caterpillars and other insects, which it gleans from foliage, and occasionally on small vertebrates and fruits (Bent 1940, Preble 1957). It is monogamous, with both sexes sharing in incubation of eggs and feeding of young during mid-June to late July. It nests in extremely dense willows, cottonwood, or occasionally mesquite vegetation (Hamilton and Hamilton 1965). Cuckoos inhabit densely foliated, deciduous trees and shrubs, particularly willows, with a dense understory formed by blackberry, nettles and/or wild grapes, and which abut on slow-moving watercourses, backwaters, or seeps (CDFG 1983). River bottoms and other mesic habitats, including valley-foothill and desert riparian habitats are necessary for breeding. Dense low-level or understory foliage with high humidity is preferred (Gaines 1974, 1977). This taxon may avoid valley-oak riparian habitats where scrub jays are abundant.

The western yellow-billed cuckoo has been recorded in the Firebaugh and Mendota Dam quadrangles (CNDDB 2002). Restoration actions that influence riparian scrub could affect this species.

9.5.3.15. Willow Flycatcher (*Empidonax traillii*)

The willow flycatcher is listed as endangered under CESA. Currently, 2 subspecies, *E. t. brewsteri* and *E. t. adastus*, are fairly common migrants in riparian habitats of the Central Valley. A third subspecies, Southwestern willow flycatcher (*E. t. extimus*), a rare breeder along the South Fork Kern River (Whitfield et al. 1999), is also listed as endangered under the federal ESA.

This species is a rare to locally uncommon summer resident in wet meadow and montane riparian habitats. The willow flycatcher most often occurs in broad open river valleys or large mountain meadows with lush growth of shrubby willow.

Within the San Joaquin River floodplain, willow flycatchers are rare spring and uncommon fall migrants in riparian habitats of the San Luis and West Bear Creek units of the San Luis NWR (JSA et al. 2000). The Point Reyes Bird Observatory (PRBO) banded migrant willow flycatchers in riparian habitats of the San Joaquin River in spring and fall (Ballard and Geupel 1999). Restoration actions that influence willow scrub in riparian areas and meadows may affect this species.

9.5.3.16. Bank Swallow *(Riparia riparia)*

The bank swallow is listed as threatened under the CESA. The bank swallow historically occurred along the larger lowland rivers throughout California, with the exception of southern California, where the species occurred principally along the coast and at the mouths of large rivers such as the Los Angeles River (Humphrey and Garrison 1987, Laymon et al. 1988). This species has now been extirpated from southern California and its range has been reduce by 50% since 1900 (Laymon et al. 1988, CDFG 1997). It is currently confined to the Sacramento River above the town of Colusa, where colonies averaging about 250–410 burrows each have been documented since 1986 (Humphrey and Garrison 1987, Laymon et al. 1987, CDFG 1993), and is scattered in colonies in northern California. During a survey conducted in 1987, 111 colonies were located and the statewide population was estimated at 18,800 pairs, about 70% of which occurred along the Sacramento River (Laymon et al. 1988, CDFG 1993). The last stronghold for the bank swallow is along the banks of the Sacramento River (CDFG 1992) and its major tributaries (Humphrey and Garrison 1987). The population estimate as of 2000 of 4,990 nesting pairs, based on annual CDFG monitoring surveys, indicates a population decline of about 73% since 1987.

The bank swallow is a migrant that breeds primarily in the Central Valley of California and winters in South America. It arrives in California in mid-March, with numbers of birds peaking in May (Humphrey and Garrison 1987, Laymon et al. 1988). The bank swallow requires bluffs or banks with soft sand and sandy loam soil primarily immediately adjacent to still or running water. Gravel extraction sites, such as those along Cache Creek in Yolo County, are sometimes used for nesting. Sacramento River colonies have ranged from 78 in 1987 to the current total of 42. The species constructs burrows 2–3 feet deep into the nearly vertical eroding banks where it chooses to establish nesting colonies. The bank swallow breeds and lays a clutch of 4–5 eggs in April; the young hatch in May and 2–3 young are fledged by July each year in a single breeding attempt. The adults and young-of-the-year remain along the riverbanks until they migrate south in the fall.

Bank swallows occur near Mendota Pool. Restoration actions that influence the structure or flooding of high river banks could affect this species.

9.5.3.17. Least Bell's Vireo (*Vireo bellii pusillus*)

The least Bell's vireo is listed as endangered by both the USFWS and the state of California (CDFG 2000). Formerly, the vireo was known to breed from interior northern California near Red Bluff in Tehama County south through the Sacramento and San Joaquin valleys and Sierra Nevada foothills, and in the coastal ranges from Santa Clara County south to the approximate vicinity of San Fernando in Baja California. It historically nested throughout riparian areas in the Central Valley and in other low-elevation riparian zones in California (CPIF and RHJV 1998). The bird also occurred in the Owens and Death valleys in Inyo County and at scattered oases and canyons throughout the Mojave Desert (CDFG 2000).

The species was characterized as abundant at one time (USFWS 1998, as cited by CPIF and RHJV 1998), but is now absent from most of its historical range. In 1973, no members of the species were found during an extensive search of formerly occupied habitat between Tehama County and San Joaquin County (Gaines 1974, as cited by CPIF and RHJV 1998). By 1980, the species was extirpated from the entire Central Valley (USFWS 1998, as cited by CPIF and RHJV 1998). Currently, its breeding range is restricted to Southern California, with large populations in Riverside and San Diego counties and smaller populations in Santa Barbara, Ventura, and San Diego counties and in northern Baja California (CDFG 2000). However, recent observations indicate that the species' range is expanding northward and individuals are currently recolonizing areas that have been unoccupied for decades (USFWS 1998, as cited in CPIF and RHJV 1998). The vireo is threatened by loss and degradation of its habitat through human and human-induced activities and by nest parasitism of the brown-headed cowbird. Adverse impacts to vireo habitat result from clearing of land for urban and suburban development and for agriculture, water projects, severe flooding due to water releases from dams, military activities (e.g., troop training), fires, off-road vehicles, livestock activities, invasion of non-native plant species, and long-term camping activities (CDFG 2000).

The least Bell’s vireo is a summer resident of cottonwood-willow forest, oak woodland, shrubby thickets, and dry washes with willow thickets at the edges (CDFG 2000). It inhabits low, dense riparian growth along water or along dry parts of intermittent streams and gleans insects from foliage and branches. The least Bell’s vireo is typically associated with willow, cottonwood, coyote bush, wild blackberry, or mesquite in desert localities, as they afford nesting and roosting cover.

The least Bell’s vireo has not been recorded in the study area quadrangles (CNDDB 2002). Restoration actions that influence riparian scrub and forest could affect habitat for this species and the potential for its recolonization of the area.

9.5.3.18. Riparian Brush Rabbit (*Sylvilagus bachmani riparius*)

The riparian brush rabbit is listed as endangered under both the federal and state ESA. Historically, the brush rabbit was found along portions of the San Joaquin River and its tributaries on the valley floor from Stanislaus County to the Sacramento-San Joaquin Delta. Currently, due to habitat destruction, the entire remaining population of this species is believed to be confined to Caswell Memorial State Park, at the confluence of the Stanislaus River with the San Joaquin River.

Riparian brush rabbits are found in small clearings amongst dense riparian vegetation, where they feed on grasses, sedges, clover, forbs, and leaves. They tend to avoid riparian forests with a continuously closed canopy because this type of habitat does not support shrubs and forbs preferred as food (Williams et al. 1997). The riparian brush rabbit has been heavily impacted by construction of large dams in the Central Valley and the conversion of large tracts of land to agriculture, which has fragmented riparian habitat. The remaining population of riparian brush rabbits suffered heavy mortality during the floods of 1986 and 1997 (Williams et al. 1997). The recovery strategy for the riparian brush rabbit includes establishment of new populations at sites other than Caswell Memorial State Park to reduce the risk of catastrophic floods or wildfires driving this species to extinction.

The taxon is not known to occur in the study area and has not been documented in the CNDDB in the vicinity of the study area. Restoration actions that influence the formation and maintenance of riparian scrub could affect habitat for this rabbit, and its potential to re-colonize the study area.

9.5.3.19. San Joaquin (Nelson’s) Antelope Ground Squirrel (*Ammospermophilus nelsoni*)

The San Joaquin antelope ground squirrel is listed as endangered by the state of California. The historical distribution of the San Joaquin antelope ground squirrel included the western and southern portions of the Tulare Basin, San Joaquin Valley, and the contiguous areas to the west in the upper Cuyama Valley and on the Carrizo and Elkhorn plains. The species ranged from western Merced County on the northwest, southward along the western side of the San Joaquin Valley to its southern end (Williams et al. 1998). San Joaquin antelope squirrels range in elevation from about 165 feet (50 meters) on the San Joaquin Valley floor to about 3,600 feet (1,100 meters) in the Temblor Mountains. Loss of habitat to agricultural developments, urbanization, and petroleum extraction is the principal factor threatening San Joaquin antelope ground squirrels (Williams et al 1998). Another threat to these ground squirrels on private land may be the long-term effects of excessive grazing by livestock (Williams et al. 1998).

In the southern and western San Joaquin Valley, San Joaquin antelope ground squirrels are associated with open, gently sloping land with shrubs. Typical vegetation includes saltbushes and ephedra (Hawbecker 1975, as cited in Williams et al 1998).

Hawbecker (1975, as cited in Williams et al. 1998) reported that near Los Banos, Merced County, and near Mendota, Fresno County, the habitat is mostly devoid of brushy cover. Extant, uncultivated habitat for San Joaquin antelope squirrels was estimated in 1979 to be 275,000 hectares (680,000 acres) (Williams 1980, as cited in Williams et al 1998). None of the best habitat described by Grinnell and Dixon (1918, as cited in Williams et al 1998) remained.

This species has been documented in the Mendota Dam and Tranquility quadrangles (CNDDB 2002). Restoration actions that influence open habitat with brushy cover could affect the species.

9.5.3.20. Fresno Kangaroo Rat (*Dipodomys nitratoides exilis*)

The Fresno kangaroo rat is listed as endangered under ESA and CESA. The Fresno kangaroo rat is a subspecies of the San Joaquin kangaroo rat and is the smallest of California’s kangaroo rats (Culbertson 1946, Grinnell 1922). The historical range of the Fresno kangaroo rat probably extended north through north-central Merced County and south through southwestern Madera and central Fresno counties (Hoffman 1974, CDFG 1991). A survey in the late 1970s indicated that the Fresno kangaroo rat remained on only 857 acres in western Fresno County (Hoffman and Chesemore 1982). The last known capture was in late 1992 in the Alkali Sink Ecological Reserve (USFWS 1998, as cited in Kucera et al. 2001), and extensive trapping since 1993 in Fresno and Madera counties have not documented additional kangaroo rats (Kucera et al. 2001).

The Fresno kangaroo rat has narrow habitat requirements, only occupying alkali desert scrub communities between 200 and 300 feet elevation (CDFG 1992) within the alkali desert scrub habitat type. Seasonally flooded or arid alkaline plains with alkaline, clay-based soil and sparse growths of grassland or low brush are used. Vegetation such as saltbush, iodine bush, saltgrass, and alkali bite provide food and cover for this subspecies (Culbertson 1946). Areas with a hummocky land surface are used as sites for burrow systems (Culbertson 1946). The Fresno kangaroo rat is not known to use areas that are cultivated or irrigated.

Fresno kangaroo rats have been documented in the Fresno North, Mendota Dam, and Tranquility quadrangles (CNDDB 2002). They were captured at the Alkali Sink Ecological Reserve and Mendota Wildlife Management Area near the study area in 1981, 1985, and 1992. There is an unconfirmed report of capture of Fresno kangaroo rats in the Gravelly Ford area on the San Joaquin River (P. Kelly, pers. comm., as cited in Newman et al. 2001). Recent trapping at well locations in Reach 2 revealed only Heerman’s kangaroo rat (*D. heermanii*) (Wolfe and Assoc. 2000 and 2001, Kucera et al. 2001), and this species is considered by some to be extirpated along the San Joaquin River (J. Single, pers. comm. to M. Wolfe, 2002). Restoration actions that influence upland alkaline desert scrub could affect habitat for this kangaroo rat, and its potential to re-colonize the study area.

9.5.3.21. San Joaquin Valley (Riparian) Woodrat (*Neotoma fuscipes riparia*)

The San Joaquin Valley (or riparian) woodrat is listed as endangered under the ESA and is a CDFG species of special concern. It is a subspecies of the dusky-footed woodrat (*Neotoma fuscipes*). Historically found along the San Joaquin, Stanislaus, and Tuolumne rivers, the subspecies likely occurred throughout the extensive riparian forests along major streams flowing onto the floor of the northern San Joaquin Valley (Williams et al. 1997). The type locality for the San Joaquin Valley woodrat is Kincaid’s Ranch, about 3 km (2 mi) northeast of Vernalis in Stanislaus County (Hooper 1938, as cited in Williams et al. 1997).

Since 1938, the range of the subspecies has become far more restricted due to extensive modification and destruction of riparian habitat along streams in its former range in the Central Valley. The San Joaquin Valley woodrat is vulnerable to flooding of its riparian habitats because its current habitat consists of small, narrow riparian forest patches (Williams et al. 1997). Although it is arboreal and can therefore escape rising water levels, its stick nests are essential for survival and may be severely impacted by flooding. Cattle grazing may also negatively impact woodrats by trampling, browsing, and grazing in riparian areas used by the species. The only verified extant population is restricted to about 100 ha (250 acres) of riparian forest in Caswell Memorial State Park on the Stanislaus River, at the confluence with the San Joaquin River (Williams et al. 1997). There have been no reports of the San Joaquin Valley woodrat from the type locality near Vernalis since the 1970s (Williams and Kilburn 1992).

Although little is known about its diet, the San Joaquin Valley woodrat is believed to be a generalist herbivore that feeds on a wide variety of leaves, fruits, terminal shoots of twigs, flowers, nuts, and fungi (Williams et al. 1992). It is most numerous in areas where there is dense shrub cover with an overstory of valley oaks (USFWS 1998). Highest densities are often encountered in willow thickets with oak overstory (Linsdale and Tevis 1951, as cited in USFWS 1998). The San Joaquin Valley woodrat typically constructs stick houses on the ground against or straddling a log or the exposed roots of a standing tree, often in dense brush (Williams et al. 1997). It may also occasionally nest in trees and in nest boxes constructed for wood ducks (Williams 1993, as cited in Williams et al. 1997). Reproduction may occur throughout the year, with the fewest pregnancies in December and the most in February (Williams et al. 1997). Females have from one to five litters per year, consisting of three to four young each (Williams et al. 1997).

This taxon has not been documented near the study area, and there are no CNDDB records of it within the quadrangles covering the study area (CNDDB 2002). Restoration actions that influence riparian forest could affect habitat for this taxon, and its potential to re-colonize the study area.

9.5.3.22. San Joaquin Kit Fox (*Vulpes macrotis mutica*)

The San Joaquin kit fox is listed as endangered under ESA and as threatened under CESA. San Joaquin kit foxes occur in seasonal wetland, alkali desert scrub, grassland, and valley-foothill hardwood habitats (USFWS 1983). Before the rapid expansion of irrigated agriculture in the San Joaquin Valley, the alkali desert scrub association was probably the species' prime habitat (Grinnell et al. 1937). Although the precise historical range of the San Joaquin kit fox is unknown, it is believed to have extended from Contra Costa and San Joaquin counties in the north to Kern County in the south. By the 1930s, the range had been reduced to the southern and western portions of the Central Valley (Grinnell et al. 1937). Surveys conducted between 1969 and 1975 extended the known range of the kit fox back into portions of its historical range in the northern San Joaquin Valley, including Contra Costa, Alameda, and San Joaquin counties (Orloff et al. 1986). Additionally, kit foxes were found in three counties outside the originally defined historical range: Monterey, Santa Clara, and Santa Barbara counties (Orloff et al. 1986).

USFWS conducted surveys for the San Joaquin kit fox at the West Bear Creek Unit in 1981, 1993, and 1997 (JSA et al. 2000). A single fox was observed just south of the West Bear Creek/San Luis Unit boundary during the 1981 survey. One kit fox was observed in 1997 near the location of the 1981 observation (JSA et al. 2000). In 1986, a single kit fox was seen near the State Route 165 bridge over Salt Slough in the West Bear Creek Unit (JSA et al. 2000). In August 2001, there was an unconfirmed sighting in the vicinity of the Chowchilla Bifurcation Structure, located at the Chowchilla Bypass along the San Joaquin River. Researchers observed the fox at night with a spotlight (Kucera et al. 2001). A scent dog signaled the presence of suspected kit fox scat near where the fox was observed the previous night, but molecular genetics analysis of the collected scat identified it as coming from a gray fox (*Urocyon cinereoargenteus*) (Kucera et al. 2001). No observations of kit foxes have been confirmed in the West Bear Creek area since 1997. Restoration actions that influence upland and wetland habitats could affect this taxon.

9.5.4. Other Special-Status Wildlife

9.5.4.1. California Tiger Salamander (*Ambystoma californiense*)

The California tiger salamander is a candidate for federal listing (except in Sonoma County, where it is listed as engendered), and considered a species of special concern by CDFG. The tiger salamander is endemic to California. Its range includes the Central Valley and the eastern foothills of the Sierra Nevada from Yolo County (possibly up to Colusa County) south to Kern County, and coastal grasslands from Sonoma County to Santa Barbara County. In California, most populations occur at elevations of less than 455 meters (1,500 feet), but they have been recorded at elevations up to 1,370 meters (4,500 feet). The species is most commonly found in annual grassland habitat but also occurs in the grassy understory of valley foothill hardwood habitats. Adults spend most of the year in subterranean refugia, especially in ground squirrel burrows and occasionally in human-made structures. Seasonal ponds or vernal pools are crucial to breeding. Permanent ponds or reservoirs that do not contain predatory fish or bullfrogs may also be used for breeding.

USFWS conducted surveys for California tiger salamanders at 71 vernal pools at the West Bear Creek Unit of the San Luis NWR in 1992, 1993, and 1994 (JSA et al. 2000). These surveys revealed the presence of larval salamanders at 28 surveyed vernal pools (JSA et al. 2000). This species also was detected at 24 vernal pools at Great Valley Grasslands State Park (JSA et al. 2000). It has been documented in numerous quadrangles in the study area (CNDDB 2002). Restoration actions that influence seasonal or vernal pools and grasslands could affect this species.

9.5.4.2. Western Spadefoot (*Scaphiopus hammondii*)

Western spadefoot is considered a species of special concern by CDFG. The western spadefoot occurs in much of California west of the Sierra Nevada from Redding south to the Mexico (Jennings and Hayes 1994). Severe reductions of this species have occurred throughout its range; more than 80% of its habitat in southern California has been developed or altered and more than 30% of its habitat in the Central Valley has been converted such that it is unusable (Jennings and Hayes 1994).

Western spadefoot breed in temporary pools (typically vernal pools) created by winter rains in grassland habitats. Pools must last more than 3 weeks to allow for successful metamorphosis of larvae (Jennings and Hayes 1994). As pools dry, adults dig down into the soil and create a burrow where they estimate for most of the year (Zeiner et al. 1988). Adults feed on most types of insects and other invertebrates; larvae are carnivorous and feed on dead amphibians, even their own species, as well as plankton and algae (Zeiner et al. 1988).

USFWS conducted surveys for the western spadefoot at 71 vernal pools at the West Bear Creek Unit of the San Luis NWR complex in 1992, 1993, and 1994 (JSA et al. 2000). These surveys revealed the presence of larval spadefoots at 14 surveyed vernal pools (JSA et al. 2000). This species was also detected at 20 vernal pools at Great Valley Grasslands State Park (Hoopes et al. 1996). It has been documented in numerous quadrangles in the study area (CNDDB 2002). Restoration actions that influence vernal pools could affect this species.

9.5.4.3. Western Pond Turtle (*Clemmys marmorata*)

The western pond turtle is considered a species of special concern by CDFG. The western pond turtle is the only freshwater turtle native to most of the west coast of temperate North America. This species is found throughout California, principally west of the Sierra Cascade crest. Two subspecies are present in California, the southwestern pond turtle (*C. m. pallida*) and the northwestern pond turtle (*C. m. marmorata*). The San Joaquin Valley is within an intergrade zone for the two subspecies (Stebbins 1985).

Low fecundity, low hatchling and juvenile survivorship, high adult survivorship, and potentially long lifespan are characteristic of this species (Jennings et al. 1992). Potential competitive exclusion by introduced turtle species and predation on hatchlings by introduced bullfrogs, largemouth bass, and mesopredators such as raccoons are increasing threats to this species. Off-road vehicle use on streambeds and habitat destruction due to sedimentation are potential threats as well. Reasons for the decline in this species are numerous and complex; however, alteration of aquatic and adjacent upland habitats by logging and dam building are also causes for concern (Jennings et al. 1992).

The western pond turtle inhabits a wide range of fresh or brackish water habitats throughout California including ponds, lakes, slow-moving streams, ditches, pools remaining from drying of intermittent streams, and irrigation canals with muddy or rocky bottoms and emergent vegetation. Although adults are habitat generalists, hatchlings and juveniles require very specialized habitat for survival through their first few years. Habitats preferred by juveniles are relatively scarce and subject to disturbance (Jennings et al. 1992). Prime habitat for early life stages includes low-flow regions and backwater areas of rivers. Deep, still water with abundant emergent woody debris, overhanging vegetation, and rock outcrops is optimal for older life stages as basking and thermoregulation habitat. Breeding activity peaks from June to July, when females begin to search for suitable nesting sites up to 325 feet (99 m) away from the watercourse (Nussbaum et al. 1983). Egg-laying sites vary from sandy shoreline to forest soil types. In regions of California with cold winters, western pond turtles take refuge in aestivation or overwintering sites in October or November. Western pond turtles are active year-round in warmer coastal sites (Jennings and Hayes 1994). Little is known about overwintering habitat, but individuals have been recorded overwintering on land close to their summer water source, at sites up to 1,000 feet (305 m) away from water, and underwater (Rathbun et al. 1992, 1993 as cited in Jennings and Hayes 1994; Jennings and Hayes 1994).

There are verified observations of western pond turtles in Merced and adjacent counties (Jennings and Hayes 1994). Jennings and Hayes (1994) report that the western pond turtle has been documented over a half-dozen times across most portions of Stanislaus County. The CNDDB lists records for this species in San Joaquin, Stanislaus, and Merced counties (CDFG 1997). The western pond turtle has been documented in the San Luis, Kesterson, West Bear Creek, and Arena Plains units of the San Luis NWR, and the Mendota Wildlife Management Area (San Luis NWR file data, as cited in JSA et al. 2000). Two western pond turtles were observed during 2001 surveys near river milepost 202 at Mendota Pool (ESRP unpublished data, as cited in Newman et al. 2001). The species has been documented in the Delta Ranch, Firebough, Little Table Mountain, Mendota Dam, Millerton Lake West, and Tranquility quadrangles (CNDDB 2002). Restoration actions that influence lentic aquatic habitats and adjacent uplands could affect this species.

9.5.4.4. California Horned Lizard (*Phrynosoma coronatum frontale*)

The California horned lizard is considered a species of special concern by CDFG. Endemic to California, this species has a patchy distribution from Shasta County south along the edges of the Sacramento Valley into the South Coast Ranges, San Joaquin Valley, Sierra Nevada foothills to Los

Angeles, Santa Barbara, and Ventura counties (Jennings and Hayes 1994). It is found from sea level to almost 6,000 ft in elevation. The California horned lizard has been impacted by agricultural practices, housing development, and introduction of non-native predators (such as feral cats) (Jennings and Hayes 1994).

Habitats used by California horned lizards usually have some unvegetated areas near scattered shrubs with a gravelly-sandy or sandy loam substrate. Such habitats can include riparian woodlands, chamise chaparral, annual grassland, alkali flats, scattered shrubs, gravelly-sandy or sandy loam substrate, and some agricultural areas with sandy soil. California horned lizards shelter in burrows that they excavate themselves, or that are excavated by small mammals (Jennings and Hayes 1994). California horned lizards are active from April through October, and feed on ants, beetles, and other insects.

This taxon has been documented to occur in the study area, although the CNDDB contains no records for this species in study area quadrangles (CNDDB 2002). Restoration actions that influence upland, sandy habitats could affect this species.

9.5.4.5. Silvery Legless Lizard (*Anniella pulchra pulchra*)

The silvery legless lizard is considered a species of special concern by CDFG. The silvery legless lizard is a subspecies of the California legless lizard (*Anniella pulchra*). The silvery legless lizard is found in the Coast Range from the vicinity of Contra Costa County south to Mexico, and in the San Joaquin Valley (Hunt 1983, as cited in Jennings and Hayes 1994).

This lizard is found primarily in areas with sandy or loose organic soils or where there is plenty of leaf litter. It usually forages at the base of shrubs or other vegetation either on the surface or just below it in leaf litter.

Silvery legless lizard has been documented in the Arena Plains Unit of the San Luis NWR (San Luis NWR file data, as cited in JSA et al. 2000). One occurrence of this species was recorded near Reach 2A where Willow Slough meets the San Joaquin River. Restoration actions that influence upland areas with loose soils could affect this species.

9.5.4.6. San Joaquin Whipsnake (Coachwhip) (*Masticophis flagellum ruddocki*)

The San Joaquin whipsnake is a CDFG species of special concern. The range of this California endemic extends from west of Arbuckle in the Sacramento Valley southward to the Kern County portion of the San Joaquin Valley and westward into the inner South Coast Ranges.

San Joaquin whipsnake habitat includes open dry valley grassland with little or no tree cover and sandy or rocky soils (CNDDB 2002). It occurs in open terrain and is most abundant in grass desert, scrub, chaparral and pasture habitats. They seek cover in rodent burrows, bushes, trees, and rock piles, and hibernate in soil or sand approximately 0.3 m below the surface (CDFG 1988). In the western San Joaquin Valley, it occurs in valley grassland and saltbush scrub habitats (Montanucci 1965, Banta and Morafka 1968, Toflestrup 1979, Sullivan 1981, all as cited in Jennings and Hayes 1994). Whipsnakes are mainly terrestrial, but occasionally climb trees and bushes to bask, seek prey and cover (Cunningham 1959).

Little is known about nest sites. The San Joaquin whipsnake uses burrows possibly for oviposition sites and therefore may require one or more mammal associations. Although this snake probably has a high degree of dependence on mammals, the species it may depend on and the nature of such relationships are vague.

This taxon is not known to occur in study area, and no records of its occurrence near the study area are found in CNDDB (2002). Restoration actions that influence upland open habitats could affect this species if it occurs in the area.

9.5.4.7. American White Pelican (*Pelecanus erythrorhynchos*)

The American white pelican nesting colonies are considered a CDFG species of special concern. With wingspans up to 9 feet, American white pelicans are among the largest and most spectacular of North American birds. At the beginning of the 20th century, they nested at large lakes throughout California, from the Klamath Basin, through the Central Valley, to the Salton Sea. Today, most of California's breeding population is restricted to islands at Clear Lake and Tule Lake National Wildlife Refuges, near the Oregon border. During the breeding season from April to August, they are restricted to protected islands that are inaccessible to predators. They may commute more than 180 miles between their breeding and foraging grounds (Zeiner et al. 1990). From October through March, most depart their breeding grounds in northeastern California, and migrant flocks are seen throughout much of the state, including large wetlands in the San Joaquin Valley.

American white pelicans forage in water of various depths, and they dive for prey items from the water's surface. Fish are their preferred prey, but occasionally they also consume crustaceans and amphibians (Zeiner et al. 1990). Often flocks of 20 or more birds swim and wade together to herd fish into shallow water, where they can be captured more easily.

At the San Luis NWR complex, American white pelicans are fairly common visitors to large wetlands at the San Luis, West Bear Creek, and Kesterson units. They have only been recorded as a nesting species at the San Luis NWR complex since 1998 (Woolington, pers. comm., as cited in JSA et al. 2000). Restoration actions that influence fish-bearing aquatic habitats could affect this species.

9.5.4.8. Double-crested Cormorant (*Phalacrocorax auritus*)

Double-crested cormorant rookery sites are of special concern to CDFG. It is the only one of the 3 species of cormorants that occur in California that can be regularly found in freshwater habitats (Cogswell 1977). The double-crested cormorant nests along the coast from the Oregon border south to San Diego County and also inland. Coastal populations in southern California have declined significantly. The shores of the Salton Sea provide nesting areas for this species, but these populations have also declined. Large breeding populations occur on the lakes and marshes of northeastern California. Cormorants nest at 3 locations in the lower Sacramento Valley: Sacramento River near the Yolo/Colusa County border, Stone Lakes National Wildlife Refuge, and southern Yolo Bypass. Cormorants are more common from fall to spring in the Central Valley than during summer months (Cogswell 1977). Although this species is locally common, Grinnell and Miller (1944) noted that population declines were evident in the 1940s. The population of this species continued to decline in the late 1960s and 1970s but have since recovered somewhat. Their numbers, however, have not yet reached original levels (Small 1994). Many of the former nesting grounds of the San Joaquin Valley, especially in the Tulare Lake and Buena Vista Lake basins, are no longer suitable (Remsen 1978).

Along the coast, the double-crested cormorant nests along cliffs; inland, they use tall trees near water to build nests out of sticks and debris. The breeding period is from April to July, but the species may breed considerably earlier in southern rookeries. Cormorants nest in large colonies of up to several hundred pairs (Zeiner et al. 1990). Nesting sites are often in secluded areas because this species is particularly sensitive to human disturbance (Remsen 1978). The cormorant's diet consists mainly of fish, but it will also feed on amphibians and crustaceans (Zeiner et al. 1990).

Double-crested cormorants nest along with great egrets and great blue herons in at least 2 colonies at the West Bear Creek Unit of the San Luis NWR, where up to 50 nests have been counted (USFWS file data, as cited in JSA et al. 2000). Double-crested cormorants also are fairly common visitors to managed wetlands throughout the San Luis NWR complex in the nonbreeding season (JSA et al. 2000). Restoration actions that influence the habitat at and accessibility of humans to their colonies could affect this species.

9.5.4.9. Western Least Bittern (*Ixobrychus exilis hesperis*)

The nesting western least bittern is designated as a species of special concern by CDFG. Historically, the western least bittern was a fairly locally common summer resident. It was most common in the Sacramento Valley, the San Joaquin Valley, and southern California (Grinnell and Miller 1944). The populations in the Central Valley have been much reduced and the species is now common as a breeder only at the Salton Sea and lower Colorado River (Small 1994). Elsewhere in southern California, it is a very local breeder and is rare during winter. It is a rare spring and fall transient along the coast from Santa Barbara County to Marin County and a rare summer breeder in Little Shasta Valley (Siskiyou County), Klamath Basin, and Great Basin marshes. In the Sacramento and San Joaquin valleys, this species is now an uncommon breeder and rare winter visitor (Small 1994).

Western least bitterns occupy marshes and other freshwater bodies of water, where they hide among the dense emergent vegetation. Associated plant species include tules and cattails (Zeiner et al. 1990). Individuals arrive at nesting grounds from March to May and breed from mid-April to July. They nest in tules and cattails and build nests over the water (Zeiner et al. 1990). Western least bitterns also use dense emergent vegetation to forage for small fish, invertebrates, amphibians, and small mammals (Zeiner et al. 1990).

The western least bittern has been documented to occur at the San Luis Unit of the San Luis NWR (San Luis NWR file data, , as cited in JSA et al. 2000). Restoration actions that influence wetlands could affect this species.

9.5.4.10. Great Blue Heron (*Ardea herodias*)

Colonial nesting sites of great egret are designated as sensitive by the California Department of Forestry and Fire Protection. Colonies of great blue herons were reported in Marin, Humboldt, and Placer counties in the early 1970s (Pratt 1970, Ives 1972, Wilburn 1971). They are fairly common throughout most of California year-round in shallow estuaries and fresh and saline emergent wetlands. Few rookeries have been found in southern California but many are scattered throughout the Central Valley (Zeiner et al. 1990). Knowledge of rookery locations is incomplete (Mallette 1972, Belluomini 1978, Garrett and Dunn 1981).

The species winters throughout California (Zeiner et al. 1990). The Central Valley and San Francisco Bay Area are considered a key wintering areas in North America for great blue herons (Mikuska et al. 1998).

The great blue heron arrives at breeding grounds in February. Eggs are laid in late February or March. In June or July, after breeding, individuals disperse from the nesting colonies to outlying areas, but there is little regular migration (Gill and Mewaldt 1979). Great blue heron nests are similar to and often occur in mixed colonies with great egrets (Cogswell 1977). Herons usually nest in colonies in the tops of secluded large snags or live trees, usually among the tallest trees available (Zeiner et al. 1990).

Great blue herons require habitat containing fish-bearing waters; 75% of their diet consists of fish. They also eat crustaceans, frogs, salamanders, lizards, snakes, large aquatic insects, and small rodents (Cogswell 1977). The species is active year-round and feeds both night and day, but is most active at dawn and dusk (Terres 1980).

Heronry surveys were conducted at the San Luis NWR complex from 1987 through 1998 (JSA et al. 2000). There are 3 active heronries at the West Bear Creek Unit. Site G1, located near the boundary between the West Bear Creek and San Luis units, had the highest nest count, with 152 great blue heron nests in 1998 (JSA et al. 2000). Suitable habitat for this species is found throughout the remainder of the project area. Restoration actions that influence rookeries (and human access to them), aquatic habitats, and wetlands could affect this species.

9.5.4.11. Great Egret (*Casmerodius albus*)

Colonial nesting sites of great egret are designated as sensitive by the California Department of Forestry and Fire Protection. Historically, great egret rookeries were found in Humboldt, Bolinas, and San Francisco bays; the Central Valley (south from the upper Sacramento Valley); the lower Colorado River; and the southern end of the Salton Sea (Cogswell 1977). The current distribution of rookeries includes Humboldt, Bolinas, and San Francisco bays and the Central Valley. Historical nesting sites on the lower Colorado River and the southern end of the Salton Sea are now abandoned. Many of the colonies in the San Francisco Bay and in the Central Valley have declined or disappeared (Cogswell 1977).

Great egrets nest mostly along large streams, lakes, and rivers, such as the Sacramento River, American River, Putah Creek, Yolo Bypass, Cosumnes River, and Comanche River. This species winters throughout the Central Valley, Suisun Marsh, and San Francisco Bay Area.

Great egrets are residents year-round throughout most of their California range. They nest mainly from March to July, and populations are concentrated near nesting colonies. After nesting, individuals disperse over a wide range (Zeiner et al. 1990). Great egrets require groves of trees that are suitable for nesting and roosting, are relatively isolated from human activities, and are near aquatic foraging areas. Nests are constructed from sticks and stems of marsh plants and are built in large trees. Great egrets feed and rest in fresh and saline emergent wetlands; along the margins of estuaries, lakes, and slow-moving streams; on mudflats and salt ponds; and on irrigated croplands and pastures. They eat mainly fishes, amphibians, snakes, snails, crustaceans, insects, and small mammals (Zeiner et al. 1990).

Heronry surveys were conducted at the San Luis NWR complex from 1987 through 1998 (JSA et al. 2000). There are 3 active heronries at the West Bear Creek Unit. Site G1, located near the boundary between the West Bear Creek and San Luis units, had the highest nest count, with 129 great egret nests in 1998 (JSA et al. 2000). Restoration actions that influence rookeries (and human access to them), aquatic habitats, and wetlands could affect this species.

9.5.4.12. White-Faced Ibis (*Plegadis chihi*)

The white-faced ibis rookery sites are of special concern to CDFG. The white-faced ibis was once common, but by the 1940s, the white-faced ibis' population was declining (Grinnell and Miller 1944). By the 1970s, there were virtually no breeding white-faced ibises in California (Remsen 1978). In the 1980s, after decades of decline, the population of this species began to rebound. Since 1980, rookery sites have been recorded in Colusa, Yolo, Fresno, Kings, Siskiyou, and Modoc counties (CNDDB 1998). Nesting sites have also been recorded at the Salton Sea (Imperial County), Lake Guajome (San Diego County), Piute Ponds (Los Angeles County), and in Sierra Valley (Plumas County). Some white-faced ibises in California are summer breeders that winter in Mexico; others are winter residents that breed in areas north and east of California, especially Utah. Still others are California residents that migrate between their wintering and breeding sites in California (Small 1994).

The white-faced ibis requires freshwater marshes and other wetlands for nesting sites and for winter foraging grounds. The species nests from May to July in dense freshwater marsh vegetation near foraging areas (Zeiner et al. 1990). Nests are built among tall marsh plants out of dead tules or cattails. It may also nest in very low trees (Cogswell 1977). The ibis forages in shallow waters, including seasonal wetlands and rice fields, or on muddy banks where it probes for invertebrates, small fish, and amphibians (Zeiner et al. 1990).

White-faced ibis are regularly recorded at wetlands throughout the San Luis NWR complex, including the West Bear Creek, San Luis, Kesterson, and Arena Plains units (USFWS file data, as cited in JSA et al. 2000). They have been recorded nesting within the floodplain of the Kesterson Unit (JSA et al. 2000). They have also been observed near the Chowchilla Canal east of Mendota on the San Joaquin River (Kucera et al. 2001). White-faced ibis have been observed in and adjacent to Reach 2 (M. Wolfe, pers. obs., 2000 and 2001).

Restoration actions that influence wetlands and flooded rice fields may affect this species.

9.5.4.13. Fulvous Whistling Duck (*Dendrocygna bicolor*)

The nesting fulvous whistling duck is considered a species of special concern by CDFG. It once nested along the southern California coast, in the San Joaquin Valley, in the San Francisco Bay Area. Historically a common breeding species in wetlands near Los Banos, the fulvous whistling duck has not been reported as a breeding species in San Joaquin Valley since the early 1960s. It currently nests in only a few locations in Imperial Valley. Destruction of marsh habitat has probably been the main cause for the decline.

The fulvous whistling-duck is found in fresh emergent wetlands, shallow lacustrine and quiet riverine waters; it also feeds in wet croplands and pastures (Remsen 1978, as cited in CDFG 1983). The fulvous whistling-duck feeds mostly nocturnally but also diurnally on rice, other grains, seeds, and green shoots of herbs. It searches for food by walking over wet fields or in shallow water; swimming in shallow water and taking food from the surface, as well as by tipping and making shallow dives (Palmer 1976, as cited in CDFG 1983). In California, the fulvous whistling-duck usually rests by day in dense emergent wetland, rarely perching in trees or using wooded habitats (Cogswell 1977, as cited in CDFG 1983). Nesting typically occurs between April and September (Cogswell 1977, as cited in CDFG 1983), with most of the breeding population migrating to wintering areas in Mexico between September and February (CDFG 1983).

There are no records in the CNDDB (2002) of this species in the study area, and it is believe to have been extirpated from the area. Restoration actions that influence wetlands and flooded fields could affect this species' habitat and its potential for reintroduction.

9.5.4.14. Osprey (*Pandion haliaetus*)

The nesting osprey is considered a species of special concern by CDFG, and designated a sensitive species by the California Department of Forestry and Fire Protection. Ospreys breed in northern California from the Cascades south to Lake Tahoe, and along the coast south to Marin County. Regular breeding sites include Shasta Lake, Eagle Lake, Lake Almanor, other inland lakes and reservoirs, and northwest river systems. Pesticides have caused reproductive failure through eggshell thinning in the past (Garber 1972), but reproductive success has increased since the early 1970s (Airola and Shubert 1981). Loss of breeding habitat and declining fish numbers may threaten some populations (Ehrlich et al. 1992); however, populations of this species are apparently increasing (Zeiner et al. 1990).

Ospreys are strictly associated with large fish-bearing waters, primarily in ponderosa pine and mixed conifer habitats. These birds require open, clear water for foraging, which may occur in rivers, lakes, reservoirs, bays, estuaries, and surf zones. These raptors nest on platforms of sticks at the tops of large trees, snags, dead-topped trees, cliffs, or human-made structures. Nests are usually located within one-quarter mile of fish-producing waters. Birds arrive on the nesting grounds in mid-March to early April, and breeding occurs in March through September (Zeiner et al. 1990). Osprey feed primarily on fish, though they also take a few mammals, reptiles, birds, amphibians, and invertebrates (Zeiner et al. 1990).

This species has been documented in the Kesterson, West Bear Creek, San Luis, and Arena Plains units of the San Luis NWR (San Luis NWR file data, as cited in JSA et al. 2000). CNDDB has no records for osprey rookeries in the study area quadrangles (CNDDB 2002). Restoration actions that influence fish-bearing waters and roosting trees could affect this species.

9.5.4.15. White-tailed Kite (*Elanus leucurus*)

The white-tailed kite is listed as fully protected by CDFG. Only nesting sites are covered under the fully protected designation. This kite is a common to uncommon resident of coastal and valley lowlands west of the Sierra Nevada throughout the year. It is nonmigratory but may make slight seasonal range shifts in coastal areas (Zeiner et al. 1990). Rapid urbanization of agricultural lands in southern California resulted in declines in white-tailed kite populations in the 1980s (Small 1994). There is evidence of an upswing in the California population of this species, possibly due to increased habitat for microtine rodents (Small 1994).

White-tailed kites are found in coastal and valley lowland agricultural areas. Preferred foraging habitats include wetlands and grasslands. Prime habitat includes herbaceous lowlands with minimal tree growth and abundant small mammal prey. Groves of trees are required for perching and nesting. This raptor is generally monogamous and breeds from February to October. It nests in loosely piled sticks built near the top of dense oak or other tree stands 18–61 feet (5.5–18.6 m) above ground (Dixon et al. 1957). Breeding behavior peaks from May to August, when a single clutch of four to eight eggs is laid. This species preys on voles and other small mammals, as well as birds, insects, and reptiles. They often roost communally in winter (up to 100 or more birds) but are usually solitary hunters (Ehrlich et al. 1992).

White-tailed kites have been observed in Lost Lake Park (Stillwater Sciences, pers. obs., 2002). Restoration actions that influence wetlands, grasslands, and trees could affect this species.

9.5.4.16. Northern Harrier (*Circus cyaneus*)

Nesting northern harriers are considered a species of special concern by CDFG. The northern harrier is a fairly common winter visitor, and formerly nested throughout California. Northern harriers historically bred throughout California, except in deserts, woodlands, and forested mountains. Breeding localities in California included the interior from Siskiyou County south to western Riverside and San Bernardino counties and coastal regions from Marin County to San Diego County (Grinnell and Miller 1944). Destruction of wetlands and annual grasslands throughout California has led to a decline in northern harrier populations. In addition, grazing and agricultural practices, including plowing and burning of nesting areas during early stages of the nesting season, have contributed to the decline of this ground-nesting species (Remsen 1978). Currently, 2 main populations of northern harriers exist: one at the Klamath Basin refuges and the other in the Delta. The breeding range of the northern harrier includes most of the Central Valley, Delta, Suisun Marsh, and portions of the San Francisco Bay Area (Zeiner et al. 1990).

The northern harrier uses tall grasses and forbs in wetlands and field borders for cover (Zeiner et al. 1990). It roosts on the ground in shrubby vegetation, often near the marsh edge (Brown and Amadon 1968). The species' breeding season is between April and September, with peak activity in June and July. Harriers nest on the ground in shrubby vegetation, usually along the edge of marshes (Brown and Amadon 1968). Nests are constructed of large, loosely mounded sticks in wet areas or a small cup of woven grasses at drier sites. Preferred habitats include flat, hummocky, open areas with tall grasses, shrubs, and aquatic edges (Zeiner et al. 1990). The northern harrier feeds mostly on voles and other small mammals, birds, frogs, reptiles, and crustaceans; it occasionally takes fish as well. Grasslands, meadows, and wetlands are optimal habitat types, although harriers occur within lodgepole pine and alpine meadow habitats in some areas (Remsen 1978).

Northern harriers are fairly common nesters and residents in grasslands throughout the San Luis NWR complex, including the West Bear Creek, San Luis, Kesterson, and Arena Plains units, and throughout the region (USFWS file data, as cited in JSA et al. 2000). They were also frequently observed near the Chowchilla Canal east of Mendota on the San Joaquin River (Kucera et. al 2001) and have been documented in the Turner Ranch quadrangle (CNDDB 2002). There is suitable nesting habitat for this species throughout the study area. Restoration actions that influence wetlands, grasslands, and scrub could affect this species.

9.5.4.17. Golden Eagle (*Aquila chrysaetos*)

The golden eagle is considered a species of special concern, a fully protected species by the CDFG, and designated a sensitive species by the California Department of Forestry and Fire Protection. This species occurs throughout most of California as a resident, migrant, or wintering species (Zeiner et al. 1990). On the floor of the Central Valley, it is a winter visitor but not a breeding species. This species nests on cliff faces with suitable ledges or in large trees in open areas (Zeiner et al. 1990). Golden eagles forage over open terrain and feed primarily on rabbits and rodents.

Within the study area, golden eagles are uncommon winter visitors to the West Bear Creek, San Luis, Kesterson, and Arena Plains units of the San Luis NWR complex (JSA et al. 2000). They also have been observed at Great Valley Grasslands State Park (JSA et al. 2000). Restoration actions that influence open foraging habitats could affect this species.

9.5.4.18. Merlin (*Falco columbarius*)

The merlin is considered a species of special concern by CDFG. This species is widely distributed in North America. It breeds from Alaska and northern Canada south to Oregon, Minnesota and Nova Scotia (Ehrlich et al. 1992). In California, it is found as an uncommon wintering species and migrant from September to May, predominantly in the western half of the state (CDFG 1992). Due to its dependence on small birds for prey, the merlin is particularly susceptible to bioaccumulation of pesticides in the food chain. Massive reproductive failures in Canadian populations have been directly linked to DDT poisoning (Fox 1971). In addition, habitat loss and shooting have negatively affected populations of this species. Juvenile merlins are sometimes taken by falconers (Remsen 1978). Populations throughout the United States and Canada are believed to have declined (Remsen 1978).

This species forages along shorelines, in open grasslands, savannahs, woodlands, wetlands, and early seral stage habitats (Zeiner et al. 1990), feeding primarily on small birds, which may make up 90 percent of its diet (Ehrlich et al. 1992). It also preys on insects and some small mammals. This species is usually found at elevations below 3,900 ft (Zeiner et al. 1990).

This species is documented to occur at the Kesterson and San Luis units of the San Luis NWR (San Luis NWR file data, as cited in JSA et al. 2000). The CNDDB has no records for this species in study area quadrangles (CNDDB 2002). Restoration actions that influence wetlands and open upland habitats could affect this species.

9.5.4.19. Prairie Falcon (*Falco mexicanus*)

Nesting prairie falcons are considered a species of special concern by CDFG. This species is an uncommon permanent resident and migrant in California, ranging from southeastern deserts northwest along the inner coast ranges and Sierra Nevada (Zeiner et al. 1990). It is vulnerable to DDT poisoning and predation by mammals and predatory birds.

The species is primarily associated with perennial grasslands, savannahs, rangeland, some agricultural fields, and desert scrub areas. Prairie falcons use open terrain for foraging small mammals, birds, and reptiles, and nest where there are canyons, cliffs, escarpments, or rock outcrops. Nesting usually occurs in a scrape on a sheltered ledge of a cliff overlooking a large, open area. The prairie falcon sometimes nests on old raven or eagle stick nests on cliffs, bluffs, or rock outcrops (CDFG 1983). Breeding occurs from mid-February through mid-September, peaking in April to early August. Young begin to disperse in June and July (Enderson 1969, Denton 1975, both as cited in CDFG 1983).

Prairie falcons have been documented to occur in the West Bear Creek area (San Luis NWR file data, as cited in JSA et al. 2000). The CNDDB has no records for this species in the study area quadrangles (CNDDB 2002). Restoration actions that influence open upland foraging habitat could affect this species.

9.5.4.20. Sharp-shinned Hawk (*Accipiter striatus*)

Nesting sharp-shinned hawks are considered a species of special concern by CDFG. This species occurs as a migrant or winter resident throughout most of California (Zeiner et al. 1990). Although few historical nesting sites were documented, the sharp-shinned hawk’s summer distribution in California extended south from the Oregon border through the coastal mountains to Alameda and Monterey counties, and through the Cascade Range and Sierra Nevada to the mountains of southern California (Grinnell and Miller 1944). This species prefers to nest in coniferous or deciduous forest habitats. Sharp-shinned hawks prey primarily on small birds, and they forage in wooded or scrub habitats and in adjacent open areas (Zeiner et al. 1990).

Sharp-shinned hawks are fairly common, non-breeding visitors to riparian habitats at the San Luis NWR complex (JSA et al. 2000). Restoration actions that influence riparian, woodland, or scrub habitat may affect this species.

9.5.4.21. Cooper’s Hawk (*Accipiter cooperii*)

Nesting Cooper’s hawks are considered a species of special concern by CDFG. The historical range of the Cooper’s hawk is similar to its current range, although the species is less common in the Central Valley than it was historically. Cooper’s hawks are currently found throughout most of the United States as well as southern Canada and northern Mexico. Northern populations are said to be migratory and southern populations resident; however, some southern populations apparently migrate as well (Rosenfield and Bielefeldt 1993). The Cooper’s hawk breeds throughout most of California in a variety of woodland habitats (Harris 1991). The highest densities probably occur in the foothill oak woodlands of the Sierra Nevada and Transverse ranges (Asay 1987).

The Cooper’s hawk usually nests in deciduous, conifer, and mixed woodlands (Garrett and Dunn 1981), but also nests in urban areas and seems to be tolerant of human disturbance near the nest (Palmer 1988). The hawks nest and forage near open water or riparian vegetation. Prey comprises small birds, a variety of small mammals, reptiles, and amphibians (Zeiner et al. 1990). The species usually breeds after 2 years (Rosenfield 1982, Henny et al. 1985, Asay 1987) and pairs generally return to the same territory year after year, but will often build a new nest in the vicinity of the existing one (Reynolds and Wight 1978).

Cooper's hawks are fairly common, non-breeding visitors to riparian habitats at the San Luis NWR (JSA et al. 2000). Restoration actions that influence aquatic and riparian habitats could affect this species.

9.5.4.22. Ferruginous Hawk (*Buteo regalis*)

The ferruginous hawk is considered a species of special concern by CDFG. This species is an uncommon winter resident and migrant in the Modoc Plateau, Central Valley, and Coast Ranges of California, as well as along the coast. It is frequently seen in grasslands and agricultural areas in southwestern California and occurs infrequently in the northeast portion of the state (Small 1994). This species is not known to breed in California, although appropriate habitat is available.

The ferruginous hawk forages in a variety of open areas. Ferruginous hawks forage over open grasslands and agricultural areas for hares and cottontails, ground squirrels, birds, and reptiles (CDFG 2000). It frequents open grasslands, agricultural lands, sagebrush flats, desert scrub, low foothills, and fringes of pinyon-juniper habitats. It roosts in open areas, typically in a lone tree or utility pole (Zeiner et al. 1990). The wintering population may be declining in California (Remsen 1978).

Ferruginous hawks have been documented in the West Bear Creek area (San Luis NWR file data, as cited in JSA et al. 2000). The CNDDB has no records for this species in the study area quadrangles (CNDDB 2002). Restoration actions that influence open upland habitats could affect this species.

9.5.4.23. Yellow Rail (*Coturnicops noveboracensis*)

The yellow rail is considered a species of special concern by the state of California (Remsen 1978). The species nests principally in Canada. Small numbers historically bred in California, in grassy meadows of Mono County, and probably in Plumas County and along the eastern edge of the Sierra Nevada (Grinnell and Miller 1944, as cited in Remsen 1978). Because the species is so difficult to detect, it was likely more widespread than historical records indicate. Some yellow rails may still persist in California, although thorough searches of some former breeding localities have not been successful (Stallcup and Winter 1975; T. Heindel, pers. comm., both as cited in Remsen 1978). The species has been recorded historically during the winter at 16 localities along the coast from Humboldt County to Orange County and inland in Merced County and Riverside County (Grinnell and Miller 1944, as cited in Remsen 1978). Since 1944, however, very few observations have been documented. Grazing of the wet grassy meadows may be the primary reason for the decline of the breeding population (Stallcup and Winter 1975, as cited in Remsen 1978).

Wintering habitat of the yellow rail includes freshwater and saltwater marshes, and estuaries. The species feeds in shallow water on aquatic invertebrates.

There are no records of the species for study area quadrangles (CNDDB 2002). Although yellow rails are very rare and may be extirpated from California, restoration actions that influence wetlands could affect habitat for this species in its potential for re-colonization.

9.5.4.24. Mountain Plover (*Charadrius montanus*)

The mountain plover is proposed as threatened under the ESA, and is designated as California species of special concern. The breeding range is the dry tablelands of the western Great Plains and the Colorado Plateau. The winter range extends from northern California (rarely) through southern California, southern Arizona, and central and coastal Texas to north-central Mexico (Cogswell 1977, Knopf 1996).

Mountain plovers do not breed in California, but approximately 70% of the continental population winters in the state. The major wintering areas in California are in the Sacramento, San Joaquin, and Imperial valleys. Smaller numbers winter in the west Mojave Desert, San Jacinto Valley, Santa Maria Valley, Salinas Valley, the Carrizo Plain, Seal Beach, Tijuana River Valley, and the Lower Colorado River Valley.

After the breeding season (late March to early August), mountain plovers disperse across the southern and western Great Plains before migrating to their wintering areas. The migration of the species to and from California is more of an east-west movement than the typical north-south movement of migrating shorebirds in North America. In California, mountain plovers have been recorded rarely in late July, but most arrive in mid-October or later. Mid-November to early February is the period of peak abundance in California, and most birds are back on the breeding grounds by late March or early April. Mountain plovers forage for large insects on alkaline flats, plowed ground, and grazed pasture.

The occurrence of mountain plover has been documented at the Arena Plains Unit of the San Luis NWR. This species is likely to occur at the San Luis, West Bear Creek, and Kesterson units (San Luis NWR file data, as cited in JSA et al. 2000), and could occur in other upland habitats along the study reach. Restoration actions that influence open upland habitat could affect this species.

9.5.4.25. Long-billed Curlew (*Numenius americanus*)

Nesting long-billed curlews are considered a species of special concern by CDFG. It nests in Siskiyou, Modoc, and Lassen counties, and winters along the coast and in the Central and Imperial valleys. This species usually leaves for southern wintering grounds as early as June. Winter habitat for this species includes grasslands and croplands, where if feeds on invertebrates and berries.

Large flocks of long-billed curlews have been observed in the study area, foraging in alfalfa fields directly adjacent to the river in Reach 2 (M. Wolfe, pers. obs., 1999–2002) . CNDDB has no records for this species in the study area quadrangles (CNDDB 2002). Restoration actions that influence grasslands and croplands could affect this species.

9.5.4.26. Black Tern (*Chlidonias niger*)

The black tern is designated as a species of special concern by CDFG. The black tern was once a common and even abundant summer breeder and migrant throughout much of California (Grinnell and Miller 1944). The species has declined and now breeds only in the northeast (Siskiyou, Modoc, and Lassen counties) and Central Valley, although in much-reduced numbers (Zeiner et al. 1990). Although this species can be found in great numbers at the Salton Sea, it is not known to breed there (Small 1994).

The black tern requires freshwater habitats for breeding grounds. Nesting sites are found on lakes, ponds, marshes, and agricultural fields (Grinnell and Miller 1944). During migration, this species can be common on coastal bays, river mouths, and well offshore over pelagic waters (Cogswell 1977). Nests are built on floating mats of dead vegetation among anchored vegetation or along the shore where they are built by scraping out the soil (Zeiner et al. 1990). The black tern feeds on insects by plucking them out of the air, scooping them out of the water, or plucking them off vegetation. It also eats amphibians, fish, and crustaceans (Zeiner et al. 1990).

The occurrence of black terns has been documented at the San Luis, West Bear Creek, Kesterson, and Arena Plains units of the San Luis NWR (San Luis NWR file data, as cited in JSA et al. 2000).

Additionally, nesting has been documented at the West Bear Creek Unit (San Luis NWR file data, as cited in JSA et al. 2000). Restoration actions that influence lentic aquatic habitats, wetlands, and agricultural lands could affect this species.

9.5.4.27. Western Burrowing Owl (*Athene cunicularia hypugea*)

The western burrowing owl is considered a species of special concern by CDFG. Burrowing owl nests are also protected by California Fish and Game Code Section 3503.5. This species nests and winters in lowlands throughout California, including the Central Valley. The western burrowing owl is a ground-nesting raptor that typically uses the burrows of other species, such as ground squirrels. Suitable habitat for this species includes sparsely vegetated grasslands, deserts, and agricultural fields. Burrowing owls feed primarily on insects and small mammals, and are also known to take reptiles, amphibians, and bird prey.

Western burrowing owl has been documented at San Luis, West Bear Creek, Kesterson, and Arena Plains units of the San Luis NWR; a nesting pair was documented at the Arena Plains Unit (San Luis NWR file data, as cited in JSA et al. 2000). There is a record of a burrowing owl near Mendota Pool. Restoration actions that influence open upland habitats could affect this species.

9.5.4.28. Long-Eared Owl (*Asio otus*)

Nesting long-eared owls are designated a species of special concern by CDFG. It was once a common resident throughout California. Its numbers have been declining since the 1940s, mostly severely in the Sacramento Valley, San Joaquin Valley, and San Diego area (Remsen 1978). The species is an uncommon breeder in the northeastern part of the state, in the Owens Valley, and the foothills east of the Central Valley. It also nests in the Coast Range from Sonoma and Lake Counties south to Santa Barbara County (Small 1994). The long-eared owl winters in the Central Valley from Tehama County to Kern County (Zeiner et al. 1990).

Long-eared owls require dense tree stands near open areas for hunting (Small 1994). This species occurs in riparian habitats as well as oak thickets and conifer forests at higher elevations (Zeiner et al. 1990). Long-eared owls use old nests of crows, magpies, and hawks for nesting sites. The species' breeding season is from early March to late July (Zeiner et al. 1990). Voles, shrews, other rodents, and birds make up the majority of the long-eared owl's diet. Open grassy fields, meadows, and wetlands are preferred hunting areas (Johnsgard 1988).

Long-eared Owls have been recorded breeding in riparian habitats of the San Luis Unit of the San Luis NWR complex (San Luis NWR file data, as cited in JSA et al. 2000). Restoration actions that influence riparian and upland forest, and upland open areas, may affect this species.

9.5.4.29. Short-Eared Owl (*Asio flammeus*)

Nesting short-eared owls are designated as a species of special concern by CDFG and as a migratory non-game bird of management concern by USFWS. The short-eared owl historically bred throughout California, west of the deserts (Grinnell and Miller 1944). This species has declined dramatically throughout the state. Its numbers are greater in winter, concentrating in areas with little snow cover and abundant prey, but even those numbers have declined (Remsen 1978). Breeding populations are reported to have been extirpated from the southern coast and perhaps from the San Joaquin Valley (Remsen 1978). The species still breeds in the southern portion of the Sacramento Valley (Yolo and Solano Counties), the Delta, Suisun Marsh, northeastern portion of the state, in the Coast Ranges from Sonoma to Santa Barbara Counties, and in the Owens Valley (Small 1994, Zeiner et al. 1990).

Nests are built on the ground in tall stands of grasses in lowland habitats near hunting grounds in marshes, meadows, and agricultural fields (Grinnell and Miller 1944). The breeding season is from late March to July (Zeiner et al. 1990). Wintering habitats include grasslands, dunes, meadows, irrigated lands, and wetlands. This species feeds primarily on small mammals.

Short-eared owls probably nest in the San Luis NWR complex, and have been documented at the San Luis, West Bear Creek, and Kesterson units (San Luis NWR file data, as cited in JSA et al. 2000). This species is likely to occur at the Arena Plains Unit. Restoration actions that influence open upland and wetland habitats may affect this species.

9.5.4.30. California Horned Lark (*Eremophila alpestris actia*)

The California horned lark is considered a species of special concern by CDFG. Historically, this subspecies was a common resident of the lowlands of California; its range included the coastal region of the state from Humboldt County south to San Diego County, as well as the lowlands of the San Joaquin Valley (Grinnell and Miller 1944). Horned larks continue to be common winter residents throughout open habitats in California (Small 1994).

Wintering flocks of horned larks frequent grasslands, plowed agricultural fields, and other open habitats with low, sparse vegetation; they find cover in clumps of grasses, rocks, and other surface irregularities. Horned larks eat mostly insects and seeds in the nonbreeding season.

California horned larks annually use grazed and burned upland habitats in the West Bear Creek area of the San Luis NWR (JSA et al. 2000). Restoration actions that influence open upland habitats could affect this species.

9.5.4.31. Loggerhead Shrike (*Lanius ludovicianus*)

The loggerhead shrike is considered a species of special concern by CDFG. It occurs in the Central Valley, northeastern plateau, Great Basin, and southern California. Fairly common residents and winter visitors in lowlands and foothills throughout California, loggerhead shrikes prefer open habitats with scattered shrubs, trees, posts, fences, utility lines, and other perches (Zeiner et al. 1990).

In California, loggerhead shrikes lay eggs from March into May, and the young are independent of the adults by July or August (Zeiner et al. 1990). Loggerhead shrikes eat mostly large insects, but they also take small birds, mammals, amphibians, reptiles, fish, carrion, and various other large invertebrates. They frequently impale prey on thorns, twigs, or barb wire to cache for later feeding. Loggerhead shrikes are fairly common residents in the West Bear Creek area of the San Luis NWR (JSA et al. 2000). Restoration actions that influence open upland habitats may affect this species.

9.5.4.32. California Yellow Warbler (*Dendroica petechia brewsteri*)

The nesting California yellow warbler is considered a species of special concern by CDFG. The California yellow warbler was once common throughout the entire northern portion of California, the Coast Ranges from the Oregon border to the Mexican border, the Central Valley, the Lower Colorado River Valley, the western and eastern slopes of the Sierra Nevada, and the foothills of the Transverse and Peninsular Ranges (Small 1994). This species has virtually disappeared as a nester from the Sacramento and San Joaquin valleys, with only 5% of available habitat being occupied in the upper Sacramento Valley (Remsen 1978). There are still breeding populations in the Sierra Nevada, coastal mountains, Owens Valley (Mono and Inyo Counties), and along the Mojave River (San Bernardino County). The largest breeding populations in southern California are in the Santa Ynez River Valley (San Bernardino County) and South Kern River Preserve (Kern County) (Small 1994).

The California yellow warbler is a migratory bird that arrives in California to breed in April. By October, this warbler has left the state for wintering grounds (Zeiner et al. 1990). The species' breeding season is mid-April to early August, peaking in June (Zeiner et al. 1990). It nests in riparian habitats of the lowlands and foothill canyons but will also nest in chaparral habitats with scattered trees and in montane coniferous forest below an elevation of 9,000 feet (Small 1994). During migration, it uses woodland, forest, and scrub habitats (Zeiner et al. 1990). The California yellow warbler feeds on insects and spiders (Zeiner et al. 1990).

Yellow warblers are fairly common spring and fall migrants in riparian habitats of the San Luis and West Bear Creek units of the San Luis NWR complex (JSA et al. 2000). The Point Reyes Bird Observatory banded migrant yellow warblers in riparian habitats of the San Joaquin River in spring and fall (Ballard and Geupel 1999). Restoration actions that influence riparian and upland woodland, forests, and scrub may affect this species.

9.5.4.33. Tricolored Blackbird (*Agelaius tricolor*)

Tricolored blackbird nesting colonies are considered a species of special concern by CDFG. Historically, tricolored blackbirds nested throughout much of California west of the Sierra Nevada, in coastal southern California, and in portions of northeastern California (Beedy and Hamilton 1999). Breeding colonies were observed in the Shasta region, Suisun Valley, and Solano County and near Stockton, San Diego, Los Angeles, Santa Barbara, Glenn County, Sacramento County, Butte County, Colusa County, Yolo County, and Yuba County (Heermann 1853, Belding 1890, Baird 1870, Neff 1937, Orians 1961, Payne 1969). Extensive marshes and uplands that provided ample breeding habitat for tricolored blackbirds in the Central Valley from overflowing river systems had been reduced by 90% by the mid-1980s (Frayer et al. 1989). Additionally, native perennial grasslands, which are primary foraging habitat, have been reduced by more than 99% in the Central Valley and surrounding foothills (Kreissman 1991). Currently, tricolored blackbirds primarily breed in the Sacramento Valley, San Joaquin Valley, along the central coast, southern California, and the northeast interior of California; however, sizes of populations in many of these areas have been greatly reduced (Beedy and Hamilton 1999).

Tricolored blackbirds leave wintering areas in the Delta and along coastal central California in late March and early April. The species' breeding season is from mid-April to late July. Breeding colonies will return to the same area year after year if the site continues to provide adequate nesting sites, water, and suitable foraging habitat (Dehaven et al. 1975).

For breeding-colony sites, tricolored blackbirds require open accessible water, a protected nesting substrate that is usually flooded or has thorny or spiny vegetation, and a foraging area that provides adequate insect prey within a few kilometers of the nesting colony (Beedy and Hamilton 1999). Types of vegetation necessary in the colony area include cattails, tules, willow, blackberry, wild rose, and tall herbs. In addition to consuming insects, the tricolored blackbird also eats seeds and cultivated grains, such as rice and oats. They often forage in croplands, pastures, grassy fields, and in flooded fields (Beedy and Hamilton 1999).

Since 1970, tricolored blackbird colonies have been documented at the West Bear Creek, San Luis, Kesterson, Freitas, and Arena Plains units, and nonbreeding flocks of this species forage and roost throughout wetlands of the San Luis NWR complex (JSA et al. 2000). At the West Bear Creek Unit, a colony of approximately 900 adults was documented in 1991, and in 1994 a colony of approximately 80,000 adults nested in a silage field (JSA et al. 2000). The 1994 colony appeared to be a one-time event and may have been in response to optimal foraging conditions that existed in adjacent native grasslands (Woolington, pers. comm., as cited in JSA et al. 2000). Tricolored blackbirds have not been reported nesting in this area since the new wetlands were created (JSA et al. 2000). Tricolored blackbirds are annually found foraging and drinking/bathing in the native grasslands/vernal pool complex on the West Bear Creek Unit (JSA et al. 2000). Tricolored blackbirds also use West Bear Creek Unit riparian habitat for midday roosting. Tricolored blackbirds could also occur in Reaches 2–5 where there is suitable habitat (JSA et al. 2000). Restoration actions that influence wetland and open upland habitat could affect this species.

9.5.4.34. Pale and Pacific Townsend's (Western) Big-eared Bat (*Corynorhinus townsendii pallescens* and *townsendii*)

There are two subspecies of Townsend's (western) big-eared bats: pale Townsend's big-eared bat (*Corynorhinus (=Plecotus) townsendii townsendii*), and Pacific Townsend's big-eared bat (*C.t. townsendii*). Both are considered species of special concern by CDFG. These sub-species are treated here as a group because there is little subspecies-specific information available on distribution and habitat requirements. Townsend's big-eared bats are an insectivorous species found from humid coastal regions of northern and central California to arid grassland and desert. The species is considered to be a resident species that prefers mesic habitats, and hibernates for all or part of the winter months. These bats are relatively sedentary and make only short movements to hibernation sites. In California, bats have been declining due to timber harvest, oak woodland conversion, pest control exclusion, renewed hard rock mining, bridge replacement, disturbance at roost sites, building demolition, agricultural spraying, recreational caving, and/or pest control (Brown and Pierson 1996). Roosting sites are a limiting factor for this species. They are extremely sensitive to disturbance.

Roost sites generally include rock outcrops, mines, caves, hollow trees, buildings, bridges, cracks in cliffs and boulders, or trees (especially large hollow trees or snags, or trees with big slabs of broken bark). These bats will only roost in the open, hanging from walls and ceilings. Townsend's big-eared bats consume small moths as their principal food source, capturing their prey in flight using echolocation, or by gleaning from foliage.

There are no records for either sub-species in the CNDDB for study area quadrangles (CNDDB 2002). Restoration actions that influence large roosting trees, bridges, and buildings could affect this species.

9.6. SUMMARY

Future restoration activities may impact the numerous special-status plant and animal species in various ways, either positively or negatively. While it is beyond the scope of this chapter to speculate on the myriad of potential restoration actions that may be recommended, and assess the benefits and impacts of these potential actions on the numerous species discussed in the previous sections, a simplified matrix has been prepared to predict general trends. Table 9-3 (fish species), Table 9-4 (invertebrate, amphibian, reptile, mammal species), Table 9-5 (bird species), and Table 9-6 (plant species) shows the possible effects (positive, negative, or neutral) on these species from a number of restoration activities being considered in the Restoration Study planning process. Because these restoration actions have not been precisely defined and in most cases are not site-specific, they are intended to provide only a very general indication of possible effects.

Some generalizations of impacts and benefits of restoration actions can be made. First, the temporal scale of impact and benefit can vary. Large-scale reconstruction projects, such as levee setbacks, gravel pit filling, or channel reconstruction can cause significant short-term impacts to species; however, the goal of most of these projects is to provide long-term improvement to species. For certain species, care must be given during the restoration process to ensure that the short-term impacts of the project do not impair the ability of the project to achieve long-term restoration goals (e.g., restoration causes mortality of the target species to the point where reproduction can no longer occur). Second, restoration projects that (1) increase the diversity of habitats, (2) increase the scale of the riparian corridor, and (3) improve natural physical and biological processes should provide benefits to the greatest number of species. Third, restoration efforts within the riparian corridor will likely benefit those species that have longer residency times in habitats supported by the riparian corridor than those species that have a more transient or seasonal use of riparian habitat.

Although the special-status species that occur in the project area exhibit a wide range of life history strategies and require a wide variety of habitats, a few generalizations can be made about important habitat types. The broad group of habitat types historically found along the San Joaquin River corridor includes alkaline grasslands, riparian/cottonwood forests, riparian scrub/willow thickets, tule marshes, sloughs, exposed gravel bars, exposed sand bars, vernal pools, and instream aquatic habitat with large wood structure. Many of the sensitive plant, invertebrate, and amphibian species are associated with vernal pools, a rare habitat type that occurs outside of the river channel, typically in grasslands. In addition, a number of the sensitive plants are specially adapted to alkaline soils. Many of the sensitive wildlife species are associated with riparian scrub and forest, emergent wetlands, or fish-bearing waters, all of which could be directly affected by restoration actions. Restoration of valley oak woodlands and cottonwood forests would greatly benefit cavity nesting birds, raptors, as well as herons and egrets. Restoration of riparian scrub and associated understory vegetation would greatly benefit migratory songbirds. Improving the flow regime along the entire length of the San Joaquin River would increase the amount of habitat available to sensitive fish species; rehabilitation of this habitat through reconstruction efforts and/or addition of wood structure would further benefit fish species, amphibians, and herptefauna. Upland habitat adjacent to the riparian corridor should also be integrated into restoration planning due the large number of special-status wildlife species dependent on this habitat for breeding or foraging, especially in grasslands, agricultural fields, and other open habitats adjacent to the riparian corridor. Incorporating these upland areas into the planning process for the San Joaquin River could greatly benefit a wide range of sensitive native species.

The Restoration Study will be evaluating specific habitat needs for many of these sensitive species, and will be incorporating these habitat needs into draft restoration objectives for the San Joaquin River. The Restoration Study and subsequent site-specific restoration project design/environmental assessment will be providing more detailed consideration of the benefits and impacts of future restoration activities to sensitive species.

Table 9-3. Special-status fish species with potential to occur in the study area.

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor bemefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	White Sturgeon *(Acipenser transmontanus)*	Green Sturgeon *(Acipenser medirostris)*	Sacramento sucker *(Catostomus occidentalis)*	Sacramento perch *(Archoplites interrruptus)*	Prickly sculpin *(Cottus asper)*	Riffle sculpin *(Cottus gulosus)*	California roach *(Lavinia symmetricus)*	Hardhead *(Mylopharodon conocephalus)*	Hitch *(Lavinia exilicauda exilicauda)*	Sacramento blackfish *(Orthodon microlepidotus)*	Sacramento pikeminnow *(Ptychocheilus grandis)*	Speckled dace *(Rhinichthys osculus)*	Sacramento splittail *(Pogonichthys macrolepidotus)*	Thicktail chub *(Gila crassicauda)*	Tule perch *(Hysterocarpus traski traski)*	Threespine stickleback *(Gasterosteus aculeatus)*	Kern brook lamprey *(Lampetra hubbsi)*	Pacific lamprey *(Lampetra tridentata)*	River lamprey *(Lampetra ayresi)*	Western brook lamprey *(Lampetra richardsoni)*	Chinook salmon *(Oncorhynchus tshawytscha)*	Rainbow trout *(Onchorhynchus mykiss)*	Steelhead *(Oncorhynchus mykiss)*
Modify dam releases to improve fish habitat	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	●●●	●●●	●●●
Modify dam releases to inundate bars and secondary channels	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●●	●●
Modify dam releases to mobilize existing gravel sources	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●●	●●	●●	●●	●●●	●●●	●●●
Remove or disturb armor layer on gravel bars and banks	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●●	●●	●●	●●	●●●	●●●	●●●
Remove vegetation from gravel bars and banks	0	0	○	○	○	○	○	○	○	○	○	○	○○	○	○	○	○	○	○	○	●	●	●
Import gravel	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●●	●●	●●	●●	●●	●●	●●
Fill gravel pits	0	0	○○	○○	0	0	○○	○○	○○	○○	○	○○	0	○○	○○	○○	0	0	0	0	●●	●	●●
Bypass gravel pits	0	0	○○	○○	0	0	○○	○○	○○	○○	○	○○	0	○○	○○	○○	0	0	0	0	●●	●	●●
Construct hydraulic controls	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	●	●	●
Place large woody material in the channel	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	●●	●●●	●●●
Modify dam releases to inhibit warm○water fish species	0	0	○○	○○	○○	○○	○○	○○	○○	○○	○○	○○	0	○○	○○	○○	0	0	0	0	●	●●	●●
Remove non○native warm○water predatory fish species	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	●●	●●	●●
Increase turbidity to reduce salmonid predation during outmigration	0	0	0	○	○	○	○	○	○	○	○○	○	0	○	○	○	0	0	0	0	●●	0	●
Install fish screens on water diversions	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	●●	●	●●
Dredge sand from channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●●	●	●●
Minimize structural fish passage barriers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●●	●●	0	●●●	●	●●●
Bypass Mendota Pool	0	0	○	○	○	○	○	○	○	○	○	○	0	○	○	○	0	●	●	0	●●	0	●●
Reconstruct fish ladder on Mendota Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●●●	0	●●●
Provide spawning habitat on Little Dry Creek	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	●	●	●
Route flow to Lone Willow Slough as alternate fish pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●●	0	●●
Route flow to Salt Slough as alternate fish pathway	0	0	0	0	0	0	0	0	0	0	0	0	●	0	0	0	0	●	●	0	●●	0	●●
Route flow to Cowchilla Bypass as alternate fish pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●●	0	●●

Table 9-3. continued

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor benefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	White Sturgeon *(Acipenser transmontanus)*	Green Sturgeion *(Acipenser medirostris)*	Sacramento sucker *(Catostomus occidentalis)*	Sacramento perch *(Archoplites interrruptus)*	Prickly sculpin *(Cottus asper)*	Riffle sculpin *(Cottus gulosus)*	California roach *(Lavinia symmetricus)*	Hardhead *(Mylopharodon conocephalus)*	Hitch *(Lavinia exilicauda exilicauda)*	Sacramento blackfish *(Orthodon microlepidotus)*	Sacramento pikeminnow *(Ptychocheilus grandis)*	Speckled dace *(Rhinichthys osculus)*	Sacramento splittail *(Pogonichthys macrolepidotus)*	Thicktail chub *(Gila crassicauda)*	Tule perch *(Hysterocarpus traski traski)*	Threespine stickleback *(Gasterosteus aculeatus)*	Kern brook lamprey *(Lampetra hubbsi)*	Pacific lamprey *(Lampetra tridentata)*	River lamprey *(Lampetra ayresi)*	Western brook lamprey *(Lampetra richardsoni)*	Chinook salmon *(Oncorhynchus tshawytscha)*	Rainbow trout *(Onchorhynchus mykiss)*	Steelhead *(Oncorhynchus mykiss)*
Divert water from San Luis Reservoir at Mendota Pool	0	0	●	●	●	●	●	●	●	●	●	●	0	●	●	●	●	●	●	●	○	0	○
Modify dam releases for dispersal and establishment of riparian vegetation	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●●	●●
Modify dam releases for sustenance of riparian vegetation	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●●	●●
Remove invasive exotic riparian plant species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	●
Grade floodplain to facilitate wetland and riparian hydrology	0	0	●●	●●	●	●	●●	●●	●●	●●	●●	●●	●	●●	●●	●●	●●	●●	●●	●●	●	0	●
Plant riparian and wetland plant species	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●●	●●
Construct set○back levees	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●●	●●
Remove internal, private levees	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●	●●
Create levee breaches, overflow structures, or regulated inflows	0	0	●●	●●	●●	●●	●●	●●	●●	●●	●●	●●	●	●●	●●	●●	●●	●●	●●	●●	●●	●	●
Purchase conservation easements	0	0	●●	●●	●●	●●	●●	●●	●●	●●	●●	●●	●	●●	●●	●●	●	●	●	●	●●	●●	●●
Purchase flood easements	0	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Flood○proof existing infrastructure	0	0	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●
Route flow to Fresno Slough as alternate flood pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●●	●●	●●

Table 9-4. Special-status invertebrate, amphibian, reptile, and mammal species with potential to occur in the study area.

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor bemefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	INVERTEBRATES					AMPHIBIANS			REPTILES							MAMMALS						
	Conservancy fairy shrimp Branchinecta conservatio	Longhorn fairy shrimp Branchinecta longiantenna	Vernal pool fairy shrimp Branchinecta lynchi	Vernal pool tadpole shrimp Lepidurus packardi	Valley elderberry longhorn beetle Desmocerus californicus dimorphus	California tiger salamander Ambystoma californiense (= *A. tigrinum c.*)	Western spadefoot *Scaphiopus hammondii*	California red-legged frog Rana aurora draytoni	Western pond turtle *Clemmys marmorata*	Blunt-nosed leopard lizard *Gambelia*(= *Crotaphytus*) *silus*	California horned lizard *Phrynosoma coronatum frontale*	Silvery legless lizard *Anniella pulchra pulchra*	San Joaquin whipsnake (= coachwhip) *Masticophis flagellum ruddocki*	Giant garter snake *Thamnophis gigas*	Pale Townsend's (= western) big-eared bat *Corynorhinus townsendii pallescens*	Pacific Townsend's (=western) big-eared bat *Corynorhinus townsendii townsendii*	Riparian brush rabbit *Sylvilagus bachmani riparius*	San Joaquin (Nelson's) antelope ground squirrel *Ammospermophilus nelsoni*	Fresno kangaroo rat *Dipodomys nitratoides exilis*	San Joaquin Valley (Riparian) woodrat *Neotoma fuscipes riparia*	San Joaquin kit fox Vulpes macrotis mutica
Modify dam releases to improve fish habitat	0	0	0	0	0	0	0	●●●	●●	0	0	●●	0	●●●	●	●	0	0	0	0	0
Modify dam releases to inundate bars and secondary channels	0	0	0	0	0	0	0	●●●	●●	○○	○○	●●●	0	●●●	●	●	○○	0	0	0	0
Modify dam releases to mobilize existing gravel sources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove or disturb armor layer on gravel bars and banks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove vegetation from gravel bars and banks	0	0	0	0	0	0	0	●	0	●	0	○○	0	○	0	0	0	0	0	0	0
Import gravel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fill gravel pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bypass gravel pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construct hydraulic controls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Place large woody material in the channel	0	0	0	0	0	0	0	●●●	●●●	0	0	●	0	●	●	●	0	0	0	0	0
Modify dam releases to inhibit warm-water fish species	0	0	0	0	0	0	0	●●	●	0	0	●●	0	0	0	0	0	0	0	0	0
Remove non-native warm-water predatory fish species	●●	●●	●●	●●	0	0	0	●●●	●●	0	0	●●●	0	●●	0	0	0	0	0	0	0
Increase turbidity to reduce salmonid predation during outmigration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install fish screens on water diversions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dredge sand from channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimize structural fish passage barriers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bypass Mendota Pool	0	0	0	0	0	0	0	○	○○	0	0	○○	0	○○	0	0	○○	0	0	0	0
Reconstruct fish ladder on Mendota Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide spawning habitat on Little Dry Creek	0	0	0	0	0	0	0	●	0	0	0	0	0	0	0	0	0	0	0	0	0
Route flow to Lone Willow Slough as alternate fish pathway	0	0	0	0	●	0	0	●	●	0	0	●	0	●●	●●	●●	●●	0	0	●	0
Route flow to Salt Slough as alternate fish pathway	0	0	0	0	●	0	0	●	●	0	0	●	0	●●	●●	●●	●●	0	0	●	0

Table 9-4. continued

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor bemefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	INVERTEBRATES					AMPHIBIANS			REPTILES						MAMMALS						
	Conservancy fairy shrimp Branchinecta conservatio	Longhorn fairy shrimp Branchinecta longiantenna	Vernal pool fairy shrimp Branchinecta lynchi	Vernal pool tadpole shrimp Lepidurus packardi	Valley elderberry longhorn beetle Desmocerus californicus dimorphus	California tiger salamander Ambystoma californiense (= *A. tigrinum c.*)	Western spadefoot *Scaphiopus hammondii*	California red-legged frog Rana aurora draytoni	Western pond turtle *Clemmys marmorata*	Blunt-nosed leopard lizard *Gambelia*(= *Crotaphytus*) *silus*	California horned lizard *Phrynosoma coronatum frontale*	Silvery legless lizard *Anniella pulchra pulchra*	San Joaquin whipsnake (= coachwhip) *Masticophis flagellum ruddocki*	Giant garter snake *Thamnophis gigas*	Pale Townsend's (= western) big-eared bat *Corynorhinus townsendii pallescens*	Pacific Townsend's (=western) big-eared bat *Corynorhinus townsendii townsendii*	Riparian brush rabbit *Sylvilagus bachmani riparius*	San Joaquin (Nelson's) antelope ground squirrel *Ammospermophilus nelsoni*	Fresno kangaroo rat *Dipodomys nitratoides exilis*	San Joaquin Valley (Riparian) woodrat *Neotoma fuscipes riparia*	San Joaquin kit fox Vulpes macrotis mutica
Route flow to Cowchilla Bypass as alternate fish pathway	0	0	0	0	●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Divert water from San Luis Reservoir at Mendota Pool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Modify dam releases for dispersal and establishment of riparian vegetation	0	0	0	0	●●	0	0	●●●	●●	0	0	●●	0	●●●	●●●	●●●	●●●	0	0	●●●	0
Modify dam releases for sustenance of riparian vegetation	0	0	0	0	●●	0	0	●●●	●●	0	0	●●	0	●●●	●●●	●●●	●●●	0	0	●●●	0
Remove invasive exotic riparian plant species	0	0	0	0	●●	0	0	0	0	0	0	0	0	●	●●	●●	0	0	0	●●	0
Grade floodplain to facilitate wetland and riparian hydrology	0	0	0	0	0	0	0	●●●	●●	○	○	0	0	●●●	●●●	●●●	●●●	0	0	●●●	0
Plant riparian and wetland plant species	0	0	0	0	●●●	0	0	●●●	●●	0	0	0	0	●●●	●●●	●●●	●●●	0	0	●●●	0
Construct set-back levees	●	●	●	●	●●	0	0	●●●	0	0	0	●	0	●●●	●	●	0	0	0	●	0
Remove internal, private levees	●	●	●	●	●●	0	0	●●	0	0	0	●	0	●●●	●	●	0	0	0	●	0
Create levee breaches, overflow structures, or regulated inflows	●	●	●	●	●●	0	0	●●●	0	0	0	●	0	●●●	●●	●●	0	0	0	●	0
Purchase conservation easements	●●●	●●●	●●●	●●●	● ● ●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●	●●	●●	●●	●●	●●●	●●
Purchase flood easements	●	●	●	●	●	0	0	●●	●	0	0	●●	0	●●	0	0	0	0	0	●●	0
Flood-proof existing infrastructure	○○	○○	○○	○○	○○	0	0	0	0	0	0	0	0	0	0	0	0	0	0	○○	0
Route flow to Fresno Slough as alternate flood pathway	0	0	0	0	0	0	0	●	●	0	0	●	0	●●	●●	●●	●●	0	0	0	0

Table 9-5. Special-status bird species with potential to occur in the study area.

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor bemefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	BIRDS																																			
	American white pelican (nesting colony) *Pelecanus erythrorhynchos*	Double-crested cormorant (rookery site) *Phalacrocorax auritus*	Western least bittern (nesting) *Ixobrychus exilis hesperis*	Great blue heron (nesting colonies) *Ardea herodias*	Great egret (nesting colonies) *Ardea alba*	White-faced ibis (rookery site) *Plegadis chihi*	Fulvous whistling duck (nesting) *Dendrocygna bicolor*	Osprey (nesting sites) *Pandion haliaetus*	White-tailed kite (nesting) *Elanus leucurus*	Bald eagle *Haliaeetus leucocephalus*	Northern harrier (nesting) *Circus cyaneus*	Golden eagle *Aquila chrysaetos*	Merlin (wintering) *Falco columbarius*	American peregrine falcon *Falco peregrinus anatum*	Prairie falcon (nesting) *Falco mexicanus*	Sharp-shinned hawk (nesting) *Accipiter striatus*	Cooper's hawk (nesting) *Accipiter cooperii*	Swainson's hawk *Buteo swainsoni*	Ferruginous hawk (wintering) *Buteo regalis*	Yellow rail *Coturnicops noveboracensis*	Greater sandhill crane *Grus canadensis tabida*	Western snowy plover (inland population) *Charadrius alexandrinus nivosus*	Mountain plover *Charadrius montanus*	Long-billed curlew (nesting) *Numenius americanus*	Black tern (nesting colony) *Chlidonias niger*	Western yellow-billed cuckoo *Coccyzus americanus occidentalis*	Western burrowing owl *Athene cunicularia*	Long-eared owl (nesting) *Asio otus*	Short-eared owl (nesting) *Asio flammeus*	Willow flycatcher *Empidonax traillii*	California horned lark *Eremophila alpestris actia*	Bank swallow *Riparia riparia*	Loggerhead shrike *Lanius ludovicianus*	Least Bell's vireo *Vireo bellii pusillus*	California yellow warbler (nesting) *Dendroica petechia brewsteri*	Tricolored blackbird (nesting colony) *Agelaius tricolor*
Modify dam releases to improve fish habitat	●	●●●	●	●	●	●	●●	●●●	●●	●●●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●●	0	0	0	0	0	0	0	●●	0	0
Modify dam releases to inundate bars and secondary channels	●●●	●●	●●	●●●	●●●	●●●	●●●	●●●	●●	●●●	0	0	0	0	0	0	0	0	0	●	0	0	0	0	●	●●	0	●●	●●	0	0	0	0	●●	0	0
Modify dam releases to mobilize existing gravel sources	0	0	0	0	0	0	0	0	0	●●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove or disturb armor layer on gravel bars and banks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove vegetation from gravel bars and banks	●●●	0	0	0	0	0	0	●	0	●●	0	0	0	0	0	0	0	0	0	0	0	●●	●●	0	●●	0	0	0	0	0	0	●	0	0	0	0
Import gravel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fill gravel pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bypass gravel pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construct hydraulic controls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Place large woody material in the channel	0	0	0	0	0	0	●●	0	0	●●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	0	0	0	0	0	0
Modify dam releases to inhibit warm-water fish species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove non-native warm-water predatory fish species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Increase turbidity to reduce salmonid predation during outmigration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install fish screens on water diversions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dredge sand from channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimize structural fish passage barriers	0	0	0	0	0	0	0	●●	0	●●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bypass Mendota Pool	0	0	○○	○	○	○	○	0	○○○	○○	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	○○○	0	○	○	0	0	0	0	0	0	○○
Reconstruct fish ladder on Mendota Dam	0	●	0	0	●	●	0	●	●●●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide spawning habitat on Little Dry Creek	0	0	0	●	●●	●●	●●	●●	●	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	0	0
Route flow to Lone Willow Slough as alternate fish pathway	0	0	●●	●●	●●	●●	●●	●●	●	●●	●	0	●	●	●	●	●	●	●	●	●	0	0	0	●	●●	0	●●	●●	●	0	0	0	●	●	●
Route flow to Salt Slough as alternate fish pathway	0	0	●●	●●	●●	●●	●●	●●	●	●●	●	0	●	●	●	●	●	●	●	●	●	0	0	0	●	●●	0	●●	●●	●	0	0	0	●	●	●
Route flow to Cowchilla Bypass as alternate fish pathway	0	0	●	●	●	●	0	0	●	0	●	0	0	0	0	0	0	0	0	0	0	●	●	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 9-5. continued

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor benefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	BIRDS																																			
	American white pelican (nesting colony) *Pelecanus erythrorhynchos*	Double-crested cormorant (rookery site) *Phalacrocorax auritus*	Western least bittern (nesting) *Ixobrychus exilis hesperis*	Great blue heron (nesting colonies) *Ardea herodias*	Great egret (nesting colonies) *Ardea alba*	White-faced ibis (rookery site) *Plegadis chihi*	Fulvous whistling duck (nesting) *Dendrocygna bicolor*	Osprey (nesting sites) *Pandion haliaetus*	White-tailed kite (nesting) *Elanus leucurus*	Bald eagle *Haliaeetus leucocephalus*	Northern harrier (nesting) *Circus cyaneus*	Golden eagle *Aquila chrysaetos*	Merlin (wintering) *Falco columbarius*	American peregrine falcon *Falco peregrinus anatum*	Prairie falcon (nesting) *Falco mexicanus*	Sharp-shinned hawk (nesting) *Accipiter striatus*	Cooper's hawk (nesting) *Accipiter cooperii*	Swainson's hawk *Buteo swainsoni*	Ferruginous hawk (wintering) *Buteo regalis*	Yellow rail *Coturnicops noveboracensis*	Greater sandhill crane *Grus canadensis tabida*	Western snowy plover (inland population) *Charadrius alexandrinus nivosus*	Mountain plover *Charadrius montanus*	Long-billed curlew (nesting) *Numenius americanus*	Black tern (nesting colony) *Chlidonias niger*	Western yellow-billed cuckoo *Coccyzus americanus occidentalis*	Western burrowing owl *Athene cunicularia*	Long-eared owl (nesting) *Asio otus*	Short-eared owl (nesting) *Asio flammeus*	Willow flycatcher *Empidonax traillii*	California horned lark *Eremophila alpestris actia*	Bank swallow *Riparia riparia*	Loggerhead shrike *Lanius ludovicianus*	Least Bell's vireo Vireo bellii pusillus	California yellow warbler (nesting) Dendroica petechia brewsteri	Tricolored blackbird (nesting colony) *Agelaius tricolor*
Divert water from San Luis Reservoir at Mendota Pool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Modify dam releases for dispersal and establishment of riparian vegetation	0	●●●	●●●	0	0	0	●●●	●●	●●●	●●●	0	0	●●	●●	●●	●●	●●	●●	●●●	●	●	0	0	0	●	0	0	●●	●●	●●●	0	●●	0	●●●	●●●	●●
Modify dam releases for sustenance of riparian vegetation	0	●●●	●●●	●●	●●	●●	●●●	●●●	●●●	●●●	0	0	●●	●●	●●	●●	●●	●●	●●	●	●	0	0	0	●	0	0	●●	●●	●●●	0	●●	0	●●●	●●●	●●
Remove invasive exotic riparian plant species	0	0	●●	0	0	0	0	●	0	●	0	0	0	0	0	0	0	0	0	●	0	0	0	0	●	●	0	0	0	●●	0	0	0	●●●	●●	0
Grade floodplain to facilitate wetland and riparian hydrology	●●●	●●●	●●●	●●●	●●●	●●	●●	●●●	●●	●●●	●●	0	●●	●●	●●	●●	●●	●●	0	●●●	●●●	●●	●●	●	●●●	●●●	0	●●	●●	●●●	0	●●	0	●●	●●	●●●
Plant riparian and wetland plant species	●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	0	0	●	●	●	●	●	●	0	●●●	●●●	0	0	0	●●●	●●●	0	●●	●●	●●●	0	●●	0	●●●	●●●	●●●
Construct set-back levees	0	0	●●●	●●●	●●●	●●●	●●●	0	●●	●	●●●	0	●	●	●	●	●	●●	0	●●●	●●●	0	0	●●	●●●	●●●	0	0	0	0	0	0	0	●●●	●●	●●●
Remove internal, private levees	0	0	●●●	●●	●●	●●	●●●	0	●●	●	●●●	0	●	●	●	●	●	●●	0	●●●	●●	0	0	●●	●●●	0	0	0	0	0	0	0	0	0	●●	●●
Create levee breaches, overflow structures, or regulated inflows	0	0	●●●	●●●	●●●	●●●	●●●	0	●●	●	●●●	0	●	●	●	●	●	●●	0	●●●	●●●	0	0	●●	●●●	0	0	0	0	0	0	0	0	0	●●	●●●
Purchase conservation easements	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●	●●
Purchase flood easements	0	0	●●●	●	●	●	0	●	●●	0	●●	0	●	●	●	●	●	●●●	●	●●●	●●●	●	●	●●	●●●	0	0	0	0	0	0	0	0	0	●●●	0
Flood-proof existing infrastructure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	○○○	0	0	0	0	0	0	0	0	○○	0	0	0	0	○○	○○
Route flow to Fresno Slough as alternate flood pathway	0	●	●	●●	●●	●●	●●	●	●	●●	●	0	●●	●●	●●	●●	●●	●●	●●	●	●	0	0	●	●	●	0	●●	●●	●	0	0	0	0	●	●

Table 9-6. Special-status plant species with potential to occur in the study area.

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor bemefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	Alkali milk-vetch *Astragalus tener* var. *tener*	Heartscale *Atriplex cordulata*	Crownscale *Atriplex coronata* var. *coronata*	Brittlescale *Atriplex depressa*	San Joaquin spearscale *Atriplex joaquiniana*	Lesser saltscale *Atriplex minuscula*	Vernal pool smallscale *Atriplex persistens*	Subtle orache *Atriplex subtilis*	Lost Hills crownscale *Atriplex vallicola*	Succulent (Fleshy) owl's-clover *Castilleja campestris* ssp. *succulenta*	Hoover's spurge *Chamaesyce hooveri*	Hispid bird's-beak *Cordylanthus mollis* ssp. *hispidus*	Palmate-bracted bird's-beak *Cordylanthus palmatus*	Recurved larkspur *Delphinium recurvatum*	Four-angled spikerush *Eleocharis quadrangulata*	Round-leaved filaree *Erodium macrophyllum*	Delta button-celery *Eryngium racemosum*	Spiny-sepaled button celery *Eryngium spinosepalum*	Munz's tidy-tips *Layia munzii*	Madera linanthus *Linanthus serrulatus*	Prostrate navarretia *Navarretia prostrata*	Colusa grass *Neostapfia colusana*	San Joaquin Valley Orcutt grass *Orcuttia inaequalis*	Hairy Orcutt grass *Orcuttia pilosa*	Slender-leaved pondweed *Potamogeton filiformis*	Hartweg's golden sunburst *Pseudobahia bahiifolia*	Sanford's arrowhead *Sagittaria sanfordii*	Wright's trichocoronis *Trichocoronis wrightii* var. *wrightii*
Modify dam releases to improve fish habitat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●	0	0	0	0	0	0	0	0	0	●	0	●	0
Modify dam releases to inundate bars and secondary channels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●●	0	●	0	0	0	0	0	0	0	●●	0	●●	0
Modify dam releases to mobilize existing gravel sources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove or disturb armor layer on gravel bars and banks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove vegetation from gravel bars and banks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Import gravel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fill gravel pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bypass gravel pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construct hydraulic controls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Place large woody material in the channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	●●	0	0	0	0	0	0	0	0	0	0	0	0	0
Modify dam releases to inhibit warm-water fish species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remove non-native warm-water predatory fish species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Increase turbidity to reduce salmonid predation during outmigration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install fish screens on water diversions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dredge sand from channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimize structural fish passage barriers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bypass Mendota Pool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reconstruct fish ladder on Mendota Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide spawning habitat on Little Dry Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 9-6. continued

Potential benefits/impacts ●●● Large benefit ●● Moderate benefit ● Minor bemefit 0 No benefit ○ Minor impact ○○ Moderate impact ○○○ Large impact	Alkali milk-vetch *Astragalus tener* var. *tener*	Heartscale *Atriplex cordulata*	Crownscale *Atriplex coronata* var. *coronata*	Brittlescale *Atriplex depressa*	San Joaquin spearscale *Atriplex joaquiniana*	Lesser saltscale *Atriplex minuscula*	Vernal pool smallscale *Atriplex persistens*	Subtle orache *Atriplex subtilis*	Lost Hills crownscale *Atriplex vallicola*	Succulent (Fleshy) owl's-clover *Castilleja campestris* ssp. *succulenta*	Hoover's spurge *Chamaesyce hooveri*	Hispid bird's-beak *Cordylanthus mollis* ssp. *hispidus*	Palmate-bracted bird's-beak *Cordylanthus palmatus*	Recurved larkspur *Delphinium recurvatum*	Four-angled spikerush *Eleocharis quadrangulata*	Round-leaved filaree *Erodium macrophyllum*	Delta button-celery *Eryngium racemosum*	Spiny-sepaled button celery *Eryngium spinosepalum*	Munz's tidy-tips *Layia munzii*	Madera linanthus *Linanthus serrulatus*	Prostrate navarretia *Navarretia prostrata*	Colusa grass *Neostapfia colusana*	San Joaquin Valley Orcutt grass *Orcuttia inaequalis*	Hairy Orcutt grass *Orcuttia pilosa*	Slender-leaved pondweed *Potamogeton filiformis*	Hartweg's golden sunburst *Pseudobahia bahiifolia*	Sanford's arrowhead *Sagittaria sanfordii*	Wright's trichocoronis *Trichocoronis wrightii* var. *wrightii*
Route flow to Lone Willow Slough as alternate fish pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	0	●	0	0	0	0	0	0	●	0	●	0
Route flow to Salt Slough as alternate fish pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●	●	0	0	0	0	0	0	●	0	●	0
Route flow to Cowchilla Bypass as alternate fish pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●	●	0	0	0	0	0	0	●	0	●	0
Divert water from San Luis Reservoir at Mendota Pool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Modify dam releases for dispersal and establishment of riparian vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	●	●	0	●●	●●	0	0	0	0	0	0	●	0	●	●
Modify dam releases for sustenance of riparian vegetation	0	0	0	0	0	0	0	0	0	0	0	●	●	●●	●●●	0	●●●	●●	0	0	0	0	0	0	●●●	0	●●●	●
Remove invasive exotic riparian plant species	0	0	0	0	0	0	0	0	0	0	0	0	0	●●	●●	0	●●	●●	0	0	0	0	0	0	●●	0	●●	●●
Grade floodplain to facilitate wetland and riparian hydrology	●	0	0	0	0	0	0	0	0	0	0	●●	●●	●●●	●●●	0	●●●	●●●	0	0	0	0	0	0	●●●	0	●●●	●●●
Plant riparian and wetland plant species	●	0	0	0	0	0	0	0	0	0	0	●●●	●●●	●●●	●●●	0	●●●	●●	0	0	0	●	●	●	●●●	0	●●●	●●●
Construct set-back levees	●●	0	0	0	0	0	0	0	0	0	0	●●●	●●●	●●●	●●●	0	●●●	●●●	0	0	0	●●●	●●●	●●●	●●	0	●●	●●
Remove internal, private levees	●●	0	0	0	0	0	0	0	0	0	0	●●	●●	●●	●●	0	●●	●	0	0	0	●●	●●	●●	●	0	●	●●
Create levee breaches, overflow structures, or regulated inflows	●●	●	●	●	0	●	0	0	●	0	0	●●●	●●●	●●	●●	0	●●	●●	0	0	0	●●	●●	●●	●●	0	●●	●●●
Purchase conservation easements	●●●	●●●	●●●	●●●	0	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
Purchase flood easements	●	●●●	●●●	●●●	0	●●●	●●	0	●●●	●	●	●	●	●	●	0	●●●	●●●	0	0	0	●	●	●	●	0	●	●●
Flood-proof existing infrastructure	○○	○○	○○	○○	0	○○	0	0	○○	○	○	○○	○○	○○	○○	0	●●●	●	0	0	0	○○	○○	○○	○○	0	○○	○○
Route flow to Fresno Slough as alternate flood pathway	0	0	0	0	0	0	0	0	0	0	0	0	0	●●	●●	0	●●	●●	0	0	0	0	0	0	●●	0	●●	●●

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CHAPTER 10. LAND USE AND OWNERSHIP

10.1. INTRODUCTION

Most of the land along the San Joaquin River is under private ownership, and the primary land use is agricultural. This land use and ownership has greatly influenced the evolution of the San Joaquin River corridor, and will continue to impose constraints to restoration along the river in the future. However, there are opportunities associated with land use and ownership along the San Joaquin River that will assist restoration efforts. Additionally, restoration activities may conflict with local regulations (e.g., county General Plans), as well as add new constraints to the existing land uses. Therefore, the goals of this chapter are to: (1) provide a history of the valley's land use and ownership, (2) describe, delineate, and evaluate current land use, ownership, and regulatory jurisdictions, in each study reach, and (3) analyze land use and ownership opportunities and constraints to restoring the San Joaquin River within the study reach. To achieve these goals, we present an historical chronology and a quantitative description of land use and ownership along the river. Then, based on this information, and on observations of restoration efforts on other San Joaquin River tributaries, we end the chapter with a summary of opportunities and constraints imposed by and on land use and ownership on the San Joaquin River. These opportunities and constraints will play key roles in developing and implementing restoration strategies on the San Joaquin River.

10.1.1. A Brief History of Land Use and Land Ownership

Under historical unimpaired conditions, the valley floor of the San Joaquin River basin contained four major environments: upland grassland prairie, tule marsh/flood basins, riparian forest, and aquatic areas. The grassland prairie environment was the first to be altered in the late 1700's with the introduction of exotic grasses (Bakker 1971, cited in Gutierrez and Orsi 1998). Tule marsh/flood basin reclamation began in the late 1800's with levee construction along the rivers, blocking off sloughs, draining marshes, and removing the tules. The riparian forest was first impacted by clearing timber to fuel the steamers plying the waterways of the San Joaquin River; impacts culminated with the first wave of farmers cultivating drier riparian areas situated on natural levees along the river. The aquatic environment was first impacted by the formation of irrigation and canal companies that diverted water upriver to be used on non-riparian or reclaimed riparian lands. Completion of the Central Valley Project and State Water Project greatly increased water diversions from the San Joaquin River, removing most of the flows responsible for maintaining the river in a healthy condition. A short history of land use in the San Joaquin River Basin is summarized as follows:

- Prior to the arrival of Spanish missionaries and explorers in the late 1770s, the Yokut Tribe subsisted on plants, animals, and fish along the San Joaquin River corridor. The Southern Valley Yokuts inhabited the Tulare Lake basin, while the Northern Valley Yokuts inhabited the San Joaquin Valley. Both tribes had similar land use and subsistence patterns, with the notable exception that the Northern Valley Yokuts had greater access to acorns and salmon than the southern tribe (Wallace 1978). Most land use was passive, gathering acorns, tule roots, grass seeds, and eggs, as well as hunting waterfowl and larger land mammals. Intentional burning of tule marshes is often cited as a Yokut land use practice, but whether this was true or merely supposed by early American settlers is uncertain. Harvesting of willows and grasses, however, was common; willows and grasses were primarily used for basketry.
- From 1772 to 1821, Spanish missions were established along coastal California. Spanish missionaries and explorers introduced cattle, horses, and exotic annual grasses (e.g., wild

oats), which spread rapidly through the San Joaquin Valley. The exotic annual grasses and weeds began to replace the native grasses over much of the historic grassland prairies (Gutierrez & Orsi 1998).

- From 1832 to 1844, the Hudson Bay Company's southern fur trapping brigade set up its headquarters at French Camp near Stockton, to commercially exploit beaver and otter (Mackie 1997). While the fur trapping period was short, the trappers shot large quantities of deer and elk for subsistence, as well as for hides. At this time, malaria was introduced to the Yokut people, whose population was decimated by an 1833 epidemic (Wallace 1978, Gutierrez & Orsi 1998).
- At approximately the same time (1835), the first land grant was issued in the San Joaquin Valley by the Mexican government. By 1843, the mission lands were secularized, and a campaign of privatizing land for cattle production was underway. After the Bear Flag Revolt in 1846, the United States imposed military rule, by which time the Mexican government had awarded 341,794 acres in land grants. These land grants were issued to just 12 Californio rancheros in the San Joaquin River Basin (Minnick 1982, Perez 1996).
- In 1848, gold was discovered; the impact on rivers draining into the San Joaquin Valley began with placer mining, followed by construction of dams, ditches, and diversions to hydraulically mine the hill slopes. The mining debris washed into the rivers leaving a covering of silt and debris referred to as "slickens" in its wake. While hydraulic mining was prohibited in 1893, dredging of river bottoms in the lower courses of the rivers entering the San Joaquin Basin persisted until the 1950s (Rawls & Orsi 1999).
- In 1850, California became the 31st state. The Arkansas Act of 1850 granted all "swamp and overflowed lands" to the State of California, which could sell the land to private individuals if it would be reclaimed. A new wave of land privatization ensued. The population of the San Joaquin Valley was only 21,000 persons, with only 3,000 acres under cultivation (raising wheat and other seasonal grains). During this era of dry land grain farming, tule marshes were drained and leveed, creating vast land holdings that supported cattle and hogs. Mr. Henry Miller, of Miller and Lux, vigorously acquired riparian lands and water rights along the San Joaquin River that would eventually total 900,000 acres (CSDE 1942, Fox 1987, Rose 1992, Vileisis 1997).
- In 1871, the Central Pacific Railroad arrived in the San Joaquin Valley. At the same time, construction of the San Joaquin and Kings River Canal began, which signaled the end of dry land farming. The era of appropriated water rights and irrigation, new concepts to the American farmer, began by utilizing water rights developed earlier for hydraulic mining. Throughout the 1870s, canal companies and irrigation districts were formed, and in 1878, William Hall (State Engineer for California) began studies to improve irrigation, drainage, and navigation in the San Joaquin River. By 1880, the population increased to 150,000, with 2,000,000 acres under cultivation. With the passage of the 1887 Wright Irrigation Act, approximately fifty active irrigation districts were formed in the Central Valley, building more than six hundred dams. Canals delivered irrigation water to non-riparian lands where fruit and vegetables were raised. By 1892, the large landholdings in the San Joaquin Valley led the nation in wheat in production (CSDE 1942, Fox 1987, Patterson 1989, Rose 1992). Intensive farming required more water than could be supplied from surface sources, and ground water pumping escalated, which drastically decreased groundwater elevations. Underground water deposits were overdrawn, and by 1936, lands that were intensively farmed earlier were abandoned. In 1921, the State funded the Marshall Plan to develop a comprehensive water development plan to resolve the recurring problems of floods and droughts, and also to devise a system to move surplus water in the north to the south in the Central Valley.

- In 1935, the Federal Government took over the Central Valley Project, and three years later, the US Bureau of Reclamation (Reclamation) entered into a contract to construct Shasta Dam. In 1939, a contract was issued for constructing Friant Dam. Friant Dam was completed two years later and began delivering water into the Friant-Madera Canal and Friant-Kern Canal by 1948. After construction of Friant and Shasta dams, over 5 million acre feet of water could be released through a network of canals and riverbeds that run almost the whole length of the Central Valley. In 1951, the Central Valley Project was completed, and 98% of the San Joaquin River water was diverted into the Friant-Kern and Friant-Madera Canals to irrigate upland agricultural lands (CSDE 1942, Rose 1992). The completion of the Friant Unit of the Central Valley Project provided the final impetus for ultimate agricultural expansion of the San Joaquin Valley. However, the completion of Friant Dam and the associated diversion canals did not occur without a significant environmental cost, as portions of the San Joaquin River were dewatered downstream of Friant Dam, extirpating salmon and steelhead populations, and degrading habitat along the riparian corridor.

10.2. OBJECTIVES

The objective of this chapter is to identify and describe restoration opportunities and constraints resulting from land use and ownership that would influence restoration strategies of the Restoration Plan. Specific to land use and ownership, the April 2000 Scope of Work lists several objectives:

- Describe, evaluate, and map other existing and potential land uses within the pre-dam 100-year floodplain.
- Describe and map land ownership patterns which differentiate public and private land

To achieve these objectives, primary information needs are: 1) the extent of the pre-dam 100-year floodplain to define the study area boundary, 2) public versus private land ownership within the study area boundary, 3) types of land use within the study area boundary, and 4) a discussion of existing and potential future opportunities and constraints resulting from potential activities of the Restoration Plan.

10.3. STUDY AREA BOUNDARY

The length of the study area is defined as the San Joaquin River basin, from Friant Dam down to its confluence with the Merced River. The width of the study area varies depending on source of the data utilized. The Bureau of Reclamation provided land ownership data for properties along the river; therefore, for analyzing opportunities and constraints due to land ownership, the study area width is defined by extending an approximate boundary line at least ½ mile from the San Joaquin River's centerline. This creates at least a 1-mile wide study area width that extends from Friant Dam to the confluence of the Merced River. For land use, data was compiled from the Department of Water Resources; this data covered an area approximately 1,500 feet or greater beyond the river centerline on both banks, for a total study area width of at least 3,000 feet.

10.4. DATA SOURCES AND METHODS

Land use data were provided by the Department of Water Resources (DWR) as described above (approximately 3,000 ft width along the river). Land ownership data for the study area (covering a width approximately 1-mile wide along the river) was provided by the Bureau of Reclamation, the San Joaquin River Parkway and Conservation Trust, and the State Lands Commission. Data sources and methods are described in more detail below.

10.4.1. Land Use

Present day land use practices were compiled from DWR’s GIS databases for Merced (1995), Madera (1995), and Fresno (1994) counties. Land use types were inventoried by the following broad land uses: agricultural, open space, and urban. Each of these broad land uses was further subdivided into “types”. For agricultural land use, subdivision types include:

- Annual crops, such as field crops (cotton, sweet corn, sugar beets, dry beans, and safflower), truck, nursery and berry crops (lettuce, bell peppers, strawberries, melons, nursery products, eggplant, garlic, onions, asparagus, squash, broccoli, peas, and tomatoes), pasture (forage, irrigated, and range lands, and may include alfalfa, clover, and other native or mixed pasture plant species), grain and hay crops (alfalfa, barley, wheat, oats, and other mixed grain and hay), and rice.
- Vineyards, such as raisin, table, and wine grapes.
- Orchards, such as citrus and subtropical crops (kiwifruit, lemons, nectarines, olives, and oranges), deciduous fruit and nut crops (almonds, apples, sweet cherries, dried figs, peaches, persimmons, pistachios, plums, pomegranates, and walnuts).
- Semi-agricultural and incidental to agriculture, such as apiary products, cattle, poultry, dairy, and wool. This category also includes other agriculture-related infrastructure such as agricultural disposal areas, equipment maintenance areas, and storage areas.

Open space lands were also subdivided into these types:

- Idle land, such as cropland that is fallow but has been farmed within the past 3 years, or land that is being prepared to be placed in agricultural production.
- Native vegetation, such as wetland/marsh, grassland, shrub/brush, and forest plant communities.
- Aquatic environments, such as lakes, reservoirs, rivers, canals, and open water created by mining operations.

The urban land uses include the following subdivision types:

- Residential, such as homes, apartments, and trailer parks.
- Commercial, such as malls, small businesses, and retail and wholesale stores.
- Industrial, such as factories, manufacturers, and service industries.
- Landscaped, such as lawns, golf courses, and cemeteries.
- Vacant, such as unpaved lots, railroad rights-of-way, parking lots, paved roads, and airport runways.

Once these layers were imported into Arc-Info, a centerline was drawn and offset approximately 1,500 ft on either side of the river to define the width of the study area boundary. These offset lines were smoothed as necessary, and we then verified that the lines fell entirely within the available land use GIS information. Based on this study area boundary, a query was performed to identify the acreages for the broad land uses (Agricultural, Open Space, and Urban), as well as for the subdivision types for Agricultural and Open Space land uses. The acreages for each land use type were summed and tabulated for each of the five reaches between Friant Dam and the Merced River confluence. Note that the data used in this analysis is from 1994 and 1995, and because land use in the study area changes from year to year based on a variety of market and landowner factors, the analytical results in Section 10.5.1 should be considered representative, not absolute.

10.4.1.1. Land use production values

A production value (in average annual dollars per acre) was estimated for crops that are grown in the land use types described above. These production values were estimated using data from California Agricultural Statistic Service (2001) for Fresno, Madera, and Merced counties. The crops were organized by the DWR land use classifications *Standard Land Use Legend*, July 1993. The annual $/acreage estimates were then averaged to get production values that represent the study area (Table 10-1). Note that all of the crops listed may not be included in the project area.

Table 10-1: Summary of production values by agricultural product.

Agricultural Product	Production Value ($/acre-year)
Field crops (cotton, sweet corn, sugar beets, dry beans, and safflower)	$1,051
Truck, nursery, berry crops (lettuce, bell peppers, strawberries, melons, nursery products, eggplant, garlic, onions, asparagus, squash, broccoli, peas, and tomatoes)	$5,249
Pasture (forage, irrigated, and range lands, and may include clover and other native or mixed pasture plant species)	$80
Grain and hay crops (alfalfa, barley, wheat, oats, and other mixed grain and hay)	$398
Rice (milling rice only)	$1,078
Vineyards (raisin, table, and wine grapes)	$3,713
Citrus and subtropical crops (kiwifruit, lemons, nectarines, olives, and oranges)	$4,355
Deciduous fruit and nut crops (almonds, apples, sweet cherries, dried figs, peaches, persimmons, pistachios, plums, pomegranates, and walnuts)	$4,098

10.4.2. Land Ownership

Land ownership data were compiled from the Bureau of Reclamation’s database (2001) for lands within a 1-mile corridor of the San Joaquin River. Data depicting lands owned by the San Joaquin River Parkway and Conservation Trust was provided by GreenInfo (2002). Lands surveyed by the State Lands Commission, for fee title and public trust easement boundaries between Friant Dam and Herndon, were added (State Lands Commission, 1992). Data provided by the San Joaquin River Parkway and Conservation Trust was also added to the database. In the land use acreage tables that follow, parentheses signify the last year each data set was updated. Data from the 1989-1992 State Lands Boundary Survey located the State’s fee title (low water) and Public Trust easement (high water) claims, and were used as a baseline for property boundaries from Friant Dam to Herndon on both sides of the river. The State Lands surveys ended at Herndon; however, the absence of surveys downstream does not imply that the State does not have a claim to river bottomlands, just that those claims have not yet been quantified. Downstream of Herndon, all data were used as provided by Bureau of Reclamation, including the few locations where data overlapped in Fresno and Madera counties.

Land ownership was separated into two broad classifications: private and public. Private lands (urban, industrial, agricultural, etc) were not subdivided any further. However, public lands were delineated into Federal lands (Bureau of Reclamation and US Fish and Wildlife Service), State Lands Commission public trust and fee title lands, other State and County lands (Department of Fish and Game, San Joaquin River Levee District, Fresno County Parks), and those lands owned by the San Joaquin River Parkway and Conservation Trust.

10.5. ANALYTICAL RESULTS

Results of the GIS queries for land use and land ownership are presented in two sections below.

10.5.1. Land Use

Land use maps were overlain onto USGS 7.5 minute quadrangle sheets (Figures 10-1a through Figure 10-1q), and land use acreages were tabulated by reach for the different land uses described in Section 10.4.1 (Tables 10-2 through 10-6).

Table 10-2. Acreage of land use and land use types on the San Joaquin River for Reach 1.

	Acreage			
Land Use	**Left-Bank (acres) ***	**Right-Bank (acres) ***	**Total (acres)**	**Percent of Reach total**
Agricultural				
Annual Crops	744	528	1,271	8 %
Vineyards	1,331	1,604	2,935	19 %
Orchards	307	635	941	6 %
Semi- or incidental to agriculture	54	97	151	1 %
TOTAL AGRICULTURAL:	*2,435*	*2,864*	*5,299*	*34.8 %*
Open Space				
Idle	24	11	35	0 %
Native Vegetation	3,068	4,162	7,230	47 %
Aquatic Environments	581	483	1,064	7 %
TOTAL OPEN SPACE:	*3,674*	*4,656*	*8,329*	*54.6 %*
Urban				
Typical urban lands	1,074	540	1,614	10.6 %
TOTAL URBAN:	*1,074*	*540*	*1,614*	*10.6 %*
Total for Reach 1	**7,183**	**8,060**	**15,242**	**100 %**

* Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-3. Acreage of land use and land use types on the San Joaquin River for Reach 2.

Land Use	**Acreage** **Left-Bank (acres) ***	**Right-Bank (acres) ***	**Total (acres)**	**Percent of Reach total**
Agricultural				
Annual Crops	1,986	1,632	3,618	38 %
Vineyards	790	885	1,675	18 %
Orchards	1,145	180	1,325	14 %
Semi- or incidental to agriculture	16	6	22	0 %
TOTAL AGRICULTURAL:	*3,937*	*2,703*	*6,640*	*70 %*
Open Space				
Idle	28	117	145	2 %
Native Vegetation	1,649	1,085	2,734	29 %
Aquatic Environments	0	0	0	0 %
TOTAL OPEN SPACE:	*1,677*	*1,202*	*2,879*	*30 %*
Urban				
Typical urban lands	14	9	23	0 %
TOTAL URBAN:	*14*	*9*	*23*	*0 %*
Total for Reach 2	**5,628**	**3,914**	**9,542**	**100 %**

* Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-4. Acreage of land use and land use types on the San Joaquin River for Reach 3.

Land Use	**Acreage** **Left-Bank (acres) ***	**Right-Bank (acres) ***	**Total (acres)**	**Percent of Reach total**
Agricultural				
Annual Crops	2,716	2,906	5,622	67 %
Vineyards	0	0	0	0 %
Orchards	0	24	24	0 %
Semi-agricultural	33	13	46	1 %
TOTAL AGRICULTURAL:	*2,749*	*2,943*	*5,692*	*68 %*
Open Space				
Idle	15	52	67	1 %
Native Vegetation	928	862	1,790	21 %
Aquatic Environments	26	0	26	0 %
TOTAL OPEN SPACE:	*969*	*913*	*1,882*	*22 %*
Urban				
Typical urban lands	735	100	835	10 %
TOTAL URBAN:	*735*	*100*	*835*	*10 %*
Total for Reach 3	**4,453**	**3,956**	**8,409**	**100 %**

* Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-5. Acreage of land use and land use types on the San Joaquin River for Reach 4.

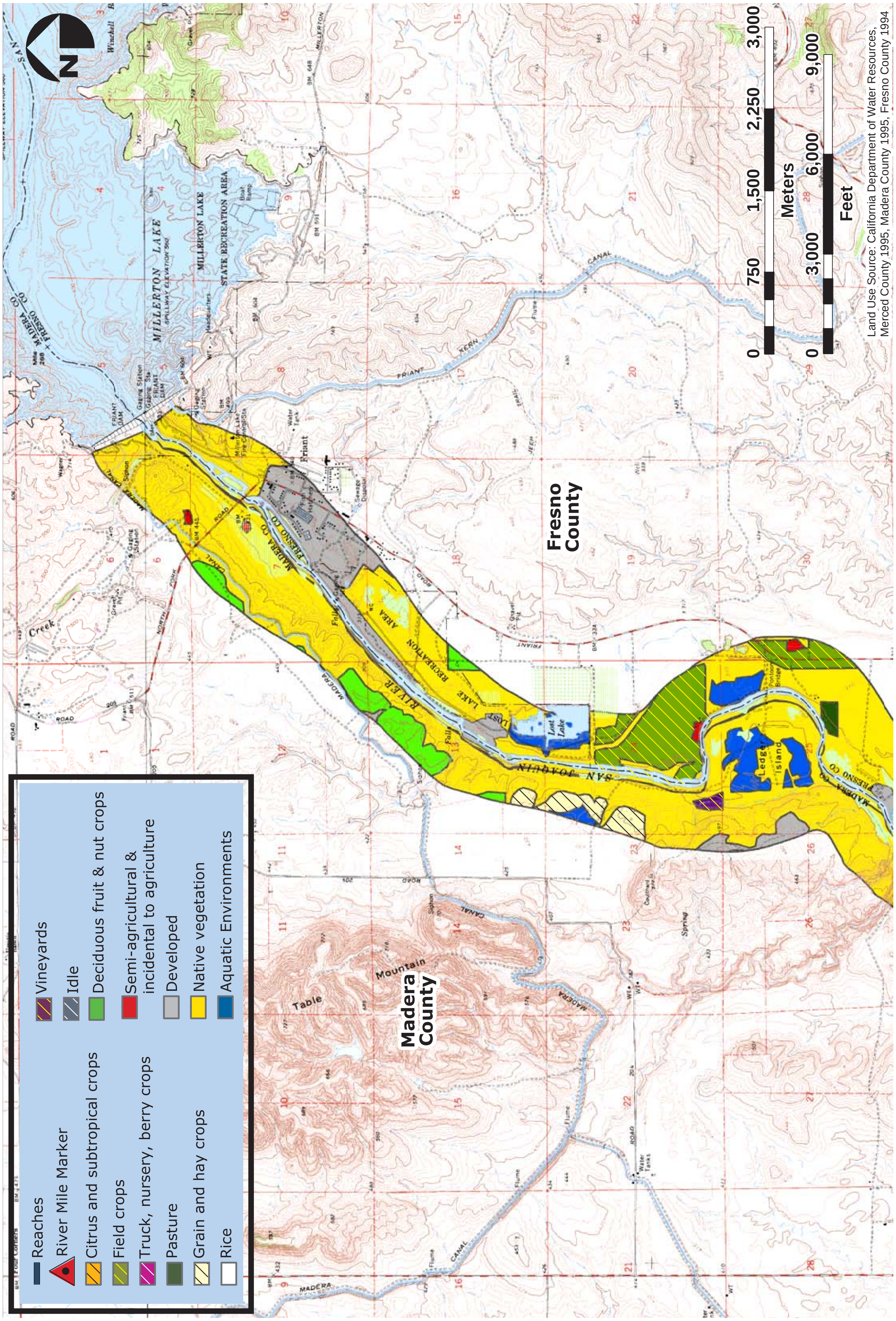
	Acreage			
Land Use	**Left-Bank (acres) ***	**Right-Bank (acres) ***	**Total (acres)**	**Percent of Reach total**
Agricultural				
Annual Crops	1,891	26,396	28,287	51 %
Vineyards	0	7	7	0 %
Orchards	64	0	64	0 %
Semi-agricultural	86	81	168	0 %
TOTAL AGRICULTURAL:	*2,041*	*26,484*	*28,526*	*51 %*
Open Space				
Idle	111	2,026	2,137	4 %
Native Vegetation	9,676	15,389	25,065	45 %
Aquatic Environments	0	13	13	0 %
TOTAL OPEN SPACE:	*9,787*	*17,428*	*27,215*	*49 %*
Urban				
Typical urban lands	66	156	223	0 %
TOTAL URBAN:	*66*	*156*	*223*	*0 %*
Total for Reach 4	**11,894**	**44,068**	**55,964**	**100 %**

* Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-6. Acreage of land use and land use types on the San Joaquin River for Reach 5.

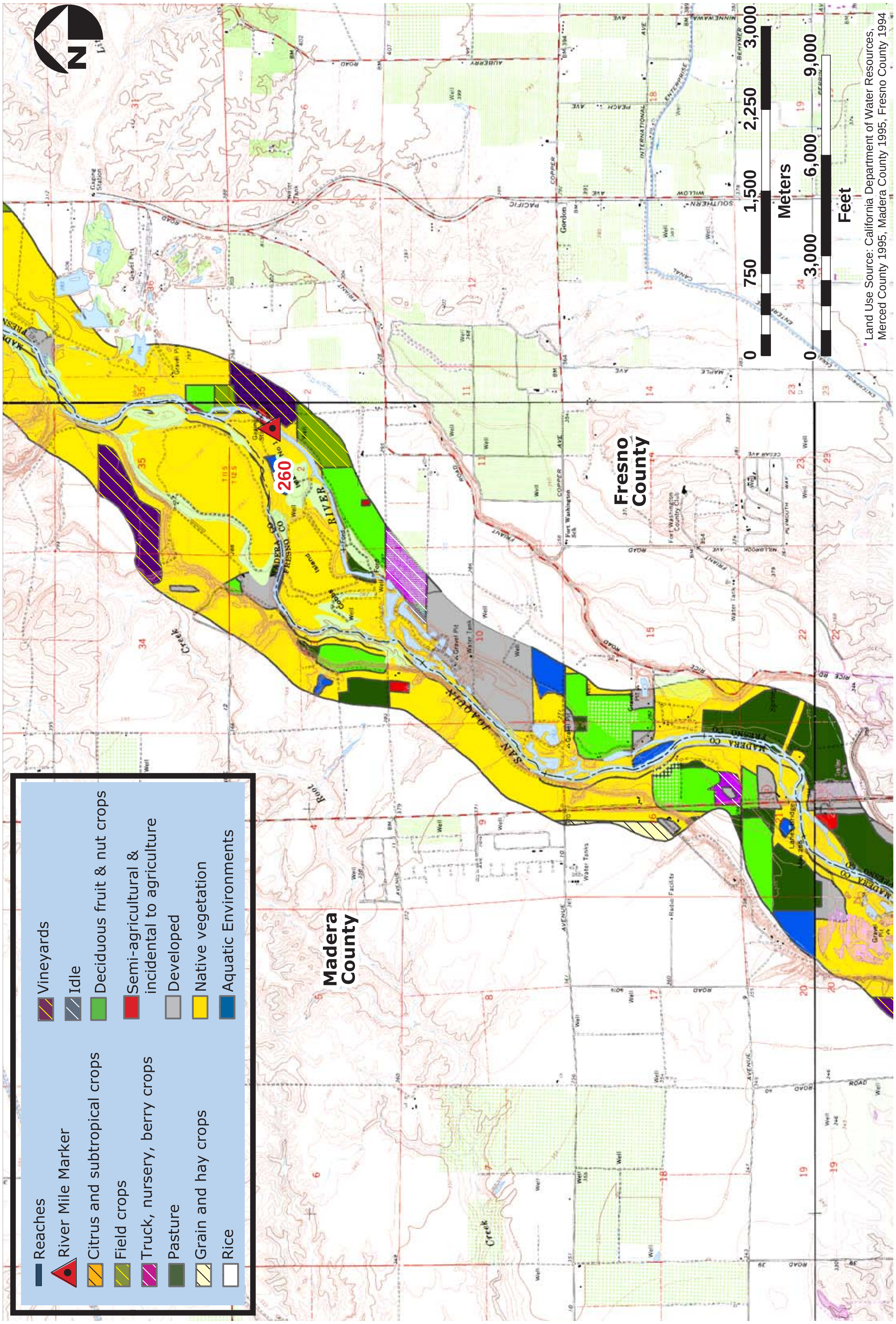
	Acreage			
Land Use	**Left-Bank (acres) ***	**Right-Bank (acres) ***	**Total (acres)**	**Percent of Reach total**
Agricultural				
Annual Crops	367	7,090	7,456	32 %
Vineyards	0	44	44	0 %
Orchards	0	28	28	0 %
Semi-agricultural	0	583	583	3 %
TOTAL AGRICULTURAL:	*367*	*7,745*	*8,111*	*35 %*
Open Space				
Idle	1,350	57	1,407	6 %
Native Vegetation	7,986	5,416	13,402	58 %
Aquatic Environments	81	4	85	0 %
TOTAL OPEN SPACE:	*9,417*	*5,477*	*14,894*	*64.5 %*
Urban				
Typical urban lands	1	109	111	0.5 %
TOTAL URBAN:	*1*	*109*	*111*	*0.5 %*
Total for Reach 5	**9,785**	**13,331**	**23,116**	**100 %**

* Left bank and right bank designations assume one is looking in the downstream direction.



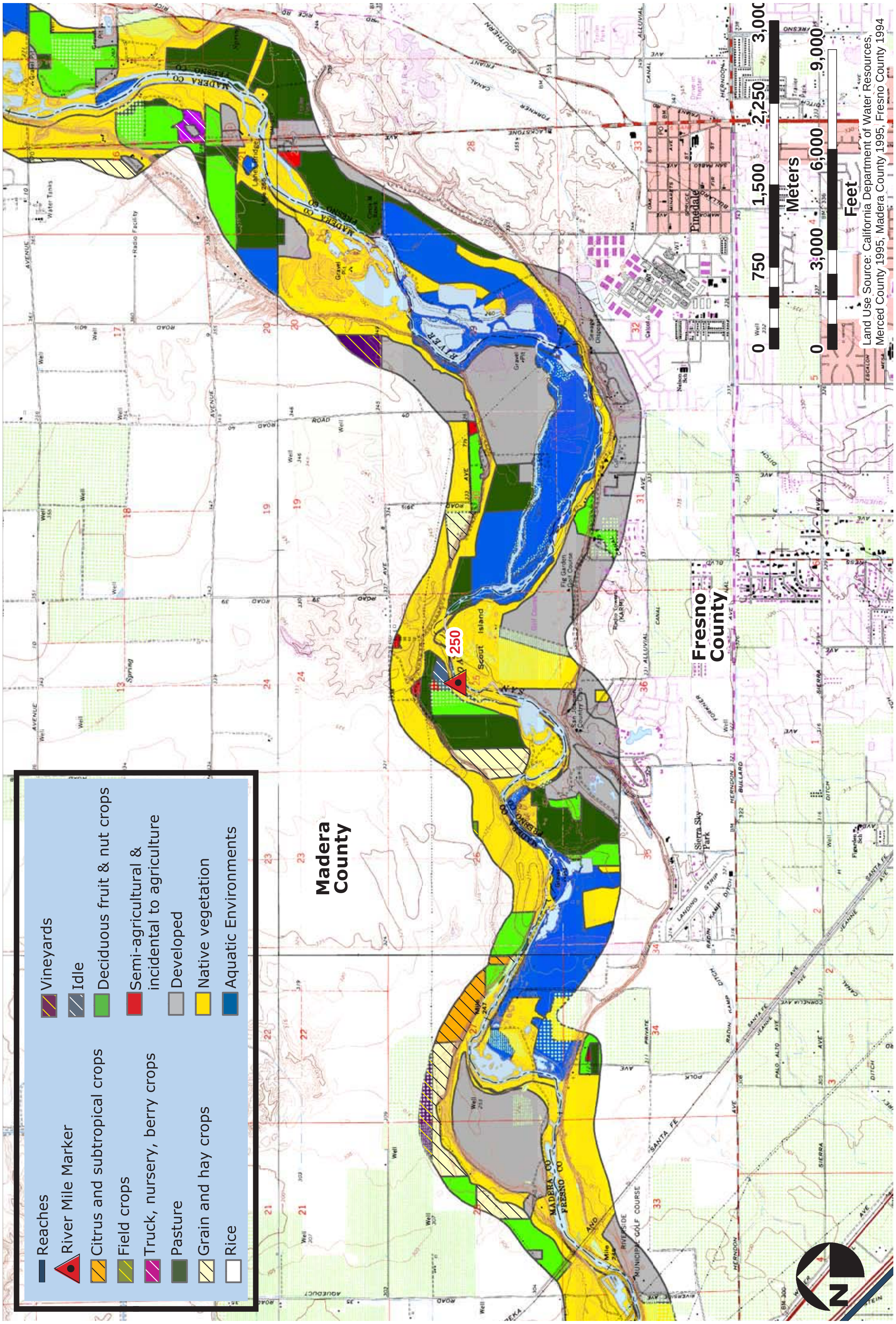
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1a. Land use along the San Joaquin River (Reach 1a)



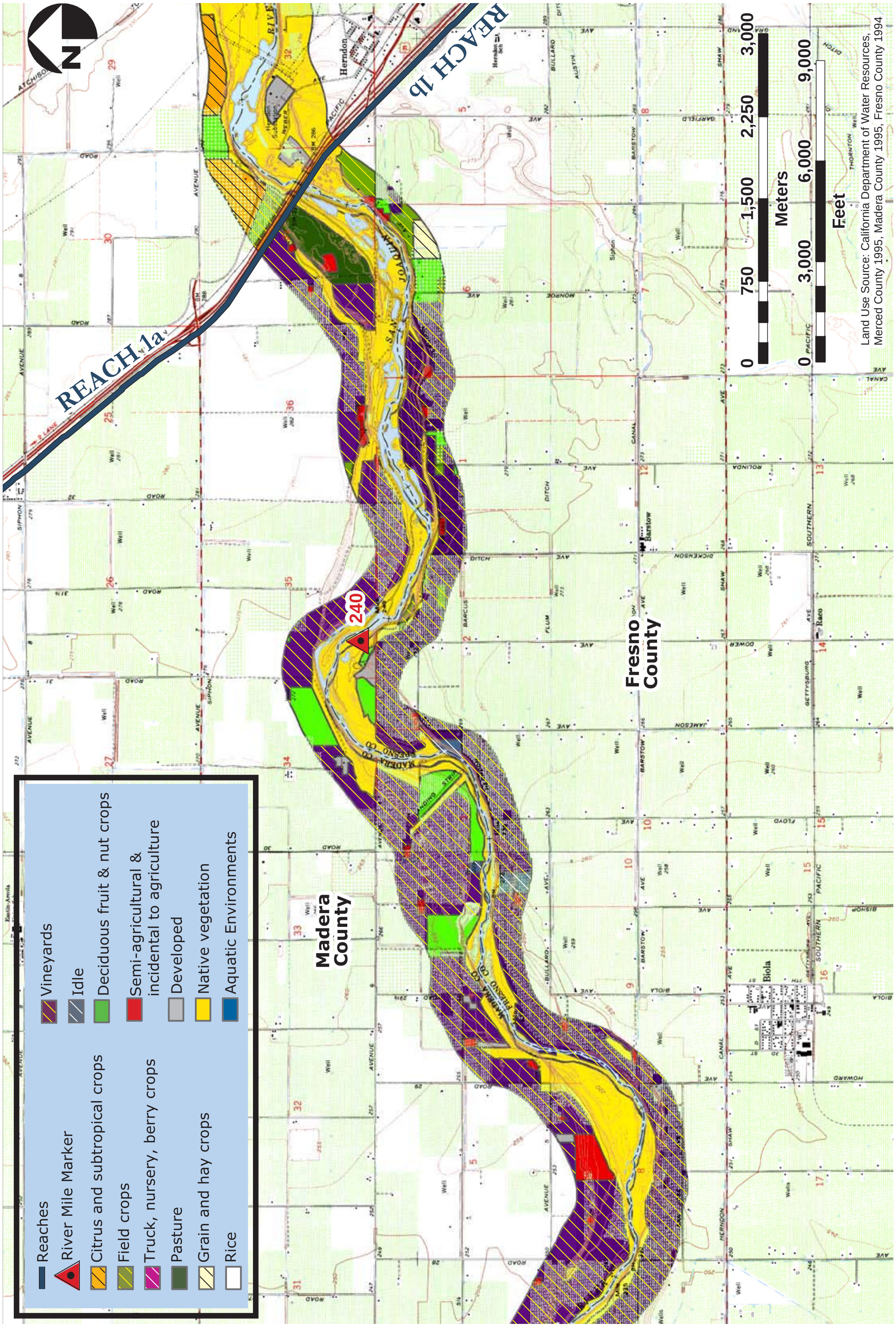
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1b. Land use along the San Joaquin River (Reach 1a)



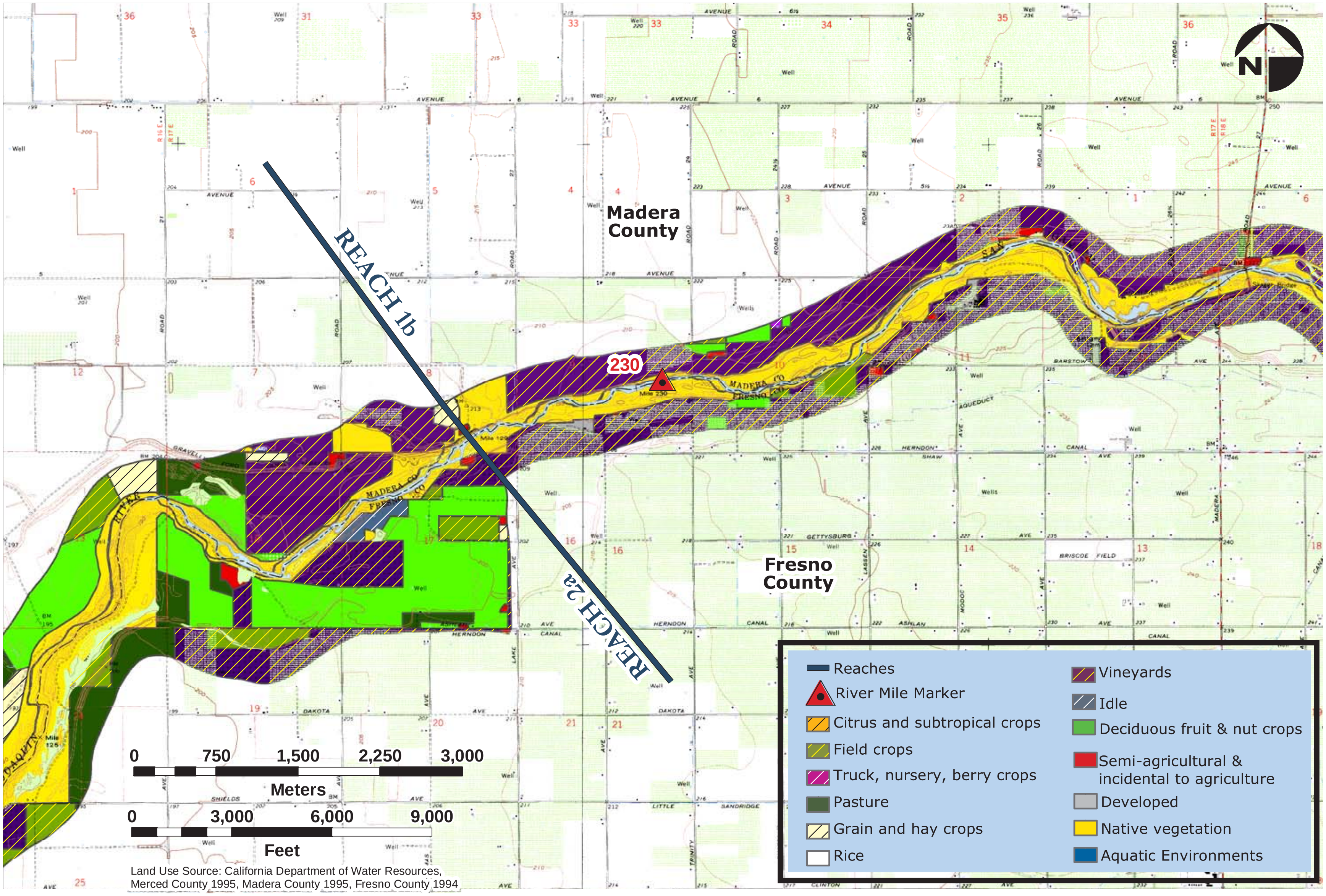
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1c. Land use along the San Joaquin River (Reach 1a)



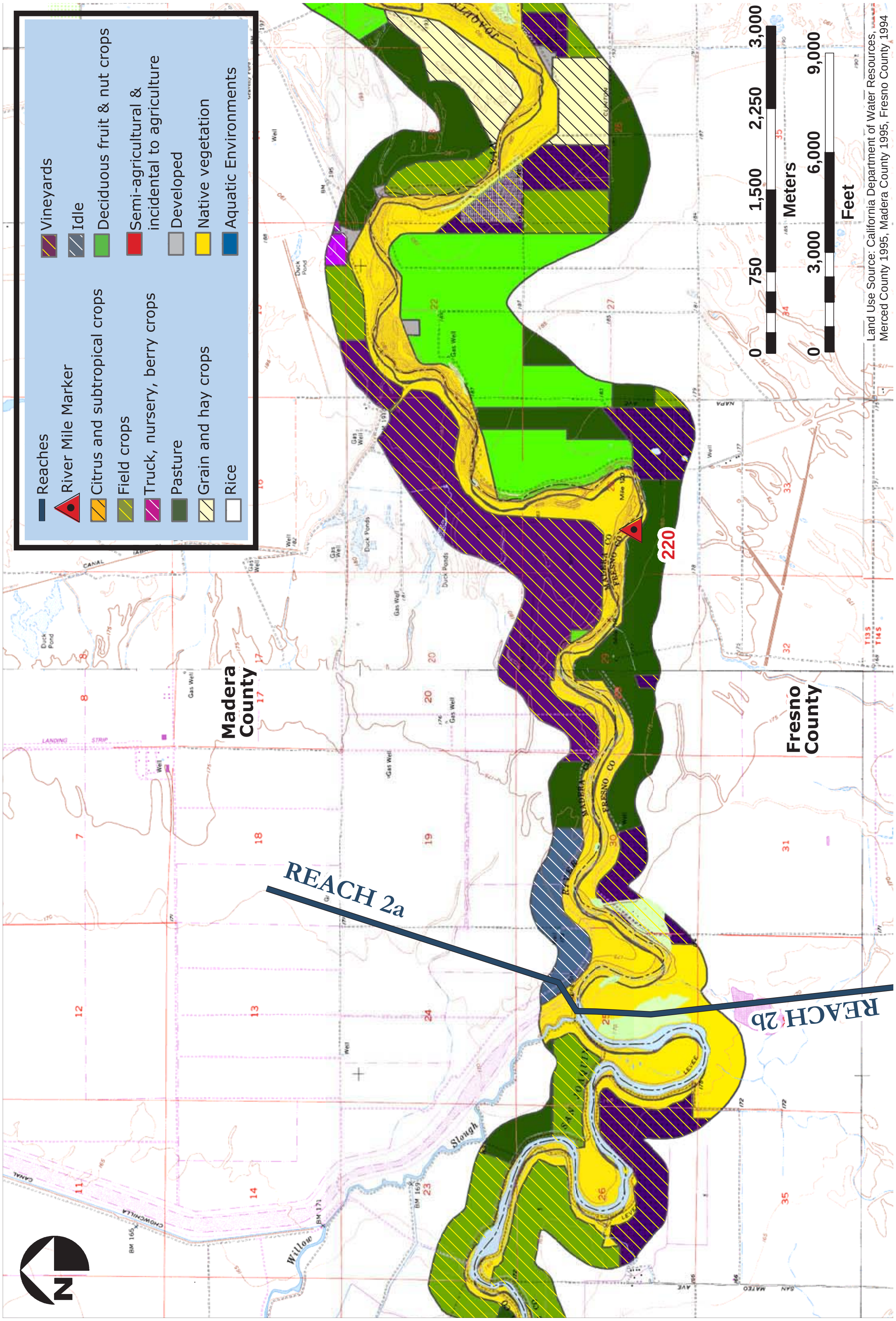
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1d. Land use along the San Joaquin River (Reach 1a & 1b)



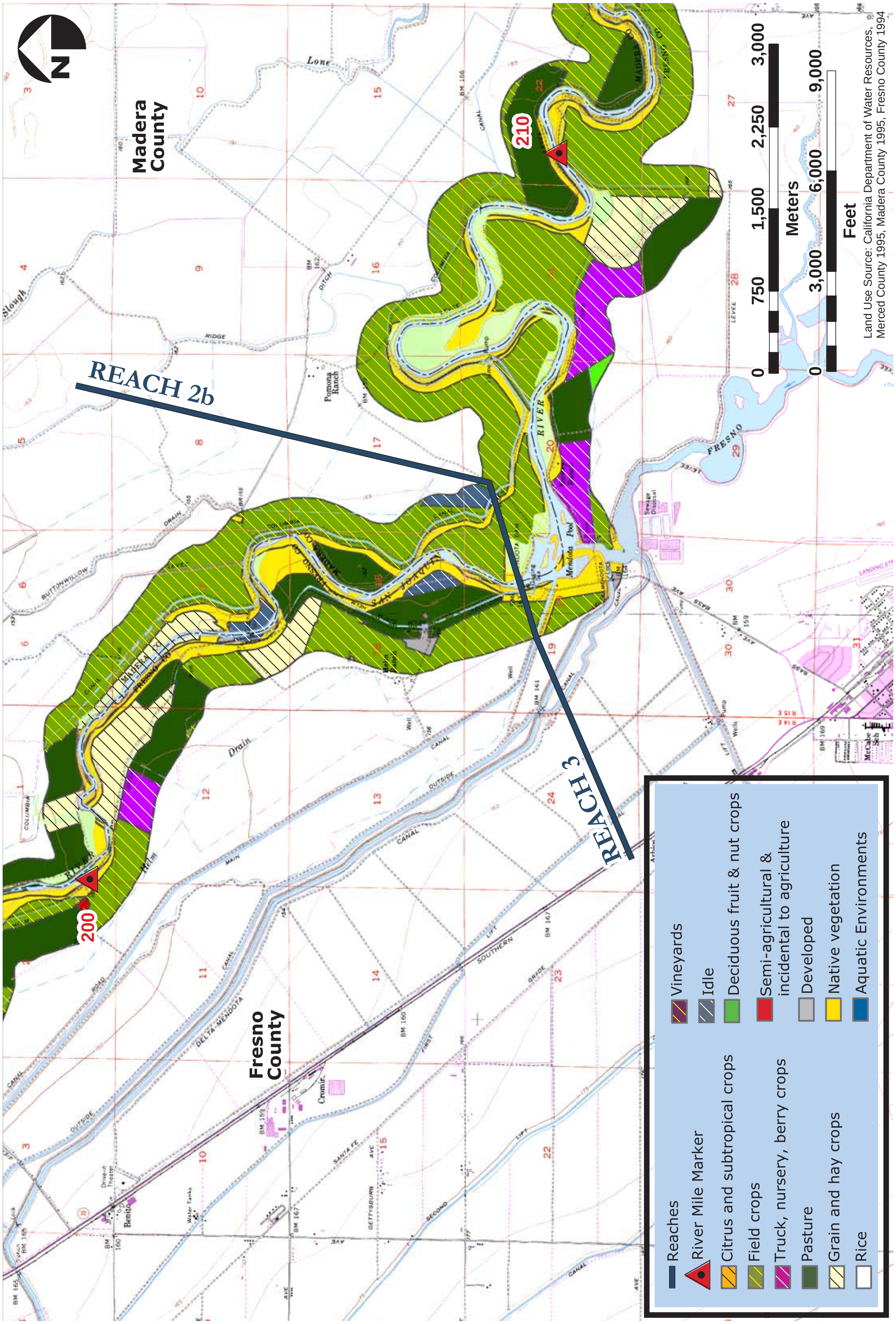
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1e. Land use along the San Joaquin River (Reach 1b & 2a)



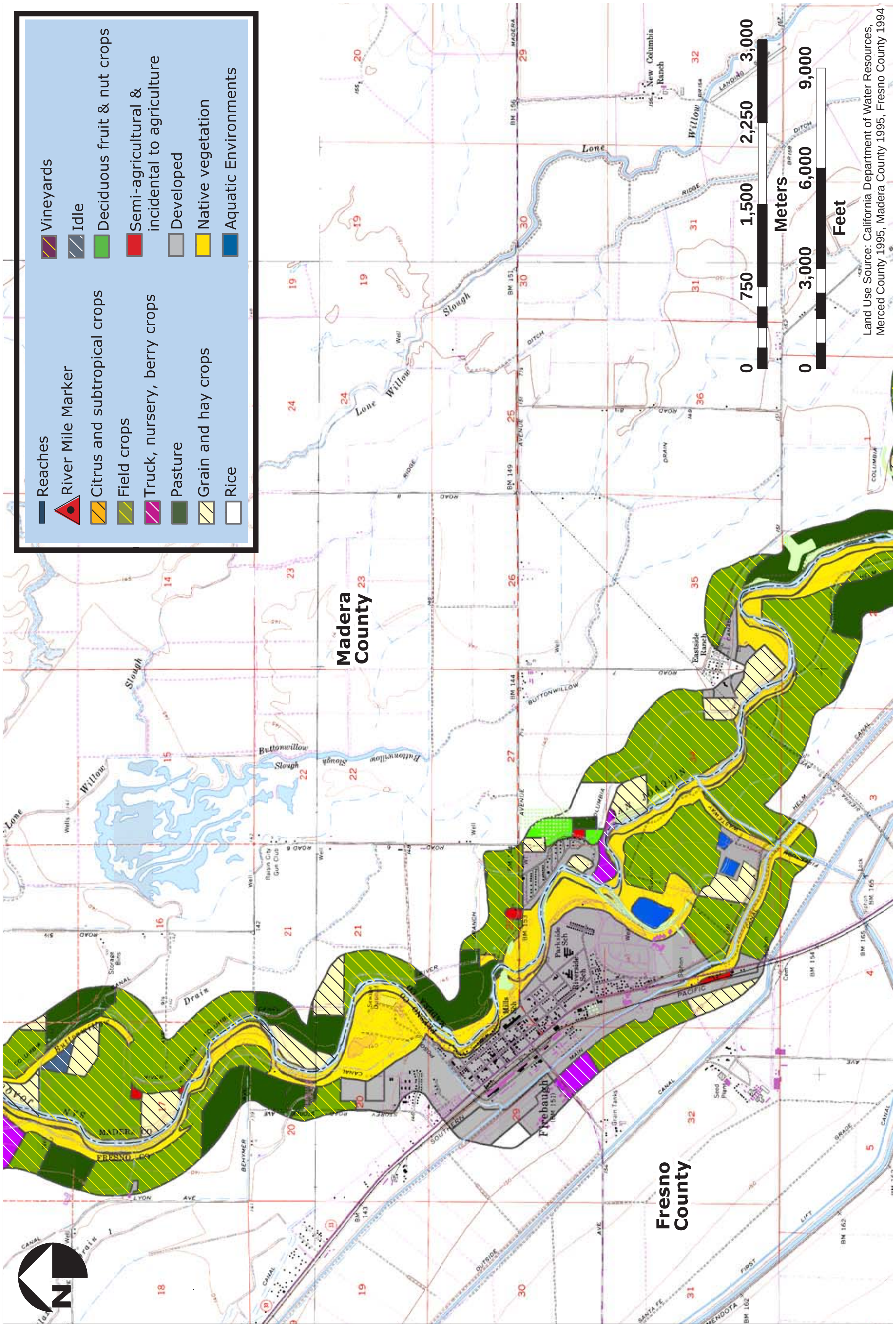
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1f. Land use along the San Joaquin River (Reach 2a & 2b)



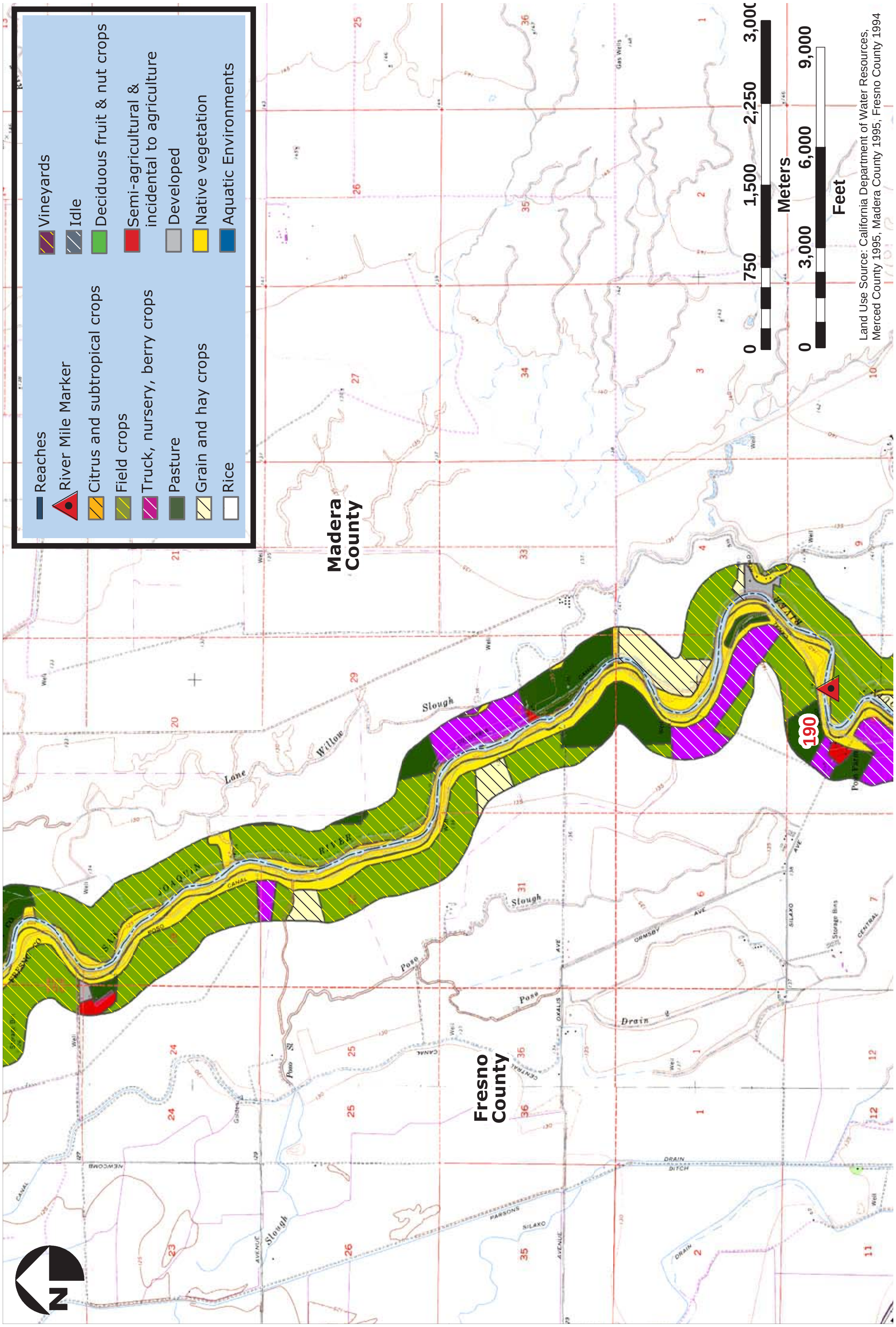
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1g. Land use along the San Joaquin River (Reach 2b & 3)



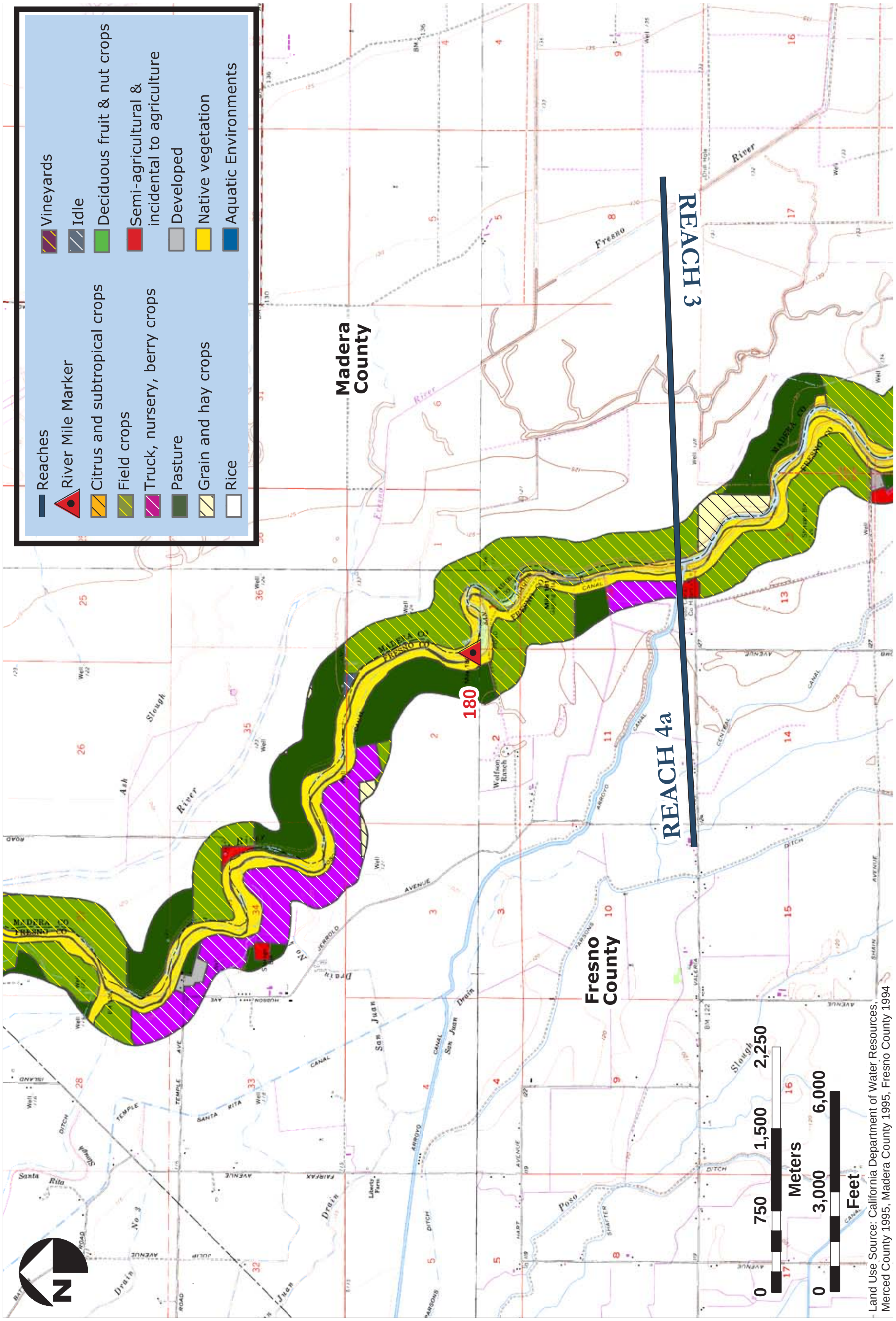
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1h. Land use along the San Joaquin River (Reach 3)



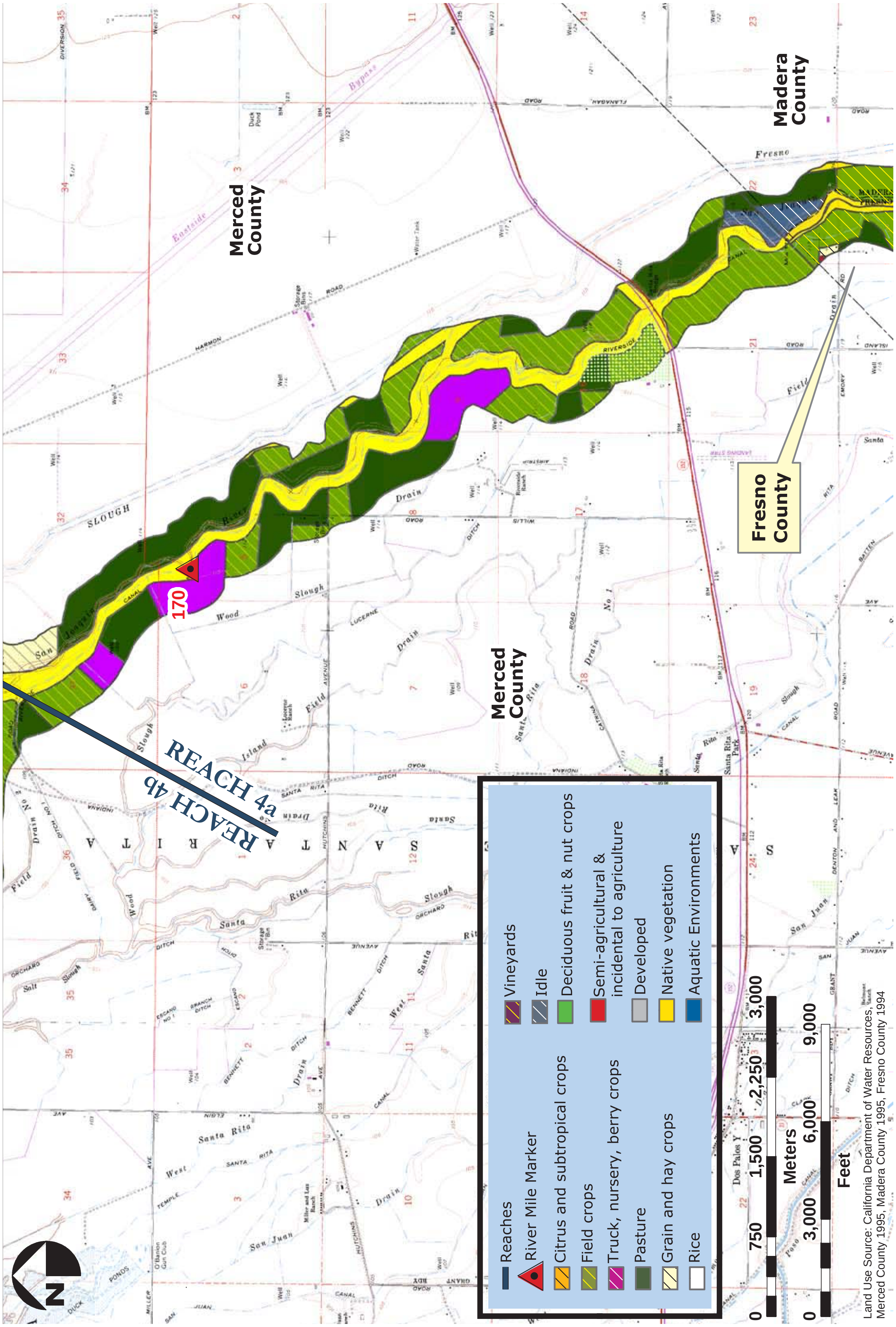
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1i. Land use along the San Joaquin River (Reach 3)



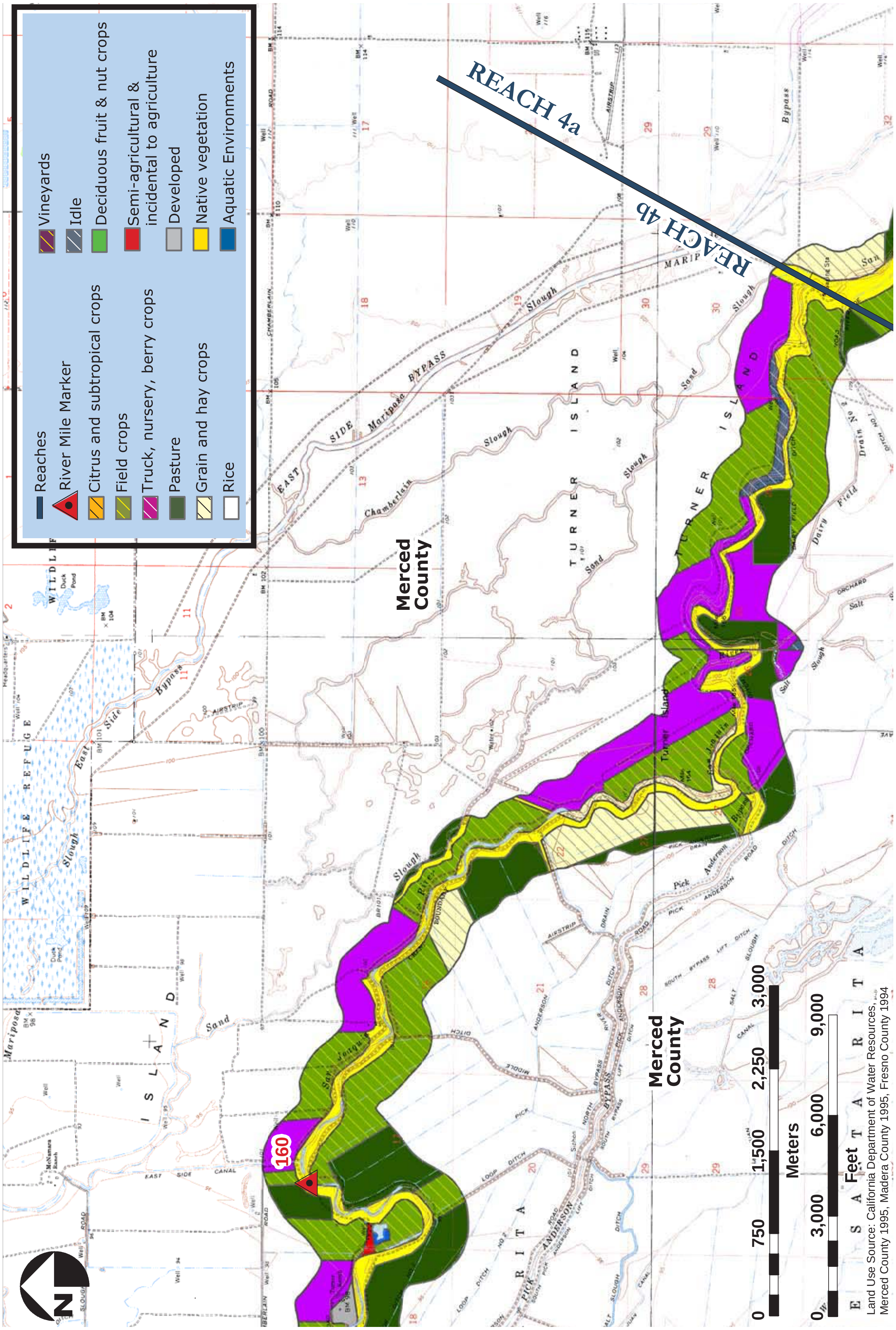
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1j. Land use along the San Joaquin River (Reach 3 & 4a)



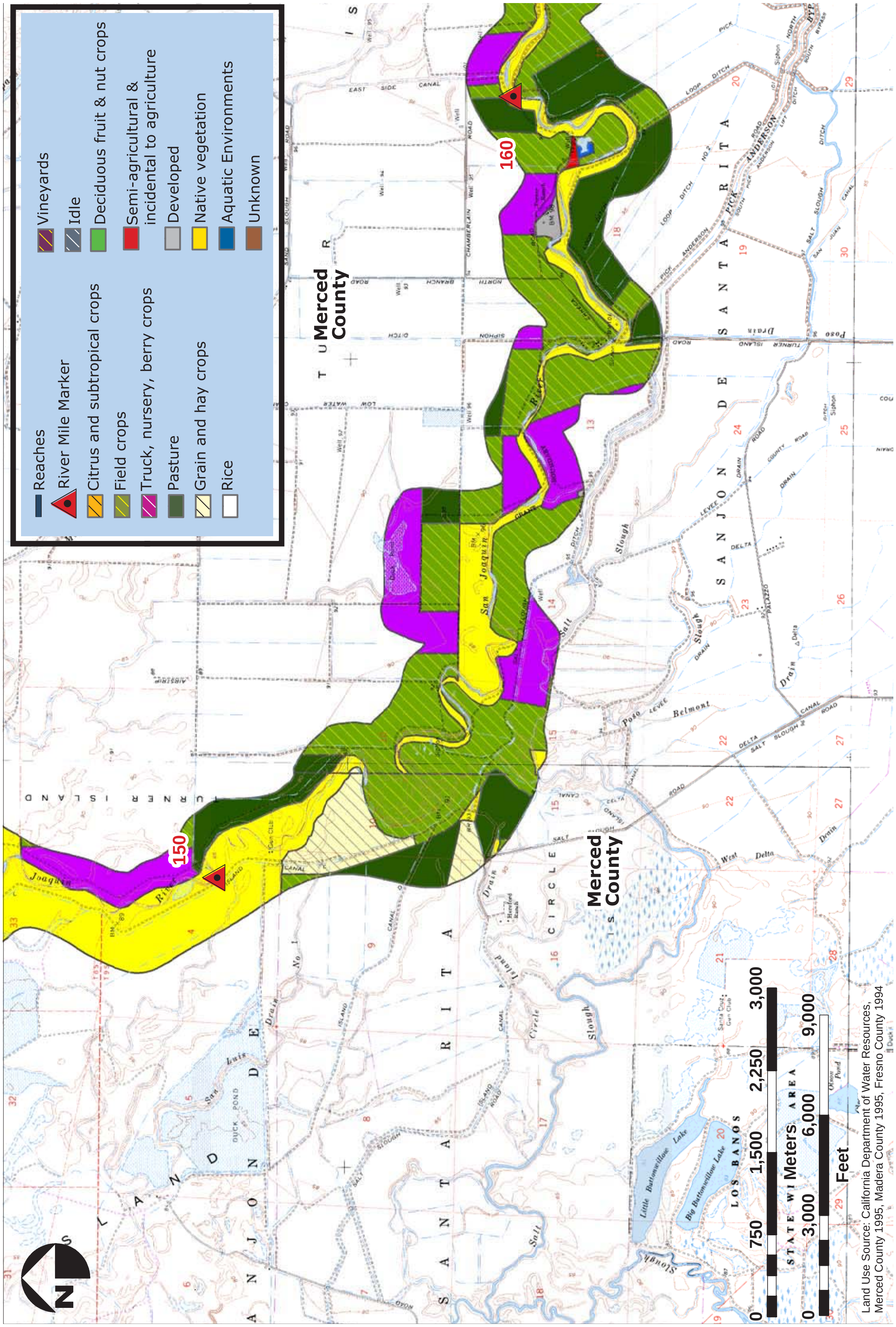
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1k. Land use along the San Joaquin River (Reach 4a & 4b)



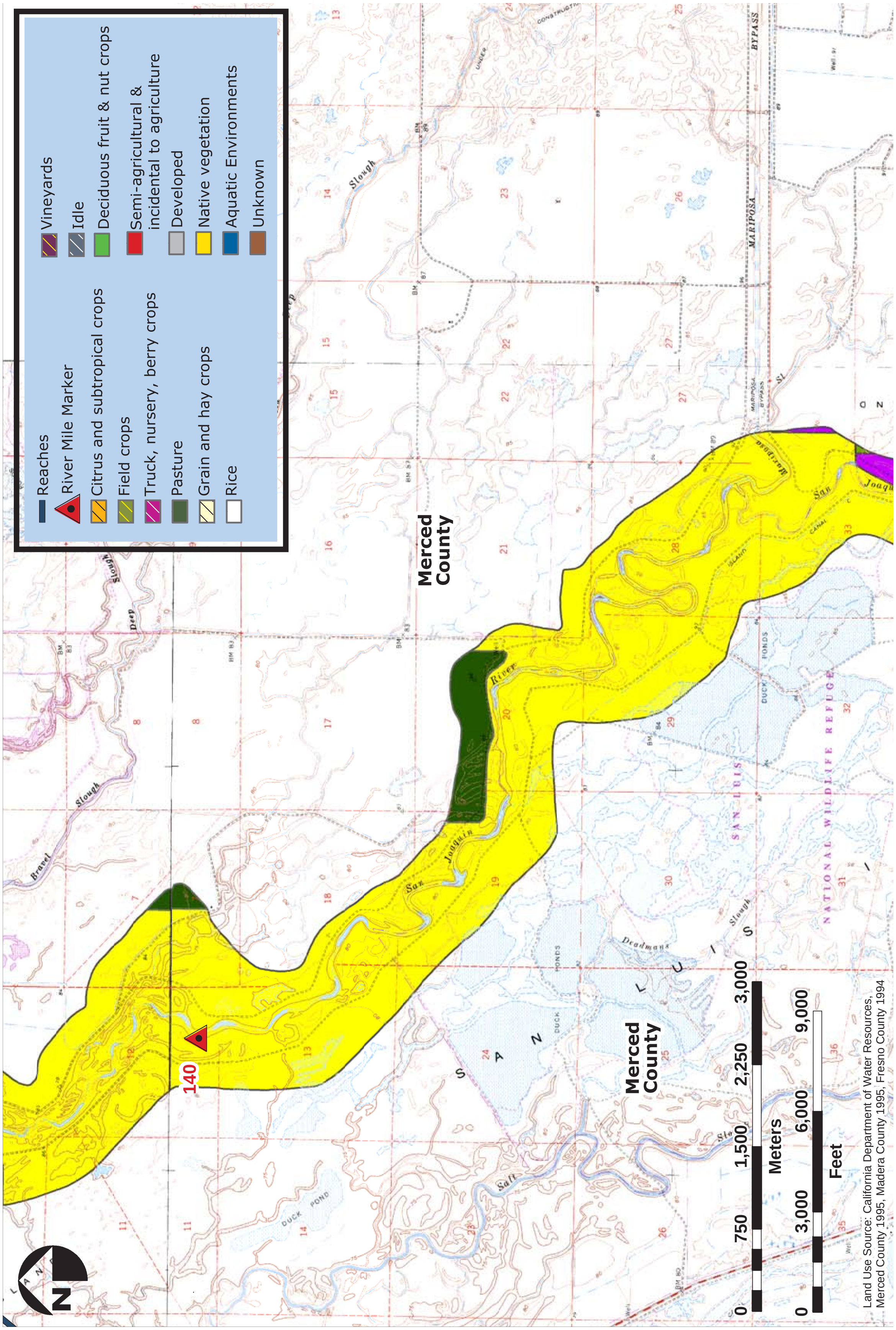
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-11. Land use along the San Joaquin River (Reach 4a & 4b)



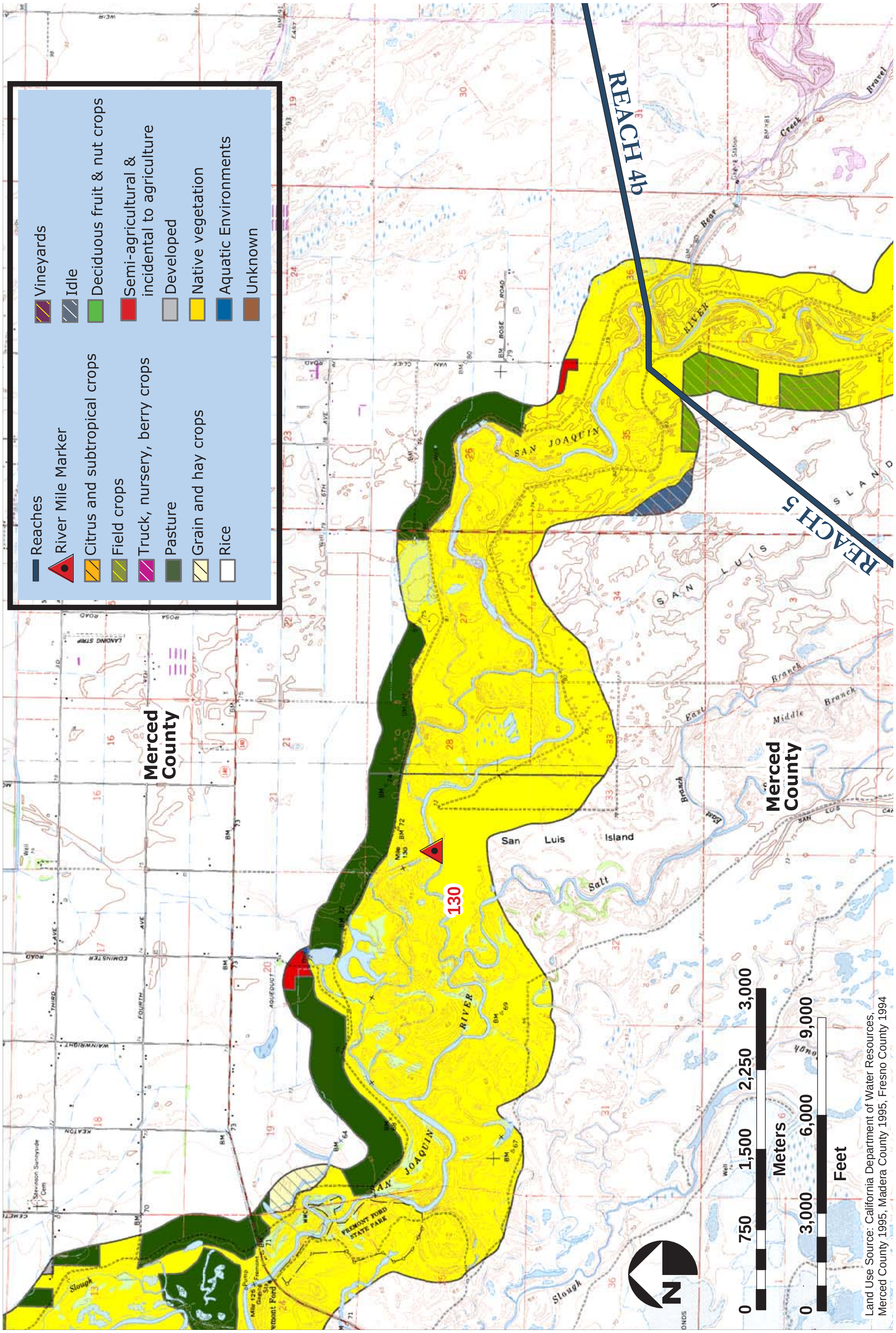
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1m. Land use along the San Joaquin River (Reach 4b)



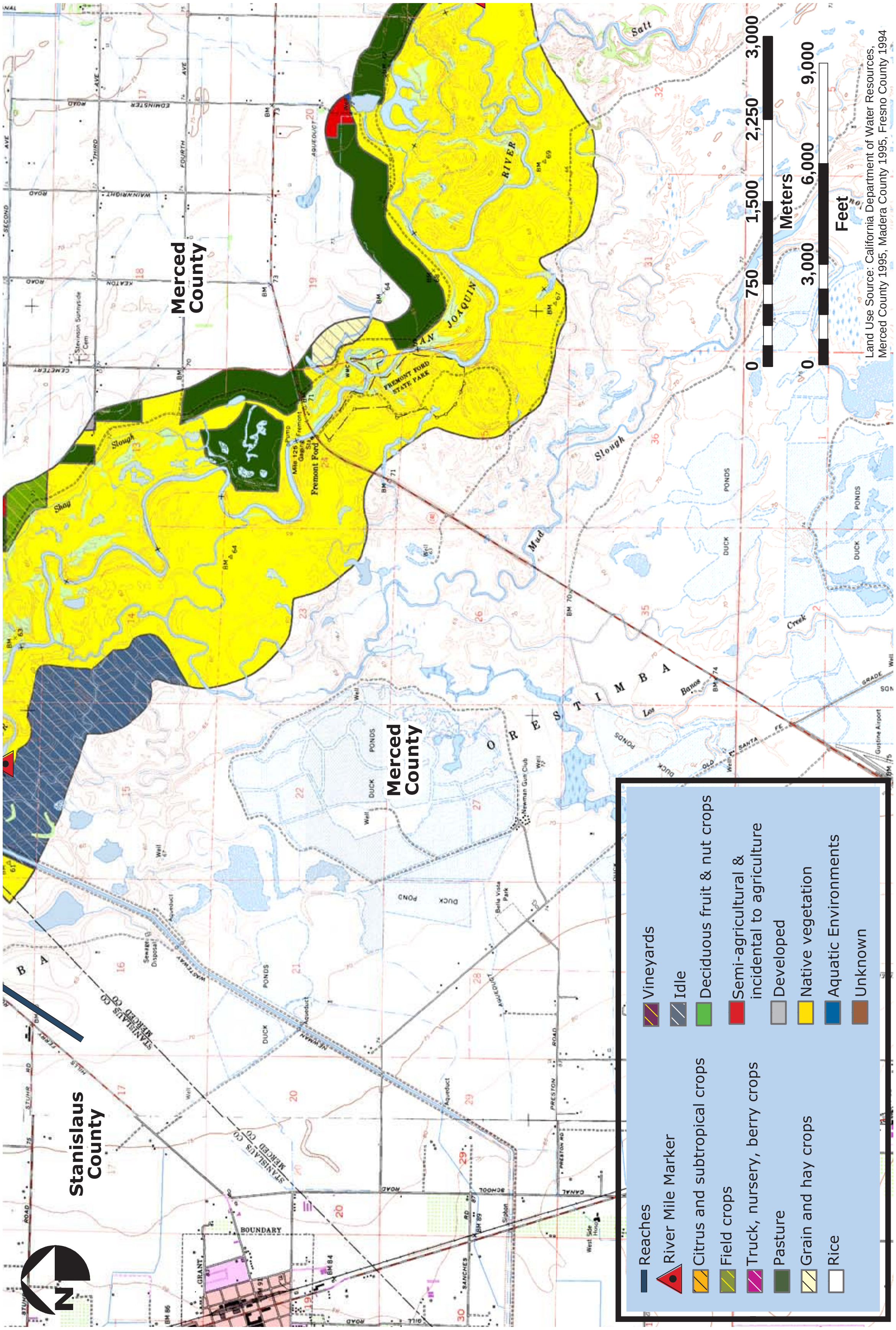
Land Use Source: California Department of Water Resources,
Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1n. Land use along the San Joaquin River (Reach 4b)



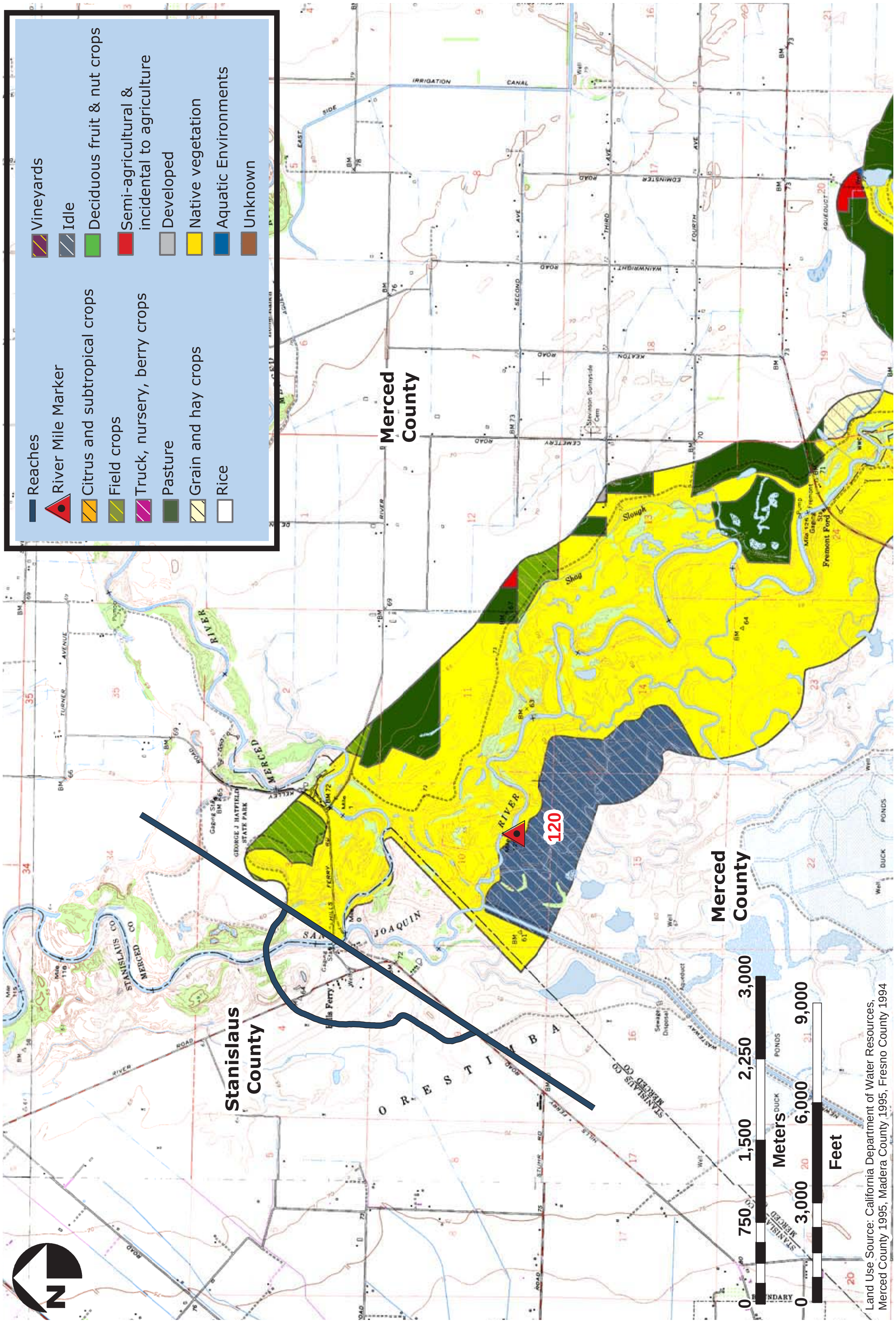
Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1o. Land use along the San Joaquin River (Reach 4b & 5)



Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1p. Land use along the San Joaquin River (Reach 5)



Land Use Source: California Department of Water Resources, Merced County 1995, Madera County 1995, Fresno County 1994

Figure 10-1q. Land use along the San Joaquin River (Reach 5)

For the land use analysis, the study area is 112,273 acres; the percent area occupied by each reach is as follows: Reach 1- 13.6%; Reach 2- 8.5%; Reach 3- 7.5%; Reach 4- 49.8%; Reach 5- 20.6%.

For each land use summarized in Tables 10-2 through Table 10-6, we plotted the percentages of each reach's land use in an attempt to normalize the data and account for differences in land use study width (thus area) variations by reach (Figure 10-2). In other words, Figure 10-2 compares the relative proportion of a given land use between reaches (e.g., which reaches are dominated by orchards versus which reaches are dominated by annual crops). Combining all reaches, the breakdown by land use is 49% in open space, 48% in agriculture, and 3% in urban. Of the agricultural land use areas (combined for all reaches), annual crops comprised 86.2%, vineyards comprised 8.7%, orchards comprised 4.4%, and semi-agricultural or incidental to agriculture uses comprised 0.7% of the land use. The results of this analysis will be applied in discussing opportunities and constraints to restoration at the end of the chapter.

10.5.2. Land Ownership

Land ownership data were overlain on USGS 7.5 minute quadrangle sheets (Figures 10-3a through Figure 10-3q); land ownership acreages were tabulated by reach for the different land ownership types described in Section 10.4.2 (Tables 10-7 through 10-11).

Table 10-7. Acreage of land ownership types along Reach 1 of the San Joaquin River.

	Acreage			Percentage	
Land Ownership	Left-Bank (acres)**	Right-Bank (acres)**	Total (acres)	Reach	Entire Study Area
Public Ownership					
Federal lands	171	0	171	0.6%	0.1%
State, County, and Special District lands	0	0	0	0.0%	0.0%
*San Joaquin River Parkway and Conservation Trust****	2,360	243	2,603	8.9%	2.2%
*State Lands Commission Ordinary Low Water**	62	149	211	0.7%	0.2%
TOTAL PUBLIC OWNERSHIP:	2,593	392	2,985	10.2%	2.5%
Private Ownership					
Agricultural, urban, and industrial	11,069	15,161	26,230	89.8%	22.0%
TOTAL PRIVATE OWNERSHIP:	11,069	15,161	26,230	89.8%	22.0%
Total ownership in Reach 1 Study Area:	**13,662**	**15,553**	**29,215**	**100%**	**24.5%**
Public Trust Easement*					
State Lands Commission Ordinary High Water	100	131	231	N/A	N/A
TOTAL PUBLIC TRUST:	100	131	231	N/A	N/A

* Only mapped to Herndon; additional lands subject to State Lands Commission claims have not been mapped to date.
** Left bank and right bank designations assume one is looking in the downstream direction.
*** Includes California Department of Fish and Game and other public parklands.

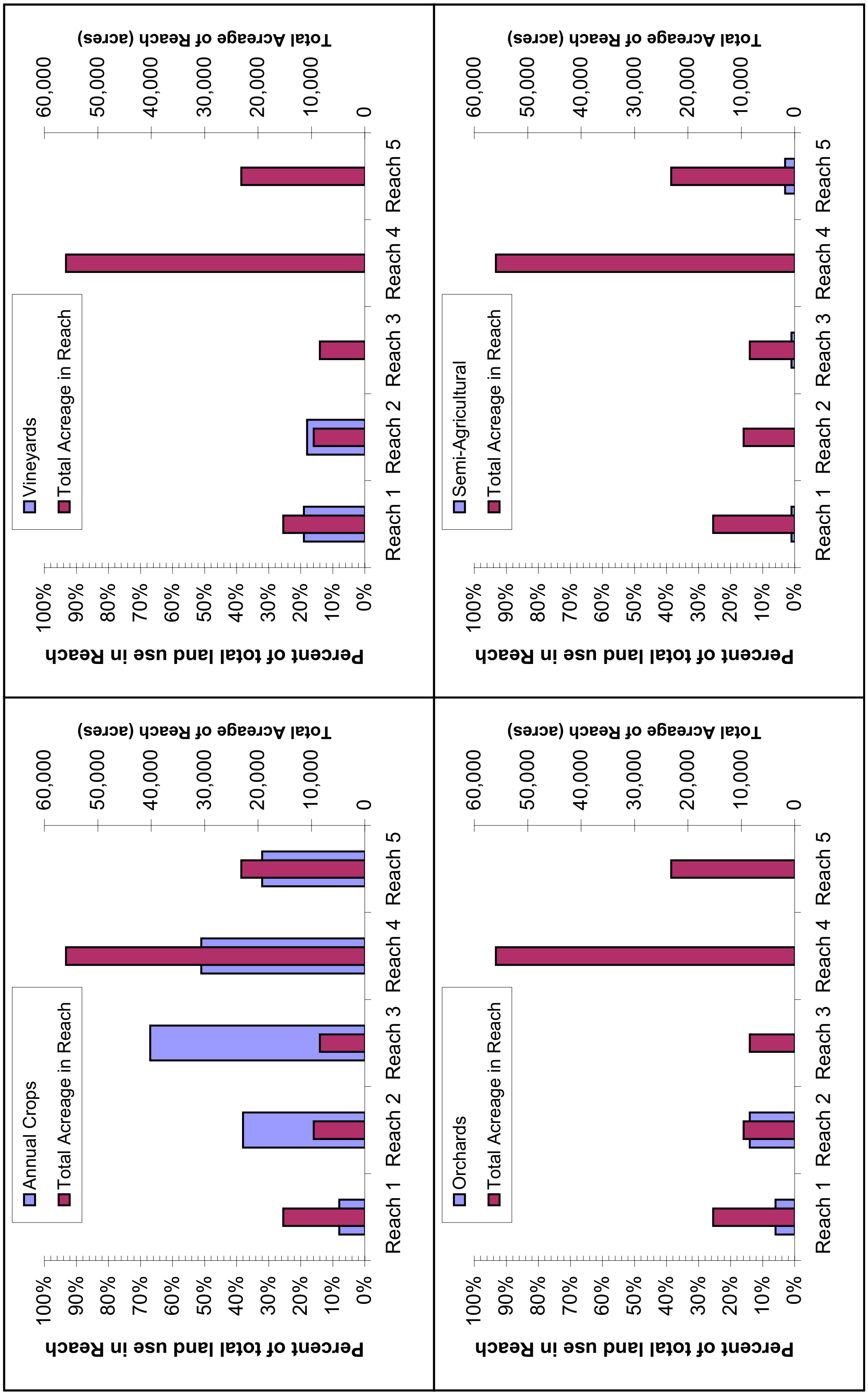


Figure 10-2a. Land use distribution between reaches for idle, native vegetation, aquatic environments, and urban land uses.

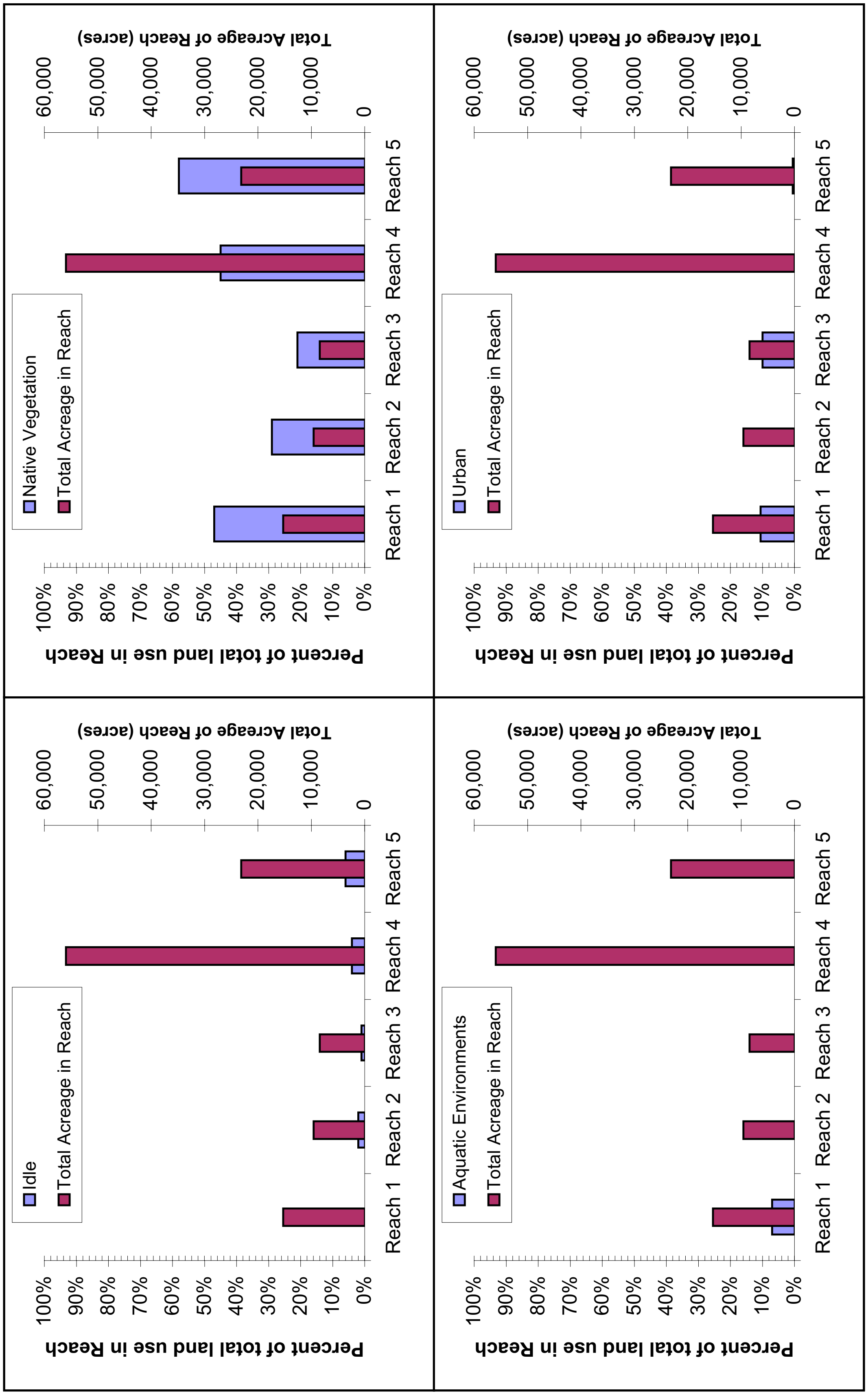


Figure 10-2b. Land use distribution between reaches for idle, native vegetation, aquatic environments, and urban land uses.

Table 10-8. Acreage of land ownership types along Reach 2 of the San Joaquin River.

Land Ownership	Acreage			Percentage	
	Left-Bank (acres) **	Right-Bank (acres) **	Total (acres)	Reach	Entire Study Area
Public Ownership					
Federal lands	64	20	84	0.4%	0.1%
State, County, and Special District lands	668	0	668	3.1%	0.6%
*State Lands Commission Ordinary Low Water**	0	0	0	0.0%	0.0%
TOTAL PUBLIC OWNERSHIP:	732	20	752	3.5%	0.7%
Private Ownership					
Agricultural, urban, and industrial	9,812	11,108	20,920	96.5%	17.5%
TOTAL PRIVATE OWNERSHIP:	9,812	11,108	20,920	96.5%	17.5%
Total ownership in Reach 1 Study Area:	**10,544**	**11,128**	**21,672**	**100%**	**18.2%**
Public Trust Easement*					
State Lands Commission Ordinary High Water	N/A	N/A	N/A	N/A	N/A
TOTAL PUBLIC TRUST:	N/A	N/A	N/A	N/A	N/A

* Only mapped to Herndon; additional lands subject to State Lands Commission claims have not been mapped to date.
** Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-9. Acreage of land ownership types along Reach 3 of the San Joaquin River.

Land Ownership	Acreage			Percentage	
	Left-Bank (acres) **	Right-Bank (acres) **	Total (acres)	Reach	Entire Study Area
Public Ownership					
Federal lands	28	0	28	0.2%	0%
State, County, and Special District lands	34	0	34	0.2%	0%
*State Lands Commission Ordinary Low Water**	0	0	0	0%	0%
TOTAL PUBLIC OWNERSHIP:	62	0	62	0.4%	0.0%
Private Ownership					
Agricultural, urban, and industrial	7,475	8,833	16,308	99.6%	13.7%
TOTAL PRIVATE OWNERSHIP:	7,475	8,833	16,308	99.6%	13.7%
Total ownership in Reach 1 Study Area:	**7,537**	**8,833**	**16,370**	**100%**	**13.7%**
Public Trust Easement*					
State Lands Commission Ordinary High Water	N/A	N/A	N/A	N/A	N/A
TOTAL PUBLIC TRUST:	N/A	N/A	N/A	N/A	N/A

* Only mapped to Herndon; additional lands subject to State Lands Commission claims have not been mapped to date.
** Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-10. Acreage of land ownership types along Reach 4 of the San Joaquin River.

Land Ownership	Acreage			Percentage	
	Left-Bank (acres) **	Right-Bank (acres) **	Total (acres)	Reach	Entire Study Area
Public Ownership					
Federal lands	5,552	2,278	7,830	20.3%	6.6%
State, County, and Special District lands	0	0	0	0.0%	0.0%
*State Lands Commission Ordinary Low Water**	0	0	0	0.0%	0.0%
TOTAL PUBLIC OWNERSHIP:	5,552	2,278	7,830	20.3%	6.6%
Private Ownership					
Agricultural, urban, and industrial	13,720	16,965	30,685	79.7%	25.7%
TOTAL PRIVATE OWNERSHIP:	13,720	16,965	30,685	79.7%	25.7%
Total ownership in Reach 1 Study Area:	**19,272**	**19,243**	**38,515**	**100%**	**32.3%**
Public Trust Easement*					
State Lands Commission Ordinary High Water	N/A	N/A	N/A	N/A	N/A
TOTAL PUBLIC TRUST:	N/A	N/A	N/A	N/A	N/A

* Only mapped to Herndon; additional lands subject to State Lands Commission claims have not been mapped to date.
** Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-11. Acreage of land ownership types along Reach 5 of the San Joaquin River.

Land Ownership	Acreage			Percentage	
	Left-Bank (acres) **	Right-Bank (acres) **	Total (acres)	Reach	Entire Study Area
Public Ownership					
Federal lands	4,536	0	4,536	33.7%	3.8%
State, County, and Special District lands	3,347	805	4,152	30.9%	3.5%
*State Lands Commission Ordinary Low Water**	0	0	0	0.0%	0.0%
TOTAL PUBLIC OWNERSHIP:	7,883	805	8,688	64.6%	7.3%
Private Ownership					
Agricultural, urban, and industrial	100	4,665	4,765	35.4%	4.0%
TOTAL PRIVATE OWNERSHIP:	100	4,665	4,765	35.4%	4.0%
Total ownership in Reach 1 Study Area:	**7,983**	**5,470**	**13,453**	**100%**	**11.3%**
Public Trust Easement*					
State Lands Commission Ordinary High Water	N/A	N/A	N/A	N/A	N/A
TOTAL PUBLIC TRUST:	N/A	N/A	N/A	N/A	N/A

* Only mapped to Herndon; additional lands subject to State Lands Commission claims have not been mapped to date.
** Left bank and right bank designations assume one is looking in the downstream direction.

Table 10-12. Summary of land ownership types for all five reaches of the San Joaquin River study area.

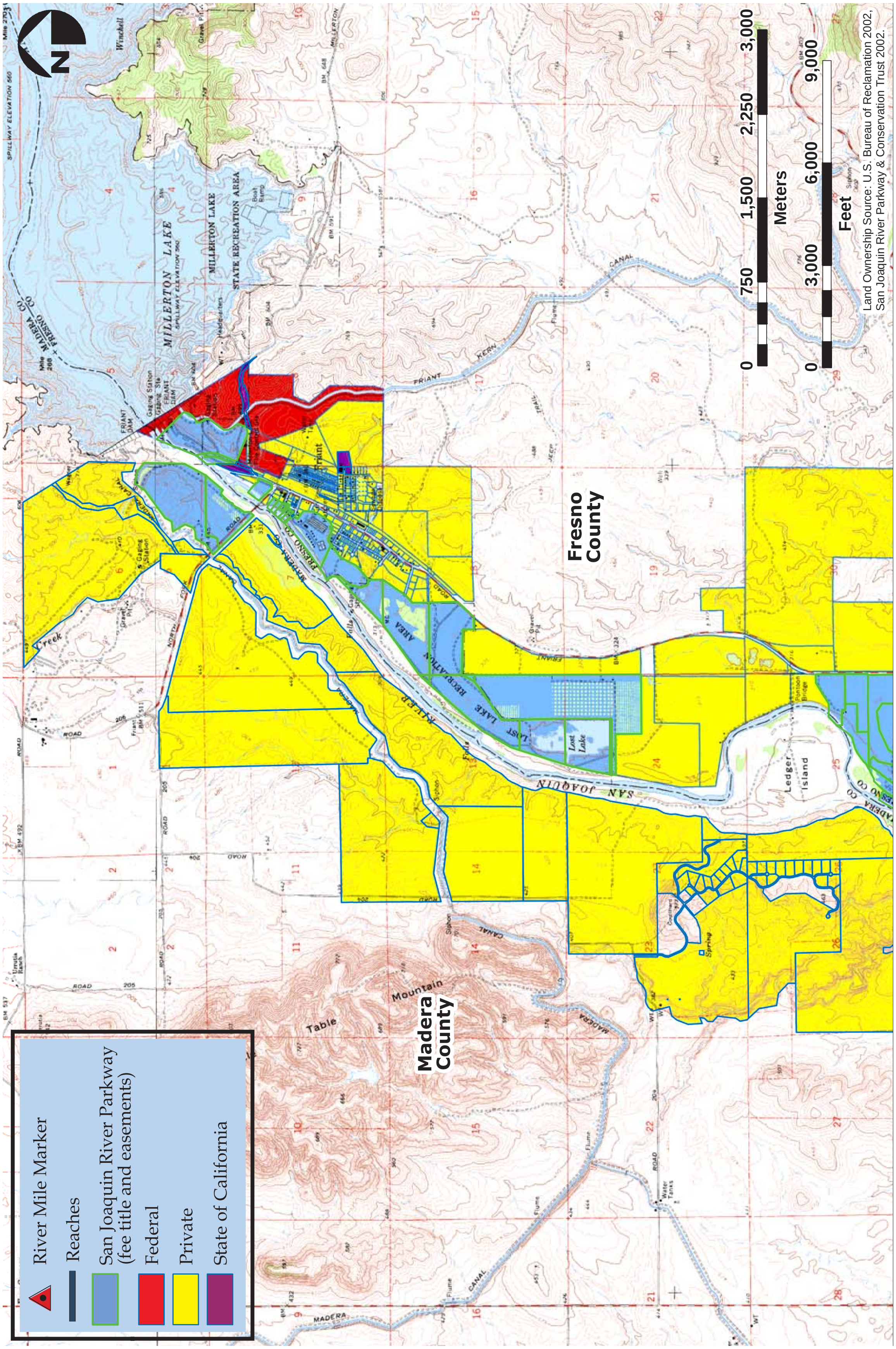
	Acreage			
Land Ownership	Left-Bank (acres) **	Right-Bank (acres) **	Total (acres)	Percentage
Public Ownership				
Federal lands	10,351	2,298	12,649	10.6%
State, County, and Special District lands	4,049	805	4,854	4.1%
San Joaquin River Parkway and Conservation Trust	2,360	243	2,603	2.2%
*State Lands Commission Ordinary Low Water**	62	149	211	0.2%
TOTAL PUBLIC OWNERSHIP:	16,882	3,495	20,317	17.0%
Private Ownership				
Agricultural, urban, and industrial	42,176	56,732	98,908	83.0%
TOTAL PRIVATE OWNERSHIP:	42,176	56,732	98,908	83.0%
Total ownership in Reach 1 Study Area:	**58,998**	**60,227**	**119,225**	**100%**
Public Trust Easement*				
State Lands Commission Ordinary High Water	100	131	231	N/A
TOTAL PUBLIC TRUST:	100	131	231	N/A

* Only mapped to Herndon; additional lands subject to State Lands Commission claims have not been mapped to date.
** Left bank and right bank designations assume one is looking in the downstream direction.

The land ownership study area encompasses 119,225 acres, of which 83.0% is held privately and 17.0% is held publicly. Review of Figures 10-3a through Figure 10-3q illustrates that the irregularity of the study area boundary is due to the irregularity of land ownership boundaries; therefore, the results should not be considered as precise as presented in Tables 10-7 through 10-12. A better use of these data is to infer trends in land ownership among and between reaches. The public lands in the San Joaquin River Parkway and Conservation Trust were tabulated separately because the data were readily available from the Trust, and the Trust is a significant river corridor landowner in Reach 1. Other parks in downstream reaches were not singled out due to their small size; thus, they were grouped into the State, County, and Special District category. The percent of land ownership varies between reaches due to variability in study area width, with Reach 1 containing 24.5% of the land ownership acreage, Reach 2 containing 18.2%, Reach 3 containing 13.7%, Reach 4 containing 32.3%, and Reach 5 containing 11.3%.

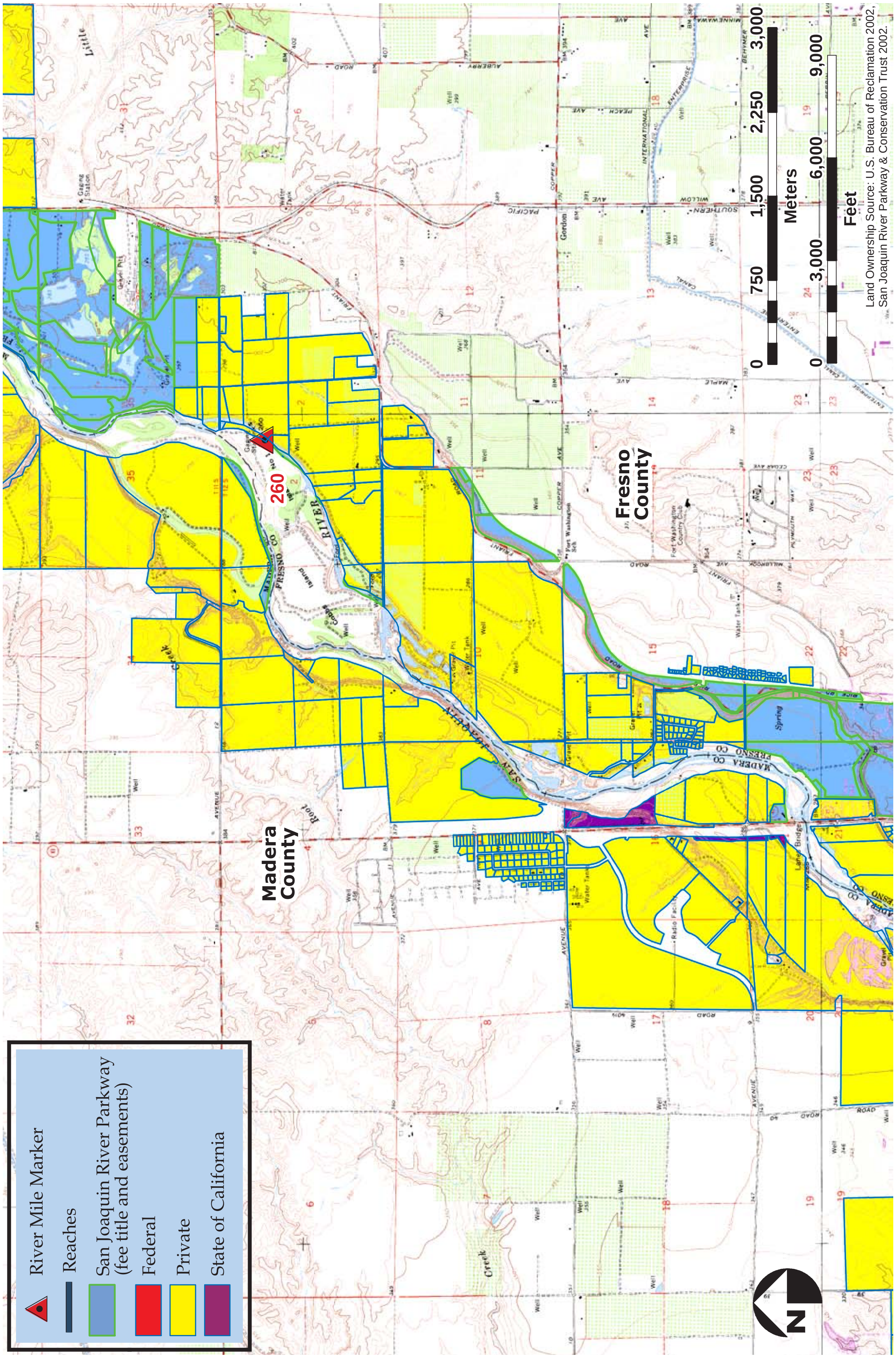
The State Lands Commission identified their fee title lands (ordinary low water) and public trust easement lands (ordinary high water) in the portion of Reach 1 between Friant Dam and Herndon (Table 10-7). Fee title lands encompass approximately 211 acres, and the public trust easement encompasses approximately 231 acres. The State Lands Commission has not quantitatively claimed the remainder of Reach 1, or any of Reaches 2 through 5.

Land ownership data were analyzed similarly as the land use data to observe differences in ownership between the five reaches (Figures 10-4a and 10-4b). A first analysis illustrates the differences in private and public land ownership for all five reaches (lower two charts in Figure 10-4b). Private lands comprise over 97% of all land ownership in Reaches 1 through 3; private land decreases to 80% in Reach 4 and 35% in Reach 5. Public ownership is less than 3% in Reaches 1 through 3, and



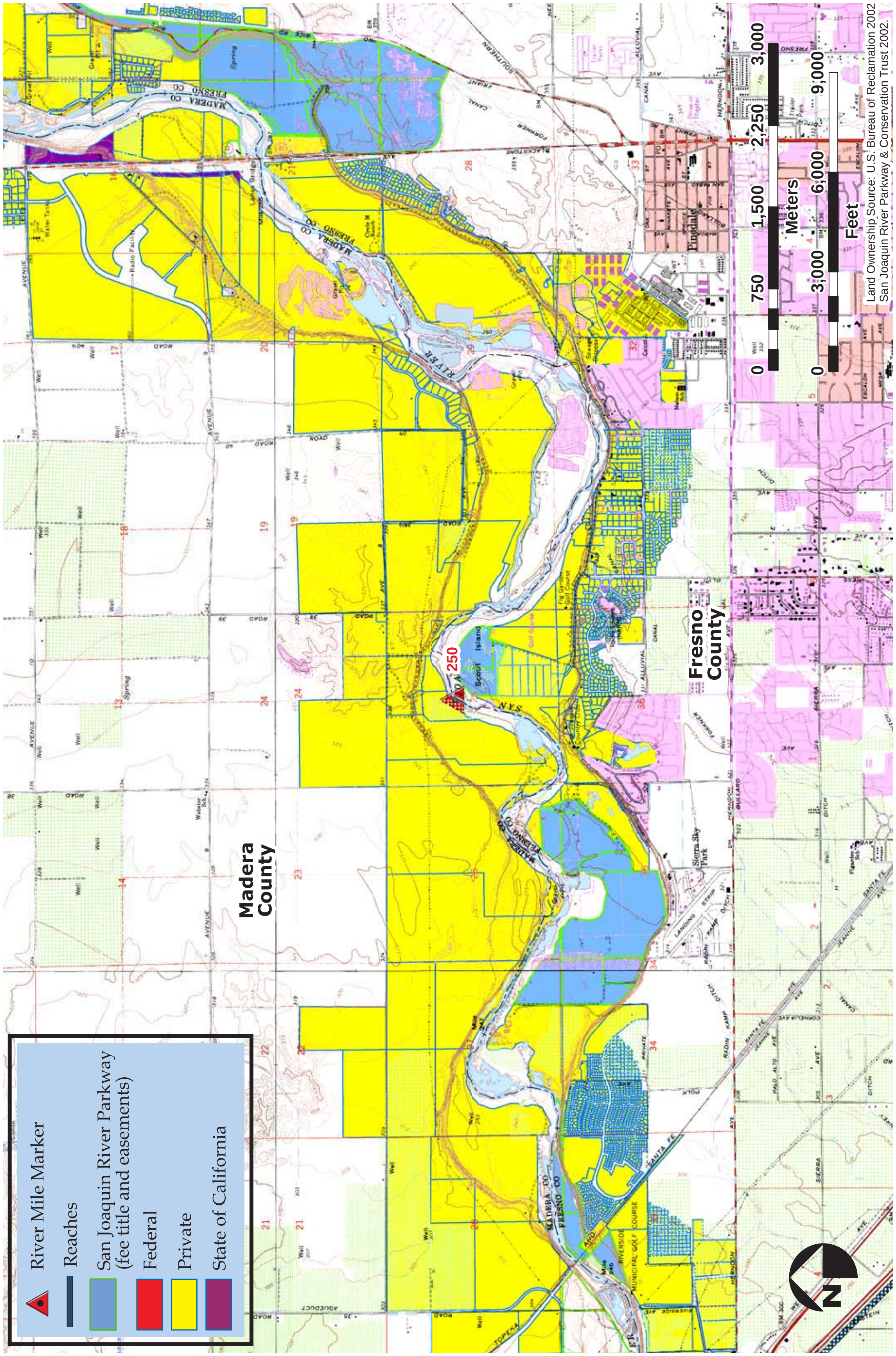
Land Ownership Source: U.S. Bureau of Reclamation 2002, San Joaquin River Parkway & Conservation Trust 2002.

Figure 10-3a. Land ownership along the San Jaoquin River (Reach 1a)



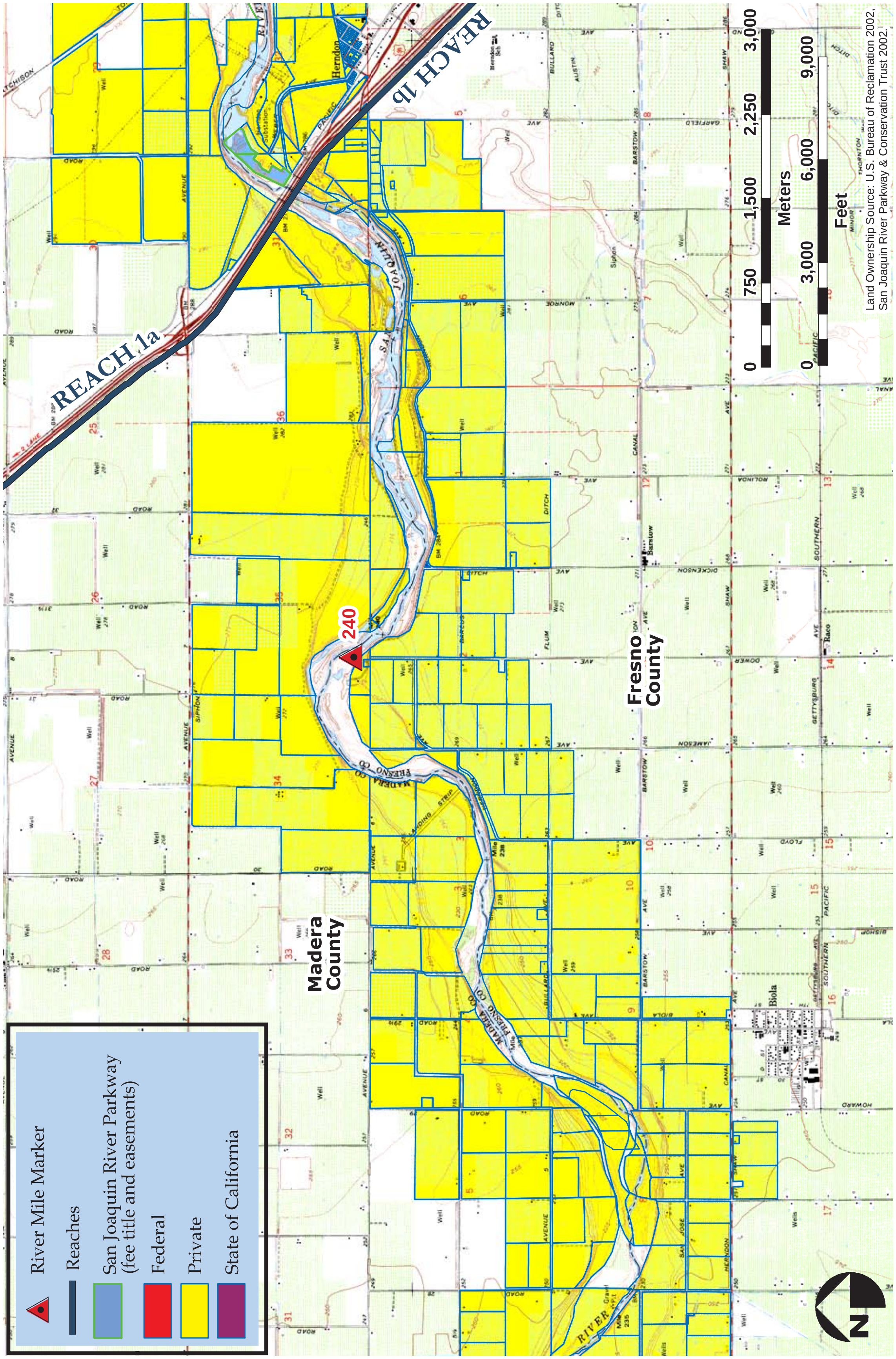
Land Ownership Source: U.S. Bureau of Reclamation 2002, San Joaquin River Parkway & Conservation Trust 2002.

Figure 10-3b. Land ownership along the San Jaoquin River (Reach 1a)



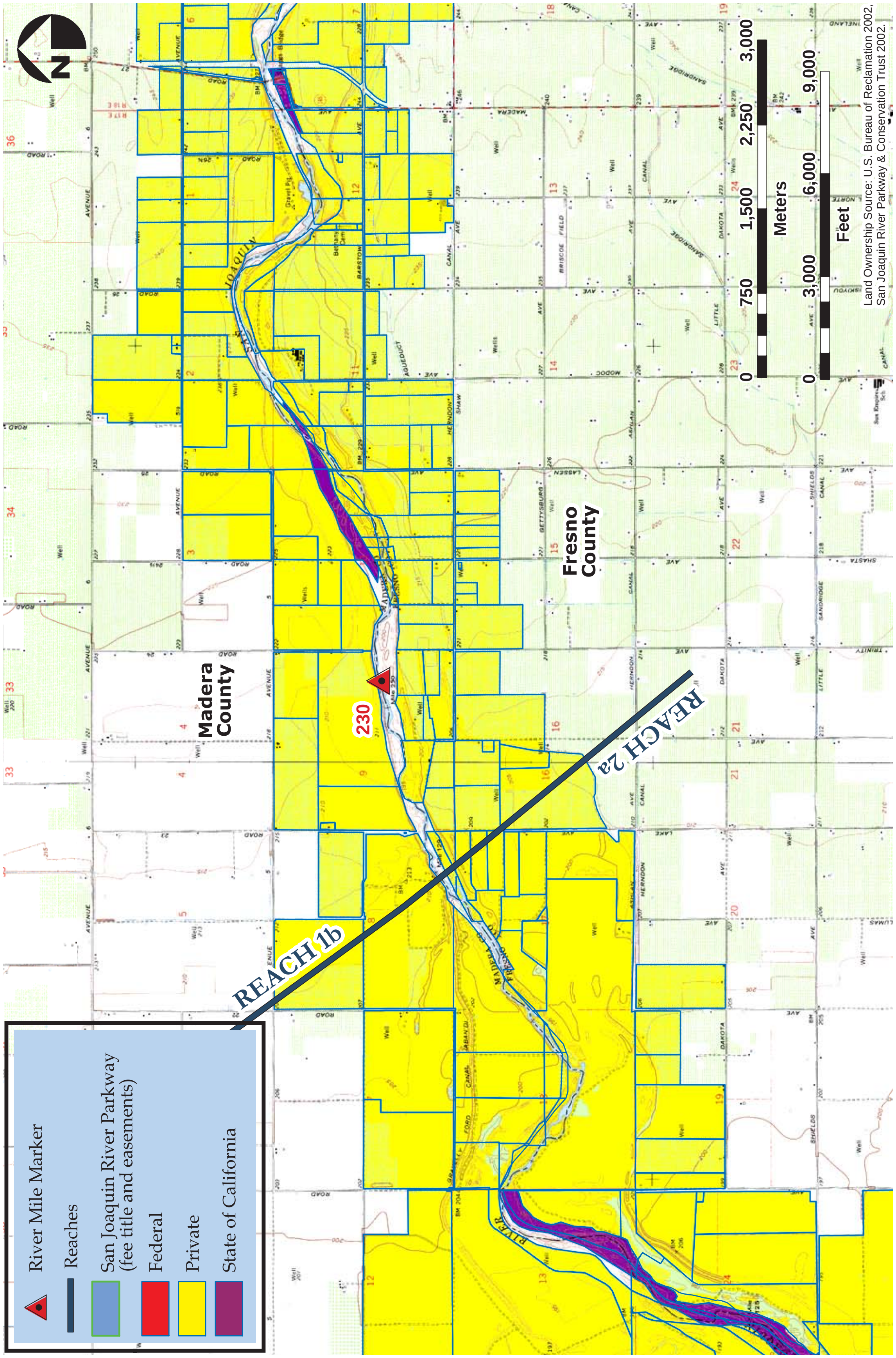
Land Ownership Source: U.S. Bureau of Reclamation 2002
San Joaquin River Parkway & Conservation Trust 2002.

Figure 10-3c. Land ownership along the San Jaoquin River (Reach 1a)



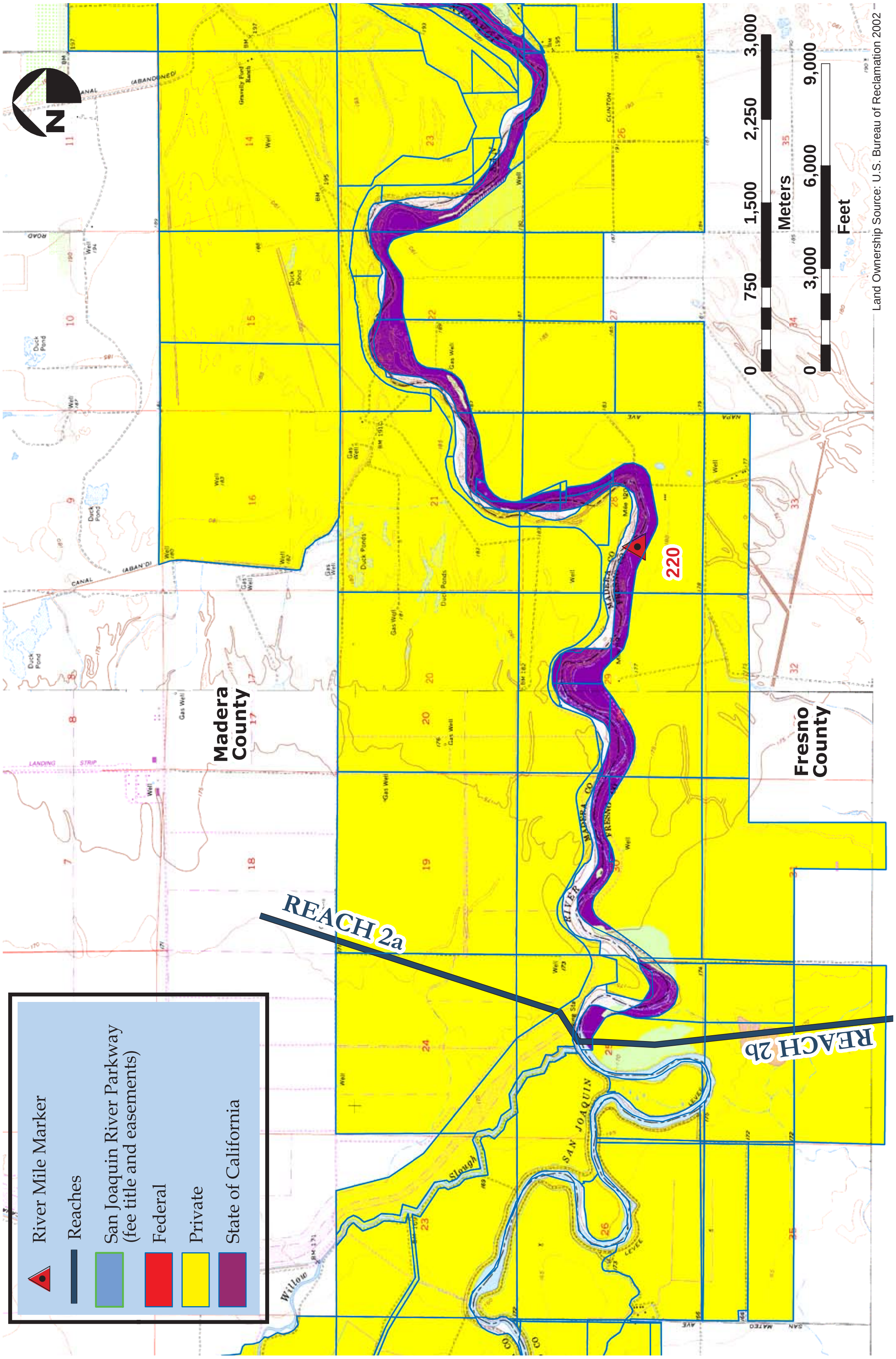
Land Ownership Source: U.S. Bureau of Reclamation 2002, San Joaquin River Parkway & Conservation Trust 2002.

Figure 10-3d. Land ownership along the San Jaoquin River (Reach 1a & 1b)



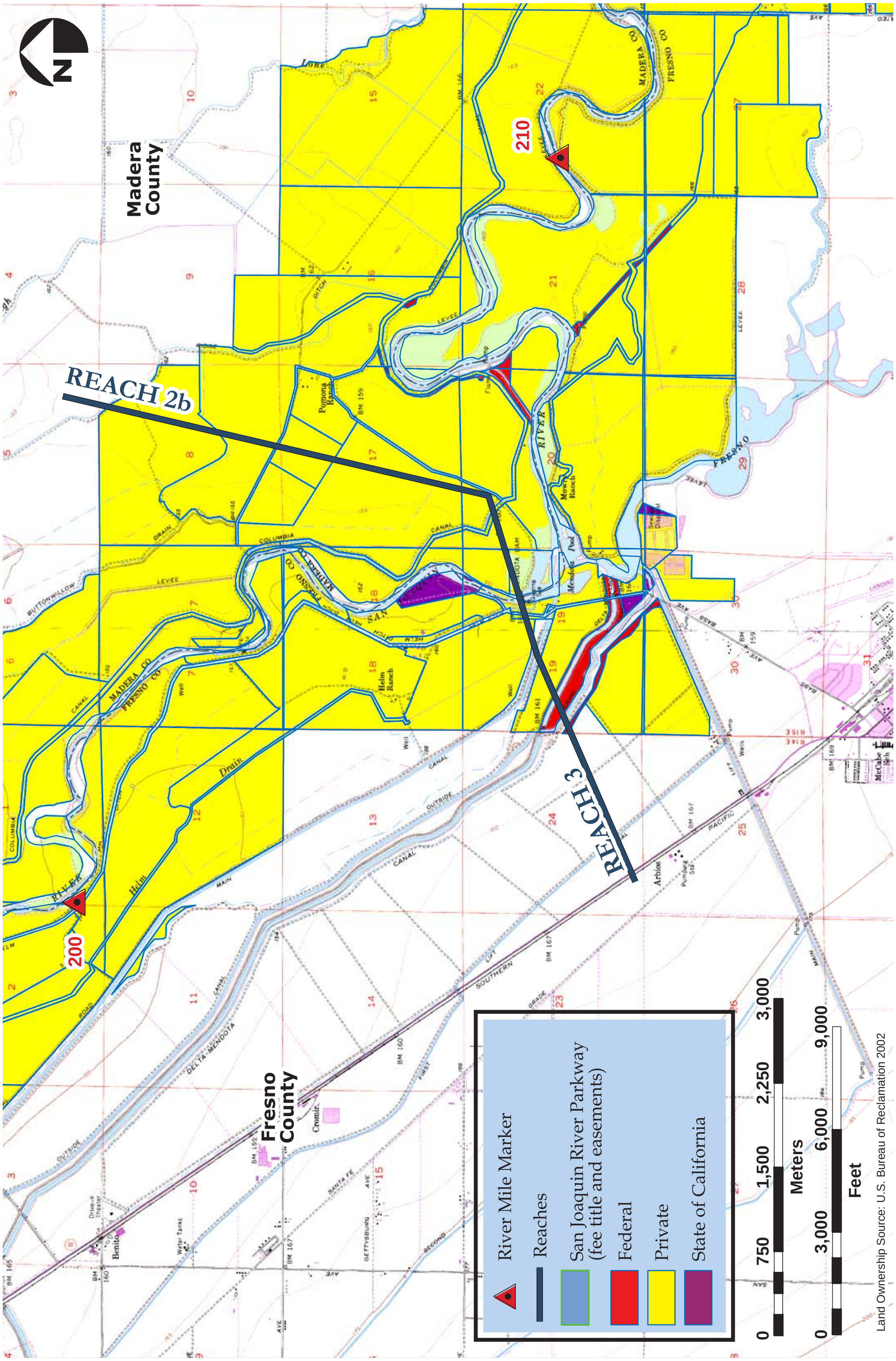
Land Ownership Source: U.S. Bureau of Reclamation 2002, San Joaquin River Parkway & Conservation Trust 2002.

Figure 10-3e. Land ownership along the San Jaquin River (Reach 1b & 2a)



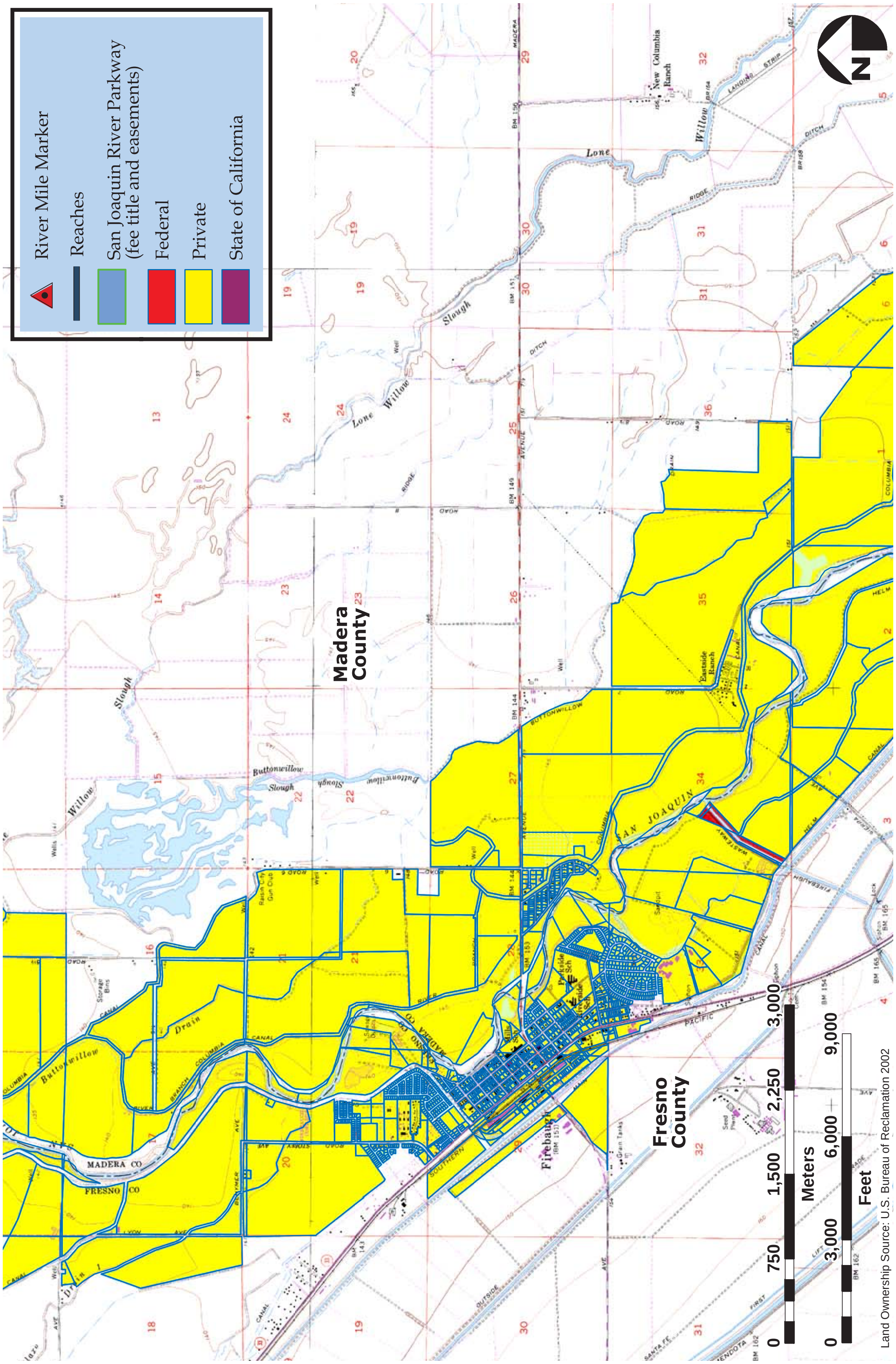
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3f. Land ownership along the San Jaoquin River (Reach 2a & 2b)



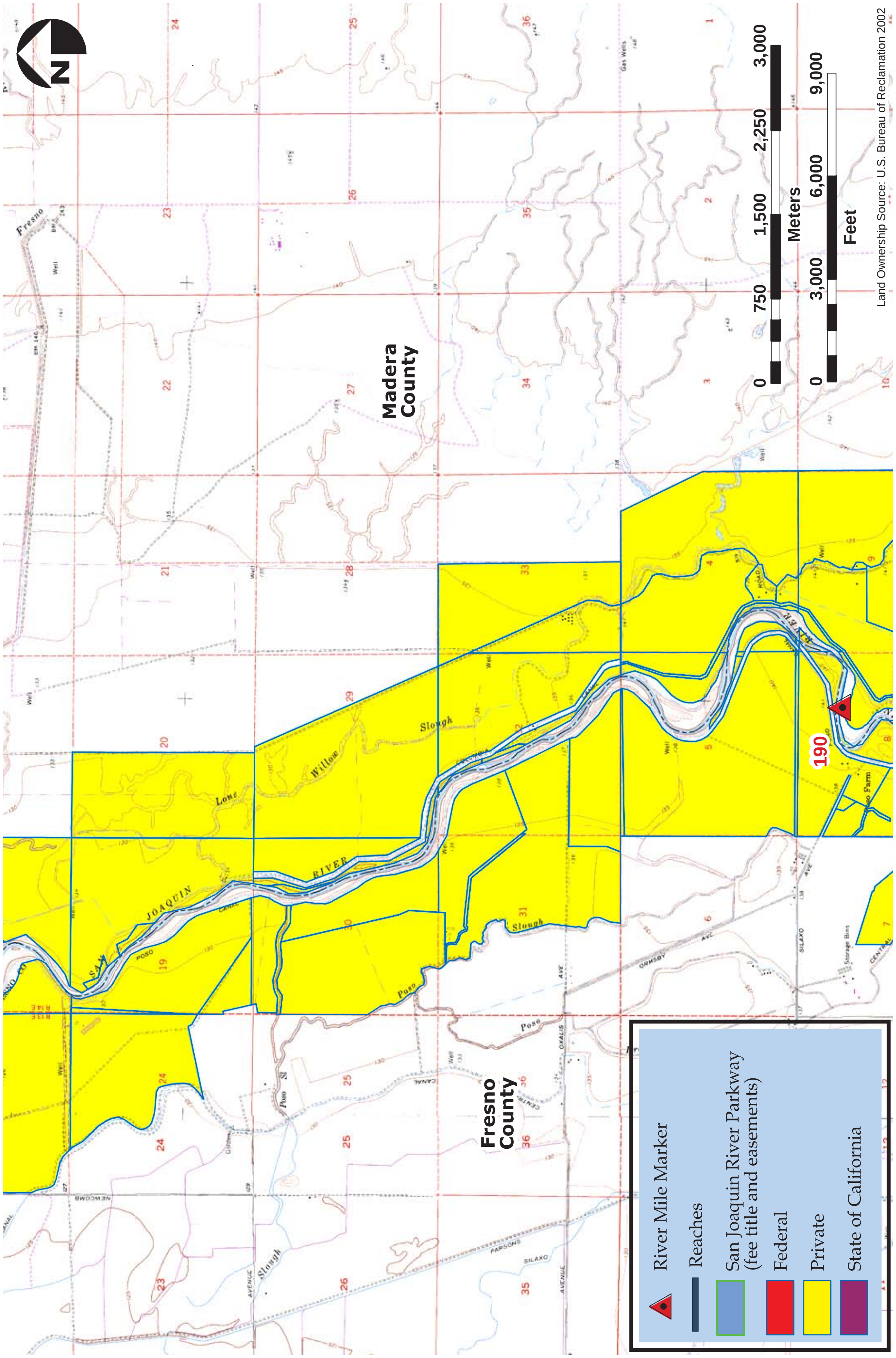
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3g. Land ownership along the San Jaquin River (Reach 2b & 3)



Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3h. Land ownership along the San Jaoquin River (Reach 3)



Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3i: Land ownership along the San Jaoquin River (Reach 3)

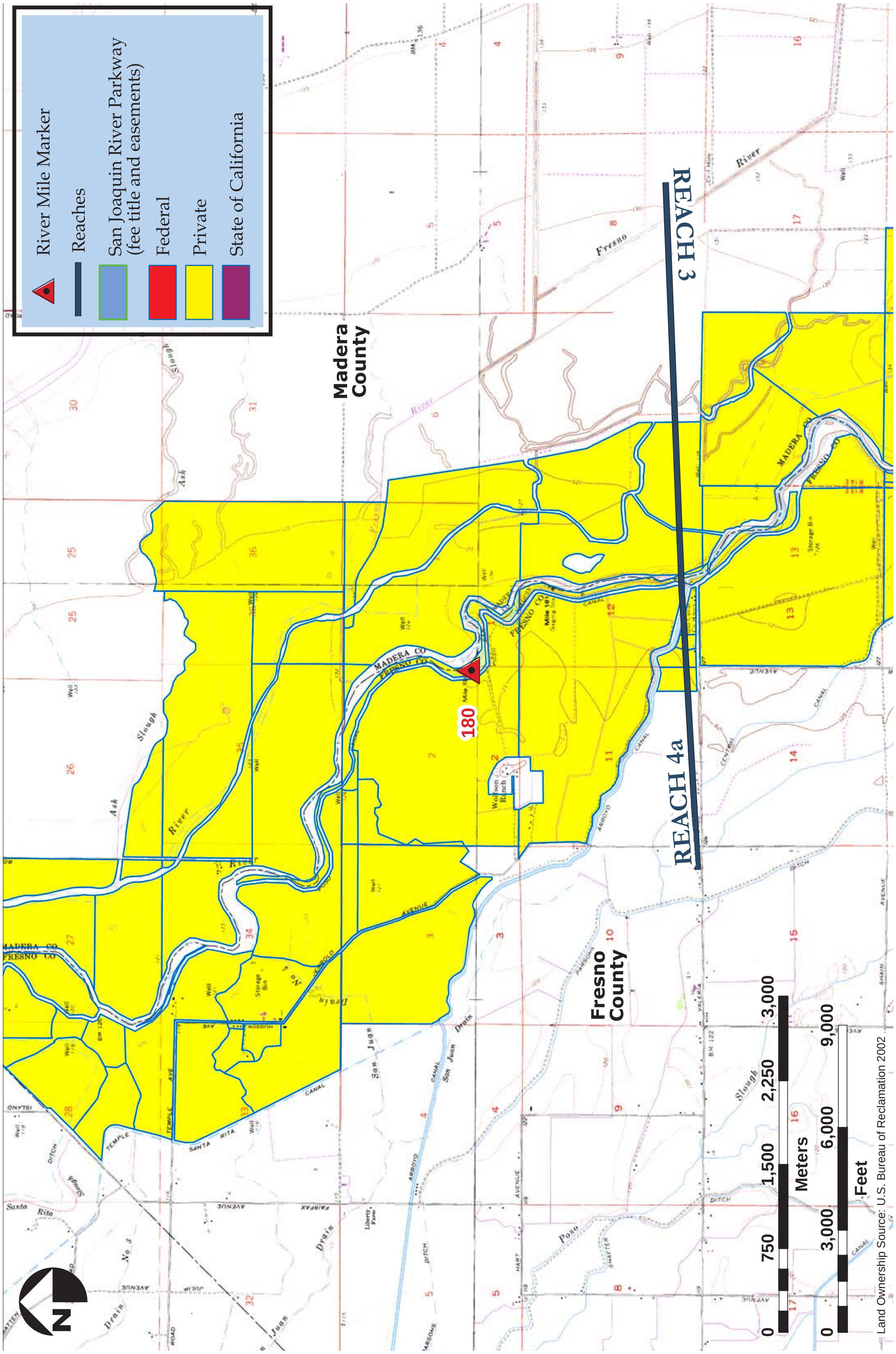
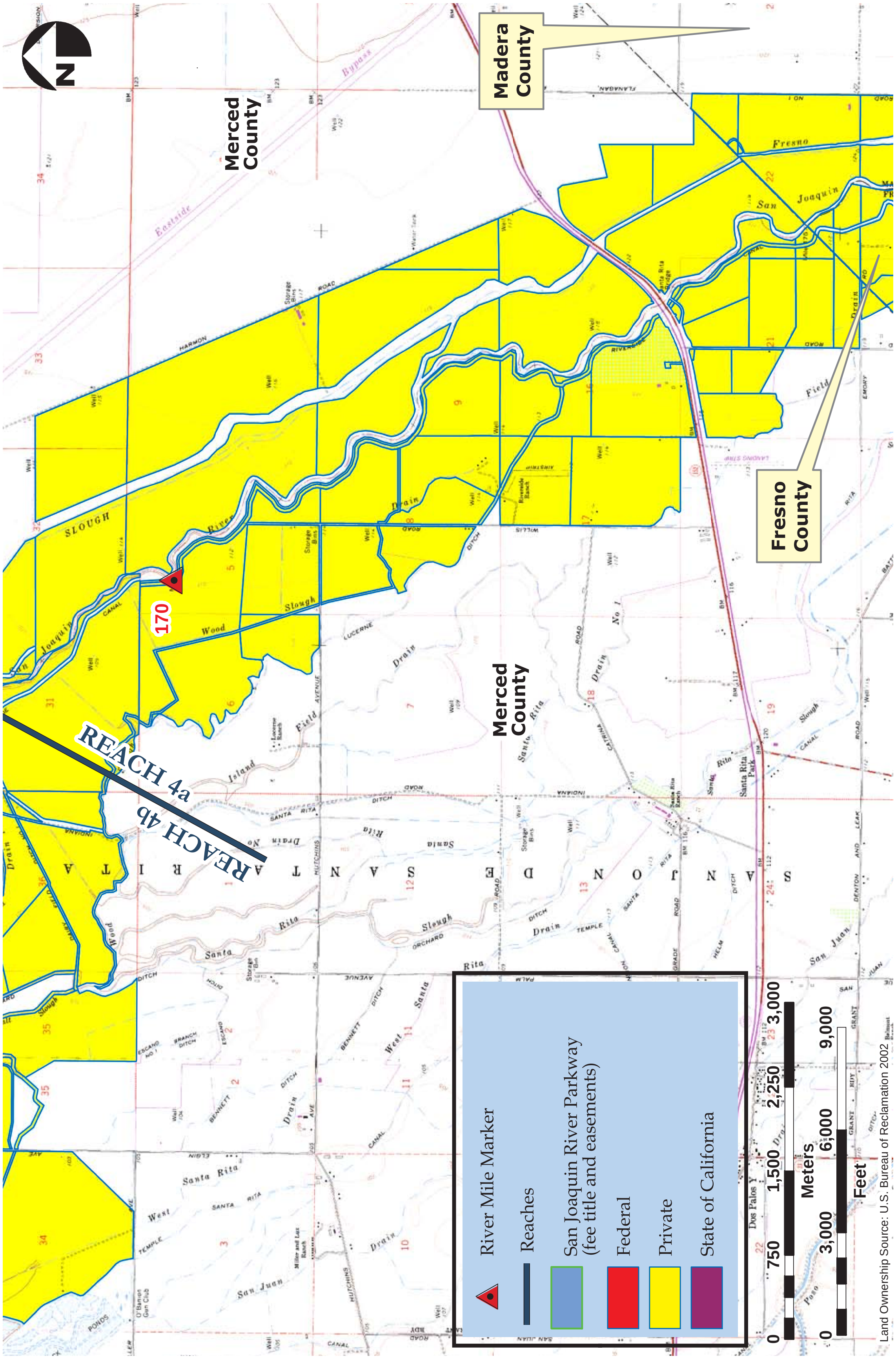
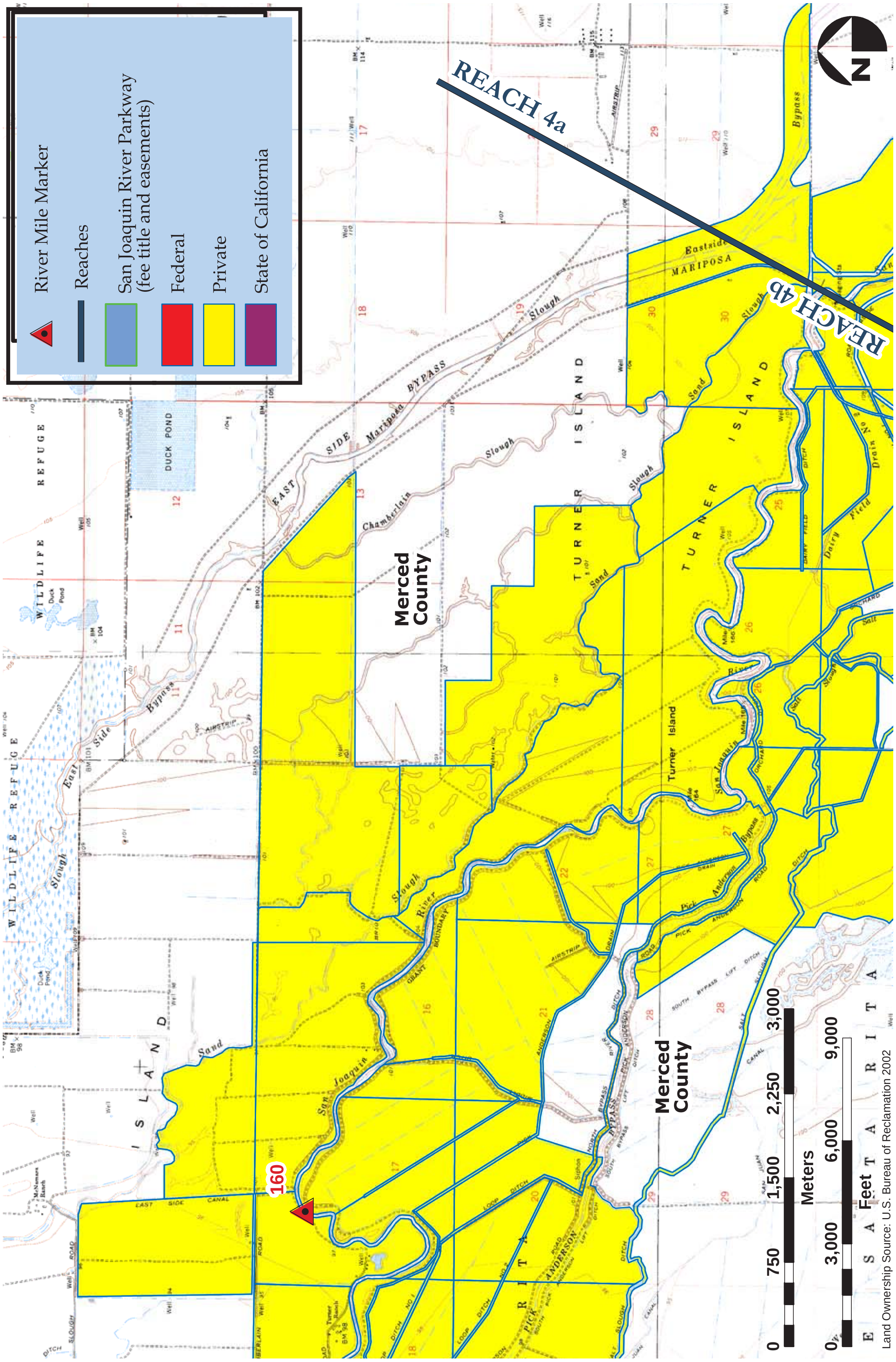


Figure 10-3j. Land ownership along the San Jaoquin River (Reach 3 & 4a)



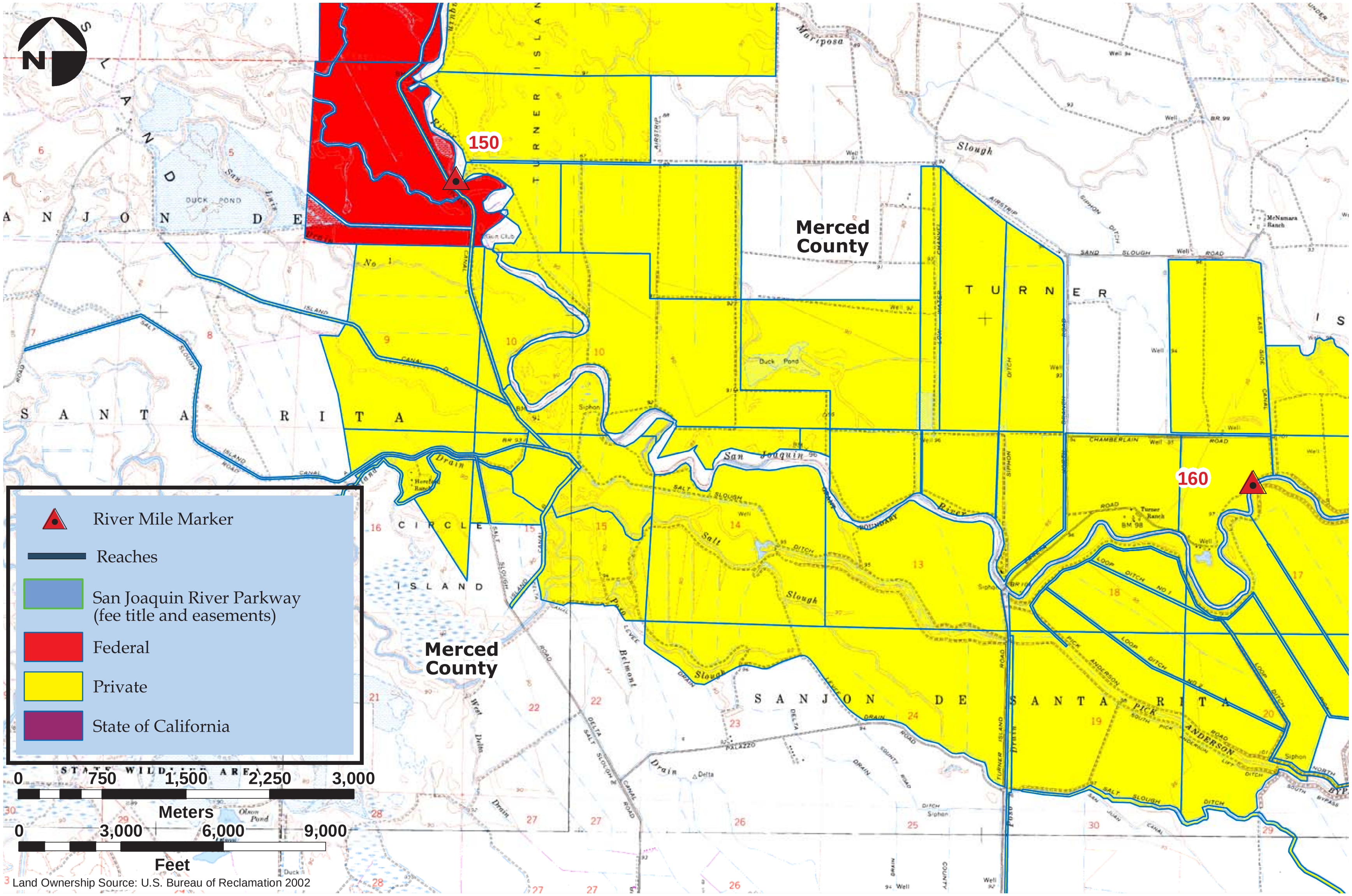
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3k. Land ownership along the San Jaoquin River (Reach 4a & 4b)



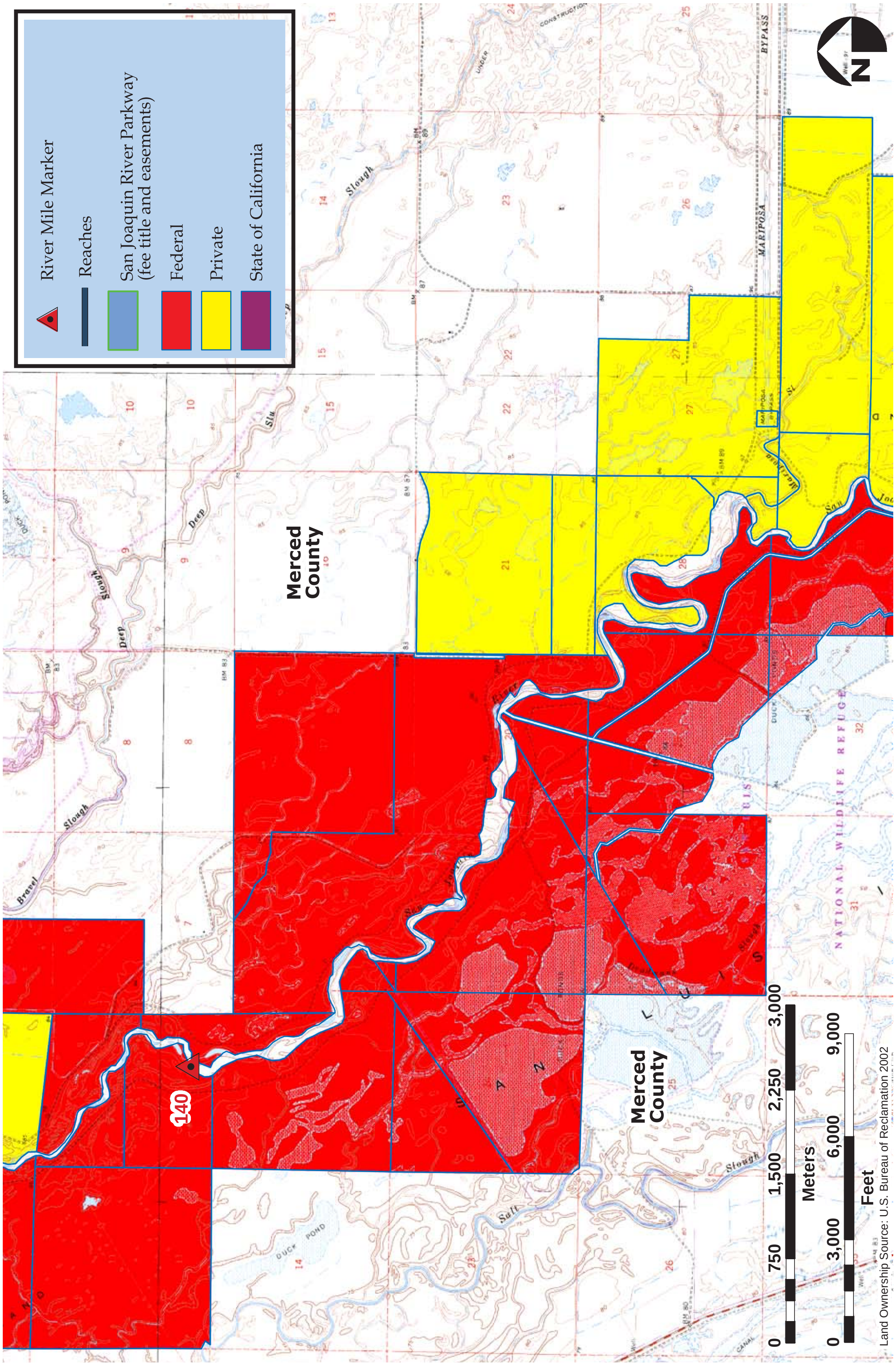
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-31. Land ownership along the San Jaoquin River (Reach 4a & 4b)



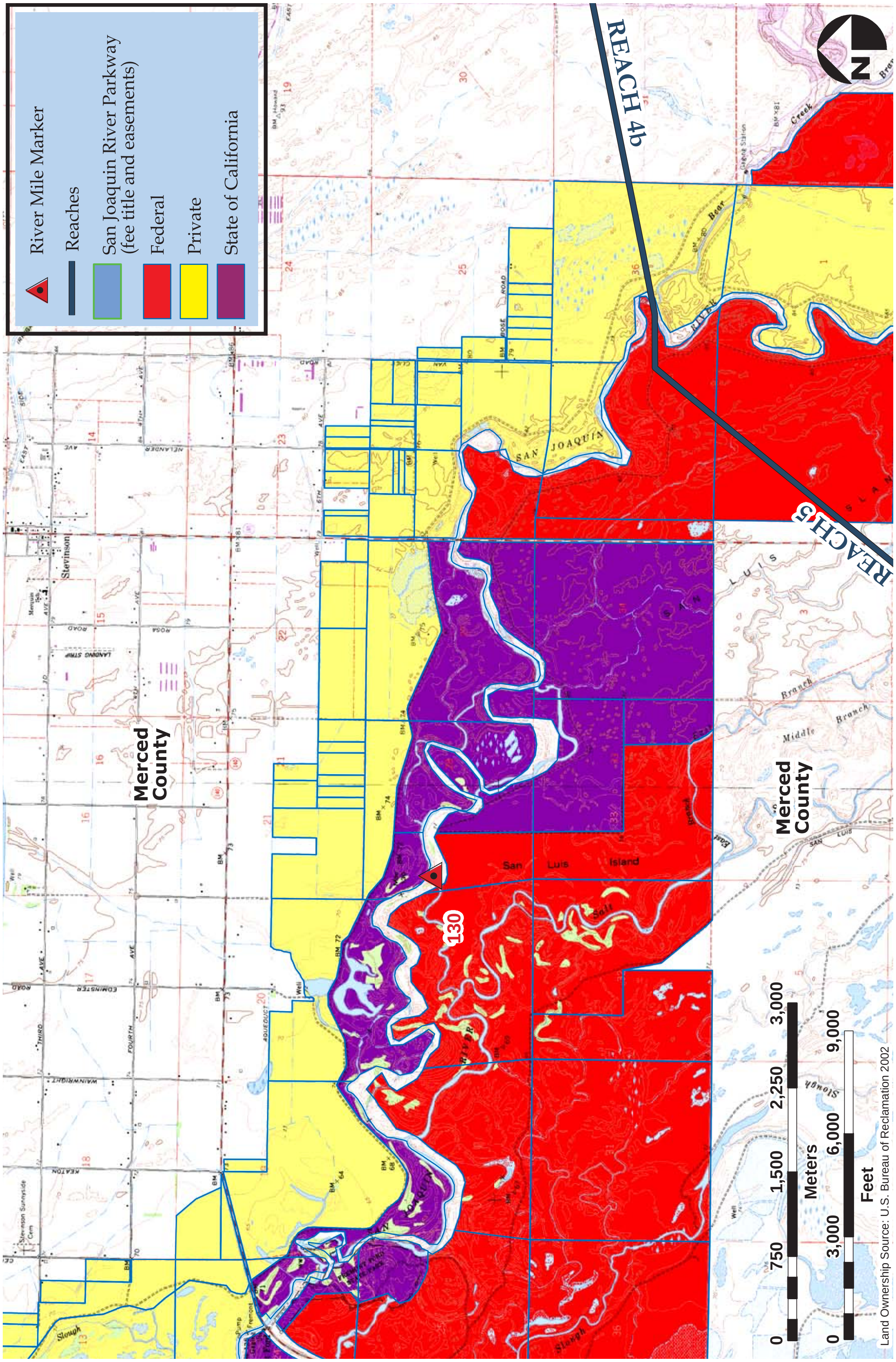
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3m. Land ownership along the San Jaoquin River (Reach 4b)



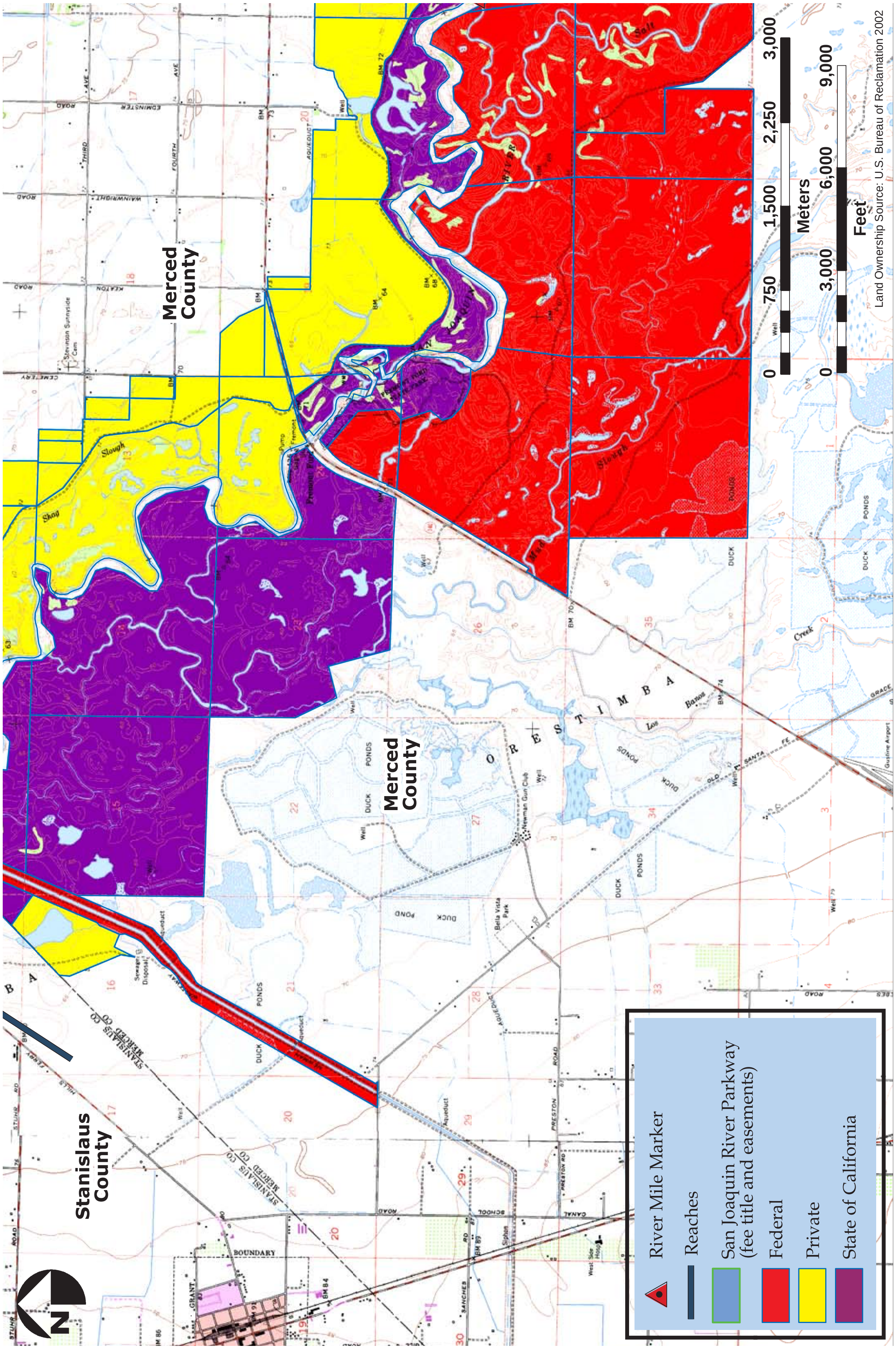
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3n. Land ownership along the San Jaquin River (Reach 4b)



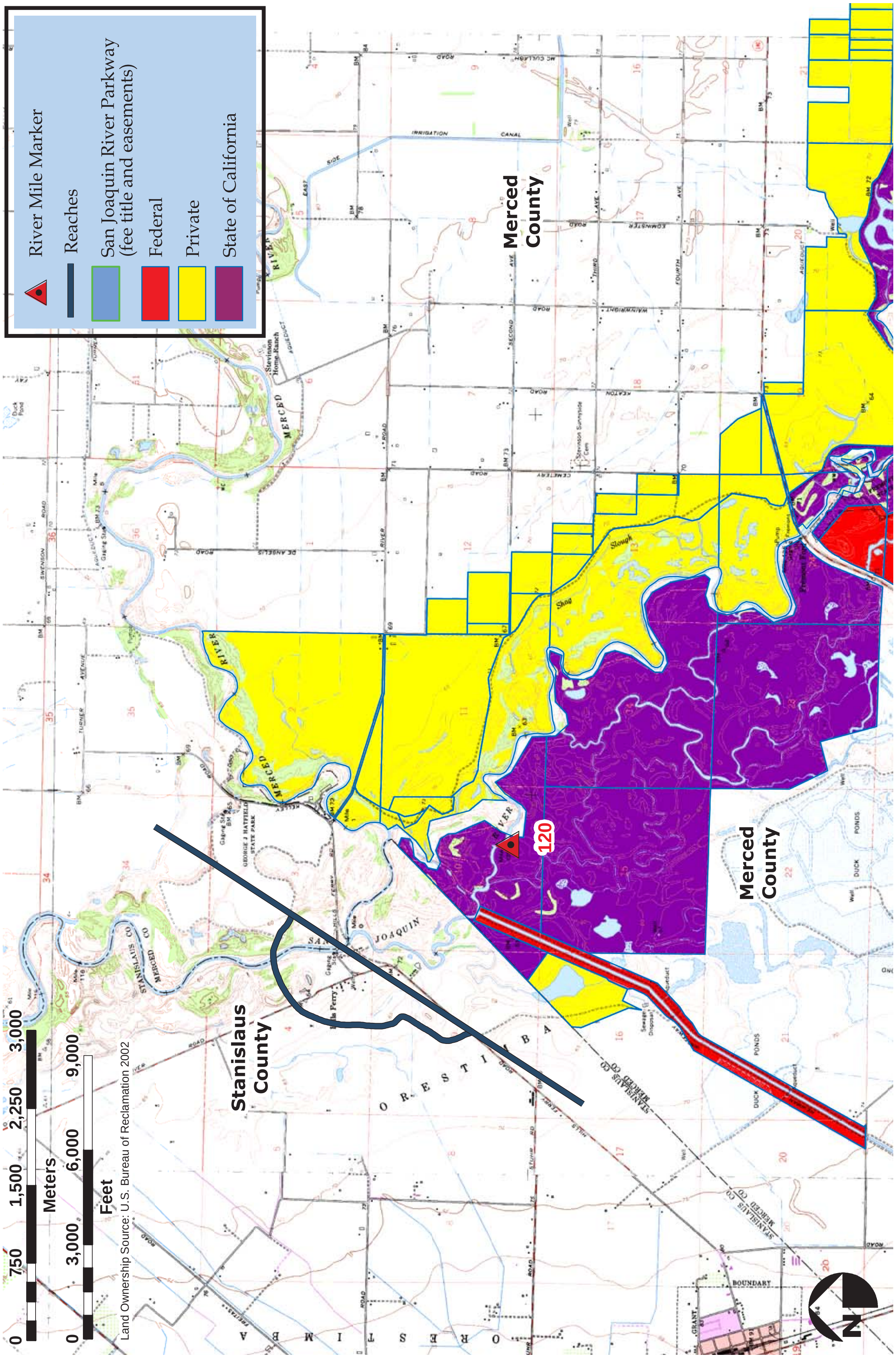
Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3o. Land ownership along the San Jaquin River (Reach 4b & 5)



Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3p. Land ownership along the San Joaquin River (Reach 5)



Land Ownership Source: U.S. Bureau of Reclamation 2002

Figure 10-3q. Land ownership along the San Jaquin River (Reach 5)

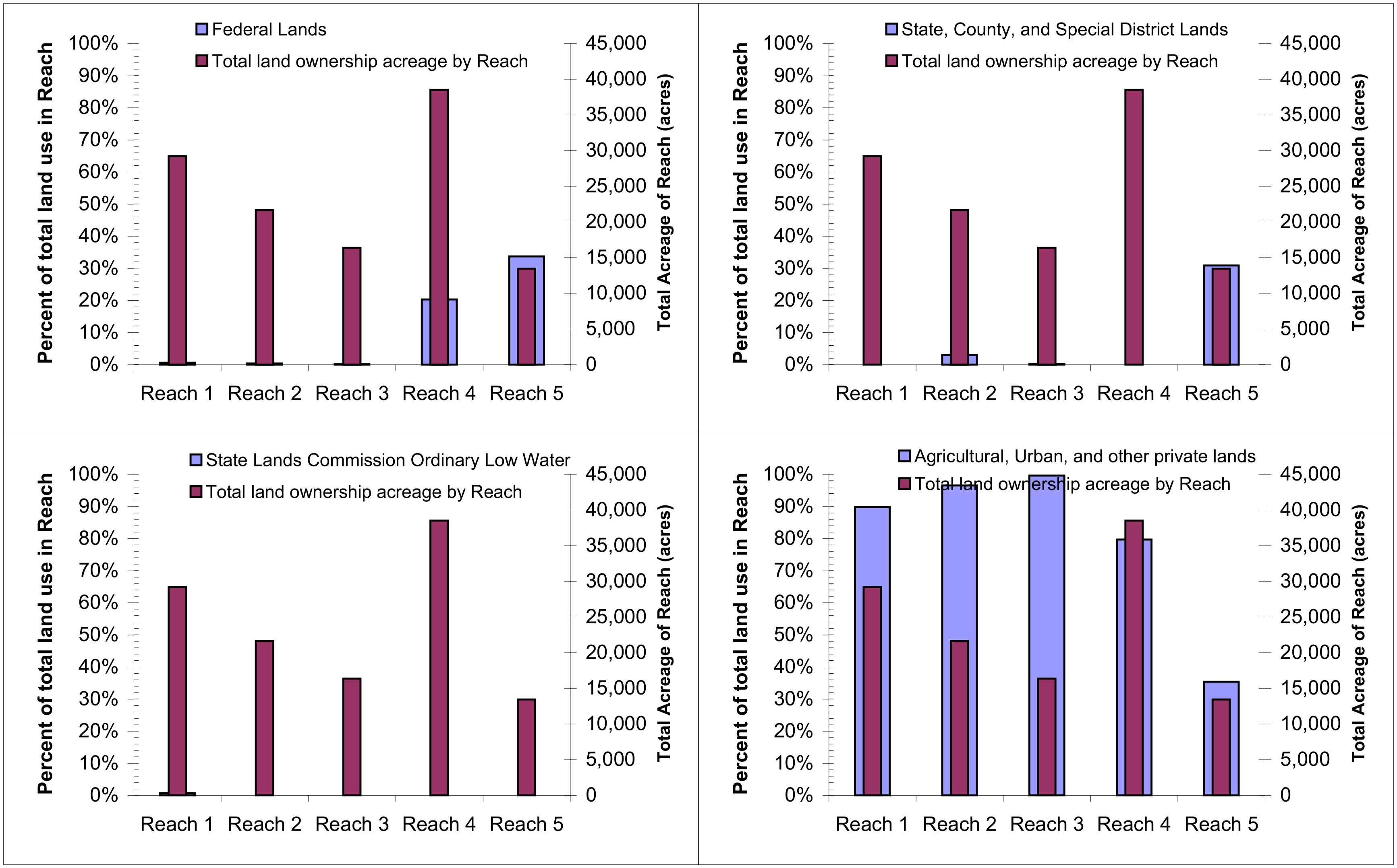
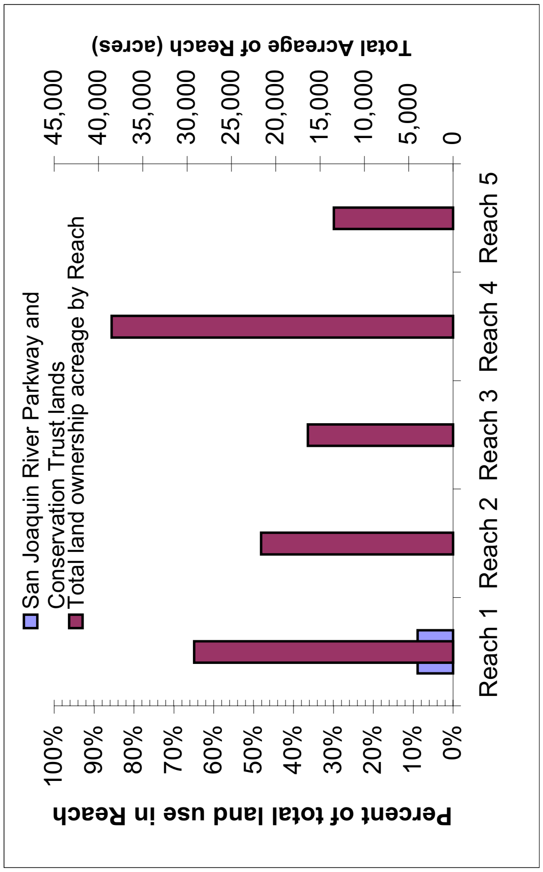


Figure 10-4a. Public and private land ownership distribution between reaches.



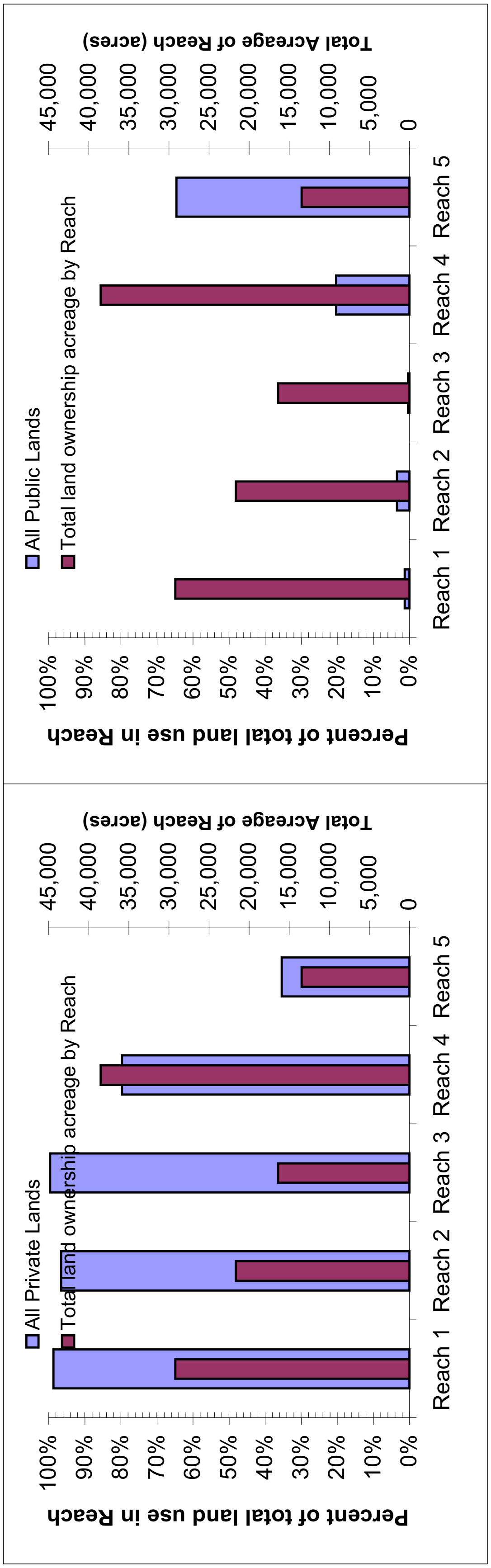


Figure 10-4b. Public and private land ownership distribution between reaches.

but begins to increase in Reach 4 (20%), and continues to increase in Reach 5 (65%). These public lands are largely US Fish and Wildlife refuges and California State Parks. Because the State Lands Commission has not issued claims to the ordinary low water in most reaches, the percentage of public lands is actually lower than it should be in all reaches. The lands classified as State, County, and Special District Lands in Reach 2 are entirely those lands on the river comprising the San Joaquin River Levee District.

The findings of this land use and ownership analysis are used to discuss opportunities and constraints in Section 10.7. Opportunities and constraints may apply to potential future restoration opportunities, as well as to existing and future land use and ownership. We discuss both in Section 10.7, emphasizing the opportunities and constraints on future restoration activities.

10.6. REGULATORY CONSIDERATIONS

Local, State and Federal land use and environmental regulations will significantly influence future restoration of the San Joaquin River; these regulations present additional opportunities and constraints to restoration efforts. County, State, and Federal agencies impose regulatory restrictions or mandates on land use (including restoration activities), and these are reviewed in this section. In addition to the general discussion of regulations for Fresno, Madera, and Fresno counties, we have included applicable objectives and policies that may affect restoration actions. These objectives and policies were obtained from the counties' General Plans, available on the Internet (see URL address in Literature Cited section).

10.6.1. County Regulations

A General Plan is a legal document, required by State law (California General Code Section 65300 et seq.), that serves as the "constitution" for land use by the local government. Every General Plan must have the following components (among others): (1) a land use element that designates the distribution and intensity of all lands uses in its jurisdiction; (2) a conservation element that addresses conservation, development, and use of natural resources including water, forests, soils, rivers and mineral deposits; and (3) an open space element that describes measures that: (a) preserve open space for protection of natural resources such as wildlife habitat, and (b) manage resources such as agriculture, outdoor recreation, and public health and safety from geologic hazards, flooding and fires. When approving a land use project, decision makers must make a Finding that the proposed land use conforms to the General Plan's goals and policies.

A County's Zoning Ordinance and parcel specific map are its most important tools for implementing its General Plan. State law mandates that development within counties be consistent with their General Plan. Because Fresno and Madera counties share a common boundary along the San Joaquin River, their General Plan policies affect land use along the river. Additionally, the General Plan policies make special note of land use restrictions along the river corridor that may affect present and future land use, including restoration activities. A General Plan's land use policies are not the total extent of local regulatory oversight to land use; resource protection policies, described in the conservation and open space elements of a General Plan, must also be reviewed. The entire General Plan should be reviewed to ensure compliance with its policies. The local Zoning Ordinance should be consulted, along with regulations promulgated by State and Federal resource agencies.

10.6.1.1. Fresno County General Plan, 2000

The Fresno County General Plan was updated in October 2000. In the study area, Fresno County's land use jurisdiction lies to the south and west of the San Joaquin River centerline, through Reaches

1, 2, 3 and into 4A. The General Plan contains 27 primary land use designations and three overlay designations (an overlay land use designation modifies the policies, standards, or procedures established for the underlying primary land use designation). One of the three overlay designations is for the San Joaquin River corridor. Each primary land use designation is defined in terms of allowable uses and intensity standards. The land use designations are implemented largely through the zoning ordinance. The following review of the Fresno County General Plan has identified allowable uses, and relevant goals, polices and implementation programs to be considered when assessing opportunities and constraints for potential future restoration activities on the San Joaquin River.

Within the Fresno County General Plan, two chapters influence restoration on the San Joaquin River: the Agriculture and Land Use chapter, and the Conservation and Open Space chapter (the use of the term “chapter” is interchangeable with “element”). Agricultural land produces crops and livestock, and contains necessary agricultural commercial centers, processing facilities, and certain semi-agricultural activities. Conservation and Open Space areas are those that are essentially unimproved and are planned to remain open in character, providing for:

- the preservation of natural resources;
- the managed production of resources, parks and recreation, thus protecting and enhancing cultural resources and providing recreational opportunities;
- the protection of the community from natural and manmade hazards.

The primary overlay on these two uses (Agricultural and Open Space) is the San Joaquin River Corridor Overlay, which provides for agricultural activities with incidental homesites, sand and gravel extraction, various recreational activities, wildlife habitat areas, and uses which serve the San Joaquin River Parkway. Within each chapter are one or more categories of use, which are discussed in the following sections. Because these uses are those contained in the corresponding General Plan of each county, the uses do not necessarily directly match with the land use designations used in the mapping exercise in Section 10.5.

10.6.1.1.1. Agriculture and Land Use Chapter: Agriculture

Agriculture is essential to the visions and goals of the Fresno County General Plan; that focus is reflected in its land use policies that guide decisions to minimize the conversion of productive agriculture land, to protect agricultural activities from incompatible land uses, and to control expansion of non-agricultural development onto productive agricultural lands. Excerpts from the Fresno County General Plan that may affect restoration activities are as follows:

Goal LU-A *“To promote the long-term conservation of productive and potentially-productive agricultural lands”…*

- Policy LU-A.2 “The County shall maintain agriculturally-designated areas for agriculture use and shall direct urban growth away from valuable agricultural lands”…
- Policy LU-A.12 “In adopting land uses policies, regulations and programs, the County shall seek to protect agricultural activities from encroachment of incompatible land uses.”
- Policy LU-A.13 “The County shall protect agricultural operations from conflicts with non-agricultural uses by requiring buffers between proposed non-agricultural uses and adjacent agricultural operations.”
- Policy LU-A.16 “The County should consider the use of agricultural land preservation programs that improve the competitive capabilities of farms and ranches, thereby ensuring long-term conservation of viable agricultural operations. Examples of programs to be

considered should include: land trusts; conservation easements; dedications incentives; new and continued Williamson Act contracts; Farmland Security Act contracts; the California Farmland Conservancy Program Fund; agricultural education programs; zoning regulations; agricultural mitigation fee program; urban growth boundaries; transfer of development rights; purchase of development rights; and agricultural buffer policies."

- Policy LU-A.17 "The County shall accept California Land Conservation contract on all designated agricultural land subject to location, acreage, and use limitations established by the County."
- Policy LU-A.20 "The County shall adopt and support policies and programs that seek to protect and enhance surface water and groundwater resources critical to agriculture."
- Program LU-A.C "The County shall develop and implement guidelines for design and maintenance of buffers to be required when new non-agricultural uses are approved in agricultural areas."

10.6.1.1.2. Agriculture and Land Use Chapter: River Influence Areas (overlay)

The San Joaquin River overlay provides for multiple uses including agriculture, sand and gravel mining, and recreation, but simultaneously, development is constrained by a high water table, poor drainage, and natural hazards such as flooding. Policies in this section seek to preserve and enhance the county's river influenced areas by avoiding adverse impacts from development and encouraging environmentally-friendly recreational and agricultural activities.

<u>*Goal LU-C*</u> *"To preserve and enhance the value of the river environment as a multiple use, open space resource; maintain the environmental and aesthetic qualities of the area; protect the quality of and quantity of the surface and groundwater resources; provide for long term preservation of productive agricultural land; conserve and enhance natural wildlife habitat; and maintain the flood-carrying capacity of the channel at a level equal to the one (1) percent flood event (100 year flood)."*

- Policy LU-C.2 "Within the San Joaquin River Corridor Overlay, the County shall accommodate agricultural activities with incidental homesites, recreational uses, sand and gravel extraction, and wildlife habitat and open space areas."
- Policy LU-C.3 "The County may allow by discretionary permit commercial activities needed to serve San Joaquin River Parkway visitors,"…"consistent with the objectives and policies of the San Joaquin River Parkway Master Plan."
- Policy LU-C.8 "Fresno County shall take into consideration the presence of the regulatory floodway or other designated floodway, the FEMA-designated 100-year floodplain, estimated 250-year floodplain, the Standard Project Flood, and the FMFCD Riverine Floodplain Policy in determining the location of future development within the San Joaquin River Parkway area. Any development sited in a designated 100-year floodplain shall comply with regulatory requirements at a minimum and with the FMFCD Riverine Floodplain Policy criteria, or requirements of other agencies having jurisdiction, were applicable."
- Policy LU-C.9 "The County shall administer its land use regulations in the San Joaquin River Corridor Overlay to preserve and protect identified wildlife corridors along the San Joaquin River. The County shall administer these regulations in consultation with the San Joaquin River Conservancy."
- Policy LU-C.10 "The County shall its land use regulations in the San Joaquin River Corridor Overlay to preserve and protect natural reserve areas in the San Joaquin River Parkway,

principally in those areas adjoining the wildlife corridor along the river where the largest acreage's of highest quality habitat exist. The County shall administer these regulations in consultation with the San Joaquin River Conservancy."

- Program LU-C.B "The County shall work with the San Joaquin River Parkway and Conservation Trust, San Joaquin River Conservancy, City of Fresno, and other interested agencies and organizations to implement the San Joaquin River Parkway Master plan."

10.6.1.1.3. Open Space and Conservation Chapter: Water Resources

This section governs surface and groundwater resources in the county.

<u>Goal OS-A</u> *"To protect and enhance the water quality and quantity in Fresno County's streams, creeks, and groundwater basins."*

- Policy OS-A.19 "The County shall require the protection of floodplain lands and, where appropriate, acquire public easements of purposes of flood protection, public safety, wildlife preservation, groundwater recharge, access, and recreation."
- Policy OS-A.20 "The County shall support the policies of the San Joaquin River Parkway Master Plan to protect the San Joaquin River as an aquatic habitat, recreational amenity, aesthetic resource, and water source."
- Program LU-C.B "The County shall work with the San Joaquin River Parkway and Conservation Trust, San Joaquin River Conservancy, City of Fresno, and other interested agencies and organizations to implement the San Joaquin River Parkway Master plan."

10.6.1.1.4. Open Space and Conservation Chapter: Mineral Resources

Policies in this section intend to preserve the future availability of mineral resources; along the San Joaquin River, this mineral resource is commercial grade aggregate. Policies in this section also seek to promote the orderly extraction of mineral resources while minimizing the impact of these activities on surrounding land uses and the natural environment.

<u>Goal OS-C</u> *"To conserve areas identified as containing significant mineral deposits and oil and gas resources for potential future use, while promoting the reasonable, safe, and orderly operation of mining and extraction activities within areas designated for such use, where environmental, aesthetic, and adjacent land use compatibility impacts can be adequately mitigated."*

- Policy OS-C.1 "The County shall not permit incompatible land uses within the impact area of existing or potential surface mining areas."
- Policy OS-C.2 "The County shall not permit land uses incompatible with mineral resource recovery within area designated as Mineral Resource Zone 2 (MRZ-2)."
- Policy OS-C.8 "The County shall, where feasible along the San Joaquin River, site recreational trails, bikeways, and other recreation areas at least three hundred feet from the edge of active aggregate mining operations and separate them by physical barriers."
- Policy OS-C.9 "The County shall require that any proposed changes in land use within areas designated MRZ-2 along the San Joaquin and Kings Rivers comply with the provisions of the State Surface Mining and Reclamation Act (SMARA)."
- Policy OS-C.10 "The County shall not permit land uses that threaten the future availability of mineral resource or preclude future extraction of those resources."

10.6.1.1.5. Open Space and Conservation Chapter: Wetland & Riparian Areas

Because of urbanization and agriculture, the broad floodplains in the San Joaquin Valley have been reduced to narrow floodways along each river, as part of regional flood control efforts. Policies in this section seek to protect riparian and wetland habitats in the county while allowing compatible uses where appropriate.

<u>Goal OS-D</u> *"To conserve the function and values of wetland communities and related riparian area throughout Fresno County while allowing compatible uses where appropriate. Protection of these resource functions will positively affect aesthetics, water quality, floodplain management, ecological function, and recreation/tourism."*

- Policy OS-D.1 "The County shall support the "no-net-loss" wetlands policies of the US Army Corps of Engineers, the US Fish and Wildlife Service, and the California Fish and Game."
- Policy OS-D.2 "The County shall require new development to fully mitigate wetland loss for function and value in regulated wetlands to achieve "no-net-loss" through any combination of avoidance, minimization, or compensation."
- Policy OS-D.3 "The County shall require development to be designed in such a manner that pollutants and siltation do not significantly degrade the area, value, or function of wetlands."
- Policy OS-D.4 "The County shall require riparian protection zones around natural watercourses and shall recognize that these areas provide highly valuable wildlife habitat. Riparian protection zones shall include the bed and bank of both low- and high-flow channels and associated riparian vegetation, the band of riparian vegetation outside the high-flow channel, and buffers of 100 feet in width as measured from the top of the bank of unvegetated channels and 50 feet in width as measured from the other edge of the dripline of riparian vegetation."
- Policy OS-D.6 "The County shall require new private or public developments to preserve and enhance existing native riparian habitat unless public safety concerns require removal of habitat for flood control or other purposes. In cases where new private or public development results in modifications or destruction of riparian habitat for purposes of flood control, the developers shall be responsible for creating new riparian habitats within or near the project area. Adjacency to the project area shall be defined as being within the same watershed sub-basin as the project site. Compensation shall be at a ratio of three acres of new habitat fore every one acre destroyed."
- Policy OS-D.7 "The County shall support the management of wetland and riparian plant communities for passive recreation, groundwater recharge, nutrient storage, and wildlife habitats."
- Policy OS-D.8 "The County should consider the acquisition of wetland, meadows, and riparian habitat areas for parks limited to passive recreational activities as a method of wildlife conservation."
- Program OS-D.A "The County shall work toward the acquisition by public agencies or private non-profit conservation organizations of creek corridors, wetlands, and areas rich in wildlife or of a fragile ecological nature as public open space where such areas cannot be effectively preserved through regulatory process. Such protection may take the form of fee acquisition or protective easements and may be carried out in cooperation with other local, State, and Federal agencies and private entities. Acquisition shall include provisions for maintenance and management in perpetuity."

- Program OS-D.A "The County shall adopt an ordinance for riparian zones identifying allowable activities in riparian protection zones and allowable mitigation techniques."

10.6.1.1.6. Open Space and Conservation Chapter: Fish & Wildlife Habitat

Policies in this section seek to protect natural areas and to preserve habitat diversity in the county.

<u>Goal OS-E</u> *"To help protect, restore, and enhance habitats in Fresno County that support fish and wildlife species so that populations are maintained at viable levels."*

- Policy OS-E.1 "The County shall support efforts to avoid the "net" loss of important wildlife habitat where practicable."
- Policy OS-E.2 "The County shall require adequate buffer zones between construction activities and significant wildlife resources, including both onsite habitats that are purposely avoided and significant habitats that are adjacent to the project site, in order to avoid the degradation and disruption of critical life cycle activities such as breeding and feeding. The width of the buffer zone should vary depending on the location, species, etc. A final determination shall be made based on informal consultation with the US Fish and Wildlife Service and/or the California Department of Fish and Game."
- Policy OS-E.6 "The County shall ensure the conservation of large, continuous expanses of native vegetation to provide suitable habitat for maintaining abundant and diverse wildlife populations, as long as this preservation does not threaten the economic well-being of the county."
- Policy OS-E.10 "The County shall support State and Federal programs to acquire significant fish and wildlife habitat areas for permanent protection and/or passive recreation use."
- Policy OS-E.11 "The County shall protect significant aquatic habitats against excessive water withdrawals that could endanger special-status fish and wildlife or would interrupt normal migratory patterns."
- Policy OS-E.12 "The County shall ensure the protection of fish and wildlife habitats from environmentally-degrading effluents originating from mining and construction activities that are adjacent to aquatic habitats.
- Policy OS-E.13 "The County should protect to the maximum extent practicable wetlands, riparian habitat, and meadows since they are recognized as essential habitats for birds and wildlife."
- Policy OS-E.14 "The County shall require a minimum 200-foot wide wildlife corridor along particular stretches of the San Joaquin River and Kings River, whenever possible. The exact locations of the corridors should be determined based on the results of biological evaluation of these watercourses."
- Policy OS-E.16 "Areas that have unusually high value for fish and wildlife propagation should be preserved in a natural state to the maximum possible extent."
- Policy OS-E.17 "The County should preserve, to the maximum possible extent, areas defined as habitats for rare or endangered animal and plant species in a natural state consistent with State and Federal endangered species laws."
- Policy OS-E.18 "The County should preserve areas identified as habitat for rare or endangered plant and animal species primarily through the use of open space easements and appropriate zoning that restrict development in these sensitive areas."

10.6.1.1.7. Open Space and Conservation Chapter: Parks and Recreation

Policies in this section seek to enhance recreational opportunities in the county by encouraging further development of public and private recreation lands, and by requiring development to help fund additional parks and recreation facilities.

Goal OS-H *"To designate land for and promote the development and expansion of public and private recreational facilities to serve the needs of residents and visitors."*

- Policy OS-H.11 "The County shall support the policies of the San Joaquin River Parkway Master Plan to protect the San Joaquin River as an aquatic habitat, recreational amenity, aesthetic resource, and water source."
- Policy OS-H.12 "The County shall in conjunction with the San Joaquin River Conservancy rehabilitate and improve existing recreation areas and facilities along the San Joaquin River at the earliest possible time, particularly Lost Lake and Skaggs Bridge Regional Parks."
- Policy OS-H.13 "The County shall require that structures and amenities associated with the San Joaquin River Parkway be designed and sited to ensure that such features do not obstruct flood flows, do not create a public safety hazard, or result in a substantial increase in off-site water surface elevations, and that they conform to the requirements of other agencies having jurisdiction."
- Program OS-H.A "The County shall work with local, State, and Federal agencies to complete a comprehensive inventory of all parks and recreation areas and services in the county and to identify other areas suitable for park acquisition and development as funds permit."
- Policy OS-I.6 "The County shall coordinate development of its Recreational Trail Master Plan with the San Joaquin River Conservancy concerning the proposed multi-purpose trail between Highway 99 and Friant Dam in the San Joaquin River Parkway."
- Program OS-I.B "The County shall investigate the potential of various land use controls for reserving areas for trails such as the acquisition of easements, open space and floodplain zoning, and subdivision control."

10.6.1.2. Madera County General Plan Policy Document, 1995

The Madera County General Plan Policy Document, adopted in October 1995, is a stand-alone document that is part of the Madera County General Plan. In the study area, Madera County's land use jurisdiction lies to the north east of the San Joaquin River centerline, and continues downstream from Friant Dam through Reaches 1, 2, 3 and, 4A. The Madera County General Plan is organized differently from the Fresno County General Plan, but shares many of the same components. The Madera County General Plan contains a section that incorporates the San Joaquin River Parkway Plan. The San Joaquin River Parkway Plan is discussed below.

10.6.1.2.1. San Joaquin River Parkway Plan

The San Joaquin River Parkway Task Force, an advisory body created by State statute in 1990, adopted the San Joaquin River Parkway Plan in 1992. The Parkway Plan is a conceptual, long-range planning document intended to help preserve, enhance, and provide for enjoyment of the natural landscape of the San Joaquin River corridor. As proposed in 1992, the parkway would include the San Joaquin River and approximately 5,900 acres of land on both sides of the river between Friant Dam and the Highway 99 crossing, as well as the existing 17-acre Skaggs Bridge Regional Park at the Highway 145 crossing. Approximately 1,900 acres of the parkway would be located in Madera County and 4,000 acres in Fresno County.

Portions of the proposed parkway are currently managed for recreational or natural resource protection, conservation, and education purposes, although other parts are privately owned and used for other purposes. Approximately 4,650 of the 5,900 acres within the proposed parkway are private land. The Parkway Plan includes the following six fundamental goals (San Joaquin River Conservancy, 1993):

- Preserve and restore a riparian corridor of regional significance along the San Joaquin River from Friant Dam to the Highway 145 crossing.
- Protect wildlife species that depend on or prefer the river environment for at least part of their existence.
- Provide for conservation, education, and recreation, particularly a continuous trail, in a cooperative manner with affected landowners.
- Protect irreplaceable natural and cultural resources in a way that will also meet people’s recreational and educational needs.
- Protect existing undeveloped areas of the river bottom, which should remain non-urbanized and be retained in open space or agriculture if feasible.
- Provide land use and management policies for the San Joaquin River and areas of the river bottom included in the parkway that will enhance the attractiveness of the Fresno-Madera metropolitan area and enhance the quality of life of its residents.

More specific goals, objectives, and policies are included in various elements. The Land Use Element in the Parkway Plan defines land use designations, and includes goals, objectives, and policies for natural resources, flood management, and recreation areas. The Parkway Plan also includes a Mineral Resources Element and a Plan Implementation Element that address land acquisition and a parkway managing entity. The Parkway Plan addresses other land uses, including agriculture, commercial services, and public services facilities. As a result of the San Joaquin River Parkway Plan, the San Joaquin River Conservancy was created in 1993 to acquire, manage, and operate parkway lands.

10.6.1.2.2. Recreation and Cultural Resources Chapter: Public Recreation and Parks

<u>Goal 4A</u> *“To designate land for and promote the development and expansion of public and private recreational facilities to serve the needs of residents and visitors.”*

- Policy 4.A.3. The County shall support and participate in the development of the San Joaquin River Parkway.
- Policy 4.A.7. The County shall encourage Federal, State, and local agencies currently providing recreation facilities to maintain, at a minimum, and improve, if possible, their current levels of service.

Implementation Program

- The County shall work with local, State, and Federal agencies to complete a comprehensive inventory of all parks and recreation areas and services in the county and to identify other areas suitable for park acquisition and development. The County shall consider preparation of a County park and recreation master plan to provide a policy framework for independent implementation by the cooperating agencies.

10.6.1.2.3. Agriculture and Natural Resources Chapter: Agriculture

Goal 5.A *"To designate adequate agricultural land and promote development of agricultural uses to support the confined viability of Madera County's agricultural economy."*

- Policy 5.A.l. The County shall maintain agriculturally-designated areas for agricultural uses and direct urban uses to designated new growth areas, existing communities, and/or cities."
- Policy 5.A.2. The County shall discourage the conversion of prime agricultural land to urban uses unless an immediate and clear need can be demonstrated that indicates a lack of land for non-agricultural uses.
- Policy 5.A.12. The County shall actively encourage enrollments of agricultural lands in its Williamson Act program, particularly on the edges of new growth areas.
- Policy 5.A.13. The County shall require development within or adjacent to designated agricultural areas to incorporate design, construction, and maintenance techniques that protect agriculture and minimize conflicts with adjacent agricultural uses.

10.6.1.2.4. Agriculture and Natural Resources Chapter: Water Resources

Goal 5.C *"To protect and enhance the natural qualities of Madera County's streams, creeks and groundwater."*

- Policy 5.C.l. The County shall protect preserve areas with prime percolation capabilities and minimize placement of potential sources of pollution in such areas.
- Policy 5.C.2. The County shall minimize sedimentation and erosion through control of grading, cutting of trees, and removal of vegetation, placement of roads and bridges, and use of off-road vehicles. The County shall discourage grading activities during the rainy season, unless adequately mitigated, to avoid sedimentation of creeks and damage to riparian habitat.
- Policy 5.C.6. The County shall require that natural watercourses are integrated into new development in such a way that they are accessible to the public and provide a positive visual element.
- Policy 5.C.8. The County shall support the policies of the San Joaquin River Parkway Plan to protect the San Joaquin River as an aquatic habitat and a water source.

Goal 5.D *"To protect wetland communities and related riparian areas throughout Madera County as valuable resources.*

- Policy 5.D.l. The County shall comply with the wetlands policies of the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, and the California Department of Fish and Game. Coordination with these agencies at all levels of project review shall continue to ensure that appropriate mitigation measures and the concerns of these agencies are adequately addressed.
- Policy 5.D.2. The County shall require new development to mitigate wetland loss in both regulated and non-regulated wetlands through any combination of avoidance, minimization, or compensation. The County shall support mitigation banking programs that can provide the opportunity to mitigate impacts to rare, threatened, and endangered species and/or the habitat, which supports these species in wetland and riparian areas.
- Policy 5.D.3. Development should be designed in such a manner that pollutants and siltation will not significantly adversely affect the value or function of wetlands.

- Policy 5.D.4. The County shall require riparian protection zones around natural watercourses. Riparian protection zones shall include the bed and bank of both low and high flow channels and associated riparian vegetation, the band of riparian vegetation outside the high flow channel, and buffers of 100 feet in width as measured from the top of bank of unvegetated channels and 50 feet in width as measured from the outer edge for the canopy of riparian vegetation. Exceptions may be made in existing developed areas where existing development and lots are located within the setback areas.
- Policy 5.D.5. The County shall strive to identify and conserve remaining upland habitat areas adjacent to wetlands and riparian areas that are critical to the feeding or nesting of wildlife species associated with these wetland and riparian areas.
- Policy 5.D.6. The County shall require new private or public developments to preserve and enhance existing native riparian habitat unless public safety concerns require removal of habitat for flood control or other public purposes. In cases where new private or public development results in modification or destruction of riparian habitat for purposes of flood control, the developers shall be responsible for creating new riparian habitats within or near the project area at a ratio of three acres of new habitat for every acre destroyed.
- Policy 5.D.7. The County shall support the management of wetland and riparian plant communities for passive recreation, groundwater recharge, nutrient catchment, and wildlife habitats. Such communities shall be restored, where possible.
- Policy 5.D.8. The County shall support the goals and policies of the San Joaquin River Parkway Plan to preserve existing habitat and maintain, enhance, or restore native vegetation to provide essentially continuous riparian and upland habitat for wildlife along the river between Friant Dam and the Highway 145 crossing.

Implementation Programs

- 5.1 The County shall inform the public and prospective developers about those sections of the California Fish and Game Code that apply to diversion or obstruction of stream channels and pollution of waterways with detrimental material. This shall be done through distribution of educational materials with building permits and as a part of project review.
- 5.2 The County shall work toward the acquisition by public or private, non-profit conservation organizations of creek corridors, wetlands, and areas rich in wildlife or of a fragile ecological nature as public open space where such areas cannot be effectively preserved through the regulatory process. Such protection may take the form of fee acquisition or protective easements and may be carried out in cooperation with other local, State, and Federal agencies and private entities. Acquisition should include provisions for maintenance and management in perpetuity.
- 5.3 The County shall adopt an ordinance for riparian protection zones identifying allowable activities in riparian protection zones and allowable mitigation techniques.

10.6.1.2.5. Agriculture and Natural Resources Chapter: Fish and Wildlife Habitat

Goal 5.E *“To protect, restore, and enhance habitats that support fish and wildlife species so as to maintain populations at viable levels.”*

- Policy 5.E.l. The County shall identify and protect critical nesting and foraging areas, important spawning grounds, migratory routes, waterfowl resting areas, oak woodlands, wildlife movement corridors, and other unique wildlife habitats critical to protecting and sustaining wildlife populations.

- Policy 5.E.2. The County shall require development in areas known to have particular value for wildlife to be carefully planned and, where possible, located so that the reasonable value of the habitat for wildlife is maintained.
- Policy 5.E.3. The County shall encourage private landowners to adopt sound wildlife habitat management practices, as recommended by the California Department of Fish and Game officials and the U.S. Fish and Wildlife Service.
- Policy 5.E.4. The County shall support preservation of the habitats of rare, threatened, endangered, and or other special status species. The County shall consider developing a formal habitat conservation plan in consultation with Federal and State agencies, as well as other resource conservation organizations. Such a plan would provide a mechanism for the acquisition and management of lands supported by threatened and endangered species.
- Policy 5.E.5. The County shall support the maintenance of suitable habitats for all indigenous species of wildlife through maintenance of habitat diversity.
- Policy 5.E.6. The County shall ensure the conservation of sufficiently large, continuous expanses of native vegetation to provide suitable habitat for maintaining abundant and diverse wildlife, if this preservation does not threaten the economic well-being of the county.
- Policy 5.E.7. The County shall support the preservation or reestablishment of fisheries in the rivers and streams within the county, whenever possible.
- Policy 5.E.8. The County shall ensure close monitoring of pesticide use in areas adjacent to habitats of special status plants and animals.
- Policy 5.E.l0. Prior to approval of discretionary development permits involving parcels within a significant ecological resource area, the County shall require, as part of the environmental review process, a biotic resources evaluation of the sites by a qualified biologist. The evaluation shall be based upon field reconnaissance performed at the appropriate time of year to determine the presence or absence 6f rare, threatened, or endangered species of plants or animals. Such evaluation will consider the potential for significant impact on these resources and will either identify feasible measures to mitigate such impacts or indicate why mitigation is not feasible.
- Policy 5.E.l1. The County shall provide for a minimum 200-foot wildlife corridor along the San Joaquin River between Friant Dam and the Highway 145 crossing, consistent with the San Joaquin River Parkway Plan. The County shall require a buffer with a minimum width of 150 feet between existing or planned urban or suburban uses. Exceptions may be necessary where the minimum width is infeasible due to topography or other physical constraints. In these instances, an offsetting expansion on the opposite side of the river should be provided.

Implementation Programs

- 5A. The County shall initiate detailed inventories of ecologically significant resource areas, including unique natural areas, wetland areas, riparian areas, habitats of rare, threatened, endangered, and other uncommon and special-status species. The inventory should be conducted as area plans, specific plans, planned unit developments (UD) or other planning projects are considered by the County. The inventory should be based on the California Wildlife Habitats Relationships (WHR) system and shall identify appropriate buffer zones around the identified resource areas in order to account for periodic, seasonal, or ecological changes. The maps should be revised on a regular basis to reflect the availability of new information from other agencies, changes in definition, or any other changes.

- The County shall maintain current maps that indicate the extent of critical habitat for important fish and game species, as these maps are made available by the California Department of Fish and Game (CDFG). The relative importance of these game species shall be determined by the County, in consultation with CDFG, based on relevant ecological, recreational, and economic considerations. These maps shall be used by the County to evaluate proposed area plans, specific plans, and any project development proposals to determine compatibility of development with maintenance and enhancement of important fish and game species.
- The County shall investigate costs and possible funding sources for development of a habitat conservation plan.

10.6.1.2.6. Agriculture and Natural Resources Chapter: Vegetation

<u>Goal 5.F</u> *"To preserve and protect the valuable vegetation resources of Madera County."*

- Policy 5.F. 1. The County shall encourage landowners and developers to preserve the integrity of existing terrain and natural vegetation in visually-sensitive areas such as hillsides, ridges, and along important transportation corridors.
- Policy 5.F.3. The County shall support the preservation of outstanding areas of natural vegetation, including, but not limited to, oak woodlands, riparian areas, and vernal pools.
- Policy 5.F.5. The County shall establish procedures for identifying and preserving rare, threatened, and endangered plant species that may be adversely affected by public or private development projects. The County shall consider developing a formal habitat conservation plan in consultation with Federal and State agencies, as well as other resources conservation organizations. Such a plan would provide a mechanism for the acquisition and management of land supporting threatened and endangered species
- Policy 5.F.6. The County shall require that new development preserve natural woodlands to the maximum extent possible.

Implementation Programs

- 5.7 The County shall prepare and maintain an updated list of State and Federal rare, threatened, and plant species known or suspected to occur in the county. The following other uncommon or special status species which occur or may occur in the county should also be included on the list: 1) plant species included in the California Native Plant Society's Inventory of Rare and Endangered Vascular Plants of California; 2) species of special concern as designated by California Department of Fish and Game; and 3) California Fully Protected animals as defined by California Fish and Game Code. In addition to updating the list as new information becomes available, the list should be reviewed and amended at least once every two years.

10.6.1.2.7. Agriculture and Natural Resources Chapter: Open Space

<u>Goal 5.H</u> *"To preserve and enhance open space lands to maintain the natural resources of the county."*

- Policy 5.H.l. The County shall support the preservation and enhancement of natural land forms, natural vegetation, and natural resources as open space. To the extent feasible, the County shall permanently protect as open space areas of natural resource value, including wetlands preserves, riparian corridors, woodlands, and floodplains.

- Policy 5.H.2. The County shall require that new development be designed and constructed to preserve the following types of areas and features as open space to the maximum extent feasible:
  a. High erosion hazard areas;
  b. Scenic and trail corridors;
  c. Streams and streamside vegetation;
  d. Wetlands;
  e. Other significant stands of vegetation;
  f. Wildlife corridors; and
  g. Any areas of special ecological significance.
- Policy 5.H.3. The County shall support the maintenance of open space and natural areas that are interconnected and of sufficient size to protect biodiversity, accommodate wildlife movement, and sustain ecosystems.
- Policy 5.H.4. Recognizing the importance of both public and privately-owned open space, the County shall encourage both private and public ownership and maintenance of open space.
- Policy 5.H.5. The County shall require that significant natural, open space, and cultural resources be identified in advance of development and incorporated into site-specific development project design.

Implementation Programs

- 5.9 The County will review and revise the planned zoning districts of the Zoning Ordinance to add provisions for the protection of significant natural, open space, and cultural resources.

10.6.1.2.8. Agriculture and Natural Resources Chapter: Mineral Resources

<u>Goal 5.J</u> *"To encourage commercial mining operations within areas designated for such extraction, where environmental, aesthetic, and adjacent land use compatibility impacts can be adequately mitigated, and to provide for the timely rehabilitation and appropriate reuse of mining sites."*

- Policy 5J.l. The County shall require new mining operations to be designed to provide a buffer between existing or likely adjacent uses, minimize incompatibility with nearby uses, and adequately mitigate their environmental and aesthetic impacts. The buffer area shall be zoned Agricultural, Rural, Exclusive-20 Acre or -40 Acre.
- Policy 5J.2. The County shall discourage the development of incompatible land uses in areas that have been identified as having potentially significant mineral resources, except where the California Department of Mines and Geology agrees that economic or environmental considerations make mineral extraction infeasible.
- Policy 5J.3. The County shall discourage the development of any uses that would be incompatible with adjacent mining operations or would restrict future extraction of significant mineral resources.
- Policy 5.IA. The County shall require that new non-mining land uses adjacent to existing mining operations be designed to provide a buffer between the new development and the mining operations.
- Policy 5.1.5. The County shall coordinate its mineral extraction policies and regulations with Fresno County, the City of Fresno, and Merced County. The County shall refer applications for mining operations in locations near or adjacent to a city or another county to the affected city or county for review and comment.

10.6.1.2.9. Health and Safety Chapter: Flood Hazards

Goal 6.B *"To minimize the risk of loss of life, injury, damage to property, and economic and social dislocations resulting from flood hazards.*

- Policy 6.B.3. The County shall restrict uses in designated floodways to those that are tolerant of occasional flooding and do not restrict or alter flow of flood waters. Such uses may include agriculture, outdoor recreation, mineral extraction, and natural resource areas.
- Policy 6.BA. The County shall require that all development within areas subject to 100-year floods be designed and constructed in a manner that will not cause floodwaters to be diverted onto adjacent property or increase flood hazards to other areas.
- Policy 6.B.5. The County shall require flood control structures, facilities, and improvements to be designed to conserve resources, incorporate and preserve scenic values, and to incorporate opportunities for recreation, where appropriate.
- Policy 6.B.6. The County shall require that flood management programs avoid alteration of waterways and adjacent areas, whenever possible.

10.6.1.3. Merced County Year 2000 General Plan

The Merced County Year 2000 General Plan was adopted in December 1990. In the San Joaquin River study area, Merced County's land use jurisdiction includes half of Reach 4A and all of Reach 5. The General Plan recognizes two primary categories of land uses: urban and rural. The Merced County General Plan's goals, objectives, and policies should be referenced when considering land use changes for restoration, to ensure that proposed changes are in compliance with the General Plan. The following subsections refer to the Merced County General Plan.

10.6.1.3.1. Open Space and Conservation Chapter

The Open Space Chapter is a plan for the comprehensive and long-range management, preservation, and conservation of "open-space lands." This chapter contains provisions for managing and conserving Merced County's natural resources, and the protection of life, health, and property from natural hazards. The natural resources addressed in this chapter include land, water, plant, animal, cultural, archaeological, scenic resources and air quality. This chapter's policies are designed to ensure that the development of Merced County will not significantly interfere with or destroy valuable natural resources, and that development will occur with recognition of sensitive resources and hazardous conditions. The purpose of the General Plan is to maintain the natural topography, vegetation, wildlife and scenic beauty of Merced County to the greatest extent possible, while recognizing that Merced County must balance needs for affordable housing and economic opportunities.

Goal 1 *"Habitats which support rare, endangered or threatened species are not substantially degraded."*

> *Objective 1.A*: *"Rare and endangered species are protected from urban development and are recognized in rural areas."*

- Policy 1 "Recognize as significant wetland habitats those areas which meet the definition of having a high wetland habitat value based on the Adamus methodology and based on the Army Corps of Engineers delineation method."
- Policy 9 "Significant aquatic and waterfowl habitats should be protected against excessive water withdrawals which would endanger or interrupt normal migratory patterns."

<u>Objective 1.B</u>: *"Local, State and Federally managed lands are recognized."*

- Policy 10 "Special agricultural commercial uses that are directly related to an a part of an agricultural enterprise or operation, and characteristically specific commercial or industrial uses in rural areas should not be located adjacent to Federal or State wildlife refuges."
- Policy 11 "The division of parcels which is determine to result in non-agricultural uses should be avoided, adjacent to Federal or State wildlife refuge areas."
- Policy 13 "Minimize the fiscal impact to the County from State and Federal programs which result in the purchase of property in fee title through the use of mutual aid agreements, required subvention payments and any other available means determined to be acceptable by the Board of Supervisors."

<u>Goal 2</u> *"Soil, water, mineral, energy, historical and air resources are properly managed."*

<u>Objective 2.A</u>: *"Soil resources are protected from erosion, contamination and other effects that substantially reduce their value."*

- Policy 4 "Flood control alterations to existing waterways which contain important riparian vegetation should avoid significant vegetation impacts and avoid soil loss through sensitive project design and implementation."

<u>Objective 2.B</u>: *"Surface and ground water resources are protected from contamination, evaporation and inefficient use."*

- Policy 5 "Ensure that land uses and development on or near water resources will not impair the quality or productive capacity of these resources."

<u>Objective 2.C</u>: *"Significant mineral resources are recognized and responsibly managed."*

- Policy 14 "Promote the orderly development of mineral resources while preserving local values for recreation, watershed, wildlife habitat, and agricultural uses."
- Policy 15 "Strict control should be maintained on sand and gravel extractions in streambed channels and within areas designated as having sensitive open space resources."

<u>Goal 3</u> *"Open space for recreation, aesthetics and protection from hazards."*

<u>Objective 3.A</u>: *"Recreational lands are available for local and regional needs."*

- Policy 3 "Establish and continue to develop a system of local and regional parks, and other recreation areas throughout the County which balance the relative importance of direct site access with management of sensitive wildlife resources."

<u>Objective 3.B</u>: *"Lands with high aesthetic value are properly managed."*

- Policy 7 "Stream corridors should be maintained in a natural conditions and retain the general character of natural slopes and formations."
- Policy 8 "Regional parks should be used to preserve areas of natural scenic beauty."

<u>Objective 3.C</u>: *"Open space lands are used for public protection purpose."*

- Policy 13 "Agriculture shall be considered a compatible land use in public and private recreation areas which must be protected and buffered."

10.6.1.3.2. Agriculture Chapter

The purpose of this Chapter is to define policies that improve the viability of agricultural operations and promote the conservation of agricultural land.

<u>Goal 1</u> *"The financial viability of the agricultural sector is improved."*

> <u>Objective 1.C</u>: *"Programs are considered which reduce the tax burden on farmland and aid in the conservation of agricultural lands if investigation indicates such programs benefit the general welfare of the County."*

- Policy 5 "Support appropriate efforts by private conservation organizations to utilize conservation easements as a tool for agricultural conservation."

<u>Goal 2</u> *"Productive agricultural lands are conserved."*

> <u>Objective 2.A</u>: *"Agricultural areas are protected from conversion to non-agricultural uses."*

<u>Goal 3</u> *"Land uses which are potentially disruptive to the agricultural economy are properly located and operated."*

> <u>Objective 3.D</u>: *"Non-urban land uses that conflict with agriculture are properly located."*

- Policy 5 "Weigh the economic benefits of surface mining with the preservation of agriculture when considering mineral excavation proposals on land classified for agriculture uses."

<u>Goal 4</u> *"The management of water resources to benefit the agricultural community is improved."*

> <u>Objective 4.B</u>: *"Agricultural and related activities are protected from flooding."*

- Policy 5 "The County will encourage implementation of programs for improved flood protection."

10.6.2. State of California

There are many State environmental laws and regulations that may require some level of compliance or consideration during the planning or implementation of the San Joaquin River restoration effort. This section identifies the three primary State agencies whose jurisdiction affects land use along the San Joaquin River, and thus may effect restoration. They are: State Lands Commission, Department of Fish and Game, and Department of Water Resources Reclamation Board.

The State Lands Commission represents the public's property interests in that portion of the San Joaquin River which was navigable in its natural condition. In 1857, the steamer *Gipsey* navigated the San Joaquin River upriver to within 3 miles of Millerton (Rose 1992), thus the entire study area is considered navigable by the State. While the State Lands Commission claims a property interest in the bed of the San Joaquin River, its specific boundaries throughout the study reaches have not been determined for all reaches. Restoration projects that could physically affect either the footprint of the public's property interest, its mineral assets, or protected Public Trust resources would first have to locate the State Lands boundaries to determine if State lands were affected, and then obtain a Lease from the State Lands Commission.

The purpose of the Department of Fish Game Streambed Alteration Program is to protect the State's fish and wildlife resources and their habitat. Restoration of the San Joaquin River will likely require physical manipulation of existing fish and wildlife habitats. Therefore, the Department of Fish and Game will function as a Trust Agency under the California Environmental Quality Act (CEQA) and as Lead Agency under the Streambed Alteration Program. The Department of Water Resources

Reclamation Board regulates a designated floodway along the San Joaquin River, which it is charged with maintaining. Physical activities within the designated floodway, such as excavation, grading, earth moving, and riparian planting would most likely require an Encroachment Permit from the Reclamation Board.

Other State agencies that may have jurisdiction over a portion of some restoration projects would be:

- Central Valley Regional Water Quality Control Board
- California Department of Transportation
- California Department of Conservation
- State Historic Preservation Office
- San Joaquin Valley Unified Air Pollution Control District

10.6.3. Federal Government

There are also many Federal environmental laws and regulations that may require compliance or consideration during the planning or implementation of the San Joaquin River restoration effort. This section identifies the two primary Federal agencies whose jurisdiction affects land use along the San Joaquin River, and therefore may effect restoration. They are: Army Corps of Engineers (ACOE) and the United States Fish and Wildlife Service (USFWS). The ACOE regulates dredging and fill activities that affect navigable waters such as the San Joaquin River. If restoration activities will expand, fill, or reconstruct the area occupied by bed and banks of the San Joaquin River, the ACOE will have jurisdiction over these phases of restoration. Working in tandem with the ACOE is the USFWS to ensure that fish and wildlife resource and their habitats are not jeopardized by actions authorized by the ACOE. Compliance with the myriad of Federal laws triggered by the involvement of these two agencies may affect the suitability or prioritization of lands to be used or acquired for restoration, as well as the scope and expense of restoration activities.

10.7. OPPORTUNITIES AND CONSTRAINTS

Based on the land use, land ownership, and regulatory compliance, we will discuss opportunities and constraints of potential restoration actions. Opportunities and constraints will strongly influence development of a restoration strategy, and may influence prioritization of restoration action and location. For each of the three factors, a short discussion of the considerations used to develop opportunities and constraints is provided, followed by an initial list of opportunities and constraints. This list is by no means comprehensive; rather it represents our current understanding based on available information on the San Joaquin River, as presented in preceding sections of this chapter, and on our experience derived from similar restoration planning efforts on other tributaries of the San Joaquin River.

10.7.1. Land Use

The existing natural or undeveloped land area upon which to base the San Joaquin River Restoration Plan is extremely small; thus, natural, undeveloped, and developed land area will likely need to expand significantly as the Restoration Plan is implemented. Natural land area has not been topographically altered, nor had significant removal of natural vegetation. Undeveloped land may be include lands that has had some topographic and vegetation changes, but has not undergone extensive changes from agriculture, urban, or other uses. Grazing on lands with natural topography would be considered “undeveloped”. Developed land area has had extensive topographic changes (land leveling, protection by dikes or levees, wetlands drained), and vegetation changes (riparian vegetation removed). Much of the historic San Joaquin River corridor is developed. The need for an expanded land base for future restoration does not necessarily require public land ownership; conservation easements can be purchased from private landowners, and private land ownership and certain land uses can be compatible with the Restoration Plan. As illustrated by the joint use of the Yolo Bypass for agriculture and floodplain/floodway, agricultural land uses are not universally incompatible with restoration efforts.

Land value is based on the “highest and best” uses allowed on that property, not just the current use. In determining the value of agricultural lands, land and crop are separate components. To determine the value of land, we must consider: (1) mineral resource value, if any, underlying the agricultural use, (2) the land’s suitability to a particular crop, (3) whether an annual crop will be harvested before the land or easement is purchased, and, (4) in the case of vineyards and orchards, the age, variety, and condition of the vines or trees, which are assessed separately. Lands used for semi-agricultural and incidental agricultural, such as producing animal commodities, would also be higher value lands, making them less suitable for restoration purposes. Table 10-1 provides approximate crop values, but land values would need to be determined on a site-by-site basis. To determine an accurate value of agricultural lands, the water sources (wells versus riparian versus irrigation district) for the agricultural use should be considered, as well as if land use is restrained, pursuant to Williamson Act contracts. [The Williamson Act encourages farmland preservation by giving a tax break to farmers who agree to keep their property in agriculture for ten years or more. The Act allows counties to assess farmland according to agricultural use rather than the land’s speculative value for urban development; the State reimburses counties for some of the lost property tax revenue. In exchange for lower taxes, agricultural landowners commit their land to farming for ten years.] In assessing the value of acquiring agricultural lands, two additional issues may affect cost: (1) whether the value of water rights can be severed from the underlying value of the land, which could be reduced, and (2) whether purchasing a conservation easement is an alternative to outright purchase of the land.

The use and valuation of land can affect the priority placed on lands in the Restoration Plan. Lands used for public facilities, or for commercial, industrial or residential uses, are not suitable for restoration, due to their high value and other intended uses as per the counties’ General Plans. Agricultural and open space lands are of lower value and lack infrastructure; thus restoration is more compatible land use under existing General Plan policies.

10.7.2. Land Ownership

Based on present-day private land ownership in the study area, land is limited for implementing potential components of the San Joaquin River Restoration Plan (e.g., restoring riparian habitat or floodplains). Therefore, those lands that can serve as a land base for the restoration effort are primary opportunities. These lands include the San Joaquin River Parkway, Fremont Ford State Park, and the San Luis National Wildlife Refuge. Additional land acquisition and/or conservation easements will be required to implement certain components of the Restoration Plan.

One important criterion for land acquisition is a willing seller, which can be an opportunity or constraint depending on landowner willingness. Land ownership was divided into four classes in the study area: (1) lands that are subject to the Public Trust Doctrine, where both ownership and use rights are held publicly, (2) lands that are subject to the Public Trust Doctrine, where the dominant property right is held publicly and the subservient right is held privately but is encumbered by an easement, (3) public lands not subject to the Public Trust, and (4) wholly private lands (also not subject to the Public Trust). Lands subject to the Public Trust Doctrine, and where fee title is also held publicly, should pose greater opportunities for restoration of those lands. Similarly, lands that are held publicly, but are not subject to the Public Trust Doctrine, should also have greater restoration opportunities, unless overriding land use would conflict with restoration activities. Lands that are held privately in fee title, yet encumbered with an easement under the Public Trust, will have more opportunity for restoration than those lands that are completely privately owned. The opportunity to restore private lands that are not subject to the Public Trust Doctrine will be determined by either (1) the willingness of the landowner to sell the land, (2) to sell a conservation easement on the land, or (3) to retain the land but agree to change their land use to be more compatible with the Restoration Plan.

10.7.2.1. Lands Subject to the Public Trust Doctrine

On September 9, 1850, California became a state, acquiring land ownership up to "ordinary high water" of all lands under its tidal or navigable waters. In 1872, California Civil Code 830 was enacted, whereby the State relinquished subservient fee title of its private proprietary rights to land above the "ordinary low water" to adjoining upland property owners on navigable waterways; the State did retain its dominant fee interest in lands beneath the ordinary low water. Land title relinquished in the 1872 act is still encumbered by the public's dominant property rights, as an easement. In 1857, the steamer *Gipsey* navigated the San Joaquin River upriver to within 3 miles of Millerton (Rose 1992). Consequently, as far upstream as Millerton, lands that were formerly inundated by the San Joaquin River at ordinary high water under natural channel conditions are lands that are still subject to the Public Trust Doctrine. The State is still a property owner of those lands that naturally are inundated by ordinary low water, and the State holds a public easement over the use of those lands that were formerly beneath the ordinary high water. Therefore, as affirmed by the Court in 1983 (National Audubon Society v Superior Court, 33 Cal. 3d 419, 1983), all State and local governmental bodies with jurisdiction over the San Joaquin River have a duty when exercising their police powers, to make land use or resource decisions, and to protect the people's common heritage in its waterways, consistent with purposes of the trust (CSLC 1993, Slade 1997). The Public Trust Doctrine will significantly moderate constraints to developing and implementing the Restoration Plan.

10.7.2.2. Public Lands

Public land is owned and operated by local, State, and Federal authorities. Entities holding land in the study area include: Fresno, Madera, and Merced counties; irrigation districts; the Lower San Joaquin River Levee District; flood control districts; the California Department of Fish and Game; the California Department of Parks and Recreation; the California Department of Water Resources, the California Department of Transportation; California State Lands Commission; the San Joaquin River Conservancy; the U.S. Bureau of Reclamation; and the U.S. Fish and Wildlife Service (USFWS). Land owned by public entities has the greatest potential for restoration if restoration does not conflict with the principal use of these lands. The greatest constraints to utilizing public lands for restoration would be determining who assumes responsibility for habitat maintenance, who provides public access, and who assumes liability should damage to private property or injury to the public occur.

10.7.2.3. Private Lands

Private lands are either encumbered or free of an easement under the Public Trust Doctrine. Private lands can be further classified by whether they are owned by a non-profit entity or by private parties. There are numerous non-profit corporations that preserve and restore open space and natural habitats (e.g., The Nature Conservancy), and lands owned by these private non-profit lands are very compatible with restoration of the San Joaquin River. Some possible constraints to utilizing non-profit lands would be funding limitations to non-profit corporations, construction and maintenance of restored lands on private property, and limiting or preventing public access to restored lands.

Private landowners in the study area are presently engaged in agricultural, commercial, industrial, or residential land uses. These landowners may support purchase of fee title or conservation easement for their land for restoration projects, but factors that influence landowner support may include: (1) how much revenue they could generate from the sale of their land or by assuming a conservation easement as opposed to continuing to use their land, (2) potential impact of restoration activities on their adjacent lands, and/or (3) potential impact on their adjacent lands from increased public access to the river. Private lands that are used as open space could be the most desirable lands to acquire or use as they have the fewest physical, economic, and regulatory constraints to restoration. In acquiring private lands, water source, crop potential, zoning, and underlying mineral rights will affect their value.

10.7.3. Regulatory Factors

The ability to use land is restricted by local, State, and Federal regulations. Depending on a particular parcel's site conditions and location, government regulations can restrict or preclude economically viable uses such as residential, commercial, industrial, or agricultural use. Regulations tend to constrain land use to a greater degree in river, riparian, wetland, and floodway areas, thus reduce the value of the land. Regulations are usually in place to protect river, riparian, wetland, and floodway values; therefore, converting these lands to restoration uses is more compatible than converting agricultural or urban land. Regulations protecting river, riparian, wetland, and floodway values represent a restoration opportunity. These regulations also represent a constraint to non-restoration land uses. Lands use can also be constrained by easements, such as the open space, floodway, or conservation easements, and in Williamson Act contracts.

Certain lands may also be designated for specific purposes that restrict their use, such as the Reclamation Board's designated floodway on the San Joaquin River, CALTRANS' right-of-way easement areas, and the lands designated in the San Joaquin River Parkway Master Plan. These lands again present opportunities for restoration, because restoration would be more closely agree with the land use restriction of these easements, and in some cases, may support the original intent of the easement. Lands that are undeveloped but contain habitat that would be protected by regulations (e.g., a potential aggregate mine in a valley oak woodland) would require environmental compliance, preservation areas, and setbacks due to local, State and Federal regulations; therefore, the value of these lands should be estimated accordingly based on these regulations.

10.7.4. Summary

Considering the above factors, the following opportunities and constraints were identified:

10.7.4.1. Opportunities

- The Reach 1 study area contains 9,600 acres that are potentially suitable for acquisition and restoration (8,329 acres of open space and 1,271 acres of annual crops). Of these potentially suitable lands, there are 3,215 acres of Reach 1 that are owned by public agencies and the San Joaquin River Parkway and Conservation Trust. Additionally, the 1992 State Lands Commission boundary study indicated that 442 acres are encumbered by the Pubic Trust Doctrine (211 acres of fee title, 231 of public trust easement). Reach 1 provides an excellent opportunity for additional restoration due to (1) the creation and support of the San Joaquin River Parkway Master Plan, (2) the establishment of the San Joaquin River Conservancy, and (3) the ongoing efforts of the San Joaquin River Parkway and Conservation Trust. The San

Joaquin River Parkway Master Plan has been incorporated into the General Plan for Madera County. The Master Plan area is currently 2,603 acres, and is proposed to encompass an area of 5,900 acres.

- Fresno County and Madera County are committed to working with many agencies and groups (including the San Joaquin River Parkway and Conservation Trust, the San Joaquin River Conservancy, the City of Fresno, and other interested agencies and organizations) to implement the San Joaquin River Parkway Master Plan. The counties' commitment is a significant opportunity for restoration and preservation in Reach 1 of the San Joaquin River. The existing parkway provides a land base upon which low-lying lands can be acquired to expand the park upstream and downstream, creating a river corridor parkway of regional significance along the San Joaquin River.
- A historical park along the San Joaquin River, near Firebaugh in Reach 3, has been proposed by the City of Firebaugh. There have also been recent efforts to increase public access and create trails along the San Joaquin River between Firebaugh and Mendota. This local support for these projects provides a significant opportunity to improve river conditions in Reach 3, which has the least amount of public land on the entire river.
- The General Plans for Fresno and Madera counties have goals and policies to protect the San Joaquin River environment (Reaches 1, 2, 3, and part of 4A) from development, and where appropriate, to acquire lands or public easements for flood protection, wildlife preservation, recreation, and open space that cannot be protected by other regulations. These goals and policies are opportunities for restoration.
- Conservation easements present a tremendous opportunity for mutually beneficial partnerships between riverside landowners and restoration proponents. Conservation easements can be quite flexible, maintaining private ownership while retaining many landowner uses and rights, thus enabling restoration and preservation. Additionally, conservation easements can facilitate enlarging floodway capacity and storage, thus reducing potential flood risks to downstream landowners. Conservation easements also maintain land under private ownership and on the tax rolls.
- Conservation easements and/or land purchases, combined with floodway expansion, can reduce flood impacts and levee failures in downstream reaches. Additionally, expanding the floodway offsets conveyance capacity that may occur from increased riparian vegetation in the floodway. Those lands that are marginal farmlands (due to frequent flooding or poor soil quality) are less valuable, thus are purchase or easement opportunities because landowners are often more amenable to sale or conservation easement, and the loss of agricultural production is smaller.
- In Reach 1, abandoned aggregate mines provide an opportunity for purchasing low cost lands and wetlands adjacent to the river, because most of the mined land's commercial value has been removed. While inexpensive to purchase, reclamation of mined areas is costly, and usually requires large volumes of aggregate to be imported to properly restore the property. However, existing wetlands can be improved, floodways and floodplains can be restored, and riparian areas can be expanded. These restoration efforts would also provide a buffer between the river corridor and residential areas on the uplands, and the still active aggregate mines.
- With a few exceptions, urban encroachment into the floodway has not occurred because large flood events continue to occur periodically, and development is often constrained or prohibited in the FEMA-designated 100-year floodplain and in the Reclamation Board

Designated Floodway. Therefore, improving flood control release capacity through the San Joaquin River would not require the expensive constraint of moving urban infrastructure out of the floodway.

- Open space and annual crop land uses provide opportunities for riparian restoration or floodway expansion due to their lower fee title and/or conservation easement costs; restoring areas with these land uses would also minimize impacts on regional agricultural production. Opportunities for riparian restoration by reach are shown in Table 10-13.

Table 10-13. Land available for riparian restoration, based on its land use.

Reach	**Total Acreage**	**Open Space Acreage**	**Annual Crops Acreage**
1	9,600	8,329	1,271
2	6,497	2,879	3,618
3	7,505	1,882	5,622
4	55,351	27,202	28,287
5	22,351	14,895	7,456

- Reaches 4B and 5 contain large tracts of land that are part of the San Luis National Wildlife Refuge and the Fremont Ford State Park, including 16,518 acres owned by the USFWS and the State of California; these lands provide a significant opportunity for a land base for restoration on the lower San Joaquin River. This land base provides the opportunity for expansion of seasonally flooded wetland and riparian habitat in Reaches 4B and 5.
- Identification and remediation of land uses along the San Joaquin River corridor that contribute to poor water quality should be prioritized in the Restoration Plan, because multiple benefits can be achieved (e.g., improved water quality, improved floodway capacity, improved riparian habitat). Lands in this category have not been identified in this Background Report; given time constraints, they may be difficult to incorporate within the initial phases of the Restoration Plan.
- Rapid population growth may be considered an opportunity for additional parkway expansion in the greater Fresno urban area, and in downstream communities (Mendota, Firebaugh). Additional parkway lands will be important for meeting the future recreational use demand of these rapidly growing, surrounding areas.
- Exercising the State Lands Commission sovereign land claim to Reaches 1B through Reach 5, via an extended boundary study, would increase the land base for restoration in downstream reaches. To our knowledge, the State Lands Commission has not indicated any intention of continuing this study downstream.

10.7.4.2. Constraints

- Based on land use and land ownership, the most formidable constraint to restoration on the San Joaquin River is the limited land base for the river corridor. Agricultural land use and ownership ranges from 35% to 99.6% percent for the five reaches of the study area. Because the restoration program does not own the land needed to restore the San Joaquin River, substantial areas of land will likely need to be acquired (either by fee title or by conservation easement from willing sellers) to implement the Restoration Plan.

- Agricultural production is another important constraint that the restoration program will need to resolve during implementation. Adjoining counties generally do not support land acquisition and/or conversion that result in a decrease in tax revenue. Additionally, conversion of agricultural land to riparian or floodway habitat potentially conflicts with Fresno, Madera and Merced counties' General Plans. These General Plans require that counties maintain agriculturally designated areas for agriculture use, and to protect those lands from encroachment of incompatible land uses. Restoration of the San Joaquin River could be regarded as an incompatible land use. In addition to county regulations, the Farm Bureau, stakeholder groups, and a large portion of the general public generally and vigorously oppose conversion of agricultural lands.
- While the Fresno, Madera, and Merced counties' General Plans contain policies to protect riparian habitat and wetlands, inconsistencies within the General Plans are numerous (e.g., agriculture within the riparian zone, etc). These inconsistencies will need to be resolved, perhaps by having all three counties incorporate the San Joaquin River Parkway into their general plans.
- Certain agricultural lands in the study area may not be available to restoration because their continued use as agricultural land may be dictated by agricultural preservation programs, including land trusts, conservation easements, Williamson Act contracts, Farmland Security Act contracts, and the California Farmland Conservancy Program Fund.
- In Reach 1 of the San Joaquin River floodway, aggregate mining is often incompatible with restoration efforts, and thus aggregate mining will likely represent a constraint to future restoration efforts. To protect the future availability of mineral resources and to prevent activities that would preclude future extraction of those resources, the Fresno, Madera and Merced counties' General Plans do not allow land uses that are incompatible with mineral resource recovery. Restoration of the San Joaquin River could be regarded as an incompatible land use because the aggregate resources protected by restoration efforts would not be available for future extraction. Additionally, the mineral resource lands in the study area may not be available for restoration purposes (e.g., gravel pit filling) because their continued availability for mineral extraction may be dictated by regionally significant mineral resource designations.
- Increased high flow releases for restoration purposes may cause downstream property damage. Owners and operators of upstream dams are typically not liable for property damage during flood control releases (act of God); however, liability may be a concern during intentional high flow releases for habitat restoration purposes.
- Increased riparian vegetation in the floodway may reduce flood conveyance capacity in the San Joaquin River flood control system. Fresno, Madera, and Merced counties require that all development within areas subject to 100-year floods be designed and constructed in a manner that will not cause floodwaters to be diverted onto adjacent property, or that will increase flood hazards to other areas. Restoration projects may sometimes conflict with this requirement, particularly if the project's goals are to encourage floodplain inundation, sediment transport, and/or channel migration. These conflicts are constraints that will need to be resolved to implement the Restoration Plan.
- Restoration projects and increased public access to the river increase potential conflicts with private land ownership. While many aspects of increased public access to the river corridor are positive, constraints are inherent as well. Littering, camping, and vandalism are common impacts on private lands adjoining public lands; minimizing these adverse impacts to adjacent private landowners typically requires increased law enforcement.

- If existing land uses adversely affect listed species or their habitats, restoring the Federally listed species (spring-run Chinook salmon, winter-run steelhead trout) may restrict land uses designated as critical habitat for these species. Areas under potentially restricted land uses also present a constraint to restoration.
- In Reach 1, aggregate mining activities are often incompatible with restoration efforts along the river. Older, in-river mining pits have not been reclaimed, and recent mining pits have been reclaimed with water depths that are too deep to be of much ecological value. Additionally, “off-channel” mining pits are often breached or captured by the river during large flood control releases. If existing Conditional Use Permits and Reclamation Plans for aggregate mining allow these deep pits in the future, the problems resulting from pit breaching, predators, and water hyacinth will continue to constrain restoration efforts on this reach of the San Joaquin River.
- While the land base for potential restoration is substantial, in Reaches 4 and 5, project levees isolate the USFWS’ refuges (historic flood basin areas) from the river. Therefore, the project levees also act as restoration constraints. Restoration goals, such as improving floodplain inundation and increasing flood residence time, may be incompatible with certain aspects of refuge management.
- The area’s rapid population growth may be considered a constraint, because additional people will cause additional stress on river resources (e.g., commercial-grade aggregate) and on river recreational opportunities. More people will likely result in higher user impacts on parkway lands, as well as secondary impacts to both private and public lands. Rapid population growth will also increase the competition for land, increasing land values and potentially making restoration more costly.

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CHAPTER 11. SOCIAL AND CULTURAL FACTORS

11.1. INTRODUCTION

The San Joaquin River has always shaped the social and cultural structure of human settlements in its valley, because the river provides the means for sustaining human populations. Water, abundant fish and game, fertile soils on floodplains and terraces, useful vegetation, and transportation were utilized by the Native American and early Euro-American settlers. Beginning in the late 1800s, floodplains and uplands were converted to agriculture, and water supply was correspondingly developed, transforming the San Joaquin Valley to a primarily agricultural-based society. Since the 1940s, the Central Valley has urbanized rapidly, and the San Joaquin River is a microcosm of the changes that have occurred in the Central Valley as a whole. The population of the Central Valley is presently over 5 million people, and is projected to triple by 2040 (USGS 1999). The City of Fresno is now the largest city in the Central Valley, and also has the fastest growing population (Figure 11-1). This urban growth has changed the social and cultural framework of the San Joaquin Valley; agricultural lands in the gravel-bedded reach near Fresno are giving way to aggregate mining in the river corridor and to urban expansion in the upland areas, which reduces the agricultural base and increases the urban base. In 1999, the United States Geologic Survey reported that the American Farmland Trust, a national organization that focuses on farmland preservation, has projected a loss of more than one million acres of Central Valley farmland by the year 2040 if current land use conversions continue (USGS 1999).

How people view the river from a social and cultural perspective will influence future restoration activity on the river. For example, Native Americans had not only a subsistence connection to the river, but a spiritual connection as well. Religious and/or ceremonial activities associated with the river, the fish, and the animals of a Tribes' territory were common. The transformation from Native American to Euro-American settlement caused drastic changes in the social and cultural structure in the San Joaquin Valley. Of all the rivers in California, the San Joaquin River is among those that have experienced the most environmental damage as its uses changed from a subsistence resource to a utilization resource (Rose 1992). The economics and politics surrounding this change in resource utilization have prevented meaningful restoration to the river over the past 60 years. There is an increasing awareness of the management impacts to the river (e.g., poor water quality, dewatering of reaches 2 & 4, and flood management) and benefits of river restoration and preservation (e.g., increased recreational opportunities, improved water quality) provides social and political opportunities for restoring the river. These social and cultural factors, as well as the potential opportunities and constraints they provide/impose, will be discussed in this chapter.

11.2. STUDY AREA

Water from the San Joaquin River is used from as far south as the edge of the Tejon Hills, Tehachapi, and San Emidio Mountains 30 miles southeast of Bakersfield, north to the Sacramento-San Joaquin Delta, and from the foothills of the Sierra Nevada to the foothills of the Coast Range. However, social and cultural issues for restoring the San Joaquin River extend far beyond the San Joaquin Valley. The social and cultural issues influencing restoration efforts on the San Joaquin River extend beyond the normal study area boundary adopted in other chapters of the Background Report. Consequently, the study area boundary for local land use issues in this chapter is the entire San Joaquin Valley, and the study area for political restoration issues is the entire State of California.

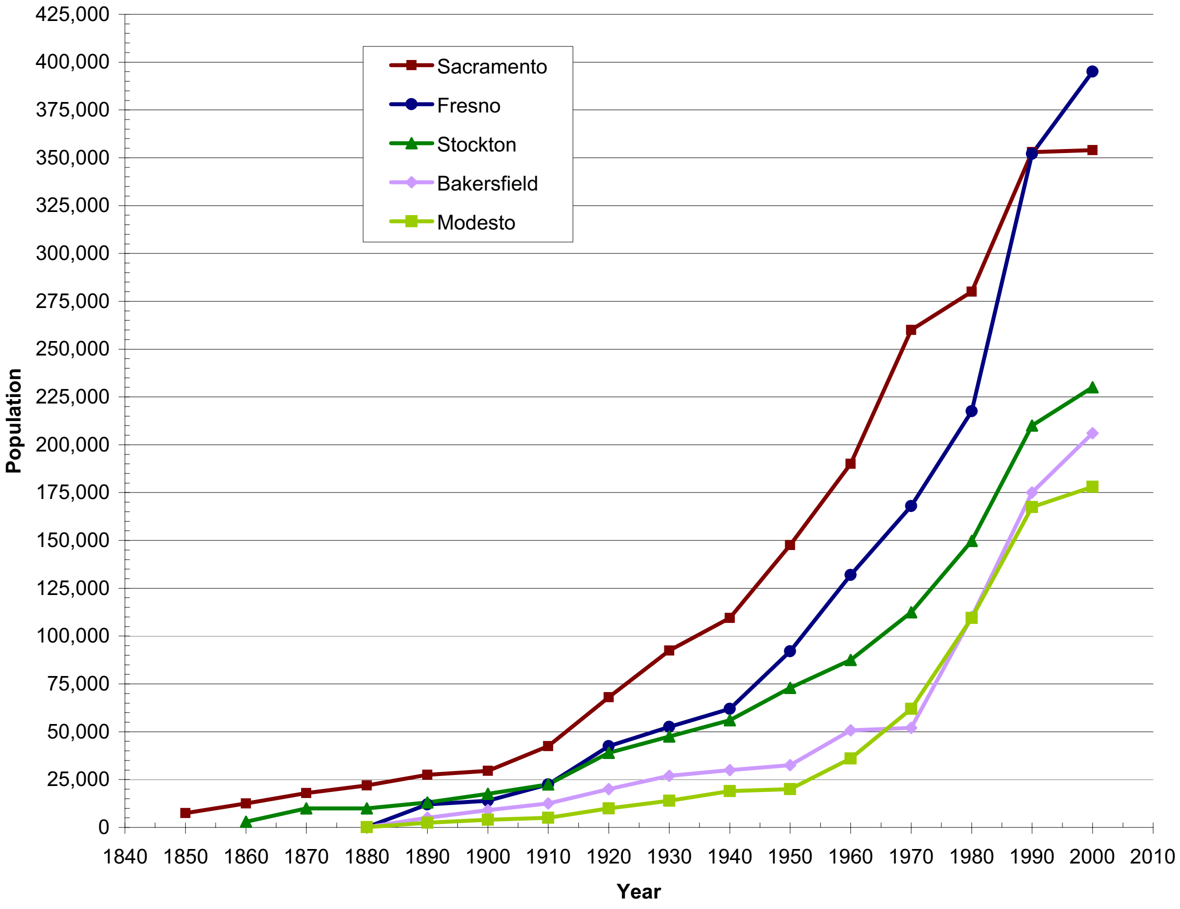

Figure 11-1. Population trends in major Central Valley cities (from USGS 1999)

11.3. OBJECTIVES

The objectives of this chapter are to discuss the general public's social and cultural perceptions that may either constrain or provide opportunities for rehabilitation of the San Joaquin River from Friant Dam to the Merced River.

11.4. SOCIAL AND CULTURAL ISSUES

People's social and cultural perspectives of the San Joaquin River can profoundly affect the river's natural environment. When Euro-American settlement increased the river's agricultural uses, droughts and floods became a larger influence in economic decisions. Now, although the San Joaquin River is an integral source of water to a highly controlled and manipulated water delivery system (primarily by the Friant Unit of the Central Valley Project), little remains of its natural riverine processes or environment below Friant Dam. This transformation in riverine processes and environment is a direct result of the dominant western political forces of the early 20th century, which engineered California's rivers into one of the largest water development and delivery systems ever created. While there was considerable social, political, and economic support in constructing the Friant Unit of the CVP, the environmentally destructive transformation of the San Joaquin River did not occur without opposition by the Department of Fish & Game, commercial fishing industry, riparian farmers below Friant Dam, and others.

A brief discussion of the dominant social and cultural issues that may influence future opportunities and constraints for restoring the San Joaquin River is provided below.

11.4.1. Subsistence

Prior to the arrival of Spaniards in the late 1700s and until the rapid immigration of American settlers in the 1850s, Native Americans subsisted on the San Joaquin River ecosystem. This direct connection between the river corridor and human survival mandated close social and cultural ties to the river. The river was lightly managed, such as harvesting of willows and grasses for baskets, harvesting of tules for boats, setting fire to oak woodlands and grasslands to promote the following year's seed crop, and other management activities. Primary food sources included acorns, salmon, waterfowl, tule roots, and possibly antelope, deer, and elk (Wallace 1978). Additional summary information on Native American use on the San Joaquin River can be found in Chapter 10; more details can be found in Wallace (1978) and Kroeber (1925). Early trappers and gold miners also depended on the San Joaquin River for subsistence, particularly for salmon, antelope, and elk. The small population of Native Americans on the San Joaquin River corridor (up to 31,000 persons as reported by Wallace 1978) resulted in small impacts to the natural environment; early trappers did not appreciably add to the human population or its resource utilization along the river.

However, large-scale immigration after 1848 transformed the cultural and social role of the San Joaquin River. Rather than an individual's dependence on the river for subsistence, larger scale grazing and crops began the transformation to subsistence for a larger community. Initially, this larger community was the gold miners in the Sierra Nevada foothills, but it has now expanded globally, with products grown in the San Joaquin Valley distributed worldwide. This regional and global expansion allows people to disassociate food from its source (the San Joaquin Valley). Farmers within the Friant Division of the CVP are still primarily small family farms; whereas larger corporate farms are becoming more dominate on the west side of the valley. This transition from small family farms to larger corporate farms has also likely caused social and cultural changes to communities along the river (e.g., less concern over land stewardship and more concern on economics). In summary, people's connectivity to the San Joaquin River has decreased over time because of the real and perceived distance between subsistence commodities directly obtained from the river corridor (e.g., fish) and commodities produced indirectly from the river (e.g., crops irrigated with water coming from a canal rather than from the river).

11.4.2. Transportation

The Native Americans concentrated their communities along the San Joaquin River, primarily along the east side of the San Joaquin Valley because favorable water and game conditions were found there. There are numerous accounts of the Native Americans using tule boats for transportation and fishing on the river and flood basins. Following the arrival of Americans in the mid-1850s, and continuing until the railroad boom of the 1870s and 1880s, the river was again used as a major transportation route in the San Joaquin Valley. Steamships made regular runs up the river, sometimes as far as Herndon, carrying manufactured goods to upriver communities, and carrying grain and livestock downstream (Brotherton 1982, Rose 1992). This early transportation dependence caused many riverside landings and communities to form along the river (Grays Landing, Firebaugh), such that the river was an important social, cultural, and economic component of these communities. The construction of the San Joaquin and Kings Canal in 1871, and the arrival of the railroad in 1872 allowed easier transportation and commodity shipping than from the San Joaquin River (Rose 1992). River-based transportation declined after the coming of the railroads, and river transportation of any significance ended in the early 20th century (Brotherton, 1982). The development of refrigerated rail cars allowed produce produced in the San Joaquin Valley to be shipped anywhere in the country, increasing the markets available for San Joaquin Valley agriculture. The railroad spawned new towns away from the river, including Modesto, Merced, Fresno, and others. Later, in the 1960s, construction of the interstate freeway system reinforced these new and rapidly growing population centers. These towns experienced rapid growth (Figure 11-1), while riverside communities either did not grow, or declined in size. This transformation in community base added to the decrease in cultural and social valuing of the river, similar to the de-valuation of subsistence discussed above.

11.4.3. Resource utilization

Initial resource utilization by Native Americans was primarily at a subsistence level, although the Yokuts likely traded local commodities (salmon and other foods and materials) with other tribes (Wallace 1978). Muir (1917) described trade between tribes on both sides of the Sierra Nevada, where salmon and other commodities of the Central Valley were traded for obsidian obtained from the east side of the Sierra Nevada.

The next phase of resource utilization came from the beaver trappers. Jedidiah Smith was reportedly the first American to explore the San Joaquin Valley in 1826-1827, and the beaver trade flourished until the mid-1840s (Brotherton 1982, Mackie 1997). American immigrants began trickling into the San Joaquin Valley in the mid 1840s, but the beginning of the Gold Rush in 1848 opened the floodgates to large-scale immigration, and causing corresponding increases in resource utilization (Rawls and Orsi 1999). Cattle ranching and seasonal grain crops dominated in the 1850s and 1860s. The introduction of irrigation to the San Joaquin Valley by Miller and Lux, and a host of others, transformed how the San Joaquin Valley was used. Seasonal grains were replaced with a wide variety of irrigated produce. The spatial extent of agriculture enlarged laterally away from the river as the canal distribution system grew, and additional storage and distribution systems were developed (e.g., Mendota Dam, Friant Dam) (CSDE 1942, Fox 1987, Rose 1992). Construction of Friant Dam, the Friant-Kern Canal, and the Friant-Madera Canal between 1942 and 1948, and the Delta-Mendota Canal between 1946 and 1951, represented the largest component of water storage and distribution along the San Joaquin River. This extensive distribution system allowed agricultural expansion laterally away from the river and south of the San Joaquin River, further distancing the agricultural community from the river (CSDE 1992).

Gold mining in the mid to late 1800s was fairly minor in the San Joaquin River watershed, as it is on the southern extent of the mother lode (Rawls and Orsi 1999). Some gold mining occurred in tributaries upstream of Friant (e.g., Finegold Creek), but large-scale hydraulic and dredge mining does not seem to have occurred on the lower river. Examination of 1937 aerial photographs downstream of Friant shows no evidence of dredge tailings. The small gold mining communities upstream of Friant were located along the river, with the primary social and cultural connection to the river being the gold that they were in search of, as well as water supply for domestic purposes and mining. Logging in the upper watershed expanded as the foothill and valley towns sprang up with the onset of the gold rush, but the impacts from logging in the upper watershed is considered negligible compared to other direct impacts to the San Joaquin River corridor.

Later development of railroads, highways, Friant Dam, Fresno, and other communities led to growing aggregate demands to support this growing infrastructure. For example, the W.H. Hall surveys document a gravel pit upstream of the Southern Pacific Railroad Bridge in 1872 (Hall 1878 as cited in Cain 1997). The 1937 aerial photographs show gravel mining in the Friant area; gravel mining in Reach 1 of the San Joaquin River has increased dramatically in response to additional roadbuilding in the 1960s, and the continued rapid growth of the Fresno urban area. Gravel mining across all time spans has been a resource extraction commodity, and has encouraged little or no social or cultural connection with the river other than via economic activities. The cost of providing aggregate is largely controlled by transportation expense from source to market. Most urban areas in the Central Valley are located adjacent to a river (e.g., Fresno), and simple economics will dictate that those sources of rock nearest to the market are utilized first, moving farther away from the market only as the nearer aggregate sources are exhausted or access is restricted by urban growth or land use restrictions.

11.4.4. Flood Management

Early American inhabitants along the San Joaquin River were very aware of annual flooding, particularly after the devastating flood in the winter of 1861-1862 (Rose 1992). The need to reduce flooding initiated several surveys and studies in the late 1800s. Storage reservoirs, dikes, and levees began to provide flood protection, with the largest component provided by the completion of Friant Dam (and the associated canals) in 1948. Flood management is a very important social service provided by upstream dams, protecting homes, bridges, property, and other important infrastructure built along the river. However, structural flood control gives people a false sense of security that they are “protected” from large floods and thus stimulates development within the historic flood plain supposedly protected by upstream dams and/or levees. Floods on the Mississippi River in 1993 and in the Central Valley in 1997 have shown that extensive damage can occur behind levees when the levees fail. The risk of levee failure is real; however, the perception of protection encourages development behind the levees, such that the losses when the levees fail are greater than what would have occurred without the levees because of the increased development behind the levees.

From a societal perspective, the flood management system is intended to reduce risk and concern from flooding. Efforts began in the late 1800’s to initiate efforts to reduce flood induced damages, and these efforts continue today. The construction of the San Joaquin Flood Control Project in the 1960’s, combined with the construction of Friant Dam in the 1940’s, are the most significant components of the flood control effort along the San Joaquin River. Despite the large sums of money spent on dams, bypasses, and levees, flooding on the San Joaquin River still occurs (e.g., 1986, 1995, 1997, and 1998). These floods and others in the 1990’s have raised serious questions about whether these traditional flood management projects are worth the costs, and whether society and taxpayers are realizing the anticipated benefits from these projects. Real or perceived reduction in flood management protection will cause a negative impact to those people who own or depend on those structures or properties. However, as shown many times since completion of Friant Dam (punctuated during the 1997 flood), flooding of low lying areas still occurs, with flood protection typically provided for a 50-yr flood recurrence interval. There has been an evolution from local, haphazard flood control to more regional public efforts, such as the ACOE Comprehensive Study, and the Floodplain Management Task Force. One of the primary purposes of the Comprehensive Study is to develop large scale, integrated improvements in the flood control project, and to do so in a way that improves ecological values within the flood control system. The goal of the Floodplain Management Task Force is to develop recommendations to better manage floods and the land uses within the floodplain. These efforts reinforce the fact that flooding is a significant societal issue for the public and stakeholders within the study area.

11.4.5. Population Growth

As shown on Figure 11-1, urban growth of cities along the Highway 99 corridor is rapidly expanding. For example, the population of Fresno County increased from 529,000 to 799,000 from 1981 to 2000 (US Census Bureau 2000). The demographics of valley communities continue to change as well; both Hispanic and non-Hispanic populations are increasing, with the exception of Merced County where the non-Hispanic population is decreasing slightly (Table 11-1).

Table 11-1. Demographics of Fresno, Madera, and Merced counties, which surround the San Joaquin River study area, change is for the period from 1990 to 2000 (Source: US Census Bureau data, 1999-2000).

County	Total population	Non-Hispanic population	Hispanic population	Percent Hispanic
Fresno – 1990	667,490	431,436	236,034	35.4 %
Fresno – 2000	799,407	447,771	351,636	44.0 %
Numerical Change	+131,917	+16,315	+115,602	
Percent Change	+19.7 %	+3.8 %	+49.0 %	
Madera – 1990	88,090	57,690	30,400	34.5 %
Madera – 2000	123,109	68,534	54,575	44.3 %
Numerical Change	+35,019	+10,844	+24,175	
Percent Change	+39.8 %	+18.8 %	+79.5 %	
Merced – 1990	178,403	120,296	58,107	32.6 %
Merced - 2000	210,500	115,034	95,466	45.4 %
Numerical Change	+32,097	-5,262	+37,359	
Percent Change	+18.0 %	-4.4 %	+64.3 %	

The most notable trend is the very sharp increase in the Hispanic population, as high as 79% for Madera County. The population increase in the State of California follows the trends of the three counties surrounding the San Joaquin River study area, but is not as steep. The corresponding annual population in California increased from 29,760,021 in 1990 to 33,871,648 in 2000, a 13.8 percent increase. The impacts to future restoration opportunities and constraints of this rapid demographic change and population growth in the Central Valley are somewhat unclear, thus subject to some speculation. By sheer numbers, the population growth is going to place more pressure on gravel resources; until alternative gravel sources are developed, gravel will be mined from the San Joaquin River as more homes, businesses, and roadways are constructed to accommodate this increasing population. However, the increasingly urban populations may tend to support restoration and preservation along the river to preserve and increase recreational opportunities. The formation of the highly popular American River Parkway (Sacramento) led to others, including San Joaquin River Parkway (Fresno) and Tuolumne River Regional Park (Modesto). These river parkways through urban centers are popular and well utilized by the public, and this urban parkway effort is gaining momentum to expand. Additionally, the growing Hispanic community appears to utilize these parklands extensively, such that overall use of river parklands will likely grow as urban populations increase and parkland acquisition increases.

The population increase in the State of California, as well as the potentially increasing public awareness of the ecological and recreational value of river bottomlands, has increased funding and restoration efforts on Central Valley rivers. Proposition 204 (1996), the CVPIA (1992), Proposition 50 (2002), Farm Bills, and other recently passed bond acts have drastically increased the funding for conservation easements, land preservation, and restoration.

11.4.6. Recreation

As mentioned in the previous section, the increasing population of the State and the three counties surrounding the San Joaquin River study reach has increased the recreational use of the San Joaquin River. Most recreation is focused in Reach 1 and Reach 3, particularly in the San Joaquin River Parkway lands (e.g., Lost Lake Park), and at other county and regional parks. Use of the San Joaquin

River Parkway is heaviest in the summer months, focusing on canoeing, picnicking, hiking, canoeing, jogging, bicycling, fishing, camping, bird watching, and other social activities. Typical yearly use on the Parkway varies with activity. Each year, approximately 13,000 children participate in outdoor education programs, and there are approximately 700 canoe tours. On one trail alone (Eaton Trail) there were 166,000 visits by 1,600 visitors in the previous year (Houser 2002). Approximately 91% of the visitors to the Parkway are from Fresno County, 5% from Madera County, and 4% from outside these two counties. The Parkway estimated that the economic value of recreational use of the Parkway is between $4.2 million and $7 million annually. The primary activities in the Parkway in order of use are fishing, biking, hiking, and jogging (Figure 11-2) (Houser 2002).

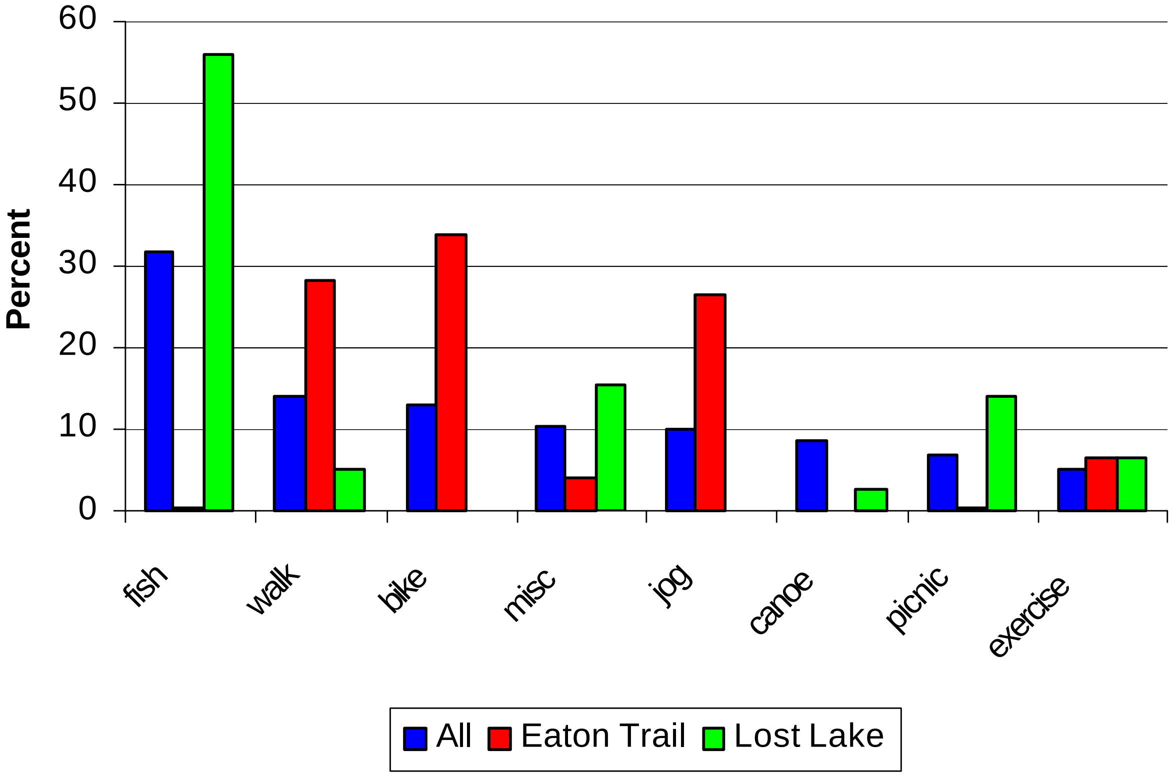

Figure 11-2. Histogram of primary recreation activities within the San Joaquin River Parkway in 2001.

A section of trail along the San Joaquin River has already been completed in Firebaugh, along with riparian vegetation plantings in the parkway. Restoring perennial flow through all reaches of the San Joaquin River, if the American River Parkway is any example should greatly increase the recreational opportunities of all reaches (over 5 million visitors per year as reported on the http://www.sacparks.net/Parks/arp.htm website). These recreational opportunities do not necessarily come without impacts to the river. Increased public use often results in damage to streambanks and vegetation, excessive littering, illegal and prolonged camping, sanitation problems, and vandalism to both public and private property.

Restoring perennial flow through all reaches will also greatly increase fishing-based recreation, primarily resident and exotic warm water species on the short-term, and perhaps eventually adult salmon in the longer term. Recent increases in salmon populations on tributaries to the San Joaquin

River have resulted in reestablishing a sport fishery for Chinook salmon on the lower portions of the Merced River and Tuolumne River (DFG 2002). Furthermore, increasing migratory fish populations (e.g., salmonids, striped bass, sturgeon) will increase recreational fishing outside of the San Joaquin River study area. Sport fishing has been shown to provide a large financial benefit to local communities from spending on food, gas, and lodging. For example, Meyer Resources Inc (1988), as cited in Lufkin (1991), valued the Chinook salmon sport fishery in the Sacramento and San Joaquin rivers as providing net revenues to the local economy at nearly $22.00 per fish, and the total commercial Chinook fishery value at nearly $47.00 per fish. The total economic valuation of a fishery depends on the factors considered, and can be partially subjective; therefore, there is a wide range of fish “values” assigned by studies in the western United States.

11.4.7. Restoration, Preservation, and Public Health

The social and cultural issues surrounding restoration efforts on Central Valley rivers are a mixture of real and perceived issues. A common perception is that restoration and economic development cannot coexist. However, recent restoration efforts funded by CALFED, NRCS, AFRP and other funding sources have shown that restoration efforts can coexist with, and even mutually benefit, land uses that have historically been assumed to be incompatible with restoration. For example, the growing awareness of the true flood risk to low lying agricultural and urban lands (e.g., 1997 flood) has allowed many conservation easement programs to develop mutually beneficial solutions to these low lying areas. Conservation easements can compensate the landowner for a large portion of the fee-title value of the land, allow many of the historical uses to continue, retain riparian water rights, and revegetate portions of the land to native riparian vegetation. Depending on the landowner, fee title purchases can be a preferable alternative. Regardless, voluntary programs of conservation easements, mineral rights purchases, and/or fee title purchases to willing sellers have been very successful on several Central Valley rivers. These cooperative efforts are beginning to break down the misperceptions that restoration and preservation efforts are universally conflicting with agricultural production. Future restoration and preservation efforts will benefit as this realization spreads to the San Joaquin River. Recent efforts by the San Joaquin River Parkway provide a good example of this changing perception (Fresno Bee 1999).

Restoration and preservation efforts often have economic benefits to local communities. Restoration and/or preservation of river bottomlands often increase the value of surrounding private lands, particularly in urban areas where existing or future home sites are or would be located. Restoration efforts also improve the aesthetic value of river bottomlands, which again increase surrounding land values and increase river usage by the public. Lastly, restoration activities can provide significant economic benefits to the local economy. Ongoing restoration activities on the Tuolumne River has provided tens of millions of dollars to the local economy as construction contractors, revegetation contractors, aggregate companies, and local landowners are funded to implement the projects.

11.5. HISTORICAL TO CONTEMPORARY PERSPECTIVE

The general public’s social and cultural perspectives towards the San Joaquin River closely follow land use patterns through time. For that reason, describing the historical social and cultural perspectives is best done using a timeline of general land use trends. These social and cultural perspectives continuously evolve as the needs and population of the San Joaquin Valley change over time. This historical review of social and cultural perspectives is valuable to assess how current social and cultural issues are a product of changes in earlier perspectives.

11.5.0.1. Prior to 1832: Native American Period

The Yokut people lived in the San Joaquin Valley harvesting the bounty from its interlinked grassland, tule-flood basins, riparian, and aquatic environments. At the time of first contact with European culture, it is estimated that over 31,000 Native Americans lived in the San Joaquin Valley (Wallace 1978). Social and cultural life in the San Joaquin Valley was centered on the San Joaquin River and its associated lake, flood basin, and slough ecosystems, which supported one the highest densities of native people in California. During this period, the first European descendants entered the San Joaquin River valley, introducing exotic animals, plants, and diseases that would forever change the valley and its original peoples (Gutierrez and Orsi 1998).

11.5.0.2. 1832 to 1848: Trappers and Mexican Land Grants

French Canadians from the Hudson Bay Company established a base at French Camp near Stockton; from there they lived and trapped beaver (Mackie 1997). Just about the time that the beaver and the trappers were gone, the Mexican government granted its first of several vast land holdings to private citizens (Perez 1996). When gold was discovered, the Mexican Rancheros' had built up vast herds of cattle for the tallow and hide trade. Cattle were allowed to graze in the natural grasslands and riparian habitats of the San Joaquin Valley. The social or cultural perspectives at this time were centered on extracting natural resources from environments of the San Joaquin River for financial gain of the few people who owned the Ranchos, and there was little inclination to permanently settle and develop the land (Gutierrez and Orsi 1998).

11.5.0.3. 1848 to 1870: Gold Rush and Dry Land Farming

Starting with the discovery of gold, the population within the San Joaquin Valley increased dramatically, with hordes of people seeking quick riches in the streams leaving the Sierra Nevada foothills. It was during this period that agriculture had its beginnings. Initially, agriculture was limited to the basic needs of feeding the miners, cattle grazing and dry land farming along the San Joaquin River and its tributaries (Rawls and Orsi 1999). This was a period when vast land holdings dominated the San Joaquin Valley, starting with the Mexican land grants and ending with the vast swamp and overflowed landholdings acquired by the Miller & Lux partnership. Steamers plying the river and its tributaries stopped at farmers' landings, and many river towns sprang up along the rivers to ship products to San Francisco. Steamships were the primary means of commercial transportation at this time. The San Joaquin River and its natural environments were important from a social or cultural perspective during this time (Rose 1992). Landowners who ran livestock in the riparian forests and tule marshes began reclaiming riparian forests and tule marshes for agriculture, and began diverting water from the river to irrigate crops. Their dependence on the river and rainfall for crops caused a fairly close connection to the river, and they prospered based on the frequency and duration of floods and droughts in the San Joaquin Valley.

11.5.0.4. 1871 to 1951: Railroads, Irrigation, and Agricultural Expansion

Agriculture dependence on river flows, and the corresponding risk of droughts, led to efforts to increase the amount, distribution, and reliability of water supplies. In many areas, artesian springs, artesian wells, and groundwater pumping began in the 1870s, initiating the groundwater overdraft problems that exist today (see Chapter 5 for more detail). The need for more reliable water supplies led to the construction of Mendota Dam and San Joaquin and Kings River Canal by the Miller & Lux partnership in the 1870s (CSDE 1942, Rose 1992). About the same time, rapid railroad expansion provided alternative commercial shipping routes, such that steamship commerce ended by the early

1900s. The Mendota Dam and associated canals expanded agriculture in Reaches 3 and 4; yet, upstream reaches and potential agricultural lands farther away from the channel still did not have reliable water supplies. During the Great Depression, development of the Central Valley Project began, resulting in water being delivered to farmers on the east side of the San Joaquin River through the Friant-Madera Canal and the Friant-Kern Canal; the Delta-Mendota Canal delivered water to west side farmers (CSDE 1942, Rose 1992).

Beginning with the construction of Mendota Dam in 1871, the diversion of the river into canals, and the arrival of the railroad marked the end of an era when the San Joaquin River was the focal point of life in the San Joaquin Valley. The steamers began to disappear, as did many of the river towns and landings, and agriculture was no longer limited to lands served by riparian water rights. This period saw a tremendous expansion in the network of dams, canals, levees, railroads and highways that serve the San Joaquin Valley. Although the rivers were still sources of water, they ceased to be the focal points for society and culture (CSDE 1942, Rose 1992).

11.5.0.5. 1951 to 1978: Post-Friant Dam period

Culminating in the completion of the Friant Unit and Delta-Mendota Canal portions of the Central Valley Project, this was a period of rapid agricultural growth. This also ushered in the era when the San Joaquin River became permanently dewatered (except for infrequent flood management releases) in Reach 2 and Reach 4. By the beginning of this period, spring-run Chinook salmon, fall-run Chinook salmon and steelhead trout had disappeared from the San Joaquin River below Friant Dam, downriver to the confluence of the Merced River (Lufkin 1991). The prevailing social, cultural, and political view during this period was that the resources of the river should be used in the most beneficial way possible for the greatest number of people, which at the time was considered to be for agricultural purposes on non-riparian lands (Rose 1992). This view resulted in dewatered reaches of the river, levees constructed to narrow and confine the floodway, reclamation of floodplains and wetlands for agriculture, and construction of flood bypasses to efficiently route floodwaters through the basin. This view of using federally impounded water for use on non-riparian lands was not specific to the San Joaquin Valley, as this approach was widely applied to rivers throughout the West. The main distinction of the San Joaquin River from other rivers was that most fish and wildlife considerations were not included when developing management protocols on the San Joaquin River, which resulted in the extirpation of salmon and steelhead, and great reductions in riparian habitat along the river. Perhaps the perspective of the time was best expressed by Governor Edmund G. “Pat” Brown (quoted by Fresno Bee in 1999):

> *“It is believed that…releases from Friant Dam [for the preservation of fish] would indeed constitute ‘a waste of water’ in view of the grave need of all available water for higher use elsewhere”*

Riparian property owners, scientific experts, conservationists, CDFG, and commercial and sport fishing industry did object to the management of the San Joaquin River, and they were ultimately supported by Judge Hall’s 1956 decision (Rank v. Krug) that the federal government was illegally storing the state’s water behind Friant Dam. When the Bureau applied to the State Water Board for water rights at its Friant Dam diversion, CDFG’s protests were undermined by Edmund G. “Pat” Brown (as State Attorney General, Opinion 1951), who stated that the dam’s purpose was not for fish, but rather for irrigation. Such views greatly overwhelmed other social, cultural, and political forces favoring more moderate resource utilization of the San Joaquin River (Rose 1992, Fresno Bee 1999).

11.5.0.6. 1978 to 2002: Beginning of the Restoration Effort

The legal interpretation of the Federal responsibility for instream flows began to change in 1978 when the U.S. Supreme Court held that federal agencies must follow state laws (such as releasing sufficient water to support fish below any dam or diversion) unless the state laws are inconsistent with congressional intent. This began the evolution away from the perspectives expressed in Governor Pat Brown's time (Rose 1992, Fresno Bee 1999). In the 1970s, a host of significant Federal and State environmental laws (e.g., Endangered Species Act, National Environmental Policy Act, California Environmental Quality Act, and others) were enacted to protect species and the environment, and the passage of these laws reflected a significant shift in perspective on how society manages rivers. In 1988, the NRDC and 14 other groups filed suit against the federal government over its renewal of water contracts without first taking into account the effects to fish, wildlife, and river habitat. This litigation was the first of many environmental lawsuits to follow in the San Joaquin Valley (Rose 1992, Fresno Bee 1999). In the 1990s, Congress and the State Legislature passed several laws that created restoration programs to protect and restore the lower San Joaquin River, such as the CVPIA's Anadromous Fish Restoration Program, CALFED's Ecosystem Restoration program, San Joaquin River Group's Vernalis Adaptive Management Plan, AB 3048's San Joaquin River Management Program, and the San Joaquin River Conservancy-San Joaquin River Parkway Master Plan. In 1997, American Rivers designated the San Joaquin River as one of the ten most endangered rivers in the country. Also in 1997, the Bureau of Reclamation, Friant Water Users Association, and NRDC jointly formed the San Joaquin River Riparian Habitat Restoration Program to begin developing mutually acceptable restoration activities, and in 1999, water was released from Friant Dam as a pilot project to restore riparian vegetation in Reach 2 of the San Joaquin River.

Since 1980, and especially in recent years, there has been a steady decline in the price index of certain agricultural commodities, due in part to globalization (Sumner, 2001) (Figure 11-3). Agriculture is and will continue to be the dominant land use in the San Joaquin Valley. Over 15,000 farmers cultivate 1 million acres of agricultural land that receive San Joaquin River water from the Central Valley Project, producing over $2 billion dollars of agricultural products annually. An additional 2 million acres of agricultural land receive northern California water from the State Water Project, producing another $2 billion dollars of agricultural products annually (Fresno Bee 1999). Although the San Joaquin Valley is rapidly urbanizing, over 3 million acres of productive agriculture land lie on the east and west sides of the San Joaquin Valley. In a state that leads the nation in agricultural production, San Joaquin Valley farm products account for more than half of California's $26.8 billion annual production (Fresno Bee 1999). The San Joaquin Valley also has the fastest growing urban population in California, which is expected to triple from 5 million people today to 15 million people by 2040 (USGS 1999). A plethora of interests compete for the water of the San Joaquin River and its former flood basin lands. The primary challenge is to achieve a balance among these interests if the San Joaquin River is ever to be restored to support additional riparian habitat, re-establish anadromous salmonids, and increase wildlife populations and diversity.

11.6. OPPORTUNITIES AND CONSTRAINTS

It would be simplistic to characterize the social and cultural issues surrounding the San Joaquin River today as just manifestations of a "farmland versus river restoration" conflict. The general public has several significant social and cultural concerns regarding the future of the San Joaquin River that can be summarized as: 1) securing/preserving an adequate water supply, 2) improving water quality, 3) preserving agricultural production in the San Joaquin Valley, 4) meeting the recreational needs of the rapidly growing urban centers, and 5) protecting and rehabilitating the San Joaquin River. Social and cultural issues surrounding each of these concerns pose opportunities and constraints to future restoration of the San Joaquin River.

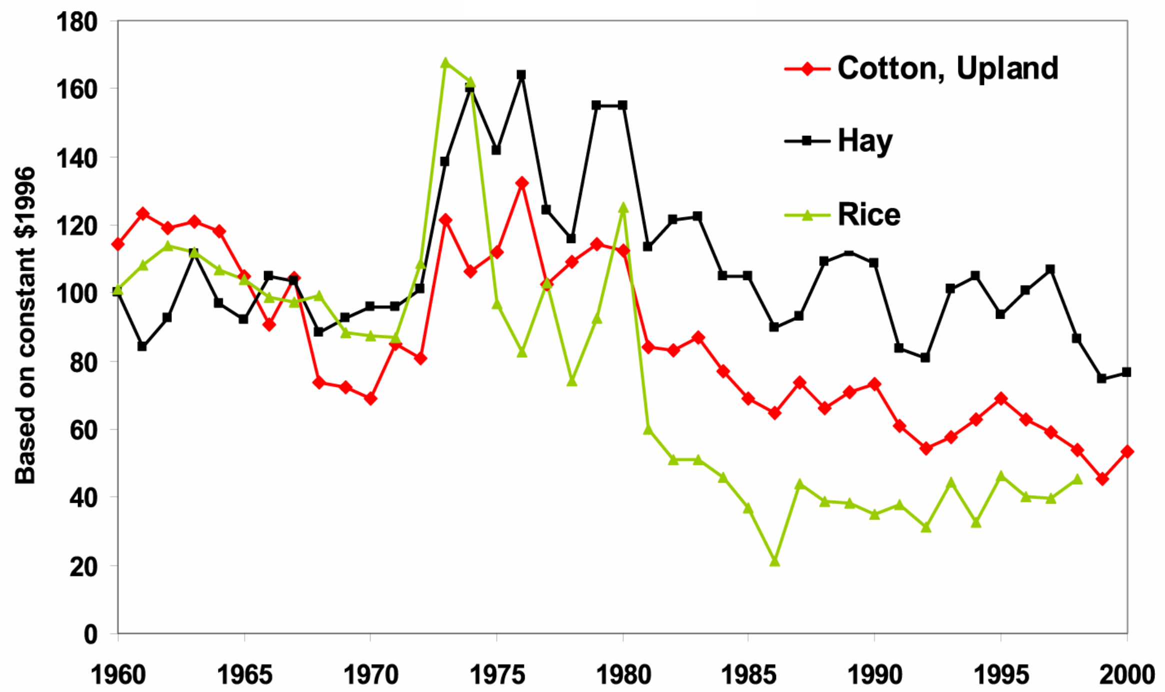

Figure 11-3. Summary of price indices for California field crops between 1960 and 2000 (in 1996 dollars).

11.6.1. Opportunities

Opportunities for future restoration provided by social and cultural issues include:

- Flood management: The existing flood management system does not provide an adequate level of flood protection in downstream reaches. Potential restoration actions that would improve flood management include purchasing flood easements and fee title from willing sellers in flood prone lands, setting back levees, and increasing flood storage in floodplains. Additionally, in many instances, the limited economic value of the lands protected by physical structures does not justify the high cost of creating the protective structures. However, the combination of levee setbacks and/or floodway easements with riparian restoration increases the overall value of the project. This is particularly true in flood-prone agricultural lands where certain seasonal crops can be grown that are compatible with ecological functions (e.g., Yolo Bypass). All of these actions could provide additional flood protection while encouraging restoration. Social and cultural concerns will benefit from additional flood protection.
- Recreation: Restoration of perennial streamflows, as well as additions to river parkways, will increase recreational use along the river (picnicking, hiking, biking, boating, camping, etc.). Restoration of streamflows will benefit resident fish, increasing populations and supporting a sport fishery of these species. Additionally, restoring salmon to the San Joaquin River will provide additional recreational fishery in the Delta and ocean, and may someday provide an in-river fishery as now exists on the lower Tuolumne and Merced rivers. Cumulatively, improved recreational use of the river brings money to the surrounding communities from both the local population as well as outside sources.

- General Public Perception: Public perception of river bottomlands has gradually changed since the 1970s, increasing the importance of healthy river ecosystems from social, cultural, and economic perspectives. This perception is anticipated to continue growing in the future, providing improved public support for restoration efforts on the San Joaquin River
- Local Public Perception: Local perspectives may also be changing, as local landowner fear of restoration activities diminish due to positive restoration-landowner collaborations on other regional rivers. Additionally, clean up efforts conducted by the San Joaquin River Regional Parkway, Bureau of Reclamation, and others have increased over the years, further indicating increasing public recognition of the river as an intrinsically valuable resource.
- Economics: Since 1980, agricultural commodity prices have been declining, making conservation easements a much more attractive option for farmers to retire marginal flood-prone lands with low value crops. Restoration efforts also bring substantial sources of revenue to the local economy from both the recreational uses, and the restoration activities themselves. Tributaries to the San Joaquin River that have received large grants for performing floodway restoration projects have benefited from millions of dollars poured into the local construction, trucking, aggregate, and nursery plant industry.
- Restoration Funding: Our society, through a variety of bonds and public laws, clearly supports restoration of river bottomlands. CALFED, CVPIA, and other funding sources have and will continue to provide large amounts of funding to future restoration efforts on the San Joaquin River.
- Farmland: Frequently flooded lands are often marginal for agriculture due to prolonged periods of inundation or seepage, and sometimes from topographic damage from breached levees and sand deposition. These economically marginal lands create opportunities to purchase for floodway or conservation easements, providing the local landowner an economically preferable way of extracting these marginal lands from production and maintenance liability. For fee title purchases, fair market value is paid, and for conservation easements, a majority of the fair market value is paid and the landowner retains ownership and many of the associated rights of land ownership (e.g., riparian water rights). This voluntary approach does not conflict with local desires to retain private ownership and property rights. When compared to urban expansion to river bottomlands, farmland is generally more compatible with restoration because there is more flexibility in flood management and water supply as opposed to the more fixed urban demands. Monetary damage, cost to protect, and risk of loss of life is also much lower for farmlands compared to urban development.
- Water Quality: The absence of perennial flows in the San Joaquin River has created major water quality and public health problems all along the river and through the Delta; improved San Joaquin River flows will improve water quality and help address many of these problems. Additionally, water imported to Reach 3 by the Delta-Mendota Canal is poorer quality than San Joaquin River water from Friant Dam, and combined with the agricultural runoff of this Delta water from saline soils on the west side of the valley in Reaches 4 and 5, cumulatively causes extremely degraded water quality on the lower San Joaquin River. The poor water quality in Reaches 3, 4, and 5 (and downstream reaches) negatively impacts public health and society that uses this water downstream. Extensive water treatment is applied to improve this water quality; thus improving water quality by increasing instream flows (dilution). Reducing agricultural point and non-point sources of contaminants represents a restoration opportunity that will benefit society in addition to river health. Reducing the amount of Delta water in the San Joaquin River (with its high salinity) will improve water quality for downriver water users and aquatic habitat.

- Expanding Existing Parklands: The City of Fresno is the largest and fastest growing urban area in the Central Valley, and the San Joaquin River traverses its northern border. The San Joaquin River Parkway represents an important social and cultural foundation for the greater Fresno area, and the Parkway's desire to expand to a 6,000 acre corridor between Friant Dam to the Highway 99 Bridge will provide a significant land base from which to restore the river. The 22-mile reach from Friant Dam to Highway 99 has the greatest opportunity for an urban population to benefit from rehabilitating the San Joaquin River. Potential future expansion of the San Joaquin River Parkway downriver below the Highway 99 Bridge, consistent with the General Plans of Fresno and Madera counties, would continue the preservation and recreational benefit of any increases in flow below Friant Dam. Developing public access trails and educational programs is an excellent way to increase public awareness of the San Joaquin River while providing for passive recreational opportunities. Like the American River Parkway, there is also a tremendous opportunity to increase recreational use in the San Joaquin River Parkway if the river received sufficient flows to restore public navigation and boating along its 22-mile corridor.

11.6.2. Constraints

Constraints for future restoration provided by social and cultural issues include:

- Flood management: The old paradigm for flood management was to build large dams to reduce or eliminate flood peaks, and to construct levees to confine floodwaters to a narrow width. This approach depends on engineering and structural approaches, and is prone to large scale failure when one component fails (e.g., breached levee). The emerging new paradigm incorporates engineering with ecological restoration to improve flood management flexibility (e.g., setting back levees to enable dam operators to release larger flood control releases in a safe manner), increase ecological health of the river corridor, and reduce risk of failure in the flood control system (e.g., increased floodway width reduces velocities and water heights, thus reducing the probability of levee failure). Restoring floodplains and flood basins, revegetating floodplains, and increasing floodway width, are the new approaches that are now being implemented on other river systems. The ACOE is now statutorily required to consider non-structural alternatives, and some of the most successful flood management projects in recent years (Napa River, Yolo Bypass) have embodied this new approach. However, this approach is not yet fully accepted by many flood prone property owners, the public, and regulatory agencies responsible for flood protection. While the perception that restoration impairs flood management is slowly receding, it still represents a significant social and cultural constraint to future restoration efforts.
- Landowner Public Perception: The public often fears change of the status quo, which can create a social/cultural impediment to restoration especially on the scale that is contemplated for the San Joaquin River. Another traditional perception is that river restoration is incompatible with agriculture. Concerns about government "taking" private property, removing agricultural land from production, reducing water supply, impairing private property rights, increasing maintenance, and impairing flood management are constraints to restoration that will need to be resolved on a case-by-case basis. While there are obvious conflicts between the two, there are often many mutual benefits that can be achieved if the groups are willing to communicate.
- Water Supply: Depending on the restoration and water supply strategy developed as part of the Friant-NRDC Settlement Agreement process, the water supply to agricultural and municipal water customers could be negatively impacted by restoration efforts, which will

have impacts to social and cultural issues of those communities. These restoration efforts could also potentially impede the rapid growth of regional urban areas along the Highway 99 corridor.

- Poaching: Restoring native resident fishes, particularly anadromous salmonids, will likely increase poaching pressure. There are numerous historical accounts of salmon poaching on the last San Joaquin River salmon in the 1940s, and future poaching of adults after salmon are restored to the San Joaquin River will represent a constraint to restoration efforts. Public education, and ultimately enforcement of poaching laws, will be required as part of the restoration effort.
- Trespassing and Vandalism: Additional public access to the river increases the likelihood of vandalism to parkland structures, and increases trespassing and vandalism to adjoining private properties. Enforcement, public education, and access restrictions are potential solutions, but societal fear of increased trespassing and vandalism represents a potential constraint to increasing public parklands.
- Reduction in Salmonid Predators: Restoring salmon populations may require reductions in fish species that feed on juveniles outmigrating from the San Joaquin River. Approaches include filling gravel pits, netting, electroshocking, and conducting fishing derbies to reduce predator populations. However, many anglers enjoy fishing for these predatory species (e.g., smallmouth bass, largemouth bass, red-eye bass), and these recreation users may not support efforts to reduce bass populations or their habitat in favor of protecting juvenile salmonids.
- Illegal Dumping and Littering: The low value historically placed on the San Joaquin River has allowed pervasive illegal dumping and littering along the river, and this lingering perception will continue to be a constraint to restoration, particularly in public areas with inadequate patrolling and isolated private lands shielded from view by law enforcement agencies. For example, along the stretch of river through the San Joaquin River Parkway, 609 tires were removed this year alone; about 2,434 tires have been removed since the Parkway cleanup program began (San Joaquin River Parkway Website, August 2002).
- Trust, Communication, and Polarization: Restoration planning efforts done under a court settlement agreement process is usually done without significant public input, updates, or participation. Lack of public information often generates suspicion of restoration efforts, which may polarize certain groups within the local community, making future restoration efforts more difficult.
- Gravel supply: Restoration and/or preservation in the gravel bedded reaches of the San Joaquin River takes aggregate out of commercial production, causing a potential constraint for future aggregate supplies needed to support infrastructure and growth in surrounding communities. This was one of the more significant concerns expressed by the public and aggregate industry responding to CEQA/NEPA documents for large scale restoration projects on the Tuolumne River. Continued urban growth in Fresno and Madera Counties will maintain or increase demand for aggregate products that historically have been supplied by gravel mining in the San Joaquin River Corridor.
- Cost: While society has made commitments to expend larger amounts of money on restoration and preservation efforts, the large cost anticipated to restore the San Joaquin River may impose a societal constraint if the costs are greater than society is willing to bear.
- Restoring Natural River Processes: The common public perceptions of flooding, bed movement, channel migration, and channel avulsion are that these processes are to be avoided, rather than embraced. These processes are the primary physical agents that create

and maintain healthy river ecosystems; however, society has typically responded to these processes with rip-rap, levees, and dams. Educating the large number of adjacent landowners, and restoring these processes without corresponding structures added to stop the processes, will be a significant constraint to future restoration efforts.

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CHAPTER 12. OTHER PROGRAMS, DOWNSTREAM OPPORTUNITIES AND CONSTRAINTS

12.1. INTRODUCTION

Previous chapters have described numerous critical issues associated with restoration in the study reach from Friant Dam to the Merced River confluence. However, the San Joaquin River does not end at the Merced River, and additional issues in the portion of river downstream of the Merced River confluence, as well as in the Bay-Delta region, must also be addressed. The restoration of the San Joaquin River must ultimately integrate with activities and programs downstream of the Merced River confluence (Figure 12-1). This is no easy task, and is made more difficult by (1) the multitude of existing programs, some with conflicting stakeholder interests and agendas, and (2) by the current degraded environmental conditions of the lower San Joaquin River, a 120-mile reach extending downstream of the junction with the Merced River to Vernalis (Figure 12-1). The upper and lower portions of the San Joaquin River are obviously linked however, and for the upper San Joaquin River restoration program to succeed, conditions in the lower San Joaquin River must be favorable as well.

In many ways, this linkage creates opportunity. In addition to improving environmental conditions in the study area, restoration actions will dramatically benefit the downstream river ecosystem, including the three major tributaries to the lower San Joaquin River. For example, by adding a “fourth” fall-run Chinook salmon spawning population in the San Joaquin basin, risks associated with low escapements during drought years could be greatly reduced. Also, additional streamflow to help convey salmonid smolts through the study reach will benefit salmon produced in other rivers as well as those from the San Joaquin River. Other opportunities for improving environmental conditions include expanding low-lying, flood-prone grasslands and wildlife refuges to improve flood management, water supply, and water and habitat quality along the lower San Joaquin River, and improving lower San Joaquin River and Delta rearing habitat for juvenile Chinook salmon.

With these opportunities come additional complexities. The purpose of this chapter is to consider opportunities and constraints provided by the lower San Joaquin River that will affect restoration efforts in the upper San Joaquin River, and to discuss how current programs and plans on the lower San Joaquin River will eventually affect programs and plans of the upper San Joaquin River. To better clarify our references to the different reaches of the San Joaquin River, the study area from Friant Dam to the Merced River is referred to as the “upper” San Joaquin River, and the reach outside the study area downstream of the Merced River is referred to as the “lower” San Joaquin River (Figure 12-1). This distinction is made only in this chapter.

12.2. OBJECTIVES OF THIS CHAPTER

The objectives of this chapter are to:

- Describe and evaluate other existing or planned State, Federal, regional, and local programs and regulations (including flood control regulations) that currently affect or will affect the management of the San Joaquin River or that would provide additional information on San Joaquin River ecosystem functioning.
- Discuss “downstream” opportunities and constraints for improved flood management, water supply, water quality, and habitat improvement, from the Merced River confluence to Sherman Island in the South Delta.

12.3. STUDY AREA

The geographic focus is different for each of the two chapter objectives. For the “other programs” objective, the focus is on the entire San Joaquin River basin and includes the numerous State and Federal resource agencies with regulatory jurisdiction or policy management for the San Joaquin basin. Several of the programs discussed, such as the CALFED Bay-Delta Program (CALFED), have a much broader area of concern than just the San Joaquin River basin. We have tried to present material for these programs as they specifically relate to the San Joaquin River Restoration Program.

In assessing downstream opportunities and constraints, the study area is focused downstream of the Merced River, and generally includes two distinct ecological zones: the approximately 50 miles of lower San Joaquin River where the Merced, Tuolumne, and Stanislaus rivers join the San Joaquin River, and the South Delta, from approximately the head of Old River downstream to Sherman Island, where the San Joaquin River joins the Sacramento River (Figure 12-1).

12.4. OTHER PROGRAMS

The Sacramento-San Joaquin River Delta is a key region within California for water supply and water quality, and it is also critically important to numerous plant, fish and wildlife species that either inhabit the Delta or use the Delta seasonally. For these reasons, several large regulatory programs and much attention has focused on this region, particularly in the last several decades. In assessing these other programs, we offer two caveats. First, we have not attempted to discuss in detail how each of these programs will integrate with efforts to restore the San Joaquin River. Integrating this Restoration Study with existing programs will be the responsibility of the San Joaquin River Restoration Program. Second, with a river as large and complex as the San Joaquin, considering all programs, big and small, is impossible. We have included only the major regulatory or stakeholder programs that currently have or eventually will have a direct involvement in restoration of the San Joaquin River.

Several existing programs within the Central Valley and the Bay-Delta region may offer substantial opportunities for cooperation or integration with this Restoration Study. Components of the CALFED and Central Valley Project Improvement Act (CVPIA) programs, for example, should be integrated with the San Joaquin River Restoration Program.

12.4.1. CALFED

The CALFED Bay-Delta Program (CALFED) was formed in 1995 as a cooperative effort among 23 State and Federal agencies that manage and regulate the Sacramento–San Joaquin River Delta (Delta). The mission of CALFED is to develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta. CALFED is focusing on long-term measures to address problems affecting the Bay-Delta estuary and surrounding watersheds.

In August 2000, the program concluded a five-year planning phase, during which the program: (1) expanded from its original mission to include 11 major program elements, (2) developed and finalized a programmatic environmental document (EIS/EIR), (3) established a Science Program, and (4) received signature on the Record of Decision (ROD). CALFED is now moving forward to implement the ROD, with Stage-1 implementation planned to occur over the next seven years.

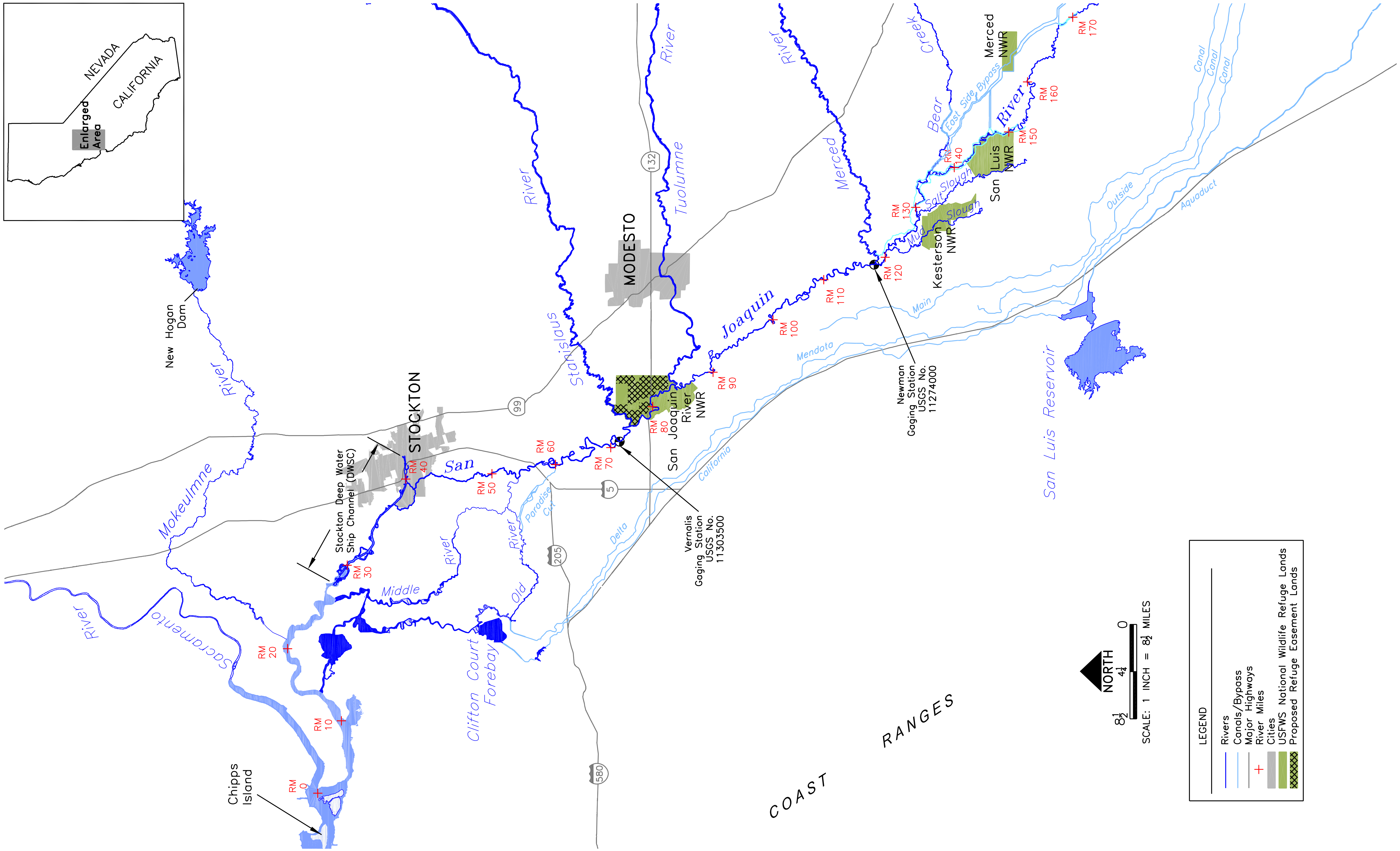

Figure 12-1. Location map for the San Joaquin River.

While the upper San Joaquin River was not among the CALFED Ecological Management Zones, CALFED has nevertheless been involved in the entire San Joaquin River basin, and has continually expanded its role in the basin. Specifically relating to upper San Joaquin River Restoration Program, CALFED has:

- Funded the San Joaquin River Riparian Habitat Restoration Program Pilot Project to establish and maintain riparian habitat, using releases from Friant Dam to disperse and germinate native tree seed in the spring.
- Launched the Salinity and Selenium Project and began design of a pilot plant to treat agricultural drainage and produce water for reuse.
- Explored a water quality exchange partnership between the Friant Water Users Association and the Metropolitan Water District.
- Began evaluating the San Joaquin River's discharge of selenium on the Delta.

12.4.1.1. CALFED Ecosystem Restoration Program

The CALFED Ecosystem Restoration program and the San Joaquin River Restoration Program have much in common. CALFED is directing enormous financial resources to restore ecosystem form and function, as a way to improve overall ecosystem health and benefit priority species. While this approach is relatively new, most scientists generally agree this approach provides the best opportunity to restore ecosystem health and priority species within highly regulated conditions, and will likely be the preferred approach on the San Joaquin River. Experimentation with large scale channel reconstruction and gravel augmentation in the San Joaquin River tributaries will test the effectiveness of these approaches, and yield information which can then be evaluated for similar restoration opportunities in the San Joaquin River. CALFED has also invested heavily in screening riparian water diversions to reduce fish mortality caused by entrainment at unscreened pumps. Below the Merced River, the lower San Joaquin River is a critical stretch of river, not only for the upper San Joaquin restoration efforts, but also for the Merced, Tuolumne, and Stanislaus rivers. Improvements in this lower reach, funded by CALFED, will directly benefit San Joaquin River restoration efforts upstream of the Merced River.

12.4.1.2. Integrated Storage Investigation

In the ROD, CALFED identified among other things, investigating the potential for new groundwater and surface water storage as a possible way to increase water supply reliability, and to provide water for the environment. The ROD mandates: (1) the investigation of the feasibility of creating 500,000 to 1 million acre-feet of additional supplies through groundwater banking, (2) for conjunctive use projects, and (3) State and federal investigation of an additional 950,000 acre-feet of off-stream surface storage in the northern Central Valley. Twelve potential surface water projects and many groundwater banking sites were identified by CALFED for further evaluation during Stage 1. One project that is called out for evaluation is an enlargement Friant Dam, or the creation of its functional equivalent, in order to increase storage by 250,000 to 700,000 acre-feet. The Upper San Joaquin River Basin Storage Investigation project is being conducted jointly by USBR and DWR in two phases. The Phase I Appraisal Study has a proposed purpose statement to "Determine if CALFED agencies should pursue a water storage feasibility study that could meet the CALFED goals for upper San Joaquin River Basin storage and assist in solving other regional problems." Phase II would include a Feasibility Study and EIS/EIR. The program held three workshops in 2002. Additional information can be found at http://www.mp.usbr.gov/sccao/storage/.

12.4.1.3. Water Transfer

CALFED’s Water Transfer Program proposes a framework of actions, policies and processes that will facilitate water transfers and develop a statewide water transfer market. The program calls for establishing a California Water Transfer Information Clearinghouse to facilitate public understanding of transfers, through research and data collection conducted by CALFED. Other actions call for streamlining the current water transfer approval process; increasing the availability of State and Federal storage and conveyance facilities for use in transfers; reducing transfer costs by creating certain classes of “pre-approved” transfers; and establishing “On-Tap,” an on-line water transfers information source for California water market transactions.

12.4.1.4. South Delta Improvement Project

The South Delta Improvement Project resulted from the CALFED ROD, and is being implemented by DWR and USBR, with assistance from the US Army Corps of Engineers (ACOE), the California Department of Fish and Game (CDFG), the US Fish and Wildlife Service (USFWS), and the National Marine Fisheries Service (NMFS). The program goal is to incrementally maximize the diversion capability into the Clifton Court Forebay, while maintaining an adequate water supply for the South Delta Water Agency. Diversion into Clifton Court Forebay would allow the State Water Project (SWP) to maximize pumping capability at the Banks Pumping Plant, when risks to aquatic resources are low, thus reducing exports during more sensitive times. This South Delta Improvement Project’s activities include:

- Constructing a new screened intake at Clifton Court Forebay.
- Constructing an operable barrier at the head of Old River to reduce entrainment of migrating salmonids into the pumping plants.
- Implementing other actions that ensure water availability while simultaneously contributing to restoring the ecological health of aquatic resources in the lower San Joaquin River and Delta (these actions include dredging , screening agricultural intakes, constructing operable barriers, and improving levees.
- Changing the SWP operating rules to allow export pumping up to the current physical capacity of the SWP export facilities.

The South Delta Improvement Project Alternatives Study Draft Project was released in June 2000, and activities are now in the planning phase. Temporary barriers have been constructed at the Head of Old River during the past several years.

12.4.2. The Central Valley Project Improvement Act (CVPIA)

In 1992, Congress passed the Central Valley Project Improvement Act (CVPIA) to reform management and operations of the Central Valley Project (CVP), particularly to protect, restore, and enhance fish and wildlife. CVPIA amended previous authorizations of the CVP to include: (1) a statement that fish and wildlife protection, restoration, and mitigation are project purposes having equal priority with irrigation and domestic water uses, and (2) language stating that fish and wildlife enhancement has a priority equal to that of power generation. Additional background information can be found at <http://www.mp.usbr.gov/cvpia/index.html>. Section 3406 c(1) specifically addresses the San Joaquin River from Friant Dam to the Merced River:

> 3406 (c) SAN JOAQUIN AND STANISLAUS RIVERS. - The Secretary shall, by not later than September 30, 1996:

> (1) develop a comprehensive plan, which is reasonable, prudent, and feasible, to address fish, wildlife, and habitat concerns on the San Joaquin River, including but not limited to the streamflow, channel, riparian habitat, and water quality improvements that would be needed to reestablish where necessary and to sustain naturally reproducing anadromous fisheries from Friant Dam to its confluence with the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Such plan shall be developed in cooperation with the California Department of Fish and Game and in coordination with the San Joaquin River Management Program under development by the State of California; shall comply with and contain any documents required by the National Environmental Policy Act and contain findings setting forth the basis for the Secretary's decision to adopt and implement the plan as well as recommendations concerning the need for subsequent Congressional action, if any; and shall incorporate, among other relevant factors, the potential contributions of tributary streams as well as the alternatives to be investigated under paragraph (2) of this subsection. During the time that the Secretary is developing the plan provided for in this subsection, and until such time as Congress has authorized the Secretary to implement such plan, with or without modifications, the Secretary shall not, as a measure to implement this title, make releases for the restoration of flows between Gravelly Ford and the Mendota Pool and shall not thereafter make such releases as a measure to implement this title without a specific Act of Congress authorizing such releases. In lieu of such requirement, and until such time as flows of sufficient quantity, quality and timing are provided at and below Gravelly Ford to meet the anadromous fishery needs identified pursuant to such plan, if any, entities who receive water from the Friant Division of the Central Valley Project shall be assessed, in addition to all other applicable charges, a $4.00 per acre-foot surcharge for all Project water delivered on or before September 30, 1997; a $5.00 per acre-foot surcharge for all Project water delivered after September 30, 1997 but on or before September 30, 1999; and a $7.00 per acre-foot surcharge for all Project water delivered thereafter, to be covered into the Restoration Fund.

The CVPIA includes several programs that will benefit future restoration activities in the upper San Joaquin River. Within the CVPIA 'core programs', water conservation standards (Section 3405(e)) have increased the firm water supply available to the CVP. Within 'other programs', upgrades to the Tracy and Contra Costa Pumping Plant fish protection facilities have reduced the juvenile salmonid mortality associated with entrainment at the pumping facilities (Section 3406(b)(4-5)). Implementation of the Non-Flow Stream Restoration Actions (Section 3406(b)(13)) has resulted in installation of fish protection devices at Banta-Carbona, planning and design components for West Stanislaus, Patterson, and El Solyo Irrigation District diversions, as well as screens at numerous small riparian diversions. The CVPIA also has helped to fund the San Joaquin River Riparian Habitat Restoration Program that is a partnership of Friant Water Users Authority, NRDC, the Pacific Coast Federation of Fishermen's Associations, the San Joaquin River Exchange Contractors, USFWS and the USBR.

12.4.2.1. Anadromous Fish Restoration Program (AFRP)

The Anadromous Fish Restoration Program (AFRP) is one of the central programs originating from the CVPIA legislature, with the directive to "develop and implement a program that makes all reasonable efforts to at least double natural production of anadromous fish in California's Central Valley streams." The U.S. Fish and Wildlife Service (USFWS) has assumed lead responsibility for the Anadromous Fish Restoration Program (AFRP). The AFRP program developed a three-volume *Working Paper on Restoration Needs*, completed in 1995. Volume I describes the process for completing the Restoration Study, and summarizes the production goals, limiting factors, and restoration actions developed by AFRP technical teams. Volume II provides detailed background information for Central Valley rivers, historic and existing conditions, and identifies roles and responsibilities of State and Federal resource agencies. Volume III includes the complete production goals, limiting factors, and restoration actions sections as submitted by the AFRP technical teams.

The AFRP Program released a Revised Draft Restoration Plan (USFWS AFRP 1997) to be used to guide the long-term development and implementation of the AFRP program. The AFRP Restoration Plan provides a programmatic-level description of the AFRP, and is used to guide implementation of all sections of the CVPIA that contribute to AFRP goals. The Revised Draft Plan was adopted as Final in 2001.

The AFRP is the implementation arm of the CVPIA's Central Valley Project Restoration Fund, and has funded numerous, large restoration projects throughout the Central Valley since 1995. Prior to FY2001 funding cycle, AFRP developed an annual workplan that delineated projects to be funded by the CVPIA Restoration Fund. In 2000, for example, AFRP funded approximately $5.4 million in projects in the Central Valley. In 2001 and 2002, AFRP was integrated into the CALFED Ecosystem Restoration Program proposal solicitation process, with the opportunity to select projects that specifically meet AFRP priorities. AFRP priorities were also considered during development of the CALFED Ecosystem Restoration Plan (ERP) Stage 1 Implementation Plan. The CVPIA legislation explicitly precludes expenditure of CVPIA Restoration Funds for projects upstream of the Mendota Pool.

12.4.2.2. CVPIA Comprehensive Plan

In Section 3406(c)(1) of the CVPIA, the USBR and USFWS were directed to:

> *"develop a comprehensive plan which is reasonable, prudent, and feasible, to address fish, wildlife, and habitat concerns on the San Joaquin River, including but not limited to the streamflow, channel, riparian habitat, and water quality improvements that would be needed to reestablish where necessary and to sustain naturally reproducing anadromous fisheries from Friant Dam to its confluence with the San Francisco Bay Sacramento-San Joaquin Delta Estuary."*

The USBR and USFWS began work on the Comprehensive Plan, and an initial draft report was prepared by 1995. However, the Working Group (consisting of the Friant Water Users Authority, the Natural Resources Defense Council, and the Pacific Coast Federation of Fisherman's Associations) could not reach consensus on several components of the Plan, and the Plan was not completed. The Working Group recognized that the Secretary of the Interior was directed by Federal statute to complete the Comprehensive Plan, subject to Congressional appropriation of funds for that purpose. The Working Group also recognized that use of a Friant Surcharge to complete San Joaquin River Basin restoration projects would require a study or other biological analyses in order to fund proposed projects. To that end, a partnership between the Friant Water Users Authority (FWUA) and the Natural Resources Defense Council (NRDC) created the San Joaquin River Riparian Habitat Restoration Project. The partnership is now developing a more comprehensive plan for restoring native fish and wildlife on the San Joaquin River below Friant Dam. The Comprehensive Plan, as a result of public and political pressures was not funded by Congress and was never completed.

The incomplete draft of the original Comprehensive Plan contained descriptions of historical and existing conditions and a fairly exhaustive list and descriptions of fish and wildlife species within the San Joaquin basin, but it did not contain a substantive implementation component.

12.4.2.3. San Joaquin River Riparian Habitat Restoration Program

The San Joaquin River Riparian Habitat Restoration Program was established in 1997 and is a collaborative effort involving the Friant Water Users Authority, Natural Resources Defense Council and the Pacific Coast Federation of Fishermen's Associations, the US Bureau of Reclamation, the US Fish and Wildlife Service, and the San Joaquin River Exchange Contractors to improve environmental conditions in and along the San Joaquin River. Through this program, several reports have been prepared, describing riparian conditions along the San Joaquin River, including (these reports are found on the web at http://www.mp.usbr.gov/cvpia/sjr/index.html):

- Historical Riparian Habitat Conditions of the San Joaquin River: Friant Dam to the Merced River (JSA 1998a).
- Analysis of Physical Processes and Riparian Habitat Potential of the San Joaquin River: Friant Dam to the Merced River (JSA 1998b).
- A Draft Evaluation of Opportunities for Riparian Restoration and Open Space Uses at Firebaugh, CA (JSA 1999).

Current projects sponsored by the Riparian Program include:

- Development of a restoration plan for the Milburn Ecological Reserve and Hanson Property in partnership with the San Joaquin River Parkway Trust, CDFG and the DWR;
- Long-term bird monitoring in partnership with the PRBO;
- Development of an invasive exotic weed management plan in conjunction with the San Joaquin River Parkway Trust.

Completed projects on the river include activities such as a river clean-up at San Marcos Avenue.

12.4.2.4. Experimental Pilot Projects

Experimental pilot projects have been implemented on the upper San Joaquin River in the Study Area under a Work Plan of the Friant-NRDC partnership since 1999. These pilot projects are intended to fill data gaps regarding critical processes and functions of the San Joaquin River necessary for the development of a restoration plan. Each of these studies has examined particular aspects of restoring the river, and have generated valuable data on: (1) germination and establishment of woody riparian vegetation, (2) modeling and evaluating roughness relative to vegetation establishment, (3) water temperatures, (4) losses from seepage and priming rates, and (5) hydrologic effects of varied flow regimes. These projects have been funded by a combination of sources, including the CVPIA for NEPA documentation and some of the modeling, CALFED, Proposition 13, the water districts and partners.

12.4.3. Water Acquisition Programs

In the last decade, several programs have been established to either purchase or reallocate water for the environmental benefit of the Central Valley. These water acquisition programs include: (1) CALFED Environmental Water Account; (2) CALFED Environmental Water Program; (3) CVPIA Section 3406(b)(2) and (b)(3), and (4) the CVPIA Water Acquisition Program.

12.4.3.1. CALFED Environmental Water Account (EWA)

Provisions for creating and implementing the CALFED Environmental Water Account (EWA) are contained in the CALFED EIS/EIR and ROD. It is cooperatively managed by the U.S. Bureau of Reclamation (USBR), California Department of Water Resources (DWR), USFWS, NMFS, and CDFG. The EWA is a component of CALFED's Water Management Strategy; its intent is to protect endangered and threatened fish species of the Bay-Delta by changing SWP and CVP operations, while maintaining deliveries for agricultural and urban uses. Through the EWA, the CALFED agencies control a package of "assets" that includes money, water, and storage and conveyance rights. The assets package allows more flexible operations to benefit environmental resources. For example, the EWA assets can be used to augment instream flows and Delta outflows, modify exports to benefit fisheries, and replace any water reduced by changes in project operations.

12.4.3.2. CALFED Environmental Water Program (EWP)

The CALFED Environmental Water Program (EWP) is intended to acquire water for flow -related goals contained in the CALFED Ecosystem Restoration Program (ERP). Through the EWP, the CALFED agencies will:

- Acquire water from sources throughout the Bay-Delta watershed, to provide flows and improve habitat conditions for fishery protection and recovery.
- Restore critical instream and channel-forming flows in Bay-Delta tributaries.
- Improve Delta outflows during critical periods.
- Improve salmon spawning and juvenile survival in upstream tributaries, as defined by the ERP and ERP Strategic Plan. Improvement will be accomplished by purchasing up to 100,000 acre-feet of water per year by the end of Stage 1; some of these flows may contribute to the CALFED EWA.

The EWP is relatively new, and was not specifically addressed in the CALFED EIS/EIR and ROD. Therefore, sources or uses of water are not limited or specifically restricted. The EWP program defines how water will be acquired, managed, and developed, as CALFED agencies and stakeholders build the program's framework. Because the EWP program is associated with the CALFED ERP, the CALFED Science Program will likely be included with the EWP's implementation and adaptive management.

12.4.3.3. CVPIA Water Acquisition Programs

The CVPIA included three sections specifically addressing water acquisition and reallocation: Sections 3406(b)(1), (b)(2), and (b)(3). Section 3406 (b)(1) requires re-operating the CVP and creating the Anadromous Fish Restoration Program (AFRP), which were discussed previously. Section (b)(2) dedicated 800,000 acre feet of Central Valley Project yield "for the primary purpose of implementing the fish, wildlife, and habitat restoration purposes". This water was not intended to be obtained from the Friant Division of the CVP, and has no direct implications on the San Joaquin River Restoration Study.

Section 3406 (b)(3) requires that a program be developed and implemented to acquire water supplies that will assist in achieving restoration goals of the AFRP program. This mandate led to the CVPIA Water Acquisition Program (WAP). The WAP's intent is to meet two specific CVPIA goals: (1) to beneficially augment instream flows in Central Valley rivers and streams; and (2) to provide water for State and Federal wildlife refuges and the Grasslands. Since the program was enacted in 1992, the WAP has acquired water annually to meet the water needs of anadromous fish and wildlife refuges.

The WAP is coordinated by USBR, with cooperation from NMFS and USFWS. The USFWS is defining the biological needs and hydrologic characteristics of several regulated and unregulated Central Valley rivers and streams, as well as water needs at wildlife refuges.

12.4.4. San Joaquin River Management Program

The San Joaquin River Management Program (SJRMP) originally was authorized by Assembly Bill 3603 and signed by the Governor on September 18, 1990. The SJRMP includes the entire river from Friant Dam to the Bay-Delta, and provides a forum for identifying and supporting projects and programs that address water quality, water supply, flood protection, fisheries, recreation, and wildlife in the San Joaquin River system. The San Joaquin River Management Plan, completed in 1995, identified nearly 80 consensus-based restoration actions and studies that would benefit the San Joaquin River system and its many users. The SJRMP provides a regional forum in the San Joaquin River basin for local, state, and federal agencies and interested stake holders including agricultural, business, recreational interests as well as environmental groups and landowners.

The program funded several projects on the Stanislaus River, reviewed and recommended projects for other grants, consistent with SJRMP goals. To increase the value of its restoration efforts, the program has recently become coordinated with CALFED, plans to hire a full-time program director, and will obtain funding to implement some of its projects.

12.4.5. VERNALIS ADAPTIVE MANAGEMENT PROGRAM

As part of on-going efforts to restore and protect fish resources, and yet maintain water supply reliability, State and Federal resource agencies, the San Joaquin River Group, CVP/SWP interests, and environmental interests developed a Draft San Joaquin River Agreement (SJRA) to meet the San Joaquin River flow objectives contained in the SWRCB 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (SWRCB 1995). The SJRA includes the Vernalis Adaptive Management Plan (VAMP).

The VAMP program is an experimental program designed to determine juvenile salmonid survival under various river flows and SWP/CVP export operations. In 1999, VAMP began implementing annual 31-day pulse flows during the spring outmigration period. Pulse flows are coordinated with releases of large groups of tagged, hatchery-reared, juvenile salmon, which were wire-tagged and provided by the Merced River Hatchery. The VAMP experiments measure salmon survival rates under six combinations of flow and export rates. Under each of the experimental conditions, Chinook salmon survival rates were then calculated. The primary recapture locations were: (1) Chipps Island (a location where FWS conducted previous studies), and (2) at an intensively sampled location in the lower San Joaquin River near Antioch, (3) at the SWP and CVP fish salvage facilities, and (4) in the ocean fishery. VAMP is scheduled to conduct pulse-flow studies through 2010. In addition to assessing the relationship between CVP/SWP export rates and salmon survival, the controlled spring pulse–flows will also allow the evaluation of temperature and water quality issues, in the San Joaquin River and Bay-Delta, related to flow magnitude and timing.

12.4.6. US Army Corps of Engineers Comprehensive Study

The US Army Corps of Engineers (ACOE) and the Reclamation Board of California initiated the Sacramento and San Joaquin River Basins Comprehensive Study, to develop a system-wide, comprehensive flood management plan for the Central Valley, which would reduce flood damage and provide ecosystem restoration. Three broad planning objectives were identified for the Comprehensive Study: (1) improve flood risk management throughout the system; (2) to ensure that future project meet the dual objectives of increased flood damage reduction and ecosystem restoration; and (3) resolve policy issues and address limiting institutional procedures.

The Comprehensive Study conducted a system-wide evaluation of the Sacramento and San Joaquin River Basins, and developed ways to analyze system changes. A suite of hydrologic and hydraulic models allow an understanding of how floods of various frequencies move through nearly 70 reservoirs, 500 miles of river channels, and over 2 million acres of floodplain. These models were used to assess potential system-wide effects when the existing flood management system was modified. The models' results were then used as a basis for future project development.

The ACOE has released the "Sacramento and San Joaquin River Basins Comprehensive Study, California: Interim Report, December 6, 2002". This report is available on the web at www.compstudy.org. Basin-wide evaluations led to several important findings about the flood management system, including:

- The system cannot safely convey the flows that it was formerly considered capable of accommodating.
- If levee reliability were improved system-wide, substantial increases in flood storage capacity would be necessary to avoid transferring increased flood risks to downstream areas.
- A comprehensive solution to improve public safety, reduce flood damages, and restore degraded ecosystems will require a combination of measures that increase conveyance capacity, increase flood storage, and improve floodplain management.

The Comprehensive Study stopped short of providing an integrated plan for implementing projects to improve flood risk management and ecosystem restoration. However, the Comprehensive Study developed a process to develop future projects that meet the equal goals of: (1) improved flood management, and (2) ecosystem restoration. The Comprehensive Study process consists of a set of "guiding principles" that include:

- Recognize that public safety is the primary purpose of the flood management system.
- Promote effective floodplain management.
- Recognize the value of agriculture.
- Avoid hydraulic and hydrologic impacts.
- Plan system conveyance capacity that is compatible with all intended uses.
- Provide for sediment continuity.
- Use an ecosystem approach to restore and sustain the health, productivity, and diversity of the floodplain corridors.
- Optimize use of existing facilities.
- Integrate with the CALFED Bay-Delta Program and other programs.
- Promote multi-purpose projects to improve flood management and ecosystem restoration.
- Protect infrastructure.

The Interim Report sets the foundation for future modifications to the flood management system, first by identifying the need to manage the rivers of the Sacramento and San Joaquin River Basins in a comprehensive and system-wide manner, then by providing guiding principles to help achieve this goal.

12.4.7. San Joaquin Valley Drainage Program

The San Joaquin Valley Drainage Program was formed in 1984 as an interagency organization composed of the USBR, US Geological Survey (USGS), USFWS, CDFG, and DWR. Its purpose was to investigate drainage and drainage-related problems, and to develop possible solutions in the San Joaquin Valley. In 1990, the Program finalized *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley* (Management Plan) that sought to address environmental concerns and drainage management, but did not address the Valley's long-term salt balance issues. The Management Plan can be found on the web at: http://www.dla.water.ca.gov/agriculture/drainage/implementation/hq/sjvlib.htm

The major components of the Management Plan are:

- Source control—On-farm improvements in applying irrigation water to reduce the source of deep percolation.
- Drainage usage—Plans for drainage-water reuse on progressively salt-tolerant plants.
- Evaporation system—Plans for evaporation ponds that store and evaporate drainage water that remains after reuse on salt-tolerant plants.
- Land retirement—Retirement of areas where underlying groundwater contains elevated levels of selenium and where soils are difficult to drain.
- Groundwater management—Pumping of the semi-confined aquifer, where near-surface water tables can be lowered and where water pumped out is of suitable quality for irrigation or wildlife habitat.
- Discharge to the San Joaquin River—Controlled and limited discharge of drainage water from the San Luis portion of the study area to the San Joaquin River.
- Protection, restoration, and provision of substitute water supplies for fish and wildlife habitat—Provides fresh water to substitute for drainage contaminated water that was previously used on wetlands.
- Institutional change—Changes include tiered water pricing, improved water delivery schedules, water transfers and marketing, and forming regional drainage management organizations.

The Management Plan was then used as the primary guide for the San Joaquin Valley Drainage Implementation Program, developed through a memorandum of understanding (MOU) among Federal and State agencies. This Program provides a framework that will allow the present rate of agricultural development in the valley to continue, while protecting fish and wildlife and helping to restore their habitat to the levels that existed before direct impact by the contaminated drainage water. The MOU is available on the web at: http://www.dla.water.ca.gov/agriculture/drainage/implementation/hq/mem.htm

12.4.8. San Luis National Wildlife Refuge Complex

The USFWS's San Luis National Wildlife Refuge Complex (NWRC) includes the San Luis National Wildlife Refuge (NWR) (Kesterson, East Bear Creek, West Bear Creek, and Blue Goose), the Merced NWR, and the San Joaquin NWR. These refuges form a mosaic of wetlands, grasslands, and riparian habitats, and agricultural fields, formed from former agricultural lands, by flooding and breeching levees. Most of the refuge lands are periodically maintained by controlled burns and periodic tilling to maintain vegetation succession. In addition, forage crops are planted for the waterfowl. Collectively, the 47,700 acres of wildlife refuge provide habitat to the recently de-listed Aleutian Canada Goose (San Joaquin River NWR), many other waterfowl and neotropical migratory birds.

The NWRC is preparing long-term (15-year) program planning documents. Beginning with the San Joaquin NWR, the documents will guide present and future development of the NWRC. One critical issue is the potential expansion of the NWRC to include additional parcels, especially land surrounding the confluences of the Merced, Tuolumne, and Stanislaus Rivers with the San Joaquin River. This potential expansion could play a key role in the San Joaquin River restoration program, in lower San Joaquin flood management, and in water quality issues of the entire river.

12.4.9. Lower Tributaries Restoration Programs

The three mainstem tributaries of the lower San Joaquin River include the Merced, Tuolumne and Stanislaus Rivers. The Stanislaus River is regulated by the New Melones Reservoir, owned and operated by the USBR. Dams on the Merced and Tuolumne Rivers are both privately owned, and have well-developed stakeholder organizations and restoration programs. Coordinating the San Joaquin River restoration efforts with those of these three tributaries will be critical to the success of the San Joaquin River efforts, particularly in maximizing restoration opportunities along the lower San Joaquin River.

The Turlock and Modesto Irrigation Districts (the Districts), in cooperation with CDFG and the FWS, conducted extensive studies of Chinook salmon population dynamics and habitat in the lower Tuolumne River, as part of the Don Pedro Project FERC Study Program. The objective of these studies was to identify potential management actions that would increase Chinook population abundance and improve Chinook salmon habitat in the Tuolumne River. In 1995, through the Don Pedro FERC relicensing process, the Districts and the City and County of San Francisco entered into a FERC Settlement Agreement with the FWS, CDFG, and several environmental groups. The FERC Settlement Agreement established minimum flow requirements for the Tuolumne River downstream of the Don Pedro Project, and it set forth a strategy to recover the lower Tuolumne River Chinook salmon population. The Tuolumne River Technical Advisory Committee (TRTAC) developed the *Habitat Restoration Plan for the Lower Tuolumne River Corridor* (McBain and Trush 2000), that integrates fluvial geomorphic processes with ecosystem recovery and Chinook salmon restoration . Because this strategy will be carried out under contemporary regulated flow and sediment regimes, this goal targets a “scaled-down” version of a dynamic alluvial river (sediment transport and scour, floodplain inundation, channel migration) that creates and maintains habitats favored by Chinook salmon and other fish, bird, and wildlife populations. Several large-scale channel reconstruction projects are identified in the Habitat Restoration Plan, and these projects are currently being implemented by the Districts, CCSF, CDFG, FWS, Friends of the Tuolumne, and Tuolumne River Preservation Trust.

The Merced River restoration program, initiated in 1997, includes a broad spectrum of participants, including the Merced County Planning and Community Development Department, CDFG, DWR, , and the Merced River Stakeholder Group and Technical Advisory Committee. The *Merced River Corridor Restoration Plan* (Stillwater Sciences 2002) was completed in February 2002, and the plan provides a technical basis for restoration, unifies public support, and guides implementation of the restoration program. The goal of the Merced Restoration Plan is to improve, to the extent feasible, ecological conditions that benefit native fish and wildlife, while recognizing, protecting, and addressing the concerns and rights of property owners and other stakeholders (Stillwater Sciences 2002). Several large channel reconstruction and habitat enhancement projects are being implemented by DWR on the Merced River, to improve ecological conditions, riparian habitat, and habitat for fall-run Chinook salmon.

The Stanislaus River's stakeholder group and restoration program are still developing and may be less advanced than programs on the Tuolumne or Merced Rivers, but the Stanislaus has nevertheless implemented several studies and restoration projects to improve conditions for fall-run Chinook salmon and steelhead populations. Spawning gravel replenishment projects have been implemented in Goodwin Canyon and at Knights Ferry. Radio-tracking experiments with emigrating juvenile salmon have also been conducted on the Stanislaus River to evaluate salmonid predation (Demko et al. 1999).

The three tributaries of the lower San Joaquin River are critically important to the restoration program in the San Joaquin River. The above mentioned CALFED projects will yield useful information for implementing restoration on the San Joaquin River; plus, the tributaries' fall-run Chinook and steelhead will likely provide the best genetic stock for reintroduction into the San Joaquin River. Recent tributary restoration efforts and/or improved hydrologic and ocean conditions have helped improve and sustain escapement numbers in the past several years, rebounding from critically low levels in the early 1990s.

The AFRP population targets for the three tributaries total 78,000 fall-run Chinook salmon (Table 12-1). Targets for spring Chinook and steelhead are not provided for individual tributaries, but for the entire Sacramento and San Joaquin River drainage, the targets are 68,000 spring-run Chinook and 13,000 steelhead. Achieving the AFRP and other program escapement targets will directly affect the success of the San Joaquin River restoration program, by providing a strong, local population base for transplant and/or straying. Steelhead appear to be more abundant in the Stanislaus River than in the other tributaries, and the Stanislaus River may be an important source for recolonizing and establishing a viable steelhead population on the San Joaquin River.

Table 12-1. Escapement, harvest, and production targets for fall-run Chinook salmon in each of the tributaries to the San Joaquin River established by the AFRP program. No production targets were established for spring-run Chinook salmon or steelhead in San Joaquin basin tributaries.

	Total Production Goal	**Escapement**	**Harvest**	**Production**
Stanislaus River	22,000	4,800	6,040	11,000
Tuolumne River	38,000	8,900	9,950	19,000
Merced River	18,000	4,500	5,330	9,900
San Joaquin River	not specified	not specified	not specified	not specified
TOTAL	78,000 (not including San Joaquin River)	18,200	16,520	39,900

12.4.10. Floodplain Management Task Force

AB 1147 signed by Governor Davis last year, authorizes twelve flood control projects, modifies the State local cost-sharing formula for participation in federal flood protection projects, significantly increases the State's oversight on federal flood control projects and recommends establishment of a Floodplain Management Task Force. This Task Force must complete its work by December 31, 2002.

The focus of the Task Force is to examine specific issues related to State and local floodplain management, including actions that could substantially reduce potential flood damages and to make recommendations for more effective statewide floodplain management policies.

12.4.11. CALFED ERP 2002 Projects that are Recommended for Funding

River restoration activities within the San Joaquin basin have accelerated in the last decade, primarily because of the availability of funding from CALFED and CVPIA/AFRP. There are too many projects to present in this chapter that may have information relevant to the San Joaquin River restoration effort. Instead we provide an example of projects that recently received funding from CALFED. This is intended to provide managers with a better understanding of the types of restoration activities that offer opportunities for coordination with the San Joaquin River restoration effort.

12.4.11.1. Tri-Dam Project: Stanislaus -Lower San Joaquin River Water Temperature Modeling and Analysis

This proposal is to improve temperature models for the Stanislaus River and lower San Joaquin River to improve water temperatures from reservoir releases to benefit salmon, steelhead, and other fish, and was recommended for $661,902 in funding. This proposal extends the existing water temperature model to the entire river system, from New Melones to the Bay-Delta, including that portion of the San Joaquin River between the Stanislaus River confluence and Mossdale Bridge. New information will refine the temperature model and help improve water temperature in the Stanislaus River and Lower San Joaquin River.

12.4.11.2. Water Tech Partners: Full-Scale Demonstration of Agricultural Drainage-Water Recycling Process Using Membrane Technology

This demonstration project was funded for $316,090 and seeks to test whether sustained, full-scale operation of an on-farm, tile-water recycling process can eliminate off-farm drainage disposal. This recycling process is the most technically, economically, and environmentally viable process for achieving the selenium water quality objectives for the San Joaquin River watershed. If the prototype full-scale demonstration project is successful, more plants will be built, possibly decreasing selenium discharge into the San Joaquin River by 80 percent.

12.5. DOWNSTREAM OPPORTUNITIES AND CONSTRAINTS

The lower San Joaquin River is an integral component of the success of restoration efforts in the upper San Joaquin River. Besides the obvious hydrologic connectivity, the two river sections also share flood control system components, similar urban and agricultural land uses, and water quality issues. Many of the downstream issues are both opportunities and constraints, depending on how the issue is viewed. For example, existing water quality conditions in the lower San Joaquin River may pose a critical constraint to the restoration of anadromous salmonids in the upper San Joaquin River, simply in terms of their survival of those conditions. But adding more water from the San Joaquin River may allow improvements to water quality, with consequent benefits that extend beyond just anadromous salmonids. Several other issues are similarly balanced.

12.5.1. Flood Management

The climate and geology of the Central Valley dictate inevitable periodic flooding of the major river systems. Since Euro-American settlement in California, many large floods have occurred, occasionally with loss of life and property damage. Beginning as early as 1910, frequent flooding resulted in coordinated flood protection planning, flood control structures, and non-structural alternatives, which have converted vast areas of undeveloped and uncontrolled floodplain into reclaimed agricultural lands, and more recently, into urban population centers throughout the Central Valley. The primary flood control strategy was the construction of large reservoir impoundments, channel straightening and confinement, levee construction, and flood bypass channels.

The primary opportunity in terms of improved flood management is to increase the flood capacity and storage in the 65 mile-long reach from the Merced River confluence to the Delta, by such actions as setting back levees or creating transitory storage areas like the Yolo bypass. This activity has enormous benefits not only to flood management, but also to several ecosystem components and functions, such as: (1) a restored floodplain that can provide high quality habitat for native fish and anadromous salmonids, (2) an increase in riparian habitat available for avian and wildlife species, and (3) potential for channel migration, large wood recruitment, and other important fluvial processes that are important to river ecosystem maintenance. Opportunities for restoring river corridor habitat, while maintaining flood control capacity, occur in the lower San Joaquin River from the mouth of the Stanislaus River downstream to Old and Middle rivers (Figure 12-1). Opportunities also exist along the San Joaquin Channel into the Central Delta. As addressed in the Comprehensive Study (ACOE 2001), opportunities exist for expanding shaded riverine aquatic habitat on the San Joaquin River and on its lower tributaries, from Stockton upstream to the mouth of the Merced River along Federal levees.

Waterside slopes of levees are subject to erosion from wind-generated waves, boat wakes, and water flowing at high velocity. State and local governments have invested millions of dollars in the past 10 years to maintain and repair eroded levees. The Delta Levees Maintenance Subvention Program (Senate Bill 1065) was developed to assist in levee maintenance, but requires that no net loss of fish and wildlife habitat should be associated with levee maintenance along the San Joaquin River below Stockton. SB 1065 also provided $3 million to mitigate past habitat loss in this area.

Improvements to Delta levees and channels are included in the CALFED ROD to reduce the risk of floods from earthquake and general deterioration of the levees. These improvements to system integrity will be accomplished through developing and implementing the Delta Long-term Levee Protection Plan. The plan will include a maintenance/stabilization element and a Special Projects element; the two elements will address levee maintenance, stabilization improvements, subsidence, emergency levee management, beneficial reuse of dredged material, and establishment of habitat corridors, as mitigation for impacts caused by maintenance and stabilization. The Delta Long-term Levee Protection Plan will provide a uniform approach for improving system reliability. Uniform funding and guidance for levee maintenance and/or improvements to a construction standard would be available to Delta islands on a cost-shared basis. Funding for flood control and habitat improvements would be distributed through a priority system, to ensure long-term protection of Delta system functions, which provide the highest public benefit.

12.5.2. Project Levees

Federal flood control levees channelize the lower San Joaquin River, from the mouth of the Merced River to Stockton, and along its lower tributaries. In their present condition, these levees confine the river, reduce inundated area, and degrade main channel habitat (McBain and Trush 2000). Considerable opportunity exists to simultaneously address flood control problems and re-create high quality floodplain and aquatic habitat in the lower river by pulling levees back and expanding the floodway corridor width. Expansion of the floodplain can reduce flood risks while improving river and floodplain habitats for San Joaquin River native fish populations, as well as for many avian and wildlife populations. Setback levees can add substantial rearing habitat for juvenile salmon and steelhead emigrating from the upper San Joaquin River and tributary rivers during periods of high flows. This habitat includes floodplains, side channels, sloughs, riparian forests, and wetlands that are seasonally inundated at high river stages. Tidal and seasonal wetland habitat in the floodplain of the lower San Joaquin River would substantially add to the rearing habitat available for juvenile salmonids of upper San Joaquin River origin, as well as salmonids originating from the Merced, Tuolumne, and Stanislaus rivers. Lower river and estuary rearing habitat is presently impaired by reclamation projects. The present condition of late winter and springtime salmonid rearing habitat in the mainstem river can limit growth of juvenile salmonids, particularly under high turbidity and low temperatures typical of snowmelt and winter runoff conditions. Expansion of the floodplain into a dual-purpose floodway/wildlife habitat corridor would improve these conditions.

12.5.3. Entrance to Old River

In the Bay-Delta and lower San Joaquin River, many barriers and bypass channels hinder migrating adult and juvenile salmonids, thus affecting their survival. These migratory barriers are discussed in more detail in Chapter 7. However, several barriers are planned in the South Delta as part of the DWR/CALFED South Delta Program that benefit emigrating juvenile salmonids, including the barrier at the mouth of Old River. This barrier is installed temporarily during juvenile and smolt outmigration period, and is designed to keep fish in the San Joaquin River and away from the CVP and SWP diversions at Clifton Court Forebay. The barrier would thus reduce juvenile salmonid mortality associated with entrainment at Delta pumping facilities and reduce migration travel time through the Delta.

12.5.4. CDFG Fish Screen and Fish Passage Program

The California Department of Fish and Game manages the Fish Screen and Fish Passage Program, which has the following goals (Raquel et al. 2002):

- Inventory water diversion and fish passage problems.
- Evaluate and prioritize fish screening and fish passage problems.
- Implement and/or coordinate fish protection activities.
- Evaluate existing and proposed fish protective installations.
- Review fish screening and fish passage literature.

Downstream of Vernalis, the program has identified over 2,200 diversions. Of these, only 1% have fish barrier structures that meet delta smelt or salmon design criteria. The majority (approximately 45%) of diversions/barriers in the Delta are siphons. Of the unscreened diversions:

- 5 diversions have intakes larger than 250 inches in diameter.
- 18 diversions have intakes between 51-65 inches in diameter.
- 131 diversions have intakes between 21-50 inches in diameter.
- 2,064 diversions have intakes smaller than 20 inches in diameter.

In the lower San Joaquin River from the Merced River to Vernalis, the program identified 62 diversions, with only a single screened diversion (the Banta-Carbona Irrigation District) that meets delta smelt, steelhead, and salmon design criteria. Unscreened diversions include (Raquel et al. 2002):

- 2 diversions with intakes larger than 65 inches in diameter (both >249 cfs capacity).
- 1 diversion with intake between 21-50 inches.
- 59 diversions with intakes larger than 20 inches in diameter.

These diversions are a significant constraint to native fish restoration efforts in the upper San Joaquin River. Clearly, the lower San Joaquin River and Delta has considerable potential to impact native fish populations, including anadromous salmonids, and will continue to contribute to fish mortality and impaired fish populations until most or all these diversions are screened or removed. However, from the perspective that these diversions have been operating for so long, screening or removing the diversions represents a significant opportunity to reduce fish mortality caused by diversions.

12.5.5. Streamflows in lower San Joaquin River

The CALFED and CVPIA programs evaluate the potential for increasing flows on the lower San Joaquin River and its tributaries by re-operating and purchasing water from willing sellers. Flow increases at key times of the year can potentially improve survival of up- and downstream migrating salmon and steelhead. The Vernalis Adaptive Management Program is studying the potential benefits of increased spring flows from tributaries. Federal Energy Regulatory Commission (FERC) hydropower license programs also mandate further study of benefits from increased river discharge at key times of the year. Increased flows will not only improve upstream and downstream passage, but will also provide improved and/or increased floodplain habitat, which would benefit salmonids and limit survival and production of warm-water, non-native, predatory species.

12.5.6. Connectivity of Riparian Habitats with lower SJR Tributaries (Stanislaus, Tuolumne, Merced Rivers)

The lower portions of these tributaries are generally channelized by Federal flood control levees. These channelized reaches interrupt the continuity between the tributaries’ extensive riparian habitats and the riparian habitats of the San Joaquin River floodplain. Improving the tributaries’ riparian habitats will increase connectivity, which is important to migrating and growing juvenile salmonids. The floodplain riparian forests are important because they provide shade and cover, nutrients, organic material, large woody debris, and insects important in the diet of young salmonids. Riparian habitats also cool the air and shade the water, which can lower water temperatures and potentially extends the period when young salmonids can rear in the lower river in spring. Finally, reconnecting and expanding these riparian habitats may be vitally important to certain native and special-status species (e.g., yellow-billed cuckoo) that require relatively large patches of habitat for their populations to rebound and thrive. Many of the necessary habitat improvements can be accomplished under existing Federal and State programs, including the CALFED program and others identified in previous sections.

12.5.7. Water Quality in the lower San Joaquin River and Delta

Water quality in the lower San Joaquin River and Delta is a significant constraint to restoring fish and aquatic resources in the San Joaquin River (see Chapter 6). Several water quality parameters, including water temperature, salinity, and dissolved oxygen, are of particular concern due to their direct and potentially lethal effects on juvenile salmon and steelhead migrating through the Delta, as well as other native fish species. Additional flow releases would likely substantially assist in attaining water quality objectives in the lower San Joaquin River by diluting the lower river with high quality streamflow. However, if water quality in the lower San Joaquin River and Delta does not substantially improve, impaired water quality conditions will continue to constrain juvenile and adult anadromous salmonid migrations.

12.5.8. Army Corps of Engineers (ACOE) Comprehensive Study

In response to the 1997 flood, the ACOE was directed to conduct a comprehensive assessment of the entire flood control system in the Sacramento and San Joaquin basins. The first step in this comprehensive study was preparation of a comprehensive *Post - Flood Assessment* for the Central Valley (ACOE 1999). This report listed numerous infrastructural and operational problems with the existing flood control system, including:

- The San Joaquin River levee and channel system lacks the capacity to convey design flood flows, and does not extend far enough into the Delta to adequately pass design flows.
- No single entity has responsibility for maintaining the capacity of the river channel from the Merced River downstream to the Delta, resulting in continually decreasing capacity.
- Parts of the levee system do not reliably protect against floods due to structural instabilities, poor foundation conditions, and/or excessive seepage.
- Current operation plans for existing reservoirs, plus the lack of flood storage in reservoirs and in the floodplain, prevent optimal use of the flood management system.

In addition, flood release travel times from Friant Dam are several days longer than travel times of releases from the tributaries. This difference increases the difficulty of management in the lower San Joaquin River.

12.5.9. The Nature Conservancy Restoration Site Studies

This section contains information about restoration opportunities on 12 potential restoration sites (Figure 12-1) on the San Joaquin River, between the Merced River and Old River. These restoration opportunities were developed for a report sponsored by The Nature Conservancy (JSA 1999). The listed opportunities include breaching levees, setting back levees, reconnecting channels, expanding floodplains, and restoring old floodplains to native habitat with a mosaic of native riparian, oak woodland, and grasslands. The report details the locations, habitat descriptions, land uses, and infrastructure for each site. Summaries of the restoration sites follow. References to right bank and left bank are based on a downstream orientation.

12.5.9.1. Paradise Cut (Site 1)

Paradise Cut is an overflow channel of the San Joaquin River, which connects to the Delta. Flow into Paradise Cut is regulated by a weir (the Paradise Cut flood relief structure) and channel capacity is 15,000 cfs. Paradise Cut is bordered on both sides by levees, and it is linear and narrow. Before the levees' construction, this channel likely had greater sinuosity; old meander bends are evident in the soil signatures of adjacent lands. Riparian habitat is limited within Paradise Cut due to agricultural encroachment, channel straightening, and levee construction. Riparian habitat now consists of a narrow band of trees along the bases of the levees. Downstream of the Interstate 5 Bridge, the cut widens. As of July 1998, extensive agricultural fields covered much of the area. Fields within the project levees on both sides of Paradise Cut are protected from flooding by local levees. Some riparian trees grow at the edge of ponded areas within the channel. Several levee breaches occurred along Paradise Cut in the 1997 floods.

Increasing flood conveyance through Paradise Cut has been suggested as a flood-control measure for the San Joaquin River. Several restoration opportunities could improve riparian and wildlife habitat, including:

- Purchasing fee title or conservation easements to adjacent agricultural lands, then breaching the local levees within Paradise Cut, and converting the agricultural lands within these levees to riparian habitats.
- Purchasing fee title or conservation easements, then breaching or setting back levees within the Stewart Tract, and allowing portions of the Stewart Tract to flood during high flows. This would increase temporary flood storage, and would provide habitat for migratory birds and waterfowl. Construction of a levee system to protect the town of Mossdale would be required.
- Restoring riparian and wetland vegetation to appropriate sites within the Stewart Tract, in association with breaching of levees.

12.5.9.2. San Joaquin River RM 57 to 69 (Site 2)

Within this reach, several restoration opportunities could have substantial flood conveyance benefits. Potential projects include:

- Purchasing fee title or conservation easements and setting back levees. Project levees between RM 60 and 61.5, and RM 63 to 65, constrict the floodway. Straightening levees between bends in these two areas would greatly reduce the levee length. Levees currently surrounding two oxbow lakes are only one mile apart, and connecting them would replace approximately 5 miles of existing levee. Straightening levees would return some currently farmed land to the floodplain.
- Removing local levee at RM 68 and purchasing flood-prone agricultural lands on the left bank, between RM 65.5 and 68.5. This action may allow the river to naturally cut off over time, and presents opportunities for natural riparian regeneration. Historically, much of this land was forested.
- Breaching or removing project levees between the Banta-Carbona Canal intake and the site's upstream end at RM 70. The alluvial fan of a tributary draining the Coast Range lies adjacent to the river at this point ,and may be close enough to fully contain flood flows.
- Breaching or removing local levees that protect flood-prone agricultural fields within the project levee system.

Some lands within the project levees may be unsuitable for riparian vegetation because the river channel has degraded and the floodplain's elevation above the current river channel is too high to allow natural regeneration. Other plant species may be more appropriate here.

12.5.9.3. Walthall Slough (Site 3)

Walthall Slough, another potential restoration site, is an historical slough system on the right bank of the San Joaquin River, between Weatherbee Lake at RM 57 and RM 67.5. To the west, this site is partially bordered by project levees along the right bank of the San Joaquin River; to the east, it is bordered by local levees and a series of roads to the east. At the upstream end, Walthall Slough is currently separated from the river by project levees and it flows into an old oxbow channel connected to the main river channel at the town of Weatherbee Lake. Portions of the slough connect several existing oxbow lakes, relatively far from the current channel to the west. Much of the historical riparian forest and marsh vegetation has been replaced by agriculture, although a narrow band of riparian trees line the remaining slough channels.

Reconnecting both ends of Walthall Slough with the San Joaquin River would enhance riparian habitat and increase the flood conveyance capacity of the system. Habitat quality is currently limited because flows are cut off at the slough's upstream. Before levee construction, this slough was likely a natural bypass for floods, and reconnecting it to the main San Joaquin River would restore this bypass function, and convey flow past several constrictions between RM 57 and RM 70. Some options for reconnecting the slough include:

- Reconnecting the slough to an oxbow channel at RM 58.3 rather than at its current point downstream. (The downstream location could negatively affect the town of Weatherbee Lake).
- Re-grading the slough, or constructing a bypass levee system to restrict flows to the slough itself, thereby minimizing impact to surrounding farmlands.
- Constructing a weir or other flow-regulating structure at the upstream end of the slough. The slough would likely have a more consistent water supply, which would improve riparian habitat quality. This option does not have flood control benefits, but additional levee construction may not be needed.

12.5.9.4. Red Bridge Slough (Site 4)

Red Bridge Slough lies along the right bank of the San Joaquin River, between RM 67 and 75, below the confluence with the Stanislaus River. The slough is bordered by San Joaquin River to the west, and the Stanislaus River to the south. The site includes the lowermost two river miles along the right bank of the Stanislaus River.

Red Bridge Slough, like Walthall Slough to the north, appears to be an overflow channel of the San Joaquin River, and may be the site of an historical overflow channel of the Stanislaus River. Both the upstream (RM 67) and downstream (RM 72) ends of Red Bridge Slough are disconnected from the river, lying outside the project levees. In the vicinity of the historical inlet for Red Bridge Slough, another highly degraded slough channel may have been connected to Red Bridge Slough or to the San Joaquin River. Some riparian vegetation grows along Red Bridge Slough, especially in areas with standing water, but much of the riparian and marsh vegetation that probably occurred in this area has been replaced by agriculture.

Restoration opportunities for Red Bridge Slough are similar in concept to those recommended for the Walthall Slough. Reconnecting Red Bridge Slough with the river would enhance riparian habitat and improve flood conveyance. However, Red Bridge Slough may have fewer restoration benefits than Walthall Slough, and may be more difficult to implement.

12.5.9.5. San Joaquin River: RM 70 to 77 (Site 5)

This restoration site is a reach of the San Joaquin River, from the City of San Joaquin to the Hwy 132 Bridge (RM 70 to 77). The upstream end of the site lies on the right bank of the river, and the downstream end lies along the left bank. Along this section of river, native vegetation is better developed than at sites downstream, and the vegetation forms a relatively broad riparian corridor. Numerous oxbows are present. Valley oak is abundant on higher ground, and cottonwood, willow, and box elder grow at lower elevations. The levee system starts south of Sturgeon Bend and continues upstream along the left bank. Two oxbow lakes located at the site's southern end are cut off from the main river by the levee system and agricultural fields. However, these oxbows are frequently flooded, support emergent wetland vegetation, and are surrounded by native trees and shrubs.

The left bank portion of this site is exceptionally well-suited for nonstructural flood control and riparian habitat restoration. Because of the alluvial fan to the west, breaches in the project levees along the east bank could be allowed to pass into and through the southernmost 500-odd acres of the site. Restoration activities would have little impact on infrastructure. Potential restoration actions include:

- Purchasing fee title or conservation easements and breaching or removing project levees from Hwy 132 to Sturgeon Bend.
- Purchasing fee title or conservation easements and replacing agricultural fields with riparian forest vegetation within the low floodplain and connecting riparian habitat between the river and off-channel oxbow lakes.
- Setting back project levees along the right bank between Airport Road and Sturgeon Bend, and restoring riparian habitat to the reconnected floodplain.

12.5.9.6. Riley Slough (Site 6)

Much of the reach from the Tuolumne River downstream to the Stanislaus River is part of the 11,000-acre San Joaquin River National Wildlife Refuge (NWR), where extensive floodplain restoration projects are in progress. Riley Slough extends along the right bank of the San Joaquin River from the confluence with the Stanislaus River at RM 75 upstream to Hwy 132. A continuous project levee lines the right bank of the San Joaquin River and the left bank of the Stanislaus River for the entire length of the site. Riparian forest grows between the river and the project levees, connecting to Caswell Memorial State Park along the Stanislaus River. Within the levees, and near the confluence with the Stanislaus River, some land is under cultivation. This land was formerly riparian forest according to 1914 CDC maps (ACOE 1917). Several oxbow lakes and Riley Slough were historically connected to the riparian system, and they are now separated from the river by the project levees. This site offers enormous potential for expansion of the San Joaquin River corridor. Incorporating this site into the NWR would connect the entire right bank floodplain of the San Joaquin River from the Tuolumne River downstream to the Stanislaus River, offering substantial flood storage and conveyance benefits, as well as waterfowl, fish, and wildlife habitats.

12.5.9.7. San Joaquin River RM 77 to 84 (Finnegan’s Cut Area-Site 7)

This site extends along both banks of the San Joaquin River from Hwy132 to RM 86, approximately halfway between the confluence with the Tuolumne River and the town of Grayson. This portion of the river is characterized by an actively evolving channel with a very wide floodplain. The main river channel currently flows through Finnegan’s Cut, and the historical San Joaquin channel is now abandoned. Numerous other sloughs, oxbows, and abandoned channels, with accompanying riparian forest vegetation, provide excellent wildlife habitat. Because of agricultural conversion and levee construction, many of the riparian forest patches are relatively narrow, containing willows, box elder, Oregon ash, Fremont cottonwood, and valley oak. Natural regeneration of many of these native species is occurring within the site. The channel at this site is partially contained within levees, most of which are local and protect agricultural fields in the floodplain. These fields were inundated by the 1997 flood, and incurred extensive damage. Many of the fields have not been farmed since then.

This site offers opportunities for both flood control and habitat enhancement, including reconnecting the mainstem of the river to the floodplain by removing or breaching levees that protect agricultural fields, which would allow periodic inundation of more than 3,000 acres of land and allow temporary storage of floodwaters. There is little infrastructure in this area that would impede restoration efforts; the only significant structure is the intake for the West Stanislaus Main Canal.

12.5.9.8. San Joaquin River RM 84 to 92.5 (Laird Slough Area-Site 8)

This restoration site extends from the confluence of the Tuolumne and the San Joaquin rivers (RM 84) to the Brush Lake and Richie Slough area (RM 92.5). This reach actively meanders with abundant evidence of old and recent cutoffs. This area is highly agriculturally developed. Up to 400 acres of this site experienced levee breaches and sand splays during the 1997 flood. The width of riparian vegetation buffer is highly variable. Outside the levees, the active floodplain includes large tracts of uncultivated land, supporting valley oak woodland and mixed-willow riparian forest. Channel dynamics have allowed large pieces of habitat to develop, in particular between RM 87 and RM 89.5, where a mosaic of open water, wetlands, and riparian habitats persists. The site contains many ponds created by abandoned oxbows and sloughs, and presents several floodplain restoration opportunities.

If levees were to be set back in this area, some infrastructure would need to be protected or moved. Ring levees around farms and other buildings would be necessary. Roads may need to be raised, and bridge abutments may need to be reinforced. Building setback levees and removing or breaching existing levees and other infrastructure modifications would be expensive for this project.

12.5.9.9. San Joaquin River RM 92.5 to RM 99 (Site 9)

This site is along the San Joaquin River, from 0.5 mile downstream of the San Joaquin and Del Puerto Creek confluence (RM 92.8), to the Las Palmas Avenue Bridge. Project levees extend along almost the entire western side of the river, but they are set further back than at the upstream sites. The City of Modesto sewage disposal ponds are located on the historical right bank floodplain. Private levees extend along the left bank from RM92.5 to RM 92.8 and from RM 94 to RM 97. The area includes numerous abandoned sloughs and oxbow cutoffs. Extensive and diverse riparian and wetland vegetation extend to the west and northwest of the sewage ponds. On the left bank, the river has breached the private levees at several points and created extensive sand deposit areas on agricultural fields. Restoration opportunities in this reach mainly include expanding and protecting riparian habitat, reducing grazing pressure on grasslands and riparian areas, and setting back project and private levees.

12.5.9.10. San Joaquin River RM 99 to 107 (Site 10)

This restoration site is located along the San Joaquin River from the Las Palmas Avenue Bridge (RM 99) to the Crows Landing Bridge (RM 107). The site’s width varies from 0.5 to 2 miles. Along the right bank of the river, the floodplain is narrowly confined by project levees, and the left bank of the river is flanked by a project levee. A short local levee extends from along the left bank from RM106.6 to RM 106.9. The left bank floodplain from RM 105.5 to RM 106.6 is confined by coalesced alluvial fans along the valley’s west side. The site has numerous cutoff oxbows and dry swales. The higher and intermediate floodplain surfaces are drier than in the downstream reaches; Great Valley mixed riparian forest and black-willow stands are found along the abandoned oxbows and the riverbank. Recent floods have created low floodplain surfaces on high-water cutoff chutes and point bars. Willow scrub and herbaceous riparian wetland species are colonizing these recently created surfaces. Salt crusts and salt grass indicate that salinity may limit riparian regeneration at some locations. Natural vegetation remains on alternate bars, but agricultural fields have encroached between bars.

This site presents several restoration opportunities, including converting adjacent agricultural fields to riparian and wetland habitat, setting back project levees, removing riprap, and allowing the river channel to migrate into lands that are currently agricultural fields, and restoring riparian vegetation along a secondary channel between RM 105 and RM 106.5.

12.5.9.11. San Joaquin River RM 107 to 112 (Site 11)

This site is located along the San Joaquin River, from the Crows Landing Bridge at RM 107 to the Stanislaus–Merced County line at RM 112. The site includes approximately four complete meanders of the San Joaquin River and the confluence of the river with Orestimba Creek. Project levees extend along the entire right bank of the river. Outside bends along the right bank are located directly against the levee. To the west, the floodplain is confined by coalesced alluvial fans. Natural riparian vegetation is found within the point bars and along an abandoned slough east of the river. The floodplain is relatively arid with many chutes that have cut through the point bars, sand splay deposits, and active bars. The bend cutoff causes local sedimentation, where riparian vegetation can regenerate. An exception to the arid floodplain and sparse woody vegetation is the small Orestimba Creek confluence area, where a diversity of riparian forest in successional stages is found, with scrub and herbaceous wetland. A larger patch of riparian forest is found upstream of Crows Landing Bridge, where the slough channel was historically connected to the river.

Restoration opportunities for this site include (1) protecting and expanding riparian and marsh habitat at the Orestimba Creek confluence; (2) reestablishing connections of the abandoned slough channel with the river at high flows and converting agricultural fields along the channel to riparian habitat; (3) setting back the project levees along the right bank of the river and reestablishing a wider meander belt; and (4) removing local levees and bank armoring along the left bank.

12.5.9.12. Merced Slough: San Joaquin River RM 112 to 118 (Site 12)

This site extends from the Merced–Stanislaus County line at RM 112 to Hills Ferry Bridge at RM 118, downstream of the river's confluence with the Merced River. The Merced Slough and an intermittent slough on the north are included in this restoration site. The site is part of a non-leveed floodway, with local levees from RM 112 to RM 113.5 and near RM 116. The northern portion of the Merced River's alluvial fan is also included; meander scroll topography is extensive, and dry ridges alternate with wetter swales. The 1914 CDC maps show secondary channels on both sides of the San Joaquin River, particularly in the northern portion of the site. On both sides of the meander belt, some of the flood basins have been developed as duck ponds and rice fields. Several old oxbows are now relatively dry and have become Valley Oak stands. Great Valley mixed riparian forest is extensive on lower terraces near the channel. In bend cutoff chutes, several examples of willow and cottonwood regeneration were created by the flood of 1997. Previous floods have also created bar deposits and scoured areas (conducive to cottonwood regeneration) that are now patches of Great Valley cottonwood riparian forest.

This site provides the opportunity to protect the substantial riparian vegetation that remains, deepen secondary channels on the site to restore high-flow conveyance, restore historical flood basins to seasonal or permanent wetlands, and widen riparian corridors along slough connections between the Merced and San Joaquin Rivers.

12.5.10. Summary

Legislative acts, programs, committees, plans, and agencies have a common goal in the San Joaquin basin: to improve fish and wildlife habitat while recognizing constraints of irrigation, flood control, and domestic water supply. In some cases, restoration can be accomplished by changing operations or infrastructure. This chapter identified locations and circumstances where coordinated restoration opportunities could be found downstream.

12.5.10.1. Downstream Constraints

- Poor water quality in the lower river (see Chapter 6) is a potential constraint for Chinook salmon and steelhead, and numerous other native fish species. Nutrient concentrations in the lower San Joaquin River are high from concentrated inputs from agricultural drainage, wastewater-treatment plants, and runoff from dairies and feedlots. These high concentrations are diluted to some extent by varying inflows from the three major east-side tributaries. Regulated streamflows from the San Joaquin River and tributaries also contribute to increased water temperatures, which are also a constraint to salmonids.
- Entrainment of young salmon on their downstream migration into irrigation diversions can potentially occur at literally thousands of locations in the lower river and Delta;
- The stream channel and associated floodplain and riparian habitat have been severely degraded by channelization and floodplain development along the lower San Joaquin River. The degradation results in passage problems, high water temperatures, and limited rearing habitat for juvenile salmon migrating downstream from tributaries and the upper San Joaquin River.
- Water temperature is a constraint for salmon in the lower San Joaquin both in the fall when adults migrate upstream and in the spring when young are migrating downstream. High water temperatures may delay or block movement and increase mortality.
- Low fall flows in the lower river may impede adult upstream passage in some areas of the stream channel.
- Streamflow is a critical factor for salmon in the fall, winter, and spring particularly in dry years. Flow in the lower river is significantly related to subsequent survival to the Bay. Low flow leads to poor water quality, high temperatures, greater levels of entrainment into water diversions, increased predation, and constraints on passage
- Predation by striped bass, black bass, pikeminnow, and other predatory fish species in the lower river is a significant risk to salmon and steelhead restoration on the upper San Joaquin River. Populations of these native and non-native fishes have benefited from many of the habitat changes that have hurt salmon and steelhead.
- Hatchery production in the lower San Joaquin River tributaries could result in increased competition, predation, and potential loss of genetic integrity of San Joaquin basin salmon, and thus potentially constrain restoration of wild salmon stocks in the upper river.
- Downstream flood management continues to be seen by stakeholders of the lower San Joaquin River as a constraint to restoration from fears of increased floodplain overflows and restoration that may lead to increased downstream flooding potential.

12.5.10.2. Downstream Opportunities

- Water quality control and monitoring have been proposed along with pilot studies exploring solutions to specific water quality problems. Aerators are being considered to increase dissolved oxygen in the DWSC and Port of Stockton and a stakeholder-led effort has been developing a DO TMDL for the lower San Joaquin River within the Delta.
- The CALFED ERP, the AFRP, CDFG, and USBR Fish Screening Programs are working with local irrigation districts in the design and construction of fish screens. An example is the Banta-Carbona Fish Screen on the San Joaquin River. The Patterson Irrigation District has received funding to screen its intakes on the San Joaquin River.
- Conservation easements, channel reconfiguration, riparian vegetation, and floodplain restoration are being considered to improve habitats in the lower San Joaquin River for juvenile salmon that migrate through and may rear in this reach.
- The Stanislaus -Lower San Joaquin River Water Temperature Modeling and Analysis Project with funding support from CALFED will develop models for operating reservoir releases to improve water temperatures at critical times of the year for salmon migration. The Project will update existing water temperature and operation models for the tributaries and river.
- Proposed improvements to floodplain habitats and the river channel discussed in Section 12.5.9 are designed to improve fish habitat throughout the lower river.
- Flow management studies are being conducted by a number of Federal, State, and local agencies as part of FERC licensing, and CVP and CALFED. The Vernalis Adaptive Management Program and other CVPIA water programs, and the CALFED Environmental Water Account are being designed and tested to improve stream flow in the lower San Joaquin River and its tributaries.
- Hatchery programs that exist in the tributaries such as the Merced River Hatchery as well as other Central Valley hatcheries are undergoing reevaluation for improved management by State and Federal resource agencies responsible for maintaining and recovering wild salmon and steelhead stocks. Such scrutiny is already being planned by agencies involved in managing the San Joaquin River salmon resources.
- Federal funding provided through Natural Resources Conservation Service (NRCS) for acquisition of fee title or conservation easements and conversion to riparian habitats has been successful on the Tuolumne River in improving riparian habitats and a similar process could be implemented on the lower San Joaquin River.

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APPENDIX A

ANNUAL HYDROGRAPHS OF SELECTED GAGING STATIONS ON THE SAN JOAQUIN RIVER AND TRIBUTARIES

APPENDIX A-1

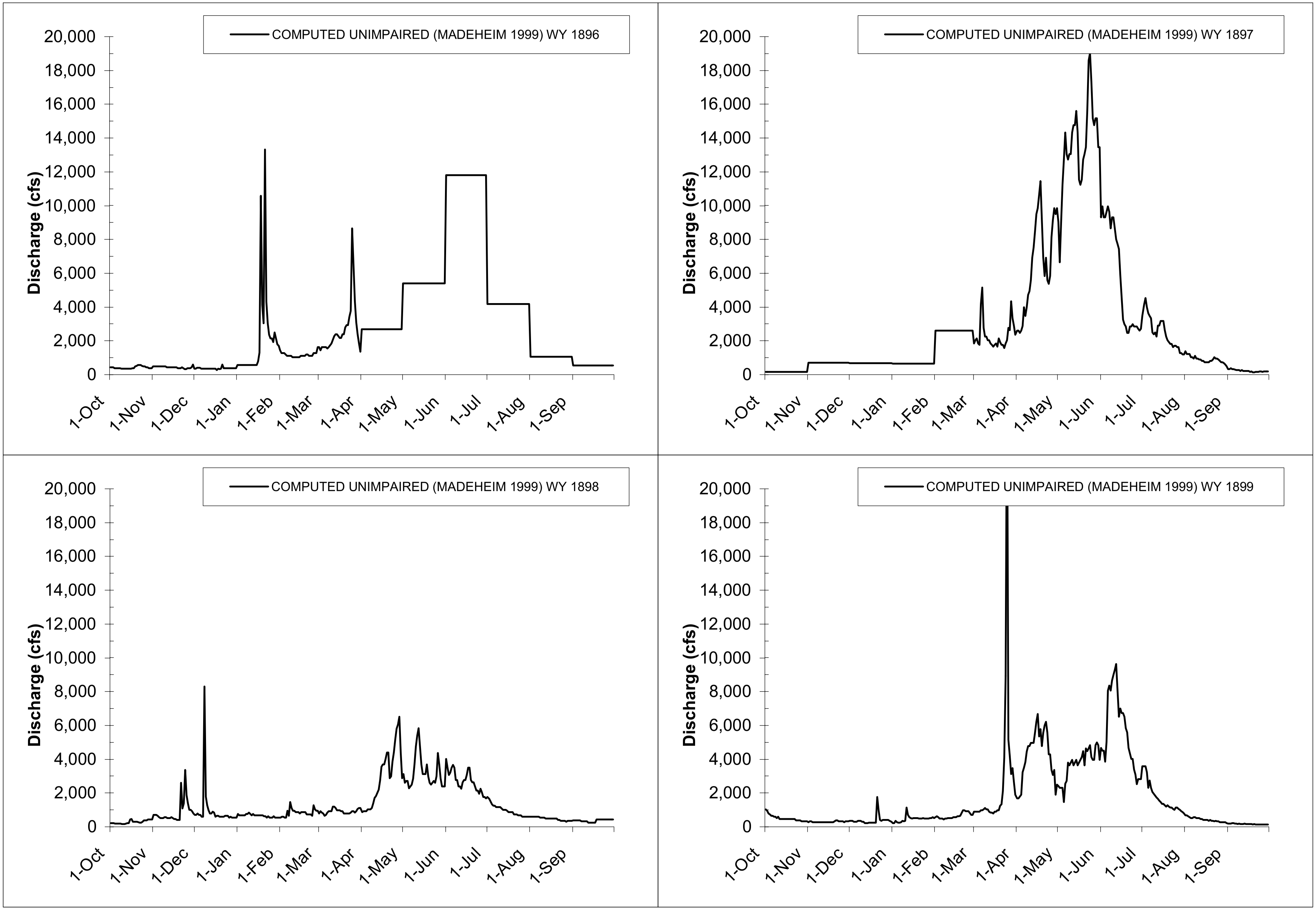
SAN JOAQUIN RIVER AT FRIANT

USGS GAGING STATION # 11-251000

TOTAL DRAINAGE AREA=1,676 SQ MI

UNREGULATED DRAINAGE AREA APPROXIMATELY = 40 SQ MI

PERIOD OF RECORD: 1908-PRESENT



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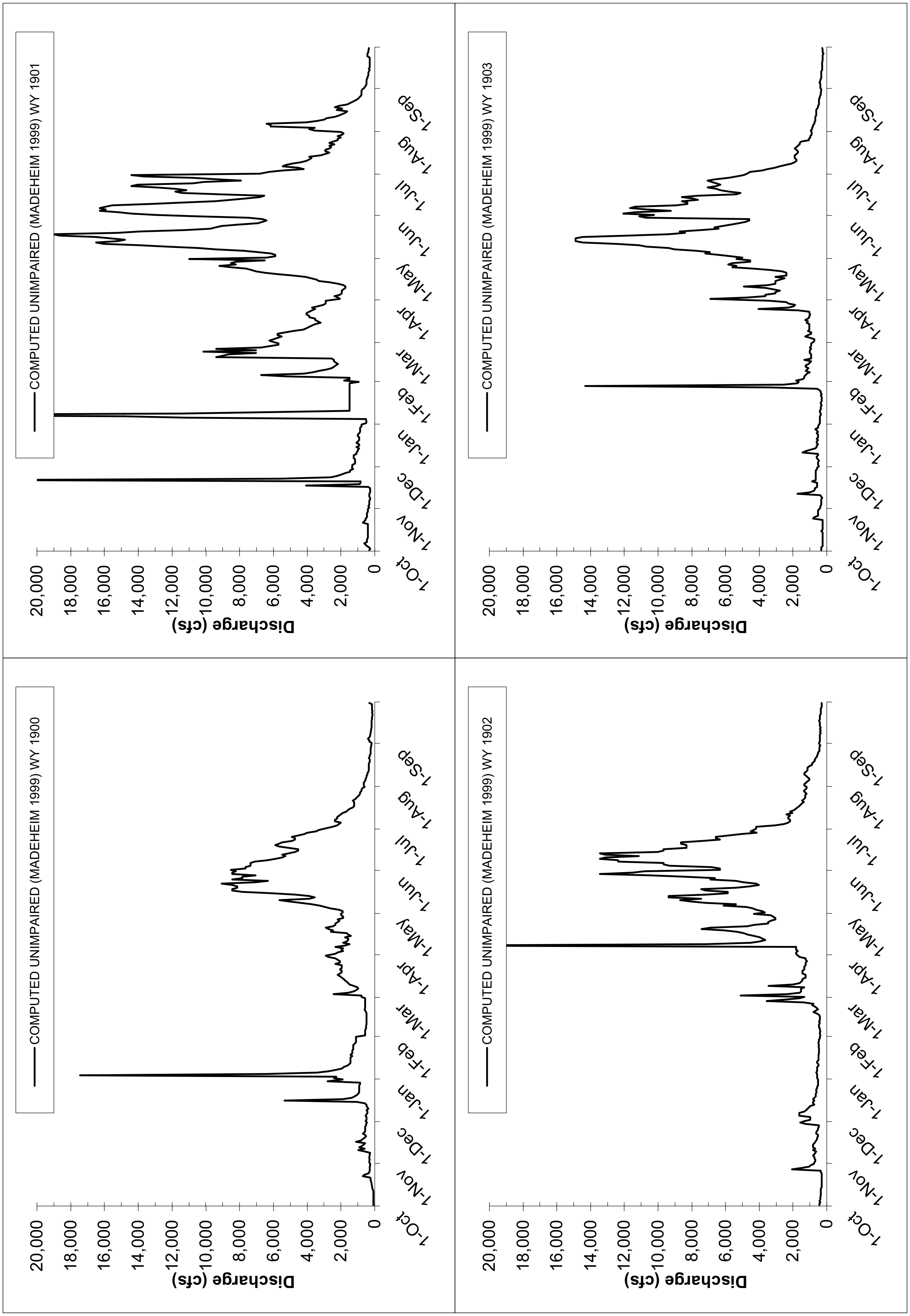

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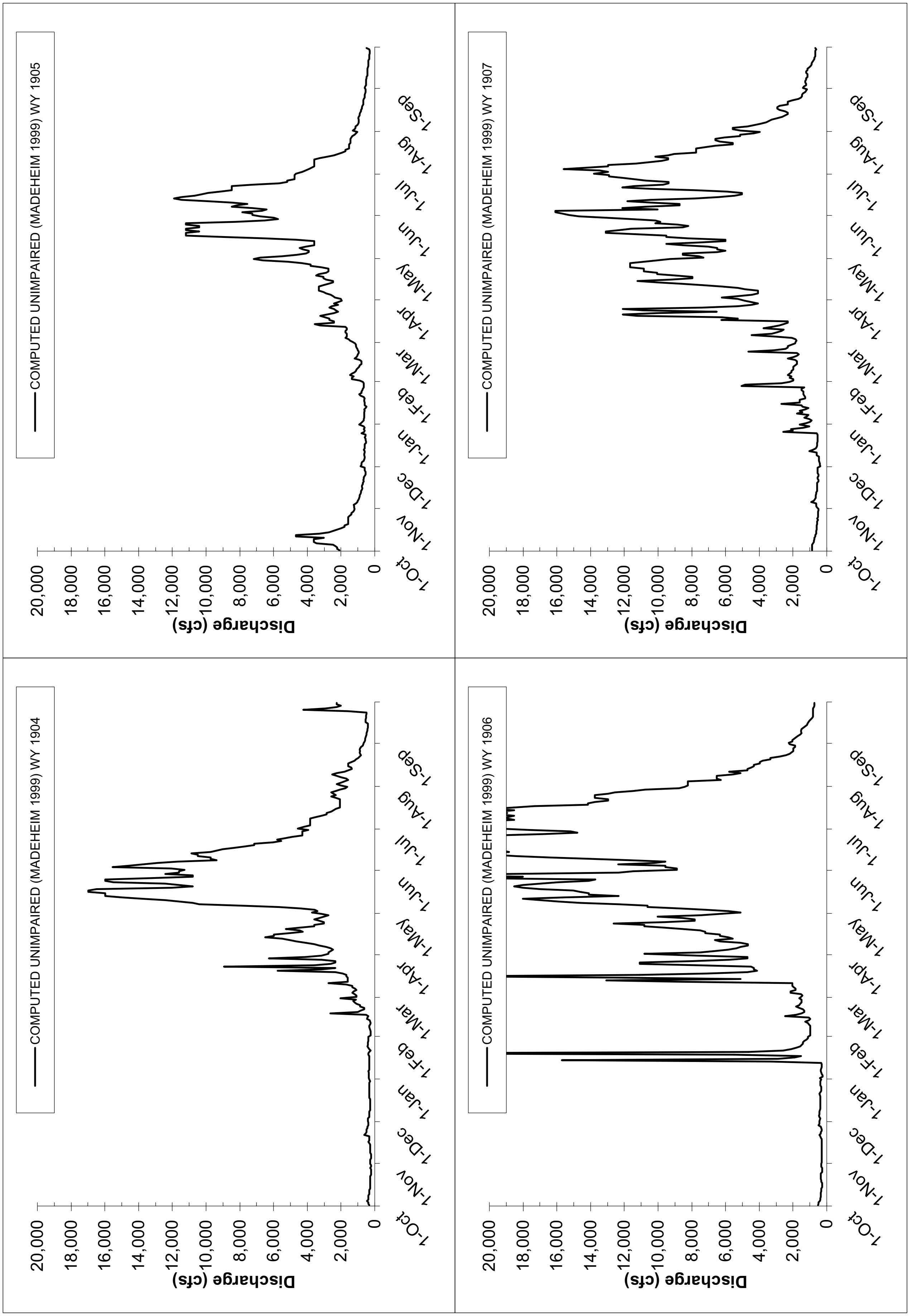

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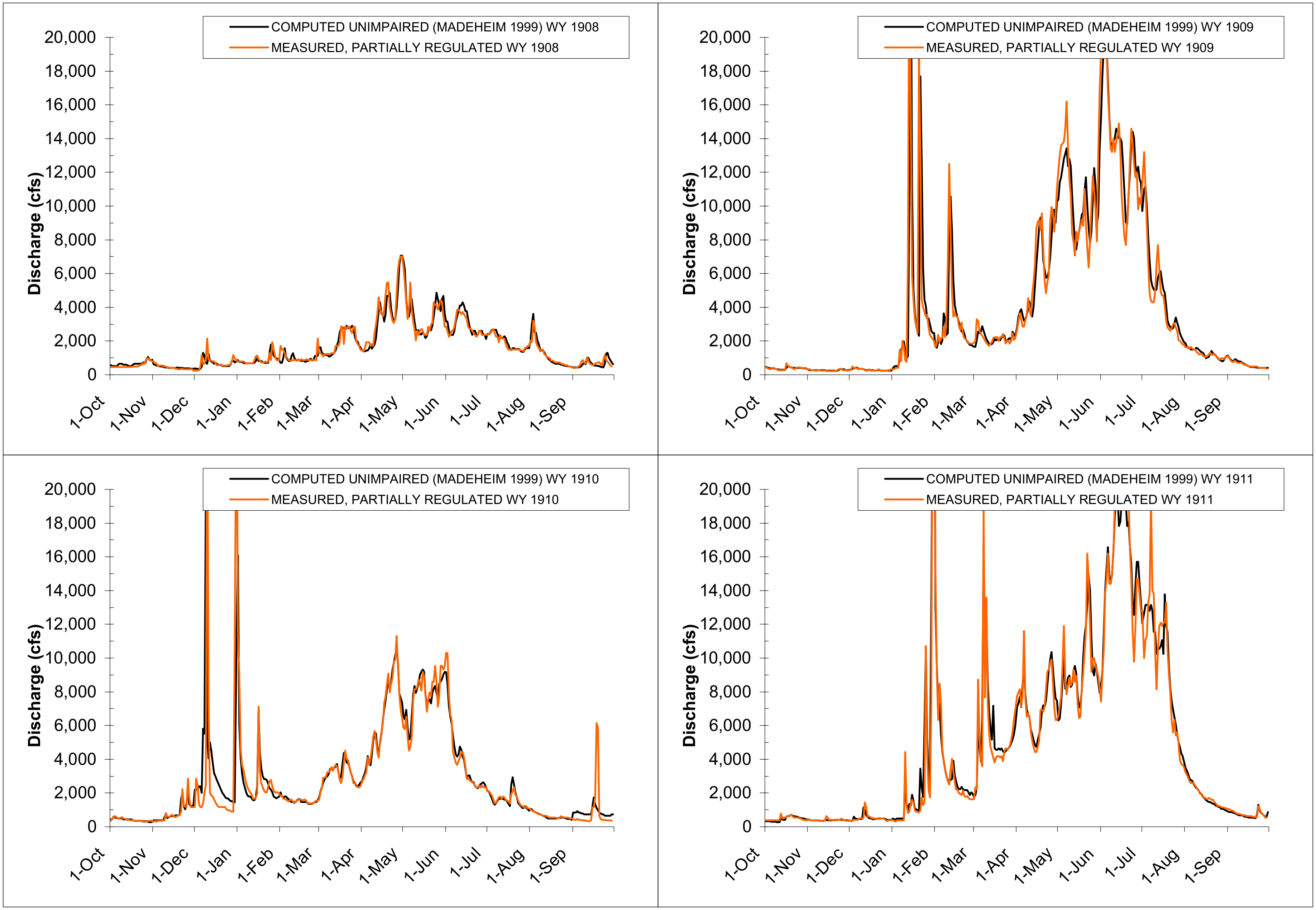

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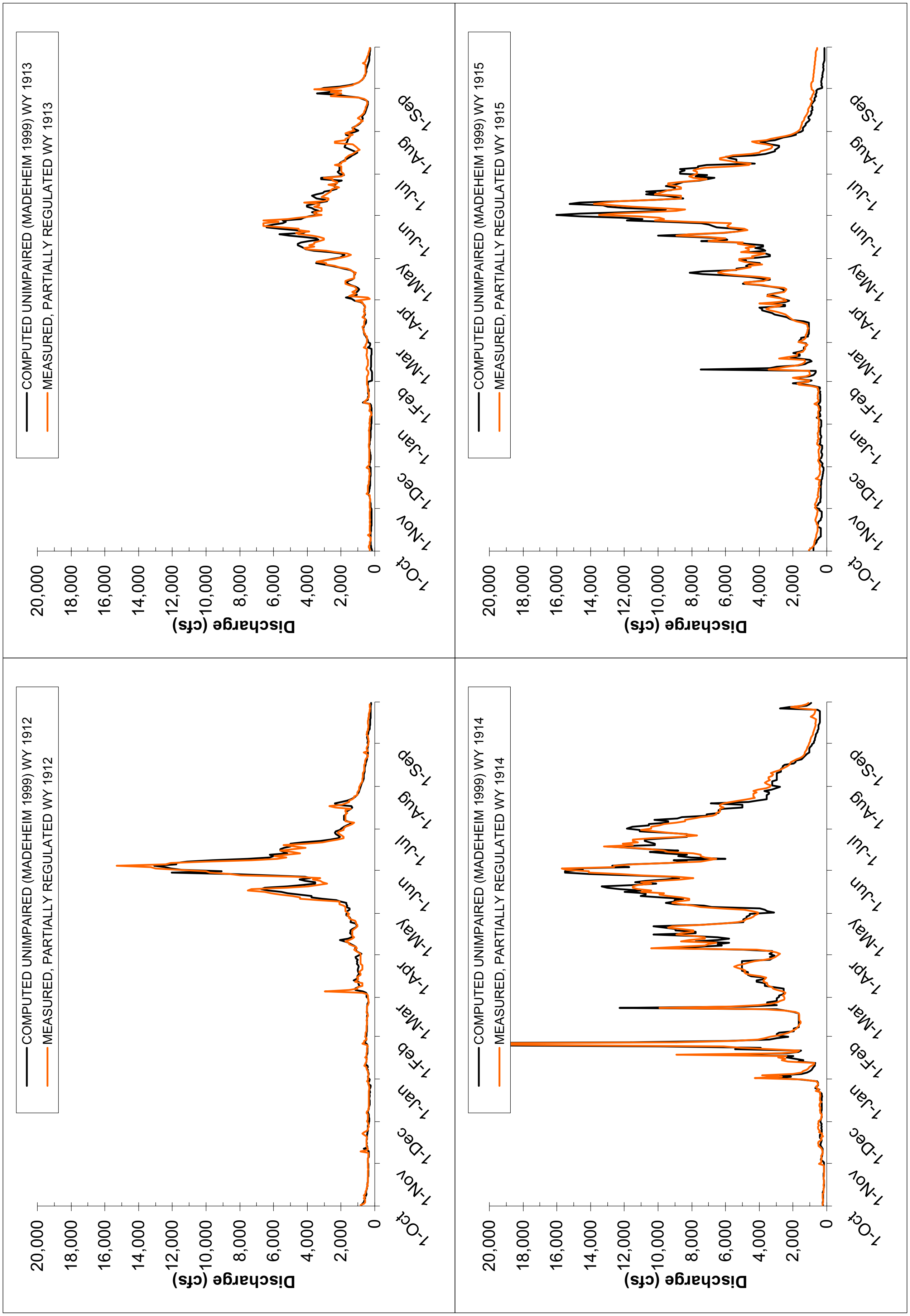

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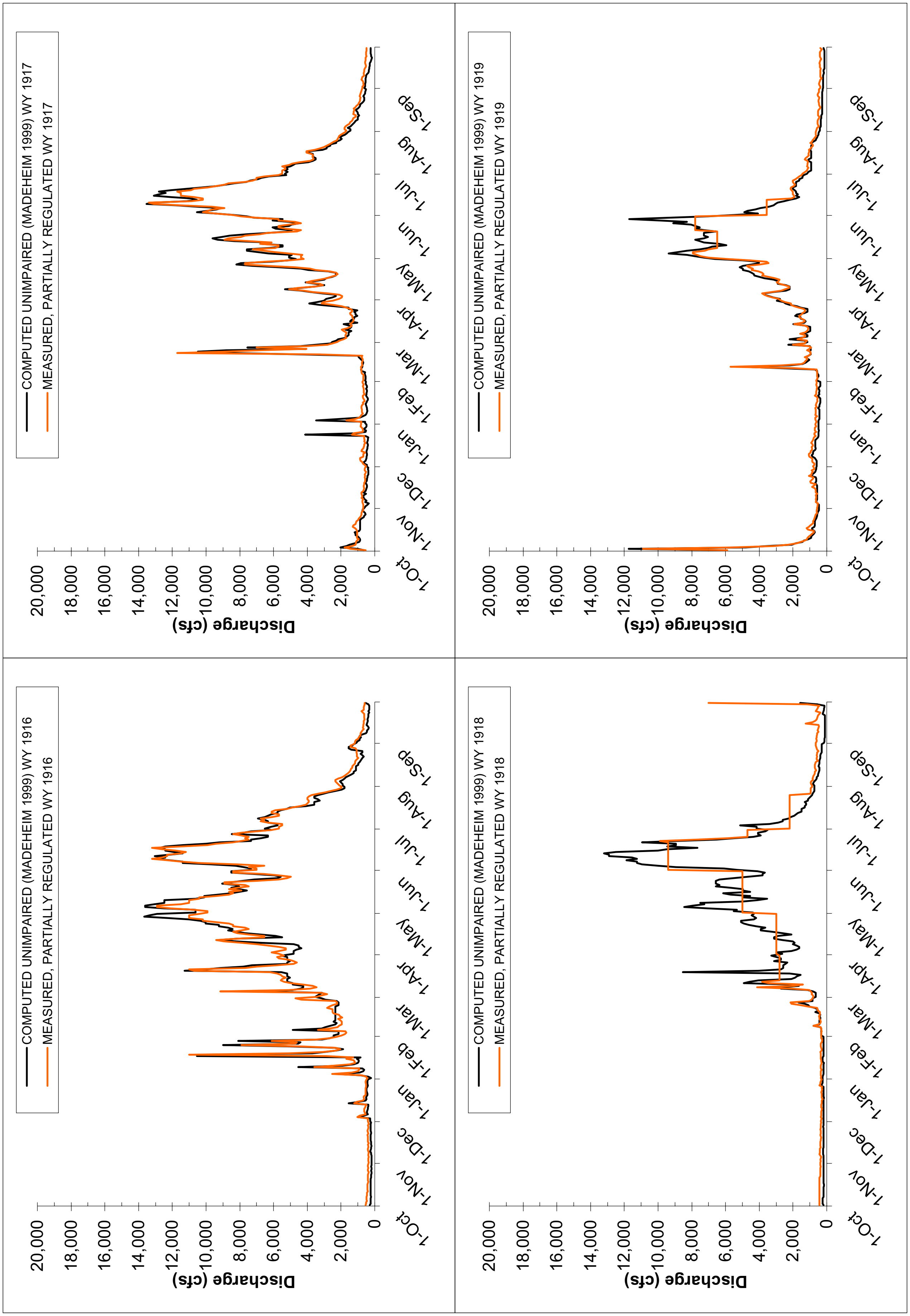

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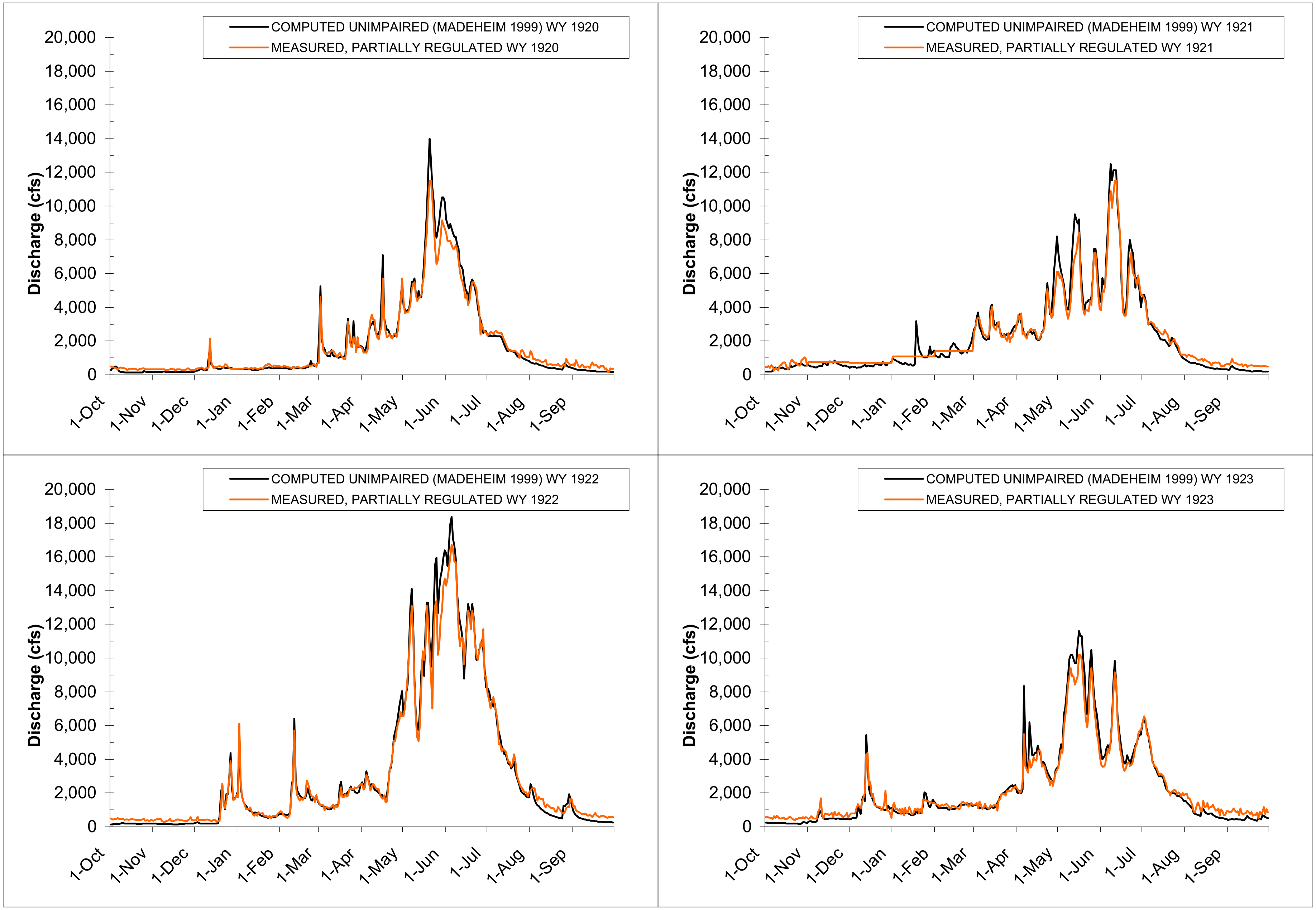

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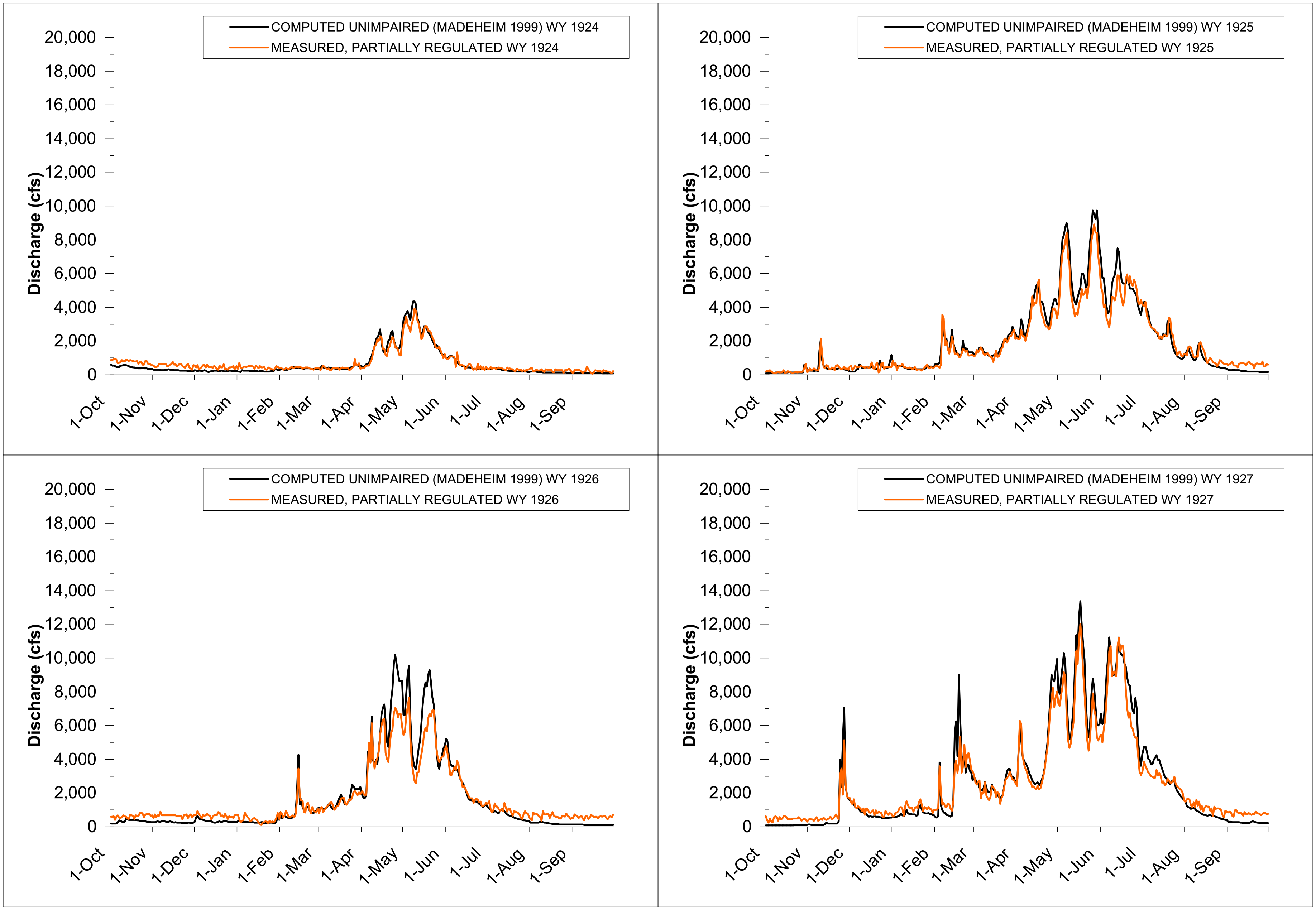

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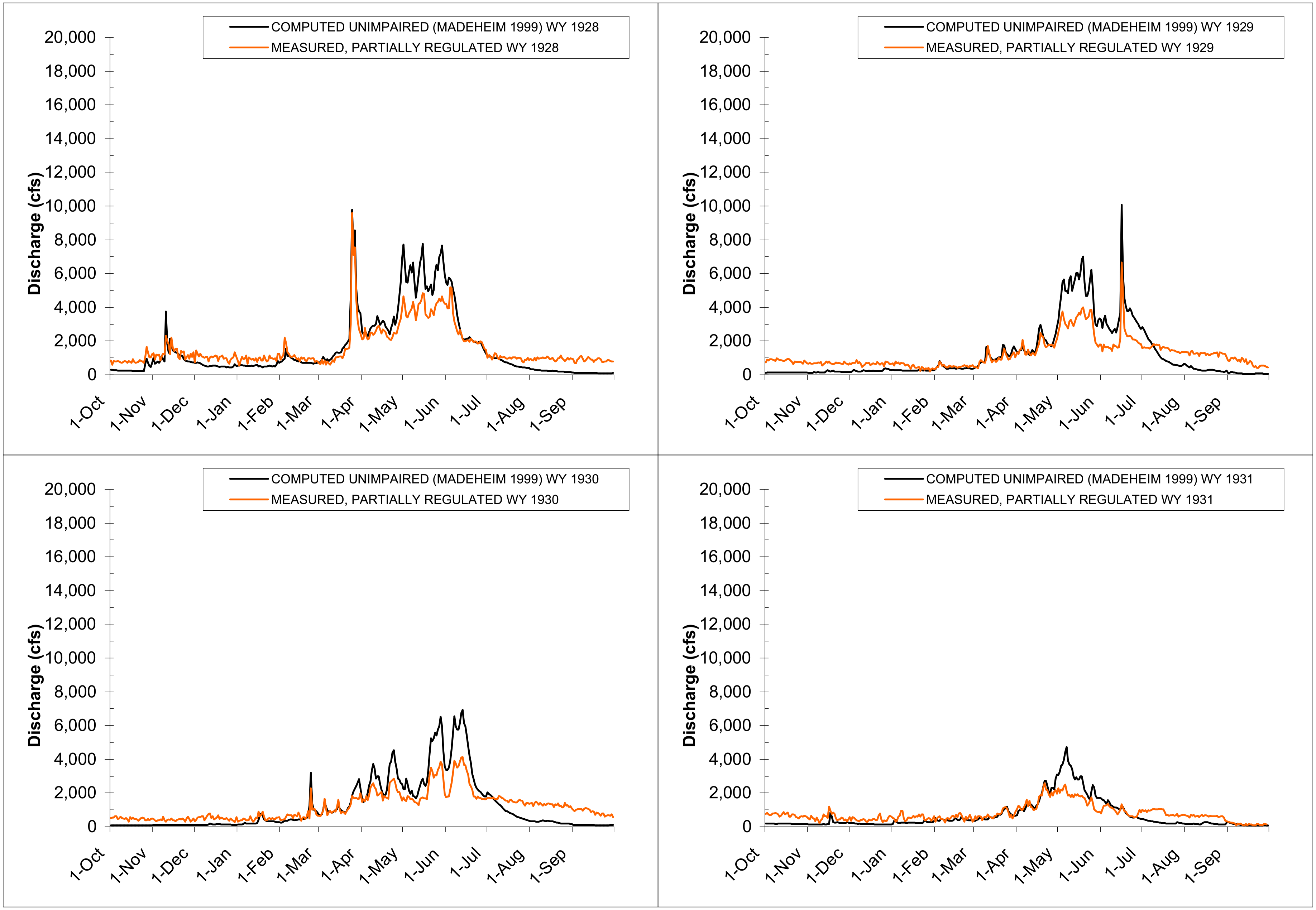

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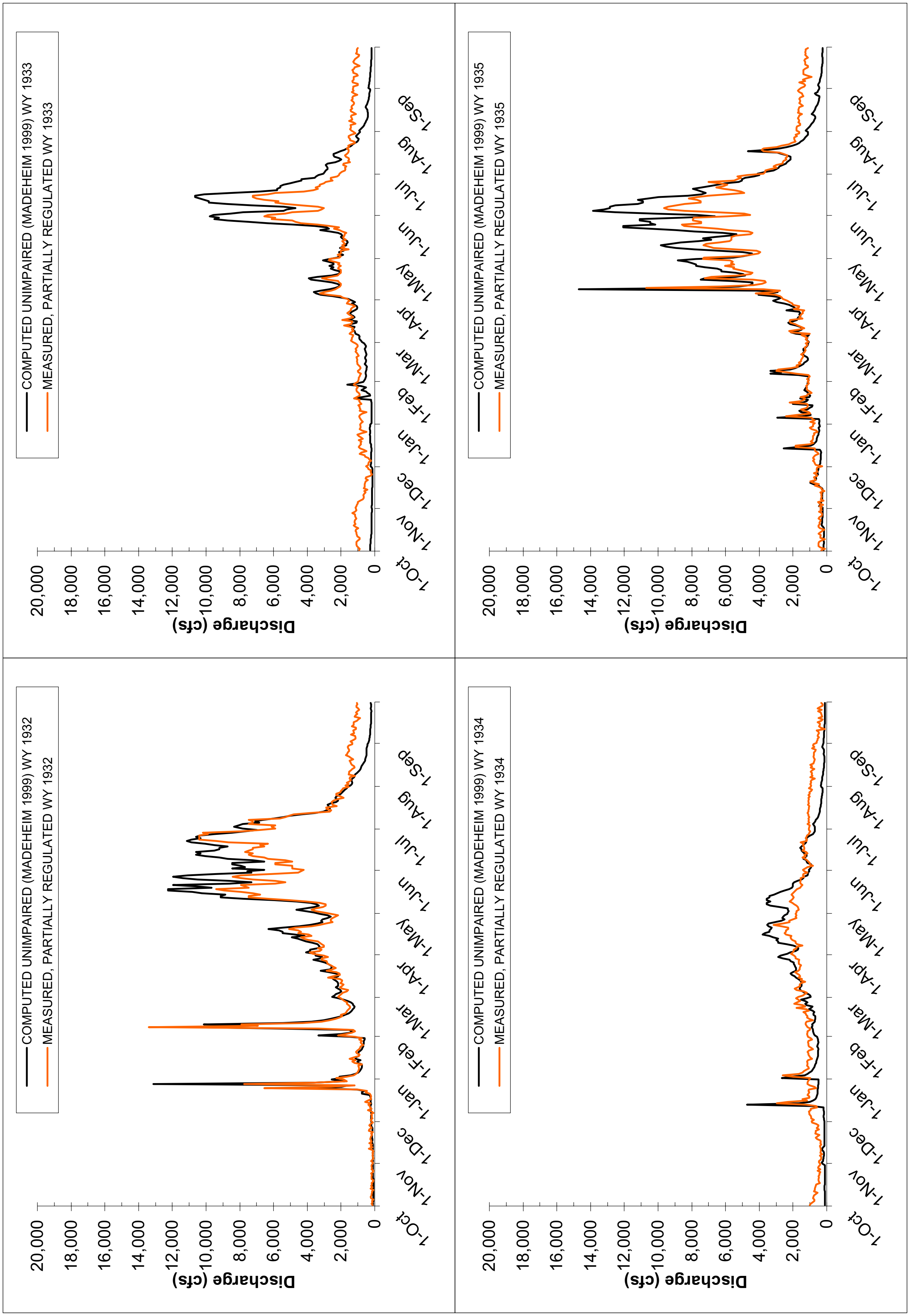

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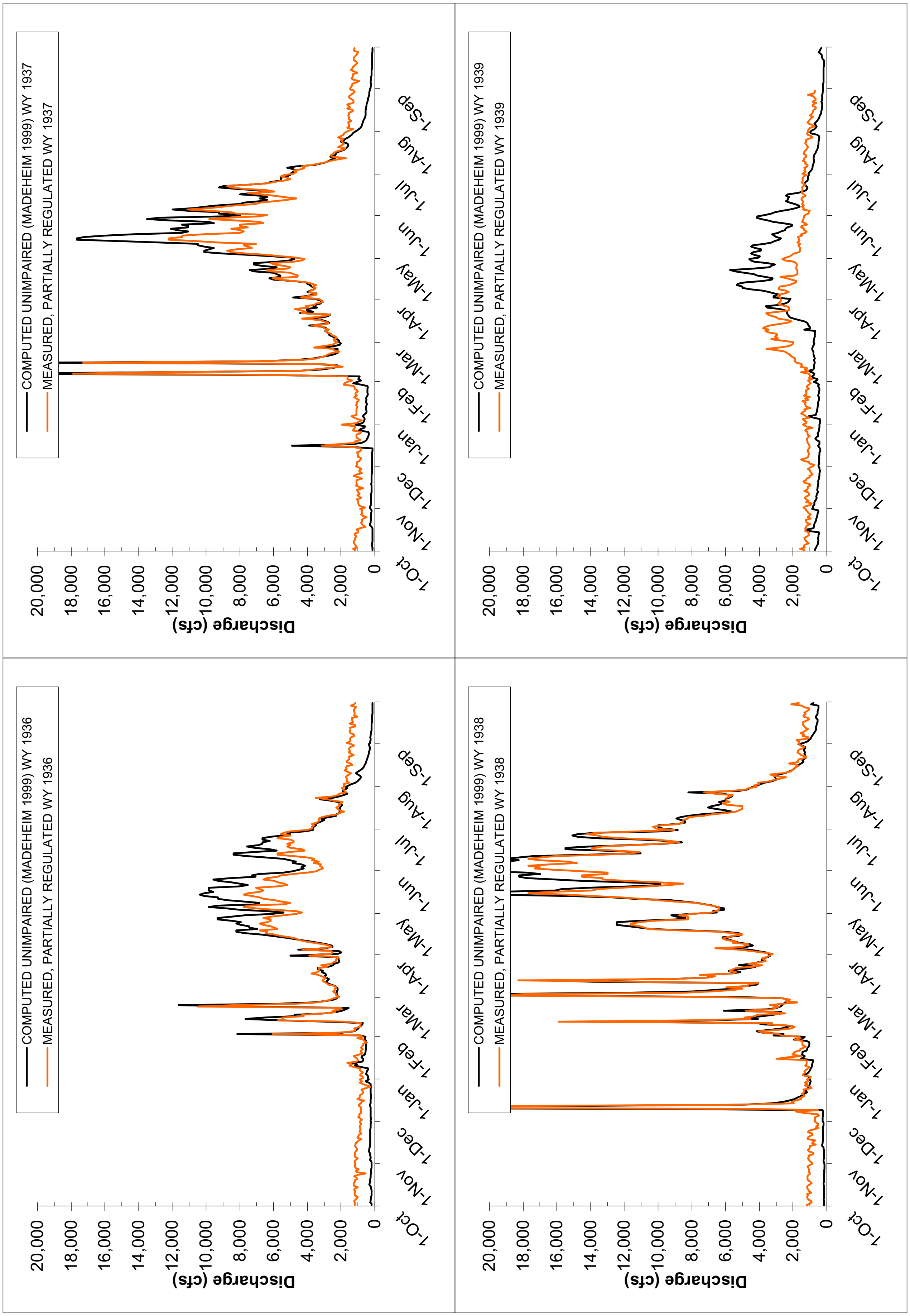

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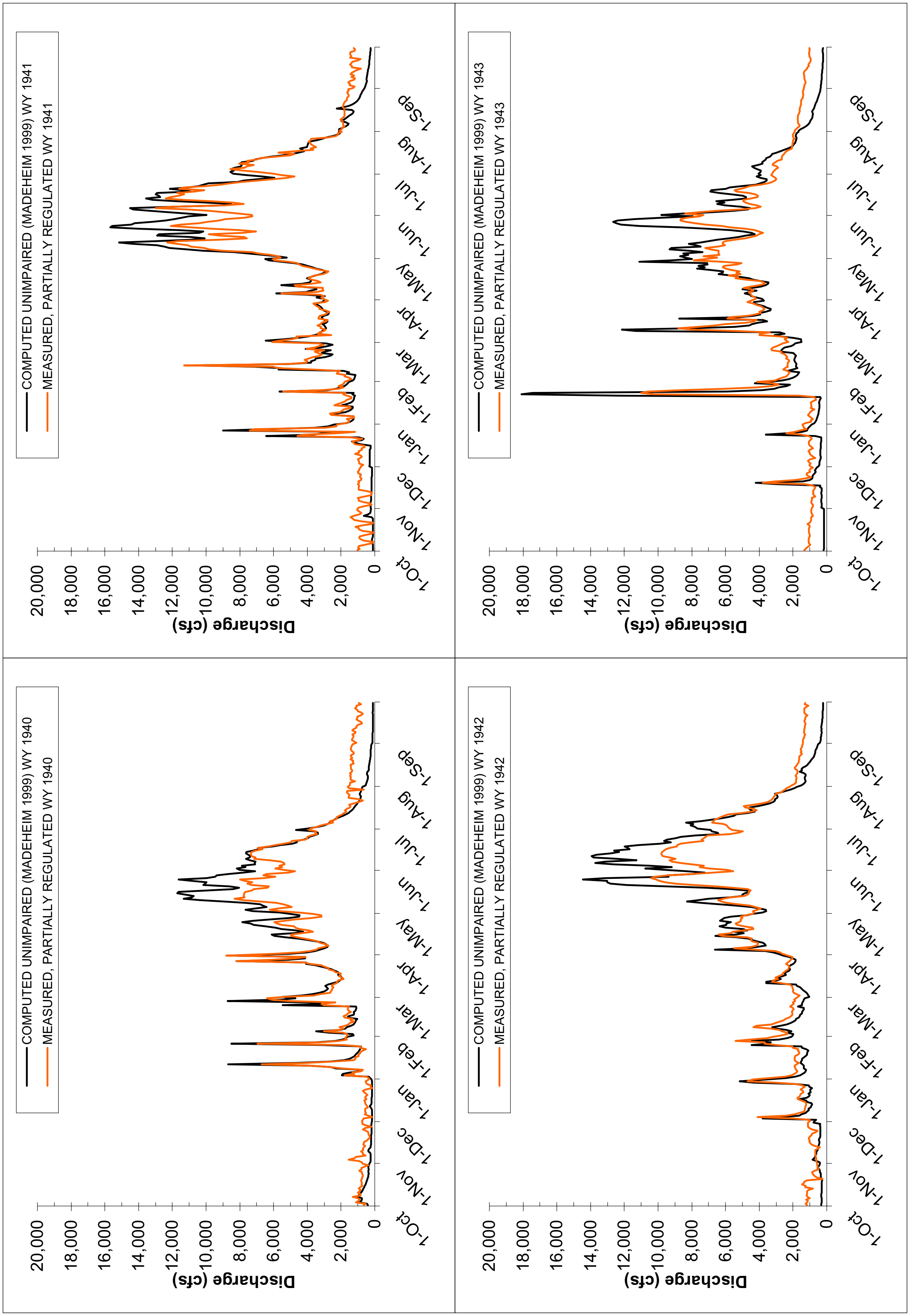

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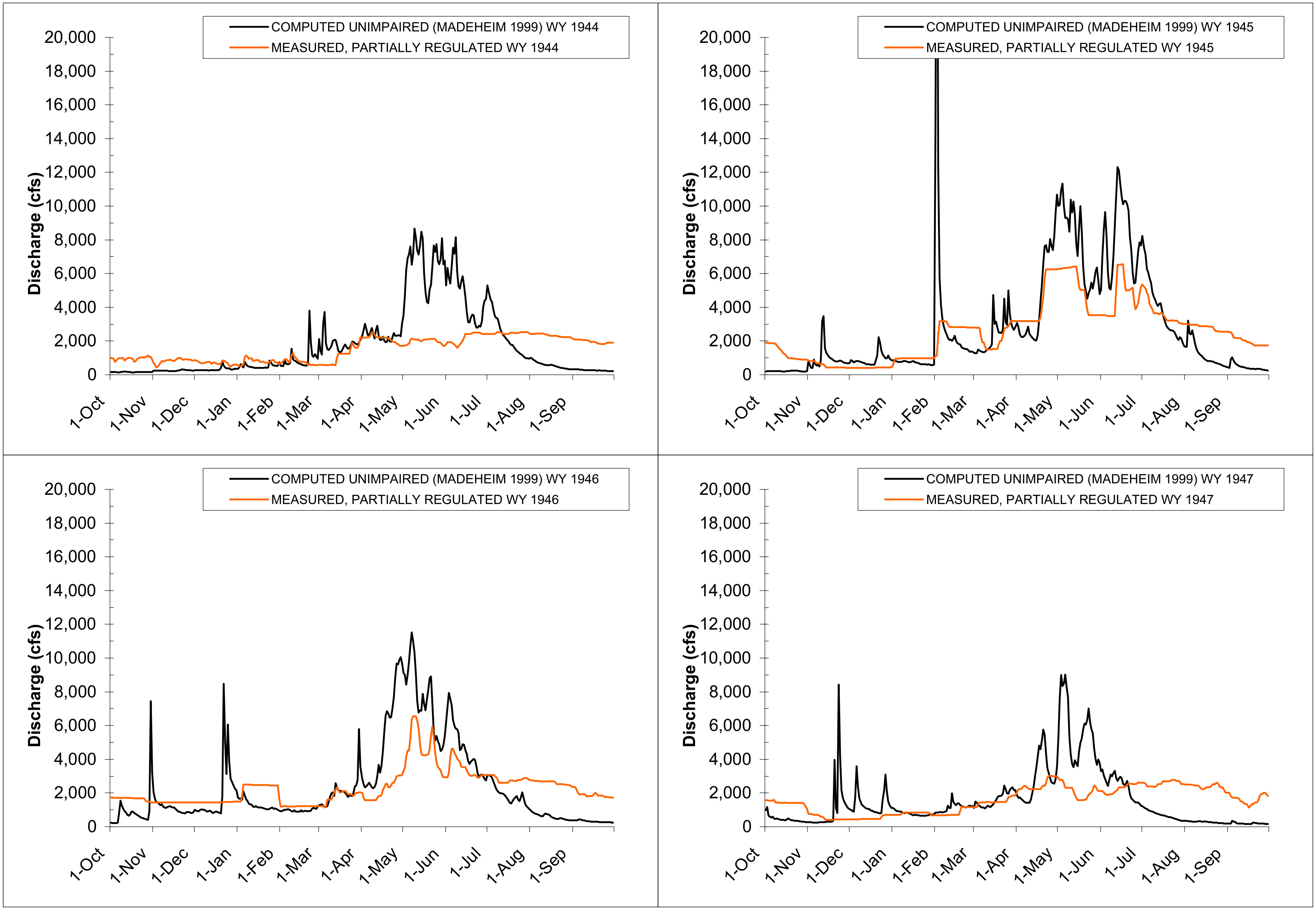

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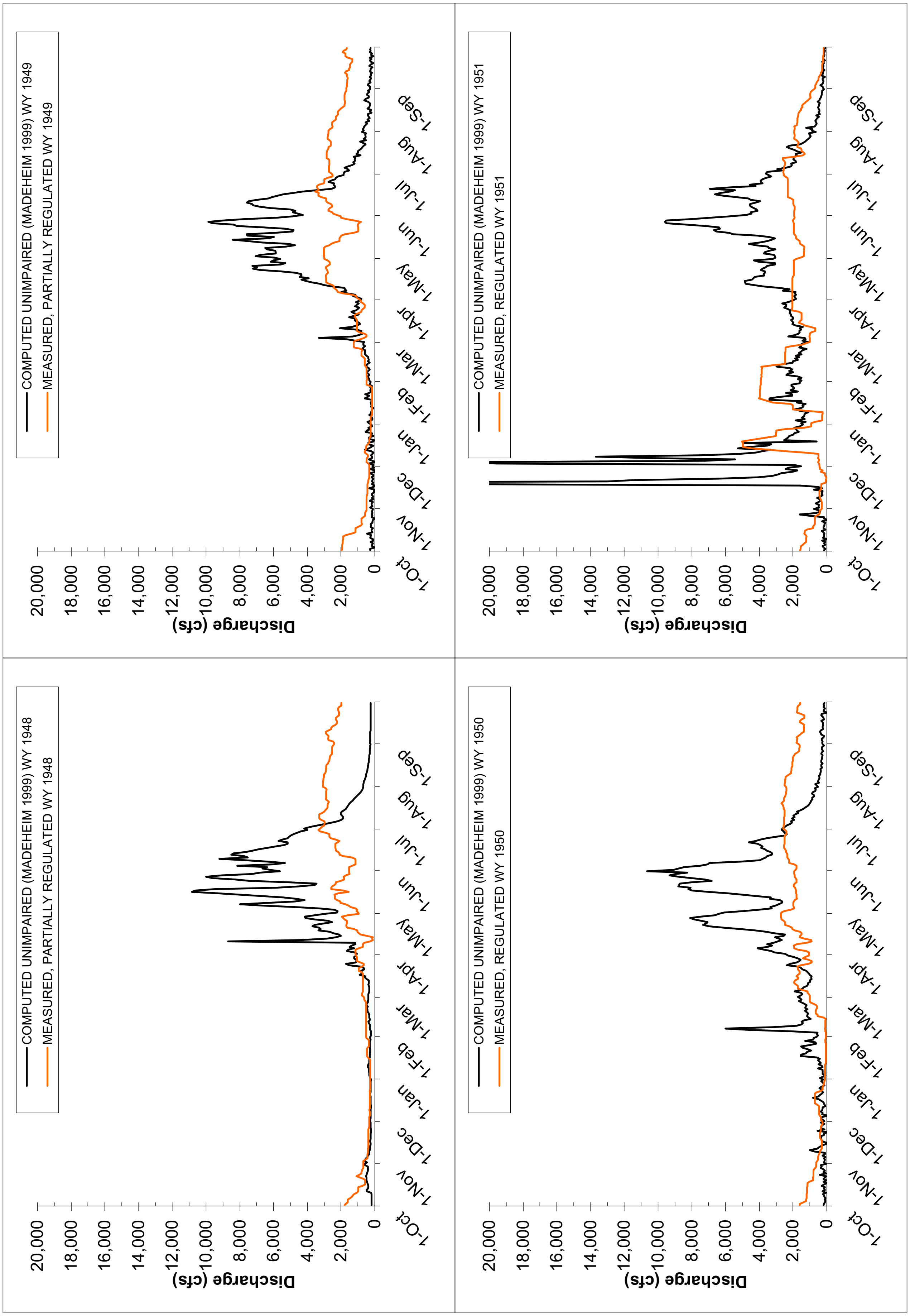

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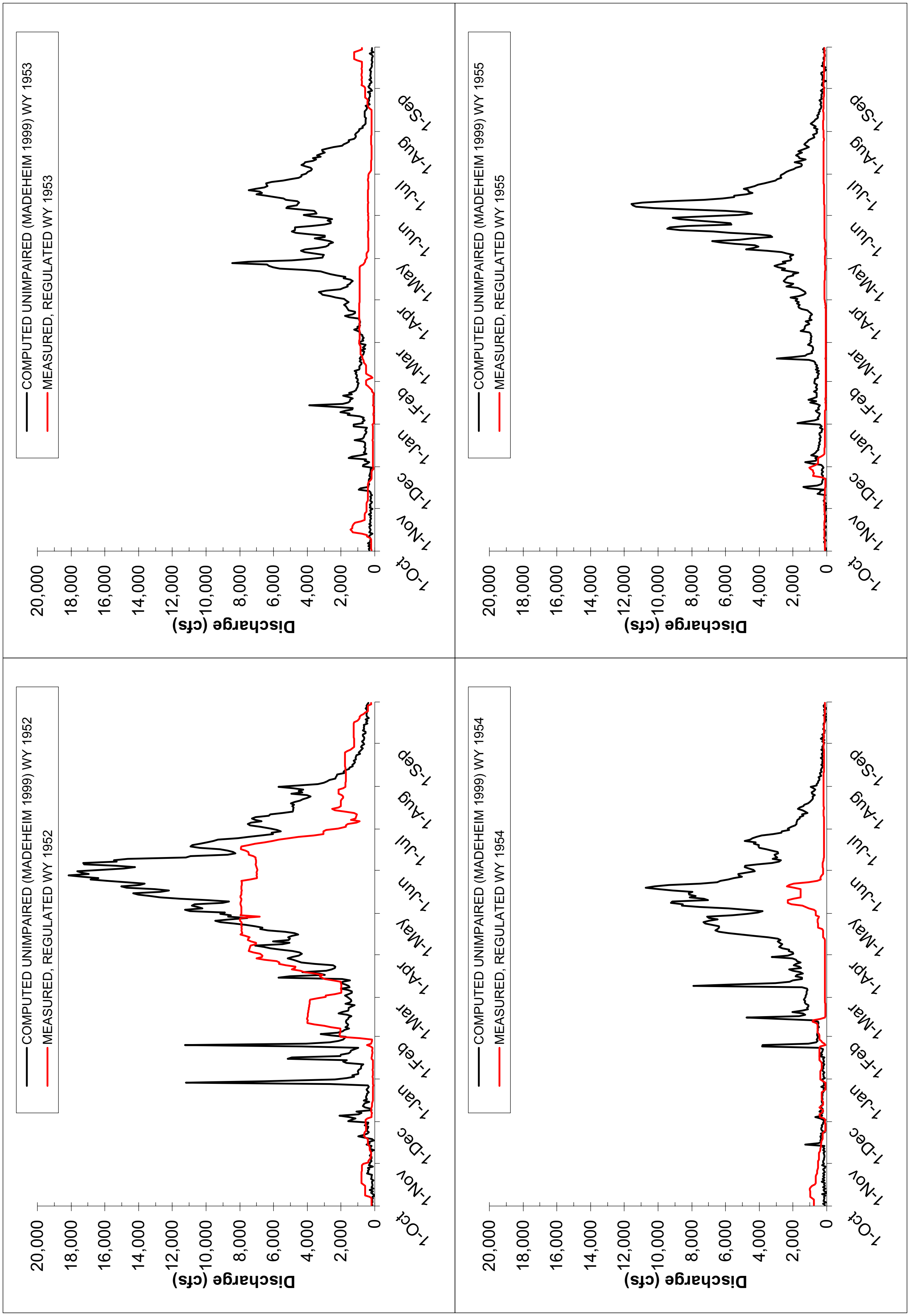

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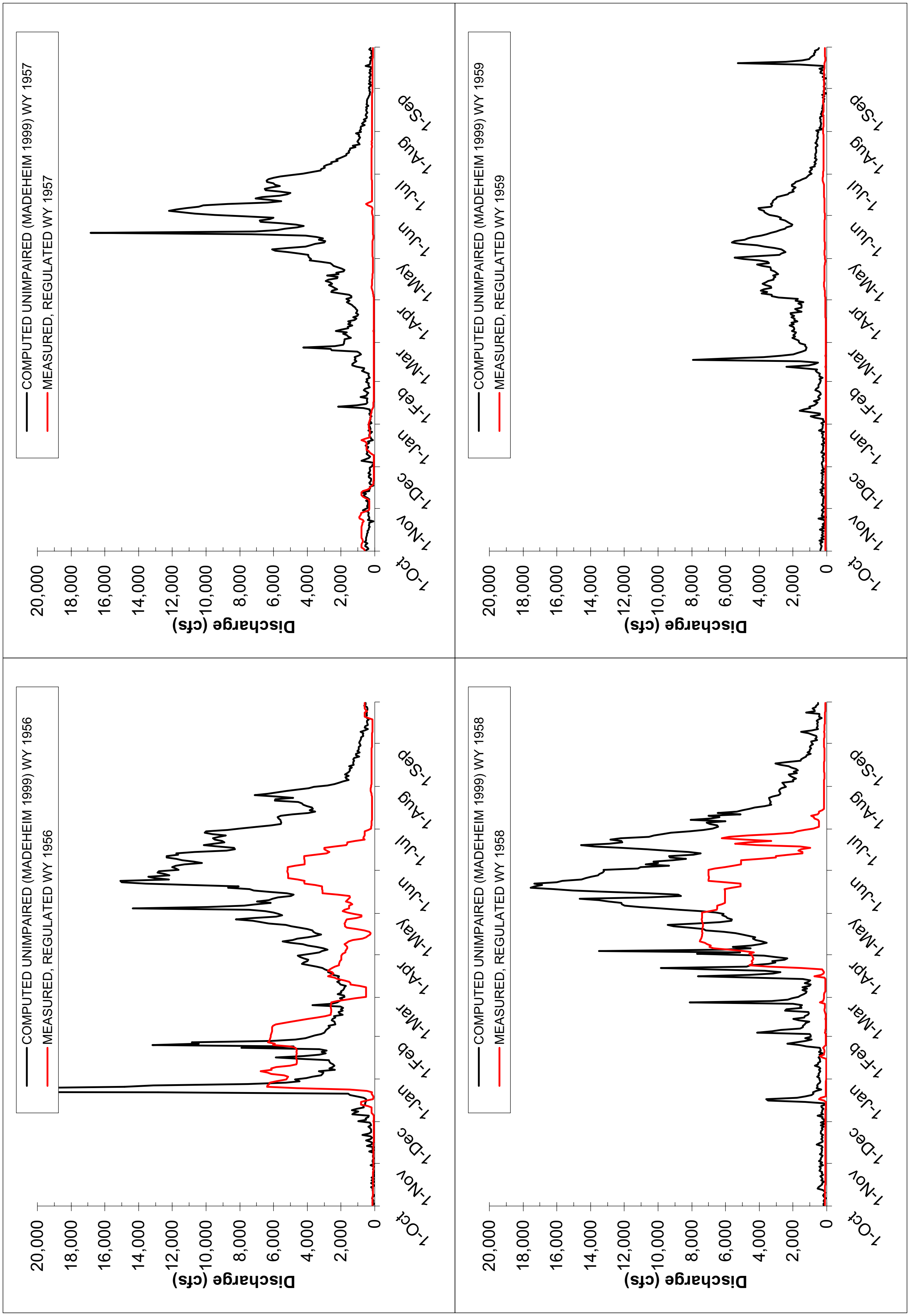

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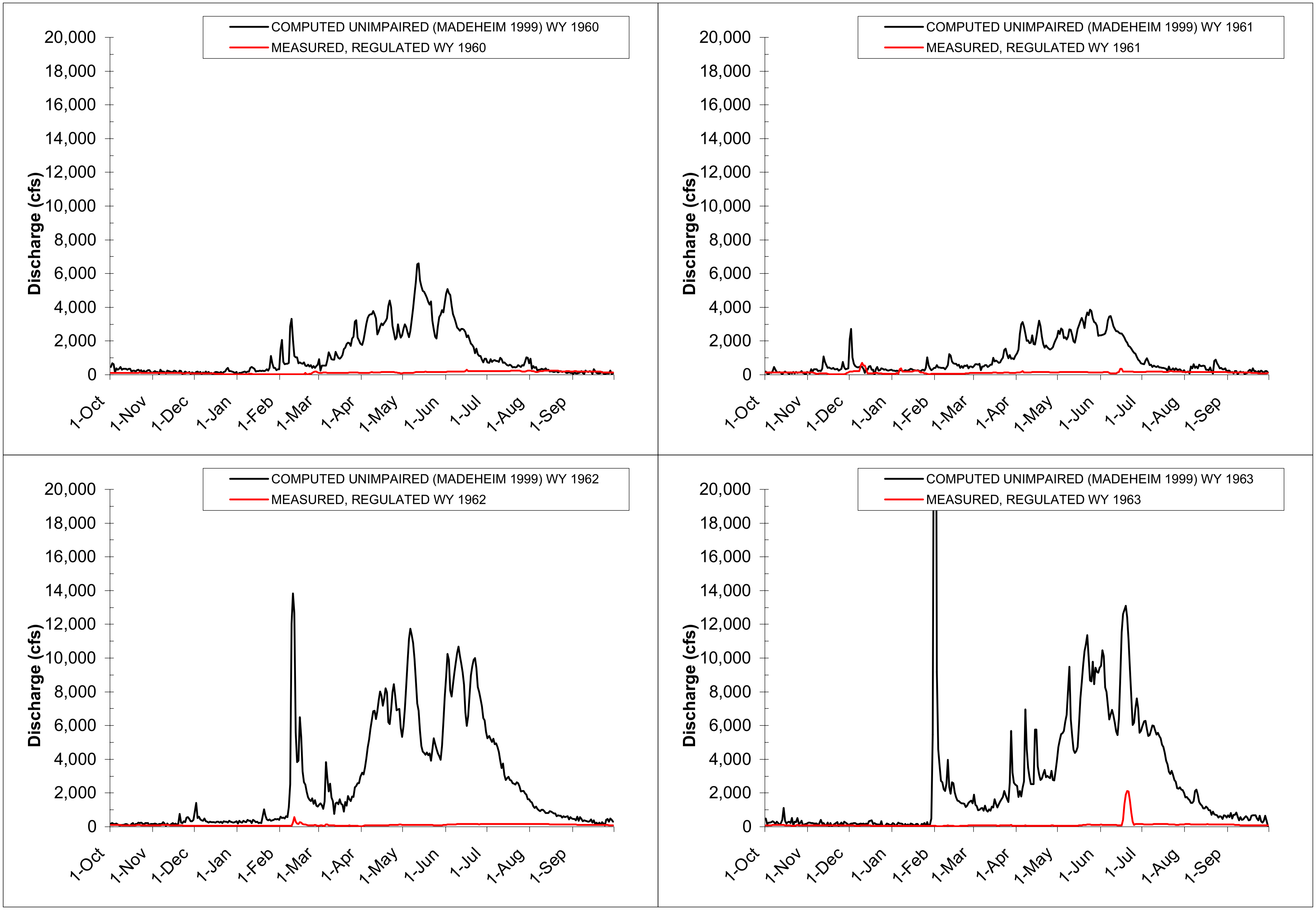

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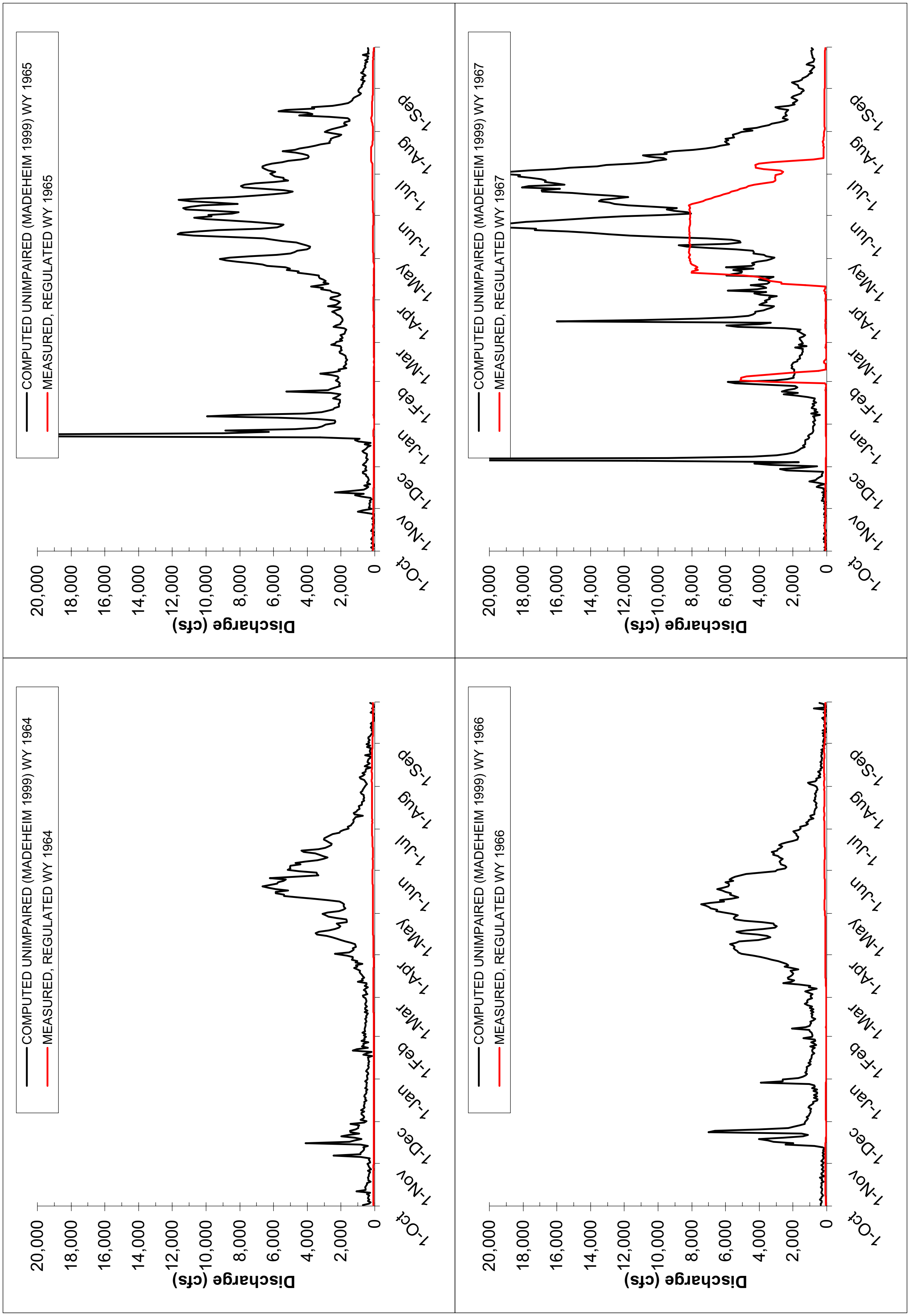

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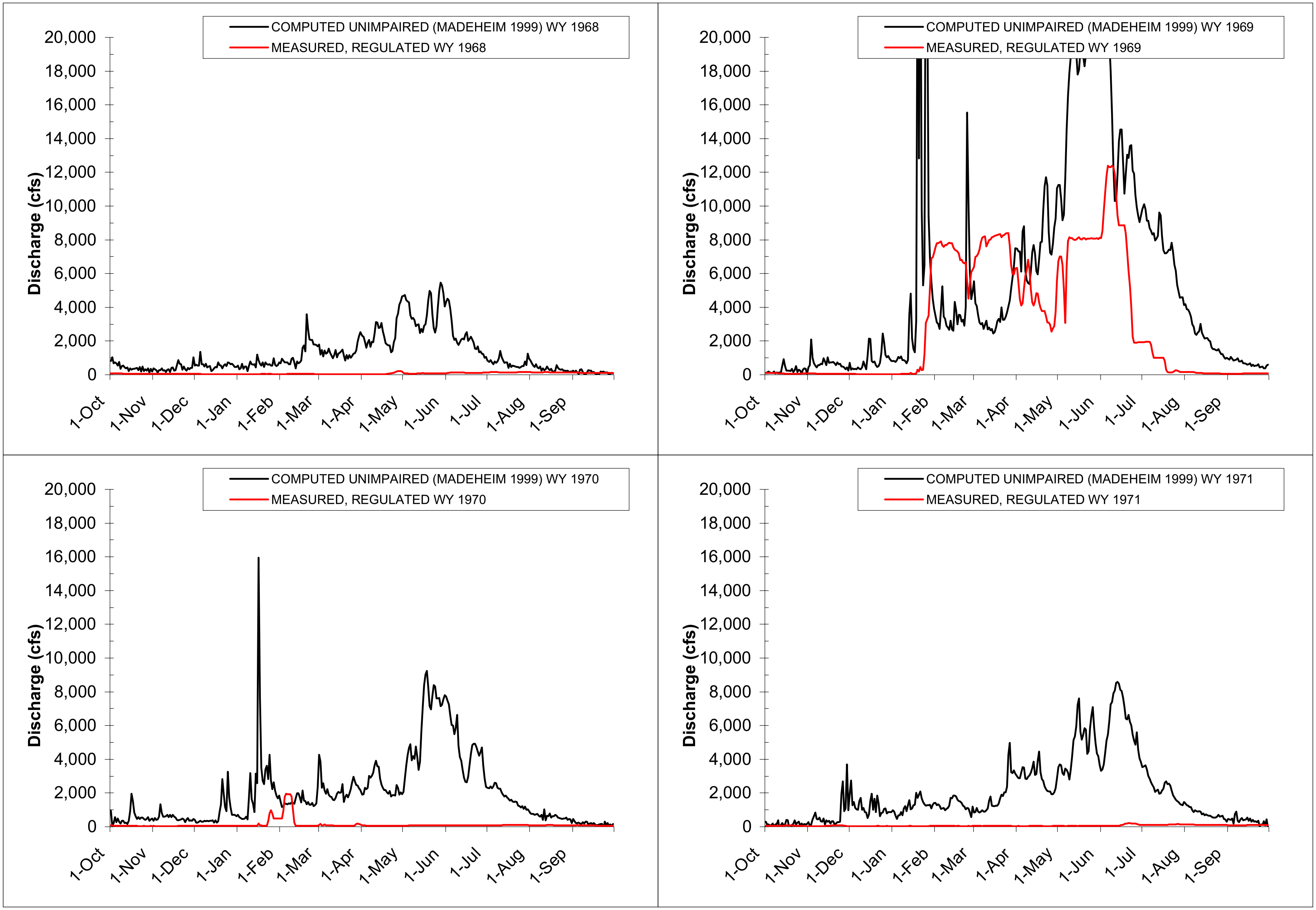

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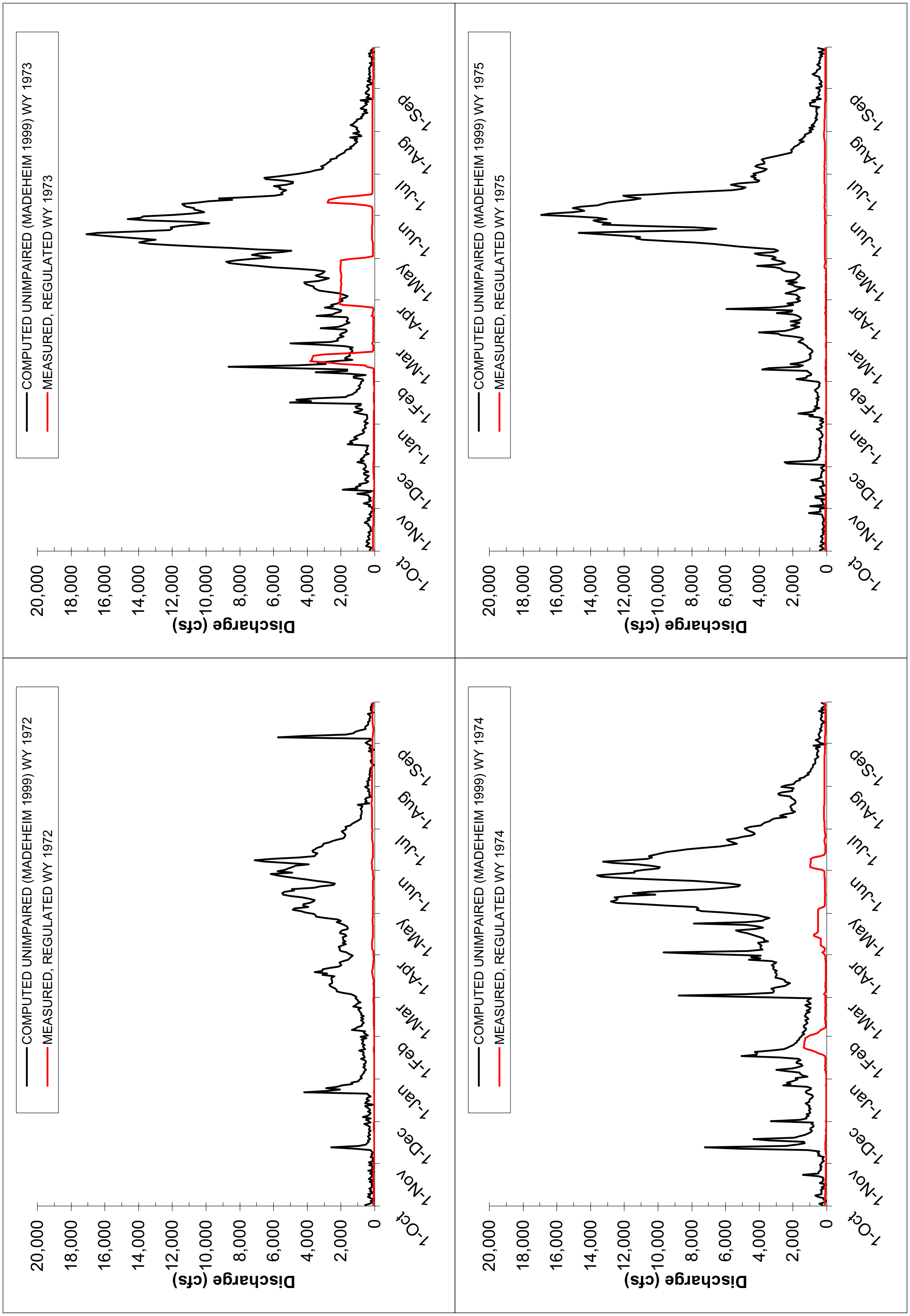

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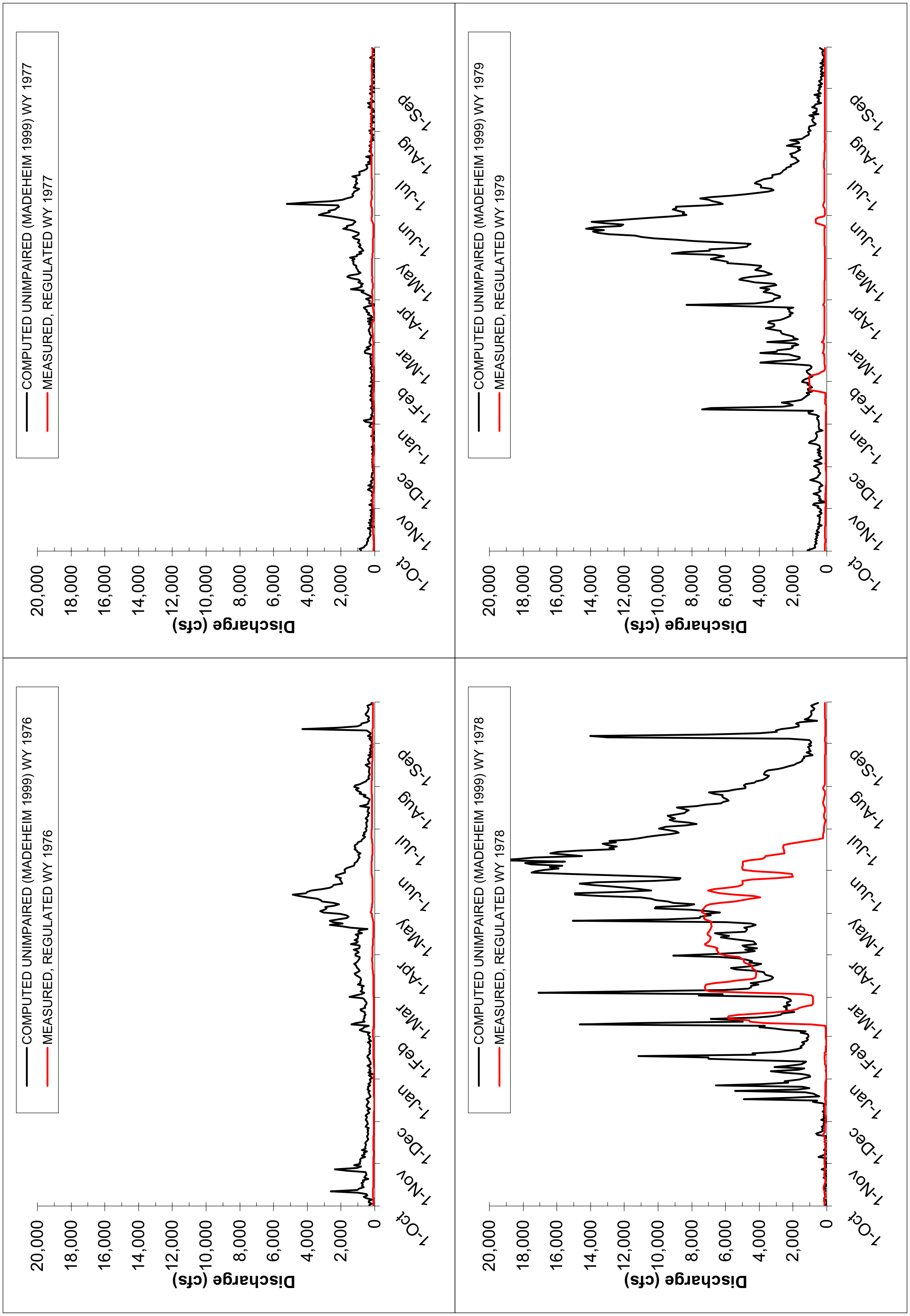

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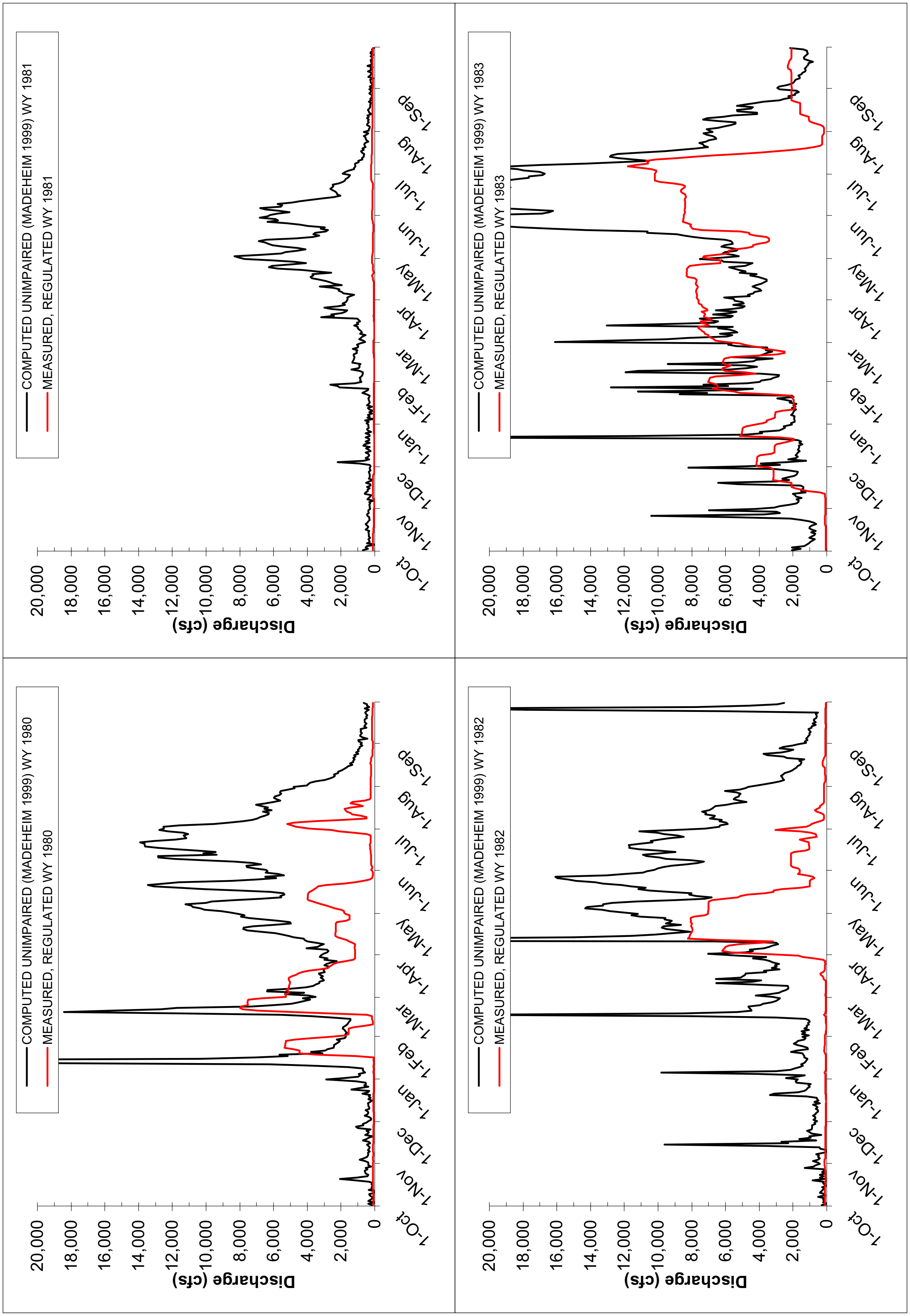

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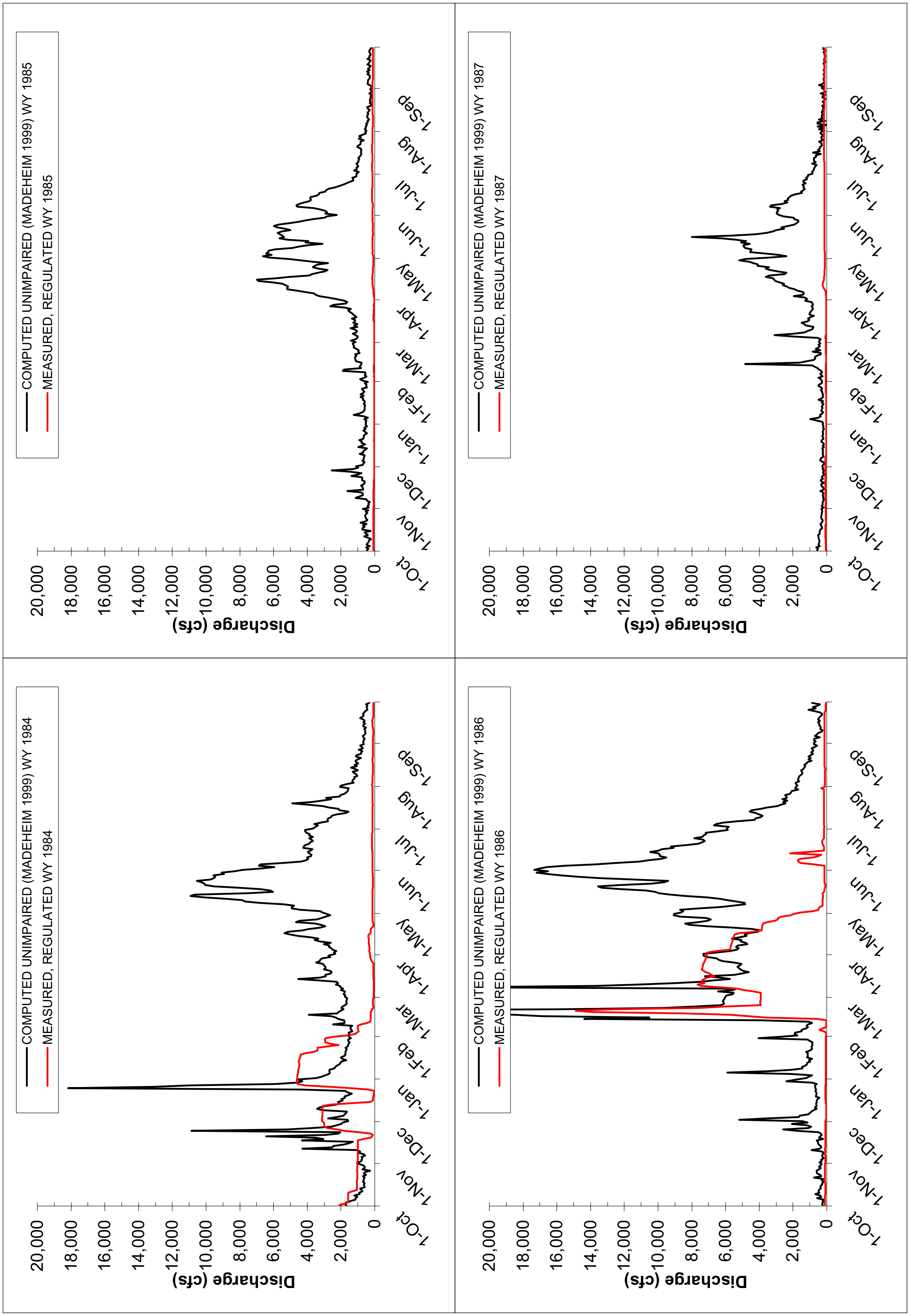

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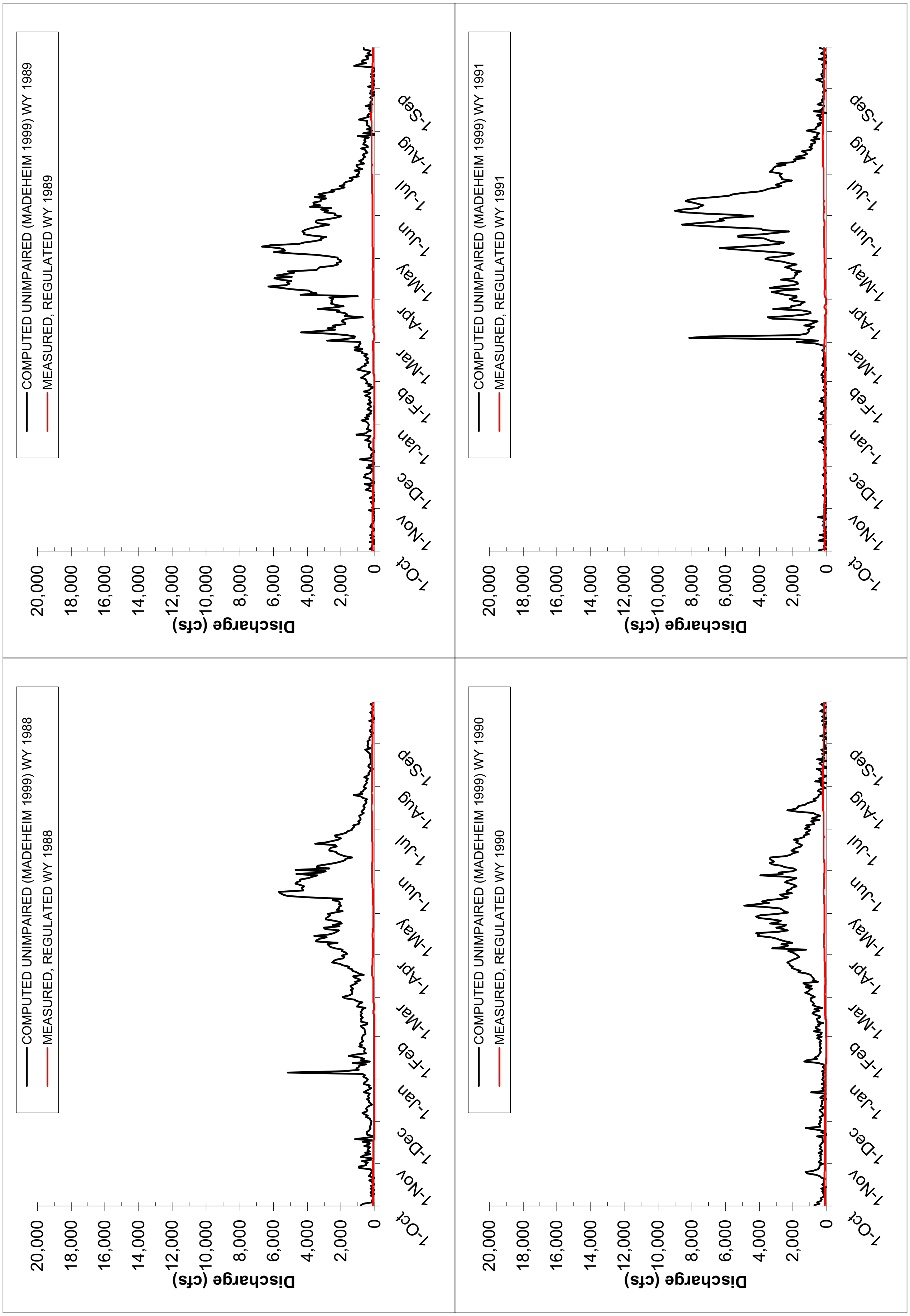

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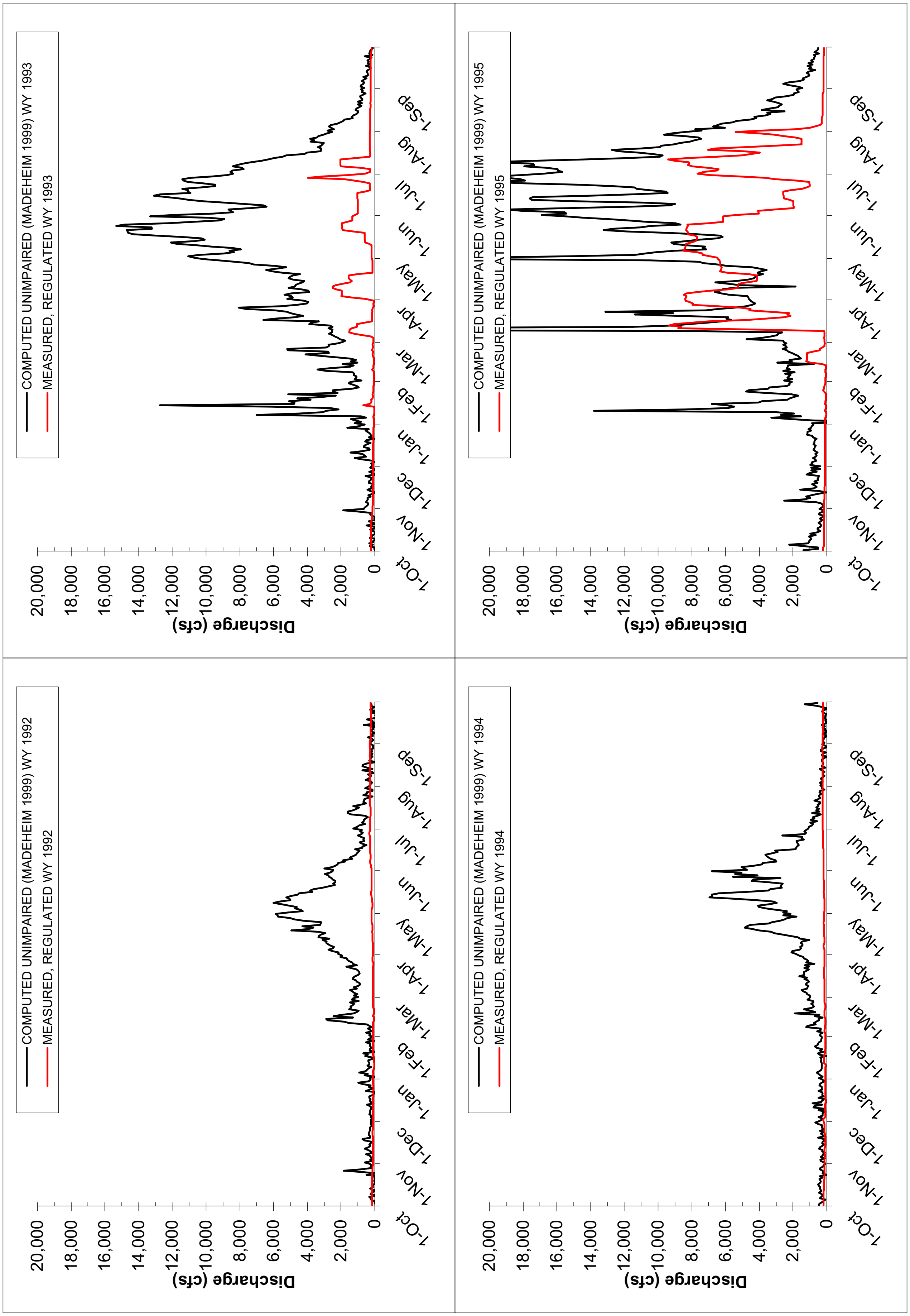

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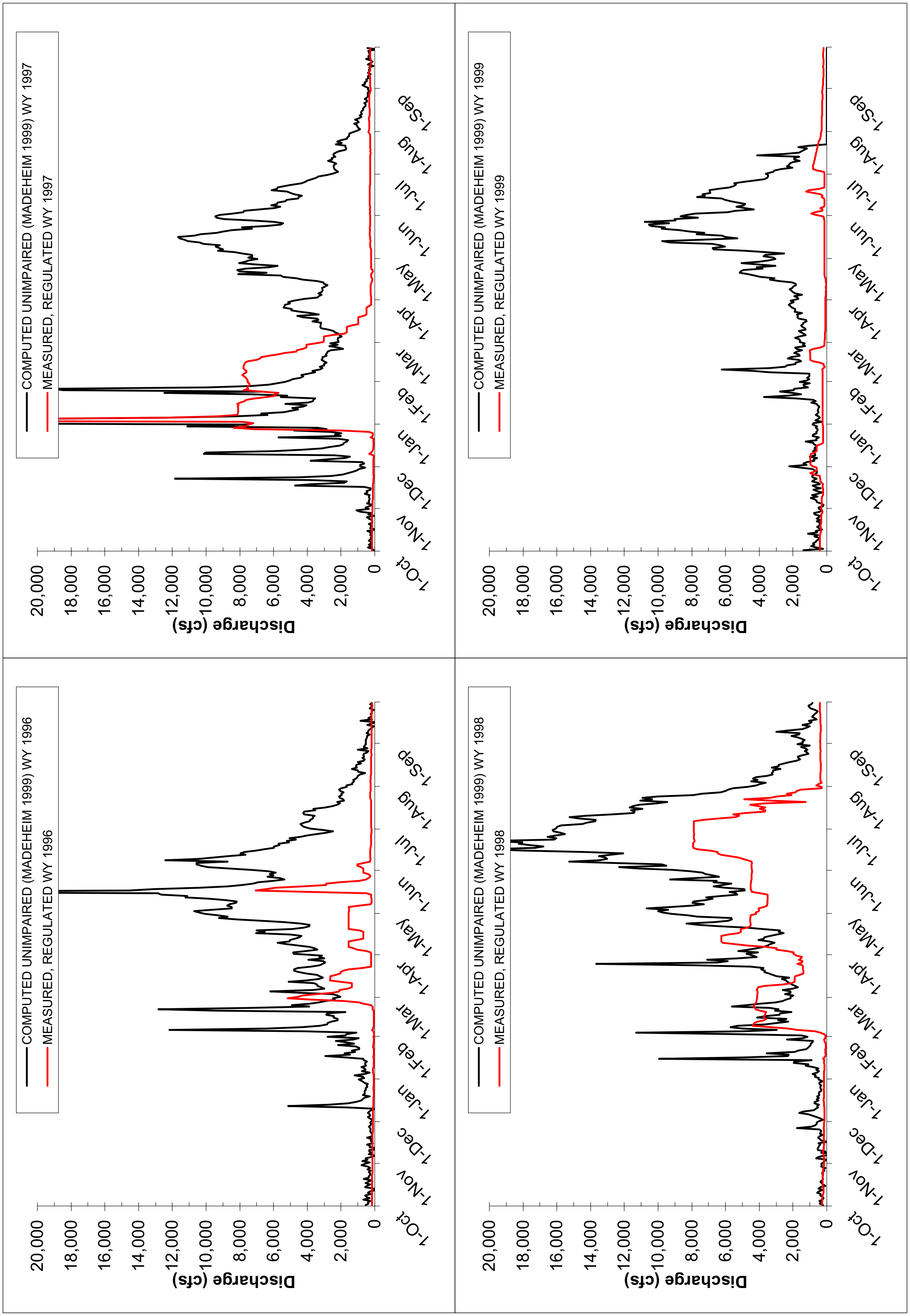


San Joaquin River blw Friant CA hydrographs for WY 1896-1999 (USGS 11-251000)

APPENDIX A

ANNUAL HYDROGRAPHS OF SELECTED GAGING STATIONS ON THE SAN JOAQUIN RIVER AND TRIBUTARIES

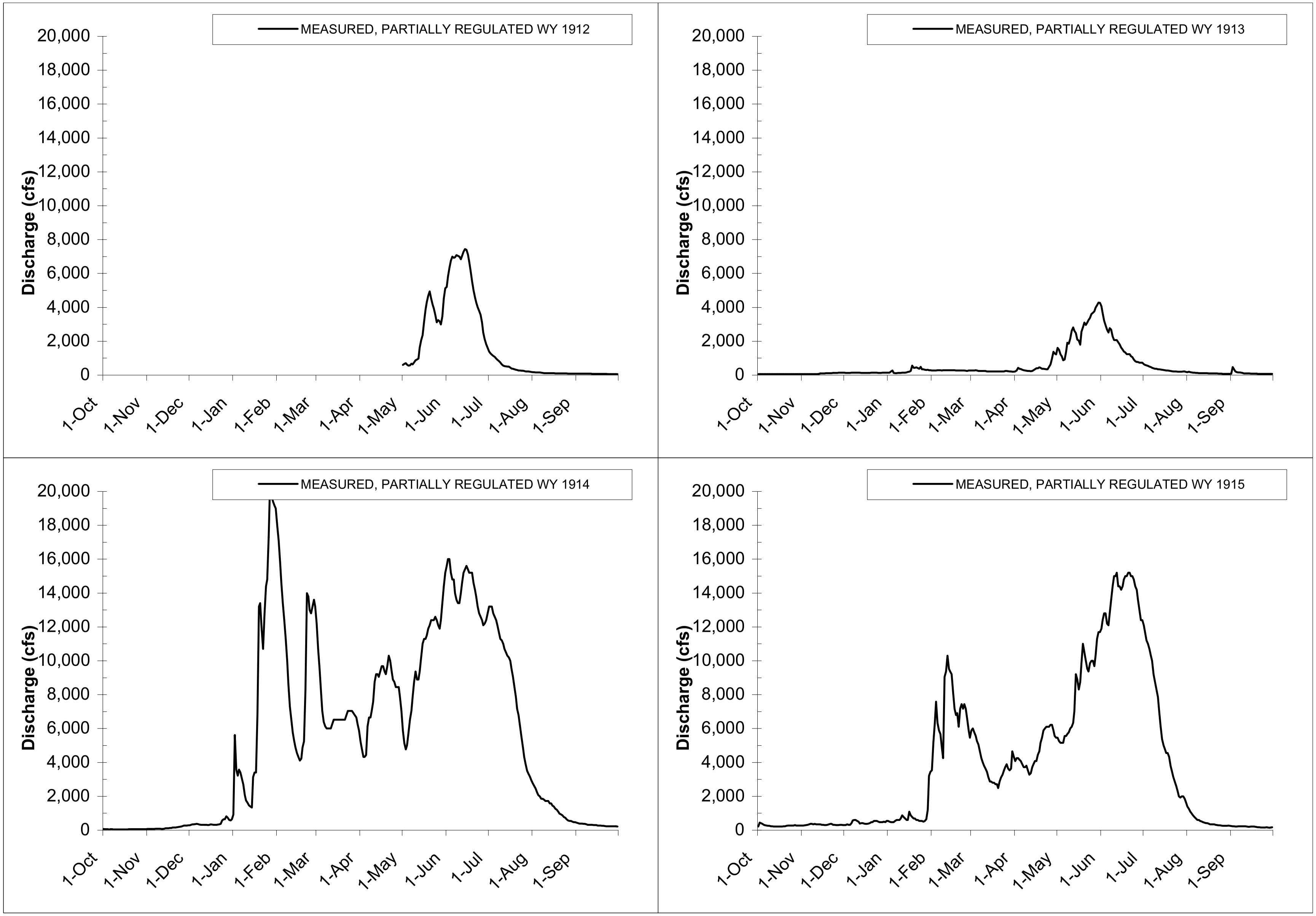
APPENDIX A-2

SAN JOAQUIN RIVER NEAR NEWMAN

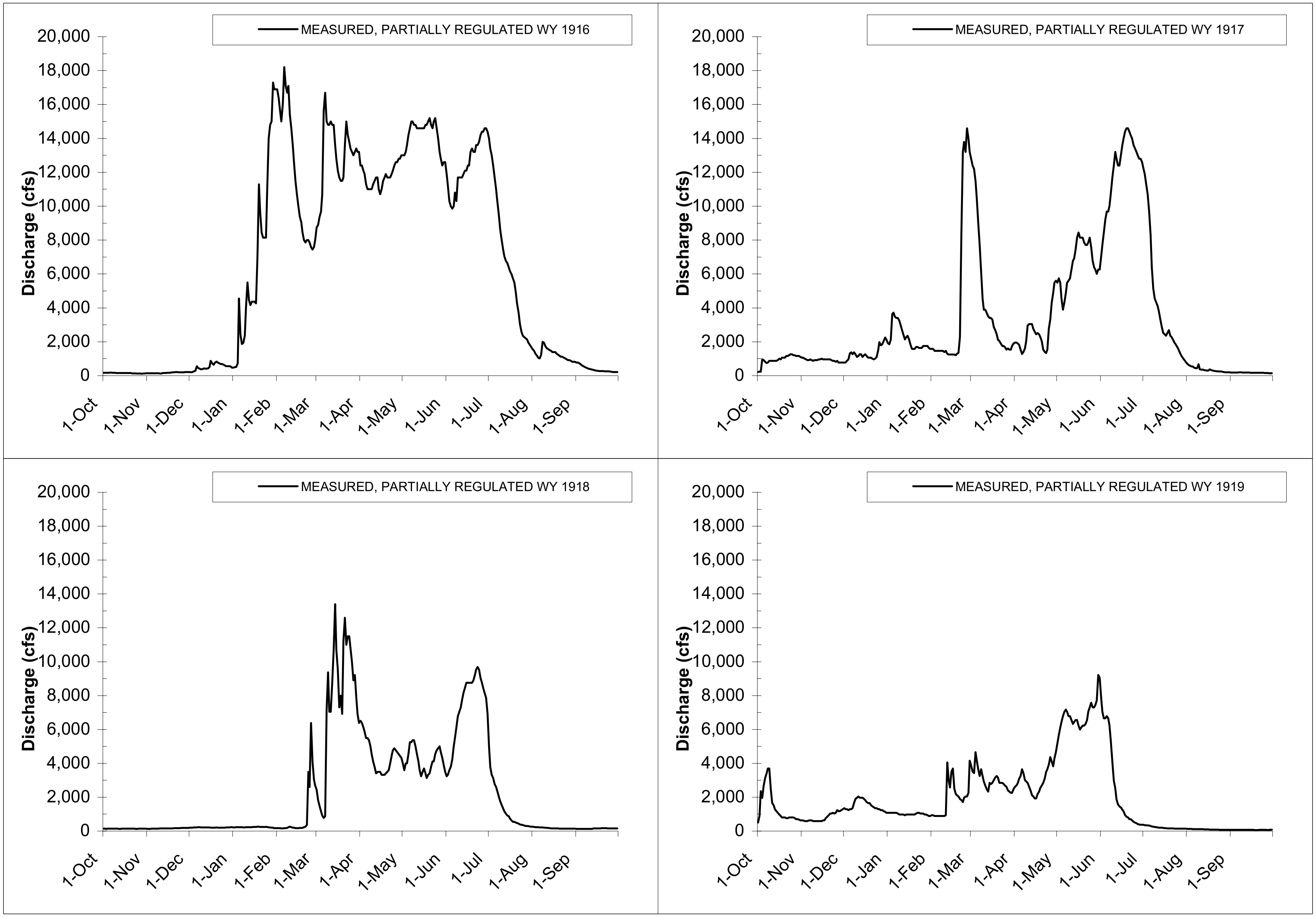
USGS GAGING STATION # 11-273000

TOTAL DRAINAGE AREA=9,520 SQ MI

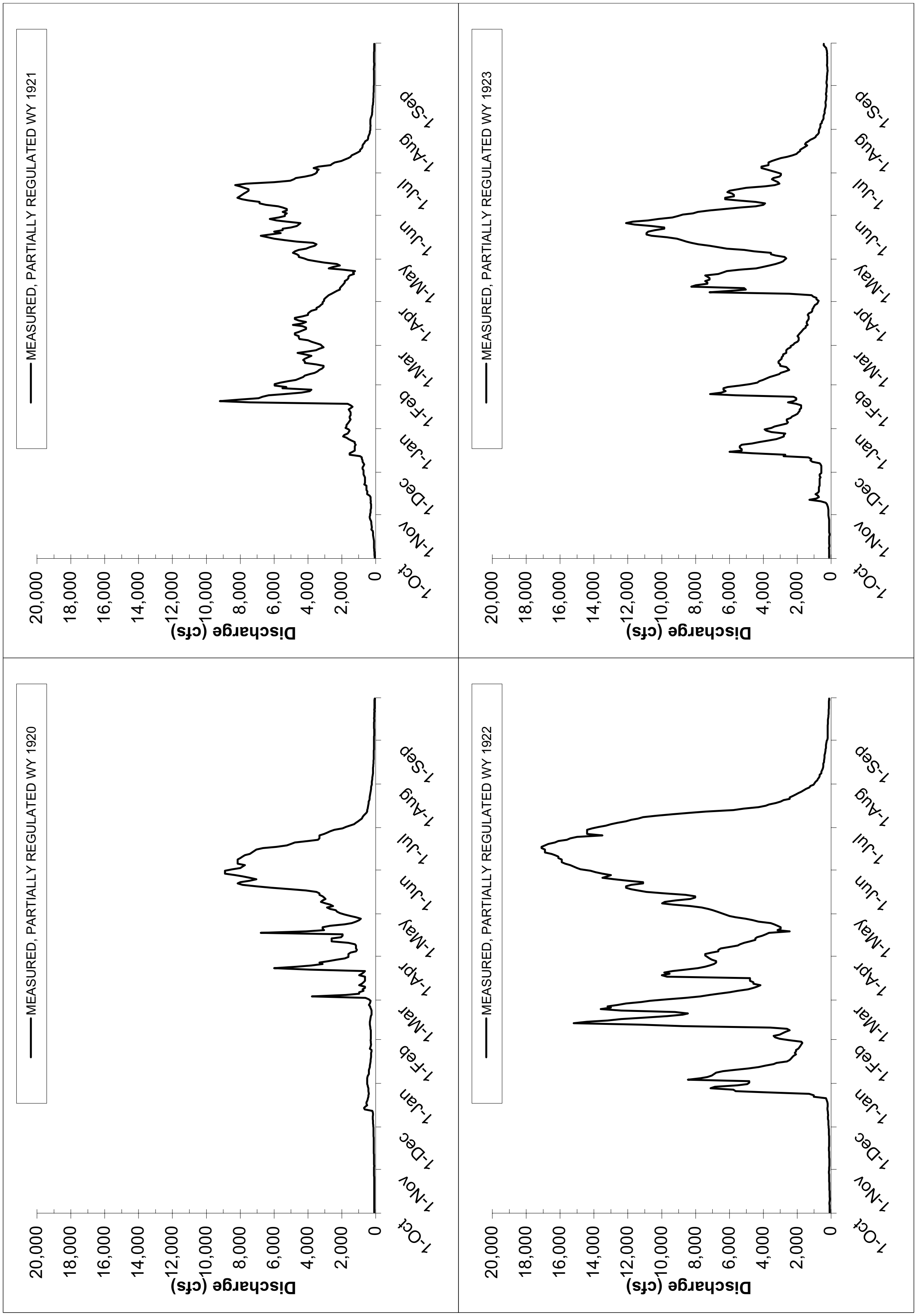
PERIOD OF RECORD: 1913-PRESENT



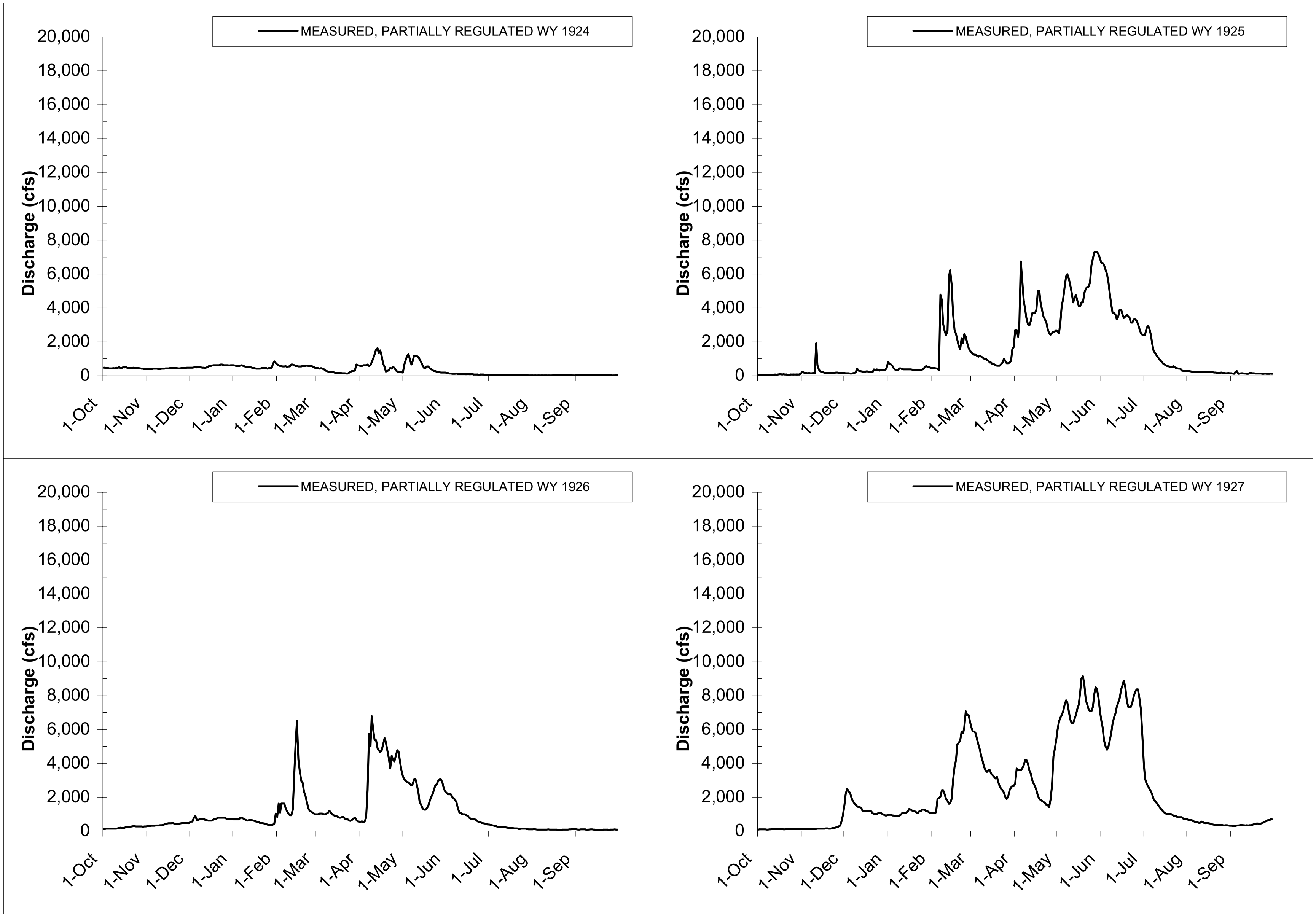
San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



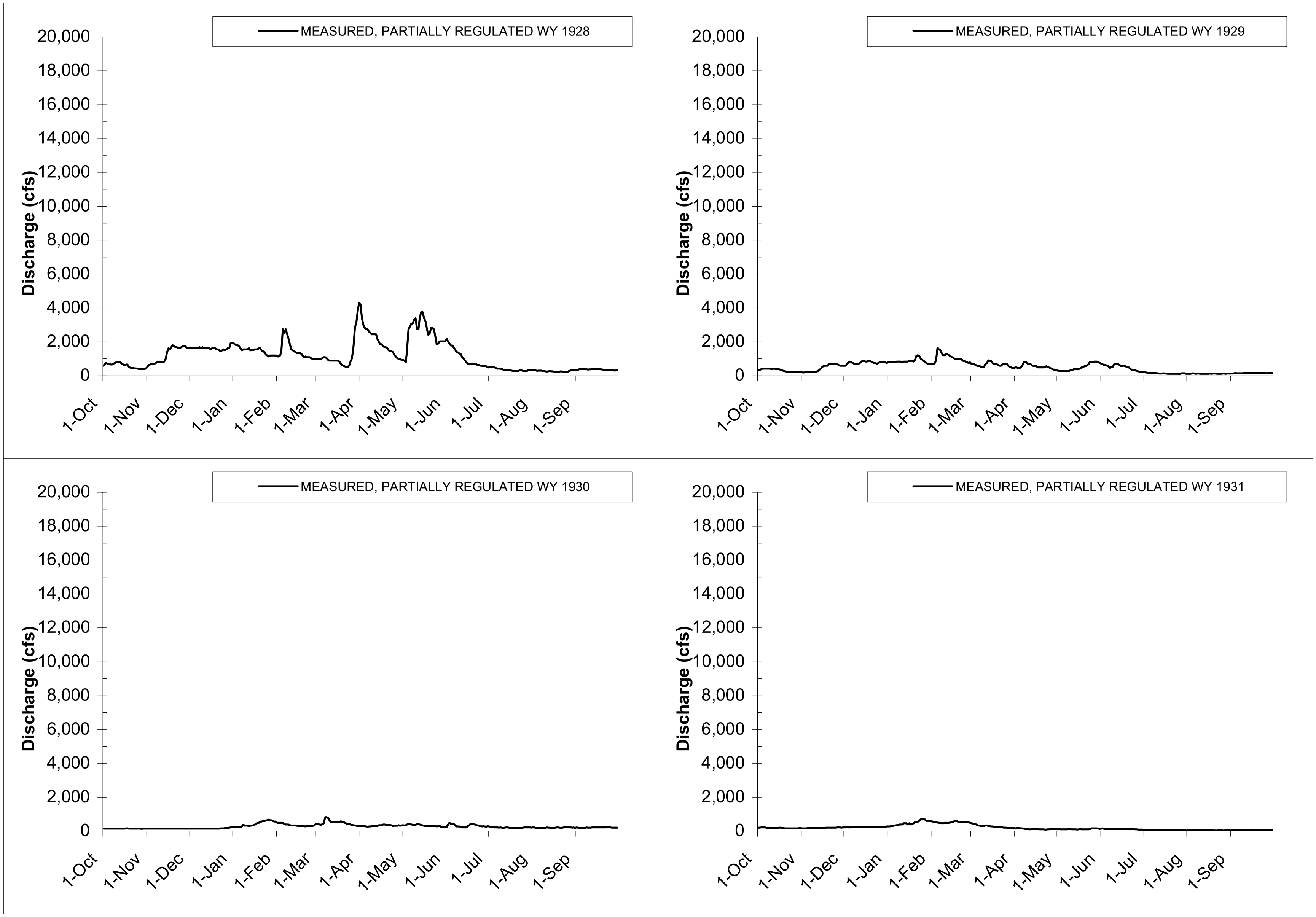
San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



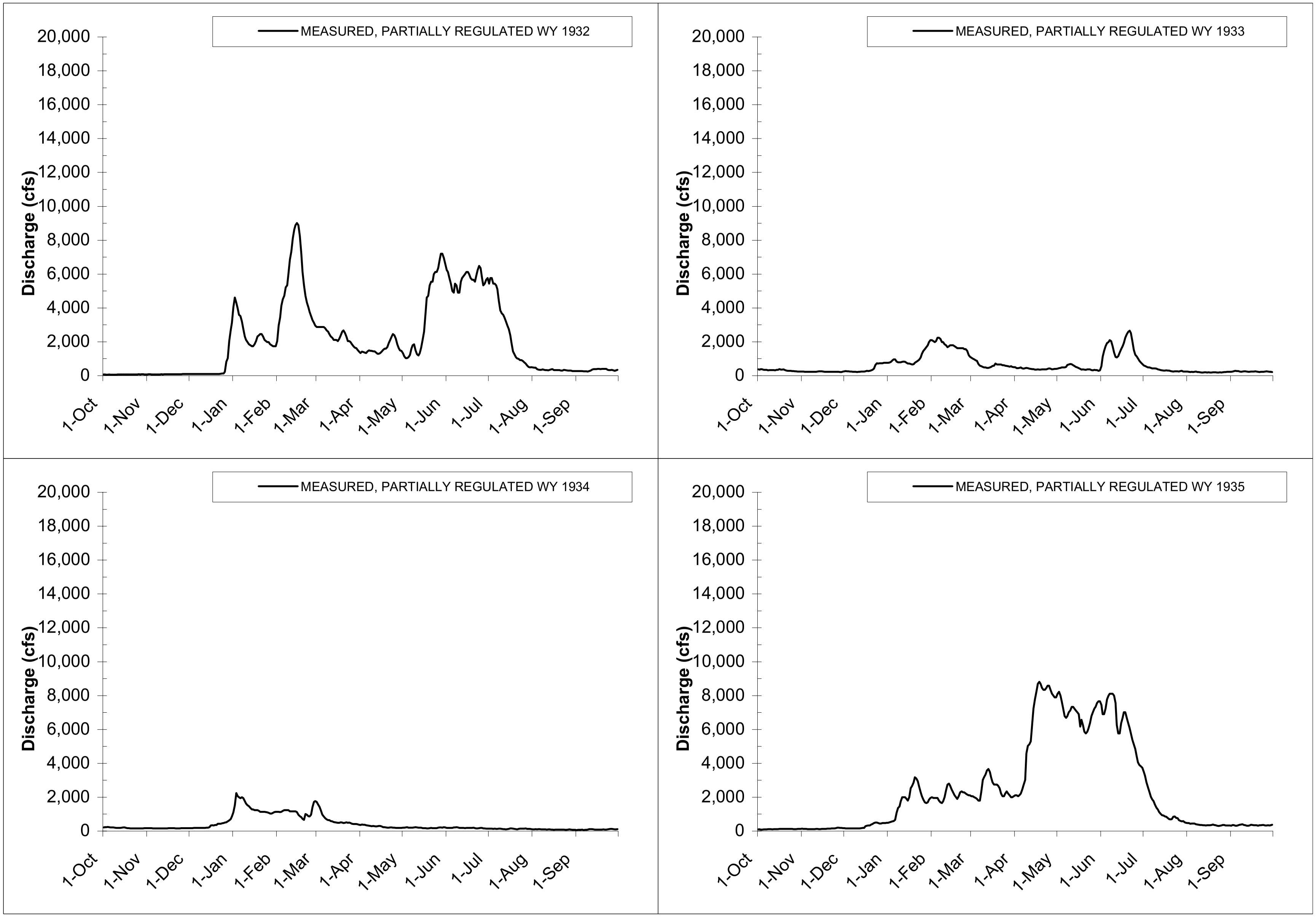
San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



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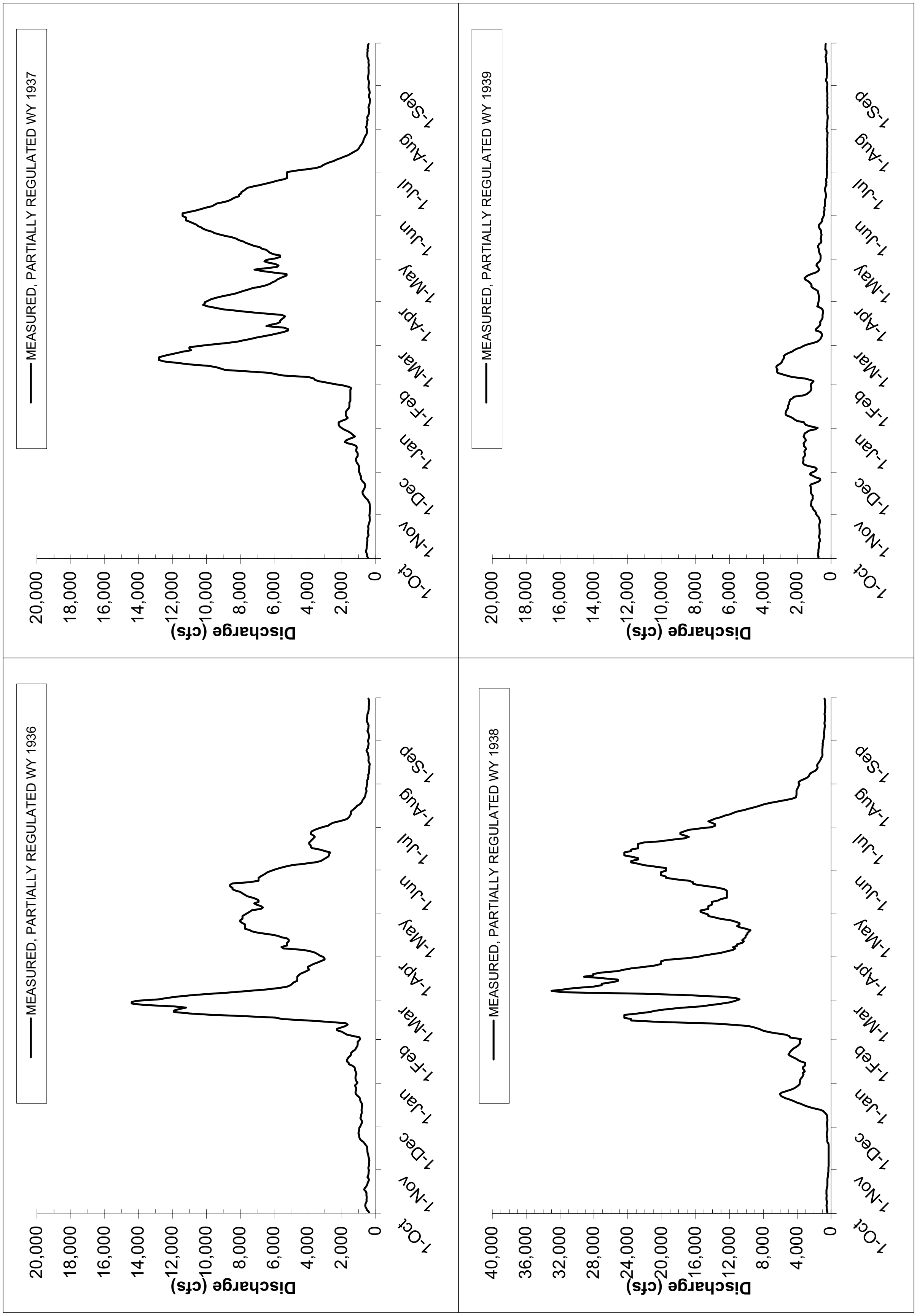

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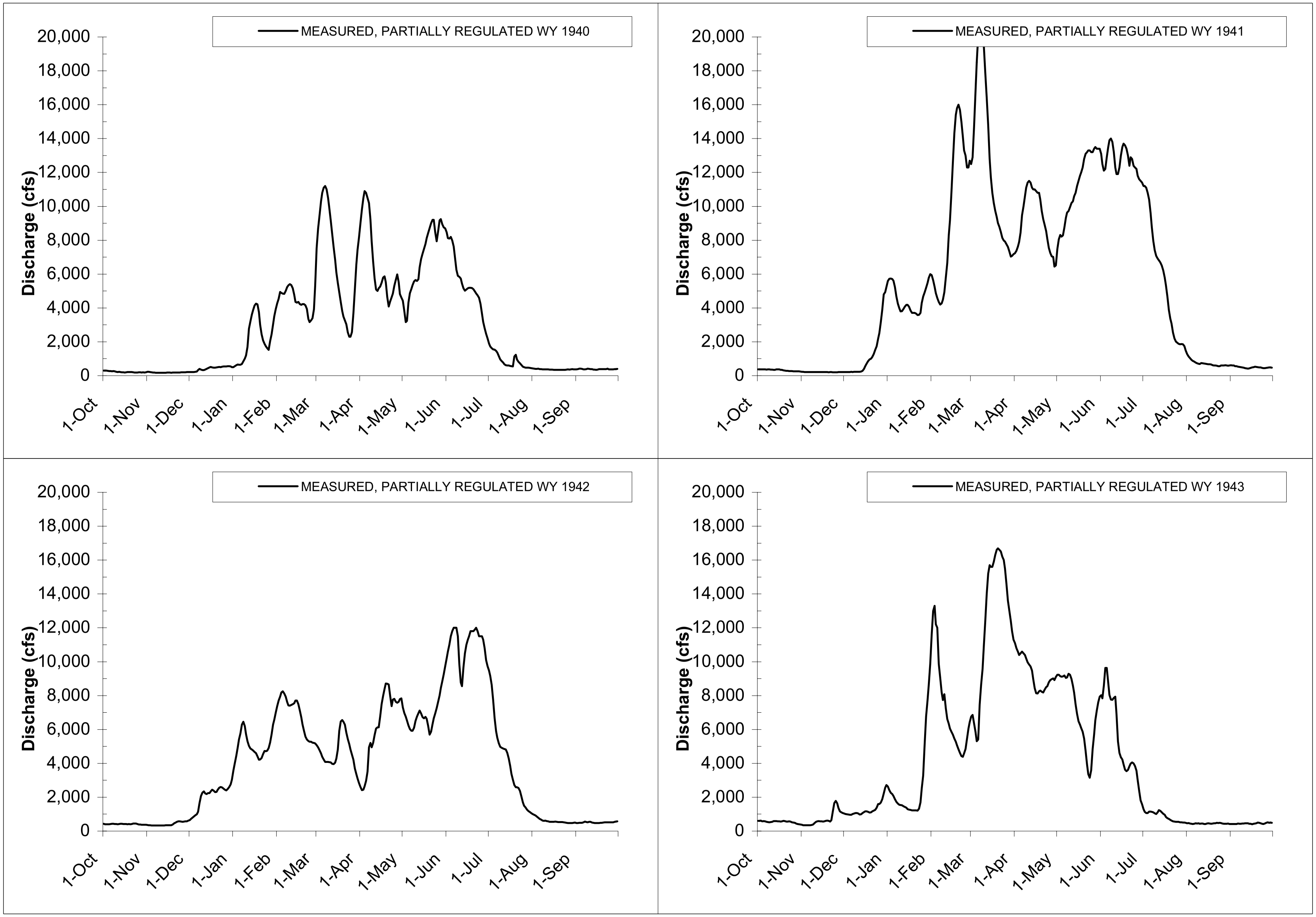

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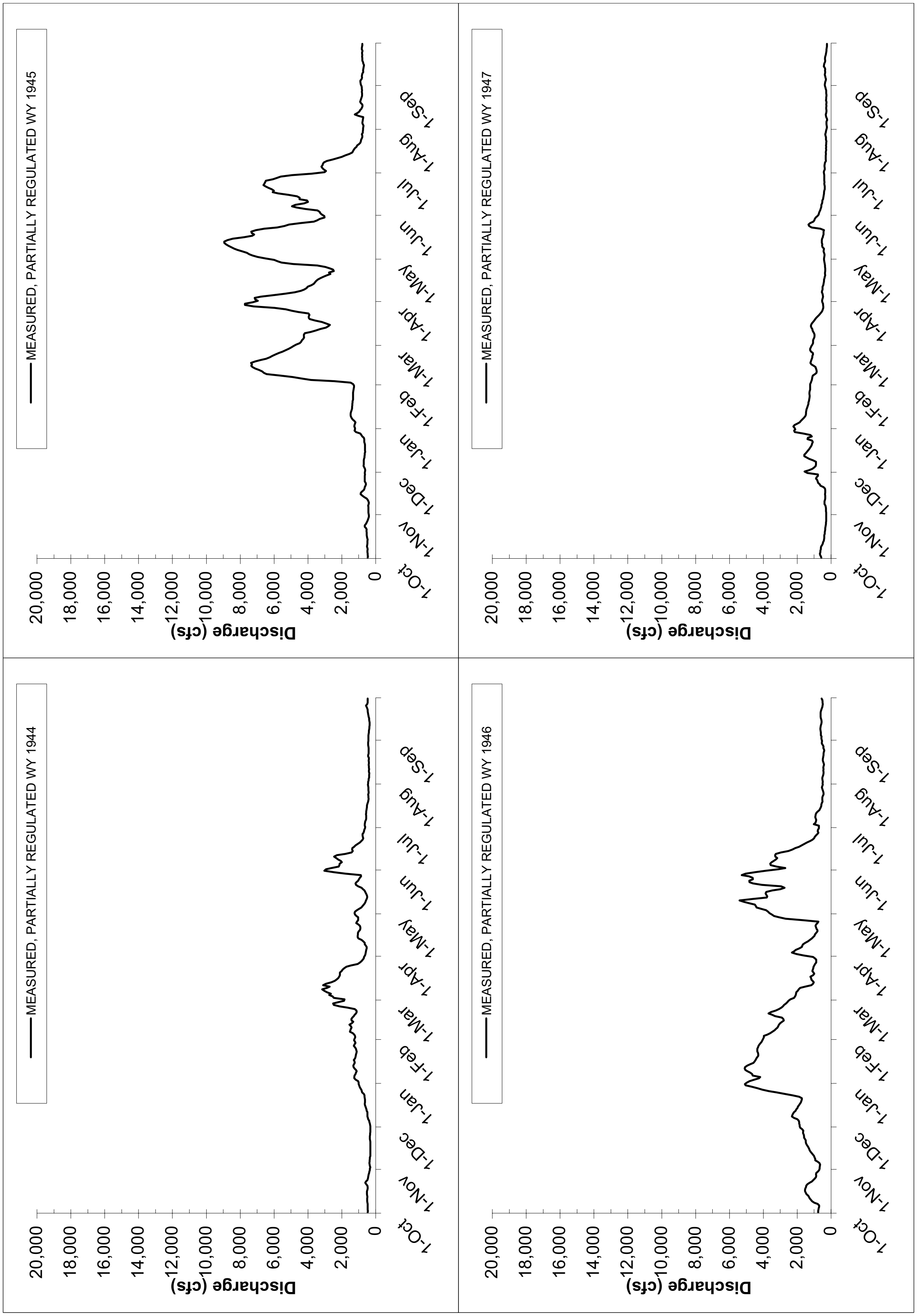

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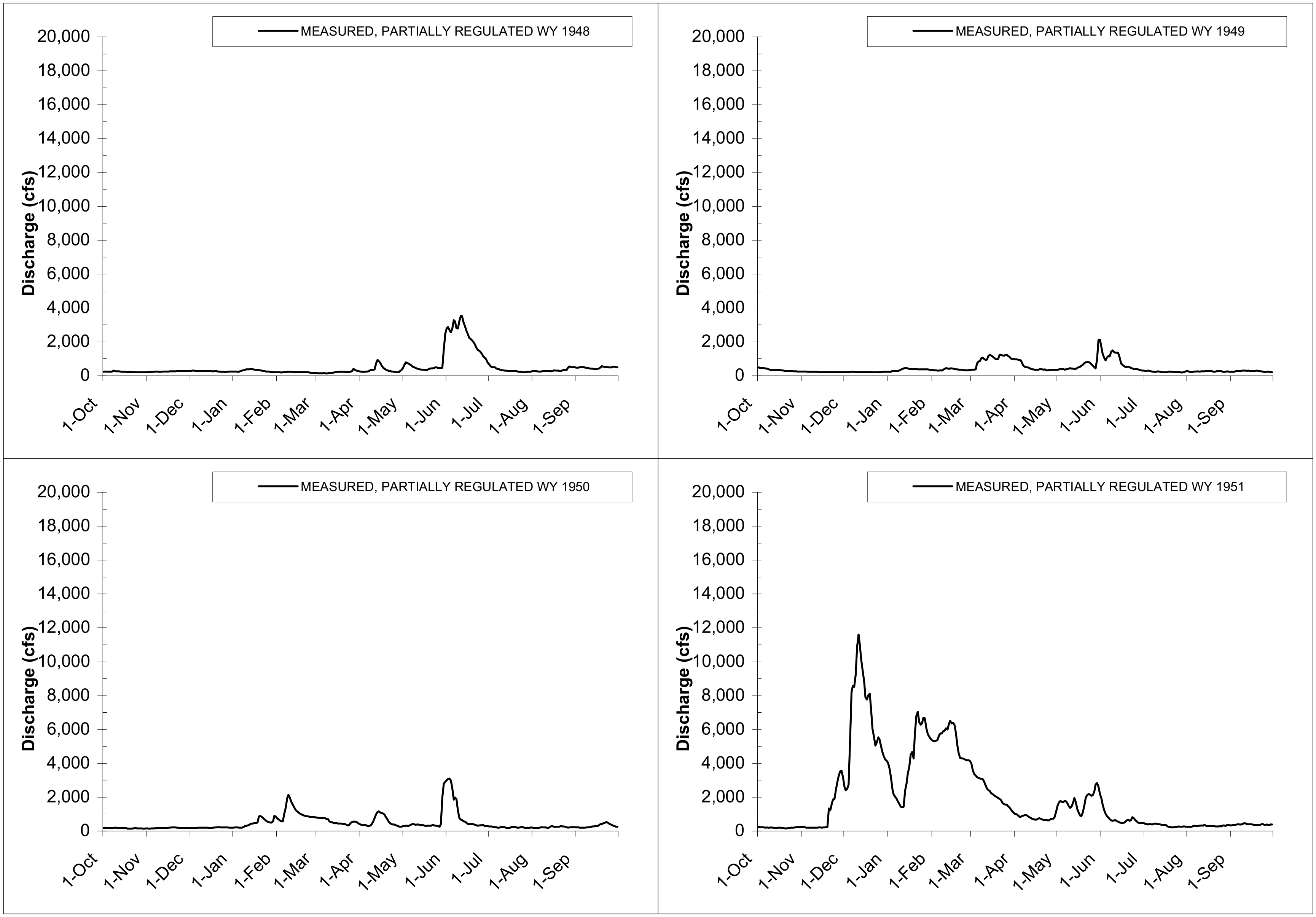

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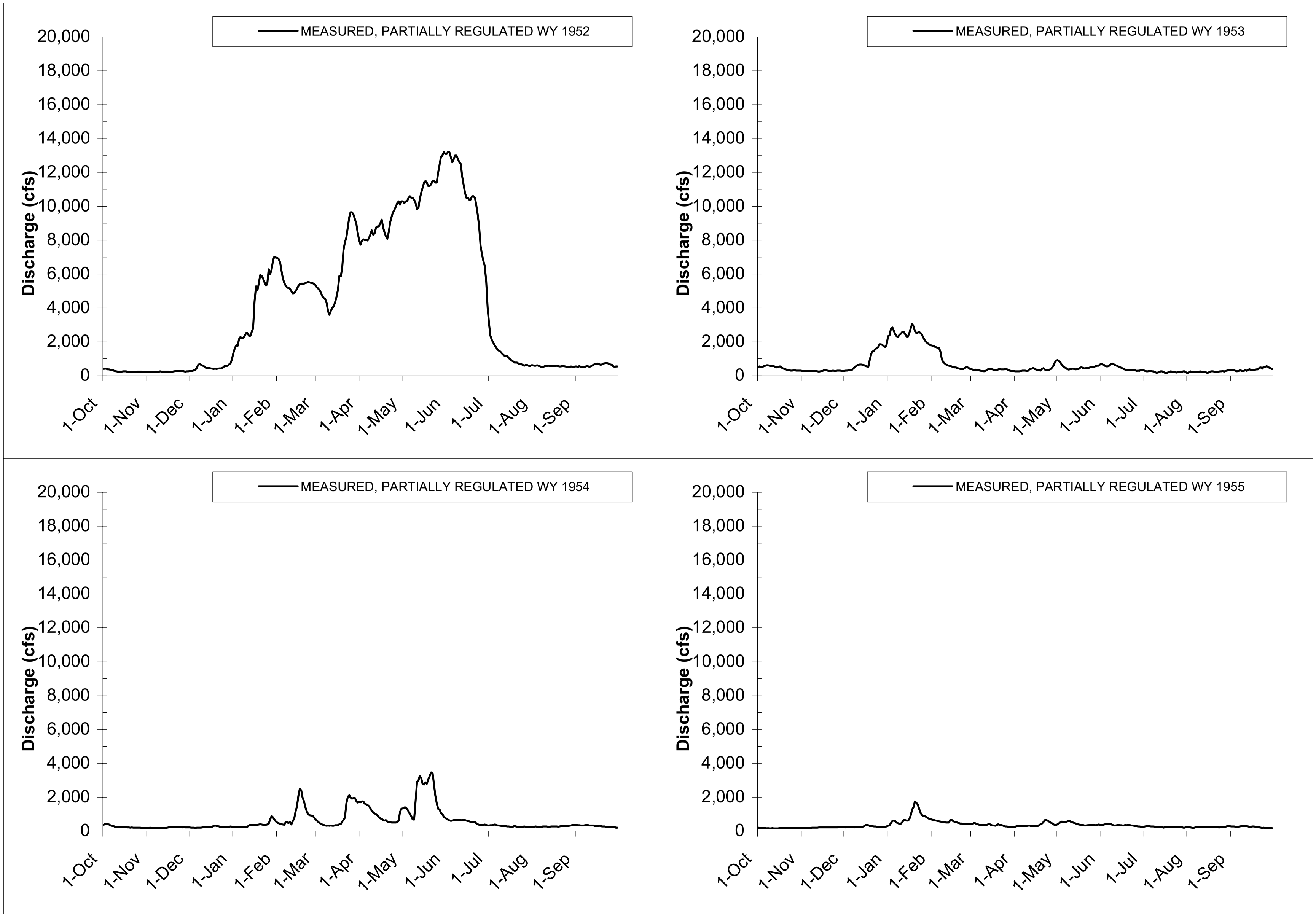

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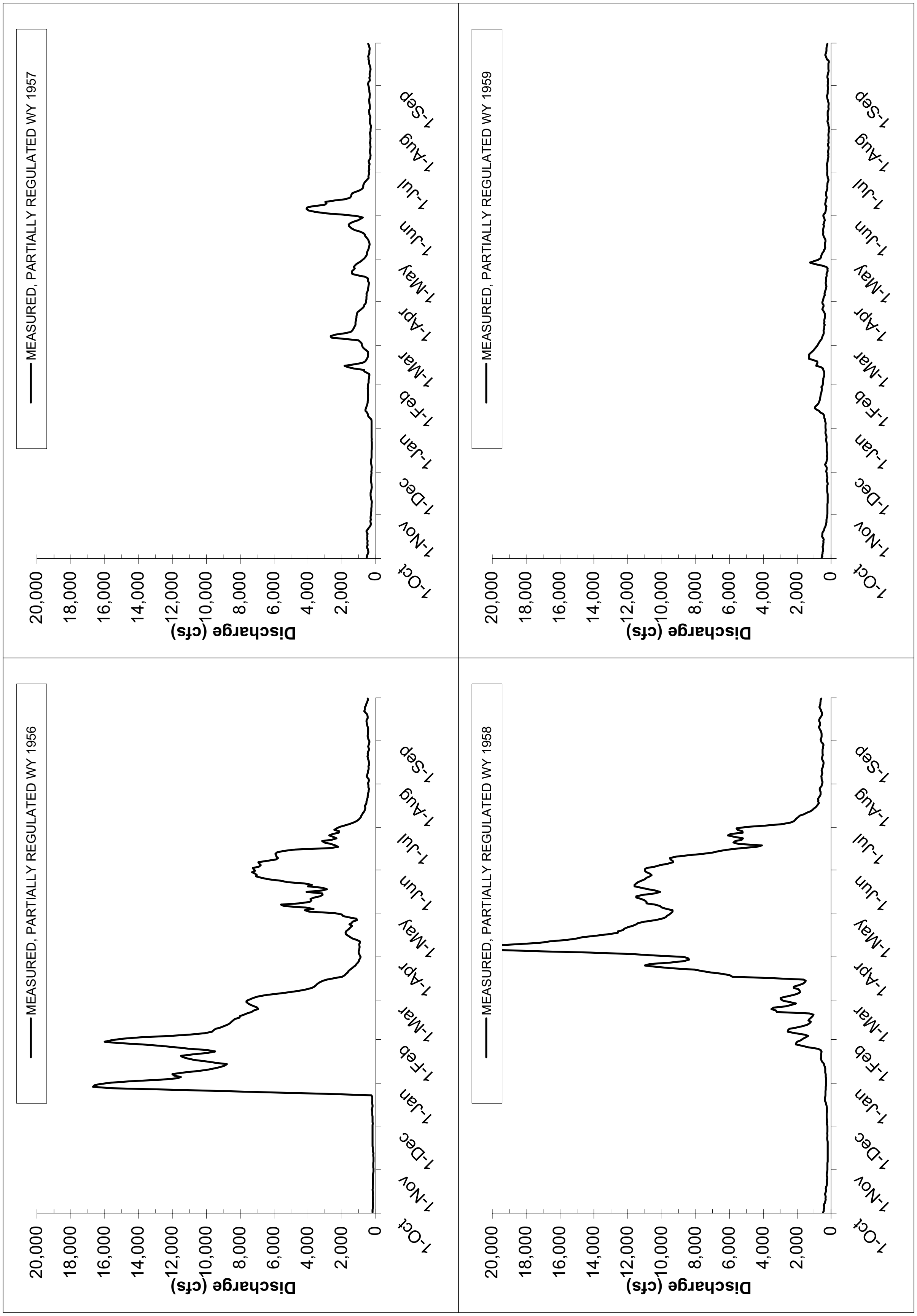

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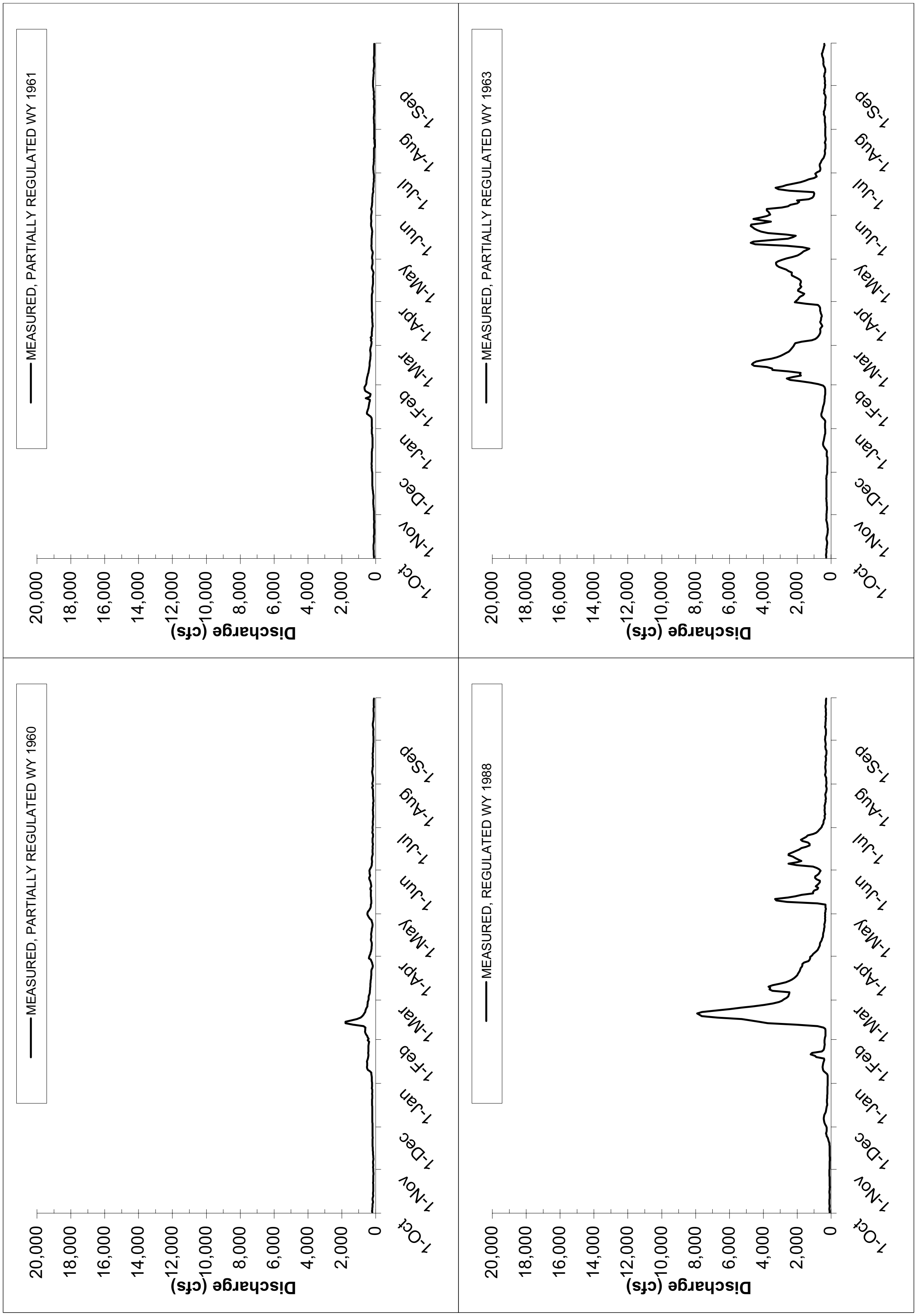
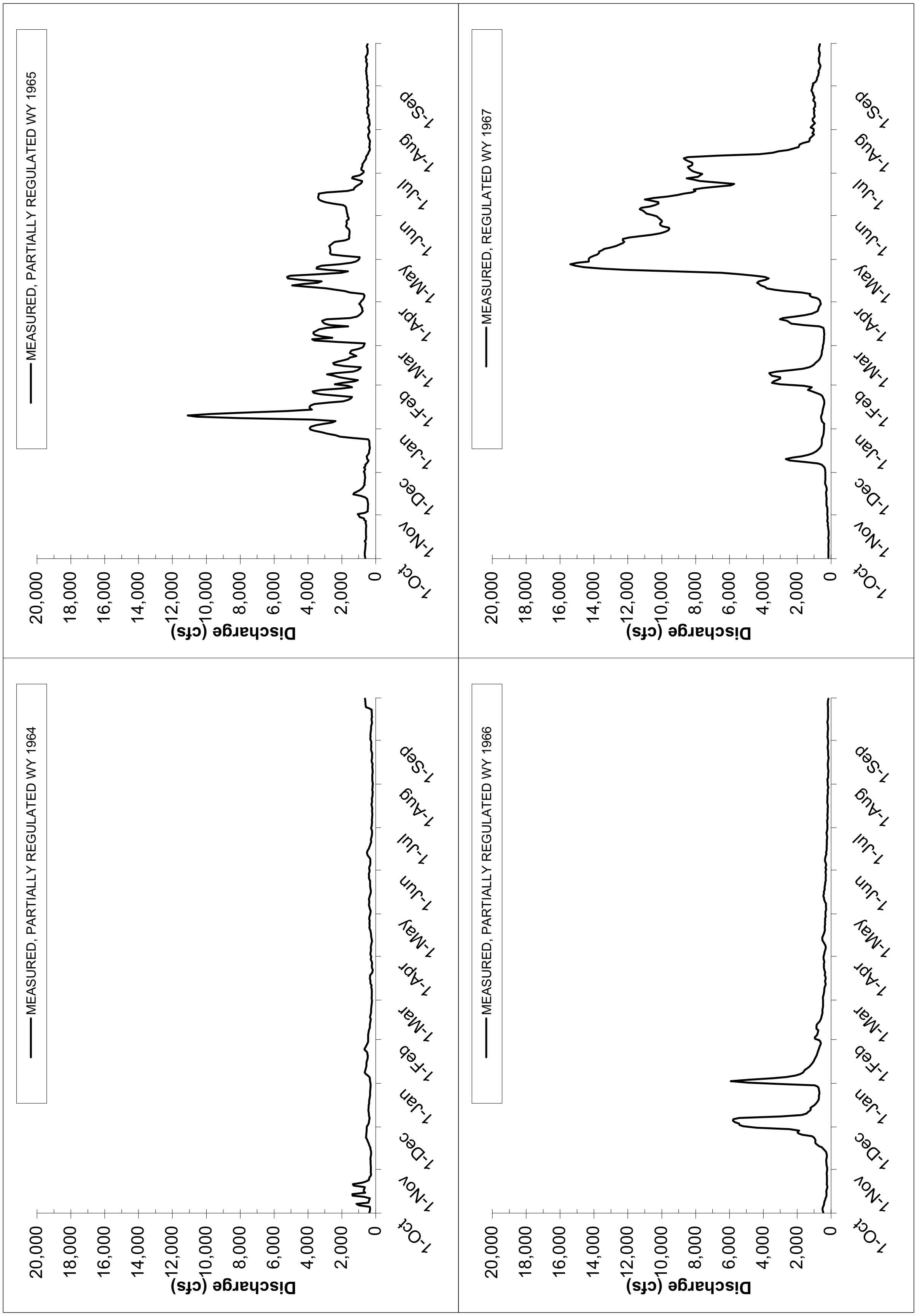
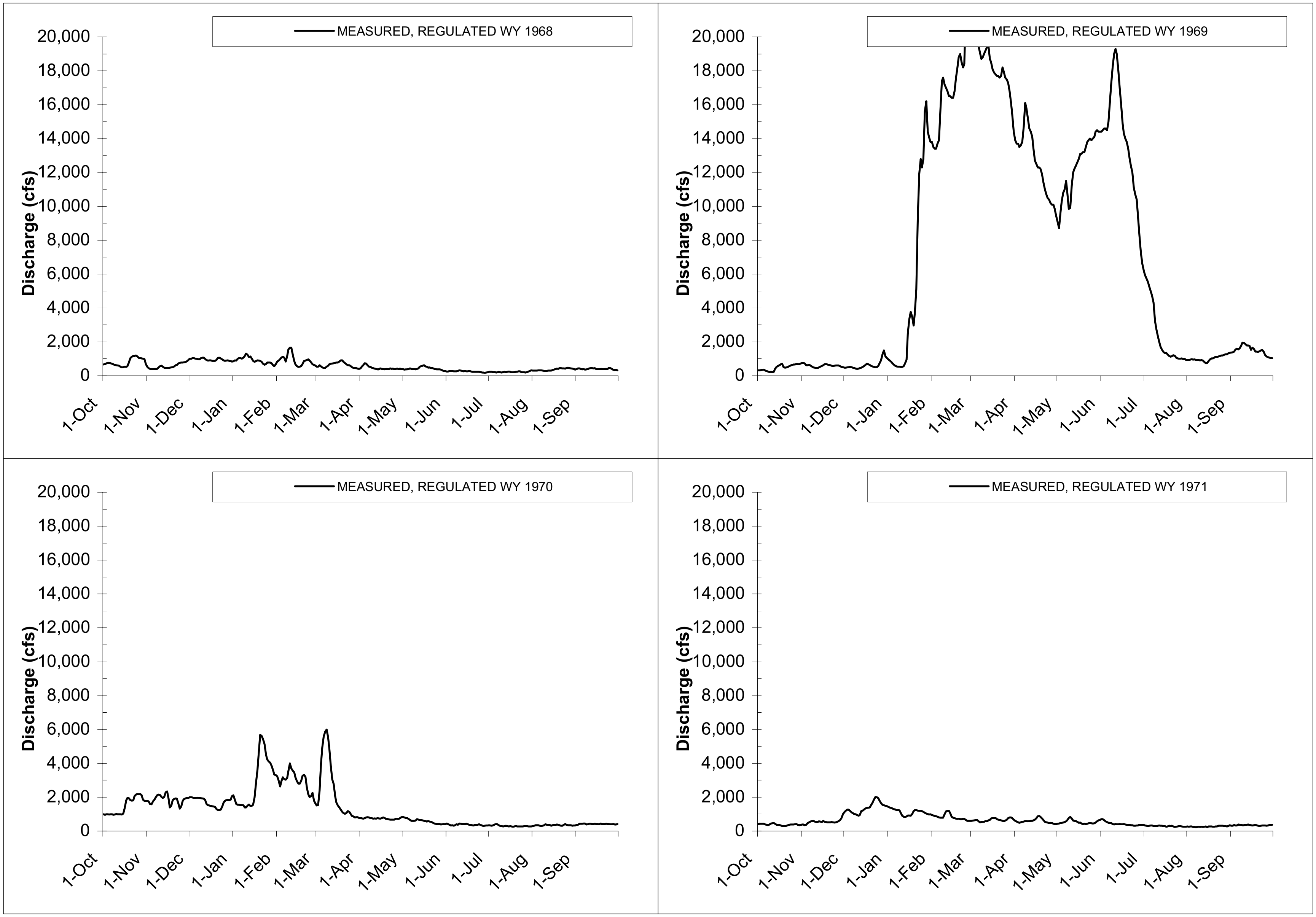


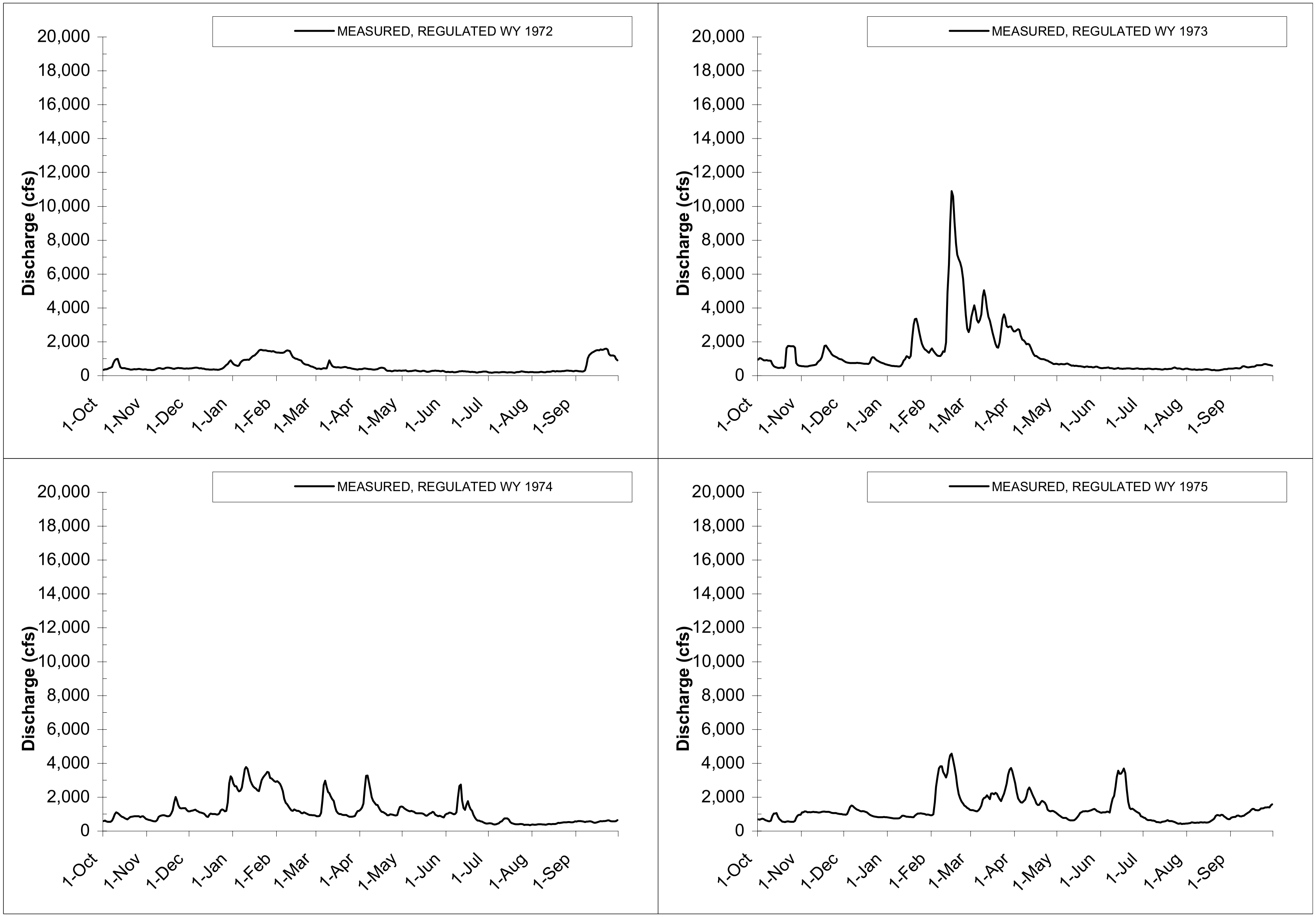
San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



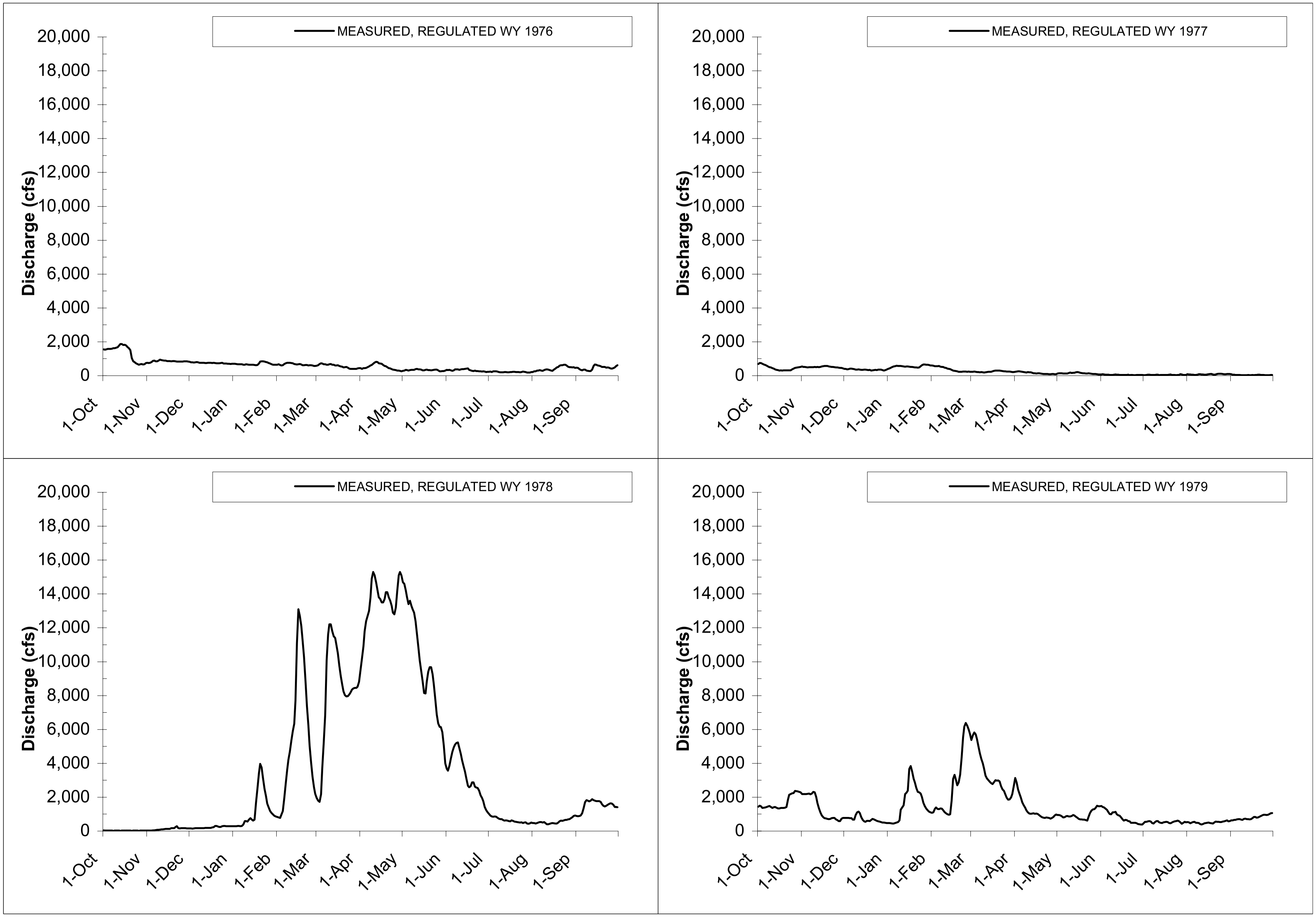
San Joaquin River near Newman, CA (USGS Stn 11-274000)



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



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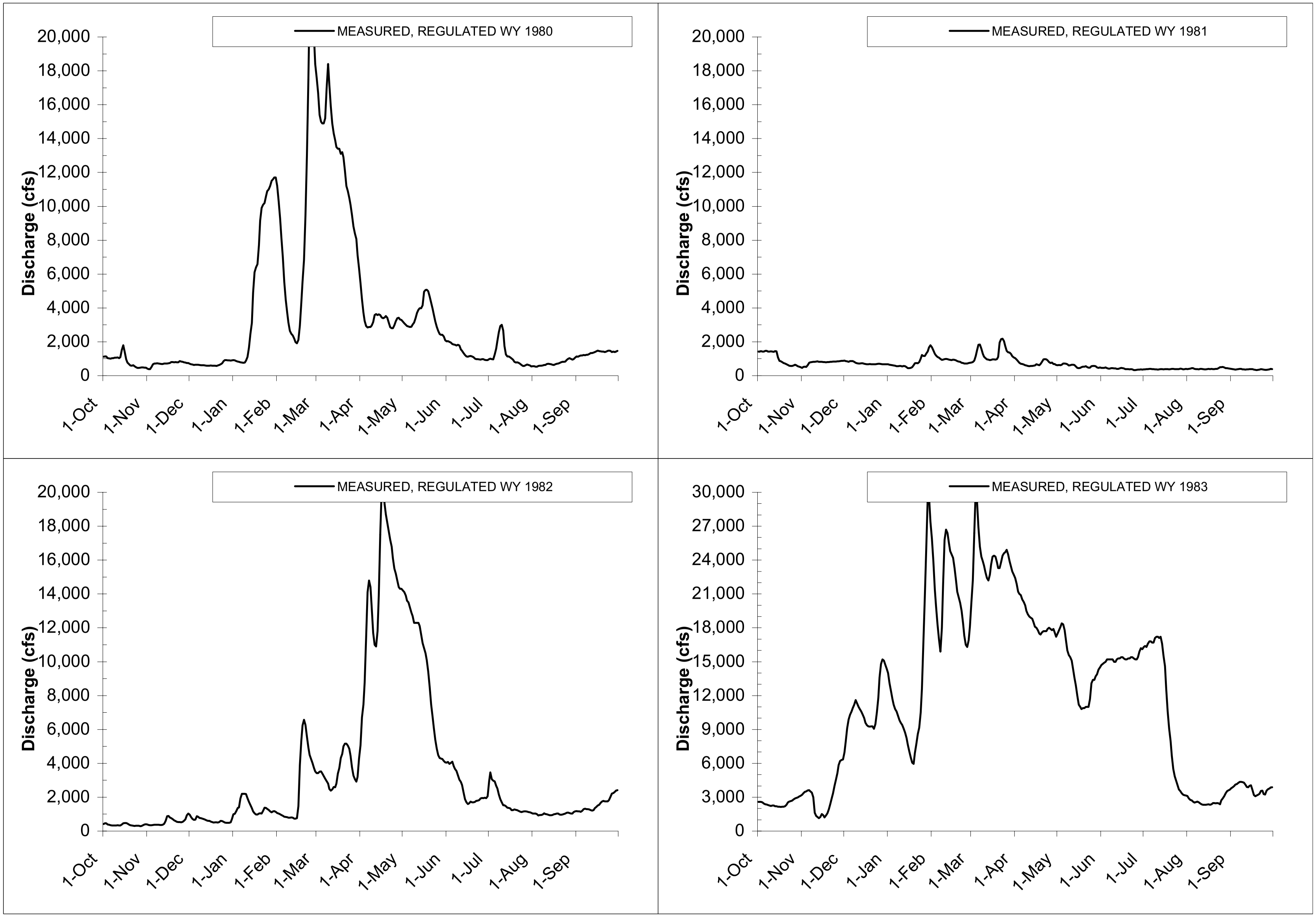

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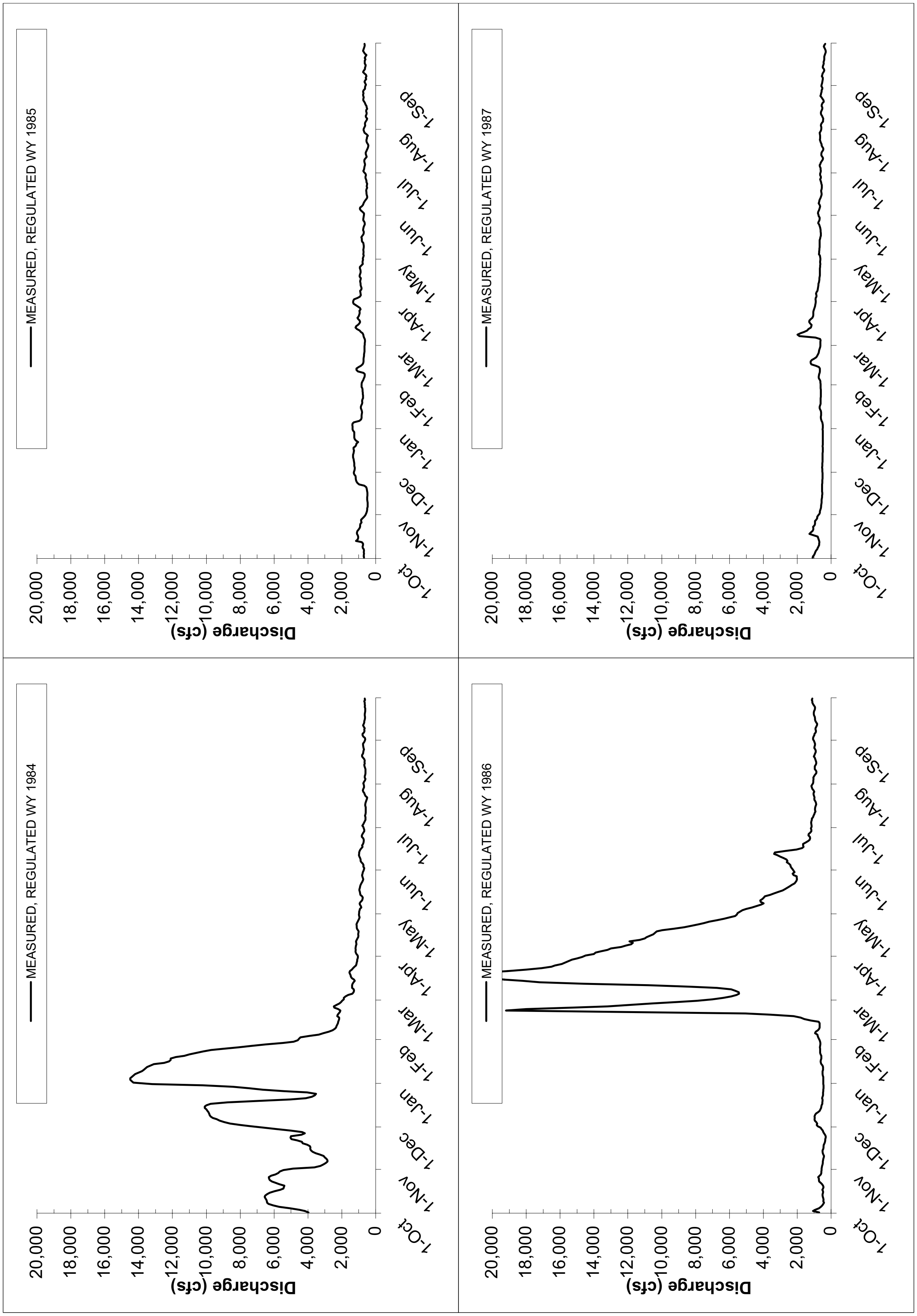

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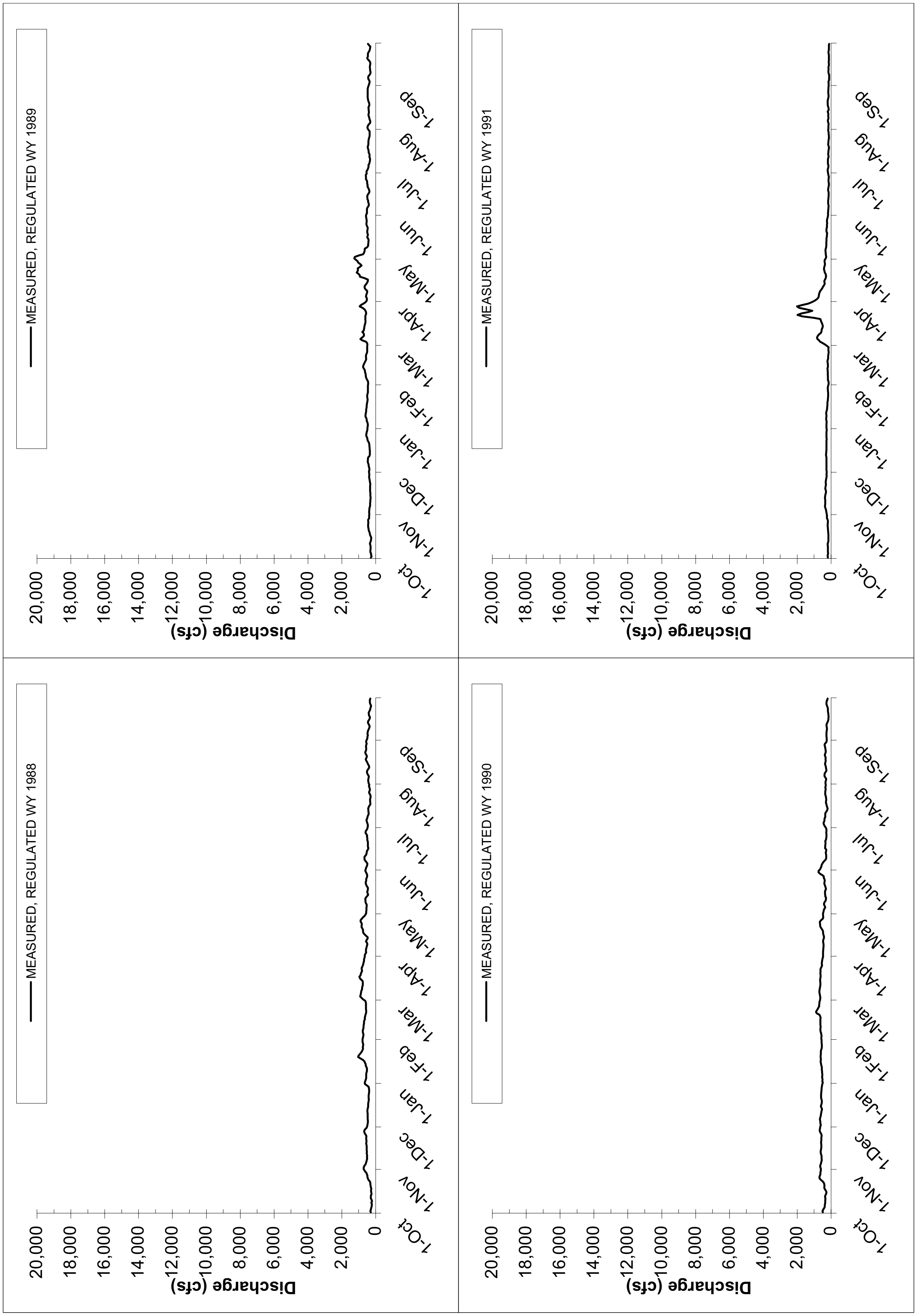
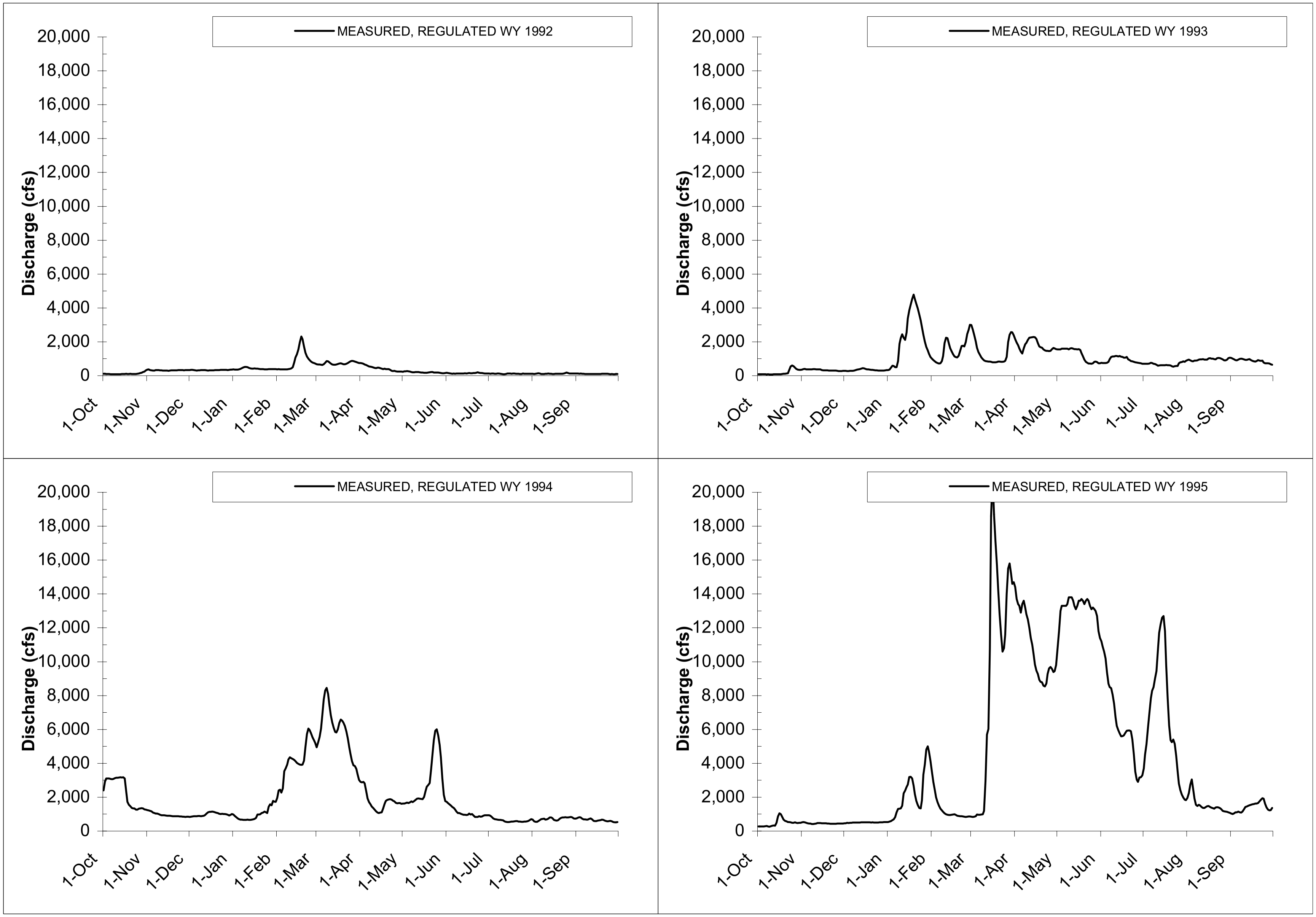
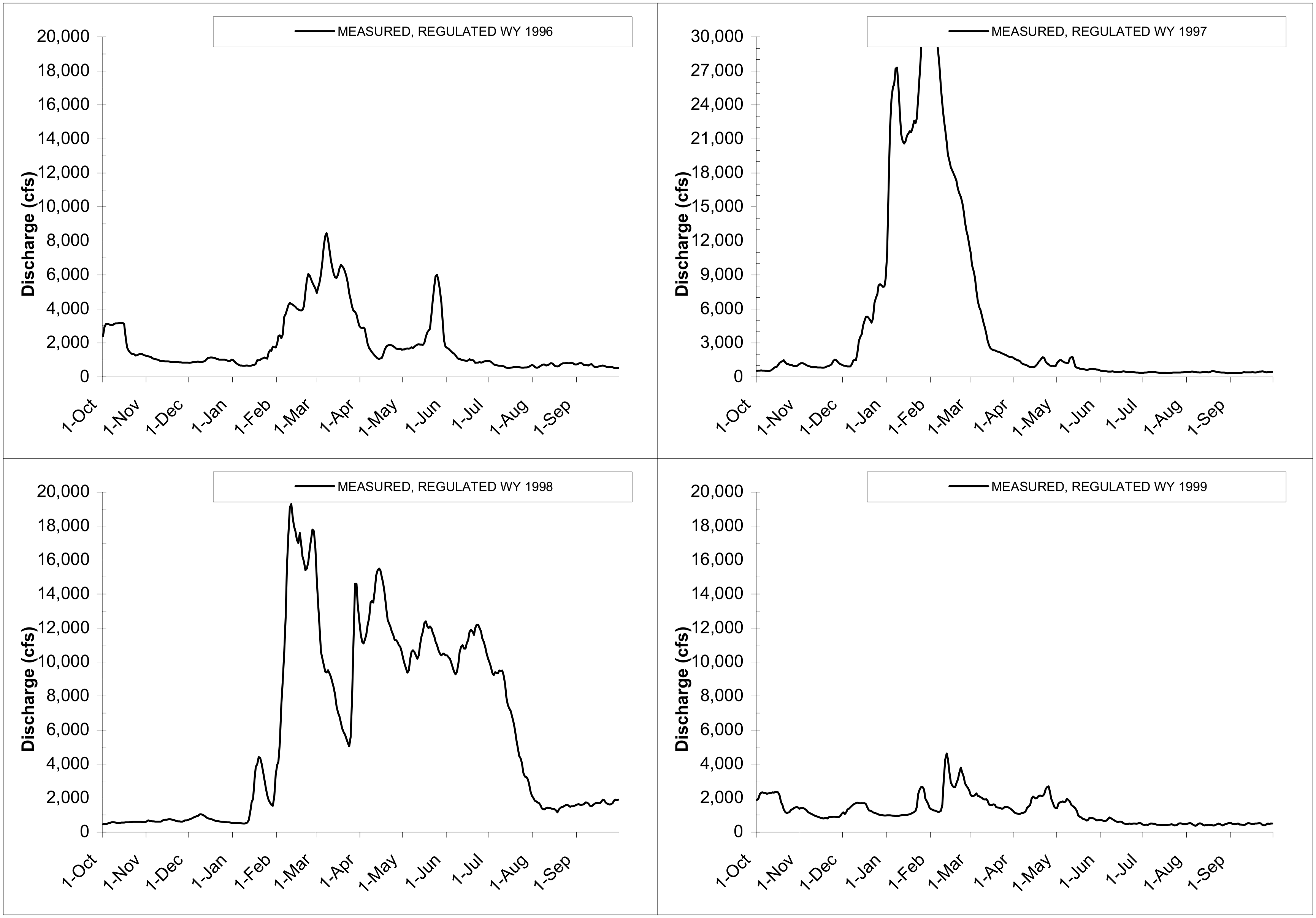


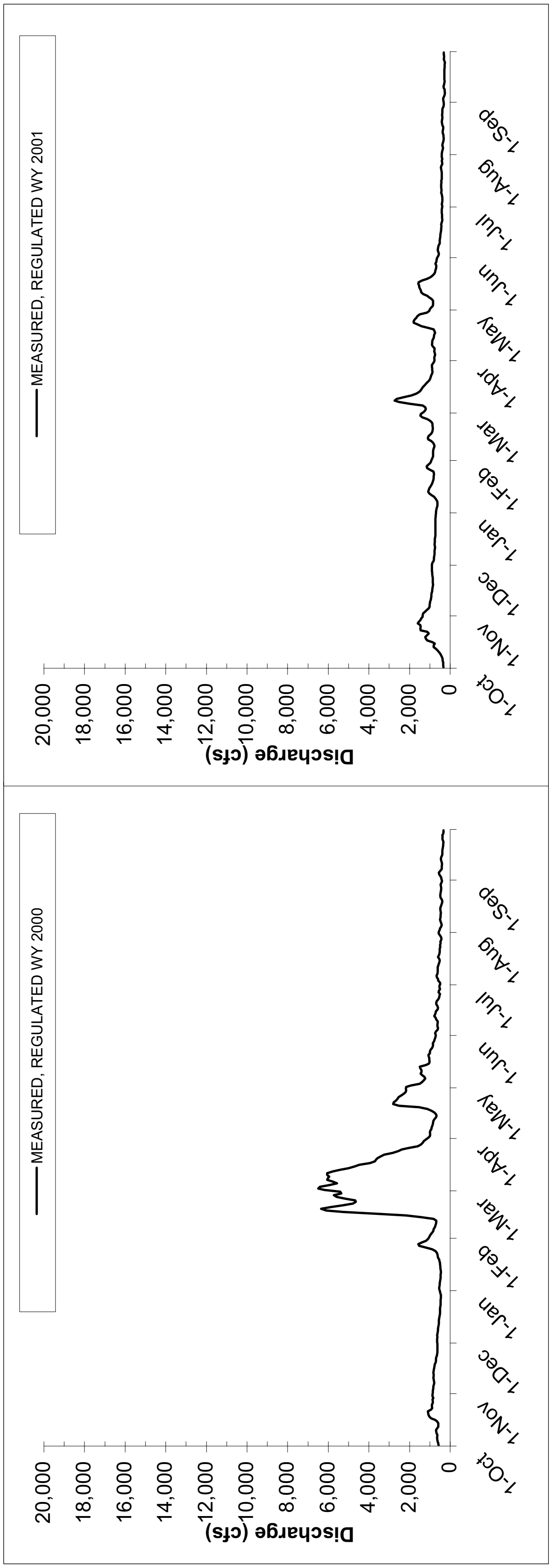
San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.



San Joaquin River near Newman, CA (USGS Stn 11-274000). Includes flow from the Merced River.

APPENDIX A

ANNUAL HYDROGRAPHS OF SELECTED GAGING STATIONS ON THE SAN JOAQUIN RIVER AND TRIBUTARIES

APPENDIX A-3

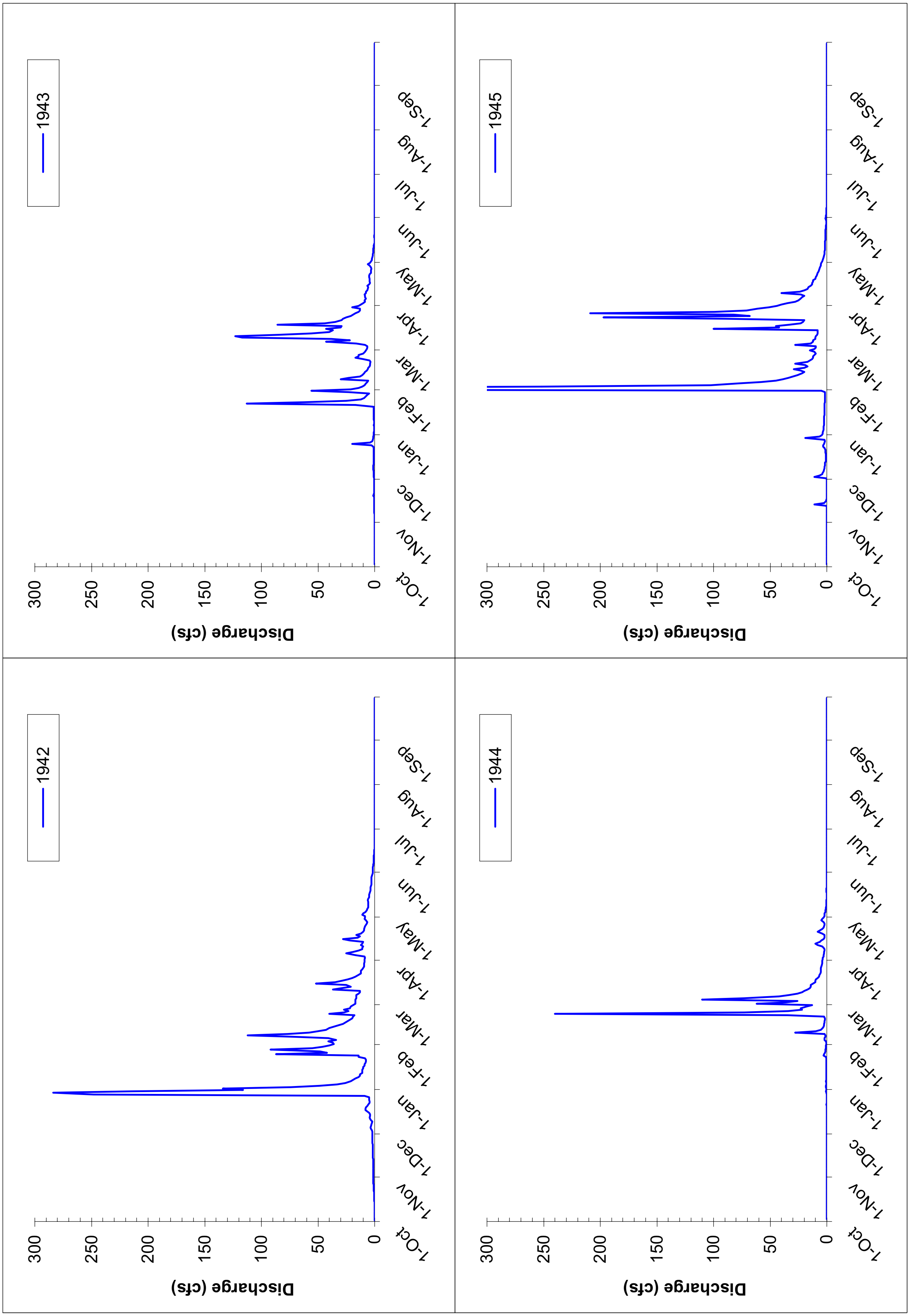
LITTLE DRY CREEK NEAR FRIANT, NEAR MOUTH

USGS GAGING STATION # 11-251600

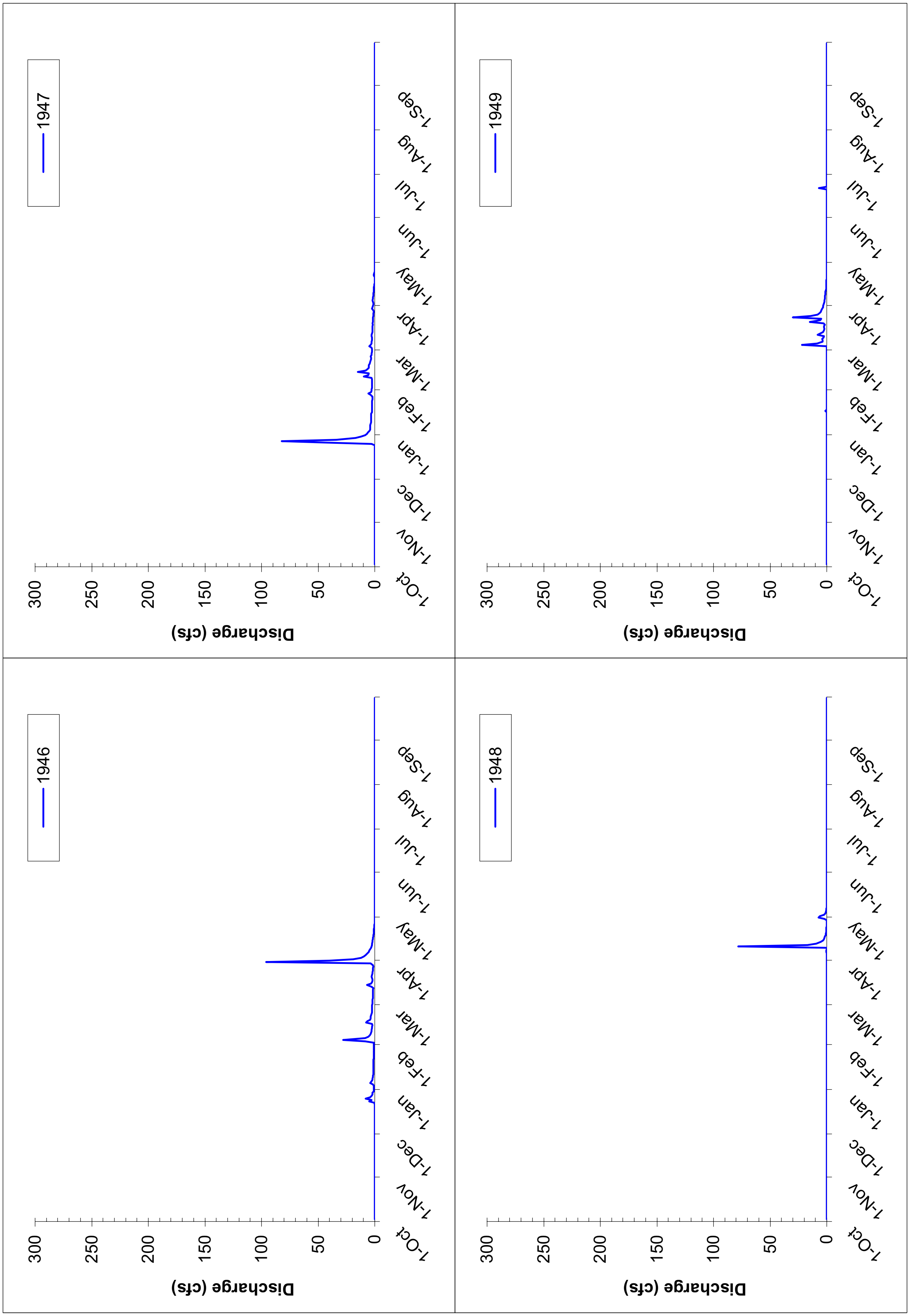
TOTAL DRAINAGE AREA=77.4 SQ MI

PERIOD OF RECORD: 1957-1961

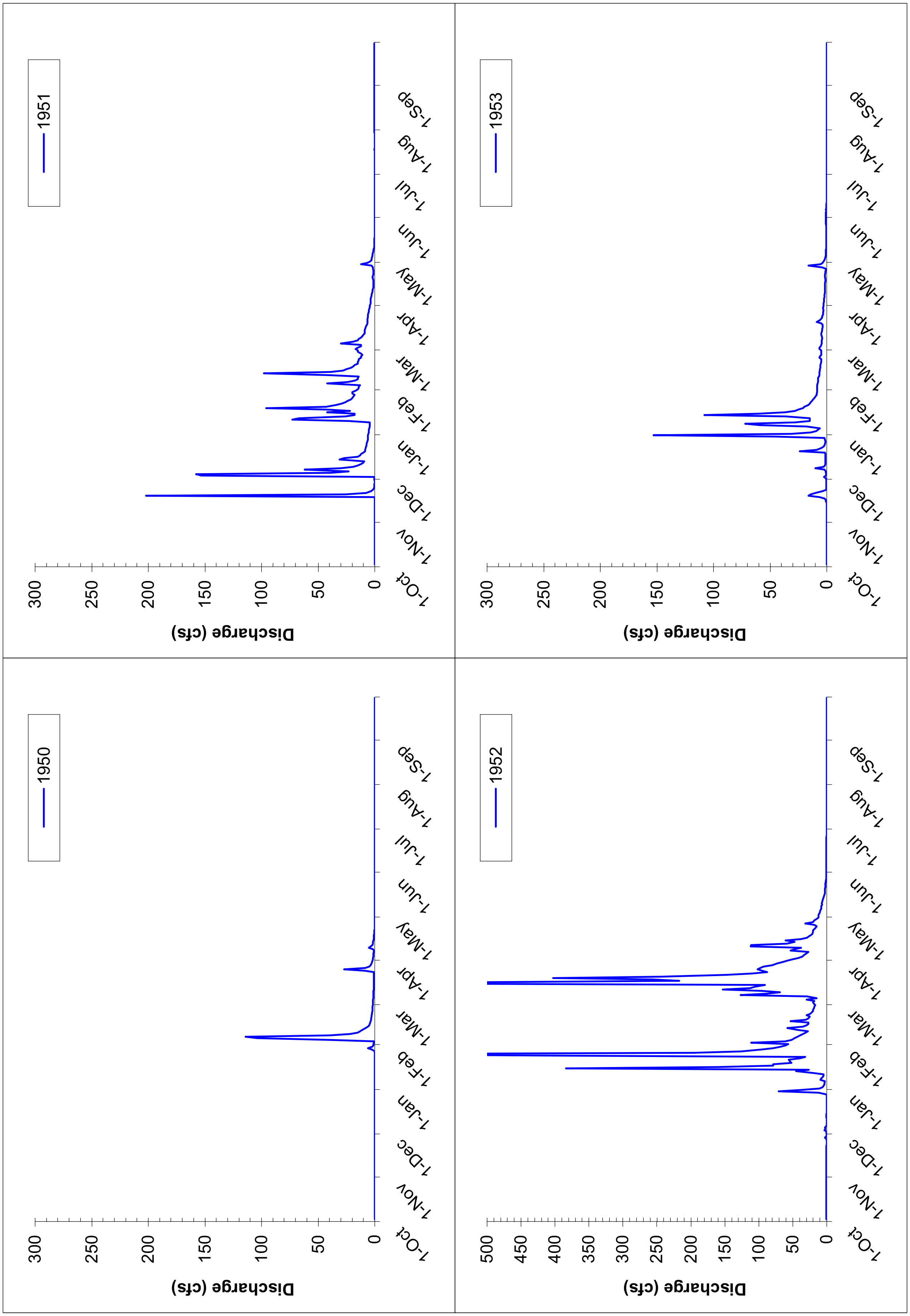
(gage restarted by USBR & DWR in 1998)



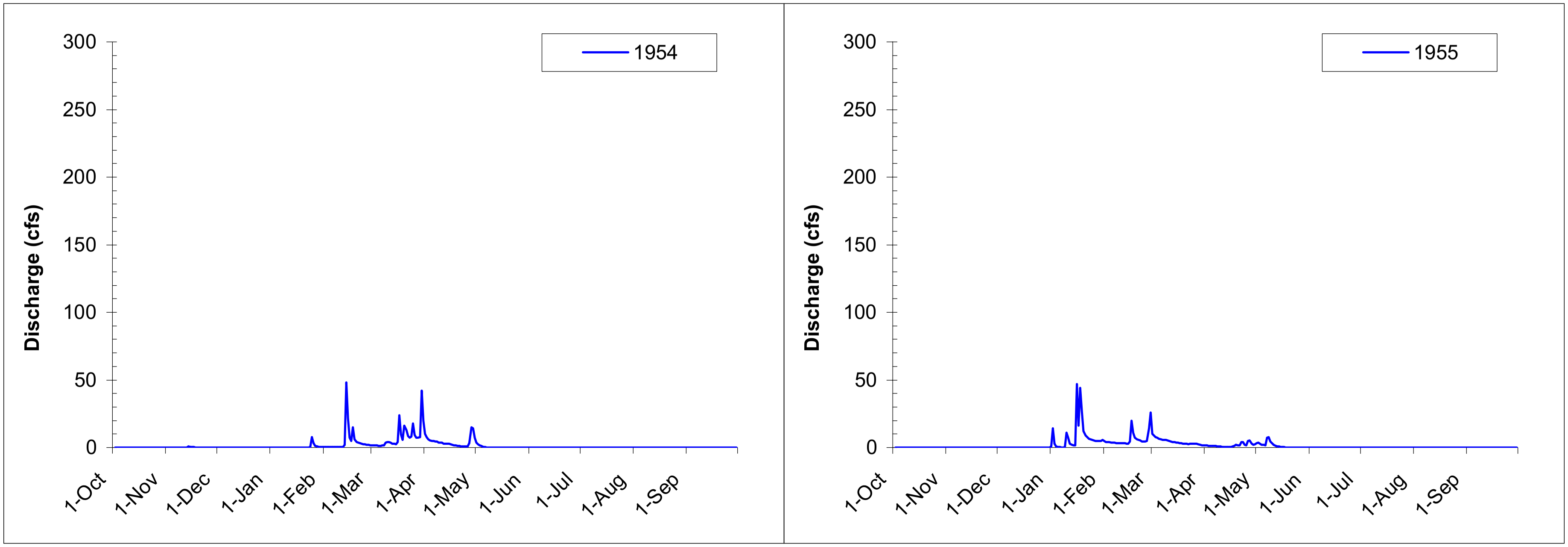
Little Dry Creek near Friant, CA (USGS Stn 11-251500)



Little Dry Creek near Friant, CA (USGS Stn 11-251500)



Little Dry Creek near Friant, CA (USGS Stn 11-251500)



Little Dry Creek near Friant, CA (USGS Stn 11-251500)

APPENDIX A

ANNUAL HYDROGRAPHS OF SELECTED GAGING STATIONS ON THE SAN JOAQUIN RIVER AND TRIBUTARIES

APPENDIX A-4

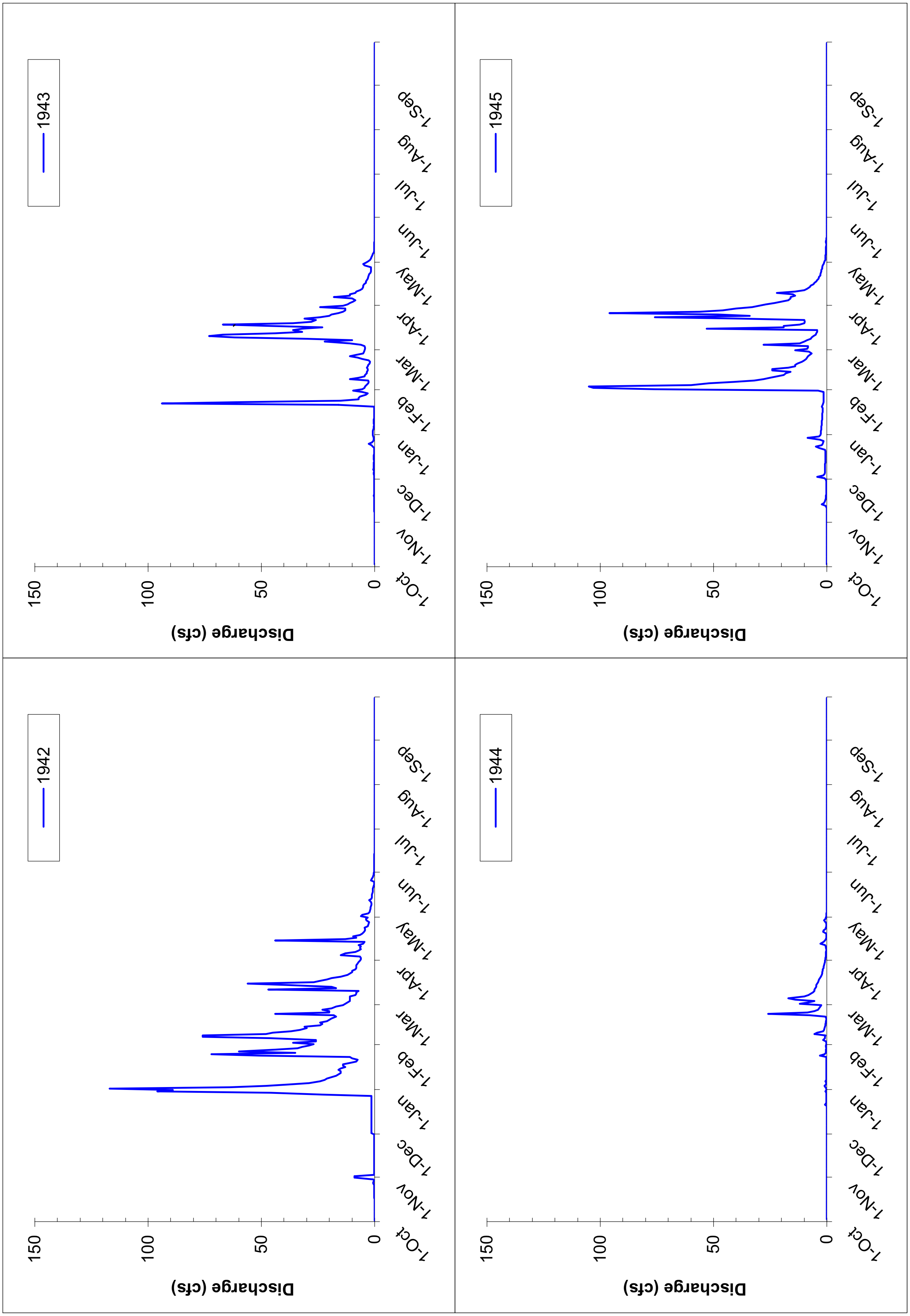
COTTONWOOD CREEK NEAR FRIANT

USGS GAGING STATION # 11-251000

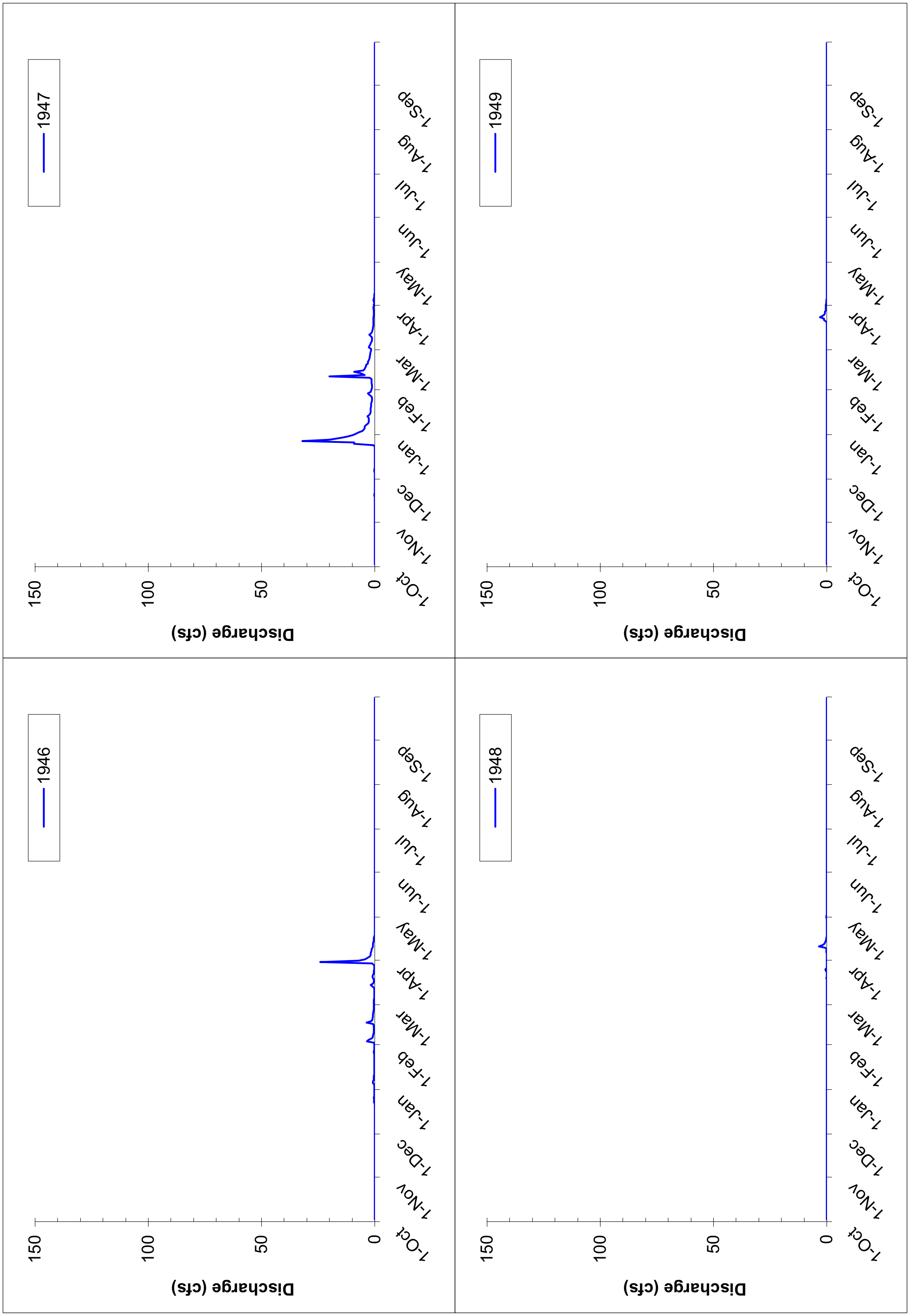
TOTAL DRAINAGE AREA=35.6 SQ MI

PERIOD OF RECORD: 1942-1951

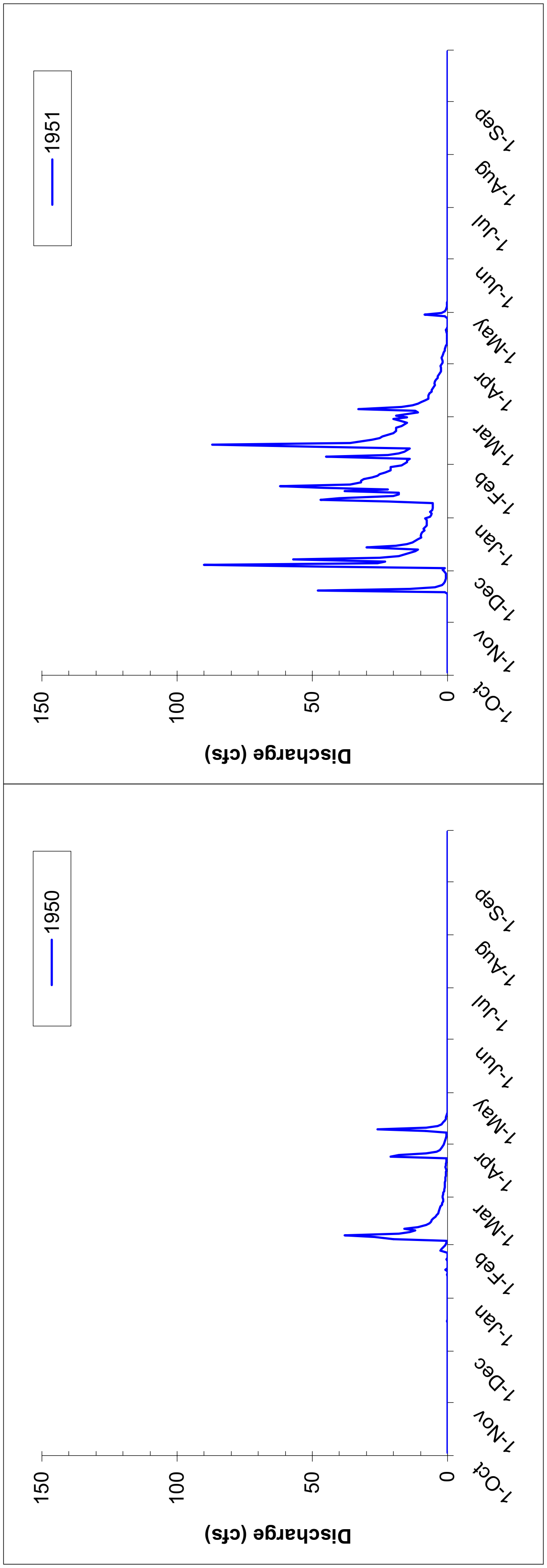
(gage restarted by USBR & DWR in 1998)



Cottonwood Creek near Friant, CA (USGS Stn 11-250500)



Cottonwood Creek near Friant, CA (USGS Stn 11-250500)



Cottonwood Creek near Friant, CA (USGS Stn 11-250500)

APPENDIX B

NATIVE AND INTRODUCED FISHES OF THE SAN JOAQUIN RIVER SUMMARY OF DISTRIBUTION, LIFE HISTORY, AND HABITAT REQUIREMENTS

Preface

The San Joaquin River was historically inhabited by a unique and diverse native fish community, and more recently by numerous non-native (introduced) species. A thorough description of all fish species is beyond the scope of this Background Report; however, we nevertheless felt it important to include many of the non-salmonid fish species that are frequently overlooked or de-emphasized in other restoration and management programs.

This appendix summarizes key aspects of 46 fish species that were historically present in the San Joaquin River study area, and potentially can be maintained in or restored to the San Joaquin River, as well as those non-native species presently in the San Joaquin River study area that will influence restoration strategies. This summary provides readers with an abbreviated description (generally one page) of the species' common and scientific names, legal status, historical and present distributions, life history, habitat requirements, ecological interactions, and key uncertainties. Some of this information was paraphrased, by generous permission of the author, from the recently revised and expanded book: *Inland Fishes of California* (Moyle 2002; University of California Press, Berkeley). Readers interested in more information than is provided in this appendix should consult this book. We also included information from other literature sources, particularly for the anadromous salmonid species, for which more expanded descriptions are provided.

Common Name	Scientific Name (family)
White sturgeon	*Acipenser transmontanus (*Acipenseridae)

Legal Status:

Federal	None
State	None

Distribution

White sturgeon have a marine distribution spanning from the Gulf of Alaska south to Ensenada, Mexico, but a spawning distribution ranging only from the Sacramento-San Joaquin basin northward. Currently, self-sustaining spawning populations are only known to occur in the Sacramento, Fraser, and Columbia Rivers. In California, primary abundance is in the San Francisco estuary with spawning occurring mainly in the Sacramento and Feather rivers. Spawning may occur in the San Joaquin River when flows and water quality permit. Landlocked populations are located above major dams in the Columbia River basin, and residual non-reproducing fish above the Shasta Dam can occasionally be found. In the ocean, white sturgeon have been known to migrate broad distances, but spend most of their life in brackish portions of large river estuaries.

Life History

Reports of maximum size and age of white sturgeon are as great as 6 m fork length (820 kg) and >100 yr, although they generally do not exceed 2 m fork length or 27 years of age. Males mature in 10-12 years (75-105 cm FL) and females in 12-16 years (95-135 cm FL). Maturation depends largely on temperature and photoperiod. Sturgeon migrates upstream when they are ready to spawn in response to increases of flow. Only a portion of the adult population spawns each year and is dependent on favorable conditions such as pulses of high flows, which appears to stimulate sizeable numbers of sturgeon to spawn. Because of this, successful year classes tend to occur at irregular intervals and therefore numbers of adult fish within a population can fluctuate significantly. Females are highly fecund, and average roughly 200,000 eggs each. Eggs become adhesive subsequent to fertilization, and adhere to the substrate until they hatch 4-12 days later depending on temperature. The yolk sac is absorbed within 7-10 days, at which time they are free to move about the estuary. White sturgeon are benthic feeders and juveniles consume mainly crustaceans, especially amphipods and opossum shrimp. Adult diets encompass mainly fish and estuarine invertebrates, the bulk of which is clams, crabs, and shrimps.

Habitat Requirements

White sturgeon primarily live in brackish portions of estuaries where they tend to concentrate in deep sections having soft substrate. They move according to salinity changes, and may swim into intertidal zones to feed at high tide. Juvenile sturgeon are often found in upper reaches of estuaries in comparison to adults, which suggests that there is a correlation between size and salinity tolerance. Spawning occurs over deep gravel riffles or in deep pools with swift currents and rock bottoms between late February and early June when temperatures are between 8-19°C.

Ecological Interactions

There are valuable commercial, sport, and Native American fisheries for white sturgeon in California. Although they may be vulnerable to overfishing, current management of this species is thought to allow for sustainable yield, and in addition white sturgeon are being cultured successfully. One other consequence of their life history is heightened bioaccumulation potential of toxic substances such as PCBs as well as selenium, which is thought to be passed on from the introduced overbite clam which is a favorite food of the sturgeon. Another possible hazard to these fish is alteration of estuary habitat, such as in the Sacramento-San Joaquin Delta, which may decrease successful spawning and rearing.

Key Uncertainties

The potential to restore white sturgeon populations using cultured juvenile white sturgeon is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Green sturgeon (Acipenseridae)	*Acipenser medirostris*

Legal Status:

Federal	The status review by NMFS to determine whether or not *Acipenser medirostris* should be listed as a threatened or endangered species under the ESA is due June 2002. Upon completion of the review, NMFS is to publish its findings and make a ruling on the listing.
State	Species of Special Concern

Distribution

Green sturgeon have been found from Mexico north to Canada, Russia (Commonwealth of Independent States), Korea, and Japan, although Asian populations are thought to belong to a separate species. In North America, green sturgeon reside in oceanic waters from the Bering Sea south to Ensenada, Mexico, and in rivers from British Columbia south to the Sacramento River. Historically spawning rivers included the San Joaquin, Fraser, Columbia, Umpqua, Eel, and South Fork Trinity Rivers, although they are currently only confirmed to spawn in the Sacramento, Klamath, Trinity, and Rogue Rivers.

Life History

Green sturgeon is anadromous, migrating from the ocean between March and July to spawn when temperatures are 8-14°C. Females produce 60,000-140,000 eggs that are broadcast in swift water and are then fertilized externally. Eggs hatch in about 8 days (at 12.7°C). Juveniles generally outmigrate in spring or autumn between years 1 and 3. At this time, they remain in close proximity to estuaries, and subsequently migrate far distances as they grow. Males tend to grow less and mature more rapidly than females, and consequently spend only 3 to 9 years at sea before returning whereas females spend 3 to 13 years. Mature fish are typically 15–20 years old. Juveniles are known to consume prey items including small fish and amphipods, while adults tend to eat sand lances, callianassid shrimp, anchovies, and clams.

Habitat Requirements

Green sturgeon probably have similar spawning and larval habitat requirements as white sturgeon. Green sturgeon have larger egg sizes and thinner chorions than white sturgeon eggs, suggesting that green sturgeon may require colder, cleaner water for spawning than white sturgeon. Spawning occurs in fast, deep (>3 m), water in substrates ranging from clean sand to bedrock, although large cobble is preferred. Small amounts of silt appear to increase egg survival by preventing eggs from adhering to each other.

Ecological Interactions

Green sturgeon in the Sacramento-San Joaquin are caught by anglers that are targeting white sturgeon. Green sturgeon are caught less frequently than white sturgeon and are therefore considered to be more rare.

Key Uncertainties

Due to low abundance, limited spawning distribution, and low sport and commercial fishing value, the ecology, population dynamics and life history of green sturgeon has not been well studied. Green sturgeon appear to be diminishing throughout their range. Effects of fisheries targeting this species are not understood, particularly in the Sacramento-San Joaquin and Klamath River drainages.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento sucker (Catostomidae)	*Catostomus occidentalis*

Legal Status:

Federal None
State None

Distribution

Sacramento suckers are common and have a wide distribution within central and northern California including streams and reservoirs of the Sacramento-San Joaquin drainage; on the coast in the Mad, Bear, Eel, Navarro, Russian, Pajaro, and Salinas Rivers, and in Lagunitas Creeks; and watercourses within and surrounding the Morro Bay drainage from water transfers. They are also likely to be distributed within southern California reservoirs that receive water from the California Aqueduct. Sacramento suckers can inhabit a wide array of habitats ranging from cool, high-velocity streams to warm sloughs to low-salinity portions of estuaries.

Life History

Sacramento suckers typically feed at nighttime on such items as algae, detritus, and small benthic invertebrates. Sucker growth is highly variable, and includes one specimen from Crystal Springs measuring 560 mm FL and 30 years of age. First spawning takes place during years 4-6, and typically takes place over gravel riffles during the months of February through June when temperatures are approximately 12-18°C. Females can spawn up to 7 years, and may produce between roughly 5,000-32,000 eggs/spawning period that adhere to gravel bits or pieces of detritus upon fertilization. After embryos hatch in 2-4 weeks, larvae remain in association with the substrate until they are swept into warm shallows or among flooded vegetation.

Habitat Requirements

Sacramento suckers are most commonly found in cold, clear streams and moderate elevation lakes and reservoirs. They chose microhabitat according to size, and typically move from shallow, low-velocity peripheral zones to areas of deeper water as they grow. They can tolerate a wide range of temperature fluctuations from streams that rarely exceed 15-16°C to those that reach up to 29-30°C. They have also been observed to have high salinity tolerances, and have been found living in reaches where salinities surpass 13 ppt. Due to their relatively high tolerances, Sacramento suckers have the ability to colonize new habitats readily.

Ecological Interactions

Sacramento suckers are generally associated with other native minnows such as Sacramento pikeminnows, hardhead, and California roach, but can also be common in watercourses dominated by nonnative fishes.

Key Uncertainties

The ecology of Sacramento suckers is poorly understood. They may play major ecological roles that include keystone species with impacts on invertebrate communities, and high-energy food resources for juvenile salmonids and trout.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento perch (Centrarchidae)	*Archoplites interruptus*

Legal Status:

Federal	None
State	Species of Special Concern

Distribution

The native range for the endemic Sacramento perch was throughout the Central Valley, the Pajaro and Salinas Rivers, and Clear Lake. Currently, they only reside in Clear Lake and Alameda Creek within their historical native distribution. Populations that presently occur outside of their native distribution within California include those in the upper Klamath basin and in the Cedar Creek, Mono Lake, Owens River and Walker River watersheds. They are typically found in reservoirs and farm ponds, and are frequently associated with beds of rooted, submerged, and emergent vegetation, but may also be abundant in shallow, highly turbid environments with no aquatic vegetation.

Life History

Growth rates are highly variable and are influenced by both biotic and abiotic factors. They can live over nine years, and in California have been known to exceed 1.5 kg. Breeding begins during their second or third year from March through early August. Fecundity varies with size, and can exceed 120,000 eggs/female. Males create nests out of shallow pits in substrate ranging from silt to gravel which they defend both prior and subsequent to fertilization, until larvae are able to leave the nest. After living for 1-2 weeks as planktonic larvae, young-of-the-year descend into aquatic vegetation or shallow areas. The type of prey consumed by Sacramento perch is dependant upon size, food availability, and time of year. Prey items include small crustaceans, copepods, insect pupae and larvae, other fish including their own young-of-the-year, planktonic and surface organisms, and aquatic insects.

Habitat Requirements

Sacramento perch can tolerate environmental conditions including high turbidity, temperatures up to 30°C, and elevated salinity and alkalinity concentrations. They can survive and also reproduce in salinities up to 17 ppt and in sodium-potassium carbonate concentrations of over 0.8 ppt. Young-of-the-year tend to inhabit shallow areas, and require moderately clear water containing aquatic plants.

Ecological Interactions

Sacramento perch are thought to be able to persist in their chosen habitats due to the absence of other centrarchids, especially black crappie and bluegill, which are usually excluded from these habitats due to high alkalinities or lack of introduction. When present, these nonnative species can successfully compete for food and space, and possibly prey on perch embryos and larvae. Decline of this species within their native range is assumed to be caused by such factors as interspecific competition, embryo predation, and habitat destruction, especially draining of lakes and sloughs and reduction of aquatic plant beds.

Key Uncertainties

Limited genetic lineage of populations may restrict their long-term survival potential. Reviews of their distribution and status are needed in order to be certain that they are being protected.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Prickly sculpin	*Cottus asper* (Cottidae)

Legal Status:

Federal	None
State	None

Distribution

Prickly sculpins residing on the coast can be found from the Kenai Peninsula, Alaska, down to the Ventura River in southern California. Within California, there are also inland Central Valley populations in low elevations of most streams up to Keswick Dam on the Sacramento River, and in the San Joaquin Valley south to the Kings River. They have also been spread to reservoirs and associated streams within southern California that receive water from the California Aqueduct. A separate form is also located in Clear Lake. Prickly sculpin can live in a multitude of environments that include fresh, brackish, and seawater, streams that range from small and cold to clear to large and warm and turbid, and lakes and reservoirs from small to large, and eutrophic to mesotrophic.

Life History

Growth of prickly sculpins can vary greatly, and it is possible they can exceed 200 cm SL and live >7 years. Maturity occurs during years 2-4, and spawning can last from February through June when water temperatures reach 8-13°C. During this period, sculpins will move into freshwater or intertidal reaches where males will dig nests by forming small hollows in the substrate underneath a rock. Depending on size, females will produce somewhere between about 300-11,000 eggs, and since males will mate with more than one female, up to 30,000 embryos can be found in one nest. Males protect the nest until embryos hatch. After hatching, larvae move down into large pools, lakes, and estuaries where they spend 3-5 weeks as planktonic fry. At this time, they begin to settle to the bottom, and start to move upstream or into shallow water of lakes or pools. The primary food items for prickly sculpins are large benthic invertebrates, but other aquatic insects, mollusks, isopods, amphipods, and small fish and frogs are also consumed.

Habitat Requirements

In the Central Valley, prickly sculpins are generally found in medium-sized, low-elevation streams with clear water and bottoms of mixed substrate and dispersed woody debris. The most vital habitat characteristic for sculpin residing in streams is probably the presence of cover such as rocks, logs, and overhanging vegetation. In the San Joaquin Valley, they are absent from warm, polluted areas, which suggests their distribution is regulated by water quality. In the area near Friant, prickly sculpins have been found in abundance in the cool flowing San Joaquin River, in the large, warm water Millerton Reservoir, and in the small, shallow Lost Lake where bottom temperatures exceed 26°C in the summer.

Ecological Interactions

Prickly sculpin have highly migratory life cycles, and because of this many populations have been eradicated or diminished due to the construction of barriers on streams.

Key Uncertainties

The degree of genetic isolation of prickly sculpin populations due to the effects of barriers is unknown.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Riffle sculpin	*Cottus gulosus* (Cottidae)

Legal Status:

Federal	None
State	None

Distribution

Riffle sculpin have a scattered distribution pattern throughout California that includes parts of the Sacramento-San Joaquin drainage, the San Francisco Bay Region, and coastal streams having historical connections to the Central Valley. They are also found in coastal streams from Puget Sound in Washington south to the Coquille River in Oregon. Their distribution indicates that they may have difficulties dispersing from one drainage to the next. They are most plentiful in undisturbed streams, especially headwaters or just below dams, where there are cold, permanent flows and an abundance of riffles and rocky substrates.

Life History

Riffle sculpins are benthic, opportunistic feeders. They grow mostly during the warmer months, and rarely exceed 100 mm total length. Maximum age is not well studied, but is probably no more that four years. Maturity takes place in their second year, and spawning occurs between February and April. Females can spawn >1000 eggs, which they deposit on the underside of rocks in swift riffles or inside cavities of submerged logs. Males guard the embryos, which hatch in 11-24 days, as well as yolk-sac fry. When fry reach approximately 6 mm total length, they begin a benthic existence.

Habitat Requirements

Riffle sculpin prefer habitats that are fairly shallow and have moderately swift water velocities. They can also live in small pools as long as they are cool and contain adequate cover. They select for areas where water temperatures do not surpass 25-26°C, as temperatures over 30°C are generally lethal. Riffle sculpin are restricted to flowing water due to their requirement of oxygen levels near saturation.

Ecological Interactions

Although they cannot easily disband to new locales, populations reductions through drought and toxic substance exposure can recover, albeit not quickly. Sculpin numbers can also be reduced when gold dredging practices destroy riffle habitats and loosen gravel utilized by the sculpin. Because they are so sensitive to degradation of water and habitat quality, their presence is generally a sign of a healthy salmonid habitat. Although they generally do not interact with salmonids due to niche separation, they will occasionally prey upon one another. Sculpin can be fairly aggressive toward other benthic fishes, such as speckled dace, and may feed upon or even displace them.

Key Uncertainties

Little is known about the effects of populations' isolation and the potential for local extirpation.

Key References

Moyle (2002)

Common Name	Scientific Name (family)
California roach	*Lavinia symmetricus* (Cyprinidae)

Legal Status:

Federal	None
State	Species of Special Concern (Sacramento-San Joaquin roach subspecies)

Distribution

California roach were first described from a specimen found in the San Joaquin River near Friant. They are endemic to the Sacramento-San Joaquin Province and have distributions spanning the Sacramento-San Joaquin River drainage, including the Pit River and tributaries to Goose Lake. They also occur in coastal streams including the Navarro, Gualala, and Russian rivers, tributaries to Tomales Bay, Pescadero Creek, and several rivers within the Monterey Bay drainage. Introduced populations have been described in the Eel River, Soquel Creek, and the Cuyama River (although this population may be native). California roach are typically found in small tepid streams, and are most plentiful in mid-elevation streams in the foothills of the Sierras and lower portions of coastal streams.

Life History

California roach as old as 6 years have been reported but they usually seldom live longer than three years, and growth within this period is highly variable based on season and stream characteristics. Most growth occurs in early summer, and 120 mm standard length is rarely exceeded for these fish. Maturity occurs when these fish attain 45-60 mm standard length (2-3 years). Spawning is regulated by water temperatures, and occurs from March to July when 16°C is exceeded. Roach spawn in large aggregations in shallow areas where the dominant substrate is 3-5 cm gravel. Depending on their size, females will deposit from 250-2000 adhesive eggs within interstices of the substrate. Hatching takes place in 2-3 days, and fry remain in crevices until they are able to actively swim. Roach are omnivores and will digest such items as terrestrial insects, filamentous algae, aquatic insect larvae and adults, crustaceans, and detritus.

Habitat Requirements

California roach are found in a broad variety of habitats within their wide distribution. They can be found in extreme conditions such as those with high temperatures (30-35°C) and low dissolved oxygen (1-2 ppm) as well as cold, clear, and well–aerated conditions. They have been noted from headwaters to lower reaches, including the main channel and highly modified reaches. Roach are unable to tolerate high salinities; mortality has been noted in the Navarro River when tidal influence increased salinity to 9-10 ppm.

Ecological Interactions

The presence of predatory pikeminnow can force roach from the open waters of sizeable pools to shallow areas at the periphery of pools and riffles, and nonnative green sunfish and largemouth bass have the ability to totally exclude them from streams. Though the Sacramento-San Joaquin roach subspecies is abundant, it has been eliminated from certain areas where it traditionally occurred. Currently populations are often confined to reaches below barriers such as dams, diversions, and polluted waters containing predatory fishes, and are becoming increasingly more isolated. Additionally, much of their habitat is located within private lands where activities such as heightened grazing pressure leads to diminished stream flow and degraded habitat. Predatory fish are often introduced into remaining deep pools where roach can easily be eliminated.

Key Uncertainties

Although this subspecies is still abundant, has disappeared from a portion of its range, and has not had a comprehensive study of its status, systematics, and distribution. The suitability of streams in the Pit and San Joaquin River drainages that can be managed as refuges for local populations is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Hardhead	*Mylopharodon conocephalus* (Cyprinidae)

Legal Status:

Federal	none
State	none

Distribution

Hardhead is endemic to the Sacramento-San Joaquin Province and occurs in sections of the larger low and mid-elevation streams of the Sacramento-San Joaquin drainage. They are largely absent from the lower Central Valley reaches. Hardhead are widely distributed in foothill streams and may be found in a few reservoirs such as the Redinger and Kerkhoff Reservoirs on the San Joaquin River, which are used for hydroelectric power generation. Their range extends from the Pit River system south to the Kern River. Hardhead also occur in the Russian River drainage.

Life History

Hardhead begin spawning at three years of age during the months of April and May. Spawning may continue through August. Fish in larger rivers or impoundments may migrate as far as 75 km to tributary streams for spawning. Spawning behavior is not known, however observed large aggregations during spawning season indicate behavior similar to hitch or pikeminnows. Females lay 7,000-24,000 eggs on gravel in riffles, runs or the heads of pools. The early life history of hardhead is not well known. Hardheads can reach 30 cm SL in 4-6 years in the larger rivers but rarely exceed 28 cm SL in the smaller streams. The maximum size for hardheads is believed to be around 1 meter TL and they may live more than 10 years. Adult hardhead are bottom-feeding omnivores in deep pools. Juveniles may take insects from the surface. Prey items may include insect larvae, snails, algae and aquatic plants, crayfish, and other large invertebrates.

Habitat Requirements

In the Central Valley, hardhead occupy the relatively undisturbed reaches of low and mid-elevation streams in the Sacramento-San Joaquin system. They also are known to occur in the mainstem Sacramento. Hardhead prefer water temperatures of above 20º C with optimal temperatures around 24-28º C. In the colder Pit River system they prefer the warmest available water where temperatures peak at 17-21ºC. Their distribution is limited to well-oxygenated streams and the surface water of impoundments. They are often found in clear deep pools (>80 cm) and runs with slower water velocities of 20-40 cm/s. Hardhead distribution in streams appears to be limited by their poor swimming ability in colder waters. Larvae and post larvae may occupy river edges or flooded habitat prior to seeking deeper low velocity habitat once they have grown larger.

Ecological Interactions

Hardhead are often absent from streams where introduced species such as centrarchids are established. They are also usually absent from streams that have been heavily altered by human activity. Hardhead decline appears to be associated with habitat loss and predation by non-native fishes. When present, hardhead are often found in association with Sacramento pikeminnow and Sacramento suckers which both have similar ecological requirements. Hardheads closely resemble the Sacramento pikeminnow but differ in the following in their morphology: the head is not as pointed and the body is deeper and heavier, the maxillary does not reach past the front margin of the eye, and a frenum, or small bridge of skin, connects the premaxillary bone, or upper lip, to the head.

Key Uncertainties

The decline of hardhead populations is similar to the decline of other native California fishes. Habitat alteration and predation by introduced species has adversely effected hardhead populations throughout their range. It is not known if hardhead populations can be stabilized. There are many information gaps in the life history and habitat requirements of hardheads. Spawning behavior has not been documented and early life history is poorly known.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
Hitch	*Lavinia exilicauda exilicauda* (Cyprinidae)

Legal Status:

Federal	None
State	*L. exilicauda chi (*Clear Lake subspecies) is a Species of Special Concern.

Distribution

Hitch are endemic to the Sacramento – San Joaquin Province. There are three subspecies within this species: *L.e. chi* from Clear Lake, *L.e. harengus* from the Pajaro and Salinas drainages, and *L.e. exilicauda* from the Sacramento-San Joaquin drainage (Lee et al. 1980). In addition to these regions, hitch are native to the Russian River, and are also found in the San Francisco Bay region and the Monterey Bay region. Additionally, they have been introduced into reservoirs within their native range, and have subsequently been carried via the California Aqueduct to several other reservoirs.

Life History

Hitch generally live for 4-6 years, reaching an ultimate size of up to 350 mm fork length. Females grow larger and more rapidly than males, and growth is correlated with productivity and summer temperatures. Maturation can occur from years 1-3 for both sexes. Mass spawning migrations typically take place when flows increase from spring rains in locales such as rivers, sloughs, ponds, reservoirs, drainage ditches, and riffles of lake tributaries. Females will lay anywhere from 3,000-63,000 eggs which sink to gravel interstices where they swell to approximately four times their preliminary size and remain lodged within the substrate. Hatching occurs in 3-7 days (15-22°C) and larvae take another 3-4 days to emerge. When they reach adequate size, they move into perennial water bodies where they will shoal for several months in association with aquatic vegetation or other complex vegetation before moving into open water. Hitch are omnivorous and feed in open waters on filamentous algae, aquatic and terrestrial insects, zooplankton, aquatic insect pupae and larvae, and small planktonic crustaceans.

Habitat Requirements

Hitch occur in warm, low elevation lakes, sloughs, and slow-moving stretches of river, and in clear, low-gradient streams. Among native fishes, hitch have the highest temperature tolerances in the Central Valley. They can withstand high temperatures of up to 38°C, although they prefer temperatures of 27-29°C. Hitch also have moderate salinity tolerances, and can be found in environments with salinities up to 7-9 ppt. For spawning, hitch require clean, fine to medium gravel and temperatures of 14-18°C. When larvae and small juveniles move into shallow areas to shoal, they require vegetative refugia such as tule beds to avoid predators. Larger fish are often found in deep pools containing an abundance of aquatic and terrestrial cover.

Ecological Interactions

Hitch are declining in numbers, and some populations in streams of the San Joaquin Valley have recently become extirpated. Factors for decline include loss of adequate spawning flows due to dams and diversions, loss of summer rearing habitat, and predation by nonnative fishes. Besides piscine predators, hitch are preyed upon by avian predators, raccoons, mink, otter, and bears, especially during mass spawning migrations. In disturbed habitats, hitch are associated with introduced species such as catfish, centrarchids, and mosquitofish whereas they are linked with Sacramento perch, Sacramento blackfish, thicktail chub, and splittail in less disturbed locales. When Sacramento blackfish share their same habitat, the two species often hybridize as a consequence of having to share spawning areas.

Key Uncertainties

Little is known about the abundance, distribution, status and systematics of hitch

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento blackfish	*Orthodon microlepidotus*
(Cyprinidae)	

Legal Status:

Federal	None
State	None

Distribution

Sacramento blackfish are endemic to the Sacramento-San Joaquin Province. They are found primarily in central and southern California, being native to major tributaries and low elevation reaches of the San Joaquin and Sacramento Rivers, the Pajaro and Salinas Rivers, and Clear Lake. Although they were abundant in the (now exhausted) sizeable lakes of the San Joaquin Valley, they are currently common in sloughs and oxbow lakes of the Sacramento-San Joaquin Delta. They have also been identified in the Russian River, but it is currently unknown if they are native there. They occur in a few central California reservoirs (including Shasta, Alameda, and Lagoon Valley), the San Francisco Bay Delta, and several creeks within the Bay region. Additionally, they have been transported via the California Aqueduct to reservoirs receiving water from this source. They have also been introduced into the Lahontan Reservoir, and have consequently spread to lakes of Stillwater Marsh and the Humboldt River drainage.

Life History

Scale samples suggest that Sacramento blackfish live up to five years, although 7-9 years may be a better estimate based on inaccuracies associated with using scale samples to date cyprinids. They grow rapidly within their first and second years, in the third year females tend to fractionally surpass the males, and each year after growth rates diminish and seldom exceed 50 mm FL and 1.5 kg. Depending on environmental conditions, blackfish will mature within years 1-4, although males tend to mature sooner. Fecundity is correlated with size, and a single female can produce anywhere from about 14,700 to 346,500 eggs at lengths of 171 to 466 mm FL, respectively. Spawning occurs in shallow areas with dense aquatic vegetation between May and July when water temperatures range between 12-24°C. Fertilized eggs attach to substrate within this aquatic vegetation, and larvae are frequently found in similar shallow areas, although they have been noted in open water. Juvenile blackfish are often found in large schools within shallow areas associated with cover. Sacramento blackfish are generally suspension feeders on planktonic algae and zooplankton.

Habitat Requirements

Sacramento blackfish are frequently abundant in warm, typically turbid, and often highly modified habitats. They have been found in locations ranging from deep turbid pools with clay bottoms such as the Pajaro River to warm, shallow, seasonally highly alkaline, and greatly turbid environments such as the Lagoon Valley Reservoir. Blackfish have a remarkable ability to adapt to extreme environments such as high temperatures and low dissolved oxygen. Although optimal temperatures range from 22-28°C, adults can regularly be found in waters exceeding 30°C, and laboratory experiments have shown juveniles can survive in temperatures up to 37°C. Their ability to tolerate extreme conditions affords them survival during periods of drought or low flow.

Ecological Interactions

Through introductions and aqueduct linkage, blackfish have been and are continuing to be spread to a number of reservoirs and streams. At this time, consequences and possible impacts of this spread on other organisms is generally not known. In the Lahontan Reservoir, blackfish have replaced native tui chub as the most abundant species. When blackfish densities are elevated, algae blooms, increased nutrient levels, and other various lake ecosystem changes may occur as a result of selective consumption of algae-grazing zooplankton.

Key Uncertainties

Through introductions, Sacramento blackfish have spread to a number of water bodies within California, and their complete distribution is not currently known. In turn, their impact on organisms within these areas is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento pikeminnow	*Ptychocheilus grandis* (Cyprinidae)

Legal Status:

Federal	none
State	none

Distribution

Sacramento pikeminnow are endemic to the Sacramento-San-Joaquin Province and are native to creeks and rivers in the Sacramento-San Joaquin Rivers, the Pajaro and Salinas Rivers, the Russian River, the Clear Lake basin, and the upper Pit River. In the 1970s Sacramento pikeminnow were spread throughout the state through introductions and via the aqueduct system. They are now found in Chorro and Los Osos Creeks (tributaries to Morro Bay, San Luis Obispo County), southern California reservoirs, and Pillsbury Reservoir and the Eel River (Mendocino and Humboldt Counties).

Life History

Sacramento pikeminnow become sexually mature when they are 3-4 years old when they are 22-25 cm SL. Males mature before females. Sexually mature fish move upstream in April and May when water temperatures are 15-20ºC. Spawning occurs over gravel riffles or the base of pools in smaller tributaries. Spawning occurs at night and has not been well documented but is probably similar to the closely related northern pikeminnow (P. oregonensis). Males congregate and await females who swim by and attract a number of males. The female releases a small number of eggs close to the bottom during a number of passes and the males fertilize the eggs. Fertilized eggs sink and adhere to the gravel. The number of eggs a female carries is related to size. A female 31-65 cm SL can spawn 15,000-40,000 eggs. Eggs probably hatch in 4-7 days at 18ºC. In approximately one week, larvae form shoals and occupy shallow areas before moving to deeper water and dispersing. Pikeminnow are slow growing and may live longer than 12 years. The largest known specimen was 115 cm SL and weighed 14.5 kg and was captured near the Kings River, Fresno County. Prior to the introduction of larger predatory fish such as basses, pikeminnows may have been the apex predator in the Central Valley. Pikeminnow prey includes insects, crayfish, larval fish and fish, amphibians, lamprey ammocoetes, and occasionally small rodents. Pikeminnow larger than 150 mm SL are primarily piscivorous.

Habitat Requirements

Sacramento pikeminnow prefer intermittent and permanent rivers and streams in low to mid-elevation areas with clear water, deep pools, slow runs, undercut banks, and vegetation. They do not prefer turbid or polluted water or areas where centrarchids have become established. Sacramento pikeminnow prefer summer water temperatures above 15ºC with a maximum of 26ºC. Temperatures above 38ºC are usually lethal. Pikeminnow can tolerate salinities as high as 8 ppt but are rarely found in waters above 5 ppt.

Ecological Interactions

Sacramento pikeminnow prefer vegetated reaches of streams that are relatively undisturbed. In these types of habitats they are usually associated with other native fish species such as hardhead and Sacramento sucker. They are usually absent where centrarchid basses have become established. Pikeminnow may have adverse impacts on salmonids under some conditions. They opportunistically prey on juvenile salmonids in the Eel River, where pikeminnow were introduced, and in locations in the Sacramento River, where dams and diversions have altered natural habitat conditions, including flows. Sacramento pikeminnow have gained an undeservedly bad reputation due to their predatory nature. Pikeminnow have been implicated for predation on juvenile salmon and affecting their population numbers in the Central Valley system. Both species naturally occur there. Where habitat has been altered, such as the Red Bluff Diversion dam, both salmon and pikeminnow migrations have been delayed, which resulted in large pikeminnow adults preying on outmigrating juvenile salmonids. Efforts to improve fish passage reduced predation and improved the situation. In many instances, pikeminnow populations have suffered due to introduced predator species and adverse affects from altered habitat.

Key Uncertainties

Sacramento pikeminnow spawning behavior and early life history has not been well documented.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
Speckled dace	*Rhinichthys osculus* (Cyprinidae)

Legal Status:

Federal	None
State	None

Distribution

Speckled dace are native to all major western drainage systems from Canada south to Sonora, Mexico. They are widely distributed throughout many portions of California, though do not occur in most small coastal drainages and various other drainages and watercourses including the San Joaquin drainage, Clear Lake basin, Russian River, and Cosumnes River drainage. Dace are typically considered second or third order stream specialists, although they are known to occupy a variety of habitats such as springs, high velocity brooks, pools in intermittent streams, higher order streams, and deep lakes. In some watersheds, however, speckled dace are potentially limited to small areas of suitable habitat, which may lead to extinction of these isolated populations.

Life History

Speckled dace generally live no longer than three years, and seldom exceed 85 mm FL. Depending on environmental factors, population density, and food availability, speckled dace tend to grow 20-30 mm FL in their first year, and 10-15 mm in years thereafter; females growing marginally faster than males. Maturation generally occurs in their second summer, and spawning generally occurs in the months of June and July. Females have been documented to spawn between roughly 200-800 eggs within crevices of gravel substrate where they adhere. Hatching occurs in about 6 days (at 18-19°C), after which larval fish will remain in the interstices for 7-8 days. Upon emergence, fry tend to seek warm shallow reaches associated with cover. Speckled dace are specialized to feed on small, benthic invertebrates living in riffles, but will also consume zooplankton and large terrestrial insects.

Habitat Requirements

Though speckled dace can occupy a wide variety of habitats, they each tend to have similar characteristics including clear, moving, well-oxygenated water, and plentiful deep cover such as submerged and overhanging vegetation, woody debris, and rocks. They prefer shallow (<60 cm) and rocky riffles and runs, and may actually be more abundant in channelized streams or those with reduced flows due to an increased quantity of preferred habitat. Certain populations of dace are tolerant of periodic extreme temperatures ranging from 0 to >31°C, and dissolved oxygen levels as low as 1 ppm. If threshold levels are exceeded and local populations are eliminated or seriously depressed, dace have an extraordinary ability to recolonize and repopulate areas.

Ecological Interactions

Speckled dace tend to be more abundant in reaches where sculpin are absent due to overlapping food niches. They also display avoidance behavior in response to avian predators, oftentimes being more nocturnally active. When avian predators are scarce, populations may be active during the day as well. Dace may also not be able to persist when there is an overabundance of nonnative predators. During spawning, dace may hybridize with Lahontan redside because they can spawn at the same time and place.

Key Uncertainties

Speckled dace may be present in headwaters of tributaries on the west side of the San Joaquin Valley but their presence has not been confirmed.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento splittail	*Pogonichthys macrolepidotus* (Cyprinidae)

Legal Status:

Federal	Threatened (listed February 1999)
State	Species of Special Concern

Distribution

Sacramento splittail are endemic to the Sacramento and San Joaquin river systems of California, including the waters of the Sacramento-San Joaquin Delta and the San Francisco Estuary. Historically, splittail were found in the Sacramento River as far upstream as Redding, in the Feather River to Oroville, and in the American River upstream to Folsom. In the San Joaquin River they were once documented as far upstream as Friant (Rutter 1908, as cited in Moyle 2002). Splittail are thought to have originally ranged throughout the San Francisco Estuary, with catches reported by Snyder (1905, as cited in Moyle 2002) from southern San Francisco Bay and at the mouth of Coyote Creek.

In wet years Sacramento splittail have been found in the San Joaquin River as far upstream as Salt Slough (Baxter 2000, Baxter 1999, Brown and Moyle 1993, all as cited in Moyle 2002, Saiki 1984) and in the Tuolumne River as far upstream as Modesto (T. Ford, Turlock Irrigation District, pers. comm. 1998, as cited in Moyle 2002), where the presence of both adults and juveniles during wet years in the 1980s and 1990s indicated successful spawning.

When spawning, splittail can be found in the lower reaches of rivers and flooded areas. Otherwise they are primarily confined to the Delta, Suisun Bay, Suisun Marsh, the lower Napa River, the lower Petaluma River, and other parts of the San Francisco Estuary (Meng and Moyle 1995, Meng et al. 1994, as cited in Moyle 2002). In general, splittail are most abundant in Suisun Marsh, especially in drier years (Meng and Moyle 1995), and reportedly rare in southern San Francisco Bay (Leidy 1984). Splittail abundance appears to be highest in the northern and western Delta when population levels are low, and they are somewhat more evenly distributed throughout the Delta during successful year classes (Sommer et al. 1997, Turner 1966, both as cited in Moyle 2002).

Splittail are largely absent from the upper river reaches where they formerly occurred, residing primarily in the lower parts of the Sacramento and San Joaquin rivers and tributaries and in some Central Valley lakes and sloughs (Moyle 2002, Moyle et al. 2001). In wet years, however, they have been known to ascend the Sacramento River as far as Red Bluff Diversion Dam and into the lower Feather and American rivers (Baxter 2000, Baxter 1999, Baxter et al.1996, Sommer et al. 1997, all as cited in Moyle 2002). Currently the Sutter and Yolo bypasses along the lower Sacramento River appear to be important splittail spawning areas (Sommer et al. 1997). Splittail now migrate into the San Joaquin River only during wet years, and use of the Sacramento River and its tributaries is likely more important (Moyle 2002).

Accounts of early fisheries suggested that splittail had large seasonal migrations (Walford 1931, as cited in Moyle et al. 2001). Splittail migration now appears closely tied to river outflow. In wet years with increased river flow, adult splittail will still move long distances upstream to spawn, allowing juvenile rearing in upstream habitats. The upstream migration is smaller during dry years, although larvae and juveniles are often found upstream of the city of Sacramento to Colusa or Ord Bend on the Sacramento River (Moyle et al. 2001). Currently the tidal upper estuary, including Suisun Bay, provides most juvenile rearing habitat, although young-of-the-year may rear over a broader area, including the lower Sacramento River. Brackish water apparently provides optimal rearing habitat for splittail.

Life History

Adult splittail move upstream beginning in late November to late January, foraging in flooded areas along the main rivers, bypasses, and tidal freshwater marsh areas of Montezuma and Suisun sloughs and San Pablo Bay prior to the onset of spawning (Moyle et al. 2001). Feeding in flooded riparian areas prior to spawning may contribute to spawning success and survival of adults after spawning (Moyle et al. 2001). Splittail are adapted to the wet-dry climatic cycles of northern California, and thus appear to concentrate their reproductive effort in wet years when potential success is greatly enhanced by the availability of inundated floodplain (Meng and Moyle 1995, Sommer et al. 1997). Splittail are thought to be fractional spawners, with individuals spawning over a protracted period—often as long as several months (Wang 1995, as cited in Moyle 2002). Older fish are believed to begin spawning first (Caywood 1974, as cited in Moyle 2002).

Larger females may lay 100,000 eggs. Splittail eggs, which are 0.4–0.6 inches (1.0–1.6 mm) in diameter (Wang 1986, Feyrer and Baxter 1998, both as cited in Moyle 2002), begin to hatch within 3–7 days, depending on temperature (Bailey et al. 2000, as cited in Moyle 2002). Eggs laid in clumps hatch more quickly than individual eggs (Moyle et al. 2001). Within 5–7 days after hatching, swim bladder inflation occurs and larvae begin active swimming and feeding (Moyle 2002). Larval splittail reared in captivity reach 0.4 inches (10–11 mm) within 15 days following hatching (Bailey et al. 1999, as cited in Moyle et al. 2001).

The adhesive eggs are released by the female, fertilized by one or more attendant males, and adhere to vegetation until hatching (Moyle 2002). Females are typically highly fecund, with the largest individuals potentially producing 100,000 or more eggs (Daniels and Moyle 1983, Feyrer and Baxter 1998, both as cited in Moyle 2002). Fecundity has been found to be highly variable, however, and may be influenced by food supplies in the year prior to spawning (Moyle et al. 2001). Little is known regarding the tolerance of splittail eggs and developing larvae to dissolved oxygen, temperature, pH, or other water quality parameters, or to other factors such as physical disturbance or desiccation.

After emergence, most larval splittail remain in flooded riparian areas for 10–14 days, most likely feeding among submerged vegetation before moving off floodplains into deeper water as they become stronger swimmers (Sommer et al. 1997, Wang 1986, both as cited in Moyle 2002). Although juvenile splittail are known to rear in upstream areas for a year or more (Baxter 1999, as cited in Moyle et al. 2001), most move to tidal waters after only a few weeks, often in response to flow pulses (Moyle et al. 2001). The majority of juveniles apparently move downstream into shallow, productive bay and estuarine waters from April–August (Meng and Moyle 1995, as cited in Moyle 2002). Growth is likely dependent on the availability of high-quality food, especially in the first year of life (Moyle et al. 2001).

Non-breeding splittail are found in temperatures ranging from 5 to 24°C (41–75° F), depending on the season, and acclimated fish can survive temperatures up to 33°C (91° F) for short periods (Young and Cech 1996, as cited in Moyle 2002). Juveniles and adult splittail demonstrate optimal growth at 20º C (68° F), and signs of physiological distress only above 29ºC (84° F) (Young and Cech 1995 as cited in Winternitz and Wadsworth 1997).

Because splittail are adapted for living in brackish waters with fluctuating conditions, they are quite tolerant of high salinities and low dissolved oxygen levels. Splittail are often found in salinities of 10–18 ppt, although lower salinities may be preferred (Meng and Moyle 1995, as cited in Moyle 2002), and can survive low dissolved oxygen levels (0.6–1.2 mg/L for young-of-the-year, juveniles, and subadults) (Young and Cech 1995, 1996). Because splittail have a high tolerance for variable environmental conditions (Young and Cech 1996), and are generally opportunistic feeders (prey includes mysid shrimp, clams, copepods, amphipods, and some terrestrial invertebrates), reduced prey abundance will not likely have major population-level impacts. Year class success appears dependent on access and availability of floodplain spawning and rearing habitats, high outflow, and wet years (Sommer et al. 1997).

Habitat Requirements

Rising flows appear to be the major trigger for splittail spawning, but increases in water temperature and day length may also be factors (Moyle et al. 2001). Spawning typically takes place on inundated floodplains from February through June, with peak spawning in March and April. Available information indicates that splittail spawn in open areas with moving, turbid water less than 5 feet (1.5 meters) deep, amongst dense annual vegetation and where water temperatures are less than about 59°F (15°C) (Moyle et al. 2001). Perhaps the most important spawning habitat in the eastern Delta is the Cosumnes River floodplain, where ripe splittail have been observed in flooded fields with cool temperatures (<59° F [15° C]), turbid water, and submerged terrestrial vegetation (Moyle, Crain, and Whitener, unpublished data, as cited in Moyle et al. 2001).

Splittail eggs are deposited in flooded areas amongst submerged vegetation, to which they adhere until hatching. Juveniles are strong swimmers and are usually found in shallow (<2 m [6.6 ft] deep), turbid water (Young and Cech 1996). As their swimming ability increases, juveniles move away from the shallow areas near spawning sites into faster, deeper water (Moyle 2002). Floodplain habitat offers high food quality and production and low predator densities to increase juvenile growth.

The following is a review of the scientific literature to select habitat criteria for each Sacramento splittail life history stage, focusing as much as possible on relevance to the Sacramento River.

Table 1. Life history stage criteria for splittail.

Criteria	Adult Up-Migration and Spawning	Egg/Alevin Rearing	Juvenile Rearing	Adult
Water Temperature (°C)	Increase to 14–19°C may trigger spawning(a); spawn where water is < 15°C(c)	≤ 18.5°C(c,e)	7–28°C; but 21–25°C preferred(d)	7–24°C(a,d); but 19°C preferred(d)
Water Salinity (ppt)	≤ 18 ppt(b)		< 16 ppt(d)	10–18 ppt, but prefer lower(b); can briefly tolerate up to 29 ppt(d)
Water Depth (cm)	50–200 cm for spawning(a)		< 200 cm(a)	<400 cm(c)
Water Velocity			tidal currents(a)	slow moving(a)
Substrate	spawn on floodplains with flooded vegetation(a)	floodplains with flooded vegetation	variable—may prefer soft bottoms with fine substrate and emergent vegetation(a,b)	variable—may prefer soft bottoms with fine substrate and emergent vegetation(a,b)

Sources:

a Moyle 2002
b Meng and Moyle 1995
c Moyle et al. 2001
d Young and Cech 1996
e Bailey et al. 2000, as cited in Moyle 2002

Ecological Interactions

Human activities, such as extensive dam construction, water diversions, channelization, and agricultural drainage, have resulted in splittail disappearing as permanent residents from portions of the Sacramento and San Joaquin valleys. Much of the lowland habitat that they once occupied has been altered so that it is now inaccessible except during wet years.

The USFWS listed Sacramento splittail as a threatened species in February 1999 because of the reduction in its historical range and because of the large population decline during the drought of 1987–1993 (Moyle et al. 1995, USFWS 1996, USFWS 1999, all as cited in Moyle 2002). The CDFG (1992) estimates that splittail during most years are only 35–60 percent as abundant as they were in 1940. CDFG midwater trawl data indicate considerable fluctuations in splittail numbers since the mid-1960s, with abundance often tracking river and Delta outflow conditions. The overall trends include a decline from the mid-1960s to the late 1970s, somewhat of a resurgence through the mid-1980s, and another decline from the mid-1980s through 1994 (Moyle 2002). In 1995 and 1998 the population increased dramatically, demonstrating the extreme short-term and long-term variability of splittail recruitment success and the apparent correlation with river outflow (Sommer et al. 1997). Outflow in February–May can explain between 55 percent and 69 percent of the variability in abundance of splittail young, depending on the abundance measure. Age-0 abundance of splittail declined in the estuary during most dry years, particularly in the drought that began in 1987 (Sommer et al. 1997). Not all wet years result in high splittail recruitment, however, since recruitment success is largely dependent on the availability of flooded spawning habitat. In 1996, for example, most high river flows occurred in December and January, prior to the onset of the splittail spawning season (Moyle 2002). Splittail are preyed upon by striped bass and other piscivores.

In summary, the long-term decline of splittail is due to the following factors, in order of importance: 1) reduction in valley floor habitats, 2) modification of spawning habitat, 3) changed estuarine hydraulics, especially reduced outflows, 4) climatic variation, 5) toxic substances, 6) introduced species, 7) fishing exploitation.

Key Uncertainties

A variety of surveys have compiled splittail abundance data. None of these, however, was specifically designed to systematically sample splittail abundance, and definitive conclusions are therefore not possible (Moyle et al. 2001). Combined, the survey data indicate that some successful reproduction occurs on a yearly basis, but large numbers of juvenile splittail are produced only when outflow is relatively high. Thus the majority of adult fish in the population probably result from spawning in wet years (Moyle et al. 2001). The stock-recruitment relationship in splittail is apparently weak, indicating that given the right environmental conditions a small number of large females can produce many young (Sommer et al. 1997, Meng and Moyle 1995, both as cited in Moyle 2002).

The effects of pesticides and other toxics on splittail are not known but are considered to be potentially negative. The effects of introduced species on splittail are poorly understood, although it is recognized that changes in the food web are likely to have negative consequences.

Key References

Bailey, H. C., E. Hallen, T. Hampson, M. Emanuel and B.S. Washburn. 2000. Characterization of reproductive status and spawning and rearing conditions for splittail *Pogonichthys macrolpeidotus*, a cyprinid of Special Concern, endemic to the Sacramento-San Joaquin estuary. Unpublished manuscript, University of California, Davis.

Common Name	**Scientific Name (family)**
Thicktail chub	*Gila crassicauda* (Cyprinidae)

Legal Status:

Federal	None
State	SE 01-10-74. Delisted 10-02-80 (EXTINCT)

Distribution

Thicktail chub are endemic to the Sacramento-San Joaquin Province. Historical distribution was in lowland areas of the Central Valley, Clear Lake, the Pajaro and Salinas Rivers, and in tributaries to the San Francisco Bay. The species is now extinct. It is assumed that thicktail chub became extinct due to their inability to adapt to extreme modifications of valley floor habitats, especially removal of tule beds, drainage of large shallow lakes, reduction in stream flows, and modification of stream channels. Another important source of their demise was the introduction of exotic predators, especially striped and largemouth bass.

Life History

Based on morphology, it is likely that thicktail chubs were carnivorous and probably fed on small fish and large aquatic invertebrates.

Habitat Requirements

Thicktail chubs were abundant in lowland lakes, sloughs, and slow-moving sections of rivers.

Ecological Interactions

Thicktail chubs were able to hybridize with hitch, and were part of the original valley floor fish assemblage that included hitch, Sacramento sucker, Sacramento blackfish, Sacramento perch, and tule perch.

Key Uncertainties

Little is known about this extinct species.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Tule perch	*Hysterocarpus traski traski* (Embiotocidae)

Legal Status:

Federal	None
State	Russian River Tule Perch (Hysterocarpus traski pomo) is listed as a Species of Special Concern.

Distribution

Historically the endemic Sacramento-San Joaquin subspecies of tule perch was widespread throughout the lowland rivers and creeks in the Central Valley. Currently in the San Joaquin drainage they occur in the Stanislaus River, occasionally in the San Joaquin River near the Delta, and the lower Tuolumne River. The other subspecies are *H. t. pomo* in the Russian River and its lower tributaries and *H. t. lagunae* in Clear Lake. In addition, tule perch have been carried via the California Aqueduct to Silverwood and Pyramid Reservoirs in southern California. They can be found in a number of lowland habitats including lakes, estuarine sloughs, and clear streams and rivers.

Life History

Tule perch generally search on the bottom or within aquatic plants for food items, but will also feed midwater. They are primarily adapted to feed on small invertebrates and zooplankton and have been observed to ingest small amphipods, midge and mayfly larvae, small clams, brachyuran crabs, mysid shrimp. Principal growth occurs within the first year, and a maximum length of 20 cm standard length is rarely exceeded. They can live for up to 7-8 years, but more often do not survive past 5 years. Age at first maturity varies with environment, and number of young produced varies with size of the female. Females mate multiple times between July and September, and sperm is stored until January when fertilization occurs. Young develop within the female, and are born in June or July when food is most abundant. Juveniles begin to school soon after birth.

Habitat Requirements

Tule perch inhabiting rivers can usually be found within beds of emergent plants, in deep pools, and near banks with complex cover. They require cool, well-oxygenated water for their persistence, and tend not to be found in water exceeding 25°C for extended periods. They have a remarkable capability to tolerate high salinities, and can even persist at salinities of >30 ppt.

Ecological Interactions

Tule perch that reside in lakes are commonly associated with bluegill and other alien centrarchids, but in streams they are associated primarily with other native fishes. They tend to not be found in environments dominated by exotic fishes, but this appears to be a result of poor water quality. The fact that they are viviparous lowers their vulnerability to competition and predation by nonnative fishes. Poor water quality and toxic chemical exposure seem to be responsible for their extirpation from the Pajaro and Salinas Rivers, a majority of the San Joaquin basin, and various other smaller streams. They are rare in areas that have been greatly anthropogenically modified.

Key Uncertainties

Tule perch appear to have been extirpated from most of the San Joaquin basin, but the exact causes are not known.

Key References

Moyle (2002)

Common Name	Scientific Name (family)
Threespine stickleback	*Gasterosteus aculeatus* (Gasterosteidae)

Legal Status:

Federal *G. a. williamsoni* is listed as endangered (10-13-70), *G. a. aculeatus* and *G.a. microcephalus* have no federal listing. Critical habitat was proposed for *G.a. williamsoni* 11-17-80.

State *G. a. williamsoni* is listed as endangered (06-27-71), *G. a. aculeatus* and *G.a. microcephalus* have no state listing.

Distribution

Threespine stickleback populations are distributed in North America from the East Coast southward to Chesapeake Bay, and from the West Coast southward as far as Baja California. They have resident, anadromous, and unarmored subspecies, and are found in coastal streams, estuaries, and bays. In California, anadromous populations are present from the Oregon border south to Monterey Bay, while fully plated nonmigratory populations can occur southward as far as San Luis Obispo Creek. In the Central Valley, populations may be found from the lower Kings River to approximately Redding in the Sacramento River drainage, including the San Joaquin River where they are present below Friant Dam as well as a small stream above Kerckoff Reservoir. Unarmored threespine sticklebacks are presently only found naturally in the upper Santa Clara River, San Antonio Creek, and Whitewater River.

Life History

Though the majority of threespine sticklebacks complete their life cycle within one year, there is evidence that they have the potential to survive for up to two or three years. In California, resident populations rarely exceed 50 mm TL whereas anadromous populations typically reach 80 mm TL. Often females are larger than males. All forms of threespine stickleback breed in freshwater from April through July when daylight hours and water temperature increase, although anadromous forms tend to spawn earlier. Males construct nests out of algae, aquatic vegetation, and a sticky kidney secretion in which females will lay 50-300 eggs over several spawning periods. Males are responsible for protection and maintenance of the embryos, which hatch in 6-8 days at 18-20°C. Upon hatch, fry remain in the nest for several days while being cared for by the male, until they begin to swim in shoals.

Habitat Requirements

Preferred habitat for threespine sticklebacks includes calm-water shallow pools and backwaters containing vegetation, or associated with emergent plants at stream edges located above gravel, sand, and mud. A major requirement for this species is water clarity that is great enough to allow growth of aquatic plants used for building nests. Water clarity is also important due to the fact that they are visual feeders. Anadromous forms are typically pelagic, and tend to stay close to shore. This species generally requires cool water (<23-24°C) for long-term survival, and have broad salinity tolerances. Unless breeding, they shoal to more readily locate prey that consists of bottom-dwelling organisms, or those living in aquatic vegetation.

Ecological Interactions

Although these fish have spines and bony plates for armor and protection, the combination of small size, sluggish motion, and shallow-water preference make them an ideal prey for both avian and piscine predators. The distribution of this species is largely determined by predation pressure; when predation is high, they will most likely be found in association with dense aquatic vegetation. They are considered an important prey item of salmonids, and it has been suggested that within Central Valley river systems, pikeminnow predation can eliminate sticklebacks. They act as a host for intermediate stages of bird tapeworm that causes the infected fish to turn white and swim slowly at the surface, increasing vulnerability to kingfishers and herons that then become the final hosts.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Kern brook lamprey	*Lampetra hubbsi* (Petromyzontidae)

Legal Status

Federal	None
State	Species of Special Concern

Distribution

Kern brook lamprey are endemic to the east portion of the San Joaquin Valley, and were first collected in the Friant-Kern Canal. They have subsequently been found in the lower Merced, Kaweah, Kings, and San Joaquin Rivers. They are generally found in silty backwaters of rivers stemming from the Sierra foothills.

Life History

It is thought that this species undergoes metamorphosis in autumn, spawns in spring, and dies thereafter. Not much else is known about Kern brook lamprey, but they presumably have similar life histories to western brook lamprey.

Habitat Requirements

Ammocoetes are typically found in low-velocity portions of shallow pools and along edges of runs. They prefer habitats with substrates of mud and sand, depths of 30-110 cm, and summer temperatures that do not exceed 25°C. Ammocoetes are often intermittently abundant in the siphons of the Friant-Kern Canal because this area meets the majority of habitat requirements. Adults tend to prefer riffles containing gravel for spawning, and rubble for cover.

Key Uncertainties

There is uncertainty about the potential for extirpation of populations within the San Joaquin drainage because they are largely isolated with most populations found below dams where flow regulation typically does not address lamprey needs. The effects of channelization, work on banks, and elimination or compaction of gravel beds from various management practices on habitats required by Kern brook lamprey are not well understood.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Pacific lamprey (Petromyzontidae)	*Lampetra tridentata*

Legal Status:

Federal None
State None

Distribution

Pacific lampreys are anadromous fish that have Pacific coast distributions in streams from Hokkaido, Japan, through Alaska, and down to Rio Santo Domingo in Baja, California, although their distribution south of San Luis Obispo is intermittent. There are also landlocked populations from the Upper Klamath River, Goose Lake, and Clair Engle Reservoir on the Trinity River. Anadromous forms spend the predatory portion of their life in the ocean, and move into streams to spawn, while resident forms will spend this portion of their life in lakes and reservoirs before moving into spawning streams.

Life History

Depending on their location, lamprey will begin upstream migrations anywhere between January and September, and may spend up to a year maturing in freshwater until they are ready to spawn. Upstream migration seems to largely take place in response to high flows, and adults can move substantial distances unless blocked by major barriers such as the Friant Dam on the San Joaquin River. When they are ready to spawn both sexes will work together to build a nest. Females can produce 20,000-200,000 eggs that are released onto the gravel where they will adhere upon fertilization. Lamprey will typically die soon after spawning, though this is not always the case. Hatching occurs in approximately 19 days (at 15°C), and after spending a short period in the gravel, ammocoetes will move up into the current where they are swept downstream to an area with soft substrate where they bury themselves and filter feed on organic materials covering the substrate. Ammocoetes will move about, but will remain in this state for 5-7 years before beginning morphological changes enabling them to move into the ocean. When transformation is complete, downstream migration will take place during high flow events.

Habitat Requirements

Nests are typically built in gravel-sized substrate, where water velocity is fairly rapid, depths are 30-150 cm, and water temperatures are generally 12-18°C. Ammocoetes occur in areas with soft substrate.

Ecological Interactions

While in their predatory phase, lamprey attack a multitude of fishes, including salmon and flatfishes in the ocean, and tui chub, suckers, and redband trout in lakes and reservoirs. Overall, their effect on fish populations is considered to be minimal. They are at times, prey of other organisms such as sharks and sea lions. Highly altered or polluted streams will often exclude Pacific lamprey from inhabiting an area.

Key Uncertainties

Little is known about the status and biology of this species, in particular if multiple spawning runs exist in some rivers as well as where landlocked forms exist.

Key References

Moyle (2002)

Common Name	Scientific Name (family)
River lamprey	*Lampetra ayresi* (Petromyzontidae)

Legal Status:

Federal	None
State	Species of Special Concern

Distribution

River lampreys can be found in large coastal streams from roughly Juneau, Alaska to the San Francisco Bay. From what is known about this species, the region of primary abundance in California is in the lower Sacramento-San Joaquin drainage, especially the Stanislaus and Tuolumne Rivers. They are additionally present in Sonoma, Salmon, and Alameda Creeks, the Napa River, tributaries to the lower Russian River, and possibly the Eel River. Outside of California, their distributions are isolated and greatly scattered.

Life History

Spawning migrations occur in autumn, and spawning takes place in streams from February through May. One study in Cache Creek found females with fecundities of 11,400 to 37,300 eggs. After spawning, adults will die. After hatching, ammocoetes are hypothesized to spend 3-5 years in this stage before metamorphosis into adults. This transformation begins in the summer, and takes 9-10 months to complete. These lampreys will then enter the ocean at the end of spring where they spend 3-4 months. During this period, they will display rapid growth while feeding on a variety of fishes such as herring and salmon.

Habitat Requirements

Nests are created by formation of depressions in gravel riffles. Ammocoates occur in silty backwaters and eddies.

Ecological Interactions

River lamprey can have a substantial impact on prey populations, and in certain locations have been identified as a major source of salmon mortality. In laboratory studies, river lampreys are able to hybridize with western brook lamprey, though this has not been observed to occur in the wild.

Key Uncertainties

River lamprey population trends are unknown in the southern portion of its range, but it is probable they have declined in response to degradation of adequate spawning and rearing habitat in lower sections of large rivers. In California, the extent and timing of spawning migrations is not well known.

Key References

Moyle (2002

Common Name	**Scientific Name (family)**
Western brook lamprey	*Lampetra richardsoni* (Petromyzontidae)

Legal Status:

Federal	none
State	none

Distribution

The western brook lamprey is distributed from southeast Alaska to California including the Sacramento San Joaquin system. They may occur further south in California in larger streams and rivers.

Life History

Western brook lamprey spawn in late April to early June when water temperatures exceed 10º C. They construct nests in gravel riffles, which are occupied by 2-4 and as many as 12 individuals. Egg number varies from 1,100 to 3,700. Eggs are adhesive and hatch in approximately 10 days at 10-15.6ºC. In approximately 30 days ammocoetes burrow into the silt. Survival is apparently high as this species is one of the more abundant life forms in the lower courses of streams in the northwestern United States. Density can be as high as 170 per square meter. Western brook lamprey live 3-4 years in California and reach 13-18 cm in size. From August until November the largest ammocoetes metamorphose into adults. These individuals overwinter without feeding, sexually mature in the spring, then spawn and die.

The western brook lamprey is non-anadromous and is non-parasitic, consuming algae, including diatoms, and other organic matter.

Habitat Requirements

The species is abundant in freshwater streams and occupies backwaters and pools where silt and sand substrates exist. They may be restricted to the less disturbed sections of rivers and intolerant of high pollution levels.

Ecological Interactions

The species is probably more abundant than reported. Sculpin, salmonids, and even ravens may eat western brook lamprey eggs, spawning adults, and smaller ammocoetes. Some species may demonstrate an aversion to eating larger ammocoetes, which may be due to secretion of granular cells in the skin.

Western brook lamprey may compete with the Pacific lamprey, *E. tridentatus*, and river lamprey, *L. ayresi*, for nesting space. However, brook lamprey usually nest in smaller streams and further upstream.

Key Uncertainties

Little work has been done on the biology of western brook lamprey in California. The more isolated populations of this species may have unique characteristics and may be distinct species.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973.

Common Name	**Scientific Name (family)**
Chinook salmon	*Oncorhynchus tshawytscha* (Salmonidae)

Legal Status:

Federal Candidate/not warranted (Central Valley Fall and Late Fall ESU)

Distribution and Population Trends

Chinook salmon are distributed in the Pacific Ocean throughout the northern temperate latitudes in North America and northeast Asia. In North America, they spawn in rivers from Kotzebue Sound, Alaska south to the San Joaquin River in California's Central Valley (Healey 1991). In California, large populations are found in the Sacramento River and its major tributaries. Chinook salmon are also widely distributed in smaller California coastal streams north of San Francisco Bay (Allen and Hassler 1986). Fall Chinook occurring in the San Joaquin river belong to the Central Valley Fall and Late Fall Evolutionary Significant Unit (ESU). The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin River Basins and their tributaries, east of Carquinez Strait, California. NMFS (1999) determined that listing was not warranted for this ESU, but subsequently designated the ESU as a candidate for listing. Spring Chinook are extirpated from the San Joaquin basin, and are not included in an ESU.

Four runs of Chinook salmon occur in California fall, late fall, winter, and spring (Leet et al. 1992, Allen et al. 1986, Mills et al. 1997). Fall-run populations (or "fall Chinook") occur throughout the species' range and are currently the most abundant and widespread salmon runs in California (Mills et al. 1997). Winter-run populations are limited to the Sacramento River basin and were listed as endangered under the federal Endangered Species Act in 1994. Two apparently distinct stocks of spring-run Chinook (or "spring Chinook") occur in California: a Sacramento-San Joaquin population and a Klamath-Trinity population (Moyle et al. 1995). Moyle et al. (1995) state that although other spring Chinook populations may have existed in smaller coastal streams between these two basins, such as the Eel River, they have since been extirpated and there is no evidence of recent spawning in these streams.

The San Joaquin River system once supported large runs of both spring and fall Chinook salmon. In the San Joaquin River and its tributaries historic production is estimated to have approached 300,000 fish (Reynolds et al. 1993, as cited in Yoshiyama et al. 1998). The last large run observed in the San Joaquin River was over 56,000 fish in 1945 (Fry 1961, as cited in Moyle et al. 1995). Adult spring Chinook salmon entered the system during periods of high spring snowmelt, held over in deep pools during the summer, then spawned in the upper reaches of the San Joaquin River and its major tributaries—the Stanislaus, Tuolumne, and Merced rivers—in the early fall. Locals living on the San Joaquin River mainstem before dam construction observed spring Chinook holding in the summer in pools near Friant, and moving upstream into the gorge of the San Joaquin River to spawn (currently inundated by Millerton Lake) (CFGC 1921). Dam construction and irrigation diversions, which eliminated access to upstream spawning and holding areas, extirpated the spring run from the basin by the late 1940s (Skinner 1962).

Fall Chinook salmon are currently the most abundant race of salmon in California (Mills et al. 1997). In the San Joaquin Basin, fall Chinook historically spawned in the mainstem San Joaquin River upstream of the Merced River confluence and in the mainstem channels of the major tributaries. Dam construction and water diversion dewatered much of the mainstem San Joaquin River, limiting fall Chinook to the three major tributaries where they spawn and rear downstream of mainstem dams.

Run estimates are available from 1940, but systematic counts of salmon in the San Joaquin Basin began in 1953, long after construction of large dams on the major San Joaquin basin rivers. Comparable estimates of population size prior to 1940 are not available. Since population estimates began, the number of fall Chinook returning to the San Joaquin Basin annually has fluctuated widely. Most recently, escapement in the Tuolumne River dropped from a high of 40,300 in 1985 to a low about 100 resulting from the 1987–1992 dry period (EA 1997). With increased precipitation and improved flow conditions, escapement has increased to 3,300 in 1996 (EA 1997). Since 1991 hatchery production is estimated to compose about 30–60% of the fall Chinook run in the San Joaquin River (PFMC 1998, as cited in Yoshiyama et al. 1998). Figure 1 provides a summary of estimated escapement from 1953–2000 in the Stanislaus, Tuolumne, and Merced rivers.

Due to extensive hatchery introductions, most spring Chinook currently in Sacramento mainstem have hybridized with fall-run fish, and are heavily introgressed with fall Chinook characteristics, particularly with regard to run timing (Yoshiyama et al. 1998). Deer, Mill, and Butte Creek stocks appear to have minimal to no hatchery influence.

Life History

Overview

Chinook salmon vary in length of fresh and salt-water residency, and in upstream and downstream migration timing (Healey 1991). Chinook salmon are the largest of the Pacific salmon species, reaching weights of up to 45 kg (99 lb), although most adults in Oregon weigh 4.5–18 kg (10–40 lbs) (Healey 1991, Kostow 1995). Chinook salmon have genetically distinct runs differentiated by the timing of spawning migration, stage of sexual maturity when entering fresh water, timing of juvenile or smolt outmigration, and other characteristics (Moyle et al. 1989).

Spring Chinook typically spend up to one year rearing in fresh water before migrating to sea, perform extensive offshore migrations, and return to their natal river in the spring or summer, several months prior to spawning (these are also referred to as “stream-type” Chinook). Fall (or “ocean-type”) Chinook migrate to sea during their first year of life-typically within three months after their emergence from spawning gravels, spend most of their ocean life in coastal waters, and return to their natal river in the fall, a few days or weeks before spawning (Moyle et al. 1989, Healey 1991). The following information focuses on the life history and habitat requirements of spring Chinook salmon although information on fall Chinook is also included. Information specific to the San Joaquin River has been included where possible. Table 1 displays the timing of specific life history events for spring Chinook salmon in the San Joaquin River basin based on historical information, and recent information from similar stocks (e.g., Sacramento River basin stocks), and Table 2 displays the general timing of life history events of fall chinook in the Central Valley.

Adult upstream migration and spawning

Adult Chinook salmon migrate upstream from the ocean to spawn in their natal streams, although a small percentage may stray into other streams, especially during high water years (Moyle et al. 1989). In California rivers, adult spring Chinook typically return to fresh water between March and May while still sexually immature (Marcotte 1984). Upstream migration in the San Joaquin River historically occurred from March through June (CFGC 1921, Hatton and Clark 1942), and holding occurred from April though mid-July (Table 1). There are differences in run timing between basins within the Sacramento/San Joaquin Rivers, which have been attributed to the timing of fall decreases in water temperature. Spring Chinook salmon tend to move up into the cooler reaches of rivers earlier in the season to spawn, and spawn in warmer reaches later (after seasonal changes decrease water temperatures) (Parker and Hanson 1944, as cited in Moyle et al. 1995). Migration timing also appears to be based in part on snow-melt flows (NMFS 1999). Therefore it is likely that current run timing in the San Joaquin River would differ from both historical timing, and the timing in tributaries to the Sacramento River. Fall Chinook salmon in the San Joaquin system typically enter spawning streams from October through December (Table 2). The age of returning Chinook adults in California ranges from 2 to 5 years.

Adult Chinook salmon appear to be less capable of negotiating fish ladders, culverts, and waterfalls during upstream migration than coho salmon or steelhead (Nicholas and Hankin 1989), due in part to slower swimming speeds and inferior jumping ability compared to steelhead (Reiser and Peacock 1985; Bell 1986, as cited in Bjornn and Reiser 1991). Cruising speeds, which are used primarily for long-distance travel, range from 0 to 1 m/s (0 to 3.3 ft/s) (Bjornn and Reiser 1991). Sustained speeds, which can be maintained for several minutes, range from 1 to 3.3 m/s (3.3 to 10.8 ft/s) (Bjornn and Reiser 1991). Darting speeds, which can only be sustained for a few seconds, range from 3.3 to 6.8 m/s (10.8 to 22.3 ft/s) (Bjornn and Reiser 1991). The maximum jumping height for Chinook salmon has been calculated to be approximately 2.4 m (7.9 ft) (Bjornn and Reiser 1991).

Spring Chinook spawning in the San Joaquin River historically occurred from late August to October, with peak spawning occurring in September and October (Clark 1942). Fall Chinook in the San Joaquin system typically spawn from October through December, with spawning activity peaking in early to mid-November. Upon arrival at the spawning grounds, adult females dig shallow depressions or pits in suitably-sized gravels, deposit eggs in the bottom during the act of spawning, and cover them with additional gravel. Over a period of one to several days, the female gradually enlarges the redd by digging additional pits in an upstream direction (Healey 1991). Redds are typically 10–17 m^2 (108–183 ft^2) in size, although they can range from 0.5 to 45 m^2 (5.4–484 ft^2) (Healey 1991). Spring Chinook redds in Deer Creek average 4 m^2 (42 ft^2) (Cramer and Hammack 1952, as cited in Moyle et al. 1995).

Spring Chinook spawners tend to congregate in high densities where stream reaches offer appropriate spawning habitat (Nicholas and Hankin 1989). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Briggs (1953) observed that the defended area could extend up to 6 m (20 ft) in all directions from the redd. Redds may be defended by the female for up to a month (Hobbs 1937). Males do not defend the redd but may exhibit aggressive behavior toward other males while defending spawning females (Shapovalov and Taft 1954). Both male and female adults die within two weeks after spawning (Kostow 1995), with females defending the redd until they become too weak to maintain position over the redd or die.

Spawning gravel availability and redd superimposition

Dams have reduced the supply of spawning gravels in the many rivers in the Sacramento-San Joaquin River basin. Limitations on spawning gravels often result in redd superimposition, whereby later arriving females dig redds on top of existing redds, causing substantial mortality of the previously-deposited eggs (McNeil 1964, Hayes 1987). This has been found to be an important factor affecting Chinook populations in the Tuolumne River, and other rivers where gravel supplies may be limited by dams (EA Engineering 1992).

Clark (1942) conducted detailed surveys of the San Joaquin River for available spawning gravel. 417,000 ft^2 of suitable spawning gravel were found in 26 miles of channel between Lanes Bridge and the Kerchoff Powerhouse (upstream of Friant Dam). The Friant Dam inundated 36% of this area, leaving about 266,800 ft^2 of suitable spawning gravel in the channel below the dam, though it is not clear what criteria were used to determine suitability.

Egg incubation, alevin development, and fry emergence

In the Sacramento River, the egg incubation period for spring Chinook extends from August to March (Fisher 1994, Ward and McReynolds 2001). Egg incubation generally lasts between 40–90 days at water temperatures of 6–12^{o}C (42.8^{o}F to 53.6^{o}F) (Vernier 1969, Bams 1970, Heming 1982, all as cited in Bjornn and Reiser 1991). At temperatures of 2.7^{o}C (37^{o}F), time to 50% hatching can take up to 159 days (Alderdice and Velsen 1978, as cited by Healey 1991). The alevins remain in the gravel for two to three weeks after hatching and absorb their yolk sac before emerging from the gravels into the water column during November to March in the Sacramento River basin (Fisher 1994, Ward and McReynolds 2001).

Juvenile freshwater rearing

The length of time spent rearing in freshwater varies greatly among spring Chinook juveniles. Chinook may disperse downstream as fry soon after emergence; early in their first summer as fingerlings; in the fall as flows increase; or after overwintering in freshwater as yearlings (Healey 1991). Even in rivers such as the Sacramento River where many juveniles rear until they are yearlings, some juveniles probably migrate downstream throughout the year (Nicholas and Hankin 1989). Although fry typically drift downstream following emergence (Healey 1991), movement upstream or into cooler tributaries following emergence has been observed in some systems (Lindsay et al. 1986, Taylor and Larkin 1986).

Juveniles feed voraciously during summer, and display territoriality in feeding areas and are aggressive towards other juvenile Chinook (Taylor and Larkin 1986, Reimers 1968). Experiments conducted in artificial streams suggest that aggressive behavior among juvenile Chinook results in formation of territories in riffles and size hierarchies in pools having abundant food resources and relatively dense groupings of fish (Reimers 1968). Territorial individuals have been observed to stay closer to the substrate, while other individuals may school in hierarchical groups (Everest and Chapman 1972). At night, juvenile Chinook may move toward stream margins with low velocities and finer substrates or into pool bottoms, returning to their previous riffle/glide territories during the day (Edmundson et al. 1968; Don Chapman Consultants 1989, as cited in Healey 1991). Reimers (1968) speculated that intraspecific interactions or density-dependent mechanisms may cause downstream displacement of fry.

During winter, juvenile Chinook typically reduce feeding activity and hide in cover, conserving energy and avoiding predation and displacement by high flows (Chapman and Bjornn 1969, Meehan and Bjornn 1991). Juvenile Chinook that overwinter in fresh water either migrate downstream in the fall to larger streams that have suitable winter habitat or enter interstitial spaces among cobbles and boulders whereupon growth is suspended for the winter (Chapman and Bjornn 1969, Bjornn 1971, Everest and Chapman 1972, Carl and Healey 1984). Reductions in stream temperatures to 4–6^{o}C (39–43^{o}F) typically cause downstream migration and/or movement into the interstices of the substrate (Morgan and Hinojosa 1996). In some areas, such as the mainstem Fraser River, juveniles have been observed to continue feeding in the winter (Levings and Lauzier 1991, as cited in Morgan and Hinojosa 1996). Morgan and Hinojosa (1996) suggested that juvenile Chinook may maintain territories in winter as well.

Rearing densities

Juvenile Chinook densities vary widely according to habitat conditions, presence of competitors, and life history strategies. Lister and Genoe (1970) reported maximum densities of fall Chinook emergent fry in stream margin habitats as 7.2 fish/m^2 (0.65 fish/ft^2) and in mid-channel habitats as 7.0 fish/m^2 (0.63 fish/ft^2). In the Red River, Idaho, densities of age 0+ Chinook in August averaged approximately 0.6 fish/m^2 (0.05 fish/ft^2) and declined to approximately 0.13 fish/m^2 (0.01 fish/ft^2) in November in low-gradient (1–2%) reaches (Hillman et al. 1987). Bjornn (1978, as cited in Bjornn and Reiser 1991) recorded late-summer age-0+ Chinook densities of up to 1.35 fish/m^2 (0.12 fish/ft^2) in a productive Idaho stream, and fewer than 0.8 fish/m^2 (0.07 fish/ft^2) in less productive third- and fourth-order streams. Densities in low-gradient (0.5%) reaches of Johnson Creek, Idaho were over 1.8/m^2 (0.16 fish/ft^2) (maximum recorded density was 6.5 fish/m^2 [0.59 fish/ft^2]) in early July, whereas densities in a higher gradient (1.3%) reach averaged 0.5 fish/m^2 (0.05 fish/ft^2) (maximum recorded density was 1.4 fish/m^2 [0.13 fish/ft^2]) in late July (Everest and Chapman 1972).

Smolt outmigration and estuarine rearing

In the mainstem San Joaquin River outmigrating trapping at Mossdale in 1939, 1940, and 1941 showed that spring Chinook smolt outmigration historically occurred from January until mid-June, with a peak in February (Hatton and Clark 1942). Data from Hatton and Clark (1942) show that the average total length of age 0+ spring Chinook fry in January was 35 mm, by March fry averaged 40 mm total length, and by the middle of April most fry were between 60 and 70 mm total length. By the end of migration (June) most fish were greater than 80 mm total length. Hatton and Clark (1942) compared fish sizes from the San Joaquin with fry captured in the Sacramento River during the same time period. The January captures from the San Joaquin averaged slightly less in length than fry captured in the Sacramento River, while fry captured later in the migration period were slightly larger.

Most age 0+ outmigrants in Butte Creek move downstream at sizes of 30 to 110 mm (1.18–4.33 inches) (Hill and Weber 1999), while age 1+ outmigrants are generally larger than 120 mm (4.7 inches), and can reach 150 mm (5.91 inches) or more in Butte Creek (Hill and Weber 1999). Trapping records from the Sacramento River basin show that three stages of downstream migration occur among spring Chinook. Some age-0+ juveniles are observed moving downstream from spring to early summer (Hill and Weber 1999, Ward and McReynolds 2001, Fisher 1994). Another group of juveniles are observed migrating downstream as age 1+ from October to January (Hill and Weber 1999, Ward and McReynolds 2001), and a third wave of migrants leave the river as age 1+ yearlings the following spring (Fisher 1994). In many river systems yearling smolts typically outmigrate to the ocean in early spring, either before or during the outmigration of fry and fingerlings (Healey 1991).

In general, fall Chinook fry (length <50 mm) and juveniles (length >50 mm) outmigrate from the spawning areas between January and May. Outmigration of larger juveniles generally occurs from April though June with smolts entering the ocean between April and July (Leet et al 1992).

Juvenile Chinook feed and grow as they move downstream in spring and summer; larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989, Beckman et al. 1998), and it appears that in some systems juveniles that do not reach a critical size threshold will not outmigrate (Bradford et al. 2001). Juveniles that do not disperse downstream in their first spring may display high fidelity to their rearing areas throughout the summer rearing period (Edmundson et al. 1968). Nicholas and Hankin (1989) suggested that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures. Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Kjelson et al. (1981) observed peak seine catches of Chinook fry in the Sacramento-San Joaquin Delta correlated with increases in flow associated with storm runoff. Flow accounted for approximately 30 percent of the variability in the fry catch. Photoperiod may also be important, although the relative importance of various outmigration cues remains unclear (Bjornn 1971, Healey 1991).

Ocean phase

When fall Chinook salmon produced from the Sacramento-San Joaquin system enter the ocean they appear to head north, and rear off the northern California-southern Oregon coast (Cramer 1987, as cited in Maragni 2001). Fall Chinook typically rear in coastal waters early in their ocean life. Ocean conditions are likely an important cause of density-independent mortality and interannual fluctuations in escapement sizes.

Habitat Requirements

Adult upstream migration and spawning

Adult spring Chinook require large, deep pools with moderate flows for summer holding during their upstream migration. Marcotte (1984) reported that suitability of pools declines at depths less than 2.4 m (7.9 ft) and that optimal water velocities range from 15 to 37 cm/s (0.5 to 1.2 ft/s). In the John Day River, Oregon, adults usually hold in pools deeper than 1.5 m (4.9 ft) that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986). Adult

Chinook salmon require water deeper than 24 cm (0.8 ft) and water velocities less than 2.4 m/s (8 ft/s) for successful upstream migration (Thompson 1972, as cited in Bjornn and Reiser 1991). Water temperatures for adult Chinook holding and spawning are reportedly best when <16°C (60.8ºF), and lethal when >27°C (80.6ºF) (Moyle et al. 1995). Spring Chinook in the Sacramento River typically hold in pools below 21–25ºC (69.8–77ºF). Table 3 provides a summary of spring Chinook holding temperature criteria.

In July of 1942 Clark (1942) observed an estimated 5,000-spring Chinook holding in two large pools directly downstream of the Friant Dam. These fish appeared to be in good condition, and held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 22.2ºC (72ºF) in July. Fewer fish were seen in each subsequent visit in August, September, and October, and it was assumed they had moved downstream in search of spawning riffles. A seasonal sand dam was installed in late summer in the San Joaquin, blocking the migration of additional spring Chinook into the upper river. By September fish were observed spawning 10 miles downstream of the Friant Dam. Although some fish may have held in pools downstream of Lanes bridge, Clark (1942) concluded that the abundant spawning he observed in September and October on riffles between Friant Dam and Lanes Bridge were from fish that held in the pools below the dam and dropped back downstream to spawn.

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries 2–3 m (6.6–9.8 ft) in width (Vronskiy 1972) to large mainstem rivers (Healey 1991). Chinook prefer low-gradient (<3%) reaches for spawning and rearing, but will occasionally use higher-gradient areas (Kostow 1995). Spawning site (redd) locations are mostly controlled by hydraulic conditions dictated by streambed topography (Burner 1951). Redds are typically located near pool tailouts (i.e., heads of riffles) where high concentrations of intragravel dissolved oxygen are available.

Chinook are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). Depths most often recorded over Chinook redds range from 10 to 200 cm (3.9 to 78 in) and velocities from 15 to 100 cm/s (0.5 to 3.3 ft/s), although criteria may vary between races and stream basins. Fall Chinook salmon, for instance, are able to spawn in deeper water with higher velocities, because of their larger size (Healey 1991); spring Chinook tend to dig smaller redds and use finer gravels than fall Chinook (Burner 1951).

Substrate particle size composition has been shown to have a significant influence on intragravel flow dynamics (Platts et al. 1979). Chinook salmon may therefore have evolved to select redd sites with specific particle size criteria that will ensure adequate delivery of dissolved oxygen to their incubating eggs and developing alevins. In addition, salmon are limited by the size of substrate that they can physically move during the redd building process. Substrates selected likely reflect a balance between water depth and velocity, substrate composition and angularity, and fish size. As depth, velocity, and fish size increase, Chinook are able to displace larger substrate particles. D_{50} values (the median diameter of substrate particles found within a redd) for Chinook have been found to range from 10.8 mm (0.43 in) to 78.0 mm (3.12 in) (Kondolf and Wolman 1993). Chinook in the Central Valley have been observed to use substrate ranging from 31–66 mm (1.22–2.60 in) (Van Woert and Smith, unpublished data 1962, as cited in Kondolf and Wolman 1993; and Kondolf and Wolman 1993).

Egg incubation, alevin development, and fry emergence

Suitable water temperatures, dissolved oxygen delivery, and substrate characteristics are required for proper embryo development and emergence. Review of the literature suggests that 5.8–14.2°C (42.5–57.5°F) is the optimum temperature range for incubating Chinook salmon (Donaldson 1955, Combs and Burrows 1957, Combs 1965, Eddy 1972, Bell 1973, Healey 1979, Reiser and Bjornn 1979, Garling and Masterson 1985). Sublethal stress and/or mortality of incubating eggs resulting from elevated temperatures would be expected to begin at temperatures of about 14.4°C (58°F) for constant exposures (Combs and Burrows 1957, Combs 1965, Healey 1979).

Delivery of dissolved oxygen to the egg pocket is the major factor affecting survival-to-emergence that is impacted by the deposition of fines in the spawning substrate. Several studies have correlated reduced dissolved oxygen levels with mortality, impaired or abnormal development, delayed hatching and emergence, and reduced fry size at emergence in anadromous salmonids (Wickett 1954, Alderdice et al. 1958, Coble 1961, Silver et al. 1963, McNeil 1964, Cooper 1965, Shumway et al. 1964, Koski 1981). Silver et al. (1963) found that low dissolved oxygen concentrations were related to mortality and reduced size in Chinook salmon and steelhead embryos. Data suggest that growth may be restricted day at oxygen levels below saturation (Silver et al. 1963). Fine sediments in the gravel interstices can also physically impair the fry's ability to emerge through the gravel layer, trapping (or entombing) them within the gravel (Phillips et al. 1975, Hausle and Coble 1976).

Juvenile freshwater rearing

Juvenile Chinook salmon tend to use mainstem reaches and estuaries as rearing habitat more extensively than juvenile coho salmon, steelhead, and sea-run coastal cutthroat trout do. Spring Chinook typically rear in low gradient reaches of mainstem rivers areas and large tributaries (Nicholas and Hankin 1989).

Following emergence, fry occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry grow, they move into deeper and faster water further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Everest and Chapman (1972) observed at least small numbers of Chinook fry in virtually all habitats sampled in early summer. Because Chinook fry tend to be larger than coho fry upon emergence, they may tend to use areas with higher water velocities than coho (Murphy et al. 1989, Healey 1991). Most researchers have not addressed fry habitat requirements separately from juvenile summer habitat requirements, but there seems to be consensus that Chinook fry prefer quiet, shallow water with cover. Everest and Chapman (1972) investigated habitat use of emergent Chinook fry; they found fry using depths less than 60 cm (24 in) and water velocities less than 15 cm/s (0.5 ft/s).

Substantial variability in the depth and velocity preferences of juvenile Chinook has been reported. Juvenile Chinook have been observed in virtually all depths and velocities where researchers have sampled (Hillman et al. 1987, Murphy et al. 1989). Lister and Genoe (1970) found that juvenile Chinook preferred slow water adjacent to faster water (40 cm/s [1.3 ft/s]).

Summer rearing habitat

Juvenile Chinook salmon appear to prefer pools that have cover provided by banks, overhanging vegetation, large substrates, or LWD. Juvenile densities in pools have been found to increase with increasing amounts of cover (Steward and Bjornn, unpublished data, as cited in Bjornn and Reiser 1991). Water temperature may also influence juvenile habitat use. In the South Umpqua River basin, Roper et al. (1994) observed lower densities of juvenile Chinook where water temperatures were higher. In areas where more suitable water temperatures were available, juvenile Chinook salmon abundance appeared to be tied to pool availability.

Temperatures also have a significant effect on juvenile Chinook growth rates. On maximum daily rations, growth rate increases with temperature to a certain point and then declines with further increases. Reduced rations can also result in reduced growth rates; therefore, declines in juvenile salmonid growth rates are a function of both temperature and food availability. Laboratory studies indicate that juvenile Chinook salmon growth rates are highest at rearing temperatures from 18.3° to

21.1°C (65° to 70°F) in the presence of unlimited food (Clarke and Shelbourn 1985, Banks et al. 1971, Brett et al. 1982, Rich 1987), but decrease at higher temperatures, with temperatures >23.3° C (74° F) being potentially lethal (Hanson 1990).

Nicholas and Hankin (1989) suggest that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures.

Winter rearing habitat

Juvenile Chinook salmon rearing in tributaries may disperse downstream into mainstem reaches in the fall and take up residence in deep pools with LWD, interstitial habitat provided by boulder and rubble substrates, or along river margins (Swales et al. 1986, Healey 1991, Levings and Lauzier 1991). During high flow events, juveniles have been observed to move to deeper areas in pools and they may also move laterally in search of slow water (Shirvell 1994, Steward and Bjornn 1987). Hillman et al. (1987) found that individuals remaining in tributaries to overwinter chose areas with cover and low water velocities, such as areas along well-vegetated, undercut banks. Lakes may occasionally be used by overwintering Chinook, but they appear to avoid beaver ponds and off-channel slough habitats (Healey 1991). In the winter in the Sacramento/San Joaquin system juveniles rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook juveniles that reared on the Yolo Bypass floodplain than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. On the Yolo Bypass bioenergetic modeling suggested that increased prey availability on the floodplain was sufficient to offset increased metabolic demands from higher water temperatures (5ºC higher than mainstem). Sommer et al. (2001) believe that the well-drained topography may help reduce stranding risks when flood waters recede.

Hillman et al. (1987) found that the addition of cobble substrate to heavily-sedimented glides in the fall substantially increased winter rearing densities, with Chinook using the interstitial spaces between the cobbles as cover. Fine sediment can act to reduce the value of gravel and cobble substrate as winter cover by filling interstitial spaces between substrate particles. This may cause juvenile Chinook to avoid these embedded areas and move elsewhere in search of suitable winter cover (Stuehrenberg 1975, Hillman et al. 1987).

Tables

Figures

Table 1. Life history timing of spring Chinook in the California Central Valley

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration			░	░	▓	▓	░						Geographic area: Sacramento River basin March through July, peaking in May–June (Fisher 1994). Source of data not stated.
Upstream Migration			░	░	░	░	░	░	░				Jones and Stokes, Foundation Runs Report 2002 Geographic area: not stated Migrate to natal streams March through September (USFWS 1995). Source of data not stated.
Adult Holding					░	░	░						Geographic area: San Joaquin River Congregate in large pools near Friant from May through mid-July (CFGC 1921), and then spawn in gorge upstream. Source of data is personal observation. Fish observed holding on May 23, 1942 in the pool directly below the Friant Dam (Clark 1942). No visits were made prior to this date. Fish were continued to be observed in subsequent visits in August and September in pools downstream of the dam, and directly below the dam. It appeared that fish moved as much as 10 miles downstream from holding pools to spawn.
Adult Holding				░	░	░	░						Geographic area: Sacramento River basin, Mill Creek Holding as early as late April and early May in Mill Creek. However, no observations conducted before late April, so fish could be holding earlier. Most fish holding by July. (C. Harvey, CFG, pers. comm. 2002). Based on walking and dive surveys. General comment: Many spring Chinook migrate from holding pools to spawning areas further upstream in the watershed, while the rest remain to spawn in the tails of the holding pools (Moyle et al. 1995). No source or location of data stated.
Adult Holding					░	░	░						Jones and Stokes Foundations Runs Report Geographic area: San Joaquin River Congregate in pools after upstream migration during May to early July (Yoshiyama et al. 1998).
Spawning								░	▓	▓			Geographic area: San Joaquin River The San Joaquin River below Friant dam was surveyed for one day in late August, late September, early October, and early November of 1942. The first spawning was observed on September 21, and large numbers of fish were spawning on all the riffles observed between Friant Dam and Lanes Bridge on November 4 (Clark 1942). Clark also reports that in detailed surveys prior to dam construction 417,000 ft^2 of spawning gravel were observed between Lanes Bridge and the Kerchoff Powerhouse. He reports that 36% of this area was eliminated by construction of the Friant Dam.

Table 1. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spawning									░	░			Geographic area: San Joaquin River Spawning took place in September and early October near Friant (Hallock and Van Woert 1959). Source of data not stated.
Spawning								░	░	░			Geographic area: Sacramento River basin Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning								░	▓	░			Geographic area: Sacramento River basin Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning								░	▓	▓			Geographic area: Sacramento River basin, Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).
Spawning								░	░	░			Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Spawning August through October, depending on water temperatures (USFWS 1995). Source of data not stated.
Incubation													Embryos hatch after 5-6 month incubation. Alevins remain in gravel an additional 2-3 weeks (Moyle et al. 1995). No source or location of data stated.
Emergence	░	░	░								░	░	Geographic area: Sacramento River basin Emergence November to March in the Sacramento River basin (Fisher 1994). Source of data not stated. Emergence in Butte Creek from November to March (Ward and McReynolds 2001). Based on outmigrant trapping of recently emerged fry.

Table 1. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Rearing	░	░	░	░	░	░	░	░	░	░	░	░	Geographic area: Sacramento River basin Rear 3 to 15 months in the Sacramento River basin (Fisher 1994). Source of data not stated. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. Some juveniles outmigrate after hatching, and others move downstream during the following fall as yearlings (C. Harvey, pers. comm., as cited in Moyle et al. 1995). Source of data not stated.
Fry Dispersal	░	▓	░	░	░	░							Geographic area: San Joaquin River Before construction of Friant Dam outmigration occurred during major seasonal runoff. Fish and Game fyke netting in 1939 and 1940 at Mossdale demonstrated a measurable seaward movement of fingerling salmon between January and mid-June, with a peak in February (Hallock and Van Woert 1959).
Fry Dispersal		░	░	▓	░	░							Geographic area: San Joaquin River After construction of Friant Dam outmigration it appeared that the elimination of flood flows altered migration patterns. In 1948 fyke trapping at Mendota there was a fairly steady downstream migration between February and June, but the peak was not reached until April. In 1949 peaks were recorded in early March and again in mid-May (Hallock and Van Woert 1959).
Fry Dispersal	▓	░	░								░	▓	Geographic area: Sacramento River basin Juveniles typically outmigrate during November through Jan. during the first high flows as subyearlings, though some stay as late as March (F. Fisher, pers. comm., as cited in USFWS 1994). Source of data not stated. Juveniles typically outmigrate as fry from Butte Creek between mid-November and mid-February, with a peak in December and January (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. In the Sacramento River most downstream movement takes place December to February as parr (Vogel and Marine 1991, as cited in USFWS 1994). Source of data not stated.

Table 1. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spring Smolts (subyearling)			▨	▨	▨	▨							Geographic area: Sacramento River basin Some YOY remain in Butte Creek and outmigrate in late spring or early summer (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In the Sacramento River basin ocean entry during March to June (Fisher 1994). Source of data not stated
Fall Smolts (yearling)	▨									▨	▨	▨	Geographic area: Sacramento River basin Most yearlings outmigrate from Butte Creek in October to January (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Mill Creek some juveniles outmigrate during the following fall as yearlings (C. Harvey, pers. comm., as cited in Moyle et al. 1995). Source of data not stated.
Fall and Spring Smolts (yearling)	▨	▨	▨	▨							▨	▨	Geographic area: Sacramento River basin Ocean entry from November to April (Fisher 1994). Source of data not stated.
Spring Smolts (subyearling)				▨	▨	▨							Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated May rear in freshwater for 3 to 8 months, migrating to the ocean during spring (Raleigh et al. 1986, Moyle 1976).
Fall Smolts (yearlings)										▨	▨	▨	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Frequently rear over the summer and migrate to the ocean from October to December, after 12-14 months in freshwater (no source cited).
Juveniles enter the ocean					▨								Moyle et al. (1995) "presumes" that all fish have left the Sacramento basin by mid-may. No source of data stated.

▨	Span of Life History Activity
■	Peak of Life History Activity

Table 2. Life history timing of Fall Chinook in the California Central Valley.

LIFE STAGE	MONTH																							
	Jan		**Feb**		**Mar**		**Apr**		**May**		**Jun**		**Jul**		**Aug**		**Sept**		**Oct**		**Nov**		**Dec**	
Adult Migration																		▒	▒	▒	▒	▒	▒	
Adult Holding																								
Spawning	▒	▒																		▒	▒	▒	▒	▒
Incubation	▒	▒	▒	▒	▒															▒	▒	▒	▒	▒
Emergence (fry)	▒	▒	▒	▒	▒	▒	▒																	
Rearing (juvenile)	░	░	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Outmigration Age 0+							▒	▒	▒	▒														
Outmigration Age 1+	▒	▒	▒																		▒	▒	▒	▒

(source: Reavis 1995)

░	Span of Light Activity
▒	Span of Moderate Activity
▓	Span of Peak Activity

Table 3. Holding temperature criteria for spring Chinook salmon.

Temperature Criteria						Source and Notes
Average		Preferred		Maximum		
°C	°F	°C	°F	°C	°F	
20.3	68.5					Average temperature at mouth of Willamette River, OR, during the 1966 Chinook run (Alabaster 1988)
		3.3–13.3	37.9–55.9			Spring Chinook (Bell 1986). Source not specified.
				17.5–19.0	63.5–66.2	Egg viability and alevin survival may be reduced at temperatures between 17.5–19.0°C (Berman 1990). Yakima River, Washington.
				14.4–19.4	57.9–66.9	Egg mortalities of 50% or more of adults held at 14.4–19.4°C (B. Ready, pers. comm., as cited in Berman 1990).
				22.2	72.0	Adults holding below the Friant Dam on the San Joaquin River appeared in good condition, despite a maximum-recorded July temperature of 72°C (Clark 1942).
				24	76	Adults in the Klamath River apparently unaffected by temperatures as high as 76°F (Dunham 1968, as cited in Boles et al. 1988).
				18.3	65	Sonically tagged San Joaquin River spring Chinook were not observed migrating until temperatures dropped below 65°F (Hallock et al. 1970).
				23.0	73.4	Adult spring Chinook salmon can survive in deep pools with surface temperatures as high as 23.0°C (Hodges and Gharrett 1949, as cited in Beauchamp et al. 1983).
				13.3	56	Eggs will not develop normally if held in constant temperatures exceeding 13.3°C (Leitritz and Lewis 1976). Race or source of data not specified.
				21	70	Migrations blocked at temperatures exceeding 21°C (Major and Mighell 1967, as cited in Armour 1991). Source of data not stated.
11.7–21.1	53–70					Range used by spring Chinook salmon in Deer and Mill Creeks, Sacramento River basin (Moyle et al. 1995). Source of data not given.
		5.6–18.3	42.0–65.0	23.9	75	Maximum for survival (Brett 1959, as cited in Marcotte 1984).
				17–19	63–66	Acute mortality of Chinook salmon broodstock (R. Ducy, Pers. Comm, as cited in Marine 1992).
				18–21	64–70	Considerable pre-spawn mortality of spring Chinook observed in the Rogue River, Or when temperatures were in the range of 18–21°C (M. Everson, pers. comm., as cited in Marine 1992).
				21–25	70–77	Spring Chinook salmon in the Sacramento-San Joaquin system tributaries hold in pools that seldom exceeded 21–25°C (70–77°F) (Moyle 1976, as cited in Moyle et al. 1995).
				21.1	70	Thermal barrier to spring Chinook on the Tucannon River, Wa. (Bumgarner et al. 1997, as cited in McCullough 1999).
		10–14	50–57			Piper et al. (1982). Race not stated, source of data not stated.
20	68					Spring Chinook often hold in pools in Butte Creek, Sacramento River basin, where average daily temperatures exceed 20°C (Williams et al. 2002), though pre-spawn mortality can be high.

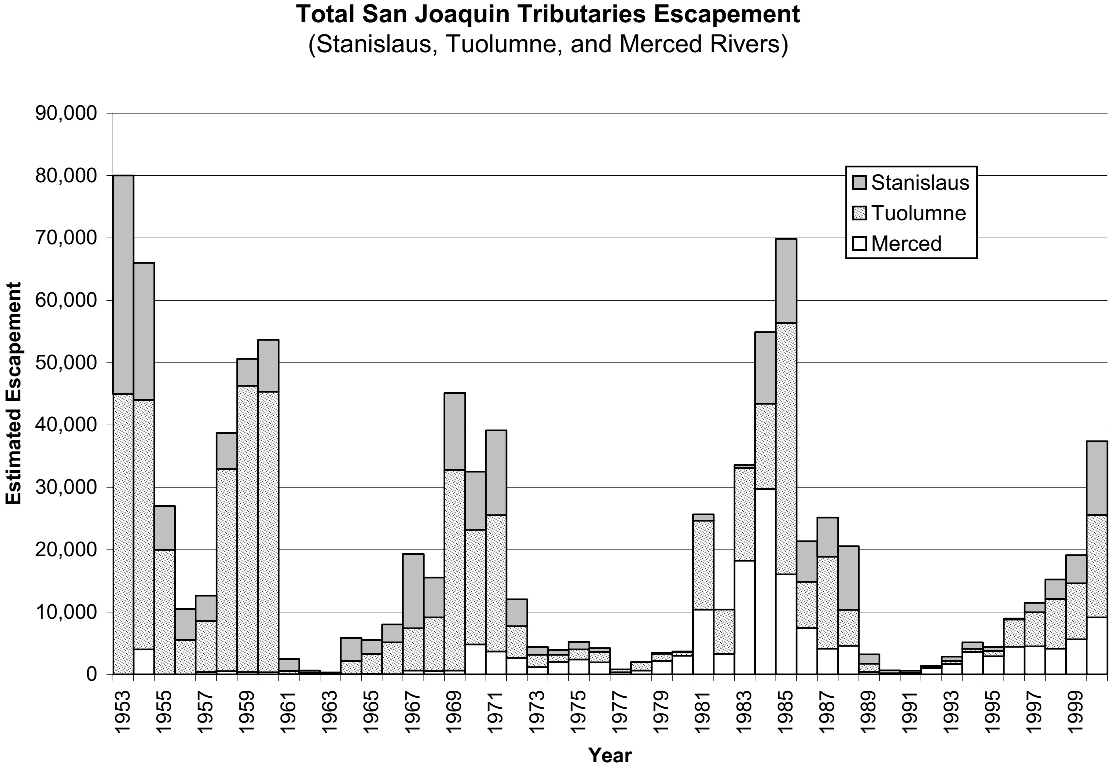


Figure 1. Chinook salmon escapement into San Joaquin basin tributaries 1953 to 2000.

Common Name	**Scientific Name (family)**
Steelhead	*Oncorhynchus mykiss* (Salmonidae)

Status

The Central Valley steelhead ESU includes naturally spawned steelhead occurring in the Sacramento and San Joaquin rivers and their tributaries and extends into the San Francisco estuary to San Pablo Bay. Steelhead is the term commonly used for the anadromous life history form of rainbow trout *(Oncorhynchus mykiss)*. Only winter-run steelhead stocks are currently present in Central Valley streams (McEwan and Jackson 1996).

The National Marine Fisheries Service (NMFS) considered including resident *O. mykiss* in listed steelhead ESUs in certain cases, including (1) where resident *O. mykiss* have the opportunity to interbreed with anadromous fish below natural or artificial barriers or (2) where resident fish of native lineage once had the ability to interbreed with anadromous fish but no longer do because they are currently above artificial barriers and are considered essential for the recovery of the ESU (NMFS 1998, p. 13350). The U.S. Fish and Wildlife Service (USFWS), which has authority under the Endangered Species Act (ESA) over resident fish, however, concluded that behavioral forms of *O. mykiss* can be regarded as separate Distinct Population Segments (the USFWS version of an ESU) and that lacking evidence that resident rainbow trout need ESA protection, only anadromous forms should be included in the ESU and listed under the ESA (NMFS 1998, p. 13351). The USFWS also did not believe that steelhead recovery would rely on the intermittent exchange of genetic material between resident and anadromous forms (NMFS 1998, p. 13351). In the final rule, the listing includes only the anadromous life history form of *O. mykiss* (NMFS 1998, p. 13369).

From this information, it seems that resident rainbow trout are not protected under the ESA and are not included in the ESU. NMFS, however, considers all *O. mykiss* that have physical access to the ocean (including resident rainbow trout) to potentially be steelhead (Chris Mobley, Dennis Smith, and Steven Edmundson, NMFS, personal communication) and will treat these fish as steelhead because (1) resident fish can produce anadromous offspring, and (2) it is difficult or impossible to distinguish between juveniles of the different life history forms. NMFS considers juvenile *O. mykiss* smaller than 8 inches (203 mm) and adult *O. mykiss* larger than 16 inches (406 mm) to be steelhead (Dennis Smith, NMFS, personal communication). NMFS does not yet have a written policy regarding this position or clarifying their relationship with the USFWS in protecting resident rainbow trout and anadromous steelhead.

Adult resident rainbow trout occurring in Central Valley Rivers are often larger than Central Valley steelhead. Several sources indicate resident trout in the Central Valley commonly exceed 16 inches (406 mm) in length. Cramer et al. (1995) reported that resident rainbow trout in Central Valley rivers grow to sizes of more than 20 inches (508 mm). Hallock et al. (1961) noted that resident trout observed in the Upper Sacramento River upstream of the Feather River were 14–20 inches (356–508 mm) in length. Also, at Coleman National Fish Hatchery, the USFWS found about 15 percent overlap in size distribution between resident and anadromous fish at a length of 22.8 inches (579 mm) (Cramer et al. 1995). NMFS's size criterion for steelhead, therefore, has significant overlap with resident rainbow trout occurring in Central Valley rivers, and many resident adult trout will be considered to be steelhead.

Geographic Distribution
Steelhead are distributed throughout the North Pacific Ocean and historically spawned in streams along the west coast of North America from Alaska to northern Baja California. The species is currently known to spawn only as far south as Malibu Creek in southern California (Barnhart 1991, NMFS 1996a). Two major genetic groups exist in the Pacific Northwest, consisting of a coastal and an inland group separated by the Cascade Range crest (Schreck et al. 1986, Reisenbichler et al. 1992). Historic steelhead distribution in the upper San Joaquin River is not known, but in rivers where they still occur they are normally more widely distributed than Chinook (Voight and Gale 1998, as cited in McEwan 2001, Yoshiyama et al. 1996), and are typically tributary spawners. Therefore it can be assumed steelhead would have been as least as far upstream as Mammoth Pool in the San Joaquin River, and probably in many smaller tributaries.

Population Trends
The National Marine Fisheries Service (NMFS 1996a) has concluded that populations of naturally reproducing steelhead have been experiencing a long-term decline in abundance throughout their range. Populations in the southern portion of the range have experienced the most severe declines, particularly in streams from California's Central Valley and south, where many stocks have been extirpated (NMFS 1996a). During this century, 23 naturally reproducing populations of steelhead are believed to have been extirpated in the western United States. Many more are thought to be in decline in Washington, Oregon, Idaho, and California. Based on analyses of dam and weir counts, stream surveys, and angler catches, NMFS (1997) concluded that, of the 160 west coast steelhead stocks for which adequate data were available, 118 (74 percent) exhibited declining trends in abundance, while the remaining 42 (26 percent) exhibited increasing trends. From this analysis, the NMFS concluded that naturally reproducing populations of steelhead have exhibited long-term declines in abundance across their range. Steelhead stocks in California, however, have declined precipitously. The current population of steelhead in California is roughly 250,000 adults, which is nearly half the adult population that existed 30 years ago (McEwan and Jackson 1996). Current estimates of all steelhead adults in San Francisco Bay tributaries combined are well below 10,000 fish (Leidy 2001). Steelhead in the San Joaquin River were historically very abundant, though data on their population levels is lacking (McEwan 2001). Currently the steelhead population in the San Joaquin River is drastically reduced from historic levels, and considered extinct by some researchers (Reynolds et al. 1990, as cited in McEwan 2001). However, there is evidence that small populations of steelhead persist in some lower San Joaquin River tributaries (e.g., Stanislaus River) (McEwan 2001). In a review of factors affecting steelhead declines in the Central Valley McEwan and Jackson (1996) concluded that all were related to water development and water management. Impassible dams have blocked historic habitat, forcing steelhead to spawn and rear in lower river reaches, where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001).

Life History
Steelhead is the term used for the anadromous life history form of rainbow trout, *Oncorhynchus mykiss*. Steelhead exhibit highly variable life history patterns throughout their range, but are broadly categorized into winter- and summer-run reproductive ecotypes. Only winter steelhead are believed to have occurred in the San Joaquin River. Winter steelhead, the most widespread reproductive ecotype, become sexually mature in the ocean, enter spawning streams in fall or winter, and spawn a few months later in winter or late spring (Meehan and Bjornn 1991, Behnke 1992). The general timing of winter steelhead life history in California is shown in Table 1. In the Sacramento River, steelhead generally emigrate as 1-year olds during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6 - 8 inches being the size of most downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Adult upstream migration and spawning

In the Central Valley adult winter steelhead migrate upstream during most months of the year, beginning in July, peaking in September, and continuing through February or March (Hallock et al. 1961, Bailey 1954, both as cited in McEwan and Jackson 1996) (Table 1). Spawning occurs primarily from January through March, but may begin as early as late December and may extend through April (Hallock et al. 1961, as cited in McEwan and Jackson 1996). No information on the run timing or life history of steelhead that occurred in the San Joaquin basin is available apart from the observation of 66 adults seen at Dennett Dam on the Tuolumne River from October 1 through November 30 in 1940 and five in late October of 1942 (CDFG unpublished data). In the Central Valley ESU, adult winter steelhead generally return at ages 2 and 3 and range in size from 2 to 12 pounds (0.9–5.4 kg) (Reynolds et al. 1993).

Adult steelhead migrate upstream on both the rising and falling limbs of high flows, but do not appear to move during flood peaks. Some authors have suggested that increased water temperatures trigger movement, but some steelhead ascend into freshwater without any apparent environmental cues (Barnhart 1991). Peak upstream movement appears to occur in the morning and evening, although steelhead have been observed to move at all hours (Barnhart 1991).

Steelhead are among the strongest swimmers of freshwater fishes. Cruising speeds, which are used for long-distance travel, are up to 1.5 m/s (5 ft/s); sustained speeds, which may last several minutes and are used to surpass rapids or other barriers, range from 1.5 to 4.6 m/s (5 to 15 ft/s), and darting speeds, which are brief bursts used in feeding and escape, range from 4.3 to 8.2 m/s (14 to 27 ft/s) (Bell 1973, as cited in Everest et al. 1985; Roelofs 1987). Steelhead have been observed making vertical leaps of up to 5.2 m (17 feet) over falls (W. Trush pers. comm., as cited in Roelofs 1987).

During spawning, female steelhead create a depression in streambed gravels by vigorously pumping their body and tail horizontally near the streambed. Steelhead redds are approximately 10–30 cm (4–12 in) deep, 38-cm (15-in) in diameter, and oval in shape (Needham and Taft 1934, Shapovalov and Taft 1954). Males do not assist with redd construction, but may fight with other males to defend spawning females (Shapovalov and Taft 1954). Males fertilize the female's eggs as they are deposited in the redd, after which the female moves to the upstream end of the nest and stirs up additional gravel, covering the egg pocket (Orcutt et al. 1968). Females then move two to three feet upstream and dig another pit, enlarging the redd. Females may dig six to seven egg pockets, moving progressively upstream, and spawning may continue for several days to over a week (Needham and Taft 1934). A female approximately 85 cm (33 in) in length may lay 5,000 to 10,000 eggs, with fecundity being related to age and length of the adult female and varying between populations (Meehan and Bjornn 1991). A range of 1,000 to 4,500 eggs per female has been observed within the Sacramento Drainage (Mills and Fisher 1994, as cited in Leidy 2001). In cases where spawning habitat is limited, late-arriving spawners may superimpose their redds atop existing nests (Orcutt et al. 1968).

Although most steelhead die after spawning, adults are capable of returning to the ocean and migrating back upstream to spawn in subsequent years, unlike most other Pacific salmon. Runs may include from 10 to 30% repeat spawners, the majority of which are females (Ward and Slaney 1988, Meehan and Bjornn 1991, Behnke 1992). Repeat spawning is more common in smaller coastal streams than in large drainages requiring a lengthy migration (Meehan and Bjornn 1991). Hatchery steelhead are typically less likely than wild fish to survive to spawn a second time (Leider et al. 1986). In the Sacramento River, California, Hallock (1989) reported that 14 percent of the steelhead were returning to spawn a second time.

Whereas females spawn only once before returning to the sea, males may spend two or more months in spawning areas and may mate with multiple females, incurring higher mortality and reducing their chances of repeat spawning (Shapovalov and Taft 1954). Steelhead may migrate downstream to the ocean immediately following spawning or may spend several weeks holding in pools before outmigrating (Shapovalov and Taft 1954).

Egg incubation, alevin development, and fry emergence

Hatching of eggs follows a 20- to 100-day incubation period, the length of which depends on water temperature (Shapovalov and Taft 1954, Barnhart 1991). In Waddell Creek (San Mareo County), Shapovalov and Taft (1954) found incubation times between 25 and 30 days. Newly-hatched steelhead alevins remain in the gravel for an additional 14–35 days while being nourished by their yolk sac (Barnhart 1991). Fry emerge from the substrate just before total yolk absorption under optimal conditions; later-emerging fry that have already absorbed their yolk supply are likely to be weaker (Barnhart 1991). Upon emergence, fry inhale air at the stream surface to fill their air bladder, absorb the remains of their yolk, and start to feed actively, often in schools (Barnhart 1991, NMFS 1996b). Survival from egg to emergent fry is typically less than 50% (Meehan and Bjornn 1991), but may be quite variable depending upon local conditions.

Juvenile freshwater rearing

Juvenile steelhead (parr) rear in freshwater before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

Juveniles typically remain in their natal streams for at least their first summer, dispersing from fry schools and establishing feeding territories (Barnhart 1991). Peak feeding and freshwater growth rates occur in late spring and early summer. In Steamboat Creek, a major steelhead spawning tributary in the North Umpqua River watershed, juveniles typically rest in the interstices of rocky substrate in the morning and evening, and rise into the water column and orient themselves into the flow to feed during the day when water temperatures are higher (Dambacher 1991). In the Smith River of Oregon, Reedy (1995) suggested that rising stream temperatures and reduced food availability occurring in late summer may lead to a decline in steelhead feeding activity and growth rates.

Juveniles either overwinter in their natal streams if adequate cover exists or disperse as pre-smolts to other streams to find more suitable winter habitat (Bjornn 1971, Dambacher 1991). As stream temperatures fall below approximately 7°C (44.6°F) in the late fall to early winter, steelhead enter a period of winter inactivity spent hiding in the substrate or closely associated with instream cover, during which time growth ceases (Everest and Chapman 1972). Age 0+ steelhead appear to remain active later into the fall than 1+ steelhead (Everest et al. 1986). Winter hiding behavior of juveniles reduces their metabolism and food requirements and reduces their exposure to predation and high flows (Bustard and Narver 1975), although substantial mortality appears to occur in winter, nonetheless. Winter mortalities ranging from 60 to 86% for 0+ steelhead and from 18 to 60% for 1+ steelhead were reported in Fish Creek in the Clackamas River basin, Oregon (Everest et al. 1988, as cited in Dambacher 1991).

Juveniles appear to compete for food and rearing habitat with other steelhead. Age 0+ and 1+ steelhead exhibit territorial behavior (Everest and Chapman 1972), although this behavior may dissipate in winter as fish reduce feeding activity and congregate in suitable cover habitat (Meehan and Bjornn 1991). Reedy (1995) found that steelhead in the tails of pools did not exhibit territorialism or form dominance hierarchies.

Parr outmigration appears to be more significant in smaller basins, when compared to larger basins (Dambacher 1991). In some areas juveniles migrate out of tributaries despite the fact that downstream rearing habitat may be limited and survival rates low in these areas, suggesting that migrants are responding to density-related competition for food and space, or to reduction in habitat quality in tributaries as flows decline (Dambacher 1991, Peven et al. 1994, Reedy 1995). In relatively small tributaries with good rearing habitat located downstream, early outmigration may represent an adaptation to improve survival and may not be driven by environment- or competition-related limitations (Dambacher 1991). Steelhead may overwinter in mainstem reaches, particularly if coarse substrates in which to seek cover from high flows are available (Reedy 1995), or they may return to tributaries for the winter (Everest 1973, as cited in Dambacher 1991).

Rearing densities for juvenile steelhead overwintering in high-quality habitats with cobble-boulder substrates are estimated to range from approximately 2.7 fish/m^2 (0.24 fish/ft^2) (W. Trush, pers. comm., 1997) to 5.7 fish/m^2 (0.53 fish/ft^2) (Meyer and Griffith 1997). Reedy (1995) observed higher densities of juvenile steelhead in the Middle Fork Smith River, California, than in the Steamboat Creek basin; he suggests that this may be due to the greater availability of large bed particles used for overwintering cover and velocity refuge in the Middle Fork Smith River than in Steamboat Creek. Everest and Chapman (1972) report age 0+ densities of 1.3 to 1.5 fish/m^2 (0.12 to 0.14 fish/ft^2) in preferred habitat in Idaho.

Smolt outmigration and estuarine rearing

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 15 to 20 cm (5.85 to 7.80 in) (Meehan and Bjornn 1991). A length of 14 cm (5.46 in) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). In the Sacramento River, steelhead generally emigrate as 2-year olds during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6–8 inches (152–203 mm) being most common for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Evidence suggests that photoperiod is the most important environmental variable stimulating the physiological transformation from parr to smolt (Wagner 1974). During smoltification, the spots and parr marks characteristic of juvenile coloration are replaced by a silver and blue-green iridescent body color (Barnhart 1991) and physiological transformations occur that allow them to survive in salt water.

Less is known regarding the use of estuaries by steelhead than for other anadromous salmonid species; however, the available evidence shows that steelhead in many systems use estuaries as rearing habitat. Smith (1990) concluded that even tiny lagoons unsuitable for summer rearing can contribute to the maintenance of steelhead populations by providing feeding areas during winter or spring smolt outmigration.

Estuarine rearing may be more important to steelhead populations in the southern half of the species' range due to greater variability in ocean conditions and paucity of high quality near-shore habitats in this portion of their range (NMFS 1996a). Estuaries may also be more important to populations spawning in smaller coastal tributaries due to the more limited availability of rearing habitat in the headwaters of smaller stream systems (McEwan and Jackson 1996). Most marine mortality of steelhead occurs soon after they enter the ocean and predation is believed to be the primary cause of this mortality (Pearcy 1992, as cited in McEwan and Jackson 1996). Because predation mortality and fish size are likely to be inversely related (Pearcy 1992, as cited in McEwan and Jackson 1996), the growth that takes place in estuaries may be very important for increasing the odds of marine survival (Pearcy 1992 [as cited in McEwan and Jackson 1996], Simenstad et al. 1982 [as cited in NMFS 1996a], Shapovalov and Taft 1954).

Steelhead have variable life histories and may migrate downstream to estuaries as age 0+ juveniles or may rear in streams up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Steelhead migrating downstream as juveniles may rear for one to six months in the estuary before entering the ocean (Barnhart 1991). Shapovalov and Taft (1954) conducted exhaustive life history studies of steelhead and coho salmon in Waddell Creek (Santa Cruz County, California) and found that coho salmon went to sea almost immediately after migrating downstream, but that some of the steelhead remained for a whole season in Waddell Creek lagoon or the lower portions of the stream before moving out to sea. Some steelhead individuals remained in the lagoon rather than moving out to sea and migrated back upstream and underwent a second downstream migration the following year. In Scott Creek lagoon (Santa Cruz County), Marston (1992, as cited in McEwan and Jackson 1996) found that half of the steelhead rearing in the lagoon in June and July of 1992 were less than 90 mm and appeared to be pre-smolts. Coots (1973, as cited in McEwan and Jackson 1996) found that 34% of juvenile steelhead in San Gregorio Creek lagoon captured in summer were juveniles less than 100 mm [3.9 in] in length. From these studies and others, it has been shown estuaries provide valuable rearing habitat to juvenile and yearling steelhead and not merely a corridor for smolts outmigrating to the ocean.

Ocean phase

The majority of steelhead spend one to three years in the ocean, with smaller smolts tending to remain in salt water for a longer period than larger smolts (Chapman 1958, Behnke 1992). Larger smolts have been observed to experience higher ocean survival rates (Ward and Slaney 1988). Steelhead grow rapidly in the ocean compared to in freshwater rearing habitats, with growth rates potentially exceeding 2.5 cm (0.98 in) per month (Shapovalov and Taft 1954, Barnhart 1991). Steelhead staying in the ocean for two years typically weigh 3.15 to 4.50 kg (7 to10 lbs) upon return to fresh water (Roelofs 1985). Unlike other salmonids, steelhead do not appear to form schools in the ocean. Steelhead in the southern part of the species' range appear to migrate close to the continental shelf, while more northern populations of steelhead may migrate throughout the northern Pacific Ocean (Barnhart 1991).

Habitat Requirements

Adult upstream migration and spawning

During their upstream migration, adult steelhead require deep pools for resting and holding (Puckett 1975, Roelofs 1983, as cited in Moyle et al. 1989). Deep pool habitat (>1.5 m) (>4.88 ft) is preferred by summer steelhead during the summer holding period.

Because adult winter steelhead generally do not feed during their upstream migration, delays experienced during migration may affect reproductive success. A minimum depth of about 7 inches (18 cm) is required for adult upstream migration (Thompson 1972, as cited by Barnhart 1986); however, high water velocity and natural or artificial barriers are more likely to affect adult movements than depth (Barnhart 1986, as cited in McEwan and Jackson 1996). Velocities over 8 ft/s (2.4 m/s) may hinder upstream movement (Thompson 1972, as cited in Everest et al. 1985). Steelhead are capable of ascending high barriers under suitable flow conditions and have been observed to make vertical leaps of up to 17 feet (5.1 m) over waterfalls (W. Trush, pers. comm., as cited in Roelofs 1987). Deep pools provide important resting and holding habitat during the upstream migration (Puckett 1975, Roelofs 1983, as cited in Moyle et al. 1989).

Temperature thresholds for the adult migration and spawning life stages are shown in Table 2. These temperatures, however, are from the general literature and may not represent preferred or suitable temperature ranges for Central Valley steelhead stocks. No Central Valley-specific temperature evaluations or criteria were identified by our review. For adult migration, temperatures ranging from 46 to 52^{o}F (8 to 11^{o}C) are considered to be preferred (McEwan and Jackson 1996), while temperatures exceeding 70^{o}F (21^{o}C) are stressful (Lantz 1971, as cited in Beschta et al. 1987). Preferred spawning temperatures range from 39–52^{o}F (4–11^{o}C) (McEwan and Jackson 1996, Bell 1973, 1991), with 68^{o}F (20^{o}C) being considered stressful and 72^{o}F (22^{o}C) considered lethal.

Areas of the stream with water depths from about 18 to 137 cm (7.02 to 53.43 in) and velocities from 0.6 to 1.15 m/s (1.97 to 3.77 ft/s) are typically preferred for spawning by adult steelhead (Moyle et al. 1989, Barnhart 1991). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). The average area encompassed by a redd is 4.4–5.9 m2 (47–65.56 ft2) (Orcutt et al. 1968, Hunter 1973, as cited in Bjornn and Reiser 1991). D_{50} values (the median diameter of substrate particles found within a redd) for steelhead have been found to range from 10.4 mm (0.41 in) (Cederholm and Salo 1979, as cited in Kondolf and Wolman 1993) to 46.0 mm (1.81 in) (Orcutt et al. 1968, as cited in Kondolf and Wolman 1993). Steelhead pairs have been observed spawning within 1.2 m (3.94 ft) of each other (Orcutt et al. 1968). Bell (1986) indicates that preferred temperatures for steelhead spawning range from 3.9º to 9.4ºC (39.0º to 48.9ºF). Steelhead may spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). In the Rogue River drainage, summer steelhead are more likely to spawn in intermittent streams, while winter steelhead typically spawn in permanent streams (Roelofs 1985).

Egg incubation, alevin development, and fry emergence

Incubating eggs require dissolved oxygen concentrations, with optimal concentrations at or near saturation. Low dissolved oxygen increases the length of the incubation period and cause emergent fry to be smaller and weaker. Dissolved oxygen levels remaining below 2 ppm result in egg mortality (Barnhart 1991). Temperature thresholds for the incubation, rearing, and outmigration life history stages are shown in Table 3. Information available in the literature indicates preferred incubation temperatures ranging from 48 to 52^{o}F (9 to 11^{o}C) (McEwan and Jackson 1996, FERC 1993),

Juvenile freshwater rearing

Age 0+

After emergence from spawning gravels in spring or early summer, steelhead fry move to shallow-water, low-velocity habitats such as stream margins and low-gradient riffles and will forage in open areas lacking instream cover (Hartman 1965, Everest et al. 1986, Fontaine 1988). As fry increase in size in late summer and fall, they increasingly use areas with cover and show a preference for higher-velocity, deeper mid-channel waters near the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). In general, age 0+ steelhead occur in a wide range of hydraulic conditions (Bisson et al. 1988), appearing to prefer water less than 50 cm (19.5 in) deep with velocities below 0.3 m/s (0.98 ft/s) (Everest and Chapman 1972). Age 0+ steelhead have been found to be relatively abundant in backwater pools and often live in the downstream ends of pools in late summer (Bisson et al. 1988, Fontaine 1988).

Age 1+ and older juveniles

Older age classes of juvenile steelhead (age 1+ and older) occupy a wide range of hydraulic conditions. They prefer deeper water during the summer and have been observed to use deep pools near the thalweg with ample cover as well as higher-velocity rapid and cascade habitats (Bisson et al. 1982, Bisson et al. 1988). Age 1+ fish typically feed in pools, especially scour and plunge pools, resting and finding escape cover in the interstices of boulders and boulder-log clusters (Fontaine 1988, Bisson et al. 1988). During summer, steelhead parr appear to prefer habitats with rocky substrates, overhead cover, and low light intensities (Hartman 1965, Facchin and Slaney 1977, Ward and Slaney 1979, Fausch 1993). Age 1+ steelhead appear to avoid secondary channel and dammed pools, glides, and low-gradient riffles with mean depths less than 20 cm (7.8 in) (Fontaine 1988, Bisson et al. 1988, Dambacher 1991).

As steelhead grow larger, they tend to prefer microhabitats with deeper water and higher velocity as locations for focal points, attempting to find areas with an optimal balance of food supply versus energy expenditure, such as velocity refuge positions associated with boulders or other large roughness elements close to swift current with high macroinvertebrate drift rates (Everest and Chapman 1972, Bisson et al. 1988, Fausch 1993). Reedy (1995) indicates that 1+ steelhead especially prefer high-velocity pool heads, where food resources are abundant, and pool tails, which provide optimal feeding conditions in summer due to lower energy expenditure requirements than the more turbulent pool heads. Fast, deep water, in addition to optimizing feeding versus energy expenditure, provides greater protection from avian and terrestrial predators (Everest and Chapman 1972).

Age 1+ steelhead appear to prefer rearing habitats with velocities ranging from 10–30 cm/s (0.33–0.98 ft/s) and depths ranging from 50–75 cm (19.5–29.3 in) (Everest and Chapman 1972, Hanson 1977, as cited in Bjornn and Reiser 1991). During the juvenile rearing period, steelhead are often observed using habitats with swifter water velocities and shallower depths than coho salmon (Sullivan 1986, Bisson et al. 1988), a species they are often sympatric with. In comparison with juvenile coho, steelhead have a fusiform body shape that is better adapted to holding and feeding in swifter currents (Bisson et al. 1988). Where the two species coexist, this generally results in spatial segregation of rearing habitat that becomes most apparent during the summer months. While juvenile coho salmon are strongly associated with low-velocity habitats such as pools throughout the rearing period (Shirvell 1990), steelhead will use riffles (age 0+) and higher velocity pool habitats (age 1+) such as scour and plunge pools in the summer (Sullivan 1986, Bisson et al. 1982).

Preferred rearing temperatures range from 48 to 58^{o}F (9 to 20^{o}C), and preferred outmigration temperatures of <57^{o}F (<13^{o}C) (McEwan and Jackson 1996) (Table 3). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments used steelhead that were reared at the Mokelumne River State Fish Hatchery from eggs were collected at the Nimbus Fish Hatchery (American River). These experiments indicate that Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures ranging from 62.6 to 68°F (17 to 20°C) and a maximum temperature tolerated (lethal critical thermal maximum) of 80°F (27°C).

Winter habitat

Steelhead overwinter in pools, especially low-velocity deep pools with large rocky substrate or woody debris for cover, including backwater and dammed pools (Hartman 1965, Swales et al. 1986, Raleigh et al. 1984, Fontaine 1988). Juveniles are known to use the interstices between substrate particles as overwintering cover. Bustard and Narver (1975) typically found age 0+ steelhead using 10–25 cm (3.9–9.7 in) diameter cobble substrates in shallow, low-velocity areas near the stream margin. Everest et al. (1986) observed age 1+ steelhead using logs, rootwads, and interstices between assemblages of large boulders (>100 cm [39.00 in] diameter) surrounded by small boulder to cobble size (50–100 cm [19.7–39.0 in] diameter) materials as winter cover. Age 1+ fish typically stay within the area of the streambed that remains inundated at summer low flows, while age 0+ fish frequently overwinter beyond the summer low flow perimeter along the stream margins (Everest et al. 1986).

In winter, 1+ steelhead prefer water deeper than 45 cm (17.5 in), while age 0+ steelhead often occupy water less than 15 cm (5.8 in) deep and are rarely found at depths over about 60 cm (23.4 in) (Bustard and Narver 1975). Below 7°C (44.6oF), juvenile steelhead prefer water velocities <15 cm/s (0.5 ft/s) (Bustard and Narver 1975). Spatial segregation of stream habitat by juvenile coho salmon and steelhead is less pronounced in winter than in summer, although older juvenile steelhead may prefer deeper pools than coho salmon (Bustard and Narver 1975).

Ocean phase

Little is known about steelhead use of ocean habitat, although changes in ocean conditions are important for explaining trends among Oregon coastal steelhead populations (Kostow 1995). Evidence suggests that increased ocean temperatures associated with El Niño events may increase ocean survival as much as two-fold (Ward and Slaney 1988). The magnitude of upwelling, which determines the amount of nutrients brought to the ocean surface and which is related to wind patterns, influences ocean productivity with significant effects on steelhead growth and survival (Barnhart 1991). Steelhead appear to prefer ocean temperatures of 9°–11.5°C (48.2°–52.7°F) and typically swim in the upper 9–12 m (29.52–39.36 ft) of the ocean's surface (Barnhart 1991).

List of Tables

Table 1. Central Valley winter steelhead life history timing.

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Adult Migration	░	░	░	░	░	░						░	░	░	░	▒	▒	█	█	▒	░	░	░	░	Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░	Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration			▒																	▓					Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░																░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning	▒	▒	▒	▒	▒	▒																			Mills and Fisher 1994
Spawning	▓	▓	▓	▓	▓	▓	▓	▓															▓	▓	Peak spawning in California streams (McEwan 2001).
Spawning	▒	▒	▒	▒	▒	▒	▒	▒															▒	▒	Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea								▒	▒	▒	▒	▒	▒												Mills and Fisher 1994
Incubation	▒	▒	▒	▒	▒	▒	▒	▒	▒															▒	Reynolds et al. 1993
Emergence																									Eggs hatch in 30 days at 51°F (Leitritz and Lewis 1980, as cited in McEwan 2001).
Emergence							▒	▒	▒	▒															Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).

Table 1. cont.

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Emergence						░	░	░	░	░	░	░	░	░	░	░	░								Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River Based on the results of emergence analysis for water temperature in SJR, Jones and Stokes estimated that emergence may occur between March 15 and August 30.
Rearing	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	In California scale analysis showed 70% Reared for two years, 29% for one year, and 1% for three years (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░	░	░	▒	▒	▒	▒	░	░	Geographic area: Sacramento River Migrate downstream in every month of the year, with a peak in the spring, and a smaller peak in the fall (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration	░	░	░	░	▓	▓	░	░	░															░	Geographic area: lower Sacramento Migrated past Knights landing in 1998 from late December through early May, and peaked in mid-March (DFG unpublished data, as cited in McEwan 2001).
Outmigration								▒	▒	▒	▒	▒	▒												Reynolds et al. 1993
Outmigration	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒											Jones and Stokes 2002 Foundation Runs Report Geographic area: Woodbridge Dam Outmigrating yearling and older steelhead detected January through July, and young of year detected April through July (Natural Resource Scientist 1998b, as cited in Jones and Stokes 2000).

░	Span of Light Activity
▒	Span of Moderate Activity
▓	Span of Peak Activity

Table 2. Temperature thresholds for steelhead adult migration and spawning

Life History Stage	Temperature	Comments	Source
Adult Migration	46–52°F (8–11°C)	preferred	McEwan and Jackson 1996
	>70°F (21°C)	stressful (Columbia River)	Lantz 1971, as cited in Beschta et al. 1987
Spawning	39–49°F (4–9°C)	preferred	Bell 1973, 1991
	39–52°F (4–11°C)	preferred	McEwan and Jackson 1996
	68°F (20°C)	stressful	FERC 1993
	>72 °F (>22°C)	lethal	FERC 1993
	75°F (24°C)	upper lethal	Bell 1991

Table 3. Temperature thresholds for incubation, rearing, and outmigration of steelhead

Life History Stage	Temperature °F (°C)	Comments	Source
Incubation	50°F (10°C)	preferred (hatching)	Bell 1991
	48–52°F (9–11°C)	preferred □incubation and emergence□	McEwan and Jackson 1996 FERC 1993
	>55°F (>12.8°C)	stressful	FERC 1993
	60°F (15.6°C)	lethal	FERC 1993
Juvenile Rearing	48–52°F (9–11°C)	preferred □fry and juvenile rearing□	McEwan and Jackson 1996
	55–65°F (12.8–18.3°C)	optimal	FERC 1993
	62.6–68°F (17–20°C)	preferred □Central Valley Steelhead□	Myrick (1998) p. 134
	50–59°F (10–15°C)	preferred	Moyle et al. 1995
	68°F (20°C)	sustained upper limit	Moyle et al. 1995
	77°F (25°C)	lethal	FERC 1993
	80°F (27°C)	lethal critical thermal maximum □Central Valley Steelhead□ □absolute maximum temperature tolerated□	Myrick (1998)
Smolt Outmigration	<57°F (14°C)	preferred	McEwan and Jackson 1996
	>55°F (13°C)	stressful (inhibit gill ATPase activity)	Zaugg and Wagneer 1973, Adams et al., 1975, both as cited in ODEQ 1995

Common Name	**Scientific Name (family)**
Inland silverside	*Menidia beryllina* (Atherinopsidae)

Legal Status:

Federal	none
State	none

Distribution

Inland silversides appear to be native to estuaries and lower reaches of coastal rivers from Maine to Florida and along the Gulf Coast from Florida to Veracruz, Mexico. They occur in the Mississippi River from southern Illinois to the coast including Texas and Oklahoma. Inland silversides were introduced from Oklahoma to Blue Lakes and Clear Lake, Lake County, California in 1967. The species rapidly spread through introductions, both illegal and those authorized by CDFG. It was well established in the San Francisco Bay area by 1975 and spread further to the San Joaquin River, and then, via the aqueduct and reservoir system, to southern California.

Life History

Silversides grow fast and have a short lifespan. Most fish reach 8-10cm TL in their first year and spawn and die during their first or second summer of life. Females grow faster and larger than males and may live a third year. Silversides are fractional spawners, meaning they can spawn using a fraction of their gonads on nearly a daily basis when temperatures reach 15-30°C. Females can produce 200-2,000 eggs per day during the California spawning season that runs from April-September. Fertilized eggs are adhesive and attach to substrate. Larvae hatch in 4-30 days depending on water temperature. Due to their reproductive capacity, silversides are now the most abundant fish throughout much of their range in California, including the San Francisco Estuary.

Habitat Requirements

Silversides are most abundant in shallow areas of warm water lakes, reservoirs, and estuaries. Silversides typically shoal in large numbers, in or near protected areas with sand or gravel bottoms. They apparently move into open waters to feed on zooplankton and move into shallow water to avoid predation at night. They occur in waters of 8-34°C with optimal temperatures of 20-25°C. Optimal salinities appear to be 10-15 ppt, but they can survive salinities as high as 33 ppt. Larval survival is highest around 15 ppt.

Ecological Interactions

The rapid expansion of the silverside population has resulted in their becoming the most abundant fish throughout much of their range in California, including the San Francisco Estuary and the San Joaquin River. They occupy the same shallow water habitat that is important for rearing of juvenile salmon, splittail, and other fishes. Silversides have the potential to deplete zooplankton populations in these habitats that may influence growth and survival of juveniles of other species. Silversides may also prey on eggs and larvae of other species of fishes. Although other factors may also be important, delta smelt populations declined shortly after the introduction of silversides to the estuary.

Key Uncertainties

The ecological interactions between the introduced silversides and other species have not been well studied. Silversides may have adverse affects on native species through predation on their larvae and eggs or competition for food.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Black crappie	*Pomoxis nigromaculatus* (Centrarchidae)

Legal Status:

Federal	none
State	none

Distribution

The natural range of the black crappie is in the fresh (and rarely brackish) waters of eastern and central North America from Quebec south to the Gulf coast and from Virginia south to Florida and from Manitoba south to central Texas. Black crappies were probably introduced into California in 1908 when white crappies were also introduced. They were introduced to the Central Valley around 1916-1919 and are now well established throughout the state in reservoirs or where there is warm quiet water.

Life History

Black Crappies mature in their second year at around 10-20 cm TL. Spawning begins when water temperatures reach 14-17ºC in March or April and may continue through July. Males construct 20-23 cm diameter nests in shallow water (<1 m) near cover such as overhanging banks or aquatic vegetation. Females can produce up to 188,000 eggs depending on the size of the fish. Males defend the nest and fry for a short period. Fry leave the nest and spend the next few weeks in the plankton before settling around structures. Young-of-the-year crappie grow rapidly and can reach 4-8 cm their first year. Black crappie can live 13 years and reach 2.2 kg in weight.

Black crappie prey in midwater on zooplankton, dipteran larvae, aquatic insects, planktonic crustaceans, and on fish such as threadfin shad, inland silversides, and juvenile striped bass. They may be somewhat less piscivorous than white crappie.

Habitat Requirements

Black Crappie prefer large warm water lakes and reservoirs and are usually associated with abundant aquatic vegetation and sandy/muddy bottoms. They prefer water that is less turbid than that preferred by white crappie. Preferred summer water temperatures are around 27-29ºC and temperatures over 37-38ºC are usually lethal. They can survive greater temperature extremes than the white crappie. Although their salinity (<10 ppt) and dissolved oxygen (>1-2 mg/liter) tolerances are similar to white crappie they are more abundant in the tidal sloughs of the San Francisco estuary.

Ecological Interactions

Black crappie can show population fluctuations in relation to abundance of competing and prey species. Black crappie are ecologically similar to Sacramento perch, a native species. Once black crappie become established, they may displace Sacramento perch from breeding sites, and through predation and competition for food.

Key Uncertainties

When black crappie first became established in the Sacramento – San Joaquin delta region in the 1920s the numbers of Sacramento perch declined. It is unclear why black crappie may displace the Sacramento perch.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	Scientific Name (family)
Bluegill (Centrarchidae)	*Lepomis macrochirus*

Legal Status:

Federal none
State none

Distribution

Bluegill are native to the freshwaters of eastern and southern North America from the St. Lawrence and Mississippi drainages south to Florida and northeastern Mexico. Bluegill were introduced to California in 1908 and became widely distributed throughout the state. They are probably the most widely distributed freshwater fish in California.

Life History

Spawning begins in spring when water temperatures reach 18-21ºC and may continue through the summer into September. Males construct nests in shallow waters that are approximately 20-30 cm in diameter. Females approach the male and deposit eggs in the nest as the male fertilizes them. Fertilized eggs adhere to debris at the bottom of the nest. Males and females spawn with multiple partners. Sunfish in general have a complex mating system. Females lay 2,000-50,000 eggs that hatch in 3-5 days. The nesting male may guard the newly hatched larvae for a short period until the next breeding cycle. Fry seek shelter in aquatic plants but may forage in the plankton before settling in plant beds near shore at 21-25 mm TL. Bluegill are opportunistic feeders, but because their mouths are relatively small they prey on a variety of smaller organisms including aquatic insects, fish, fish eggs, snails, zooplankton, and crayfish.

Habitat Requirements

Bluegill prefer warm, shallow lakes, reservoirs, ponds, streams, and sloughs but can survive as slow growing populations in colder systems. They are often associated with rooted plants and aquatic vegetation where they can hide and feed. Bluegill spend most of their lives in a small area where they become are able to find food and avoid predators. Bluegill prefer temperatures of 27-32ºC but can tolerate temperatures as low as 2-5ºC and as high as 40-41ºC. Preferred salinities are below 1-2 ppt but bluegill have been recorded in salinities up to 5 ppt in the San Francisco estuary. Salinities of 12 ppt are lethal to bluegill. Maximum growth and reproduction occur in clear waters and dissolved oxygen of 4-8 mg/liter.

Ecological Interactions

This species is known to hybridize with warmouth, green sunfish, and pumpkinseed sunfish. Bluegills are often associated with assemblages of other non-native fishes such as largemouth bass, green sunfish, redear sunfish, catfish, golden and red shiners, carp, inland silverside, and western mosquitofish. Bluegill also sometimes serve as cleaner fish for other fishes (i.e. smallmouth bass). Because bluegill are so adaptive, aggressive, and prolific, they are an alien fish that limit native fish populations through predation on larvae and indirect effects that may make native fish more vulnerable to predators.

Key Uncertainties

The long-term effects of bluegill on native fishes are not known.

Key References

Moyle 2002; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
Green sunfish	*Lepomis cyanellus* (Centrarchidae)

Legal Status:

Federal	none
State	none

Distribution

The green sunfish is native to the fresh waters of east-central North America including the great Lakes and most of the Mississippi drainage. They now occur in every state in the United States including California due to introductions. They were first introduced to California in 1891 and have been spread throughout the state since then.

Life History

Spawning begins when water temperatures reach around 19°C. Males dig 15-38 cm diameter nests in 4-50 cm deep water. Females hover around the nests while males court and spawn with them. Males and females spawn with multiple partners. Females carry 2,000-10,000 eggs which when fertilized, adhere to the nest substrate, and are guarded by males. Eggs hatch in 5-7 days. Larvae feed on zooplankton for several days before seeking cover in vegetation. Green sunfish are opportunistic predators and feed on a wider spectrum of benthic invertebrates, zooplankton, and small fish than other species of sunfish. Green sunfish rarely grow larger than 15 cm SL although they can reach 30 cm SL and live 10 years. They often form stunted populations since they can reproduce at a small size (5-7 cm SL). Green sunfish are very aggressive and older fish can be territorial forming dominance hierarchies. This aggressiveness makes green sunfish susceptible to angling. They feed on invertebrates and small fish including insects, zooplankton, benthic invertebrates, crayfish, and fish larvae including their own.

Habitat Requirements

Green sunfish can survive temperatures greater than 38°C but prefer 26-30°C. They can withstand low oxygen levels (<1 mg/L) but avoid salinities higher than 1-2 ppt. They are good colonizers and can reoccupy dewatered stream reaches by surviving in intermittent pools. Green sunfish are found in small, warm, streams, ponds and lake edges. They usually are found associated with dense growths of emergent vegetation and brush piles. They are often the sole species in warm isolated pools in intermittent streams that have been affected by human disturbance. Green sunfish are capable of surviving where other species cannot.

Ecological Interactions

Water withdrawals may be enhancing intermittent pool-type habitat that this species prefers. They are part of the introduced predator species complex in California, and they are aggressive and form stunted populations that compete with or prey on native species such as the California roach, sticklebacks, and minnows. They prevent the reestablishment of native species if their habitat requirements are similar. They are known to hybridize with bluegill and pumpkinseed sunfish.

Key Uncertainties

It is not known how to prevent further spread or creation of habitat beneficial to this species, or how to eradicate this species where it does the most harm.

Key References

Moyle 2002; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
Largemouth bass (Centrarchidae)	*Micropterus salmoides*

Legal Status:

Federal none
State none

Distribution

The native range of largemouth bass is from northeastern Mexico east to Florida, and north including the Mississippi River to Ontario and Quebec, and along the Atlantic seaboard to South Carolina. Largemouth bass were first introduced to California in 1891 from Illinois and were quickly distributed throughout California. A second introduction of Florida largemouth bass occurred in 1959 that also became widely distributed and promptly hybridized with the northern strain. Largemouth bass now occur throughout California in streams, lakes, and reservoirs.

Life History

Largemouth bass become sexually mature during their second or third year when they reach approximately 18-21 cm TL in males and 20-25 cm in females. Males construct nests in gravel or among aquatic vegetation in approximately 1-2 m of water when water temperatures reach 15-16º C. Females may lay eggs in multiple nests and may lay a total of 2,000-94,000 eggs. Eggs adhere to the substrate and hatch in 2-7 days depending on water temperature. Males guard the eggs and then the fry for up to four weeks. Fry form large schools that feed on zooplankton and patrol along vegetation and cover in shallower waters. Fry are vulnerable to predation at this time. Growth rates appear to be more variable for largemouth than for smallmouth bass. Many variables including genetics, food availability, water temperature, and competition may influence growth. Largemouth bass live to be more than 4 years old and exceed 45 cm TL. The largest largemouth on record weighed 9.9 kg and was caught in Castaic Reservoir, Los Angeles County. The Florida strain of bass, or hybrid, appears to grow larger than the northern strain. Largemouth bass eat zooplankton and insects when they are fry and then aquatic insects, fish fry, and small crustaceans as they grow. Adult largemouth bass are adaptable predators and can feed on a variety of prey including larger invertebrates, amphibians, small mammals, and fish. Largemouth bass may also cannibalize young of their own species, including when they are fry and swim in large schools.

Habitat Requirements

Largemouth bass prefer warm, quiet water lakes, ponds, sloughs, abandoned gravel mine pits, and backwaters of low gradient streams, with relatively low turbidity, and with vegetative cover. Largemouth bass are frequently found in disturbed areas and in association with other non-native species especially other centrarchids. Areas with current velocities $\leq$ 6 cm/s (0.2 ft/s) would constitute optimal habitat and velocities over 10 cm/s (0.34 ft/s) would likely be avoided. Adults prefer water temperatures of 25-30º C but can tolerate water temperatures of 37ºC. Juveniles may prefer slightly warmer waters (30-32ºC). Largemouth bass can tolerate dissolved oxygen as low as 1mg/liter and salinities as high as 16 ppt but they tend to avoid salinities over 5 ppt. Their adaptability to habitat extremes enables largemouth bass to survive in intermittent pools caused by drought or diversions. As a result they can persist in an area and their populations can quickly recover once flows resume. Habitat suitability for largemouth bass is not likely determined by depth as much as by velocity, temperature, and prey availability. In the Sacramento-San Joaquin Delta, largemouth bass and other centrarchid populations appear to be responding positively to increased habitat provided by an introduced aquatic plant, *Egeria densa*.

Ecological Interactions

Wherever largemouth bass are present they generally have adverse impacts on native species due to predation. In isolated water bodies they are capable of causing native species extirpations, and in larger systems they can effectively extirpate native species from certain areas. Largemouth bass can selectively feed on certain species to the point where they influence those populations. The reduction in a population of a native species, such a planktivore, by largemouth bass can result in a cascade effect that may cause changes to not only species composition in a water body but water quality parameters as well.

Key Uncertainties

The predation dynamics associated with increased bass and other centrarchid populations on salmonids and other native species is poorly understood.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
Pumpkinseed	*Lepomis gibbosus* (Centrarchidae)

Legal Status:

Federal	none
State	none

Distribution

Pumpkinseeds are native to eastern North America from Canada to Georgia and in the upper Mississippi drainage west to South Dakota. They were apparently introduced to California in the early 1900s and have been reported from the Klamath basin, Susan River, Sacramento-San Joaquin rivers and southern California. Due to illegal introductions, pumpkinseed can be expected throughout the state in cool, quiet waters.

Life History

Pumpkinseeds mature in approximately 2 years. Spawning occurs when temperatures reach 13-17ºC from April through June. Males build nests on the bottom in less than one meter of water and defend the nest. Males and females spawn with multiple partners. Females lay 600-7,00 eggs that hatch in 3-5 days. Males defend the larvae for a short period before the young swim into open waters and feed on zooplankton. After several weeks the young settle out and associate with vegetation and structures.

Pumpkinseeds grow slowly but live relatively long: they rarely exceed 30 cm FL but can live 12 years. Pumpkinseeds feed on hard-shelled invertebrates such as insects, snails, and bivalves that they pick from the bottom or from vegetation.

Habitat Requirements

Pumpkinseeds prefer quiet, cool, clear or slightly turbid waters in lakes, ponds, sloughs, and sluggish streams. They are usually associated with aquatic vegetation or other structure. Ecologically they are similar to redear sunfish, but can withstand cooler water temperatures. They prefer water temperatures of 24-32ºC but can withstand high temperatures of up to 38ºC and lows down to 3-4º C. They can survive higher salinities up to 17 ppt and can withstand dissolved oxygen levels as low as 4 mg/L.

Ecological Interactions

Pumpkinseeds have the potential to compete with and prey on native species. They have the potential to populate cooler waters including middle to higher elevation reservoirs and compete with native fishes there.

Key Uncertainties

Pumkinseed population dynamics are not known, but they appear to be spreading in Sacramento-San Joaquin rivers.

Key References

Moyle 2002; Scott and Crossman 1973; Lee et al. 1973

Common Name	**Scientific Name (family)**
Redear sunfish (Centrarchidae)	*Lepomis microlophus*

Legal Status:

Federal	none
State	none

Distribution

Redear sunfish are native to the southeastern United States and from Florida to the Rio Grande including the lower Mississippi drainage. The were first recorded in California in 1951 and have since been introduced to southern California, the Central Valley, the Russian River, and likely farm ponds and other waters throughout the state.

Life History

Redear sunfish usually mature by the second year and spawning occurs throughout the summer months when temperatures reach 21-24ºC. Males construct nests 25-62 cm in diameter, attract females and spawn much like other sunfishes. Females lay 9,000-80,000 eggs. Larvae appear to be planktonic before settling into aquatic vegetation. Redear sunfish feed on aquatic snails and hard-shelled invertebrates from the bottom and aquatic plants, and are known to feed on introduced mollusk species. They also feed on insect larvae and cladocerans.

Habitat Requirements

Redear sunfish prefer to inhabit deeper clear warm waters (> 2 m) of ponds, lakes, backwaters, and sloughs. They are most often found in aquatic vegetation, brush, stumps, logs and other cover. They are rarely found in the brackish waters of the San Francisco estuary but can tolerate salinities up to 20 ppt, which makes them one of the more saline tolerant sunfishes. Turbid waters can inhibit redear sunfish reproduction. Turbid waters reduce light penetration to deeper water and decreases plant growth at depth, which forces redear sunfish into shallower waters where they are forced to compete with other species such as bluegill.

Ecological Interactions

Redear sunfish compete with bluegill, green sunfish, and pumpkinseed especially where turbid waters force them into the shallows where vegetation can grow. Other introduced sunfishes may have a greater impact on native fish species than redear sunfish do. Redear are not as common as bluegill and green sunfishes and their preferred diet of snails and bivalves often includes introduced species as well.

Key Uncertainties

Little is known about the ecology and dynamics of California populations of redear sunfish. Because of their relatively recent introduction in California, their role in the decline of native fishes is poorly understood.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
Smallmouth bass (Centrarchidae)	*Micropterus dolomieu*

Legal Status:

Federal	none
State	none

Distribution

The native range of smallmouth bass is the eastern waters of North America from Minnesota and Quebec south to Alabama and west to Oklahoma. Smallmouth bass were first introduced to California in 1874 and are now widely distributed in rivers and reservoirs throughout California. Smallmouth bass now occur in most streams and reservoirs in the Central Valley, the Pit River, Russian River, Mad River, Freshwater Lagoon, Trinity River, Carmel River, Colorado River, Lake Tahoe, and other streams in southern California.

Life History

Smallmouth bass become mature in their third or fourth year and begin to spawn when water temperatures reach 13-16ºC in May and June. Males construct nests in gravel in approximately 1-2 m of water with nests containing 2,000-21,000 eggs. Males and females are apparently monogamous. Males defend eggs and fry for up to four weeks when the fry reach 20-30 mm TL and disperse into shallower waters. Growth rates appear to be less variable for smallmouth than for largemouth bass because the parameters (temperature, salinity, DO) of their occupied habitats appear to be more uniform. Smallmouth bass live to be more than 4 years old and may exceed 40 cm TL. Smallmouth bass eat zooplankton and insects when they are fry and then aquatic insects and small crustaceans as they grow. Adult smallmouth bass are predators on larger invertebrates, amphibians, small mammals, and fish. Adult smallmouth bass often feed on crayfish, which are frequently also introduced species. Smallmouth bass may also cannibalize young of their own species.

Habitat Requirements

Smallmouth bass prefer cool (20-27ºC), large, clear-water lakes and streams of moderate gradient with riffle-pool morphology, relatively low turbidity, and rocky substrates. Optimal stream reaches for adult smallmouth contain large pools, slow runs, eddies, or backwaters with abundant cover (e.g., boulders, rock ledges, undercut banks, and LWD) and prey (especially small fish and crayfish) and cobble-boulder substrates. In streams, larger adult smallmouth bass have been described variously as pool guild members, run or pool inhabitants, and habitat generalists. The biology of the smallmouth bass is quite similar to that of the largemouth bass; however, the smallmouth bass shows a somewhat greater preference for cooler streams with areas of swifter velocities. Water temperatures above 38ºC can be lethal. Smallmouth bass can tolerate dissolved oxygen as low as 1-3 mg/L but prefer oxygen levels above 6 mg/L.

Ecological Interactions

Smallmouth bass often exist with native species that have similar habitat requirements but their interactions are not well understood. Smallmouth bass may compete with hardheads for crayfish since they are a major component in the diet of both species. Smallmouth bass may also prey on juvenile Sacramento pikeminnow and hardhead and may adversely impact native frog populations. Under certain conditions, such as drought and warmer water conditions, smallmouth bass may have a reproductive advantage and have a greater impact on native fishes. Conversely, during cool years native fishes may spawn earlier and their juveniles may prey on smallmouth fry.

Key Uncertainties

Impacts on native fishes by smallmouth bass are not well known. However, impacts in water supply reservoirs may not be too severe where native fish are not very abundant. Methods to enhance native fish populations in relatively undisturbed areas where smallmouth bass coexist have not been established.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
Spotted bass	*Micropterus punctulatus* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

The native range of spotted bass was the central and lower Mississippi River and along the Gulf coast from Texas to northwestern Florida. Spotted bass were introduced from Ohio to California in 1933. Spotted bass were introduced throughout southern California and the Central Valley after 1974. They are now widely distributed in rivers and reservoirs throughout California, including those in the Central Valley.

Life History

Spotted bass become mature in their second year and begin to spawn when water temperatures reach 15-18ºC in late spring. Males construct nests in gravel in 0.5-4.6 m of water. Spawning continues until water temperatures reach 22-23ºC. Males and females are apparently monogamous but males may have more than one nest. Each nest contains 2,000-14,000 young, which are vigorously defended by the male for up to four weeks until the fry disperse when they are 30 mm TL. Growth rates are higher in warm-water reservoirs and slower in cool streams. Spotted bass can live to be 4-5 years old and may reach approximately 40 cm TL. Spotted bass are predators on larger invertebrates and fish, and larger fish eat larger prey. Fry eat zooplankton and insects and juveniles up to 75 mm eat aquatic insects and crustaceans. Fish over 75 mm eat fish, crustaceans and aquatic and terrestrial insects. The most common fish prey species are sunfishes, crappie, and threadfin shad. Spotted bass may also cannibalize young of their own species.

Habitat Requirements

Spotted bass prefer clear, low gradient waters in rivers and reservoirs. They inhabit slower more turbid water than smallmouth bass prefer, and faster water than largemouth bass. In rivers they occupy pools and avoid riffles and backwaters with heavy cover. In reservoirs they are found along steep, rocky underwater slopes, in the end where streams enter. Spotted bass prefer summer temperatures of 24-31ºC with adults just above the thermocline in moderate depths. Juveniles remain near shore in shallow water. They have a low salinity tolerance although they have been found in 10 ppt waters.

Ecological Interactions

Bluegills are common predators of spotted bass embryos and fry. Spotted bass may hybridize with smallmouth bass and redeye bass. Spotted bass may compete with, and prey on native fishes under certain circumstances.

Key Uncertainties

Impacts on native fishes by spotted bass are unknown. However impacts may not be too severe in water supply reservoirs where native fish are not very abundant. Spotted bass are capable of swimming up reservoir tributary streams on a seasonal basis where they may compete with and prey on native fishes.

The affects of hybridization with other species of bass are unknown.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
Warmouth	*Lepomis gulosus* (Centrarchidae)

Legal Status:

Federal	none
State	none

Distribution

Warmouth are native to the Mississippi River drainage, the Rio Grande, Florida and much of the Atlantic seaboard. Warmouth were introduced to California and were first mentioned in the 1930s. They are now found throughout the Central Valley and associated reservoirs. Although warmouth are established in California, they are relatively uncommon when compared to other sunfishes.

Life History

Warmouth live fairly long (6-8 years) but grow slowly. A 28 cm fish would be considered very large. They are known to have stunted populations where fish 10 cm TL are 4-6 years old. Warmouth mature in their second summer, and spawning occurs in late spring and early summer when water temperatures reach 21ºC. Males build nests near dense cover in 0.5-1.5 m deep water. Spawning behavior is similar to other sunfishes. Females produce 4,500-63,000 eggs depending on the size of the fish. Warmouth feed mainly on insects, snails, crayfish, and fish.

Habitat Requirements

Warmouth prefer abundant vegetation and cover in warm turbid, muddy bottom sloughs of the Central Valley, and they also do well in reservoirs. They are uncommon in tidal portions of the estuary. The preferred habitat parameters include summer water temperatures 22-28°C, salinities under 4 ppt, and oxygen levels above 4 mg/L although they can withstand lower levels.

Ecological Interactions

Warmouth may hybridize with bluegill.

Key Uncertainties

The ecological role of warmouth in the sloughs and reservoirs of the Central Valley is poorly understood. Their interactions with other fish species are not well known.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
White Crappie	*Pomoxis annularis* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

White crappie naturally occurred in the freshwaters of east central North America from southern Ontario and New York west of the Appalachian Mountains, south to the Gulf coast, and west to Texas and South Dakota. White crappie were apparently introduced to southern California around 1908. They were not planted north of the Tehachapi Mountains until 1951 when they were also were introduced in the north from Oregon. They are now well established in all major river systems and reservoirs in California.

Life History

White crappie become mature in 2-3 years at 10-20 cm TL, and spawning usually begins in April and May when water temperatures reach 17-20ºC. Males construct either isolated nests or nests in colonies in waters that are usually less than less than 1 m deep but sometimes as deep as 6-7 m. Females may spawn in the nests of several different males. Eggs adhere to substrate in the nest, which is defended by the male. Females may have 27,000 to 68,000 eggs that hatch into planktonic larvae. Small juveniles feed in the plankton but return to protected areas near shore. White Crappie can live longer than 7-8 years and reach a size greater than 35 cm FL.

Habitat Requirements

White crappie occur in warm, turbid, streams, lakes, ponds and slow moving rivers. They are apparently more tolerant of high turbidity, higher salinity, higher currents, and higher temperatures than the black crappie but have a lower tolerance of low dissolved oxygen levels. Black crappies displace white crappie in reservoirs that have oxygen levels less than 2-4 mg/liter. White crappies also appear to tolerate a lack of aquatic vegetation and cover better than black crappie. Nests are constructed in hard clay bottoms close to bushes or overhanging branches. Optimal temperatures for white crappie range from 27-29º C with a maximum tolerance of around 31º C. White crappie are rare in estuaries but have been reported in salinities as high as 10 ppt. White crappie are shoaling fishes that congregate around structure during the day but move into open water to feed during evening and morning periods. White crappie eat a variety of prey including planktonic crustaceans, small fish, and aquatic insects. Fish and larger invertebrates are the preferred diet of fish larger than 140 mm FL. Threadfin shad are an important prey item.

Ecological Interactions

White crappie populations may interact with native and non-native populations of fish through predation and competition. Inland silversides may compete for plankton with white crappie larvae and juveniles. Some populations of white crappie have demonstrated a boom and crash cycle in some locations (Clear Lake).

Key Uncertainties

How white crappie populations affect native fishes is not known. Effects may be minimal since most crappie populations are located in reservoirs or other highly disturbed areas where native fishes may not be present.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
American shad (Clupeidae)	*Alosa sapidissima*

Legal Status:

Federal	none
State	none

Distribution

American shad are anadromous and native to the Atlantic Coast from Labrador to Florida. They were introduced into the Sacramento River in 1871-1881. Once established, American shad spread quickly along the West Coast. Their current distribution is from Todos Santos Bay, Baja California, to Alaska and Kamchatka, USSR. In California, American shad are found in the Sacramento River system, the Delta, and the San Joaquin River system, the Klamath River, the Eel River, and the Russian River. A unique and successfully reproducing landlocked population exists in Millerton Lake, Madera County.

Life History

The anadromous American shad enter fresh water to spawn in the spring when water temperatures exceed 14º C although mature fish may occupy the estuary since the previous autumn. Males mature at 3-5 years and females at 4-5 years. Peak spawning occurs at temperatures around 18º C. The largest runs in the Sacramento are not seen until late May and early June. Fish spawn repeatedly over several days and eggs are fertilized in open water. Females can produce 20,000-150,000 eggs. Shad do not always die after spawning and surviving adults return downstream. Fertilized eggs are slightly negative buoyant, are not adhesive, and drift in the current. Eggs hatch in 8-12 days at 11-15º C but can hatch as quickly as 3 days at 24º C. Hatching success may be lower at higher temperatures. Larvae are 6-10 mm when they hatch and are planktonic for about 4 weeks. Juvenile shad can tolerate salinities of up to 20 ppt, and leave the estuary at 5-15 cm FL in September through November. However, some juveniles may use the estuary as a nursery for one to two years.

Growth may be related to water temperature and the availability of prey. Shad are reported to live up to seven years in California and males may reach 42 cm FL and females may reach 48 cm FL during that time. Young shad in the San Francisco estuary feed on zooplankton, bottom organisms, and surface insects. Little is known about shad during their 3-5 years at sea, although emigrating fish tagged in the Sacramento River have been recaptured from Monterey to Eureka. Shad may live to be 7 years old.

Habitat Requirements

American shad spend most of their adult life at sea and may make extensive migrations along the coast. American shad are anadromous and need larger rivers for reproduction and juvenile rearing. They require spring water temperatures of 14-24º C for spawning to occur. Shad ascend freshwater rivers in the spring and migrate upstream, sometimes for considerable distances. Mass spawning occurs in the main channels of rivers in 1-10 m of water over a variety of substrates. Water velocity ranges from 31-91 cm/sec.

Ecological Interactions

Shad populations have been declining and are approximately one third the number that they were 60 years ago. Dams and other obstructions impede juvenile and adult shad migration in many areas. Pollution, pesticides, and water diversions may also affect adult and juvenile shad populations.

Key Uncertainties

The affect of pesticides on larval shad and shad populations is not clear. The effects of changing ocean conditions on adult populations are not understood.

Key References

Moyle 2002; Lee et al. 1980; Scott Crossman 1973

Common Name	**Scientific Name (family)**
Threadfin shad	*Dorosoma petenense* (Clupeidae)

Legal Status:

Federal	none
State	none

Distribution

The native range of threadfin shad is from the Ohio River of Kentucky and southern Indiana, south to Texas and Florida including streams and rivers that flow into the Gulf of Mexico. Their range extends south to Guatemala and Belize. Threadfin shad were first introduced into California in San Diego County in 1953 and then were planted in reservoirs throughout the state and in the Sacramento-San Joaquin drainage in 1959. Threadfin shad are now well established in the Sacramento and San Joaquin rivers and the Delta and San Francisco Estuary. They also occur in the marine environment and have been recorded from Long Beach to Yaquina Bay, Oregon.

Life History

Spawning occurs in open water during spring when water temperatures exceed 21ºC. Eggs adhere to plants, floating or submerged objects, or under brush or logs. Threadfin shad may spawn at less than one year old. Females may release 900-21,000 eggs depending on the size of the female. Eggs hatch in 3-6 days and larvae immediately become planktonic. Larvae become juveniles in 2-3 weeks and form dense schools of similar size and age class. Threadfin shad grow fast and have short life spans, rarely living past 2 years and 10 cm TL. The largest California specimen was 22 cm TL. Like all clupeids, threadfin shad are planktivores and feed on zooplankton, phytoplankton, and detritus. They can strain food with their gill rakers or pick off individual organisms.

Habitat Requirements

Threadfin shad are found in lakes, ponds, larger rivers, estuaries, and reservoirs. They can also be found in the swifter waters of tailraces, near stream inlets and along dam faces, usually no deeper than 18 m. They prefer summer water temperatures of 22-24ºC and waters that do not become colder than 7-14ºC in winter. Threadfin shad cannot endure temperatures below 4ºC for long periods. The Sacramento-San Joaquin populations experience die offs when temperatures drop to 6-8ºC. Threadfin shad can survive and grow in seawater but apparently prefer fresh water and require it for successful reproduction.

Ecological Interactions

Threadfin shad were intentionally introduced into California as a forage fish for game fish. Their populations have the ability to rapidly increase when they are introduced into suitable habitat. At some locations the introduction has been a success with increased game fish growth rates. However, in some locations, threadfin shad proved to be unavailable as prey items to small warm water game fish due to their open water preference. In addition, threadfin shad may compete with and consume the planktonic larval stages of many warm water game fish, such as centrarchids (including the basses). The growth and survival of larval centrarchids in some reservoirs may decrease when threadfin shad are present.

Key Uncertainties

The effect of threadfin shad on native species, especially those with planktonic larvae, is poorly understood. Threadfin shad numbers have slowly declined in the Sacramento- San Joaquin Delta in the last 20 years. This may indicate a general decline of planktonic fishes in the estuary. The ecological role of threadfin shad in this ecosystem is not well known.

Key References

Moyle 2002; Lee et al 1980

Common Name	**Scientific Name (family)**
Common carp (Cyprinidae)	*Cyprinus carpio*

Legal Status:

Federal	None
State	None

Distribution

It is likely that carp evolved in the Caspian-Black Sea region. The Romans already cultured carp, which is now found in suitable waters worldwide. Due to their status as favorite food and sports fish in Europe, they were brought to California in 1872. By 1896, they were widely distributed. In California they are found in the Sacramento-San Joaquin drainage, the Salinas and Pajaro basins, the Russian River, Clear Lake, the Colorado River, some Lahontan drainage reservoirs and rivers, the Owens River, and along coastal southern California.

Life History

Common carp live in the wild rarely longer than 12–15 years. Growth varies depending on environmental conditions, and they reach approximately 7–36 cm SL. During their second year they double in length, growth slows down after the fourth year. Spawning occurs during any time of the day or night in spring and summer as soon as temperatures exceed 15°C, but especially when temperatures reach 19 –23°C. The adhesive eggs attach to plants, roots, and bottom debris. Embryos hatch in 3-6 days and drop to the bottom or attach to vegetation where they stay until they have consumed the content of their yolk sac. After a few days they start feeding on zooplankton. Most carp fry move into protective beds of emergent and submerged vegetation by the end of the first week, which they will rarely leave until reaching 7–10 cm TL.

Habitat Requirements

Common carp are most abundant in warm, eutrophic lakes, reservoirs, and sloughs with silty bottoms and growths of submergent and emergent aquatic vegetation. They can also inhabit some trout streams and coldwater reservoirs. In streams they are found in deep pools with higher turbidity and soft bottoms. Carp are active between 2–24°C, can survive high turbidities, high temperatures (31–36°C), and low oxygen concentrations (0.5–3.0 ppm). They can survive salinities up to 16 ppt.

Ecological Interactions

Common carp are probably responsible for the reduction and displacement of native fish. Due to their foraging behavior, they may increase turbidity and prevent the growth of dense beds of aquatic vegetation. Young carp are preyed upon by game fish such as largemouth bass.

Key Uncertainties

It is uncertain how to prevent carp from spreading into watersheds that have not been populated.

Key References

Moyle 2002

Common Name	**Scientific Name (family)**
Fathead minnow	*Pimephales promelas* (Cyprinidae)

Legal Status:

Federal	None
State	None

Distribution

Fathead minnow are native to much of the eastern and midwestern portions of the United States and Canada, as well as parts of northern Mexico. They were introduced into much of the western United States as a bait and forage fish, including California (in the early 1950's) where they have been reared by both commercial breeders and CDFG. This has lead to their establishment in the Sacramento-San Joaquin and Klamath basins, the Colorado drainage, a number of coastal drainages, portions of southern California, and potentially in any watersheds with adequate conditions for their survival. They can be found in an array of habitats, but appear to be most adapted to pools of small, turbid streams and in ponds where other fish are sparse.

Life History

Fathead minnow are opportunistic feeders who browse for filamentous algae, diatoms, small invertebrates, and organic matter located on the bottom, midwater, or amongst aquatic vegetation. Growth rates are extremely variable, and are largely dependent on temperature, availability of food, and population size. Maximum recorded length is 109 mm total length. First spawning can occur between a few months to two years of age, and the majority of fish die 1-2 months after the onset of spawning. Females can spawn throughout the summer season when temperatures are above 15-16°C and below 32°C, and can produce >4000 eggs. Males form nests by creating hollows in the substrate around some type of item such as a flat stone, branch, or root mass at a depth of 30-90 cm that the sticky eggs will adhere to. Males defend the nest and care for the embryos that hatch in 4-6 days (at 25°C).

Habitat Requirements

Fathead minnows are capable of surviving under extreme conditions such as, dissolved oxygen levels <1 mg/L, temperatures up to 33°C, high alkalinities, and high levels of organic pollution and turbidity. They are considered pioneer species because their ability to withstand environmental extremes allows them to inhabit and dominate temporary aquatic environments when they arise.

Ecological Interactions

When fathead minnows inhabit perennial environments, they are often poor interspecific competitors, especially with other cyprinids, but this is not always the case. In areas where they have become exceedingly abundant, such as the Upper and Lower Klamath Lakes and in Tule Lake, they have been known to displace native cyprinids such as the blue chub in these locations.

Key Uncertainties

Fathead minnows are legal baitfish within California, and are easily moved to new locations where they have the potential to establish populations. It is unknown if this practice should be eliminated to safeguard native fishes that have similar habitat preferences, such as the California roach.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Goldfish	*Carrasius auratus* (Cyprinidae)

Legal Status:

Federal	None
State	None

Distribution

Goldfish naturally occur in eastern Europe and China. They have been spread by aquarists and bait fishermen throughout the world. Established in California since the 1860s, goldfish occur in large populations in southern California reservoirs, in Clear Lake, as well as sloughs and reservoirs in the Central Valley. However, individuals and smaller populations can be found throughout the state where the water temperature is sufficiently warm.

Life History

Goldfish in the wild rarely live longer than 6-8 years, and growth during that time is variable, depending on environmental conditions. In California they usually reach 50-90 mm in their first year and can reach up to 20 cm TL. Females grow larger and live longer than males. Males mature during their second or third year. Goldfish are serial spawners and require temperatures of 16–26°C. Spawning takes place in May and April during sunrise on sunny days, over aquatic vegetation or flooded and emergent objects, such as leaves, roots, and grass. Eggs are adhesive and hatch within a week. Larvae and small juveniles seek cover among aquatic vegetation. Goldfish are omnivores feeding on algae, zooplankton, mollusks, crustaceans, organic detritus, and macrophytes. In the San Joaquin River, goldfish feed mostly on planktonic diatoms and strands of filamentous algae.

Habitat Requirements

Goldfish can survive in temperatures between 0 and 41°C, however populations generally establish in water with temperatures between 27 and 37°C. They prefer standing or slow moving water with heavy growth of aquatic vegetation but they can become established in colder lakes if there is a littoral area warm enough for breeding. They do well in disturbed and polluted areas, and can be found below reservoirs and in deep pools with dense cover in streams.

Ecological Interactions

In some areas their feeding behavior may lead to the elimination of aquatic plants and increase turbidity, especially in mud-bottomed ponds. They are often found in association with other non-native fish, especially in disturbed and polluted areas.

Key Uncertainties

Goldfish occur widely throughout California, however, their ecological role is not well understood.

Key References

Moyle 2002; Scott and Crossman 1985

Common Name	**Scientific Name (family)**
Golden shiner (Cyprinidae)	*Notemingonus crysoleucas*

Legal Status:

Federal None
State None

Distribution

Golden shiners are native throughout the majority of eastern North America form Quebec southward to Texas and Florida. In the late 1800s, they were introduced to California as a forage species, but did not have a large distribution until after 1955 when they were established as a legal baitfish. They are currently ubiquitous throughout the state. They generally inhabit warm, shallow ponds, lakes, and sloughs where they can be found in association with aquatic vegetation.

Life History

Golden shiners can obtain an ultimate length of up to 260 mm standard length, and a maximum age of nine years. They are sight feeders, and typically feed during the day on prey items such as mollusks, terrestrial and aquatic insects, small fish, aquatic insect larvae, filamentous algae, and large zooplankters such as *Daphnia sp.* Breeding season in California lasts from March through September when water temperatures are in the region of 20°C. Females are fractional spawners, with initial fecundities of 2,700-4,700+ eggs. The adhesive eggs are deposited on submerged vegetation or bottom debris where males subsequently fertilize them. Hatching occurs in 4-5 days (at 24-27°C), upon which time emergent fry begin to shoal in large numbers, generally in association with nearshore aquatic vegetation.

Habitat Requirements

Golden shiners are most abundant in low-velocity, turbid environments with muddy bottoms such as low-elevation reservoirs and sloughs, but can also be present in coldwater lakes as long as there are warm, shallow areas for breeding and rearing their young. They can endure temperatures of up to 36-37°C, and dissolved oxygen concentrations <1 mg/L.

Ecological Interactions

Golden shiners can most often be found in areas having other introduced species such as largemouth bass, various sunfish species, and mosquitofish. In some locales, piscivorous fishes may limit their abundance. They shoal in littoral or pelagic areas to avoid predators, and if predation pressure is high, may become nocturnal feeders. In coldwater lakes, golden shiners have been known to reduce growth and survival of trout by reducing zooplankton populations.

Key Uncertainties

Golden shiners are one of three legal baitfish in California, and it is challenging to predict where populations could become established, and what problems could occur as a result of their colonization.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Red shiner	*Cyprinella lutrensis* (Cyprinidae)

Legal Status:

Federal	None
State	None

Distribution

Red shiners are originally from streams in the western and central United States that drain into the Mississippi River and Rio Grande. They are used as a baitfish, and as a result have been planted in other regions including California in 1954. CDFG first planted them in the Sacramento-San Joaquin drainage and in Lake County ponds, but there is no evidence of a successful introduction. They can be anticipated to be present anywhere in the state, and are currently known to be found in the San Joaquin Valley, Coyote Creek, Sacramento Valley streams, the Colorado River drainage, Los Angeles County, San Juan, Big Tijunga, and Aliso Creeks, and various coastal streams. They prefer habitats with turbid, alkaline, shallow, and slow-flowing water such as backwaters and sloughs.

Life History

Red shiners shoal in large groups and feed on the most plentiful organisms present, which may include crustaceans, aquatic insect larvae, surface insects, algae, and larval fish. They can obtain an ultimate size of 80 mm standard length, and a maximum age of 2.5-3.0 years. They typically mature during the summer of their second year. Females are fractional spawners, and therefore fecundity among individuals will vary. Breeding season takes place when water temperatures are 15-30°C, and may be extended from May until October. Spawning takes place in slow-flowing water, and eggs will adhere to a plethora of substrates such as submerged vegetation, gravel and sand, root wads, woody debris, and active sunfish nests. Its early life history has not been described in literature.

Habitat Requirements

Favorable environments of red shiners include both unstable and highly disturbed environments such as intermittent streams, drainage ditches, and reservoirs. They avoid severe environmental conditions, but can tolerate pH values of 4-11, salinities up to 10 ppt, dissolved oxygen levels as low as 1.5 mg/L, and temperatures as high as 39.5°C. They are primarily found in water >30 cm in depth, velocities of 10-50 cm/sec, and near submerged cover over fine substrate.

Ecological Interactions

Red shiners have a great capacity to spread within a region once they become established, and can displace native cyprinids whenever this occurs. They have been linked to declines of native fishes, such as the Virgin River spinedace, through their introduction.

Key Uncertainties

Red shiners are thought to be jeopardizing the future of native cyprinids in southern and central California though there is no direct evidence to support this notion.

Key References

Moyle (2002)

Common Name	**Scientific Name family)**
Black bullhead (Ictaluridae)	*Ameiurus melas*

Legal Status:

Federal	None
State	None

Distribution

Black bullheads have native distributions spanning a great extent of the United States east of the Rocky Mountains and into southern Canada. Introductions have expanded them from their native range to locales within most western states. In California, black bullhead are quite common throughout the Central Valley, the San Francisco estuary, and in coastal drainages from San Luis Obispo County south to the Mexican border. They also have a presence in Monterey Bay tributaries, the lower Colorado River, and the Lost, Owens, and Russian River drainages.

Life History

Adult black bullhead size can range from 17–61cm total length dependant upon such factors as temperature, food availability, and degree of overcrowding. Black bullheads are omnivorous and feed on an array of organisms including aquatic and terrestrial insects, crustaceans, mollusks, earthworms, and both live and dead fish. Adults are nocturnal feeders whereas younger fish tend to have diurnal feeding habits. Spawning occurs in June and July when water temperatures exceed 20°C. Females create small hollows in the substrate as nests, and can lay between 1,000-7,000 eggs that form a cohesive yellow mass when fertilized. Parents care for their young from developing embryos to the time they are approximately 25 mm total length when young disperse to shallow reaches. Black bullhead are quite social, and can often be found shoaling together.

Habitat Requirements

Black bullhead have the ability to adapt to a wide range of environmental conditions, and have therefore been able to easily invade new areas. Their preferred habitats include sloughs and pools of low-gradient streams with muddy bottoms, slow velocities and warm, turbid water, river backwaters, and ponds and small lakes. They can be abundant in habitats such as ditches, brackish waters of estuaries, and temporary habitats such as intermittent streams. They can withstand temperatures up to 35°C, dissolved oxygen concentrations down to 1-2 mg/L, and salinities as high as 13 ppt.

Ecological Interactions

Black bullhead are becoming increasingly more prominent in highly disturbed lowland aquatic environments and can support small recreational fisheries. In California they can oftentimes be found among other introduced species with similar habitat preferences including bluegill, green sunfish, inland silverside, carp, red shiner, fathead minnow, goldfish, channel catfish, and threadfin shad.

Key Uncertainties

The distribution of black bullhead appears to be expanding, and it is not known what effect this will have on other native and nonnative species.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Brown bullhead	*Ameiurus nebulosus*
(Ictaluridae)	

Legal Status:

Federal	None
State	None

Distribution

Brown bullhead have a native range encompassing the majority of the United States east of the Great Plains and southeastern Canada, and have been introduced throughout most of southwestern Canada and the western United States where they exist in every major river system. In California they are currently in the majority of larger coastal drainages from the Klamath River to Southern California, the upper Klamath basin, all of the Sacramento-San Joaquin system, the Owens River, and potentially in California sections of the Truckee, Walker, and Carson rivers. Their greatest abundance is in large water bodies such as the sloughs of the Sacramento-San Joaquin Delta, Clear Lake, and foothill reservoirs though they have adapted to a variety of habitats ranging from warm, turbid sloughs to clear mountain lakes.

Life History

Brown bullhead can reach ultimate lengths of 53 cm total length and maximum weights of 2.2 kg, although commonly do not grow more than 30 cm total length and 0.45 kg. Spawning usually begins in their third year, and in California takes place from May through July when water temperatures surpass 21°C. Females lay 2,000-14,000 eggs in batches within nests formed from hollows dug in sand or gravel that are closely associated with in-stream cover. Hatching occurs in 6-9 days, and yolk-sac fry will remain in the nest for roughly one week while being guarded by both parents. Smaller fish primarily consume chironomid midge larvae and small crustaceans, and graduate to larger insect larvae and fish as they grow. They are both omnivorous and opportunistic and will consume most organisms of adequate size.

Habitat Requirements

Habitat preference of brown bullheads includes the deep portion of the littoral zone in association with aquatic vegetation and soft substrate, and in sluggish, turbid, low-gradient reaches of rivers. They prefer temperatures between 20-33°C, but can tolerate temperatures of 0-37°C. They can withstand a wide span of salinities (>13ppt) and pH (>9), and oxygen levels as low as 1 mg/L.

Ecological Interactions

Brown bullheads are most abundant in anthropogenically altered habitats and have become an important recreational fishery.

Key Uncertainties

The effect of this introduced species on native fishes and introduced species is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Channel catfish	*Ictalurus punctatus* (Ictaluridae)

Legal Status:

Federal None
State None

Distribution

Channel catfish originated in the Mississippi-Missouri River system and have been introduced throughout North America. It is assumed that the channel catfish population in the Central Valley originated from fish planted in the American River in the late 1920s. Catfish have been reared in hatcheries since the 1960s, which widened their distribution to all public waters and private ponds and can be expected wherever suitable conditions are available.

Life History

Channel catfish are fast growing, reaching up to 53 cm TL at 10 years of age in California. They reach sexual maturity between 2–8 years at 18–56 cm. Spawning requires temperatures between 21–29°C (optimum 26–28°C). In California, they spawn between April and August using cave-like sites for nesting, including undercut banks, log jams, or old barrels. The male guards the nest and cares for the young, including aerating the embryos with movements of his body. The embryos hatch within 5–10 days and the young leave the nest after about a week. The young may stay together for another week or two, then they disperse into shallow, flowing water. Channel catfish forage mainly on a wide variety of invertebrates and fish, but also maybe incidentally feed on detritus and plant material. Young catfish feed primarily on crustaceans and the larval aquatic insects.

Habitat Requirements

Catfish live in the mainstem of larger streams, spending days in deeper pools and foraging during the night in the water column. Young-of-year prefer living in riffles. Optimal stream habitat is characterized by clean, warm water with sand or gravel bottoms. They can survive temperatures of 36–38°C and oxygen minima of 1–2mg/liter. They can tolerate moderate salinities, but are not common in brackish water.

Ecological Interactions

They prey upon many native fish and fish larvae, as well as invertebrates and smaller mammals.

Key Uncertainties

The impacts of channel catfish on native fish, amphibians, and invertebrate assemblages are not known. However, due to their predatory behavior, it is assumed that it is negative.

Key References

Moyle 2002; Scott and Crossman 1985

Common Name	**Scientific Name (family)**
White catfish	*Ameiurus catus* (Ictaluridae)

Legal Status:

Federal	None
State	None

Distribution

White catfish evolved in the lower reached of streams of the Atlantic coast. In 1874, white catfish were planted in the San Joaquin River. They spread naturally throughout the Central Valley and were also planted in several lakes and reservoirs.

Life History

White catfish growth is variable, with the slowest populations found in the south and central Delta. Males grow faster and become larger than females and can reach up to 60 cm TL and 3 kg in their native streams and tend to be smaller in California. White catfish reach maturity when they are between 3 and 5 years old. Spawning occurs in June and July when water temperatures exceed 21°C. Eggs are spawned in a nest made by the male, who also cares for the young. Eggs hatch within a week at 24–29°C.

White catfish are mainly piscivorous, but also feed on smaller organisms, such as amphipods, shrimp, and chironomid larvae. They forage mainly along the bottom.

Habitat Requirements

White catfish prefer areas of slow velocity and avoid deep, faster velocity channel waters. During the day they avoid shallow vegetated areas, however, at night they move into shallow waters. They prefer temperatures exceeding 20°C and can survive temperature of 29–31°C and salinities as high as 11–14.5 ppt.

Ecological Interactions

White catfish can change species compositions in ecosystems where they are introduced to due to their piscivorous feeding behavior. In Clear Lake, for example, they are responsible for the decline of native cyprinids.

Key Uncertainties

The extent that white catfish are predators on outmigrating salmonids is not known.

Key References

Moyle 2002

Common Name	**Scientific Name (family)**
Striped bass	*Morone saxatilis* (Moronidae)

Legal Status:

Federal None
State None

Distribution

Striped bass originated from streams of the Atlantic coast. They were introduced into California into San Francisco Bay in 1879. There found now in salt waters between Mexico and southern British Columbia, with the main breeding population still located in San Francisco Bay. They have also been raised in hatcheries and released into reservoirs and rivers flowing into the Central Valley.

Life History

Female striped bass can reach over 30 years in age. Growth is variable but rapid during the first four years, with the largest fish caught in California measuring 30.6 kg. Females mature between 4 and 6 years and can spawn every year. Spawning begins in April and requires temperatures above 14°C and below 21°C. Eggs slowly sink but even a slight current can keep them suspended. They hatch in about 2 days and feed off their yolk sac for up to 8 days. With increasing swimming abilities they start feeding on zooplankton. In the San Joaquin River embryos stay in the same general area in which spawning took place, as outflow is balanced by tidal currents. Larvae undergo vertical migrations to actively use riverine and tidal currents. Striped bass are pelagic, opportunistic predators, feeding on invertebrates and fishes.

Habitat Requirements

Striped bass are tolerant of wide range of environmental conditions, surviving temperatures up to 34°C, low oxygen levels between 3–5ml/L, and high turbidity. They require a large cool river for spawning, a large body of water with large population of small fishes for foraging, and an estuary as a nursery ground for larvae and juveniles.

Ecological Interactions

It is possible that striped bass contributed to the decline of native fishes, including salmon, thicktail chub, and Sacramento perch, due to predation and competition. For example, striped bass consume up to 99% of juvenile salmon drawn to Clifton Court Forebay. However, other native fish, such as delta smelt and splittail, seem to be able to coexist with striped bass.

Key Uncertainties

It is unknown whether or not native fish species can recover in the presence of large striped bass populations.

Key References

Moyle 2002.

Common Name	**Scientific Name (family)**
Bigscale logperch	*Percina macrolepia* (Percidae)

Legal Status:

Federal	None
State	None

Distribution

Bigscale logperch are found in numerous Gulf Coast river systems, and in 1954 were accidentally imported into lakes within Yuba County, CA. They have since spread throughout the Sacramento-San Joaquin watershed, the San Joaquin Valley, reservoirs receiving water from the California Aqueduct, and other reservoirs within central and southern California where they were potentially introduced by bait fishermen. They inhabit an array of lake and stream habitats, especially in "slower-moving stretches of warm, clear streams or in shallow waters of reservoirs on bottoms of mud, gravel, rocks, sticks, or large pieces of debris" (Moyle 2002).

Life History

Bigscale logperch can reach a maximum size of 125 mm standard length at age 3+ years. They generally reach maturity in their second year, and during spawning females can produce 150-400 eggs. Spawning occurs between February and July in small gravel pits or within vegetation where the eggs are attached. Larvae are pelagic, and are consequently washed into side channels where they settle. Bigscale logperch are opportunistic, and their diet consists of whatever dominant insect larvae, amphipod, and planktonic crustaceans are present. They are benthic feeders, but will also rise from the bottom to collect free-swimming organisms.

Habitat Requirements

Bigscale logperch are generally inactive and reside along the edges of emergent vegetation or on the bottom, oftentimes in pits they have dug or buried within gravel substrate. They tend to prefer habitats with fine substrate and warm, turbid water. They have been found in waters with salinities of up to 4.2 ppt.

Ecological Interactions

Exotic species such as the common carp, fathead minnow, various catfish species, inland silverside, bluegill, largemouth bass, and black crappie are primarily associated with bigscale logperch in addition to the native Sacramento blackfish.

Key Uncertainties

Native and desirable game fishes may be affected by bigscale logperch but the effects may be minimal due to their exclusive use of highly disturbed habitats.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Mosquitofish	*Gambusia affinis* (Poecillidae)

Legal Status:

Federal	None
State	None

Distribution

Mosquitofish are native to central North America, and have been introduced for mosquito control throughout the world. In 1922, they were introduced to California where they have rapidly spread throughout the state both through plantings and on their own. They are ubiquitous throughout portions of the state that do not have extended periods of cool water temperatures, and are still extensively planted.

Life History

Mosquitofish are omnivorous and opportunistic feeders on whatever organisms are most abundant. Growth is dependant upon factors such as sex, and various other environmental factors including productivity and temperature. Maximum size is 35 mm total length for males and 65 mm total length for females, and is typically achieved in one growing season. Fifteen months is generally the upper limit of survival for these fish because the majority die the same summer they reach maturity. Depending on genetics and environmental conditions factors such as time to maturity, gestation period, number of embryos per brood, and broods per season will vary. Under optimal conditions, females can contain up to 315 embryos, and 3-4 generations per year are feasible, though 50 embryos per brood and two generations per season are most common in the Central Valley. Mosquitofish are livebearers, and young are usually expelled in shallow water or among aquatic vegetation. Mosquitofish are omnivorous and besides consuming mosquito larvae and pupae, they will opportunistically feed upon such organisms as algae, zooplankton, terrestrial insects, diatoms, and various aquatic insects.

Habitat Requirements

In California streams, mosquitofish occur in disturbed portions of low-elevation streams, especially warm, turbid pools with beds of emergent aquatic plants. Within watersheds, mosquitofish can inhabit a wide array of habitats including brackish sloughs, salt marshes, warm ponds, lakes, and streams. They have a remarkable capability to withstand and even thrive under extreme environmental fluctuations. Though preferred conditions fall more centrally within the ranges, they can occur in temperatures of 0.5-42°C, pH of 4.7-10.2, salinities of 0-58ppt, and dissolved oxygen levels of as low as 0.2 mg/L. They tend to be associated with aquatic vegetation, but will only be found along the periphery of plant growth if it is too thick.

Ecological Interactions

Although mosquitofish introduction can be used effectively as a biological control method for mosquito populations, plantings can have a negative affect on native populations of small fish, amphibians, and endemic invertebrates through predation on various life stages and harassment of adults that can keep breeding from occurring. They are thought to be responsible for eliminating or significantly reducing certain small fish species, such as the Amagrosa pupfish, worldwide. Mosquitofish can also develop resistance to local pesticides, although low reproductive rates have directly correlated with high selenium levels from agricultural runoff in the San Joaquin Valley.

Key Uncertainties

Methods to control populations of mosquitofish where they currently coexist with native species are not well understood.

Key References

Moyle (2002)

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Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California

Appendix C is excerpted from Chapter 7 of the Sierra Nevada Ecosystem Project: Final Report.

Sierra Nevada Ecosystem Project: Final report to Congress, vol. III, *Assessments, Commissioned Reports, and Background Information.* Davis: University of California, Centers for Water and Wildland Resources, 1996.

INTRODUCTION

The vast expanse of the Central Valley region of California once encompassed numerous salmon-producing streams that drained the Sierra Nevada and Cascades mountains on the east and north and, to a lesser degree, the lower-elevation Coast Range on the west. The large areas that form the watersheds in the Sierra and Cascades, and the regular, heavy snowfalls in those regions, provided year-round streamflows for a number of large rivers which supported substantial-- in some cases prodigious-- runs of chinook salmon (*Oncorhynchus tshawytscha*). No less than 25 Central Valley streams supported at least one annual chinook salmon run, with at least 18 of those streams supporting two or more runs each year. In the Sacramento drainage, constituting the northern half of the Central Valley system and covering 24,000 sq mi (Jacobs et al. 1993), most Coast Range streams historically supported regular salmon runs; however, those "westside" streams generally had streamflows limited in volume and seasonal availability due to the lesser amount of snowfall west of the Valley, and their salmon runs were correspondingly limited by the duration of the rainy season. Some tributary streams, such as Cache and Putah creeks, did not connect with the Sacramento River at all during dry years, and salmon runs only entered them opportunistically as annual rainfall conditions allowed. In the San Joaquin drainage, composing much of the southern half of the Central Valley system and covering 13,540 sq mi (Jacobs et al. 1993), none of the westside streams draining the Coast Range had adequate streamflows to support salmon or any other anadromous fishes.

The great abundance of chinook salmon of the Central Valley was noted early in the history of colonization of the region by Euro-American people. However, following the California Gold Rush of 1849, the massive influx of fortune seekers and settlers altered the salmon spawning rivers with such rapidity and so drastically that the historic distributions and abundances of anadromous fish can be determined only by inference from scattered records, ethnographic information, and analysis of the natural features of the streams. Probably the only species for which adequate information exists to develop a reasonably complete picture is the chinook salmon-- the most abundant and most heavily utilized of the Central Valley anadromous fishes.

In this report, we consolidate historical and current information on the distribution and abundance of chinook salmon in the major tributary streams of the Central Valley in order to provide a comprehensive asssessment of the extent to which chinook salmon figured in the historical landscape of the Central Valley region.

THE FOUR RUNS OF CENTRAL VALLEY CHINOOK SALMON

Four runs of chinook salmon occur in the Central Valley system-- more precisely, in the Sacramento River drainage-- with each run defined by a combination of adult migration timing, spawning period, and juvenile residency and smolt migration periods (Fisher 1994). The runs are named on the basis of the upstream migration season. The presence of four seasonal runs in the Sacramento River lends it the uncommon distinction of having some numbers of adult salmon in its waters throughout the year (Stone 1883, Rutter 1904, Healey 1991, Vogel and Marine 1991). The fall and late-fall runs spawn soon after entering the natal streams, while the spring and winter runs typically "hold" in their streams for up to several months before spawning (Rutter 1904, CDFG 1993). Formerly, the runs also could be differentiated on the basis of their typical spawning habitats-- spring-fed headwaters for the winter run, the higher streams for the spring run, upper mainstem rivers for the late-fall run, and the lower rivers and tributaries for the fall run (Rutter 1904, Fisher 1994). Different runs often occurred in the same stream-- temporarily staggered but broadly overlapping (Vogel and Marine 1991, Fisher 1994), and with each run utilizing the appropriate seasonal streamflow regime to which it had evolved. On the average, the spring-run and winter-run fish generally were smaller-bodied than the other Central Valley chinook salmon, and late-fall run fish were the largest (Stone 1874, F. Fisher, unpubl. data).

Prior to the American settlement of California, most major tributaries of the Sacramento and San Joaquin rivers probably had both fall and spring runs of chinook salmon. The large streams that lacked either adequate summer flows or holding habitat to support spring-run salmon, which migrate upstream during the spring and hold over the summer in pools, had at least a fall run and in some cases perhaps a late-fall run. The fall run undoubtedly existed in all streams that had adequate flows during the fall months, even if the streams were intermittent during other parts of the year. Generally, it appears that fall-run fish historically spawned in the Valley floor and foothill reaches (Rutter 1904)-- below 500 ft elevation-- and most likely were limited in their upstream migration by their egg-laden and somewhat deteriorated physical condition. The spring run, in contrast, ascended to higher elevation reaches, judging from spawning distributions observed in recent years and the reports of early fishery workers (Stone 1874, Rutter 1904). A California Fish Commission report (CFC 1890) noted, "It is a fact well known to the fish culturists that the winter and spring run of salmon, during the high, cold waters, go to the extreme headwaters of the rivers if no obstructions prevent, into the highest mountains." Spring-run salmon, entering the streams while in pre-reproductive and peak physical condition well before the spawning season, were understandably better able to penetrate the far upper reaches of the spawning streams than were fall-run fish. The spring run, in fact, was generally required to utilize higher-elevation habitats-- the only biologically suitable places-- given its life-history timing. Spring-run fish needed to ascend to high enough elevations for over-summering in order to avoid the excessive summer and early-fall temperatures of the Valley floor and foothills-- at least to ~1,500 ft in the Sacramento drainage and most likely correspondingly higher in the more southerly San Joaquin drainage.[1] If they spawned in early fall, they needed to ascend even higher-- at least to ~2,500-3,000 ft in the Sacramento drainage-- to be within the temperature range (35-58°F) required for successful egg incubation. Spring-run fish which spawned later in the season did not have to ascend quite so high because ambient temperatures would have started to drop as autumn progressed, but presumably there were constraints on how long the fish could delay spawning-- set by decreasing streamflows (before the fall rains began), ripening of the eggs, and the fish's deteriorating physical condition.

The spring run was originally most abundant in the San Joaquin system, ascending and occupying the high-elevation streams fed by snow-melt where they over-summered until the fall spawning season (Fry 1961). The heavy snow-pack of the southern Sierra Nevada was a crucial feature in providing sufficient spring and early-summer streamflows, which were the highest flows of the year (F. Fisher, unpubl. data). Their characteristic life-history timing and other adaptive features enabled spring-run salmon to utilize high spring-time flows to gain access to the upper stream reaches-- the demanding ascent facilitated by high fat reserves, undeveloped (and less weighty) gonads, and a generally smaller body size. The more rain-driven Sacramento system was generally less suitable for the spring run due to lesser

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[1] We use English units of measurements for distances and elevations in this paper for ease of comparison with information quoted from earlier published work. Some locations are given "river miles" (rm)-- the distance from the mouth of the stream under discussion to the point of interest.

amounts of snow melt and proportionately lower flows during the spring and early summer, but the spring run nonetheless was widely distributed and abundant in that system (Campbell and Moyle 1991). Some notable populations in the Sacramento drainage occurred in Cascades streams where coldwater springs provided adequate summer flows (e.g., Upper Sacramento and McCloud rivers, Mill Creek). These coldwater springs emanated from the porous lava formations around Mount Shasta and Mount Lassen and were ultimately derived from snow melt from around those peaks, and also from glacial melt on Mount Shasta.

The winter run-- unique to the Central Valley (Healey 1991)-- originally existed in the upper Sacramento River system (Little Sacramento, Pit, McCloud and Fall rivers) and in nearby Battle Creek (Fisher, unpubl. data); there is no evidence that winter runs naturally occurred in any of the other major drainages prior to the era of watershed development for hydroelectric and irrigation projects. Like the spring run, the winter run typically ascended far up the drainages to the headwaters (CFC 1890). All streams in which populations of winter-run chinook salmon were known to exist were fed by cool, constant springs that provided the flows and low temperatures required for spawning, incubation and rearing during the summer season (Slater 1963)-- when most streams typically had low flows and elevated temperatures. The unusual life-history timing of the winter run, requiring cold summer flows, would argue against such a run occurring in other than the upper Sacramento system and Battle Creek, seemingly the only areas where summer flow requirements were met. A similar constraint may apply to some extent to the late-fall run, of which the juveniles remain in freshwater at least over the summer and therefore require cold-water flows (Vogel and Marine 1991, Fisher 1994)-- whether from springs or from late snow-melt. The late-fall run probably spawned originally in the mainstem Sacramento River and major tributary reaches now blocked by Shasta Dam and perhaps in the upper mainstem reaches of other Sacramento Valley streams (Fisher 1994) such as the American River (Clark 1929). There are indications that a late-fall run possibly occurred also in the San Joaquin River, upstream of its major tributaries at the southern end of that drainage (Hatton and Clark 1942, Fisher 1994).

DISTRIBUTIONAL SURVEY: GENERAL BACKGROUND AND METHODS

As summarized by Clark (1929), makeshift barriers were built across Sierra Nevada streams as early as the Gold Rush period when mining activities significantly impacted salmon populations in a number of ways-- e.g., by stream diversions, blockages, and filling of streambeds with debris. Hydropower projects appeared in the 1890s and early 1900s, although most of the large irrigation and power dams were constructed after 1910 (Fisher, unpubl. data). The early hydropower dams of the early 1900s were numerous, however, and collectively they eliminated the major portion of spawning and holding habitat for spring-run salmon well before the completion of the major dams in later decades.

The early distributional limits of salmon populations within the Sierra Nevada and some Cascades drainages are poorly known, if at all, because of the paucity of accurate scientific or historical records pre-dating the heavy exploitation of populations and the destruction or degradation of stream habitats. It was not until the late 1920s and later that reliable scientific surveys of salmon distributions in Central Valley drainages were conducted. Reports by Clark (1929) and Hatton (1940) give information on the accessibility of various streams to salmon, and they identify the human-made barriers present at those times. They also give limited qualitative information on salmon abundance. These reports provide a valuable "mid-term" view of what salmon distributions were like in the first half of the century, after major environmental alterations had occurred and populations were significantly depleted compared to earlier times, but the survival of the populations was not yet imperiled to the extent it presently is. Fry (1961) provided the earliest comprehensive synopsis of chinook stock abundances in Central Valley streams, covering the period 1940-1959. Quantitative data were given by Fry (1961) for both spring and fall runs, but the fall-run estimates also included the winter and late-fall runs for the streams where those other runs occurred. Since then, fairly regular surveys of spawning runs in the various streams have been carried out by the California Department of Fish and Game and periodically summarized in the Department's "Administrative Reports".

In the following section we attempt to synthesize this earlier information with that available from more recent sources, with the aim of providing comprehensive descriptions for the major salmon-supporting streams of the Central Valley. For each of the major streams (excepting some tributaries in the upper Sacramento River system, for which little data exist) that are known to have had self-sustaining chinook salmon populations, we provide a narrative including their probable "original" distributions and later "mid-term" 1928-1940 distributions as indicated by published literature and unpublished documents.[2] The probable original distributions were determined by considering the presence of obvious natural barriers to upstream salmon migration together with historical information (e.g., accounts of gold miners and early settlers), and they apply to the salmon populations up to the period of intensive gold mining, ca. 1850-1890, when massive environmental degradation by hydraulic mining activities occurred. We also drew from ethnographic studies of Native American people. Much information on the material culture of the native peoples of California had been obtained by ethnographers during the early part of this century, who interviewed elder Native Americans from various groups. That information pertains to the life-experiences and traditions of the native informants during the period of their youth and early adulthood, and also to the mid-life periods of their parents and grandparents from whom they received information and instruction-- spanning essentially much of the middle and latter parts of the 19th century (e.g., Beals 1933, Aginsky 1943, Gayton 1948a). For the mid-term distributions, we relied heavily on the papers of Clark (1929) and Hatton (1940) and retained much of their original wording to faithfully represent the situation they reported at those times. We also give more recent and current (1990s) salmon spawning distributions based on government agency reports, published papers, and interviews with agency biologists.[3] The stream accounts are presented starting with the southernmost Sierra streams and proceeding northward. We also include accounts for several streams on the west side of the Sacramento Valley which are known to have had chinook salmon runs. They are representative of other small westside or upper Sacramento Valley streams that formerly sustained salmon stocks, if only periodically, but lost them because of extensive stream diversions and placement of man-made barriers.

We mention steelhead trout in several stream accounts, particularly where information on salmon is lacking. The intent is to show that certain stream reaches were accessible to at least steelhead and, hence, may have been reached also by chinook salmon-- particularly spring-run fish which typically migrated far upstream. However, the correspondence between the occurrence of steelhead and spring-run salmon in stream reaches was by no means complete. Steelhead aggressively ascend even fairly small tributary streams, in contrast to chinook salmon which generally utilize the mainstems and major forks of streams (Gerstung, pers. obs.). The migration timing of steelhead-- during the peak of the rainy season (January-March)-- aided their ascent into the small tributaries. Steelhead also are able to surmount somewhat higher waterfalls-- perhaps up to ~15 ft high-- while chinook salmon in California appear to be stopped by falls greater than 10-12 ft high (Gerstung, pers. obs.), depending on the abruptness of the drop. Furthermore, steelhead do not require as much gravel for spawning; e.g., steelhead formerly used westside streams in the upper Sacramento drainage (near Shasta Lake) that had small patches of gravel

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[2] Unpublished documents are listed separately, following the References section, as are persons cited for personal communication ("pers. comm.").

[3] Agency abbreviations are: California Department of Fish and Game (CDFG); California State Board of Fish Commissioners (CFC); United States Commission for Fish and Fisheries, or U.S. Fish Commission (USFC).

interspersed among boulder substrate, which salmon generally shunned (Gerstung, pers. obs.). Yet, in terms of ascending the main stream reaches, it may be reasonably assumed that where steelhead were, spring-run salmon often were not far behind. Using the advantage of high spring flows, the salmon could have surmounted obstacles and reached upstream areas not much lower than the upper limits attained by steelhead in some streams.

Non-game fishes such as hardhead (*Mylopharodon conocephalus*), Sacramento squawfish (*Ptychochelis grandis*) and Sacramento sucker (*Catostomus occidentalis*) also provide hints about salmon distribution. Those species are typical of Valley floor and low- to mid-elevation foothill streams (Moyle 1976), and their recorded presence in stream reaches which are not blocked by obvious natural barriers is a good indication that anadromous salmonids likewise were able to ascend at least as far, and possibly even further upstream. The presence of non-game native fish populations above obvious barriers in some streams indicates that at least some of the natural barriers were formed subsequent to the initial dispersal of those species into the upper drainages.

DISTRIBUTIONAL SYNOPSES OF SALMON STREAMS

Kings River (Fresno Co.) Chinook salmon are known to have occurred at least periodically in the Kings River, the southernmost Central Valley stream that supported salmon. The Kings River, in the past, flowed into the northeast part of Tulare Lake, and its waters occasionally ran into the San Joaquin River during wet periods when water levels became high enough in Tulare Lake to overflow and connect the two drainages (Carson 1852, Ferguson 1914). Streamflows would have been greatest during the spring snow-melt period, so it is most likely that the spring run was the predominant or, perhaps, the only run to occur there. The spring-run fish would have had to ascend to high enough elevations (probably > 1,500 ft) to avoid excessive summer water temperatures, going past the area presently covered by Pine Flat Reservoir. The mainstem above Pine Flat Reservoir is of low gradient (Gerstung, pers. obs.) and free of obstructions for some distance (P. Bartholomew, pers. comm.), so the salmon probably were able to ascend ~10-12 mi beyond the present upper extent of the reservoir. The upper range of the bulk of salmon migration in the Kings River probably was near the confluence of the North Fork (Woodhull and Dill 1942). There is an undocumented note of "a few salmon" having occurred much further upstream at Cedar Grove (28 mi above present-day Pine Flat Reservoir) "in the past-- before Pine Flat Dam was constructed" (CDFG unpubl. notes). However, it is not clear if salmon could have reached that far, due to the presence of extensive rapids below around the area of Boyden Cave (3,300 ft elev.) and below Cedar Grove. The North Fork Kings River is very steep shortly above its mouth, and salmon most likely did not enter it to any significant distance (P. Bartholomew, pers. comm.).

Native American groups had several fishing camps on the mainstem Kings River downstream of Mill Flat Creek, including one used by the Choinimni people (a subgroup of the Northern Foothills Yokuts) at the junction of Mill Creek (~2 mi below the present site of Pine Flat Dam). There, the "spring salmon run" was harvested and dried for later use (Gayton 1948b). Gayton (1946) wrote: "On the lower Kings River, the Choinimni (Y) [denoting Yokuts] and probably other tribes within the area of the spring salmon run (about May) held a simple riverside ritual at their principal fishing sites. The local chief ate the first salmon speared, after cooking it and praying to Salmon for a plentiful supply. Then others partook of a salmon feast, and the season, so to say, was officially open." The existence of a well-established salmon ritual among the native people would seem to indicate that salmon runs in the Kings River were not uncommon, even if they did not occur every year (e.g., in years of low precipitation). Drawing on testimony from one native informant, Gayton (1948a) also reported that salmon "were well known and greatly depended upon" by the Chunut people (a subgroup of Southern Valley Yokuts) who dwelt on the eastern shore of Tulare Lake-- essentially the downstream terminus of the Kings River. A second Chunut informant interviewed by Latta (1977) similarly attested to the presence of salmon, and evidently steelhead, in the Lake: "There were lots of fish in Tulare Lake. The one we liked best was *a-pis*, a bit [sic] lake trout. They were real big fish, as big as any salmon, and good meat. ... Sometimes the steelheads came in the lake too; so did the salmon. We called the steelheads *tah-wah-aht* and the salmon *ki-uh-khot*. We dried lots of fish. When it was dried and smoked, the salmon was the best." It is evident, therefore, that salmon entered Tulare Lake at least on occasion, where they were taken by Chunut fishers. The different tribes of Yokuts people around Tulare Lake and the lower Kings River each had territorial limits (Gayton 1948a, Latta 1977), and transgressions apparently were vigorously repulsed (e.g., Gayton 1948a, Cook 1960). Furthermore, there would have been little reason for the Chunut to have made special fishing excursions to areas away from Tulare Lake, given that the Lake contained an abundance and variety of high-quality fish resources (Gayton 1948a, Latta 1970). It, therefore, does not seem likely that the Chunut traveled out of their territory to the Kings River to obtain salmon, nor have we found any indication in the ethnographic literature that they did so.

Diversions from the Kings River and other streams for agricultural irrigation occurred from the early years of American settlement and farming in the San Joaquin Valley. The reduced streamflows undoubtedly diminished the frequency of salmon runs-- and perhaps extinguished them altogether-- for a period spanning the late-19th to early-20th centuries. The California Fish and Game Commission reported that after a channel was dredged out between the Kings and San Joaquin rivers ca. 1911, salmon began reappearing in the Kings River-- "a few" in the spring of 1911, a "very considerable run" in 1912 which ascended to Trimmer Springs (rm 125) near the upper end of present-day Pine Flat Reservoir, and another "very considerable run" in June 1914 (Ferguson 1914). Several small chinook salmon were caught by a CDFG biologist in the fall of 1942 near the town of Piedra on the mainstem Kings River (~2 mi downstream of the mouth of Mill Creek; W. Dill, pers. comm.); those fish were notable in that they were precociously mature males-- i.e., running milt (W. Dill, pers. comm.). A single ~5-inch chinook salmon (with "very enlarged testes") was later captured in September 1946 in the mainstem "about 8 miles above the junction of the North Fork Kings River (W. Dill- CDFG letter). Moyle (1970) later collected juvenile chinook salmon (~4 in total length) in April 1970 from Mill Creek, shortly above its mouth. Salmon that spawned in Mill Creek likely ascended the stream at least several miles to the vicinity of Wonder Valley (P. Bartholomew, pers. comm.). Salmon runs in the Kings River were observed to occur more frequently after the construction of the Kings River Bypass in 1927, with "especially noticeable runs" in 1927, 1938 and 1940 (Woodhull and Dill 1942).

The Kings River salmon run was probably bolstered by, or perhaps even periodically reestablished from, the San Joaquin River population, particularly after series of dry years during which the run would have progressively diminished. The termination of natural streamflows down the channel of the San Joaquin River since 1946, except during exceptionally wet years, resulted in the extirpation of salmon runs in both the Kings and upper San Joaquin rivers.

San Joaquin River (Fresno Co.) Spring and fall runs of salmon formerly existed in the upper San Joaquin River, and there may also have been a late-fall run present, but all salmon runs in the San Joaquin River above the confluence of the Merced River were extirpated by the late-1940s. The spring run historically ascended the river past the present site of Kerckhoff Power House in the Sierra foothills to spawning grounds in the higher reaches (CDFG 1921). A natural barrier shortly upstream of the mouth of Willow Creek, near present-day Redinger Lake, may have posed an obstruction to salmon (E. Vestal, pers. comm.). However, there is some evidence that salmon traveled further upstream to a point just below Mammoth Pool Reservoir (~3,300 ft elevation), where habitat suitable for spring-run salmon exists. The oral history of present-day Native American residents in the region includes references to salmon occurring there (P. Bartholomew, pers. comm. based on interviews with Native American informants). Suckers presently occur in the stream up to the location of a velocity barrier ~0.25-0.5 mi below

Mammoth Pool Dam, suggesting that salmon likewise could have made the ascent to that point (P. Bartholomew, pers. comm.). Based on the absence of natural barriers, it is likely that salmon entered two tributaries of the upper San Joaquin River near Millerton Reservoir-- Fine Gold Creek, possibly "as far upstream [~6 mi] as opposite Hildreth Mtn", and Cottonwood Creek, which they probably ascended as least 2 mi (E. Vestal, CDFG unpubl. notes and pers. comm.).

Native Americans belonging to Northern Foothill Yokuts groups, including the Chukchansi people from Coarse Gold Creek and the Fresno River, fished for salmon in the San Joaquin River near the area of Friant (Gayton 1948b). According to Gayton's (1948b) ethnographic account, the salmon were watched for "When the Pleiades were on the western horizon at dusk", and a first salmon ritual was held by several different Yokuts tribes when the first salmon of the season was caught. Large quantities of salmon were dried for storage: "They were put in a sack [skin?] and packed home with a tumpline. A man carried about two hundred pounds of fish" (Gayton 1948b). The areas further up the San Joaquin drainage, above the Yokuts, were occupied by Monache (Western Mono) groups. Gifford (1932) stated that the "Northfork Mono", who lived on the "North Fork" San Joaquin River (also called Northfork Creek or Willow Creek), Whiskey Creek and nearby areas, fished for and ate salmon as well as trout. The Northfork Mono also were said to have held first salmon rites (Aginsky 1943). However, it is not clear how far up Willow Creek salmon ascended.

The construction and operation of Kerckhoff Dam (ca. 1920) for power generation blocked the spring-run salmon from their spawning areas upstream and seasonally dried up ~14 mi of stream, below the dam, where there were pools in which the fish would have held over the summer (CDFG 1921). Later in the decade, Clark (1929) reported that the salmon spawning beds were located in the stretch between the mouth of Fine Gold Creek and Kerckhoff Dam and in the small tributary streams within that area, covering a stream length of ~36 mi; a few scattered beds also occurred below the town of Friant. At the time of Clark's (1929) writing, there were four dams on this river that impeded the upstream migration of salmon: the "Delta weir" (in a slough on the west side of the river, 14 mi southest of Los Banos); Stevenson's weir (on the main river east of Delta weir); Mendota weir (1.5 mi from the town of Mendota); and the impassable Kerckhoff Dam, 35 mi above Friant. The first three were irrigation diversion projects. Friant Dam had not yet been constructed. In addition to the barriers themselves, reduced streamflows due to irrigation diversions impeded and disoriented uncounted numbers of migrating salmon which went astray in the dead-end drainage canals on the Valley floor, where they abortively spawned in the mud (Clark 1930).

Hatton (1940) considered the upper San Joaquin River in 1939 to possess the "most suitable spawning beds of any stream in the San Joaquin system", and "even in the dry year of 1939, most of the suitable areas were adequately covered with water and the water level was satisfactorily constant." Hatton reported that the spawning beds in the San Joaquin River were located along the 26 mi from Lane's Bridge up to the Kerckhoff Power House, all of which were accessible, and the "best and most frequently used areas" were between Lane's Bridge and Friant. The stream above Friant, where it entered a canyon was generally unsuitable, comprising mainly bedrock, "long, deep pools" and "short stretches of turbulent water". He also estimated that the planned Friant Dam would cut off 16 mi of stream where spawning occurred, which represented ~36 percent of the spawning beds with a spawner capacity of 7,416 salmon. At that time (1939), Hatton considered the spawning beds below Friant Dam to be "so underpopulated that even after the completion of the dam more than adequate areas will still be available, if water flows are adequate". The expected negative impact of Friant Dam was not so much the elmination of spawning areas above the dam as the diversion of water from the stream channel downstream. Quoting Hatton (1940), it was "hoped that seepage from the dam and returned irrigation water will provide sufficient flow to make spawning possible". It would seem that the deleterious consequences of vestigial streamflows and polluted irrigation drainage on salmon were not yet fully appreciated at that time.

Hatton (1940) stated that the San Joaquin River where spawning occurred was "singularly free of obstructions and diversions", but there were obstructions further downstream. The lowermost barrier below the spawning beds was the Sack Dam of the Poso Irrigation District, "several miles below Firebaugh" (near Mendota), which in an average water year "destroys any possibility of a fall run up the San Joaquin" because its "compete diverson of water leaves the stream bed practically dry between that point and the mouth of the Merced River" (Hatton 1940). The sand bags constituting this dam were left in place until they were washed out by the winter floods. The only other obstruction below the spawning beds was the Mendota Weir, which was equipped with a "satisfactory fishway"; however, there were eight unscreened diversions above the dam which Hatton viewed as "a serious menace to the downstream migrants".

The numbers of salmon that at one time existed in the San Joaquin River were, by some accounts, tremendous. Clark (1929) stated that "Fifty or sixty years ago, the salmon in the San Joaquin were very numerous and came in great hordes." Indeed, it is recorded that ca. 1870 the residents of Millerton on the banks of the San Joaquin, were kept awake "by the 'myriads of salmon to be heard nightly splashing over the sand bars in the river'" (California State Historical Association 1929), the noise being "comparable to a large waterfall" (Northern California Historical Records Survey Project 1940). The site of Millerton presently lies covered by Millerton Reservoir. In reference to the fall run (and evidently steelhead), one early observer in correspondence with State Fish Commissioner B.B. Redding wrote: "...in the fall the salmon and salmon-trout find their way up here in large quantities. Last fall I helped to spear quite a number, as that is about the only way of fishing in this part of the county; but below the San Joaquin bridge I understand they were trapped in a wire corral by ranchers and fed to hogs; they were so plentiful" (USFC 1876b). The former spring run of the San Joaquin River has been described as "one of the largest chinook salmon runs anywhere on the Pacific Coast" and numbering "possibly in the range of 200,000-500,000 spawners annually" (CDFG 1990). Blake (1857) noted in reference to salmon in the vicinity of Fort Miller (just upstream of Millerton) in 1853: "It is probable, however, that they are not abundant, as the mining operations along the upper part of the stream and its tributaries sometimes load the water with impurities." While Blake's conjecture regarding the salmon evidently was not accurate at the time, it foreshadowed events to come. Although Clark (1929) reported that a "very good run" of salmon was seen at Mendota in 1916-1917 and a "fairly good" one for 1920, "very few" fish were seen in 1928 and Clark considered the salmon in the San Joaquin River to be "fast decreasing". By then there was essentially only a spring run, the water being too low later in the year to support a fall run (Clark 1929). The decline of the salmon resource was, of course, noted by the river inhabitants. Particularly affected were Native Americans who depended upon the runs for sustenance. In the words of a Yokuts man named Pahmit (William Wilson) in 1933: "Long time 'go lots salmon in San Joaquin River. My people-- maybe 2-3 thousand come *Coo-you-illik* catch salmon-- catch more salmon can haul in hundred freight wagons. Dry 'em-- carry 'em home." [Since 1909] "no salmon in river. White man make dam at old Indian rancheria *Kăh-wăh-chu*-- stop fish-- now Indian got no fish. Go river-- water there, but no fish. White man got no fish. White man got no money. Injun got no fish-- Injun got no money--*everybody* broke. That's bad businesss." (Frank Latta unpubl. papers, field notes). Coo-you-illik ("Sulphur Water") was a Dumna Yokuts village at the later site of Fort Miller (Latta 1977). The salmon were well-remembered by non-Native Americans also: "The salmon fishing in the San Joaquin River was out of this world. It was one of the finest spawning rivers for salmon. ...There were hundreds and hundreds. ...The salmon looked like silver torpedoes coming up the river " (Anthony Imperatice interview, 11 February 1988; in Rose 1992).

In spite of the general decline of salmon in the upper San Joaquin River due to increasingly inhospitable environmental conditions, particularly for the fall run, both the spring run and the fall run managed to persist. Hatton (1940) reported that the fall run occurred in "some years", "making a hazardous and circuitous journey" through natural sloughs and irrigation canals, from near the mouth of the Merced River and "miraculously" entering the San Joaquin River again above Mendota weir. By

1942, the upper San Joaquin River was stated by Clark (1943) to have had "a fair-sized spring run of king [chinook] salmon for many years" and a fall run that had "been greatly reduced". In addition to those two runs, there were indications that a late-fall run formerly may have existed in the San Joaquin River (Van Cleve 1945). In 1941, a run apparently of appreciable size entered the river, starting about December 1 and continuing through at least December 10 (Hatton and Clark 1942). The authors concluded that "a run of several thousand fish may enter the upper San Joaquin River during the winter months, in addition to the spring run during March, April and May" (Hatton and Clark 1942). This December run has been viewed as a possible late-fall run (Fisher 1994) because peak migration of late-fall-run fish characteristically occurs in December, at least in the Sacramento River system. A more likely alternative, however, is that the migration observed by Hatton and Clark was simply the fall run, having been delayed by unfavorable conditions that evidently typified the river in the early fall months. Clark (1943) in fact stated that a "late-fall run of salmon occurs after this sand dam [the Sack Dam near Firebaugh] is washed or taken out in late November", clearly indicating that the fall run was usually blocked from ascending past that point any earlier. Furthermore, spawning of Central Valley fall-run stocks tend to occur progressively later in the season in the more southerly located streams (Fisher, unpubl. data), and the spawning migration period is known to include December in the San Joaquin basin tributaries (Hatton and Clark 1942, T. Ford, pers. comm.). Yet, an actual late-fall run may have existed in earlier times in the San Joaquin River. Historical environmental conditions in the mainstem reach of the San Joaquin River just above the Valley floor may have been suitable for supporting late-fall-run fish, which require cool-water flows during the summer juvenile-rearing period. Writing of the San Joaquin River near Fort Miller in late July, 1853, Blake (1857) noted: "The river was not at its highest stage at the time of our visit; but a large body of water was flowing in the channel, and it was evident that a considerable quantity of snow remained in the mountains at the sources of the river. A diurnal rise and fall of the water was constantly observed, and is, without doubt, produced by the melting of the snow during the day. The water was remarkably pure and clear, and very cold; its temperature seldom rising above 64°Fahrenheit while that of the air varied from 99° to 104° in the shade."

Fry (1961) reported that during the 1940s prior to the construction of Friant Dam, the San Joaquin River had "an excellent spring run and a small fall run". At that time the San Joaquin River spring run was considered probably "the most important" one in the Central Valley (Fry 1961), amounting to 30,000 or more fish in three years of that decade, with a high of 56,000 in 1945 (Fry 1961) and an annual value of "almost one million dollars" (Hallock and Van Woert 1959). In 1946, the sport catch in the San Joaquin Valley included an estimated 25,000 salmon produced by the upper San Joaquin River, with perhaps another 1,000 taken by the ocean sport fishery (CDFG 1955 unpubl. document). In addition, the commercial harvest, averaged for the period 1946-1952, accounted for another 714,000 pounds of salmon that originated from the San Joaquin River (CDFG 1955 unpubl. document). The last substantial run (> 1,900 fish) occurred in 1948 (Warner 1991). The salmon runs were extirpated from the upper San Joaquin drainage, above the confluence with the Merced River, as a direct result of the completion of Friant Dam (320 ft high) in 1942 and associated water distribution canals (viz., Madera and Friant-Kern canals) by 1949 (Skinner 1958). The dam itself cut off at least a third of the former spawning areas, but more importantly, the Friant Project essentially eliminated river flows below the dam, causing the ~60-mi stretch of river below Sack Dam to completely dry up (Skinner 1958, Hallock and Van Woert 1959, Fry 1961). While not attributing the collapse of the Sacramento-San Joaquin spring salmon fishery soley to Friant Dam, Skinner (1958) noted the "striking coincidence" that in the 1916-1949 (pre-Friant) period, the spring-run catch averaged 664,979 lbs (31% of the total Sacramento-San Joaquin commercial catch) and in 1950-1957 (post-Friant) it averaged 67,677 lbs (6% of the total catch)-- a 90% reduction in absolute poundage. Skinner (1958) further chronicled the telling correlation between events in the development of the Friant Project, their effects on year-classes of fish, and the rapid deflation of the spring in-river fishery-- the latter falling from a high catch of 2,290,000 lbs in 1946 to a low of 14,900 lbs in 1953. Efforts by CDFG biologists to preserve the last cohorts of the upper San Joaquin spring-run salmon in 1948, 1949 and 1950-- thwarted by insufficient streamflows and excessive poaching-- ended in failure (Warner 1991). Since the closure of Friant Dam, highly polluted irrigation drainage during much of the year has comprised essentially all of the water flowing down the course of the San Joaquin River along the Valley floor until it is joined by the first major tributary, the Merced River (San Joaquin Valley Drainage Program 1990). In only very wet years in recent times have salmon occasionally been able to ascend to the upper San Joaquin River, the latest record being that of a single 30-in male (possibly spring-run) caught by an angler on July 1, 1969 below Friant Dam (Moyle 1970).

The San Joaquin River salmon runs were the most southerly, regularly occurring large populations of chinook salmon in North America, and they possibly were distinctly adapted to the demanding environmental regime of the southern Central Valley. The California Fish Commission (CFC 1875, USFC 1876b) regarded the summertime migration of the fall run during the seasonally hot portion of the year as extraordinary: "Large numbers pass up the San Joaquin River for the purpose of spawning in July and August, swimming for one hundred and fifty miles through the hottest valley in the State, where the temperature of the air at noon is rarely less than eighty degrees, and often as high as one hundred and five degrees Fahrenheit, and where the average temperature of the river at the bottom is seventy-nine degrees and at the surface eighty degrees." The Commissioners noted that during August-September of 1875-1877, the average monthly water temperatures for the San Joaquin River where two bridges of the Central Pacific Railroad crossed (at 37°50'N, 121°22'W and 36°52'N, 119°54'W) were within 72.1-80.7°F (considering both surface and bottom water) and maximal temperatures were 82-84°F (CFC 1877). The high temperature tolerance of the San Joaquin River fall-run salmon inspired interest in introducing those salmon into the warm rivers of the eastern and southern United States (CFC 1875, 1877, USFC 1876a,b). Quoting the California Fish Commission (CFC 1875): "Their passage to their spawning grounds at this season of the year, at so high a temperature of both air and water, would indicate that they will thrive in all the rivers of the Southern States, whose waters take their rise in mountainous or hilly regions, and in a few years, without doubt, the San Joaquin Salmon will be transplanted to all of those States."

Perhaps it was this hardiness of the fall-run fish that enabled them to persist through years of depleted streamflows to make their occasional, "miraculous" sojourns up the San Joaquin drainage mentioned by Hatton (1940). Nothing is known of the physiological and genetic basis of the seemingly remarkable temperature tolerances of upper San Joaquin River fall-run salmon, because that population has been long extinct. It is not known to what degree the remaining fall-run populations in the other tributaries of the San Joaquin basin possess the temperature tolerances and genetic characteristics of the original upper San Joaquin River fall-run. Because of extreme fluctuations in year-to-year run sizes in recent times and the probable loss of genetic variation during population bottlenecks, it is likely that present-day fall-run salmon of the San Joaquin tributaries are genetically different from their forebears, or at least from the former upper San Joaquin River fall run. Similarly, the spring-run fish of the upper San Joaquin River perhaps also were physiologically and genetically distinctive due to their extreme southerly habitation. After completion of Friant Dam, spring-run fish began to utilize areas below the dam (Clark 1943). Approximately 5,000 spring-run fish were observed by Clark (1943) over-summering in pools below the dam during May-October 1942, where water temperatures had reached 72°F by July. The fish remained in "good condition" through the summer, and large numbers were observed spawning in riffles below the dam during October and November (Clark 1943). A temperature of 80°F has been regarded as the upper thermal limit for San Joaquin River spring-run fish, above which most of them would have died (CDFG 1955 unpubl. document), although much lower temperatures (40-60°F) are necessary for successful incubation of the relatively temperature-sensitive eggs (Seymour 1956, Beacham and Murray 1990).

Merced River (Merced Co.) Both spring- and fall-run salmon historically occurred in the Merced River, although now only the fall run exists and is the most southerly occurring native chinook salmon run (CDFG 1993). According to one gold miner's account, Native Americans were observed harvesting salmon in the spring of 1852 at Merced Falls, where their "rancheria" (village) was located (Collins 1949). Oral history obtained from local residents (Snyder unpubl. memorandum, 9 May 1993) indicates that salmon occurred in the area between Bagby and Briceburg near the branching of the North Fork. There is a 20-ft waterfall below Briceburg (Stanley and Holbek 1984), but it probably was not steep enough to have posed a substantial obstacle to salmon (see below). Another gold miner's journal (Perlot 1985) indicates that salmon were caught in abundance on the mainstem Merced River some unspecified distance above the confluence of the South Fork-- probably approaching the vicinity of El Portal (~2,000 ft elevation). The section of river above El Portal is of high gradient and would have presented a rigorous challenge to migrating fish; thus, it is not clear if substantial numbers of salmon, if any, were able to ascend beyond that point.

There has been disagreement on whether any salmon reached Yosemite Valley. Shebley (1927) stated that in 1892 "steelhead and salmon ascended the Merced River to Wawona [South Fork] and into Yosemite Valley [on the mainstem] as far as the rapids below the Vernal-Nevada Falls", taking advantage of the high spring floods to surmount the low dams that were present in the river at that time. However, Shebley provided no evidence to support his statement, which was later discounted (Snyder 1993 unpubl. memo.). The absence of any clear reference to salmon in the early historical accounts of the Yosemite Valley (e.g., Muir 1902, 1938, 1961, Hutchings 1990), and the present lack of archeological and ethnographic evidence to show that native peoples subsisted on salmon in the higher elevation parts of the drainage (Snyder 1993 unpubl. memo.), seem to argue against the past occurrence of salmon there, at least in significant numbers. Snyder (unpubl. 1993 memo.), noted that there are no references to salmon in the native folklore of the Yosemite region, nor to terms related to the procedures of salmon fishing as there are in the cultural milieu of native inhabitants of the lower elevations. The paucity of suitable spawning gravels in Yosemite Valley (Gerstung, pers. obs.) also would indicate that few, if any, salmon ascended that far, although the presence of "speckled trout" (=rainbow trout, *Oncorhynchus mykiss*) in Yosemite Valley was noted in some early accounts (Caton 1869, Lawrence 1884, Hutchings 1990). Yet, B.B. Redding of the California Fish Commission noted in 1875 that "A few years since, they [salmon] spawned near the Yosemite Valley. A dam built for mining purposes, some four or five years since, prevented them from reaching this spawning-ground" (USFC 1876b). It appears, therefore, that salmon at one time and in unknown numbers had approached the vicinity of Yosemite Valley, even if they did not enter the Valley proper. For the present, the area around El Portal may be the best estimate of the historical upstream limit of salmon distribution in the mainstem Merced River, unless supporting evidence for Shebley's (1927) statement can be found.

Salmon most likely entered the South Fork Merced River at least as far as Peach Tree Bar, ~7 mi above the confluence with the mainstem, where a waterfall presents the first significant obstruction (P. Bartholomew, pers. comm.). Hardheads are limited in their upstream distribution by the waterfall, and Sacramento suckers occur even further upstream to the vicinity of Wawona (Toffoli 1965, P. Bartholomew, pers. comm.). Salmon, which often spawn in the same reaches frequented by those species (Moyle 1976, Gerstung, pers. obs.), undoubtedly reached as least as far as Peach Tree Bar. It is possible that salmon surmounted the waterfall and ranged above Peach Tree Bar, but there is no confirmatory historical information available. If they did so, their upstream limit would have been a 20-ft waterfall located near the entry of Iron Creek, ~4 mi below Wawona (Gerstung, pers. obs.). The North Fork Merced River is a relatively low watershed (~1,300 ft elevation at the lower end), but there are substantial falls located ~1 mi above the mouth (T. Ford, pers. comm.; E. Vestal, CDFG unpubl. notes) which would have prevented further penetration into the drainage by salmon. This evidently was the cascade mentioned by the gold miner J.-N. Perlot which "had at all times been an insurmountable obstacle for the fish", thus accounting for his observations that the North Fork "contained no kind of fish whatsoever, not the least white-bait, not the smallest gudgeon" (Perlot 1985).

As early as 1853, a temporary dam was erected by fishermen ~10 mi below Merced Falls, thereby blocking the salmon from their upstream spawning areas (Collins 1949). In the following decades, a succession of dams was built at Merced Falls and at locations upstream up to the Yosemite National Park boundary-- including the 120-ft high Benton Mills Dam at Bagby (built in 1859) and a later (1900) dam at Kittredge, 4 mi below Bagby (Snyder 1993 unpubl. memo). Those dams had already impeded the upstream migration of salmon by the 1920s, but it was the construction of Exchequer Dam that permanently barred the salmon from their former spawning grounds (CDFG 1921). Clark (1929) stated that the existant spawning beds were on "occasional gravel bars" located between the river mouth and Exchequer Dam, with "about 12 miles" of streambed available. These are in the lower river and therefore pertain to fall-run fish. As of 1928, there were three obstructions to migrating salmon: Crocker Huffman irrigation diversion dam near Snelling; Merced Falls ~3 mi upriver, where there was a natural fall and the 20-ft Merced Falls Dam with a defunct fishway; and Exchequer Dam, 20 mi above Merced Falls. A decade later, Hatton (1940) considered the spawning areas to occur between "a point half a mile downstream from a line due south of Balico" and Exchequer Dam. Of this 42.2-mi stretch, only 24.1 mi was accessible to salmon due to obstructions; there were four beaver dams, passable under "usual water conditions", and four impassable rock dams lacking fishways and allowing only "seepage" to pass downstream. Above these rock dams was the Merced Falls Dam, equipped with a fishway but inaccessible to the salmon because of the downstream obstructions and low water flows. Presently (1995), natural spawning by fall-run fish principally occurs in the stretch above Highway 59 to the Crocker-Huffman diversion dam, the upstream limit of salmon migration (CDFG 1993). The Merced River Hatchery (operated by CDFG) is located by this dam. Fall-run spawners ascending to this point are captured at the dam's fish ladder, for use as hatchery brood stock, or are diverted into the adjacent artificial spawning channel where spawning can also occur.

Clark (1929) had reported both spring and fall runs of salmon present in the Merced River. He mentioned reports by early residents of the river who recalled great runs of migrating upriver to spawn in summer and fall, "so numerous that it looked as if one could walk across the stream on their backs". An early newspaper account (Mariposa Gazette, 26 August 1882) reported "... the water in the Merced river has become so hot that it has caused all the salmon to die. Tons upon tons of dead fish are daily drifting down the river, which is creating a terrible stench, and the like was never known before." Judging from the date, the reference was to spring-run salmon; the fall-run fish would not have entered the tributaries so early, assuming they behaved similarly to the Sacramento River fall run. By 1928, the runs were greatly depleted; several hundred fish were reported in the Merced River in November 1928. According to Clark (1929), very low flow conditions due to irrigation diversions during the spring, summer and early fall had "just about killed off the spring and summer runs" (the "summer" run now considered to be the early portion of the fall run), and only fish arriving in late fall after the rains were able to enter the river. These fish were probably a late-running component of the fall run, rather than a true late-fall run (sensu Fisher 1994) because there was no mention by Clark (1929) of early residents referring to salmon runs in December or later that would have been more characteristic of the late-fall run. Clark also refered to late fall as including November in his account for the Mokelumne River, which is a somewhat earlier run time than is characteristic of most late-fall-run fish. Even in recent years when drought conditions and extensive irrigation diversions had reduced streamflows to very low levels, the salmon did not spawn in the Merced River "until after the first week of November when water temperatures [had] become tolerable" (CDFG 1993).

Fry (1961) considered the Merced River to be "a marginal salmon stream" due to the removal of water by irrigation diversions, and he stated that there was "a poor fall run and poor spring run". Run-size estimates for the fall run were 4,000 fish for 1954 and <500 fish for every other year during the period 1953-1959 (Fry 1961). No numerical estimates were available for the spring run at that time. After 1970, fall-run sizes increased to an annual average of 5,800 fish, reaching 23,000 spawners in 1985, due to increased streamflows released by the Merced Irrigation District and operation of the Merced River Hatchery (CDFG 1993). As in other San Joaquin basin tributaries, spawning escapements in the Merced River have dropped to "seriously low levels" in recent years, numbering less than 200 fish in 1990 and 1991, including returns to the Merced River Hatchery (CDFG 1993, Fisher, unpubl. data). However, the fall run numbered over 1,000 spawners in both 1992 and 1993, and reached almost 5,000 fish in 1994 (Fisher, unpubl. data), perhaps auguring a partial recovery of the stock. The Merced River Hatchery, operated since 1971 by CDFG, has received a major fraction of the spawning run in the Merced River, accounting for 5-39% of the annual runs during the 1980s and 19-67% of the runs in 1990-1994 (Fisher, unpubl. data). Late-fall-run salmon are said to occur occasionally in the Merced River (CDFG 1993). The spring run of this river no longer exists.

Tuolumne River (Stanislaus, Tuolumne counties) At least spring and fall runs originally utilized the Tuolumne River. Clavey Falls (10-15 ft high), at the confluence of the Clavey River, may have obstructed the salmon at certain flows, but spring-run salmon in some numbers undoubtedly ascended the mainstem a considerable distance. The spring-run salmon were most likely stopped by the formidable Preston Falls at the boundary of Yosemite National Park (~50 mi upstream of present New Don Pedro Dam), which is the upstream limit of native fish distribution (CDFG unpubl. data). Sacramento suckers (*Catostomus occidentalis*), riffle sculpins (*Cottus gulosus*) and California roach (*Lavinia symmetricus*) were observed during stream surveys between Early Intake and Preston Falls (CDFG unpubl. data; Moyle, unpubl. data), and spring-run salmon probably occurred throughout that reach as well. If they were present in the Tuolumne drainage, steelhead trout probably ascended several miles into Cherry Creek, a tributary to the mainstem ~1 mi below Early Intake, and perhaps spring-run salmon also entered that stream. Steep sections of stream in the Clavey River and the South and Middle forks of the Tuolumne shortly above their mouths most likely obstructed the salmon (T. Ford, pers. comm.), although squawfish are found within the first mile of the Clavey River and suckers and roach occur up to 10-15 mi upstream (EA Engineering, Science and Technology 1990 unpubl. report). A large (25-30 ft) waterfall in the lower South Fork (Stanley and Holbek 1984) probably prevented further access up that fork. The North Fork, with a 12-ft waterfall ~1 mi above the mouth, likewise offered limited access. Overall, probably few, if any, salmon entered those upper reaches of the Tuolumne drainage (T. Ford, pers. comm.). The waterfalls just below present Hetch Hetchy Dam on the mainstem, ~10 mi above Preston Falls, evidently stopped all fish that might have ascended that far, for John Muir wrote that the river was barren of fish above the falls (Muir 1902). There are no indications that salmon ever reached Hetch Hetchy Valley or Poopenaut Valley further downstream (Snyder 1993 unpubl. memo.). Just as with the Merced River, there is no archeological or ethnographic evidence indicating that salmon were part of the subsistence economics of the native inhabitants of the higher elevations along the upper Tuolumne River (Snyder 1993 unpubl. memo.).

The first written record of salmon in the Tuolumne River is that of the Fremont Expedition of 1845-1846. Fremont's (1848) journal entry for 4 February 1846 reads: "...Salmon was first obtained on the 4th February in the To-wal-um-né river, which, according to the Indians, is the most southerly stream in the valley in which this fish is found." It is not clear whether Fremont's party caught the salmon or obtained them from the local native inhabitants. In any case, it would seem from the wording of the account that the fish were the beginning of a run (i.e., spring run) rather than the continuation of one which for some reason could not be procured earlier by the party. Although the bulk of the spring-run salmon migration occurs during April-June, at least in the Sacramento drainage (Fisher 1994), spring-run fish have occasionally appeared in their spawning streams in early February (e.g., in Butte Creek during 1995, F. Fisher, unpubl. data; they also were observed sometime in February 1946 in the

American River, Gerstung 1971 unpubl. report). The occurrence of salmon in the Tuolumne River in those early years was also noted by John Marsh, who had arrived in California in the mid-1830s. Quoting Marsh, the pioneer Edwin Bryant wrote in his journal, "... the river of the Towalomes; it is about the size of the Stanislaus, which it greatly resembles, ... and it particularly abounds with salmon" (Bryant 1849).

Significant blockage of salmon runs in the Tuolumne River began in the 1870s when various dams and irrigation diversion projects were constructed, although dams and water diversions associated with mining had been present as early as 1852 (Snyder 1993 unpubl. memo.) and undoubtedly had some impact. Wheaton Dam, built in 1871 at the site of present-day La Grange Dam, may have blocked the salmon to some degree (T. Ford, pers. comm.). La Grange Dam, 120 ft high and considered an engineering marvel when completed in 1894, cut off the former spring-run spawning areas. Mining and other activities that degraded the river habitat probably affected the salmon runs, but to an unknown degree. John Muir (1938) recorded in his journal in November, 1877: "Passed the mouth of the Tuolumne... It is not wide but has a rapid current. The waters are brown with mining mud. Above the confluence the San Joaquin is clear..."

Clark (1929) stated that the spawning grounds in 1928 extended from the town of Waterford to La Grange, over 20 mi of "good gravel river". At the time, there were two dams of major significance: La Grange Dam and Don Pedro Dam (built in 1923) 13 mi upriver, which was 300 ft high and formed a large irrigation reservoir (Clark 1929). Hatton (1940) later stated that the spawning beds in the Tuolumne River lay between a point 2.2 mi below the Waterford railroad bridge and the La Grange Power House. As of 1939, the Modesto Weir (a low structure) had no water diversion and was passable to salmon because the flash boards were removed "several weeks in advance of the fall run" (Hatton 1940). The rest of the Tuolumne River was clear of obstructions up to the impassable La Grange Dam. Spawning now (1995) occurs in the ~20-mi stretch from the town of Waterford (rm 31) upstream to La Grange Dam (EA Engineering, Science and Technology 1992). La Grange Dam remains a complete barrier to salmon and thus defines the present upstream limit of their spawning distribution (CDFG 1993). The total area of spawning gravel presently considered available to salmon in the lower Tuolumne River (below La Grange Dam) is 2.9 million sq ft (EA Engineering, Science and Technology 1992).

The California Fish Commission (CFC 1886) noted that the Tuolumne River "at one time was one of the best salmon streams in the State", but that salmon had not ascended that stream "for some years." At the time of Clark's (1929) writing, salmon generally still were "scarce" in the Tuolumne River. As of 1928, both spring and fall runs still occurred, but the spring run was inconsequential, "amounting almost to nothing" (Clark 1929). Clark reported, however, "a good run" (evidently the fall run) for 1925 that surpassed any of the runs seen in the several years prior to that. Presently, only the fall run exists in appreciable numbers in the Tuolumne River. In the past, fall-run sizes in the Tuolumne River during some years were larger than in any other Central Valley streams except for the mainstem Sacramento River, reaching as high as 122,000 spawners in 1940 and 130,000 in 1944 (Fry 1961). Tuolumne River fall-run fish historically have comprised up to 12% of the total fall-run spawning escapement for the Central Valley (CDFG 1993). The average population estimate for the period 1971-1988 was 8,700 spawners (EA Engineering, Science and Technology 1991), but run sizes in most recent years have been extremely low-- fewer than 130 spawners in each of the years 1990-1992 and <500 fish in both 1993 and 1994 (Fisher, unpubl. data).

It has been stated that "a small population" of late-fall-run fish exists in the Tuolumne River (CDFG 1993), but the existence of such a run appears to be based mainly on the occurrence of juveniles in the river during the summer and on observations of occasional spawning in later months (January-March) than is typical for fall-run fish (T. Ford, pers. comm.). However, hydrological conditions in the Tuolumne River during the past few decades have not been conducive to the maintenance of a late-fall run-- notably the lack of consistent, cool flows during the summer to support the juveniles (CDFG 1993).

It is possible that the infrequent observations of fish with late-fall-run timing characteristics have been strays from the Sacramento River system and their progeny. Late-emerging or slow-growing fry belonging to fall-run fish, perhaps of hatchery origin, could also account for some of the juveniles that have been observed over-summering in the river.

Stanislaus River (Stanislaus, Calaveras counties). Both spring and fall runs originally occurred in the Stanislaus River. Salmon are known to have occurred in the vicinity of Duck Bar, 4.5 mi below the town of Stanislaus, which is now covered by the upper end of New Melones Reservoir. A long-time Native American resident named Indian Walker caught them there in fish traps to sell to the white community (Cassidy et al. 1981). Beals' (1933) ethnographic account states that salmon went up the Stanislaus River as far as Baker's Bridge-- the location of which is unknown to us but very likely it was innundated by New Melones Reservoir. A more recent account (Maniery 1983) reports that Miwok residents of "Murphy's Rancheria", a village near the town of Murphy that was occupied ca. 1870-1920, caught salmon at Burns Ferry Bridge ("below the old road to Copperopolis") and at Camp Nine (~13 mi upstream of the town of Melones). Spring-run and perhaps some fall-run salmon probably went up the forks considerable distances because there are few natural obstacles (B. Loudermilk, pers. comm.). In the North Fork, suckers and hardhead occurred up to the confluence of Griswold Creek (Northern California Power Authority 1993 unpubl. report), so salmon may have ascended at least to that point. The North Fork Stanislaus River is accessible to salmon up to McKay's Point (~8 mi above the confluence with the Middle Fork), where the gradient steepens. Any salmon passing that point most likely were blocked 5 mi further upstream by a 15-ft waterfall, above Board's Crossing. Similarly, there are no substantial obstacles on the Middle Fork up to the reach above the present site of Beardsley Reservoir (3,400 ft elev.) (E. Vestal, pers. comm.), although the steep gradient may have deterred most salmon. The South Fork is a small drainage and is unlikely to have supported more than a few, if any, salmon because of the paucity of habitat. We have seen no suggestions of salmon having occurred in the South Fork Stanislaus River, and for the present we do not include it as a former salmon stream.

Damming and diversion of water on the Stanislaus River, for both mining and irrigation, began soon after the Gold Rush. The earliest "permanent" dam on the river was the original Tulloch Dam, constructed in 1858 just downstream of the present Tulloch Dam (Tudor-Goodenough Engineers 1959). The original Tulloch Dam was a relatively low structure and evidently had an opening at one end (Tudor-Goodenough Engineers 1959), and its impact on the salmon runs, therefore, may not necessarily have been significant. Clark (1929) stated that the salmon spawning beds were located in over 10 mi of stream, from the marshlands above Oakdale to Knight's Ferry. Dams on the river by that time included 20-ft Goodwin Dam (completed in 1913) 18 mi above Oakdale, which had a fishway and was at times negotiable to salmon, and the 210-ft, impassable Melones Dam (completed in 1926), above the town of Melones. The spawning beds in 1939 were reported by Hatton (1940) to extend from Riverbank Bridge to the Malone Power House, although of this 32.7-mi distance, the 9.3 mi between Goodwin Dam and the Power House was "only rarely accessible to salmon". Hatton stated that the fishway over Goodwin Dam was "seldom passable" and that the fluctuating water level caused by hydroelectric operations above Goodwin Dam and the "almost complete diversion of water at the dam" made it "very nearly an impassable barrier". Fry (1961) also mentioned the blockage of migration by Goodwin Dam, the operation of which also caused low and warm flows downstream during the summer and "violent" water fluctuations (due to power-generation releases) during the fall and winter. Presently, the salmon do not ascend the Stanislaus River further than Goodwin Dam, which regulates streamflows from Tulloch Reservoir and diverts water for irrigation and power generation (CDFG 1993). Much of the spawning occurs on the extensive gravel beds in the 23-mi stretch from Riverbank upstream to Knights Ferry, which are essentially on the Valley floor (T. Ford, pers. comm.). Upstream of Knights Ferry, where the river flows throgh a canyon, spawning is concentrated at Two-mile Bar (~1 mi above Knights Ferry) but also occurs in scattered pockets of gravel (T. Ford, pers. comm.).

The California Fish Commission (1886) state that while the Stanislaus River in the past had been among the best salmon streams in the state, only occasionally was a salmon seen "trying to get over one of its numerous dams." Much later, Clark (1929) reported that the Stanislaus River "has a good spring and fall run of salmon", but he also stated that their abundance was "about the same as in the Tuolumne" where he had described them to be "scarce". Given these contradictory statements, it is not clear how abundant, even qualitatively, the salmon were in the Stanislaus at the time of Clark's survey (late-1920s). Historically, the spring run was the primary salmon run in the Stanislaus River, but after the construction of dams which regulated the streamflows (i.e., Goodwin Dam and, later, Melones and Tulloch dams), the fall run became predominant (CDFG 1972 unpubl. report). Fry (1961) described the Stanislaus River as "a good fall run stream for its size" but it had "almost no remaining spring run". Run-size estimates were 4,000-35,000 and averaged ~11,100 fall-run fish for the 1946-1959 period preceeding the construction of Tulloch Dam (in 1959); in the following 12-year period (1960-1971), the average run size was ~6,000 fish (Fry 1961, CDFG 1972 unpubl. report). Fall-run sizes since 1970 have ranged up to 13,621 (average ~3,600) spawners annually (Fisher, unpubl. data). The Stanislaus River fall run historically has contributed up to 7% of the total salmon spawning escapement in the Central Valley (CDFG 1993). Numbers of fall-run spawners returning to the Stanislaus River in recent years have been very low-- <500 fish annually during the period 1990-1993 and 800 fish in 1994 (Fisher, unpubl. data).

Presently (1995) there is essentially only the fall run, although small numbers of late-fall-run fish are said to occur (CDFG 1993). A lesser run in the winter (most likely late-fall run fish) reportedly occurred in the Stanislaus River in earlier times (CDFG 1972 unpubl. report). One gold miner's account mentions a salmon, "which must have weighed twenty-five pounds", caught in the Stanislaus River during December 1849 (the exact date unknown, but suggested to have been just after December 19) (Morgan 1970)-- a run time consistent with the peak migration period of the late-fall run, but also with the end of the fall run (Fisher 1994). As in the Tuolumne River, the occurrence of late-fall-run salmon in recent years could be due to strays moving in from the Sacramento River system.

Calaveras River (Calaveras Co.) The Calaveras River is a relatively small, low elevation drainage that receives runoff mainly from rainfall during November-April (CDFG 1993). This river was probably always marginal for salmon, and it lacks suitable habitat for spring-run fish (E. Gerstung, pers. obs.). Chinook salmon runs were known to have occurred on an "irregular basis" (CDFG 1993), although Clark (1929) reported that the Calaveras River was "dry most of the summer and fall" and so had no salmon. There was until recently an unusual salmon run in winter which spawned in late-winter and spring, but it is unknown if that run existed before the dams were built on the river. The presence of this "winter run" was documented for 6 years in the period 1972-1984 and it numbered 100-1,000 fish annually (CDFG 1993). The fish ascended to New Hogan Dam, and they held and spawned in the reach just below the dam (T. Ford, pers. comm.). Management of streamflows by the U.S. Army Corps of Engineers entailed high-flow releases from New Hogan Dam interspersed with periods of very low flow, which undoubtedly contributed to the apparent demise of this run (T. Ford, pers. comm.). Bellota Dam, 15 mi below New Hogan Dam, and at least two other diversion dams are known to have blocked upstream salmon migration during periods of low streamflow (CDFG 1993). The run's extirpation may also have been hastened, if not guaranteed, by persistently low streamflows due to the 1987-1992 drought and to irrigation diversions. It may be that the existence of salmon in this river during recent decades has been mainly the result of suitable conditions created by the dams, and perhaps their natural historical occurrence there was limited to exceptionally wet years. Fall-run salmon-- perhaps those destined for other San Joaquin River tributaries-- occasionally enter the Calaveras River when suitable fall streamflows occur. For example, several hundred fall-run fish were observed during the fall of 1995 at Bellota Dam, where they were temporarily blocked (CDFG unpubl. data).

Mokelumne River (San Joaquin, Amador counties) The Mokelumne River, in its original state, apparently supported at least fall and spring salmon runs. Some evidence suggests that a late-fall run also occurred at one time. In what is probably the earliest record of salmon in the Mokelumne River, the fur trapper Jedediah Smith, having encamped on "Rock River" (Mokelumne River), wrote in his journal for 22 January 1828: "Several indians came to camp and I gave them some tobacco. They brought with them some fine salmon some of which would weigh 15 or 20 lbs. I bought three of them and one of the men killed a deer..." (Sullivan 1934). The salmon that would have been present during that part of January in "fine" condition most likely were late-fall run or perhaps spring-run, although the timing seems extraordinarily early for the latter. Smith's party evidently was on the lower Mokelumne River on the marshy Valley floor, for "...although the ground was rolling the horses sank at every step nearly to the nees [sic]" (Sullivan 1934). Two decades later, the 49ner Alfred Doten similarly recorded (for 22 December 1851): "Saw three fine salmon, which were brought from the Moqueleme-- they averaged about 20 lbs a piece" (Clark 1973). That date is consistent with the peak migration time of the late-fall run, and although late stragglers of the fall run cannot be completely discounted, it is somewhat more likely that late-fall run fish would have been present in a physical condition that could be described as "fine".

Salmon ascended the river at least as far as the vicinity of present-day Pardee Dam (completed in 1928). Reportedly, a large waterfall (30+ ft high) was present at Arkansas Ferry Crossing, 1 mi downstream of the Pardee Dam site in a narrow rocky gorge (R. Nuzum, pers. comm.), and it may have posed a serious, if not complete, barrier to the fall run. The site of the waterfall was inundated by Camanche Reservoir, and no natural obstructions presently exist between Camanche Reservoir and Pardee Dam (S. Boyd, pers. comm.). Spring-run salmon undoubtedly would have ascended past that point in order to reach higher elevations where water temperatures were suitable for over summering. Steelhead were believed to have spawned mostly in the reaches above Pardee Dam (Dunham 1961 unpubl.). Because there are no impassable falls between Pardee and the Electra powerhouse 12 mi upstream, spring-run salmon undoubtedly also reached the latter point. Bald Rock Falls (30 ft high), 7 mi beyond Electra, is a complete fish barrier (Woodhull 1946); native fish such as hardhead and squawfish are known to have reached it (Woodhull 1946), so the falls can be reasonably taken as a likely upstream limit for salmon and steelhead as well.

However much the salmon runs had recovered from the habitat degradation of the gold mining era, the runs were believed to have started another decline after Woodbridge Dam (15 ft high) was constructed in 1910 at the town of Woodbridge (Dunham 1961 unpubl. report). Fry (1961) cited Woodbridge Dam as having been "a serious fish block" for many years, as well as providing "often too little water for the passage of salmon", and he mentioned industrial and mining pollution as having been "very serious" at times. As of 1928 the salmon spawning grounds extended from the river mouth above tidewater for ~15 mi to above Woodbridge Dam (Clark 1929). There was a small fishway at this dam which had very little water flowing down it during summer and fall (Clark 1929). Clark reported that only a fall run occurred, "usually quite late". He stated that a "considerable run" migrated upriver each year, although not as large as in former years, and that the flashboards in Woodbridge Dam were taken out in late fall (November) to allow passage of the salmon. Although this is possibly an indication of a late-fall run, it seems more likely that the fish for the most part were a late-running fall run, delayed by the lack of water. The true late-fall run, as currently recognized (Fisher 1994), probably would not have been present in the Mokelumne River or other tributaries in significant numbers until December at the earliest. However, the earliest historical references to salmon (noted above) seem to indicate that late-fall run salmon actually occurred in the Mokelumne River at least until the mid-19th century.

The construction of Pardee Dam in 1928 presented an insurmountable obstacle, cutting off the upper spawning areas (Dunham 1961 unpubl. report). Hatton (1940) stated that spawning beds on the

Mokelumne River occurred in the 22.5 mi between Lockeford Bridge and Pardee Dam. At that time (1939), the irrigation dam at Woodbridge had a fishway but was impassable at times due to "fluctuating water levels", and Hatton was of the opinion that probably most of the migrating spawners did not ascend to the spawning beds until the dam's weir boards were removed, usually "around the first week in November".

Fall-run salmon are now stopped at the lower end of Camanche Reservoir, ~10 mi below Pardee Dam. They spawn in the reach from Camanche Dam downstream to Elliott Road (J. Nelson, pers. comm.), and 95% of the suitable spawning habitat is within 3.5 mi of Camanche Dam (CDFG 1993). Prior to the completion of Camanche Reservoir (1964), the fall run also spawned upstream from Camanche Dam up to the canyon ~3 mi below Pardee Dam (CDFG 1993). The Mokelumne River Hatchery, operated by CDFG, was built in 1965 as mitigation specifically for that spawning stock component (CDFG 1993; J. Nelson, pers. comm.).

Fry (1961) reported that counts of fall-run spawners passing Woodbridge Dam ranged from <500 (in two separate years) to 7,000 fish during the period 1945-1958, and there were partial counts of 12,000 fish each in 1941 and 1942. Fry also stated that the spring run appeared to be "practically extinct". Over the period 1940-1990, total annual run sizes ranged between 100-15,900 fish (CDFG 1993); the runs averaged 3,300 spawners during 1940-1963 (prior to impoundment of Camanche Reservoir) and 3,200 spawners during 1964-1990 (post-impoundment) (CDFG 1993). The most recent annual run-size estimates for the fall run have been 367-3,223 (average ~1,760) total spawners during 1990-1994, with hatchery returns composing 16-69% of the run; the number of natural spawners during this period ranged from 182 fish (in 1991) to 1,305 (in 1994) and averaged 756 fish (Fisher, unpubl. data).

Cosumnes River (El Dorado Co.) The Cosumnes River, a branch of the Mokelumne River, historically has been an intermittent stream and from earliest times offered limited access to salmon. Yet, the river derives its name from the Cosumne tribe of the Valley Yokuts-- the "People of the Salmon Place" in the language of the neighboring Miwok people (Latta 1977). Only a fall run is definitely known to have occurred in this river. There is no indication that a spring run ever existed here (J. Nelson, pers. comm.) and the atypical streamflow regime and low elevation of the drainage make it unlikely that there was one. There is a 30-ft falls a half mile below Latrobe Highway Bridge which has been viewed as a barrier, although the salmon probably did not usually reach that far upriver. If any fish were able to surmount that obstacle, they would have been stopped by a second waterfall (50 ft high) at the Highway 49 crossing 8.5 mi further upstream. Because of the limited time available for migration into this stream, it is likely that few fish ascended past Michigan bar (rm 31).

Clark (1929) reported the presence of "a considerable run" (fall run) which he stated to be equal in abundance to that in the Mokelumne River. At that time the spawning grounds extended from the river mouth above tidewater to the irrigation diversion dam near the town of Sloughhouse, which was a barrier to the salmon. In 1939, the spawning grounds on the Cosumnes River extended along the 15.2 mi stretch from Sloughhouse Bridge up to the falls below Latrobe Highway Bridge (Hatton 1940). Hatton (1940) reported that the best spawning areas were between the Sloughhouse and Bridgehouse bridges; just above Bridgehouse the river passed through a canyon where bedrock largely replaced the gravel beds. At that time (1939), the 18-ft high Bridgehouse Dam was the only permanent dam on the river, having two "apparently satisfactory fishways" but an unscreened diversion. The lower end of the stream was dry during the months when irrigation diversions were taken, but in late fall "a run of undetermined size" took place (Hatton 1940). The fall run presently spawns in the reach from downstream of the Highway 16 crossing (Bridgehouse Bridge) up to the falls below Latrobe Road (J. Nelson, pers. comm.). Additional spawning habitat occurs downstream of the Highway 16 crossing to Sloughhouse Bridge, but below that point the substrate is largely sand and unsuitable for spawning (Gerstung, per. obs.). The sole dam in the river-- Granlees Diversion Dam (located 1 mi upstream of the Highway 16 crossing)--

presently may pose an obstacle to salmon migration because its fish ladders are sometimes inoperative. The salmon generally cannot ascend the river until late-October to November, when adequate flows from rainfall occur (CDFG 1993).

Fry (1961) reported run-size estimates for the fall run of <500 to 5,000 fish for the period 1953-1959. Historically, the run size has averaged ~1,000 fish, but recent runs have numbered no more than 100 individuals (CDFG 1993), when there was water in the streambed. In many years there has been insufficient streamflow to maintain connection with the San Joaquin River. No salmon have been observed in the Cosumnes River for at least the last four spawning seasons (1991-1994) (Fisher, unpubl. data).

American River (Sacramento, Placer counties) Spring, fall and posssibly late-fall runs of salmon ascended the American River and its branches and were blocked to varying degrees by a number of natural obstacles, at least one which no longer exists. In the North Fork, steelhead trout were observed during CDFG surveys in the 1930s at Humbug Bar, above where the North Fork of the North Fork enters (CDFG unpubl. data); because there are no substantial falls below that point, spring-run salmon no doubt also easily ascended that far. Mumford Bar, ~7 mi above Humbug Bar, was one of several salmon fishing spots for the native Nisenan people, at which "salmon [were] taken with bare hands during heavy runs" (Beals 1933). If the salmon, like steelhead trout, were able to surmount the waterfall at Mumford Bar, they would have had clear passage ~4 mi further upstream to a 10-ft waterfall at Tadpole Creek (2,800 ft elevation), which is too steep for kayakers to boat over (Stanley and Holbek 1984). If salmon were able to jump that waterfall, their upper limit would have been another 7 mi upstream at the 60-ft falls at Royal Gorge (4,000 ft elev.), which likely was the uppermost barrier to steelhead (CDFG unpubl. data). That uppermost limit would accord with Beals' (1933) statement that salmon reportedly ranged above the elevational limit of permanent habitation (~4,000 ft) of the Nisenan people of the area. On the Middle Fork American River, falls that had existed before the gold-mining era at Murderer's Bar, ~3 mi above the confluence with the North Fork, obstructed the salmon at least to some degree (Angel 1882). During spawning time, the salmon "would accumulate so thickly in a large pool just below, that they were taken in great numbers by merely attaching large iron hooks to a pole, running it down in the water, and suddenly jerking it up through the mass". That scene was not exceptional, for the "Salmon at that time ran up all the streams as far as they could get until some perpendicular barrier which they could not leap prevented further progress", and "During these times, the Indians supplied themselves with fish, which they dried in the sun" (Angel 1882). It is likely that the dense aggregations of salmon harvested by the native people below the natural obstacles were fall-run fish, impeded by the low fall-season streamflows. The spring run, ascending during the spring flood flows, presumably would have been able to transcend some of those same obstacles. Spring-run salmon probably were able to ascend the Middle Fork a fair distance due to the absence of natural barriers above Murderer's Bar. In 1938, the spawning area for salmon was reported to extend up the Middle Fork to below the mouth of Volcano Creek (1,300 ft elev.) (Sumner and Smith 1940); salmon likely reached the confluence with the Rubicon River (1,640 ft elev.), which we presently take as the historical upstream limit. Steelhead were observed in the Rubicon River during the early CDFG surveys, but a 15-ft waterfall ~4-5 mi upstream from the mouth was a likely barrier to them and to any salmon that ascended that far.

In the South Fork American River, a major part of the salmon runs went at least as far as Salmon Falls, below which they concentrated; large numbers were harvested there by gold miners and Native Americans in 1850 and 1851 (CFC 1875). As recounted by Special Indian Agent E.A. Stevenson (31 December 1853 letter to Superintendant of Indian Affairs T.J. Henley; in Heizer 1993), "I saw them at Salmon Falls on the American river in the year 1851, and also the Indians taking barrels of these beautiful fish and drying them for winter." The site of Salmon Falls is now covered by Folsom Reservoir, and there has been disagreement on whether the 20-ft falls originally were a complete barrier

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APPENDIX D.
TIMING OF LIFE - HISTORY EVENTS FOR NATIVE FISH SPECIES IN THE SAN JOAQUIN RIVER. BASED ON MOYLE 2002

LIFE HISTORY STAGE	MONTH																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
ACIPENSERIDAE																								
WHITE STURGEON																								
Upstream migration	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒										▒	▒	▒	▒	▒
Spawning				▒	▒	▒	▒	▒	▒	▒	▒													
Downstream migration of adults				▒	▒	▒	▒	▒	▒	▒	▒	▒												
Hatching of larvae					▒	▒	▒	▒	▒	▒	▒	▒												
Juvenile outmigration	Not known																							
GREEN STURGEON																								
Upstream migration				▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒										
Spawning					▒	▒	▒	▓	▓	▓	▓	▒	▒	▒										
Downstream migration of adults						▒	▒	▒	▒	▒	▒	▒	▒	▒	▒									
Hatching of larvae						▒	▒	▒	▒	▒	▒	▒	▒	▒	▒									
Juvenile outmigration (end of second year)												▒	▒	▒	▒	▒	▒							
CATOSTOMIDAE																								
SACRAMENTO SUCKER																								
Migration within the watershed to spawning stream	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒														▒
Spawning			▒	▒	▓	▓	▓	▓	▒	▒	▒	▒												
Incubation and hatching				▒	▒	▒	▒	▒	▒	▒	▒	▒	▒											
Post larvae downstream migration						▒	▒	▒	▒	▒	▒	▒	▒	▒										
CENTRARCHIDAE																								
SACRAMENTO PERCH																								
Instream migration	No spawning migration																							
Spawning						▒	▒	▒	▒	▓	▓	▒	▒	▒	▒									
Incubation and emergence							▒	▒	▒	▒	▒	▒	▒	▒	▒	▒								
Planktonic larval stage							▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒							

LIFE HISTORY STAGE	**MONTH**																							
	Jan		**Feb**		**Mar**		**Apr**		**May**		**Jun**		**Jul**		**Aug**		**Sept**		**Oct**		**Nov**		**Dec**	
COTTIDAE																								
PRICKLY SCULPIN																								
Adult movement into freshwater and intertidal areas		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
Spawning			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
Larval planktonic stage present (3-5 weeks)				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨										
Juveniles moving upstreams or into shallow areas					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨									
RIFFLE SCULPIN																								
Adult instream migration	No spawning migration																							
Spawning				▨	▨	▨	▨	▨																
Incubation and emergence					▨	▨	▨	▨	▨	▨														
Larval stage	Guarded by male until yolk-sac is absorbed																							
Rearing or juveniles present	Assume benthic existence after absorbing yolk-sac																							
CYPRINIDAE																								
CALIFORNIA ROACH																								
Adult instream migration from pools into shallow areas					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨										
Spawning					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨										
Incubation and emergence					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨										
Larval stage	Not known																							
Rearing or juveniles present	Not known																							
HARDHEAD																								
Adult migration into tributaries						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨									
Spawning							■	■	■	■	■	■	▨	▨	▨	▨								
Incubation and emergence	Not known																							
Larval stage	Larval and post larval fish remain in dense cover of flooded vegetation or fallen tree branches																							
Rearing or juveniles present	Move into deeper habitat																							
HITCH																								
Adult instream migration						▨	▨	▨	▨	▨	▨	▨	▨	▨										
Spawning									▨	▨	▨	▨	▨	▨										

LIFE HISTORY STAGE	MONTH																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Incubation and emergence										░	░	░	░	░	░									
Larval stage in littoral areas										░	░	░	░	░	░	░	░	░	░					
Rearing or juveniles present	Move into open water at about 50 mm total length																							
SACRAMENTO BLACKFISH																								
Adult instream migration	No spawning migration																							
Spawning									░	░	░	░	░	░										
Incubation and emergence	Not known																							
Larval stage										░	░	░	░	░	░									
Rearing or juveniles present	Juveniles school in shallow water																							
SACRAMENTO PIKEMINNOW																								
Adult instream migration	░	░	░	░	▓	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Spawning							▓	▓	▓	▓	░	░	░											
Incubation and emergence							░	░	░	░	░	░	░	░										
Larval stage								░	░	░	░	░	░	░	░									
Rearing or juveniles present	Move into deeper water, in runs and riffles																							
SPECKLED DACE																								
Adult instream migration																								
Spawning											░	░	░	░										
Incubation and emergence												░	░	░	░									
Larval stage	Remain in shallow areas																							
Rearing or juveniles present	Not known																							
SPLITTAIL																								
Adult instream migration	░	░																				░	░	░
Spawning					░	▓	▓	░	░	░	░	░												
Incubation and emergence						░	░	░	░	░	░	░	░											
Larval stage moving into deeper water							░	░	░	░	░	░	░	░										
Juvenile downstream migration							░	░	░	░	░	░	░	░	░	░								
THICKTAIL CHUB																								

LIFE HISTORY STAGE	MONTH																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Adult instream migration	Unknown - Extinct																							
Spawning																								
Incubation																								
Larval stage																								
Rearing or juveniles present																								
EMBIOTOEIDAE																								
TULE PERCH																								
Adult instream migration	No spawning migration																							
Mating													▨	▨	▨	▨	▨	▨						
Fertilization	▨	▨																						
Birth of young											▨	▨	▨	▨										
Rearing or juveniles present	Not known																							
GASEROSTEIDAE																								
THREESPINE STICKLEBACK																								
Migration (if anadromous)					▨	▨	▨	▨	▨	▨	▨	▨												
Spawning							▨	▨	▨	▨	▨	▨	▨	▨										
Incubation and emergence								▨	▨	▨	▨	▨	▨	▨	▨									
Larval stage	Guarded by male																							
Rearing or juveniles present	Join adult fish																							
PETROMYZONTIDAE																								
KERN BROOK LAMPREY																								
Spawning					▨	▨	▨	▨																
Incubation and emergence	Not known																							
Larval stage	Not known																							
Rearing or juveniles present	Not known																							
Metamorphosis																			▨	▨	▨	▨		
PACIFIC LAMPREY																								
Adult migration	▨	▨	▨	▨	■	■	■	■	■	■	■	■	▨	▨										

LIFE HISTORY STAGE	MONTH																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Spawning							▨	▨	▨	▨	▨	▨												
Incubation and emergence								▨	▨	▨	▨	▨	▨											
Larval stage (washed downstream)								▨	▨	▨	▨	▨	▨	▨										
Rearing or juveniles present	Filter feed in mud or sand up to 7 years																							
Outmigration	▨	▨	▨	▨	▨	▨															▨	▨	▨	▨
Ocean time	Not known																							
RIVER LAMPREY																								
Adult migration																	▨	▨	▨	▨	▨	▨	▨	▨
Spawning			▨	▨	▨	▨	▨	▨	▨	▨														
Rearing or juveniles present	Remain in silty backwaters up to 5 years																							
Metamorphosis	▨	▨	▨	▨						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Outmigration						▨	▨	▨	▨	▨														
Ocean time	Up to 2 years																							
WESTERN BROOK LAMPREY																								
Adult migration	No spawning migration																							
Spawning					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								
Incubation	Not known																							
Metamorphosis																	▨	▨	▨	▨	▨	▨		
Rearing or juveniles present	Not known																							
SALMONIDAE																								
CHINOOK SALMON (FALL RUN)																								
Adult migration															▨	▨	▨	▨	▨	▨	▨	▨		
Spawning																			▨	▨	▨	▨	▨	▨
Incubation and hatching	▨	▨	▨	▨	▨	▨													▨	▨	▨	▨	▨	▨
Larval stage	▨	▨	▨	▨	▨	▨																		
Rearing or juveniles present							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration	▨	▨	■	■	▨	▨	▨	▨	▨	▨	▨	▨												
CHINOOK SALMON (SPRING RUN)																								

LIFE HISTORY STAGE	MONTH																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Adult migration					░	░	░	░	▓	▓	▓	▓	░	░	░	░	░	░	░					
Spawning																░	░	▓	▓	░	░			
Incubation and emergence	░	░	░	░	░	░										░	░	░	░	░	░	░	░	░
Larval stage	░	░	░	░	░	░	░	░	░													░	░	░
Rearing or juveniles present	░	░	░	░	░	░					░	░	░	░	░	░	░	░	░	░	░	░	░	░
Smolt outmigration							░	░	░	░	░	░	░	░										
STEELHEAD																								
Adult migration	░	░	░	░	░	░															░	░	░	░
Spawning	░	░	░	░	░	░	░	░																
Incubation and emergence	░	░	░	░	░	░	░	░	░	░	░	░												
Larval stage	Fry live in quiet waters before they move into deeper, faster flowing waters																							
Rearing or juveniles present					░	░	░	░	░	░	░	░	░	░										
Juvenile outmigration			░	░	░	░	░	░																

Probable span of life history activity	░
Peak of life history activity	▓