State Water Resources Control Board
California Environmental Protection Agency

DRAFT TECHNICAL REPORT ON THE SCIENTIFIC BASIS FOR ALTERNATIVE SAN JOAQUIN RIVER FLOW AND SOUTHERN DELTA SALINITY OBJECTIVES

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Acronyms and Abbreviations

D-1641	Decision 1641
1978 Delta Plan	1978 Sacramento-San Joaquin Delta and Suisun Marsh Water Quality Control Plan
AFRP	Anadromous Fish Restoration Program
AGR	Agricultural Supply
BAFF	Bio-Acoustic Fish Fence
Bay-Delta	San Francisco Bay/Sacramento-San Joaquin Delta Estuary including Suisun Marsh
Bay-Delta Plan or Plan	Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary
BDCP	Bay Delta Conservation Program
BDT	San Joaquin River at Brandt Bridge
CALSIM II	CALSIM II San Joaquin River Water Quality Module
CCR	California Code of Regulations
CDEC	California Date Exchange Center
CDRR	Combined Differential Recovery Rate
CRR	cohort return ratio
CVP	Central Valley Project
CWT	Coded Wire Tagged
Delta	Confluence of the Sacramento River and San Joaquin River (as defined in Water Code section 12220)
DFG	California Department of Fish and Game
DPS	Distinct Population Segment
dS/m	deciSiemens per meter
DSM2	Delta Simulation Model
DSOD	Division of Safety of Dams
DWR	California Department of Water Resources
EC	Electrical Conductivity
Eqn.	Equation
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FERC	Federal Energy Regulatory Commission
GLCB	Grant Line Canal Barrier
HOR	Head of Old River
HORB	Head of Old River Barrier
IRP	Independent Review Panel
maf	million acre feet
MCL	Maximum Contaminant Level
mgd	million gallons per day
µmho/cm	micromhos per centimeter
µS/cm	microSiemens per centimeter
mmhos/cm	millimhos per centimeter
MRB	Middle River Barrier
MUN	Municipal and Domestic Supply
Major SJR Tributaries	Merced, Tuolumne, and Stanislaus Rivers

NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NRDC	Natural Resource Defense Council
OLD	Old River at Tracy
OMR	Old and Middle River
ORTB	Old River Near Tracy Barrier
RM	River Mile
SDWSC	Stockton Deepwater Ship Channel
SED	Substitute Environmental Document
SJR	San Joaquin River
SJRRP	San Joaquin River Restoration Program
State Water Board	State Water Resources Control Board
SWP	State Water Project
taf	thousand acre feet
TBI	The Bay Institute
TNC	The Nature Conservancy
UF Report	California Central Valley Unimpaired Flow Data, Fourth Edition Draft
UNI	Old River at Union Island
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VAMP	Vernalis Adaptive Management Plan
VER	Vernalis
Vernalis	Location on San Joaquin River (USGS gage # 11303500 at Vernalis)
Working Paper	Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California
WSI	Total Water Supply Impact
WY	Water Year

1 Introduction

The State Water Resources Control Board (State Water Board or Board) is in the process of reviewing the objectives and program of implementation for San Joaquin River (SJR) flow and southern Delta salinity contained in the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan; Plan). In this quasi-legislative process, State Water Board staff will propose amendments to the SJR flow and southern Delta salinity objectives contained in the 2006 Bay-Delta Plan, and will comply with the California Environmental Quality Act including preparing a Substitute Environmental Document (SED). The proposed amendments will include revisions to these objectives for the reasonable protection of fish and wildlife, agriculture, and municipal and industrial beneficial uses, and a program of implementation. Any changes to water rights consistent with the revised program of implementation will be considered in a subsequent adjudicative proceeding.

The information and tools described in this report are intended to provide the Board with the scientific information and tools needed to establish SJR flow and southern Delta salinity objectives, and a program of implementation to achieve these objectives. A workshop will be held to determine whether: 1) this information and these tools are sufficient to inform the Board's decision-making to establish SJR flow and southern Delta salinity objectives and a program of implementation to achieve these objectives; and 2) the Board should consider additional information or tools to evaluate and establish SJR flow and southern Delta salinity objectives, and a program of implementation to achieve these objectives. Through this process, the Board will develop the tools it will then use to prepare the SED and revisions to the objectives.

This Draft Technical Appendix contains the scientific basis and modeling used for developing alternative SJR flow and southern Delta salinity objectives and will be an appendix of the SED that is currently being prepared for modifications to these objectives. It is organized to provide information related to SJR flows, southern Delta salinity, and supporting modeling including water supply impact analyses. The State Water Board will hold a public workshop to discuss the content of this report and to receive and discuss any other technical information relevant to the establishment of flow and salinity objectives, and a program of implementation to achieve these objectives. The State Water Board will also conduct an independent peer review of the Technical Appendix, and any revisions and additions to the appendix made subsequent to the public workshop.

Section two provides a hydrological analysis of current conditions and the altered hydrological regime in the project area. Section three provides the scientific basis for developing SJR flow objectives and a program of implementation to achieve these objectives. This section includes life history information and population trends for fall-run Chinook salmon and Central Valley Steelhead, and flow needs for the protection of fish and wildlife beneficial uses. Specific support for developing alternative San Joaquin River flow objectives focuses on the importance of the natural hydrograph to the aquatic ecosystem, and flows needed for juvenile fall-run Chinook salmon. Fish flow alternatives in this section represent the probable range of alternatives that will be further developed in the SED. Alternatives are expressed as percentages of unimpaired flow. The methodology for estimating additional flows needed to satisfy these flow alternatives is presented in the water supply impacts analyses section of Section five.

Section four provides the scientific basis for developing southern Delta salinity objectives and a program of implementation to achieve these objectives, including the factors and sources that affect salinity, and the effects of salinity on crops. Information is provided on tools that can be used to: estimate salinity in the southern Delta; quantify the contribution of salinity from National Pollutant Discharge Elimination System (NPDES) discharges; and model salinity effects on crop salt tolerance. The analyses of salinity effects uses modeled salinity estimates for the SJR at Airport Way Bridge near Vernalis gage (SJR at Vernalis) as described in the water supply impact analyses discussed below. Section four also describes the threshold levels for salinity impacts on the Municipal and Domestic Supply (MUN) beneficial use. Salinity correlations between monitoring stations in the southern Delta and the SJR near Vernalis are developed for use in the water supply impact analyses discussion in Section five, to estimate the flows needed to meet southern Delta salinity objectives.

Section five describes the tools and methods that will be used in the SED to analyze the effect of alternative flow and salinity objectives on water supplies in the SJR watershed. The data, methods and tools presented in this section are used to evaluate the water supply effects of the likely range of possible alternative SJR flow objectives and the water supply effects of fully implementing the existing southern Delta salinity objectives solely through releases of additional flows. Given that the science indicates that the existing southern Delta salinity objectives are fully protective of agricultural beneficial uses, evaluating full implementation of the existing objectives will test the adequacy of the tools to evaluate the lowest possible southern Delta salinity objectives and thus the worst case scenario from a water supply perspective.

For SJR flows, a range of alternatives was selected to demonstrate applicability of the data, methods, and tools to correctly analyze the effects of the alternatives across a wide range of alternatives. The range of alternatives discussed in this document includes 20, 40, and 60 percent of unimpaired SJR flows at Vernalis for the February through June time frame. These alternatives do not necessarily represent the alternatives that will be evaluated in the SED. Instead, these alternatives represent the likely range of alternatives that will be analyzed. This range of SJR flows and southern Delta salinity objectives will be further refined to develop alternatives for analysis in the SED. The potential environmental, economic, water supply, and related impacts of the various alternatives will then be analyzed and disclosed prior to any determination concerning changes to the existing objectives.

2 Hydrologic Analysis of San Joaquin River Basin

Construction of storage infrastructure (dams) and diversions have vastly altered the natural hydrology of the SJR and its major tributaries (McBain and Trush 2000; Kondolf et al. 2001; Cain et. al 2003). The purpose of this hydrologic analysis is to describe important flow characteristics and how they have been altered within the project area by comparing unimpaired flow to actual observed flow. Unimpaired flow, which will be defined more fully in Section 2.2.2, is roughly the flow that would occur if all water remained in a waterbody instead of being stored or diverted. This report focuses on the flow characteristics of the SJR at Vernalis, but also includes background information on its major tributaries: Stanislaus River, Tuolumne River, Merced River, and Upper SJR (above Friant Dam).

2.1 Basin Characteristics and Previous Studies

In the Sierras, as in other systems dependant on snow pack and snow melt, the typical components of the natural annual hydrograph generally include: fall storm flows, winter storm flows, spring snowmelt, and summer baseflows (McBain and Trush 2000; Kondolf et al. 2001; Stillwater Sciences 2002; Cain et al. 2003). These characteristics are present in all major SJR tributaries in nearly all years, with wide temporal variations in magnitude throughout the year and from year to year, as illustrated in Figure 2-1 and Figure 2-2 for a wet and critically dry water year respectively, for the Stanislaus River. Though flow magnitudes may be different, these hydrographs for wet and critically dry years are representative of hydrographs for the Merced, Tuolumne and Upper SJR.

The SJR mainstem is 330 miles long from its headwaters in the Sierra Nevada Mountains to its confluence with the Sacramento River and drains approximately 15,550 square miles of mountainous, valley, and agricultural lands to its confluence with the Sacramento River. The SJR near Vernalis (Vernalis), at River Mile (RM) 72, on the SJR, is the location where all non-floodplain flows from the SJR basin flow into the Delta. Vernalis is also upstream of tidal effects in the Delta. Table 2-1 summarizes the basin characteristics of the three major SJR tributaries and the SJR.

The Stanislaus River flows into the SJR just three miles upstream of Vernalis. The Stanislaus River is 161 miles long and drains approximately 1,195 square miles of mountainous and valley terrain from its headwaters in the Sierra Nevada Mountains to its confluence with the SJR. Approximately 66 miles of the Stanislaus River are downstream of the New Melones Dam, 59 miles of which are downstream of Goodwin Dam, the most downstream impediment to fish passage. There are 28 Division of Safety of Dams (DSOD) dams on the Stanislaus River (and twelve additional non-DSOD dams) with a total capacity of 2.85 maf.

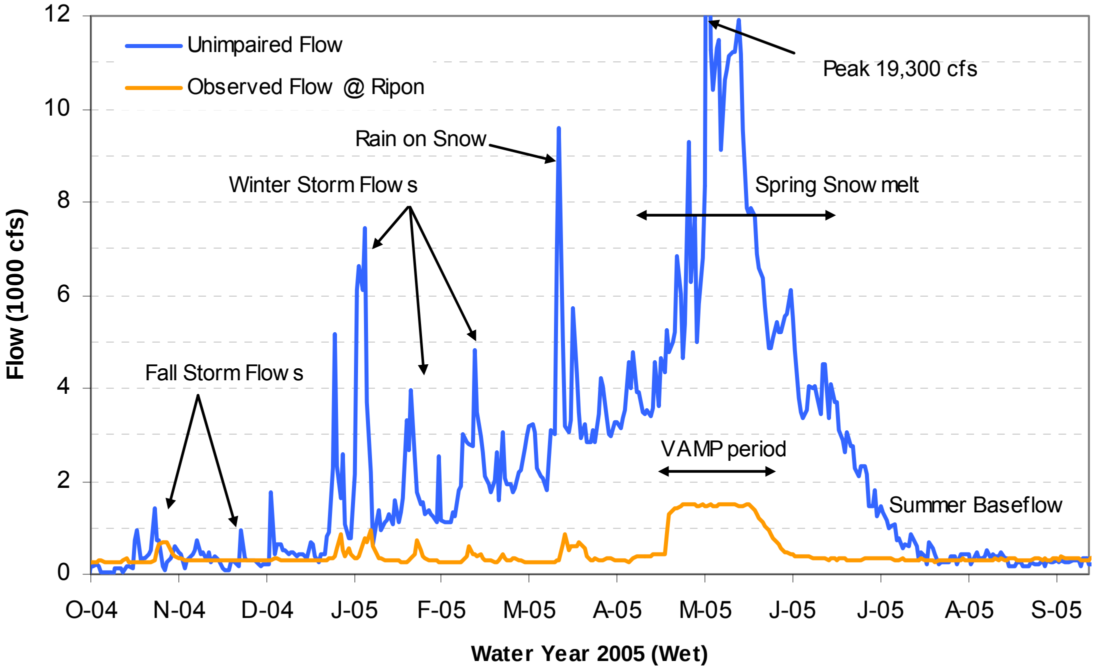

Figure 2-1. Typical Stanislaus River annual hydrograph of daily average unimpaired and observed flows during a Wet water year illustrating important hydrograph components

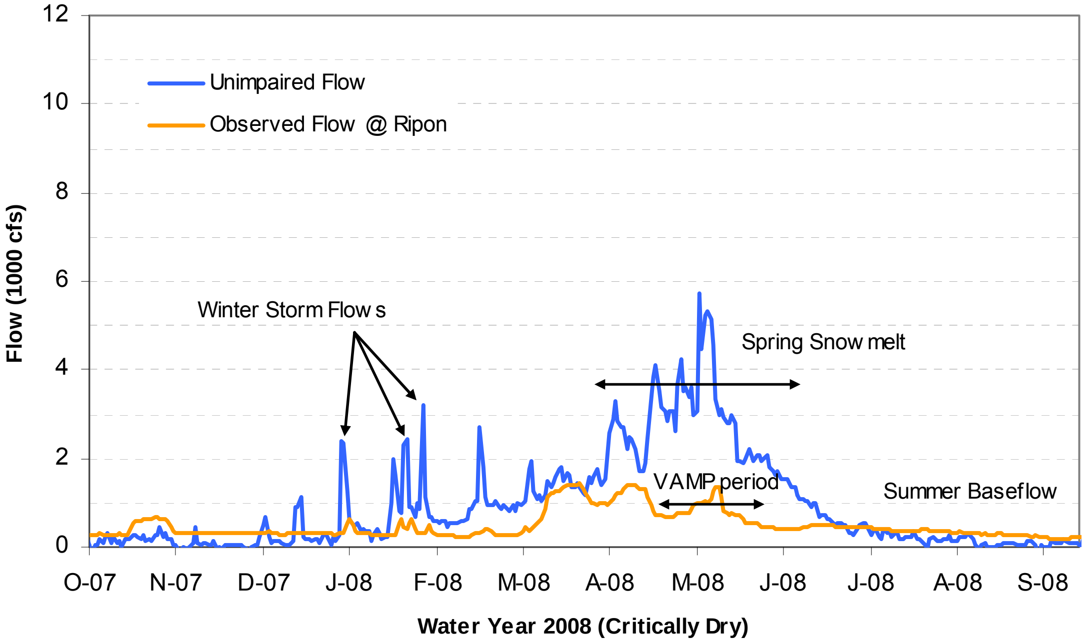

Figure 2-2. Typical Stanislaus River annual hydrograph of daily average unimpaired and observed flows during a Critically Dry water year illustrating important hydrograph components

Table 2-1. Summary of watershed and dam characteristics by San Joaquin River tributary

Characteristic	Stanislaus River	Tuolumne River	Merced River	Upper and Middle San Joaquin River
Median Annual Unimpaired Flow (1923-2008)	1.08 maf	1.72 maf	0.85 maf	1.44 maf (upstream of Friant)
Drainage Area of Tributary at confluence with San Joaquin (and percent of tributary upstream of unimpaired flow gage)[1]	1,195 square miles (82% upstream of Goodwin)	1,870 square miles (82% upstream of La Grange)	1,270 square miles (84% upstream of Merced Falls)	5,813 square miles (28% upstream of Friant)
River Length and Miles Downstream of Major Dam	161 mi New Melones: 62 mi Goodwin: 59 mi	155 mi New Don Pedro: 55 mi La Grange: 52 mi	135 mi New Exchequer: 63 mi Crocker Huffman: 52 mi	330 mi Friant: 266 mi
Confluence with SJR (river miles upstream of Sacramento River confluence)	RM 75	RM 83	RM 118	RM 118
Number of Dams[2]	28 DSOD dams (12 non DSOD)	27 DSOD dams	8 DSOD dams	19 DSOD dams
Total Dam Storage[2]	2.85 maf	2.94 maf	1.04 maf	1.15 maf
Most Downstream Dam (with year built and capacity)[3]	Goodwin, 59 miles upstream of SJR (1912, 500 ac-ft).	LaGrange, 52 miles upstream of SJR (1894, 500 ac-ft).	Crocker-Huffman, 52 miles upstream of SJR (1910, 200 ac-ft).	Friant, RM 260 miles upstream of SJR (1942, 520 taf)[4]
Major Dams (with year built, reservoir capacity, and dam that it replaced if applicable)[3]	New Melones (1978, 2.4 maf), replaced Old Melones (1926, 0.113 maf) ; Tulloch, Beardsley, Donnells "Tri-dams project" (1957-8, 203 taf); New Spicer Meadows (1988, 189 taf)	New Don Pedro (1970, 2.03 maf) replaced Old Don Pedro (1923, 290 taf); Hetch Hetchy (1923, 360 taf); Cherry Valley (1956, 273 taf)	New Exchequer (1967, 1.02 maf), replaced Exchequer (1926, 281 taf) ;McSwain (1966, 9.7 taf)	Friant (1942, 520 taf) ; Shaver Lake (1927, 135 taf); Thomas Edison Lake (1965; 125 taf) ;Mammoth Pool (1960, 123 taf)

Note: River Mile (RM) ind, Division of Safety of Dams (DSOD) dams are those > 50 ft in height and > 50 ac-ft, San Joaquin River (SJR).
Source: Adjusted from Cain et al. 2003; [1]NRCS Watershed Boundary Dataset (2009) . [2]Kondolf et. al. 1996 (adapted from Kondolf et al. 1991) as cited by Cain et al. 2003; [3]Cain et al. 2003; [4] No water through Gravelly Ford (RM 229) except during high runoff periods (SJRRP 2009).

The Tuolumne River flows into the SJR at river mile 83, approximately eight miles upstream of the Stanislaus River confluence. The Tuolumne River is 155 miles long and drains a 1,870 square mile watershed from its headwaters in the Sierra Nevada Mountains to its confluence with the SJR, approximately 10 miles west of the City of Modesto. Approximately 55 miles of the Tuolumne River are downstream of New Don Pedro Dam, 52 miles of which are downstream of La Grange Dam, the furthest downstream impediment to fish passage. There are 27 DSOD dams on the Tuolumne River with a total capacity of 2.94 maf.

The Merced River flows into the SJR at river mile 118, approximately 35 miles upstream of the Tuolumne River confluence. The Merced River is 135 miles long and drains a 1,270 square mile watershed. Approximately 63 miles of the Merced River are downstream of the New Exchequer Dam, 52 miles of which are downstream of Crocker Huffman Dam, the most downstream barrier to fish migration. There are 8 DSOD dams on the Merced River with a total capacity of 1.04 maf.

The major tributary upstream of the Merced River confluence, is the Upper SJR. It originates high in the Sierra Nevada Mountains at an elevation of roughly 13,000 feet. At the foot of the mountains, the Upper SJR is impounded by Friant Dam, forming Millerton Lake. The SJR watershed upstream of the Merced River confluence is approximately 5,800 square miles, with approximately 1,660 square miles upstream of Friant Dam. There are 19 DSOD dams in the SJR watershed upstream of the Merced River confluence with a total storage capacity of 1.15 maf.

Previous Studies

Previous studies of fish flow requirements and SJR hydrology have focused on floods and flow frequencies within the tributaries and provide less detail regarding annual, seasonal, and inter-annual trends (McBain and Trush 2000; Kondolf et al. 2001; Stillwater Sciences 2002; Cain et al. 2003, Brown and Bauer 2009). Previous studies also relied primarily on historical, daily time-step gage data rather than on daily unimpaired flow for each tributary because unimpaired flow data was not readily available for all tributaries. Using unimpaired flow allows for a more direct comparison with and assessment of the magnitude of alteration of flows relative to past conditions. Furthermore, previous studies did not relate the impacts of human alteration within the tributaries to flows at Vernalis.

Analyses by McBain and Trush and Brian Richter in the appendices to "*San Joaquin Basin Ecological Flow Analysis*" by Cain et al. (2003), are comprehensive hydrologic analyses of the hydrology of the SJR system focusing on the major SJR tributaries. These investigators used various approaches to analyze the hydrology of the SJR system including a Hydrograph Component Analysis and an analysis using Indicators of Hydrologic Alteration. McBain and Trush completed a Hydrograph Component Analysis on the major SJR tributaries (Cain et al. 2003) by taking the unimpaired flow, or "natural" flow hydrograph, and segregating various components (roughly seasonal) based on similar specific characteristics important to the natural ecosystem (Figure 2-1 and Figure 2-2). When unimpaired flow is not available, previous researchers have often separated the historical data into various periods that represent varying degrees of watershed modifications, such as the construction of dams and diversions. In some instances, the earlier gaged flow may represent natural flow; however, given that early settlement and diversions within the Central Valley began in the mid 19th Century, historical flows may not fully represent unimpaired flow. In their analyses using this approach, based on what data was available, McBain and Trush used unimpaired flow for the Tuolumne and the Upper SJR, and used observed flow from early periods representing less modified and/or pre-dam conditions for the Merced and Stanislaus Rivers (Cain et al. 2003).

The Nature Conservancy (TNC) developed the Indicators of Hydrologic Alteration software to calculate a set of metrics that evaluate magnitude, timing, and frequency of various events of interest to the researcher such as annual peak daily flow, 30-day peak flow, annual minimum flow, and 30-day minimum flow among several others (Richter et al. 1996, 1997; Cain et al. 2003, TNC 2005). Brian Richter conducted an Indicators of Hydrologic Alteration analysis for the SJR system (Cain et al. 2003). At the time of Richter's study, daily unimpaired data was only available for the Tuolumne River, thus the Indicators of Hydrologic Alteration used gage data from earlier periods to best represent pre-dam conditions in lieu of unimpaired data, and compared these to post-dam conditions.

Until recently, daily unimpaired flow was not available on all of the major SJR tributaries, thus some previous researchers have used flow gage data from periods prior to major changes in the watershed as a proxy for natural flows. This is often called pre-regulated flow or pre-dam flow, and generally represents flows that occurred prior to construction of a specific project or multiple projects within the water system. For example, pre-regulated flows could be the flows that existed prior to the construction of a hydroelectric or water supply dam. In most cases, pre-regulated flows do not fully represent unimpaired flow unless there was no development of water in the watershed for the period of time chosen by the researcher. Three potential differences or issues with using pre-regulated flow in place of unimpaired flow are: 1) each researcher may choose different periods of time to describe the alteration or pre-regulated period, 2) it is nearly impossible to get observed flows prior to all modifications, and 3) depending on the time period used, that time period may bias the results due to differences in climate, and/or decadal trends when comparing pre-regulated and present-day periods. Present-day flows are those following any project or projects built in the system, and are akin to observed or actual flows.

2.2 Hydrologic Analysis Methods

This report presents annual, inter-annual, and seasonal components of the unimpaired annual hydrograph and compares these to present-day conditions. Specifically, it focuses on changes in magnitude, duration, timing, and frequency of flows to assess what alterations have occurred. This analysis uses newly available information along with historical observed data from various United States Geological Survey (USGS) and California Department of Water Resources (DWR) gages, and extends portions of the analyses conducted by previous investigators.

Annual flow statistics and inter-annual trends are investigated using water year types and exceedance curves. The statistics are generated for SJR flows at Vernalis for two periods of time representing pre-regulated and present-day conditions. The break in the period (pre- versus post-) was selected based on the constructed volume of accumulated reservoir storage over time, separating early years with relatively little infrastructure from years following a steep rise in the total volume of storage on the various rivers. A percent chance of exceedance was assigned to each year using the

Weibull plotting positions (Viessman and Lewis 2003). This approach assigns an equal difference in percent chance exceedance per record.

To determine the extent of alteration of the unimpaired flow characteristics, the magnitude and frequency of actual fall and winter storm flows and the annual peak flow were compared to unimpaired storm flows by conducting an exceedance analysis and flood frequency analysis. Historical observed data was used because daily unimpaired flow data was not available for flows at Vernalis, thus, this analysis does not fully represent the magnitude how peak flow characteristics are altered. To quantify the alteration from natural conditions, the frequency analysis is compared to previously completed flood frequency analyses by USACE (2002). Actual spring snowmelt and summer baseflows are compared to unimpaired flow using monthly flow statistics.

2.2.1 Selection of Flow Data and Gages

This report used the most downstream USGS gage for each major SJR tributary and at Vernalis to characterize historical observed flows. The most downstream gage was selected in order to account for diversions within the tributaries (primarily within the Tuolumne and Merced Rivers) and capture as many return flows as possible prior to the most downstream gage on each tributary and upstream of Vernalis. In general, the selected flows represent flows originating within the river basin; however, there are some inter-basin transfers. For example, the Highline Canal transfers drainage and urban runoff from the Tuolumne River watershed to the Merced River through the High Line Spill. This report does not attempt to adjust for differences among river basins resulting from inter-basin transfers or return flows and other accretions from the valley floor entering downstream of the selected gages. A summary of gages used in this analysis is found in Table 2-2.

This report uses unimpaired flow at the rim dams for comparisons to the historical data from the aforementioned gages. Unimpaired flow at the rim dams is a good representation of unimpaired flow at the river mouths because precipitation in the San Joaquin Valley Floor area is substantially lower than in the Sierras, the majority of the basin and its water sources are upstream of each rim dam, and elevations are relatively flat and graded such that surface runoff is minimal or enters the SJR directly (Table 2-1). Furthermore, as described in more detail later, the “Valley Floor” unimpaired flow is taken into account at Vernalis. Daily and monthly unimpaired flow data are available for each tributary at each of the rim dams and is the best available direct comparison to the historical gage data at this time. Only monthly unimpaired flow data is currently available for application at Vernalis. To assess alterations to storm flows, daily unimpaired flow is needed.

2.2.2 Unimpaired Flow Sources and Calculation Procedures

Unimpaired flow, full natural flow, full natural runoff , natural flow, and pre-regulated flow are often used interchangeably to loosely describe runoff that would have occurred had flow remained unaltered in rivers and streams instead of stored in reservoirs, imported, exported, or diverted. In this case unimpaired flow (interchangeably used here as natural flow) is a modeled flow generally based on historical gage data with factors applied to primarily remove the effects of dams and diversion within the watersheds. Unimpaired flow differs from full natural flow in that the modeled unimpaired flow used here does not attempt to remove changes that have occurred such as channelization and levees, loss of floodplain and wetlands, and deforestation and urbanization. Where no alterations exist in the watershed, the historical gage data is often assumed to represent unimpaired flow. Observed or actual flow, in the context we apply it, is the flow that is actually observed within the river for locations where comparisons are made between recent observed flow and either unimpaired flow or pre-regulated flows.

Table 2-2. Streamflow and gage data used in hydrologic analysis and sources of data

Flow Data	River Location	Source/ Reporting Agency	Dates Available and Source
Vernalis Monthly Unimpaired Flow	Flow at Vernalis	DWR	1922 to 2003[2]; 2004 to Present[1]
Vernalis Daily Obs.	USGS #11303500 Vernalis	USGS	1923 to Present[3, 4]
Garwood Daily Obs.	USGS # 11304810	USGS	1995 to Present[3]
Stanislaus Monthly Unimpaired Flow	Inflow to New Melones	DWR	1922 to 2003[2] ; 2004 to Present[1]
Stanislaus Monthly Obs.	USGS #11303000 Ripon	USGS	1940 to 2009[3]; 2009 to Present[1]
Tuolumne Monthly Unimpaired Flow	Inflow to Don Pedro	DWR	1922 to 2003[2]; 2004 to Present[1]
Tuolumne Monthly Obs.	USGS #11290000 Modesto	USGS	1940 to Present[3]
Merced Monthly Unimpaired FLow	Inflow to Exchequer	DWR	1922 to 2003[2]: 2004 to Present[1]
Merced Monthly Obs.	USGS #11272500 Stevinson	USGS	1940 to 1995, 2001 to 2008[3]; 1995 to 1999, 2008 to Present[1]

[1] Source: CDEC Website: http://cdec.water.ca.gov/selectQuery.html (DWR 2010a)
[2] Source: DWR 2007a
[3] Source: USGS Website: http://wdr.water.usgs.gov/nwisgmap/ (USGS 2010)
[4] No data from October, 1924 - September, 1929.

DWR has authored several editions of compiled unimpaired flow data for the Central Valley; the latest edition is “California Central Valley Unimpaired Flow Data, Fourth Edition, Draft” (UF Report; DWR 2007a). The UF Report contains monthly estimates of the volume of unimpaired flow for all sub-basins within the Central Valley divided into 24 sub-basins, identified as sub-basins UF 1 through UF 24. The modeled estimates are a measure of the total water supply available for all uses after removing the impacts of most upstream alterations as they occurred over the years. Alterations such as channel improvements, levees, and flood bypasses are assumed to exist and are not factored out. In addition, unimpaired flows are generated assuming that the river channels of the valley are in their present configuration. This report uses monthly unimpaired flow at the major rim dams as reported in the DWR UF Report for analyses to represent each tributary and the flow at Vernalis:

- UF 16 - Stanislaus River at New Melones Reservoir;
- UF 18 - Tuolumne River at New Don Pedro Reservoir;
- UF 19 - Merced River at New Exchequer Reservoir;
- UF 22 – San Joaquin River at Millerton Reservoir
- UF 17, UF20, UF21, UF22, UF23 – summed to equal remainder of unimpaired flow from Upper and Middle SJR

- "San Joaquin Valley Unimpaired Total Outflow" less UF 24 – to represent unimpaired flow at Vernalis.

For the purposes of this report the "West Side Minor Streams"1, sub-basin 24 in the UF Report, was subtracted from the "San Joaquin Valley Outflow" as reported in the UF Report because this sub-basin enters downstream of Vernalis. Because the UF Report does not present unimpaired flows beyond 2003, monthly unimpaired flow data was downloaded from CDEC (sensor #65 "Full Natural Flow") for the Stanislaus, Tuolumne, Merced, and Upper SJR at Friant. To calculate flow at Vernalis for this period, these four tributaries were summed and assumed to be unimpaired flow. The individual sub-basins of the SJR (9 sub-basins identified in the UF Report) are calculated and published on a monthly timestep using similar calculation methods as described for the major SJR tributaries and are summed in the UF Report to estimate the "San Joaquin Valley Outflow". It is at this location, approximately Vernalis, that the San Joaquin Valley Floor sub-basin is taken into account, rather than within each major tributary. It is possible that some portion of the flow attributed to the Valley Floor enters the tributaries themselves rather than the mainstem SJR, however no attempt was made to distinguish between these two components.

Unimpaired flow calculations for sub-basins 16, 18, 19, and 22 are based on DWR Snow Survey records. The methods of calculation are consistent for each subbasin. Each begins with a flow gage downstream of the major rim dam and adjusts flow by adding or subtracting changes in storage within the major dams upstream, adding losses due to evaporation from the reservoir surfaces, and adding flow diverted upstream of the gage (Ejeta, M and Nemeth, S., personal communication, 2010).

Although the UF Report is used in our analyses, there are four components of flows that are not included or are not fully described in the calculations of unimpaired flow in the UF Report. These components would normally be included in naturally occurring flows in a completely unaltered system. First, it is likely that ground water accretions from the very large Central Valley floor were considerably higher under natural conditions; however, as stated by DWR, no historical data is available for its inclusion. Valley Floor unimpaired flow uses factors to estimate flows in minor streams that drain or discharge to the Valley Floor only and does not include groundwater accretions. Second, historical consumptive use of wetland and riparian vegetation in wetlands and channels of the un-altered Central Valley could be significantly higher than current consumptive use but values are difficult to estimate. Third, during periods of high flow, Central Valley Rivers under natural conditions would overflow their banks thus contributing to interactions between groundwater and consumptive use, however, the current UF Report does not attempt to quantify these relationships. Fourth, the outflow from the Tulare Lake basin under natural conditions is difficult to estimate, and the unimpaired flow reported for this sub-basin are only those observed from a USGS gage at Fresno Slough. It is uncertain to what degree these flows represent the natural condition.

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1 "West Side Minor Streams" does not include all west side streams, only those draining directly to the Delta. Other west side streams are included in the "San Joaquin Valley Floor" which is UF 17 in the UF Report (DWR 2007; personal communication, Ejeta and Nemeth 2010)

The following is a summary of cited unimpaired flow data sources used in this analysis:

- DWR 2007a – Central Valley (monthly for three tributaries and SJR total)
- CDEC (as operated by each agency) – daily and monthly unimpaired flow data for tributaries (available from website, DWR 2010a)

The California Data Exchange Center (CDEC) publishes real time average daily estimates of unimpaired flow just downstream of the major rim dams gathered from other sources for the Stanislaus River at New Melones Dam, the Tuolumne River at New Don Pedro, the Merced River at New Exchequer, and Upper San Joaquin River at Friant Dam.

2.3 Hydrology of San Joaquin River at Vernalis

The current hydrology of the SJR is highly managed through the operations of dams, and diversions.

The natural hydrologic variability in the SJR system has been severely reduced and altered over multiple spatial and temporal scales. Alterations to the natural flow regime include a reduced annual discharge, reduced frequency and less intense late fall and winter storm flows, reduced spring and early summer snowmelt flows, and a general decline in hydrologic variability (McBain and Trush 2002, Cain et al. 2003, Brown and Bauer 2009, NMFS 2009a, this report).

2.3.1 Annual Flow Delivery and Inter-Annual Trends

Figure 2-3 displays the annual difference between unimpaired flow and observed flow in the SJR at Vernalis from 1930 to 2008, the overlapping range of historical gage data and unimpaired flow data. Before 1955 the cumulative storage of reservoirs in the SJR basin was only 2 maf or less. Over the next 24 years the cumulative storage in the Basin increased to just under 8 million acre-feet by 1978. New Exchequer on the Merced River and New Don Pedro on the Tuolumne River added 750 taf and 1.7 maf of storage in 1967 and 1970, respectively. New Melones on the Stanislaus River added 2.34 maf of storage in 1978. Prior to 1955 there was little variation in the difference between unimpaired flow and observed flow; actual flows were generally between 1.5 and 3 maf lower than unimpaired flows. After 1955 and again after 1970, the annual difference in volume became larger and more variable from year to year, attributable mostly to large increases in the volume of water storage within the basin. Some of this change in variability, however, may also be attributable to changes in climate from year to year and decadal trends.

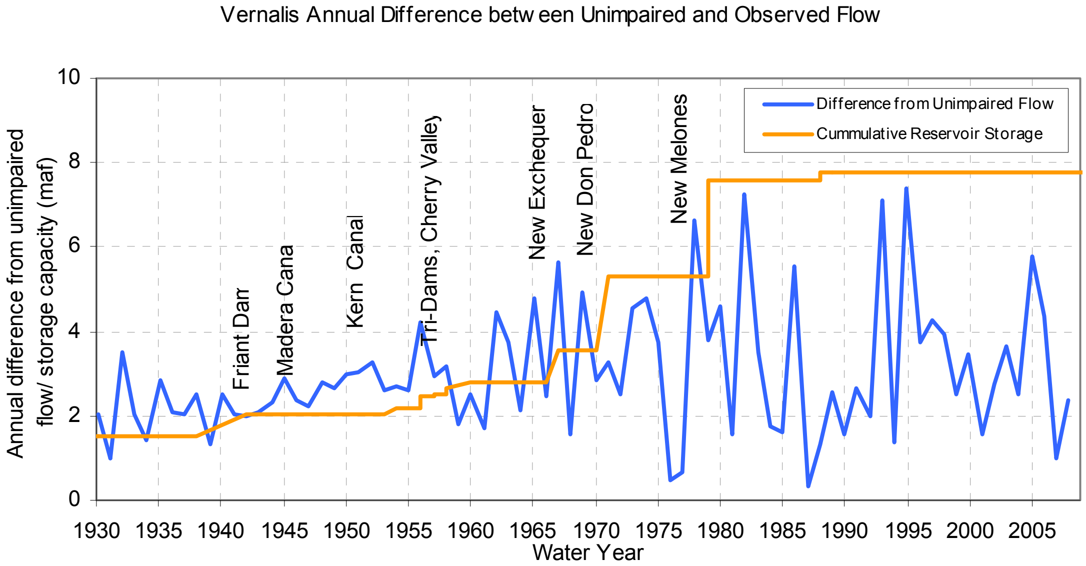


Figure 2-3. Observed flow subtracted from unimpaired flow in the SJR at Vernalis and cumulative reservoir storage capacity within the SJR river basin upstream of Vernalis

The median annual unimpaired flow in the SJR at Vernalis from water year 1930 through 2008 was 5.9 maf. In contrast, the median annual actual flow was 1.9 maf, or 32 percent of the median annual unimpaired flow. This median annual reduction in flow relative to unimpaired flow is attributable to exports of water outside the basin and consumptive use of water in the basin. As shown in Table 2-3, the reduction in flow relative to unimpaired flow for individual years tends to be greatest in below normal to critically dry years because relatively more water is stored than released, and consumptively used in such years.

The greatest volumetric reduction of annual flow has generally occurred during Wet years, and most significantly in the first year or years following a drought. WY 1995 experienced the greatest reduction from unimpaired flow on record when 7.4 maf was stored or diverted in the major SJR tributaries, ultimately reducing actual flow to 18 percent of unimpaired flow. Examples of this effect can be seen in Figure 2-4 in 1978, 1993, 1995, and again in 2005 (among others), which show large diversions to storage during wet years that follow years of drought.

The years leading up to high storage wet years were a series of dry years forming drought conditions from 1987 to 1993 and again from 2000 to 2004, during which the quantity of water stored in the major reservoirs within the major SJR tributaries (New Melones, New Don Pedro, and Lake McClure) was greatly reduced. In contrast, during the second and third wet year following a drought, 1996 to 1997 and again in 2006, less of the unimpaired flow is stored resulting in higher percentage of flow released downstream and less difference between observed and unimpaired flow than during the preceding wet years.

Table 2-3. Actual and unimpaired annual flow statistics and percent of unimpaired flow (1930 to 2008) in the San Joaquin River at Vernalis

	Number of Occurrences	Unimpaired Flow	Actual	Volume Reduction	Actual Flow as a Percent of Unimpaired Flow
	# Years (year)	(taf)	(taf)	(taf)	(%)
Average of All Years	79	6,300	3,280	2,980[1]	48%
Median of All Years[2]	79	5,890	1,850	2,630[3]	44%[3]
Wettest of Years	(1983)	18,940	15,410	3,530	81%
Average of Wet Years	25	10,590	6,210	4,380[1]	57%
Average of AN Years	14	6,840	3,840	2,990[1]	56%
Average of BN Years	11	4,610	1,620	2,990[1]	35%
Average of Dry Years	13	3,460	1,440	2,020[1]	42%
Average of Critical Years	16	2,570	1,010	1,560[1]	41%
Driest of Years	(1977)	1060	420	640	40%
Greatest % Difference	(1960)	3,050	550	2,500	18%
Greatest Volumetric Difference	(1995)	13,680	6,300	7,380	18%

[1] Difference is the average of annual differences, not the difference of average annual flow.

[2] Median is not aligned with flow from a specific year.

[3] Difference is the median of annual differences, not the difference of median annual flow.

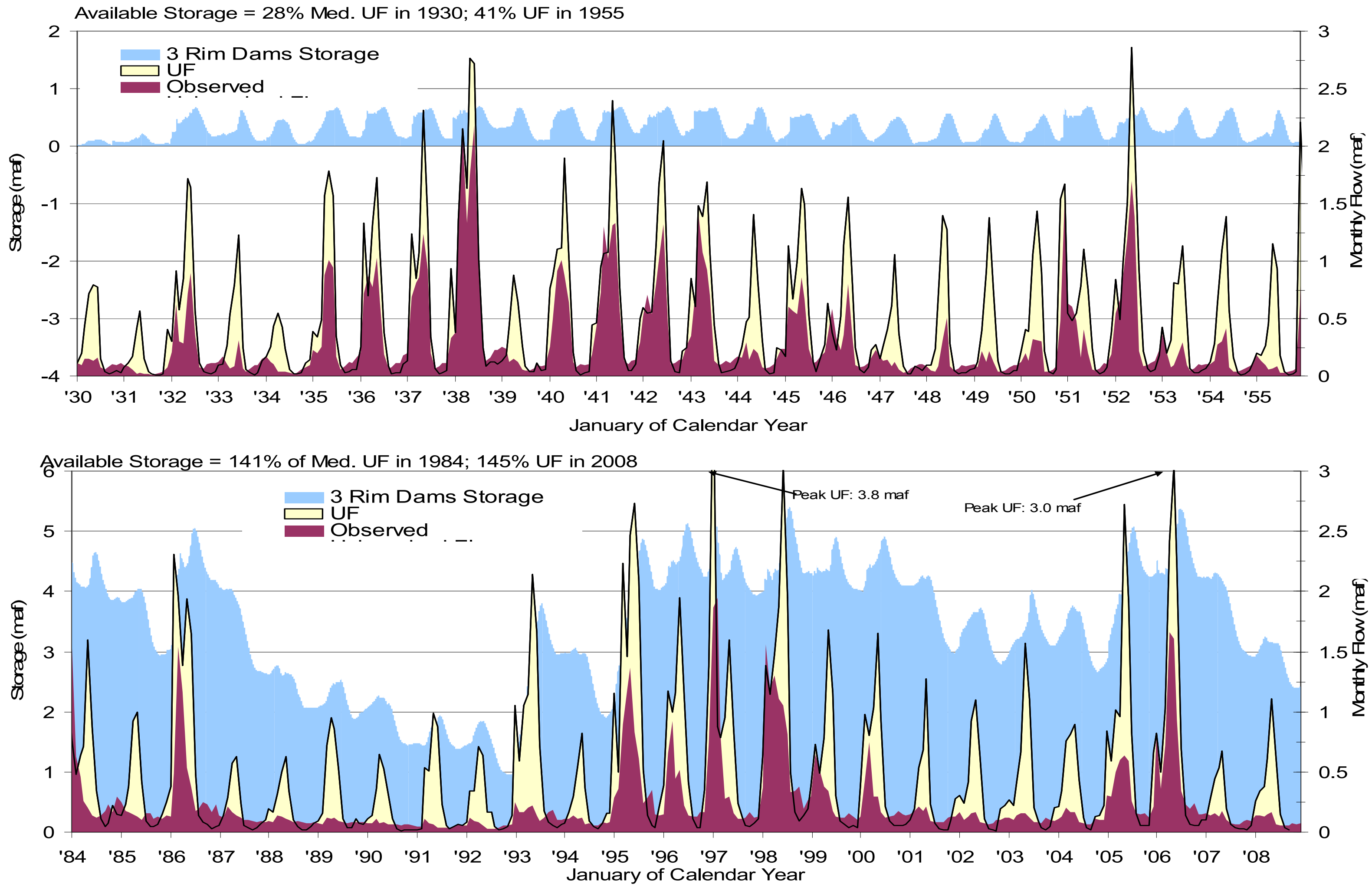


Figure 2-4. Monthly unimpaired and observed flow in the San Joaquin River at Vernalis and storage within the three major dams (excluding Friant) for two periods in time (1930 to 1955 and 1984 to 2008)

2.3.2 Annual Differences for Equal Periods and Between Periods

To help distinguish between flow changes that have occurred as a result of changes in water storage facilities and management from changes in hydrology, the hydrologic patterns for two time periods are presented: 1930 to 1955 which shows the time before major water storage projects on the Merced, Tuolumne and Stanislaus Rivers, and 1984 through 2009 which shows the time after completion and filling of major water storage projects on these tributaries; New Melones Reservoir was filled during two wet years—1982 and 1983. Table 2-4 provides summary statistics for these two time periods: a pre-regulated condition, and a present-day condition, which demonstrates that they had similar but not identical hydrological conditions. Average annual unimpaired flow for the pre-regulated and present-day periods were 5.9 maf and 6.1 maf respectively. Median annual unimpaired flow for the pre-regulated and present-day periods were 5.4 maf and 4.16 maf respectively, showing that the present-day period was skewed towards lower flows, with more critically dry years and less above normal and below normal years.

Table 2-4. Unimpaired and actual flow statistics by water year type for 1930 to 1955 and 1984 to 2008

	# Years (year) 1930-1955	# Years (year) 1984-2008	Unimpaired Flow 1930-1955 (taf)	Actual Flow 1930-1955 (taf)	Unimpaired Flow 1984-2008 (taf)	Actual Flow 1984-2008 (taf)
Average of All Years	26	25	5,900	3,520	6,070	2,990
Median of All Years[1]	26	25	5,400	2,760	4,160	1,730
Wettest of Years	(1938)	(1995)	13,370	10,840	13,680	8,490
Average of Wet Years	6	8	9,490	7,160	10,720	5,450
Average of AN Years	7	3	7,070	4,320	6,820	4,240
Average of BN Years	6	1	4,350	1,670	4,990	1,360
Average of Dry Years	4	4	3,410	1,350	3,770	1,650
Average of Critical Years	3	9	2,450	960	2,840	1,150
Driest of Years	(1931)	(1987)	1,680	680	2,160	660

[1] Median is not aligned with flow from a specific year.

The period from 1930 to 1955, pre-regulated period, is representative of conditions where total reservoir storage volume in the SJR basin ranged from 1.5 maf to 2.2 maf, or 28 to 41 percent of the long-term median annual unimpaired flow in the Basin. The present-day period from 1984 to 2008 is representative of current conditions, with reservoir storage of 7.6 maf to 7.8 maf, or 141 percent to 145 percent of the long-term median annual unimpaired flow in the basin.

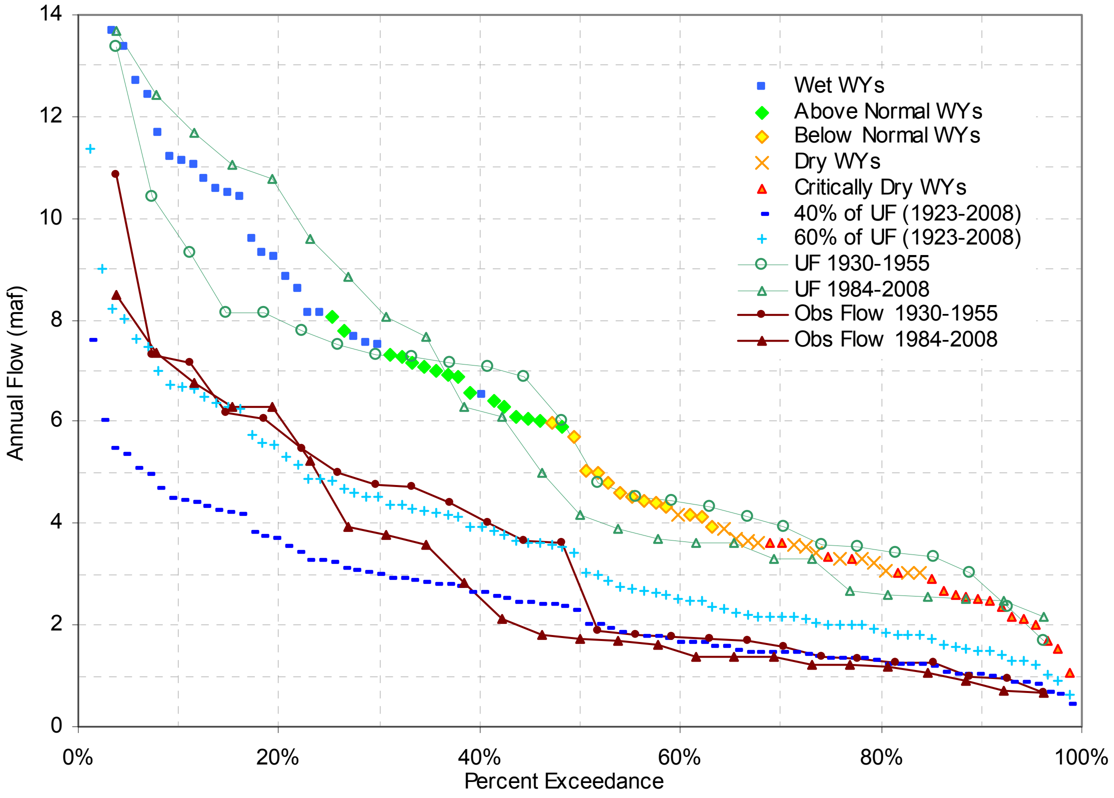


Figure 2-5. Exceedance curves of early and present-day observed and unimpaired flow hydrology on the San Joaquin River at Vernalis

Exceedance curves for unimpaired and observed flow for the two periods are superimposed on the long-term unimpaired flow for the entire unimpaired flow data set spanning 1923 to 2008 in Figure 2.5. The pre-regulated period from 1930 to 1955 was slightly wetter than the present-day period from 1984 to 2008. The pre-regulated period had less extremes; there were fewer critically dry and wet years, and more moderate, below normal and above normal years.

As a result of changes in storage and diversion, flow in the river has been reduced, resulting in dryer conditions more frequently than would have occurred under more natural conditions. From Figure 2-5, under conditions that are more natural, flow would have been less than approximately 2.5 maf in only about 10 percent of years, roughly the ten driest years on record. Now, under present-day conditions, flow is less than approximately 2.5 maf between 60 percent and 65 percent of years (the 35 percent to 40 percent exceedance level). In the pre-regulated period observed flows were less than approximately 2.5 maf in fewer than 50 percent of years.

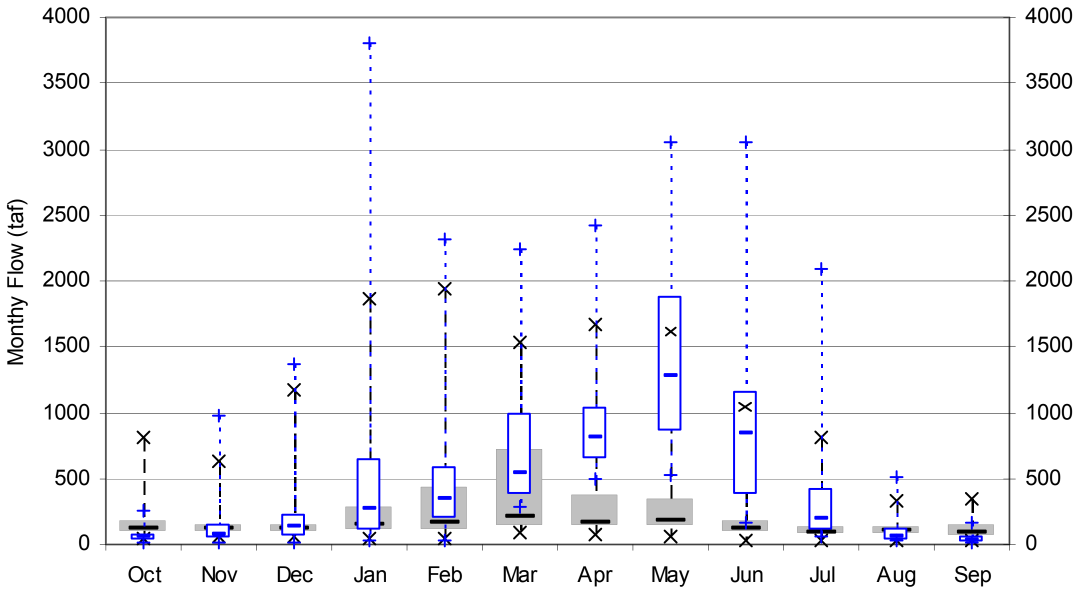
The annual reduction from unimpaired flow in the pre-regulated period was between 32 percent and 61 percent (the 25th and 75th percentile or 50 percent of years), while in the current period the reduction was between 42 percent and 66 percent. This is equivalent to 39 and 68 percent of unimpaired flow remaining in the river for the pre-regulated period, and between 34 and 58 percent remaining in the present-day period. The curves corresponding to 30 and 60 percent of unimpaired flow are overlaid for reference to the percentage of unimpaired flow not stored or diverted, ultimately remaining in the river.

In addition to inferences regarding changes over time, the long-term unimpaired flow exceedance curve in Figure 2-5 indicates that water year classification does not always accurately describe the unimpaired flow within that year; water years that are classified as a specific type often exhibit higher or lower volume than a water year in a different water year classification. For example, many of the Critical water years had higher annual flow than many of the Dry water years. This is in part because the water year classification depends partially on the preceding water year type and is predicted before the end of the water year. An exceedance curve of unimpaired flow is a more direct measurement of estimated hydrology because it is derived from hydrologic conditions and ranks them from wettest to driest. The two periods are not separated by water year type as previously completed for the long term data above for there are too few years to accurately represent each water year classification.

2.3.3 Seasonal Trends, Spring Snowmelt, and Summer Baseflow

The overall effect of increased storage and operational changes on flow is more static flow with less seasonally variable flows throughout the year (Figure 2-6). The altered flow is essentially flat-lined, especially during some seasons. There is now a severely dampened springtime magnitude and more flow in the fall, both of which combine to create managed flows that diverge significantly from what would occur under an unimpaired condition. Table 2-5 contains statistics related to the monthly unimpaired flow and observed flows at Vernalis. The greatest reduction in the median of monthly flows occurs during peak spring snowmelt months of April, May, and June exhibiting unimpaired flows that are 26 percent, 18 percent, and 19 percent of unimpaired flow, respectively. In contrast August, September, October, and November have a higher median flow (133 percent, 251 percent, 329 percent, and 133 percent of unimpaired flow, respectively) than would occur under more natural conditions (Table 2-5).

The unimpaired flow magnitude of the snowmelt varies dramatically each year as is expressed by an inter-quartile range (difference between 75th percentile and 25th percentile) of roughly 0.41, 1.04, and 0.91 maf for the months of April, May and June. Under the present-day conditions this range has been reduced to roughly 0.27, 0.26, and 0.10 maf and is slightly increased for September and October (Table 2-5). This large decrease in spring flow magnitude and variation throughout the year, as well as the augmentation of summer and fall flows is apparent in nearly all recent years. Figure 2-4 emphasizes this where in each year, especially during the later period of 1984 to 2009, observed flows are significantly lower than unimpaired flow during the wet season and are higher than unimpaired flow during the dry season.



Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow ("+"sign) and observed ("x" sign).

Figure 2-6. Monthly unimpaired flow (open bars) and observed flow (filled bars) in the SJR at Vernalis from 1984 to 2008

Table 2-5. Monthly and annual statistics of unimpaired flow, observed flow, and percent of unimpaired flow in the SJR at Vernalis from 1984 to 2008

Monthly unimpaired flow from 1984-2008 in the San Joaquin River at Vernalis

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	31	46	62	103	193	380	645	858	371	108	36	21	3,312
Med.	55	69	135	264	344	538	808	1,276	845	202	53	37	4,163
75%tile	68	143	220	650	593	998	1,037	1,876	1,151	420	122	58	8,834
Range	253	964	1,356	3,787	2,287	1,950	1,915	2,527	2,878	2,028	491	158	11,519

Monthly observed flow from 1984-2008 in the San Joaquin River at Vernalis

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	86	92	85	110	110	135	132	131	84	71	69	67	1,234
Med.	127	115	122	149	169	207	171	178	118	93	100	95	1,732
75%tile	187	150	145	283	435	720	383	341	179	136	134	144	3,945
Range	770	578	1,121	1,818	1,905	1,449	1,593	1,547	1,028	784	305	308	7,834

Monthly historical observed flow as a percent of unimpaired flow for 1984-2008 in the San Joaquin River at Vernalis

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	241	78	54	45	44	31	18	14	16	34	94	203	34
Med.	328	137	95	57	55	44	26	17	19	45	141	255	46
75%tile	420	255	154	146	87	73	39	23	30	73	211	371	58
Range	969	511	474	248	200	89	77	52	50	154	325	437	65

Under more natural conditions, timing of the wettest month is generally static, ranging between April and June. In 65 out of 85 years (74 percent of years) from 1923 to 2008, the wettest month of the year would have been May; in 12 years it would have been June, in eight years it would have been April, and in one year each it would have been January and February. Seven of the eight years that April was the wettest month of the year were either Dry or Critically Dry water years.

The wettest month of the year is now most often March, followed by May, February, and October. The early period was already severely altered with the wettest month occurring many times in either May or June and frequently in December and January. Table 2-6 summarizes the alterations to the timing of the wettest month for the two periods previously discussed using percentage of years each month was the wettest.

Table 2-6. Percent of years peak month observed and unimpaired flow occurred in each month in the San Joaquin River at Vernalis

		Percent of years peaking in											
Period	# of yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unimpaired (1930 to 1955)	26	0	0	0	8	77	12	0	0	0	0	0	4
Observed (1930 to 1955)	26	15	0	8	8	31	27	0	0	0	0	0	8
Unimpaired (1984 to 2008)	25	4	4	0	12	72	8	0	0	0	0	0	0
Observed (1984 to 2008)	25	8	16	32	4	24	0	0	0	0	12	0	4

2.3.4 Short Term Peak Flows and Flood Frequency

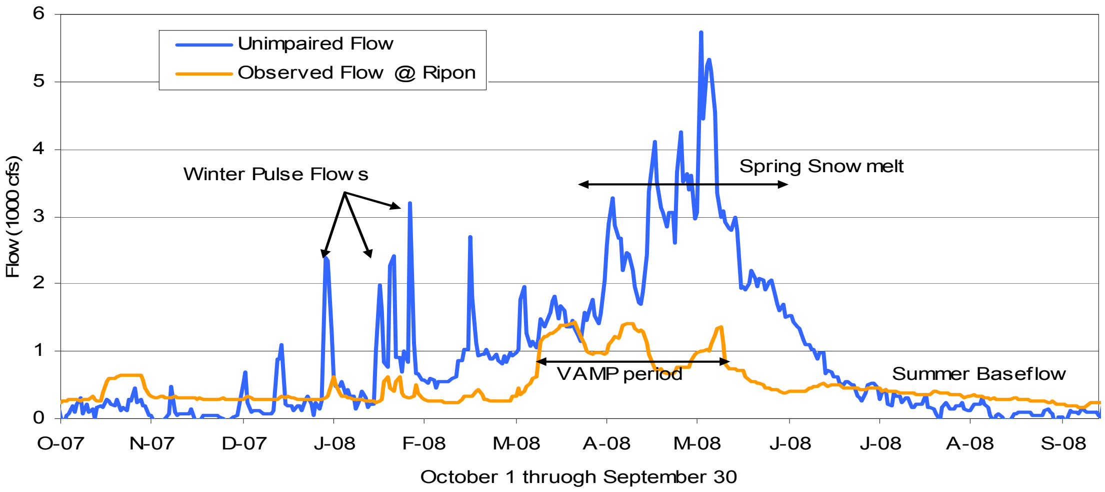
As shown in Figure 2-1 and Figure 2-2, short term peak or storm flows that occur several times within a given year, generally between November and March, are dramatically reduced under the present-day management conditions. Although tributary to the SJR, peaks on the tributaries still move downstream to Vernalis. No attempt was made to calculate the short term peak flows and flood frequencies of unimpaired flow in this report because daily unimpaired flow data is not readily available at Vernalis. The "*Sacramento-San Joaquin Comprehensive Study*", by USACE (2002), does however provide a flood frequency analysis at Vernalis. Comparisons were made between two periods, 1930 to 1955 and 1984 to 2008 using daily gage data in place of unimpaired flow data to attempt to demonstrate how pulse flows have changed over time. It is recommended that future analyses incorporate daily unimpaired flow at Vernalis and compare this to recent observed data to determine the changes from natural storm flows.

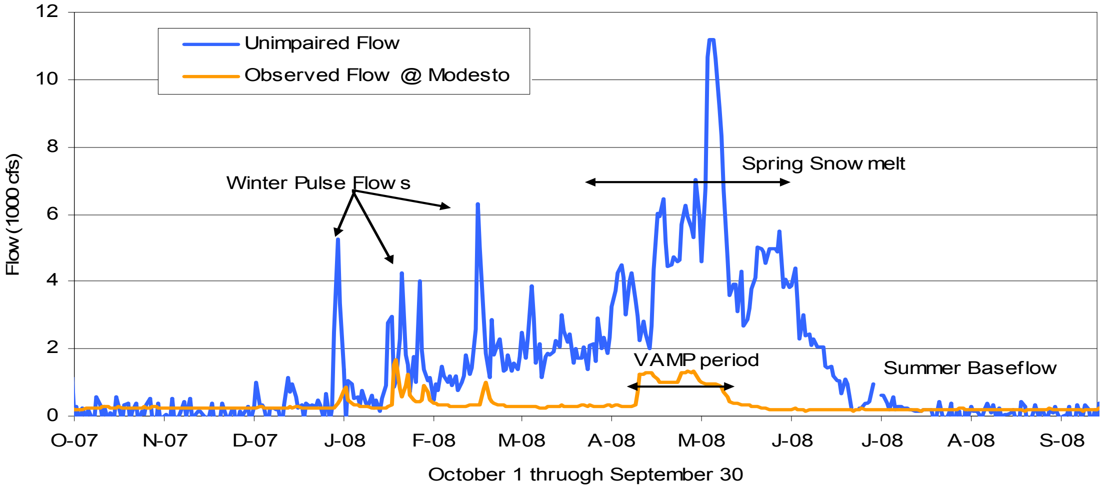
Under more natural conditions the, October to March storm flows are generally less intense than the peaks that occur during the spring snowmelt. By separating the fall and winter storm peaks from the rest of the year, it is possible to see alterations to the various components of the natural hydrograph as depicted in Figure 2-1 and Figure 2-2. In the 1984 to 2009 period, the annual peaks generally occurred between October and March, while in the 1930 to 1955 period, they occurred during the spring. Table 2-7 summarizes the exceedances of the fall and winter component as well as the spring component. The 90th percentile exceedances are the magnitude of peak flows that, in general, have occurred multiple times in a given year. In order to determine the true altered regime, it would be necessary to calculate these statistics using daily unimpaired flow data.

Table 2-7. Percent chance of exceedance of October through March and annual maximum daily average flow in the San Joaquin River at Vernalis

Percent Exceedance	Observed Flow 1930 to 1955 (cfs)		Observed Flow 1984 to 2009 (cfs)		Percent Difference from early period %	
(percentile)	Oct to Mar	Annual	Oct to Mar	Annual	Oct to Mar	Annual
Greatest Peak Flow	70,000	70,000	54,300	54,300	-22%	-22%
25 Percentile	20,400	28,200	17,400	17,400	-15%	-38%
50 Percentile	7,700	15,500	6,000	6,000	-22%	-61%
75 Percentile	4,400	6,000	4,200	4,200	-5%	-30%
90 Percentile	3,700	4,600	2,500	2,700	-32%	-41%
Smallest Peak Flow	2,000	2,100	1,900	2,000	-5%	-5%

To illustrate the loss of storm flows, including those that would have occurred several times in a given year, Figure 2-7 displays daily unimpaired flow and observed flow for WY 2007, a Critically Dry water year, for each of the Major SJR Tributaries. Even though this is a Critically Dry water year, there are significant storm pulse flows respondent to rainfall and rain falling on snow during the later fall and early winter seasons. To quantify the changes to pulse flows that have occurred, the annual peak exceedance curves were developed using the two distinct periods previously determined and compared to estimates by USACE (2002) in Table 2-8. While other studies have focused separately on the major SJR tributaries (McBain and Trush, 2000; Kondolf et al., 2001; Stillwater Sciences, 2002; Cain et al, 2003), the peak flood analysis completed by USACE is the only study known to have addressed peak flow regime at Vernalis. Even though many alterations had already occurred within the watershed prior to the early period, there are still reductions in peak flows between the two periods of 49 percent, 61 percent, and 23 percent for the 1.5 year, 2 year and 5 year return period peak flows respectively. Essentially, flows that would have occurred at least once every year or two years, of approximately 15,000 cfs, now occur upwards of once every 5 years (Table 2-8). The difference in larger floods that occur every 10 years on average is less pronounced with only a 6 percent reduction from the early period. As one would expect, the USACE (2002) estimates of peak flows are somewhat higher than those estimated here because USACE used unimpaired flow data, which estimates return frequencies prior to any alterations.





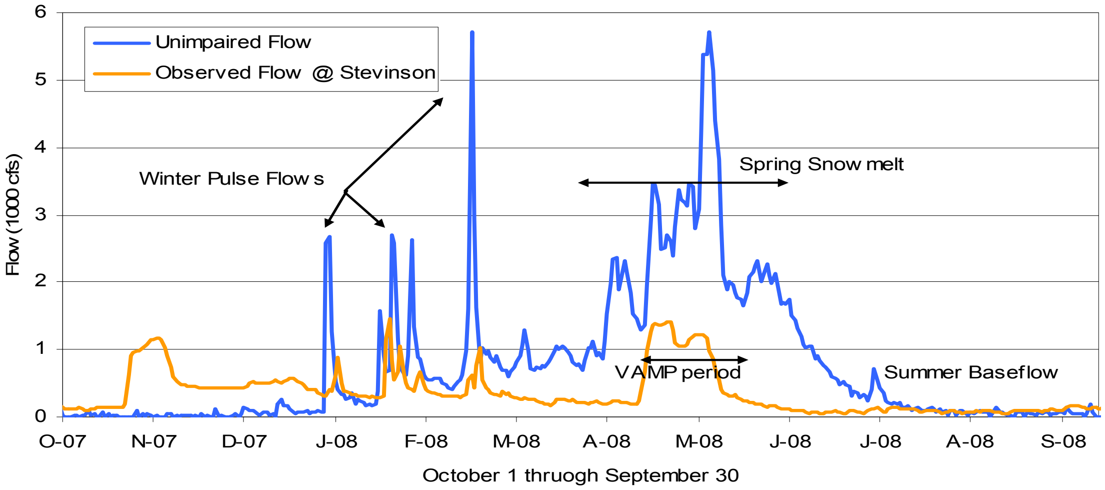


Figure 2-7. Daily unimpaired flow and observed flow for a Critically Dry water year (WY 2007) in the Stanislaus at Ripon (top), Tuolumne at Modesto (middle), and Merced at Stevinson (bottom)

Table 2-8. Frequency analyses of annual peak flows in the San Joaquin River at Vernalis as compared to USACE (2002)

Return Freq.	USACE "Unimpaired"	Observed Flow[2]		Observed Percent Difference	
	(1902 to 1997)[1] (cfs)	(1930 to 1955) (cfs)	(1984 to 2009) (cfs)	(Late period from USACE) (%)	(Late period from early period) (%)
Q1.5	~15,000	8,800	4,500	-70%	-49%
Q2	~25,000	15,500	6,000	-76%	-61%
Q5	~55,000	33,700	25,900	-53%	-23%
Q10	~100,000	37,100	34,800	-65%	-6%

[1] USACE (2002) as interpolated from 1-Day Flood Frequency Curves in attachment B.2 page 45. Values were based on a simulated unimpaired flow.
[2] Source of data USGS Gage.# 11303500.

2.4 Hydrology of Major Tributaries to San Joaquin River

The previous section describes the unimpaired flow and present-day conditions of flow in the SJR at Vernalis. Unimpaired flow in the SJR at Vernalis is largely fed by flow from the Stanislaus, Tuolumne, and Merced Rivers, and during wetter years, the Upper SJR. The alteration to flow characteristics at Vernalis is driven by the alterations that have occurred on each of the tributaries. This section summarizes the contribution to flows at Vernalis by the major SJR tributaries and the hydrologic characteristics of each.

On average, the Stanislaus, Tuolumne, Merced, and Upper SJR tributaries combined make up between 86 and 100 percent of unimpaired flow at Vernalis throughout the year and between 66 and 90 percent of present-day conditions flow (Figure 2-8).

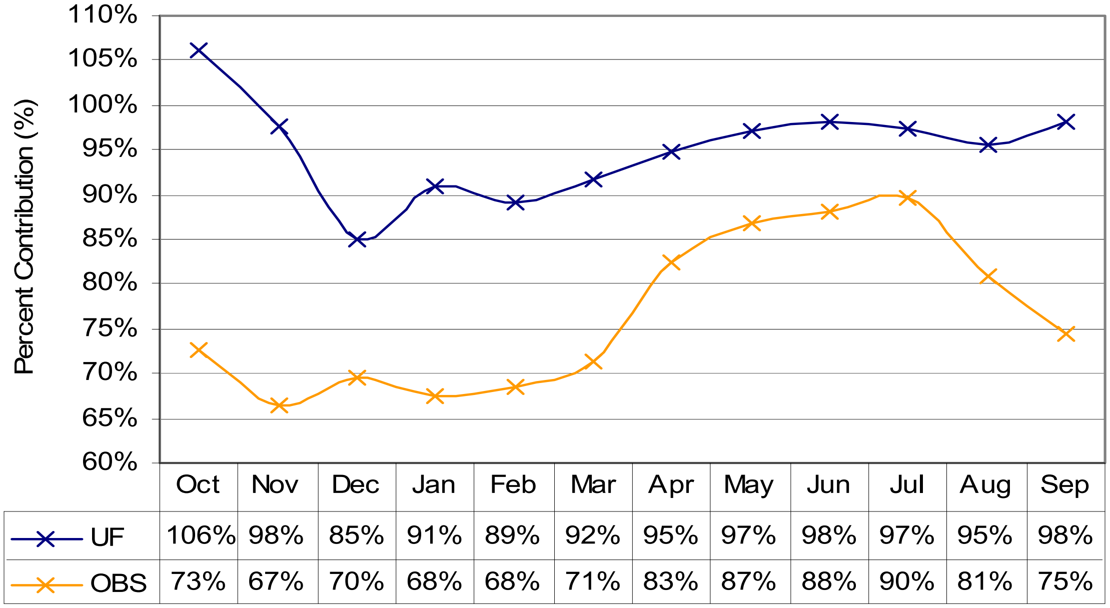


Figure 2-8. Average observed and unimpaired flow contributed by four major tributaries to the SJR combined (1984 to2009)

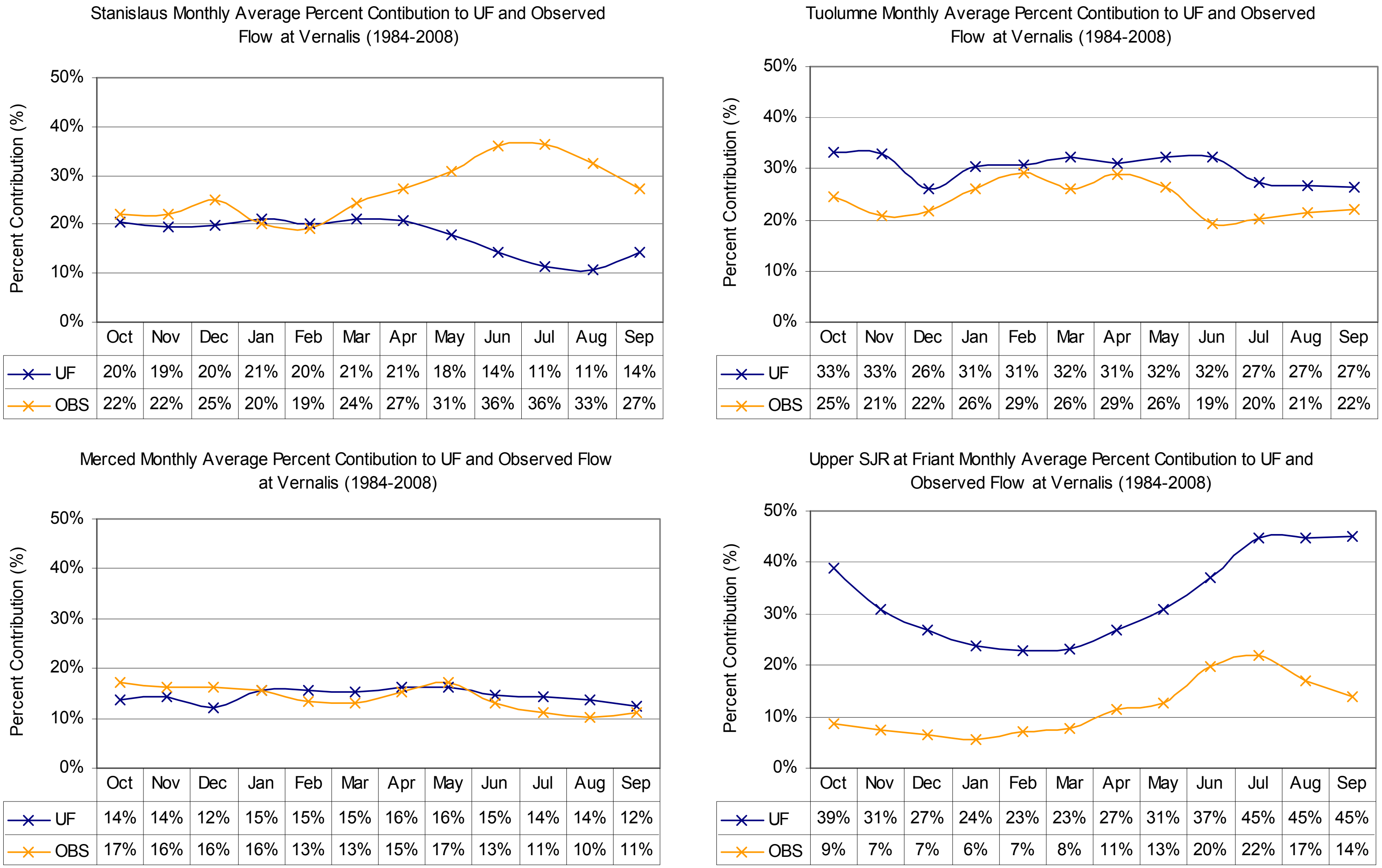
Figure 2-9 displays the average monthly flow contribution by the tributaries as a percentage of flow at Vernalis. The Major SJR Tributaries have been altered and now generally contribute different percentage of the monthly flow at Vernalis than in the past under more natural conditions. Under unimpaired conditions the Stanislaus, Tuolumne, Merced, and Upper SJR would have contributed a median of 18 percent, 31 percent, and 16 percent, and 29 percent respectively on an annual basis to the flow at Vernalis. The remainder 6 percent of flow, by method of subtraction, is assumed contributed by the remainder of the SJR basin. Under the present-day conditions, the Stanislaus and Tuolumne contribute 27 percent and 26 percent respectively, while the Merced percentage of contribution is roughly unchanged (Table 2-9). The Upper SJR now only contribute 10 percent of flow, and the remaining portion of the SJR basin contributes 22 percent. The percent of flow contributed by the Stanislaus River during June and July has increased dramatically, making up nearly 35 percent of flow during these months, while the Tuolumne has been reduced to roughly 20 percent (Figure 2-9). The Middle and Upper SJR combined contribute a similar annual volume of flow, however a higher percentage of flow is contributed in October to December, and a lower percentage of flow in January to June, compared to more natural conditions.

Table 2-9. Average annual percent contribution of unimpaired flow and observed flow by major SJR tributaries to flow at Vernalis

	Stanislaus	Tuolumne	Merced	Upper SJR at Friant	Remainder
Unimpaired Flow (1984 to 2009)	18%	31%	16%	29%	6%
Observed Flow (1984 to 2009)	27%	26%	15%	10%	22%

Spring flows in SJR tributaries have been significantly reduced while flows during late summer and fall (generally August to November) have increased, resulting in less variability in flow over the year. Additionally, the winter and spring variability from year to year has been greatly reduced. Boxplots for each of the tributaries (Figure 2-10 through Figure 2-14) depict the median, 25th percentile, 75th percentile, wettest, and driest months for 1984 to 2009. A graphical comparison of the unimpaired flow and observed flows signifies the magnitude of alteration in flows, variability, and timing that represent present-day flow characteristics.

Flows are much lower, primarily during the wet season, and with much less variation from year to year and within the year. The inter-quartile range is now much less than the unimpaired range (Table 2-10 through Table 2-14). The third quartile (75th percentile) monthly observed flows are less than the lowest monthly unimpaired flow for all tributaries during April and May. Although late summer and fall flows have been augmented, it is of less magnitude than the spring reduction such that annual flows are greatly reduced. Annual actual flows in each of the tributaries have been reduced, and now only 58 percent, 40 percent, and 46 percent of unimpaired flow remains in the rivers respectively (42 percent, 60 percent, and 54 percent reduction from unimpaired flow). The median annual unimpaired flow was 0.92 maf, 1.5 maf, 0.72 maf, and 1.17 maf for the Stanislaus, Tuolumne, Merced and Upper SJR tributaries respectively from 1984 to 2009. The median annual unimpaired flow of the middle and Upper SJR combined (upstream from the confluence with the Merced River), by subtracting the Stanislaus, Tuolumne, and Merced Rivers from the SJR at Vernalis, was 1.28 maf per year, 91 percent of which is delivered from the Upper SJR.



Stanislaus Monthly Average Percent Contibution to UF and Observed Flow at Vernalis (1984-2008)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	20%	19%	20%	21%	20%	21%	21%	18%	14%	11%	11%	14%
OBS	22%	22%	25%	20%	19%	24%	27%	31%	36%	36%	33%	27%

Tuolumne Monthly Average Percent Contibution to UF and Observed Flow at Vernalis (1984-2008)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	33%	33%	26%	31%	31%	32%	31%	32%	32%	27%	27%	27%
OBS	25%	21%	22%	26%	29%	26%	29%	26%	19%	20%	21%	22%

Merced Monthly Average Percent Contibution to UF and Observed Flow at Vernalis (1984-2008)

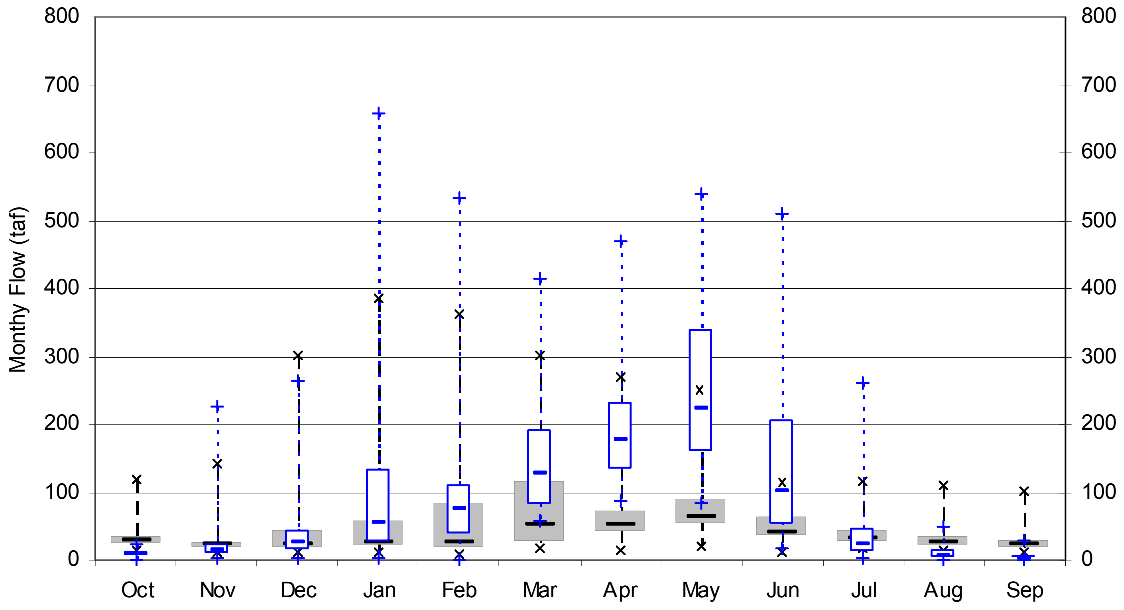
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	14%	14%	12%	15%	15%	15%	16%	16%	15%	14%	14%	12%
OBS	17%	16%	16%	16%	13%	13%	15%	17%	13%	11%	10%	11%

Upper SJR at Friant Monthly Average Percent Contibution to UF and Observed Flow at Vernalis (1984-2008)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	39%	31%	27%	24%	23%	23%	27%	31%	37%	45%	45%	45%
OBS	9%	7%	7%	6%	7%	8%	11%	13%	20%	22%	17%	14%

Figure 2-9. Average monthly unimpaired and observed tributary flow contribution to flow at Vernalis (1984 to2008)

Timing of the wettest month during the spring snowmelt period is generally static, occurring between April and May for each of the tributaries. For example in the Stanislaus River, May was the peak month for sixteen out of 25 years from 1984 to 2009; April was the peak in seven years. This corresponds to findings in Cain et al. (2003) using daily observed flows from 1896 to 1932. Cain et al. found that the date of the median pre-regulated peak was roughly May 17 for most water year types, ranging from April 21 to June 13.



Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow ("+"sign) and observed ("x" sign).

Figure 2-10. Monthly unimpaired flow (open bars) and observed flow (filled bars) in the Stanislaus River from 1984 to 2009

Table 2-10. Monthly and annual unimpaired flow, observed flow, and percent of unimpaired flow statistics in the Stanislaus River from 1984 to 2009

Monthly unimpaired flow from 1984 to 2009 in the Stanislaus River

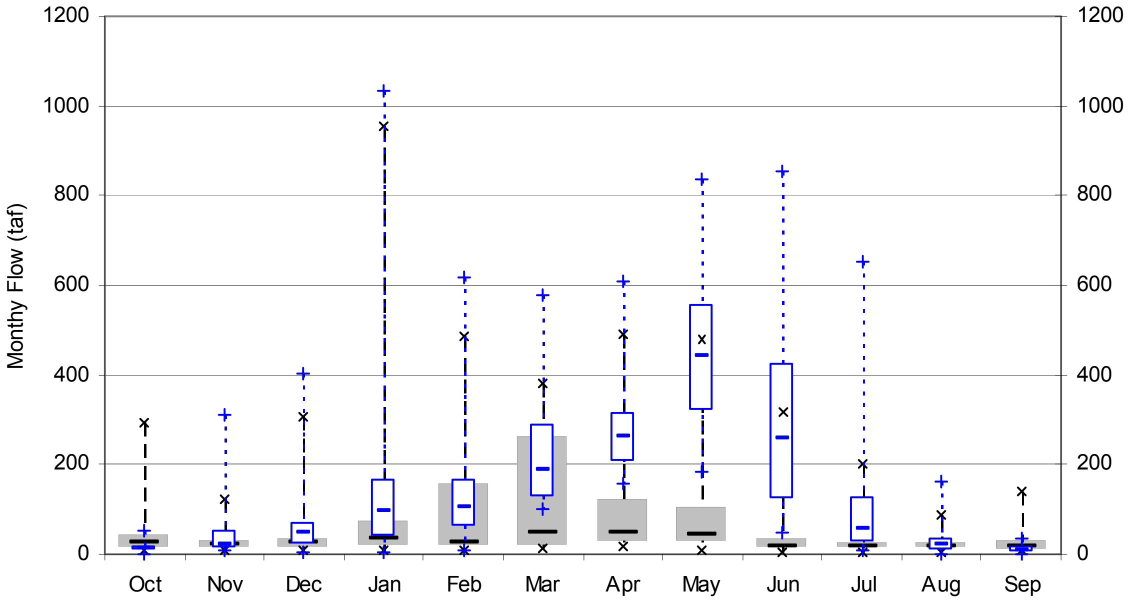
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	5	10	13	25	39	82	134	160	52	12	4	2	565
Med.	10	16	27	55	75	127	178	224	103	22	7	4	922
75%tile	13	24	43	133	110	191	231	339	207	47	15	7	1,541

Monthly observed flow from 1984 to 2009 in the Stanislaus River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	23	19	19	19	17	26	41	51	35	26	21	18	339
Med.	30	22	22	25	26	53	53	63	41	31	25	23	429
75%tile	36	25	44	59	84	116	72	90	63	44	34	28	725

Monthly historical observed flow as a percent of unimpaired flow from 1984 to 2009 in the Stanislaus River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	315	81	56	31	31	22	23	20	33	86	252	305	45
Med.	437	160	107	48	46	57	32	26	40	129	353	493	58
75%tile	523	202	182	121	81	85	45	39	69	284	701	1,395	76



Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow ("+"sign) and observed ("x" sign).

Figure 2-11. Monthly unimpaired flow (open bars) and observed flow (filled bars) in the Tuolumne River from 1984 to 2009

Table 2-11. Monthly and annual unimpaired flow, observed flow, and percent of unimpaired flow statistics in the Tuolumne River from 1984 to 2009

Monthly unimpaired flow from 1984 to 2009 in the Tuolumne River

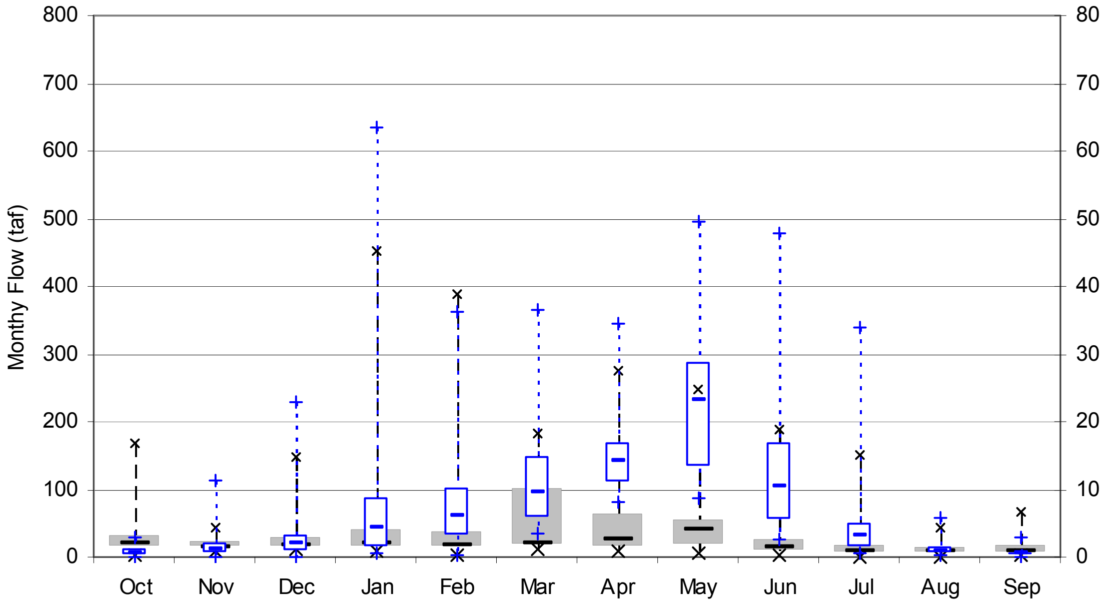
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	7	15	22	37	62	127	207	319	123	25	8	6	1,050
Med.	11	23	47	97	105	190	263	443	260	57	20	10	1,514
75%tile	19	53	72	165	168	289	317	558	424	127	35	18	2,585

Monthly observed flow from 1984 to 2009 in the Tuolumne River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	15	14	15	19	17	18	27	27	12	11	11	11	254
Med.	27	21	25	35	28	46	46	42	17	16	17	16	398
75%tile	44	29	35	76	158	264	124	106	33	27	28	32	1,388

Monthly historical observed flow as a percent of unimpaired flow from 1984 to 2009 in the Tuolumne River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	165	42	32	27	24	14	14	8	6	22	72	153	19
Med.	293	76	64	40	49	33	22	12	9	34	106	236	40
75%tile	464	162	113	104	113	83	45	19	20	52	154	307	59



Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow (“+”sign) and observed (“x” sign).

Figure 2-12. Monthly unimpaired flow (open bars) and observed flow (filled bars) in the Merced River from 1984 to 2009

Table 2-12. Monthly and annual unimpaired flow, observed flow, and percent of unimpaired flow statistics in the Merced River from 1984 to 2009

Monthly unimpaired flow from 1984 to 2009 in the Merced River

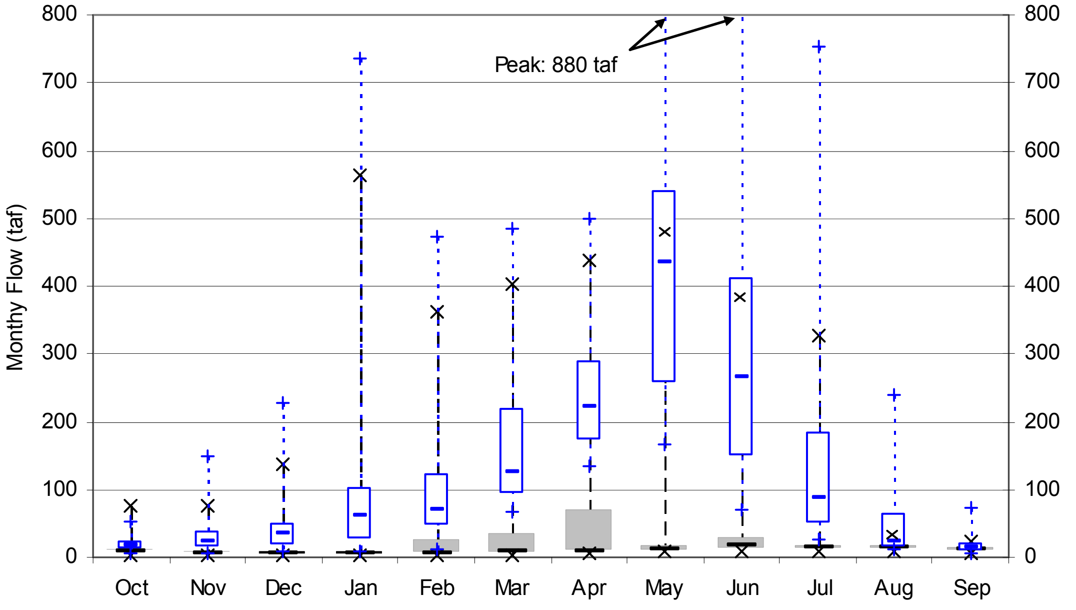
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	2	7	9	15	32	59	109	133	54	15	6	2	524
Med.	5	11	19	45	60	96	143	233	104	31	9	5	721
75%tile	12	21	33	86	102	148	168	286	167	50	14	7	1,387

Monthly observed flow from 1984 to 2009 in the Merced River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	16	14	14	14	14	16	13	17	9	6	5	5	168
Med.	20	15	16	20	18	20	27	41	13	9	8	8	271
75%tile	31	23	28	40	39	102	64	55	27	18	15	17	673

Monthly historical observed flow as a percent of unimpaired flow from 1984 to 2009 in the Merced River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	179	87	56	37	35	23	12	10	11	22	59	136	25
Med.	480	164	110	68	51	33	25	18	15	34	80	215	46
75%tile	762	235	173	121	65	60	34	29	29	45	165	392	56



Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow (“+”sign) and observed (“x” sign).

Figure 2-13. Monthly unimpaired flow (open bars) and observed flow (filled bars) in the SJR at Friant from 1984 to 2009

Table 2-13. Monthly and annual unimpaired flow, observed flow, and percent of unimpaired flow statistics in the SJR at Friant from 1984 to 2009

Monthly unimpaired flow from 1984 to 2009 in the San Joaquin River at Friant.

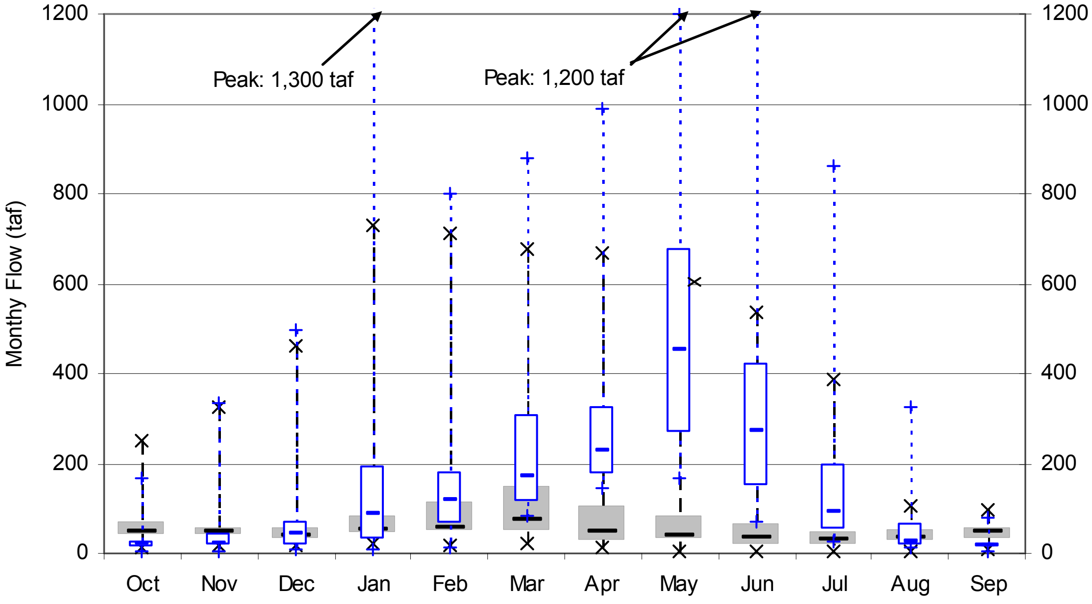
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	12	14	18	25	47	94	173	258	149	49	15	10	938
Med.	18	22	36	62	69	126	223	436	266	89	24	15	1172
75%tile	24	39	50	102	124	219	288	539	412	184	64	21	2672

Monthly observed flow from 1984 to 2009 in the San Joaquin River at Friant.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	8	6	5	4	5	6	8	9	11	12	12	10	114
Med.	10	7	6	6	6	8	10	11	17	14	14	11	142
75%tile	12	9	7	7	25	34	69	17	28	18	17	14	615

Monthly historical observed flow as a percent of unimpaired flow from 1984 to 2009 in the San Joaquin River at Friant.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	40	19	13	6	7	5	4	3	5	13	25	54	10
Med.	61	41	18	10	9	9	5	4	7	22	44	77	13
75%tile	101	52	35	24	20	17	21	8	14	30	90	127	25



Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow (“+”sign) and observed (“x” sign).

Figure 2-14. Monthly unimpaired flow (open bars) and observed flow (filled bars) in the SJR excluding Stanislaus, Tuolumne, and Merced Rivers from 1984 to 2008

Table 2-14. Monthly and annual unimpaired flow, observed flow, and percent of unimpaired flow statistics in the SJR excluding Stanislaus, Tuolumne, and Merced Rivers from 1984 to 2008

Monthly unimpaired flow from 1984 to 2008in the Middle San Joaquin River (excluding Stanislaus, Tuolumne, and Merced Rivers)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	13	17	19	30	64	115	178	269	149	55	17	11	991
Med.	20	22	42	87	120	170	230	453	272	93	26	16	1280
75%tile	25	43	69	193	179	306	326	677	420	198	64	22	3195

Monthly observed flow from 1984 to 2008 in the Middle and Upper San Joaquin River (Vernalis excluding Stanislaus, Tuolumne, and Merced Rivers)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	41	41	32	42	46	48	26	33	18	19	26	30	414
Med.	48	48	40	54	57	76	49	42	35	31	37	46	633
75%tile	69	58	57	86	114	151	105	85	67	47	54	57	1131

Monthly historical observed flow as a percent of unimpaired flow from 1984 to 2008 in the Middle and Upper San Joaquin River (Vernalis excluding Stanislaus, Tuolumne, and Merced Rivers)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	225	98	66	52	48	41	15	9	11	27	80	194	38
Med.	289	192	101	86	66	57	21	14	18	34	100	250	46
75%tile	364	314	163	132	86	62	42	17	24	47	163	308	53

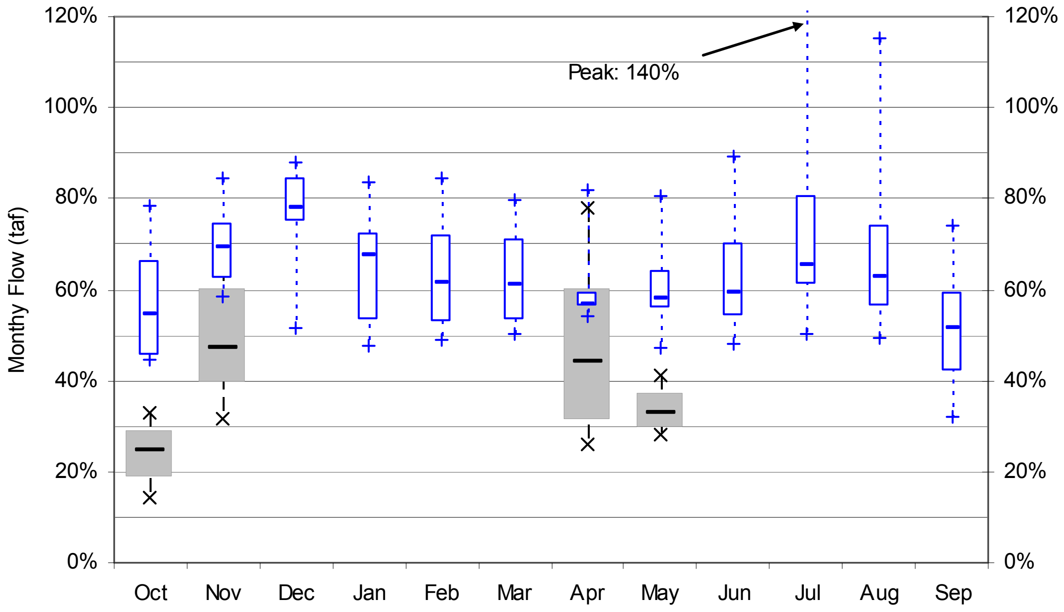
2.5 Hydrodynamics Downstream of Vernalis

As previously stated, Vernalis is the location where all non-floodplain flows from the SJR basin flow into the Delta. Downstream from Vernalis flows from the SJR are affected by numerous factors including tides, in-Delta diversions, and barrier operations. This discussion focuses on two major factors affecting flows downstream of Vernalis: the flow split at the Head of Old River (HOR); and the effects of diversions by the Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) in the southern Delta on flows through Old and Middle rivers. This section does not provide a comprehensive discussion or analysis of these issues as they are not the subject of the State Water Board's current review. Instead, information is provided to supply background on these issues as it relates to flows at Vernalis and protection of fish and wildlife beneficial uses, and southern delta salinity and protection of agricultural beneficial uses.

Downstream of Vernalis, flows from the SJR split at the HOR where water either flows downstream in the mainstem SJR toward Stockton or into Old River. Circulation of flows through the lower SJR and southern Delta is altered by several seasonally installed barriers at the head of Old River (Head of Old River Barrier or HORB), Old River near Tracy (Old River near Tracy barrier or ORTB), the Middle River (Middle River barrier or MRB), and the Grant Line Canal (Grant Line Canal barrier or GLCB). The barriers are used to mitigate for impacts of the State Water Project (SWP) and Central Valley Project (CVP) Delta pumping facilities and improve operational flexibility for the projects by: 1) improving water levels, circulation patterns, and water quality in the southern Delta area for local agricultural diversions (ORTB, MRB, and GLCB); and 2) reducing impacts to SJR fish related to the flow split at the HOR (HORB)..

The HORB has been installed in most years during the fall (roughly between September 15th and November 30th) since 1968, and in some years during the spring (roughly between April 15th and May 30th) since 1992. In general, the HORB was not installed in the spring in years with higher flows. In addition, the HORB has not been installed in the spring since 2007 due to a court order, and in its place a non-physical barrier has been installed in 2009 and 2010 (see discussion in Section 3). When installed, the HORB altered flows on the lower SJR and Old River by causing the majority of the SJR flow to flow down the mainstem SJR and continue towards the City of Stockton, and the Eastern Delta. When the HORB is not installed, the majority of flow enters Old River. By subtracting the flow gaged at Garwood Bridge from the flow gaged at Vernalis, it was possible to estimate flow that entered the southern Delta through the HOR and estimate the effect of the barriers on flow in the southern Delta. For the months when the HORB was not installed, the percentage of flow that entered Old River was generally between 50 percent and 80 percent. For the months when the HORB was installed (October to November, and April to May in most years), the percentage of flow entering Old River was generally reduced and was more variable (Figure 2-15 and Table 2-15).

Flow paths downstream of Vernalis are largely affected by export operations of the two major water diverters in the Delta, the USBR and the DWR. The USBR exports water from the Delta at the Jones Pumping Plant and the DWR exports water from the Delta at the Banks Pumping Plant. Operations of the CVP and SWP Delta export facilities are coordinated to meet water quality and flow standards set by the State Water Board, the U.S. Army Corps of Engineers (USACE), and by fisheries agencies. In addition to the SWP and CVP, there are many smaller local agricultural diversions in the southern Delta that can affect flow paths (State Water Board 1999.)



Monthly average percentage of flow entering the HOR from 1996-2009 with barrier removed (open box) and barrier installed (shaded box). Key to boxplots: median, horizontal line; box, 25th and 75th percentiles; whiskers, range barrier out ("+"sign) and barrier in ("x" sign).

Figure 2-15. Monthly average percentage of flow entering the head of Old River from 1996 to 2009

Table 2-15. Monthly average percentage of flow entering the head of Old River from 1996 to 2009

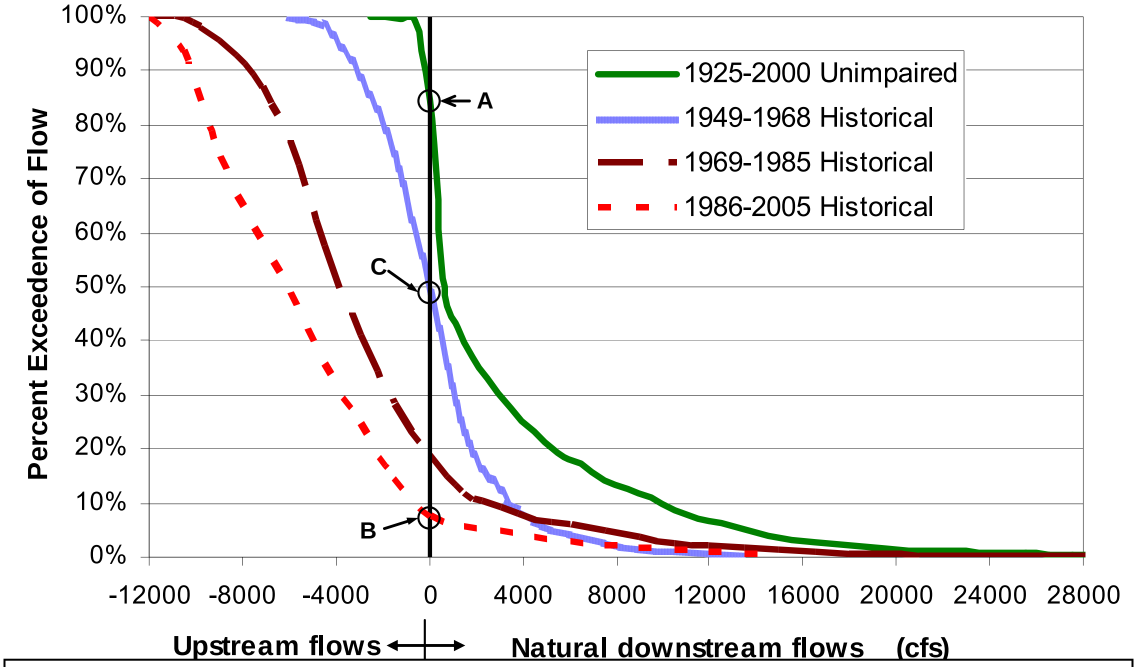
Percent of flow to OMR with barrier removed.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1st Quartile	45%	63%	75%	53%	53%	53%	57%	56%	54%	61%	56%	42%
Median	54%	69%	78%	68%	62%	61%	57%	58%	60%	65%	63%	52%
3rd Quartile	66%	75%	84%	72%	72%	71%	60%	64%	70%	81%	74%	59%

Percent of flow to OMR with barrier installed.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1st Quartile	18%	39%					31%	30%				
Median	25%	47%					44%	33%				
3rd Quartile	29%	60%					60%	37%				

Operations by the CVP and SWP pull water from the SJR down Old River to the diversion facilities increasing the amount of flow that travels down Old River to the diversion facilities instead of down the mainstem SJR. In addition, operations by the SWP and CVP increase the occurrence of net Old and Middle reverse flows (OMR reverse flows). OMR flows are now a regular occurrence in the Delta (Figure 2-16). Net OMR reverse flows are caused by the fact that the major freshwater source, the Sacramento River, enters on the northern side of the Delta while the two major pumping facilities, the SWP and CVP, are located in the south. This results in a net water movement across the Delta in a north-south direction along a web of channels including Old and Middle rivers instead of the more natural pattern from east to west or from land to sea. Net OMR is calculated as half the flow of the SJR at Vernalis minus the combined SWP and CVP pumping rate (CCWD closing comments, p. 2 as cited in State Water Board 2010). A negative value, or a reverse flow, indicates a net water movement across the Delta along Old and Middle river channels to the CVP and SWP pumping facilities.



Cumulative probability distribution of sum of OMR flows (cfs) resulting from through Delta conveyance showing unimpaired flows (green solid line) and three historical periods, 1949-1968 (solid light blue line), 1969-1985 (long-dashed brown line) and 1986-2005 (short-dashed red line) (Source: Fleenor et al. 2010, Figure 9).

Figure 2-16. Old and Middle River cumulative probability flows from Fleenor et al. 2010

Fleenor et al (2010) has documented the change in both the magnitude and frequency of net OMR reverse flows as water development occurred in the Delta (Figure 2-16). The 1925-2000 unimpaired line in Figure 2-16represents the best estimate of “quasi-natural” or net OMR values before most modern water development (Fleenor et al. 2010). The other three lines represent changes in the frequency and magnitude of net OMR flows with increasing development. Net OMR reverse flows are estimated to have occurred naturally about 15 percent of the time before most modern water development, including construction of the major pumping facilities in the South Delta (point A, Figure 2-16). The magnitude of net OMR reverse flows was seldom more negative than a couple of thousand cfs. In contrast, between1986-2005 net OMR reverse flows had become more frequent than 90 percent of the time (Point B). The magnitude of net OMR reverse flows may now be as much as -12,000 cfs.

3 Scientific Basis for Developing Alternate San Joaquin River Delta inflow objectives

3.1 Introduction

This section describes the scientific basis for developing alternative SJR Delta inflow objectives for the Bay-Delta Plan. Specifically, this section focuses on the Delta inflow needs of SJR basin fall-run Chinook salmon and steelhead as these anadromous species are among the most sensitive to inflows from the SJR to the Bay-Delta. While SJR flows upstream of the Bay-Delta, including SJR tributary flows, are important to the protection of fish and wildlife beneficial uses, the focus of this water quality control planning effort is on the Bay-Delta. The legal boundary of the Delta on the SJR is at Vernalis, where the lower SJR flows directly into the southern Delta. Accordingly, the focus of this review is on SJR flows at Vernalis for the protection of fish and wildlife beneficial uses. Other SJR flows, including tributary flows, will be the focus of future State Water Board activities, including decisions related to implementation of these flow objectives and water quality certification activities in connection with Federal Energy Regulatory Commission relicensing projects on the Merced and Tuolumne rivers.

In addition, while aquatic resources in the SJR basin have been adversely impacted by numerous factors, flow remains a key factor and is the focus of the State Water Board's current review. Many other factors affect aquatic resources in the SJR basin and need to be evaluated in protecting fish and wildlife beneficial uses, but are not the focus of this review. Factors other than flow will be discussed in the environmental document supporting any changes to the Bay-Delta Plan and will also be addressed in the program of implementation section of the Bay-Delta Plan.

3.1.1 Problem Statement

Scientific information indicates that reductions in flows and changes in the natural flow regime of the SJR basin resulting from water development over the past several decades are impairing fish and wildlife beneficial uses. As outlined in the hydrology section of this report, water development in the basin has resulted in: reduced annual flows; fewer peak flows; reduced and shifted spring and early summer flows; reduced frequency of peak flows from winter rainfall events; shifted fall and winter flows; and a general decline in hydrologic variability over multiple spatial and temporal scales (McBain and Trush 2002, Cain et al. 2003, Brown and Bauer 2009, NMFS 2009a, Richter and Thomas 2007). Currently, there is relatively little unregulated runoff from the SJR basin with dams heavily regulating at least 90 percent of the inflow (Cain et al. 2010). In addition, dams and diversions in the basin cause a significant overall reduction of flows compared to natural conditions, with a median reduction in annual flows of 54 percent and median reduction of critical spring flows between 81 and 86 percent during April and May respectively.

Since intensive water development started in the SJR basin in the 1940s and prior, Chinook salmon and Central Valley steelhead populations in the SJR basin have declined dramatically. The SJR basin once supported large spring-run and fall-run Chinook salmon populations. Now the basin only supports a diminishing fall-run population. The population of fall-run Chinook salmon in the Central Valley historically approached 300,000 adults (BDCP 2009), but has since exhibited significant reductions in peak abundance (DFG 2010c; 3,552 adults in 2009) over time suggesting that overall population resiliency is decreasing. The Central Valley steelhead population has also exhibited significant declines; enough to warrant listing as a threatened species under the Federal Endangered Species Act. In the 1995 Bay-Delta Plan the State Water Board developed SJR Delta inflow objectives primarily intended to protect fall-run Chinook salmon and provide incidental benefits to steelhead. Somewhat lower flows were then implemented under the Vernalis Adaptive Management Plan (VAMP) experiment in accordance with revised water rights Decision 1641 (D-1641). Despite these efforts, SJR basin fall-run Chinook salmon populations have continued to decline. Scientific evidence indicates that in order to protect fish and wildlife beneficial uses in the SJR basin, including increasing the populations of fall-run Chinook salmon and Central Valley steelhead, changes to the altered hydrology of the SJR system are needed to create a more natural flow regime, including increases in flow.

3.1.2 Approach

In order to develop SJR flow objective alternatives, existing scientific literature relating to SJR inflows and protection of fish and wildlife beneficial uses was evaluated. This information is summarized below. Specifically, this section describes: life-history information and population trends of SJR fall-run Chinook salmon and steelhead; fall-run Chinook salmon inflow needs, including the functions supported by inflows and the relationship between flows and SJR basin fall-run Chinook salmon survival and abundance; and the importance of the natural hydrograph in supporting ecosystem processes for Chinook salmon, steelhead, and other native species. There is very little specific information available concerning the relationship between SJR steelhead survival and abundance and flow. However, steelhead co-occurs with fall-run Chinook salmon in the SJR basin and both species have somewhat similar environmental needs for river flows, cool water, and migratory corridors. As a result, conditions that favor fall-run Chinook salmon are assumed to provide benefits to co-occurring steelhead populations, and other native fishes (NMFS 2009a).

The information discussed above concerning flow needs of fish and wildlife beneficial uses in the SJR basin is used to develop a range of potential alternative SJR flow objectives to protect fish and wildlife beneficial uses. These alternatives do not necessarily represent the alternatives that will be evaluated in the environmental document being prepared in the support of any amendment to the SJR flow objectives in the Bay-Delta Plan. Instead, these alternatives represent the likely range of alternatives that will be analyzed. This range will be further refined to develop alternatives for analysis in the environmental review process. The potential environmental, economic, water supply, and related impacts of the various alternatives will then be analyzed and disclosed prior to any determination concerning changes to the existing SJR at flow objectives. Based on this information and the following scientific information, the State Water Board will determine what, if any, changes to make to the SJR flow objectives in the Bay-Delta Plan. The State Water Board may choose to adopt one of the identified alternatives or an alternative that falls within the range of the various alternatives analyzed.

3.1.3 Life-History and Population Trends of SJR Fall-Run Chinook Salmon and Central Valley Steelhead[2]

Within the Central Valley region three Evolutionary Significant Units (ESUs) of Central Valley Chinook salmon (*Oncorhynchus tshawytscha*) and one Distinct Population Segment (DPS) of Central Valley steelhead (*Oncorhynchus mykiss)* have been identified. The three ESUs of Chinook salmon are winter-, spring-, and fall-run (late-fall run is included in the fall-run ESU) (DFG 2010b). The steelhead DPS is defined as the portion of the *O. mykiss* population that is "markedly separated" from the resident life form, rainbow trout, due to physical, ecological, and behavioral factors. These separate ESU/DPS classifications are based on the timing of spawning migration, stage of sexual maturity when entering freshwater, timing of juvenile or smolt outmigration, and by the populations' reproductive isolation and contribution to the genetic diversity of the species as a whole.

The following two sections of this report only address steelhead and Chinook salmon within the proposed project area, the mainstem SJR and the major SJR tributaries. This area contains a single diversity group known as the Southern Sierra Nevada Diversity Group. This group is currently only comprised of Central Valley fall-run Chinook salmon ESU and Central Valley Steelhead DPS.

3.2 Fall-Run Chinook Salmon

The SJR and the major SJR tributaries historically supported spring, fall, and possibly late-fall run Chinook salmon. The SJR and major SJR tributaries did not support winter-run Chinook salmon historically, which is most likely due to essential habitat not being available. Spring-run Chinook salmon in the SJR became extinct following the construction of impassible dams on the mainstem SJR and the major SJR tributaries. In addition, operating procedures of the dams created conditions that lead to the extirpation of any remaining populations of late-fall run Chinook salmon from the system. Fall-run Chinook salmon are the only remaining population present in the SJR basin and the entire population is classified under the Southern Sierra Nevada Diversity Group.

3.2.1 Life History

Chinook salmon are an anadromous and semelparous species that spend most of their adult life in open ocean waters, only returning to freshwater streams to spawn a single time before they die. The life history of Chinook salmon is exhibited in two distinct types, an ocean-type and a stream-type. Fall-run Chinook salmon exhibit the ocean-type life history; meaning that they have adapted to spend most of their lives in the ocean, spawn soon after entering freshwater in summer and fall, and as juveniles, migrate to the ocean within a relatively short time (3 to 12 months; Moyle 2002). Fall-run Chinook salmon typically remain in the ocean for 2 to 6 years before returning to their natal streams to spawn (McBain and Trush 2002). However, some salmon return to their natal streams after only one year of ocean maturation; these life history variants are called "jacks" if male and "jills" if female (PFMC 2007, Williams 2006, Moyle 2002). Jack and jill salmon

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[2] Unless otherwise cited, the information presented in this section is largely extracted from *The Public Draft Recovery Plan for the Evolutionary Significant Units of Sacramento Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead* (NMFS 2009b).

are much smaller than the typical older adult male and female fall-run Chinook salmon and are thought to serve a distinct purpose in the spawning stage of life history. Table 3-1 lists the approximate timing of fall-run Chinook salmon life history phases.

3.2.2 Adult Migration

The majority of fall-run Chinook salmon adults begin upstream migration, returning to their natal spawning areas at age three. However, migration can occur anytime between 2 to 6 years after emerging as juveniles. The literature on migration timing supports a broad range of months in which upstream migration can occur, beginning as early as July and continuing through early January (DFG 2010a, BDCP 2009, DFG 1993). However, some researchers report a truncated migration period from October through early January, with peaks in migration occurring between October and December (DFG 2010a).

Fall-run Chinook salmon enter freshwater at an advanced stage of maturity, move rapidly to suitable spawning areas on the mainstem SJR and lower reaches of the major SJR tributaries, often forgoing feeding and relying on stored energy reserves, and spawn within a few days or weeks of freshwater entry (Healey 1991). Adult fall-run Chinook salmon use olfactory and other orientation cues to locate their natal streams, many of which are related to stream flows (NMFS 2009a, DFG 2010a). If stream flows and other water quality parameters are not sufficient, adult fish may delay their migration until a more suitable year. Migrating adult Chinook salmon exhibit a crepuscular movement pattern, with the majority of migration activities occurring at dawn and dusk hours (NMFS 2009a).

Information on the migration rates of adult Chinook salmon in freshwater is lacking and primarily comes from studies conducted in the Columbia River basin (Matter and Sandford 2003). Keefer et al. (2004) found migration rates of Chinook salmon ranging from approximately 10 km per day to greater than 35 km per day. These migration rates are primarily correlated with date, and secondarily with discharge, year, and reach, in the Columbia River basin (Keefer et al. 2004). Matter and Sanford (2003) documented similar migration rates of adult Chinook salmon ranging from 29 to 32 km per day in the Snake River.

Spawning and Holding

Historically, adult fall-run Chinnok salmon spawned in the valley floor and on lower foothill reaches of the major SJR tributaries downstream of the major rim dams (DFG 1993). This limited amount of spawning habitat was probably due to the deteriorating physical condition of the fish upon freshwater entry (Rutter 1904 as cited in Yoshiyama et al. 2001). Once fall-run Chinook salmon enter freshwater and begin migration to spawning habitat they generally do not hold in pools for long periods of time (generally one week or less). This is also due to their deteriorating physical condition and is attributable to their ocean-type life history. However, they may briefly use large resting pools during upstream migration (Mesick 2001, DFG 2010a) as refuge from predators, insulation from solar heat, and to help conserve energy.

Spawning may occur at any time between October and December, with peaks in October and November (BDCP 2009, McBain and Trush 2002, DFG 1993). Redds are constructed in gravel beds that are located at the tails of riffles or holding pools, with clean, loose gravel in swift flows which provide adequate oxygenation of incubating eggs, and suitable water temperatures (NMFS 2009a). The upper preferred water temperature for spawning is 56ºF (Chambers 1956, Smith 1973, Bjorn and Reiser 1991, and Snider 2001 as cited in NMFS 2009a), and salmon will continue (or attempt to continue) upstream migration until water temperature is acceptable for spawning. The range of water depths and velocities in spawning beds that Chinook salmon find acceptable is very broad, but generally if a salmon can successfully swim in the spawning bed they can spawn (NMFS 2009a).

Adult fall-run Chinook salmon females develop redds in their natal streams by excavating gravel before depositing eggs and burring them with gravel and cobble substrate. Fall-run Chinook salmon have large eggs and carry on average 4,900 to 5,500 per spawning female (Moyle 2002). However, the actual number of eggs carried depends on the age and size of the fish (Williams 2006). Successful spawning requires closely coordinated release of eggs and sperm by the spawning fish, which follows courtship behavior that may last for several hours (Williams 2006). Competition for the chance to fertilize redds frequently occurs and adult males will often fight for a single redd. In this situation, jack salmon have a significant advantage over adult males. Being much smaller than a full sized adult male salmon, jack salmon often “sneak” past the fighting adults and fertilize the redd without being noticed (Moyle 2002). It is not uncommon for a redd to be fertilized by more than one male, and a male can fertilize more than one redd. This combination of large and small males ensures a high degree of egg fertilization (roughly 90 percent, Moyle 2002).

It is also common, if available spawning habitat is limited, for two redds to overlap. This proves to be a significant disadvantage for the bottom redd, as the top redd has greater access to a steady flow of oxygen-containing waters (Moyle 2002). After a male Chinook salmon fertilizes the female’s redd, the pair may defend the redd from other spawning salmon before death.

3.2.3 Egg Development and Emergence

Timing of egg incubation for fall-run Chinook salmon begins with spawning in October and can extend into March, depending on water temperatures and timing of spawning (BDCP 2009). Egg incubation generally lasts between 40 to 60 days, depending on water temperatures, with optimal water temperatures for egg incubation ranging from 41ºF to 56ºF (Moyle 2002). In order to successfully hatch, incubating eggs require specific conditions related to their physical habitat such as: protection from floods, siltation, desiccation, predation, poor gravel percolation, and poor water quality (NMFS 2009a).

Newly hatched salmon are called alevins, and remain in the gravel for about 4 to 6 weeks until the yolk-sac has been absorbed (NMFS 2009a). Once the yolk sack has been completely absorbed, alevins are called fry, which are roughly one inch long. Most fall-run Chinook salmon fry emerge from the gravel between November and March, with peak emergence occurring by the end of January (Table 3.1; BDCP 2009; McBain and Trush 2002). Once fry grow to be roughly two inches in length and become camouflaged in color, exhibiting vertical stripes (parr-marks) on their body, they are called parr (Williams 2006).

3.2.4 Rearing and Outmigration

Both the quantity and quality of habitat determine the productivity of a watershed for rearing and outmigrating Chinook salmon (PFMC 2000). Rearing and outmigration of fall-run Chinook salmon occurs simultaneously, and can occur in a variety of complex habitats within streams, rivers, floodplains, and estuaries (PFMC 2000). Typically rearing and outmigration occurs anywhere from December through July, with peaks in outmigration occurring between late April and May (Table 3.1; Mesick 2001, DFG 1993). Fry and parr move downstream into the mainstem SJR within a few weeks after emergence from redds (DFG 2010a). Downstream migrations of fry and parr occur in response to many factors, including inherited behavior, habitat availability, flows, competition for space and food, water temperature (Jones and Stokes 2005), increasing turbidity from runoff, and changes in day length. Common migration movements typically occur during dawn and dusk hours, following a crepuscular movement pattern, similar to that of adults.

On average, juvenile fall-run Chinook salmon rear in riverine and estuarine habitats for three to seven months before they enter the Pacific Ocean (DFG 2010a). However, some juveniles may delay outmigration to the Pacific Ocean until they are one year old, if freshwater habitat is conductive to rearing (BDCP 2009; Moyle 2002). Successful rearing is most often associated with magnitude, timing and duration of flows, and connectivity with associated riparian and floodplain habitat (Mesick 2007). Increased flows and connectivity to and between associated riparian habitat not only maintains physical habitat conditions, but also provides suitable water quality and forage species that support juvenile salmonid growth. By expanding available habitat into riparian habitats, salmon are also provided with increased amounts of shade, submerged and overhanging large and small woody debris, root wads, log jams, beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks.

In the SJR and on the major SJR tributaries a higher proportion of juvenile fall-run Chinook salmon rear in rivers, and when available, connected floodplains, for some time before migrating to the Pacific Ocean (Williams 2006). Juvenile salmonids that have the opportunity to use shallow water habitats are provided with a greater advantage than juveniles that cannot use them. Shallow water habitats benefit rearing fry and parr, and have been found to be more productive than main river channels (Sommer et al. 2001). This is due in part to higher growth rates, favorable environmental temperatures, and higher prey consumption rates, including greater selection of zooplankton, small insects, and other microcrustaceans (DFG 2010a; NMFS 2009a, Sommer et al. 2001, DFG 1993). Juveniles that use shallow water habitats become larger during smoltification than juveniles that do not, which can lead to earlier exit of the Bay-Delta and therefore gain preferred timing of ocean entry, along with a greater ability to evade predators along the way.

Smoltification usually begins when juveniles reach between three to four inches and is a physical and chemical change in the juvenile salmonid (DFG 2010a). As the juvenile salmon's body chemistry changes from freshwater tolerant to saltwater tolerant in preparation for the oceanic environment, preferred rearing is often where ambient salinity is up to 1.5 to 2.5 ppt (NMFS 2009a). Smoltification is characterized by increased levels of hormones, osmoregulatory changes to tolerate a more saline environment, and replacement of parr marks for a silvery body with blackened fins that are important for camouflage in an ocean environment. Although it is common to refer to juvenile Chinook that rear in-river for two to three months and migrate toward the Delta between April and June as smolt migrants, most are only part way along in the smolting process, at least when they begin migrating (Williams 2006). Once in the Delta, juvenile salmon can rear for an additional one to three months during the smoltification process before moving into the San Francisco Bay (Williams 2006). Juvenile Chinook salmon smolts spend, on average, 40 days migrating from the convergence of the Sacramento and SJR in the Bay-Delta to the Gulf of the Farallones at the Golden Gate Bridge (MacFarlane and Norton 2002). A summary of fall-run Chinook salmon life history stages is provided in Table 3-1.

Table 3-1. Generalized Life History Timing of Central Valley Fall-Run Chinook Salmon

	Upstream Migration Period	Spawning Period	Incubation	Juvenile Rearing and Outmigration	Rearing Duration
Overall	July to early January	October to December	October to March	December to July	3 to 12 Months
Peak	October to December	October to November	40 to 60 days	Late April to Late May	3 to 7 Months

3.2.5 Population Trends

Historically, fall-run Chinook salmon were the most abundant run in the Central Valley and were seen on every major SJR tributary and stream in the SJR basin. Total historical adult production (spawning runs plus ocean harvest) of fall- and late fall-run Chinook salmon in the Central Valley was said to have approached 300,000 fish (DFG 1993). In the SJR basin, annual numbers ranged from 1,100 to 77,500 fish from 1967 to 1997 (Moyle 2002). However, with the onset of gold mining in the Sierras, populations of Chinook salmon began to diminish. In 1928 the DFG issued a bulletin reporting that there were very few salmon remaining in the SJR above the Merced River due to increased water diversions and the operation of upstream hydropower reservoirs (NMFS 2009c). Over time, as increased infrastructure and demand for water further altered the SJR basin, Chinook salmon populations declined further, some to extinction.

The operation of the Friant Dam, which began in 1947, blocked access to about one-third of the spawning habitat in the mainstem SJR and eliminated perennial flows below the dam (Mesick 2001). Within just a few years spring-run Chinook salmon (ranging from 2,000 and 56,000 between 1943 and 1948; DFG 1993) were extirpated, and fall-run Chinook salmon populations in the SJR basin declined even further. Because of these negative effects on Chinook salmon, several legal actions were taken in the case of Natural Resource Defense Council (NRDC) et al. v. Kirk Rodgers et al., which resulted in the 2006 Settlement that was termed the San Joaquin River Restoration Program (SJRRP; NMFS 2009c). Currently, a multi-agency effort is underway to: 1) augment channels and provide structural modifications; 2) increase flows from Friant Dam to the confluence of the Merced River, and 3) return viable populations of spring-run and fall-run Chinook salmon to the reach of the SJR above the confluence of the Merced River (NMFS 2009c). Reintroduction of spring-run and fall-run Chinook salmon is currently required to take place by December 31, 2012 (SJRRP 2010).

Spring-run Chinook salmon were probably more abundant pre-disturbance, based on the habitat and hydrology of the SJR basin (Williams 2006). However, the only Central Valley Chinook salmon ESU that remains today in the SJR basin is fall-run. Annual escapement of fall-run Chinook salmon has been estimated since 1940, but is poorly documented prior to 1952. Data from 1952 to present suggests that major SJR tributary fall-run boom and near-bust cycles have existed for at least the last 80 plus years.

Methods for estimating the number of returning adults have improved over the last five decades, and in the last 30 years have shown wide fluctuations in number of returning fish (DFG 2010b). The trends in salmon escapement of the remaining major SJR tributary populations of fall-run Chinook salmon appear to be closely associated with the magnitude and duration of flows in winter and spring months when juveniles are rearing in the rivers and smolts are migrating out of the system (Mesick et al. 2007). Higher returns are correlated with Above Normal and Wet water year types, and low escapements are correlated with Below Normal, Dry, and Critically Dry water years. Figure 3-1 shows the historic escapement of fall-run Chinook salmon for each of the major SJR tributaries.

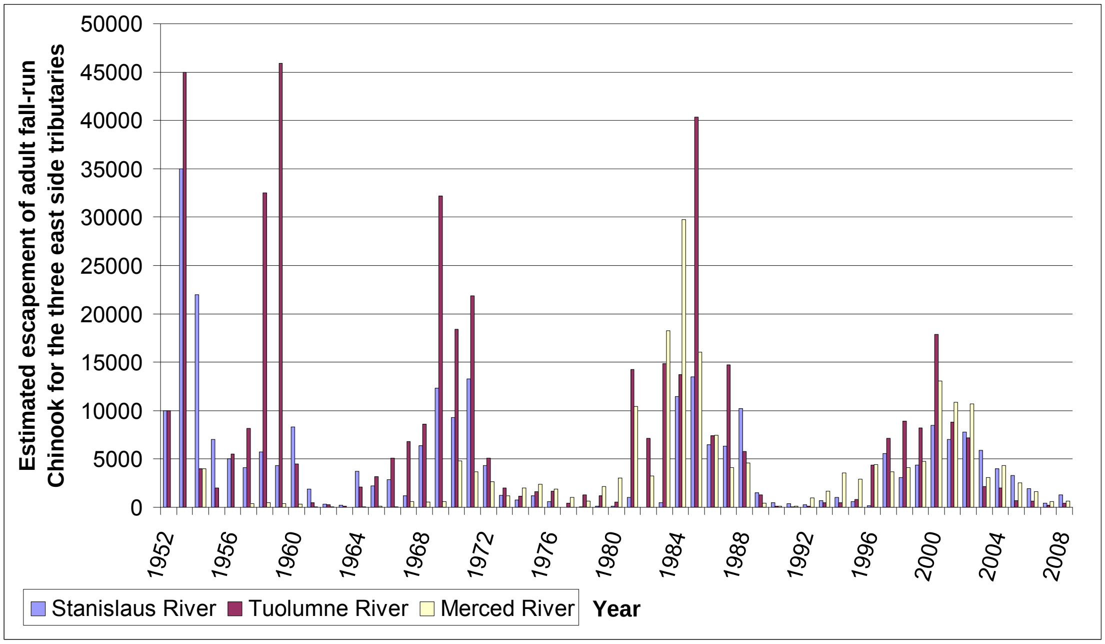


Figure 3-1. Estimated escapement of adult fall-run Chinook salmon for the major SJR tributaries 1952 to 2008 (Source: DFG 2009b Grandtab Report)

Figure 3-2 shows the historic combined escapement for the SJR basin including the major SJR tributaries. As shown in the graphs, fall-run Chinook salmon escapement to the mainstem SJR and major SJR tributaries has been relatively low since the 1950s and has exhibited a declining trend with populations ranging from several hundred adults to approximately 80,000 adults. In the mid-1960s, fall-run Chinook salmon escapement was estimated to be about 2,400 fish for the major SJR tributaries. The early1960s bust was followed by a late 1960s and early 1970s boom cycle which had an average escapement of around 45,000 fall-run Chinook salmon at its peak from1969 to 1971. This boom was followed by yet another bust from approximately 1972 to 1979 where average salmon escapement was roughly 6,000 fish. From 1980 to 1989 fall-run Chinook salmon escapement declined once again from approximately 33,000 fish to 22,000 fish on average in the 2000 to 2008 period. Record high returns since the mid-80s were estimated from 2000 to 2003; with an estimated natural spawner escapement for the year 2000 of about 40,000 fish (total spawner escapement was estimated at 47,000 fish). This was followed by a precipitous decline in 2004 which has continued through 2009.

Recent escapement of adult fall-run Chinook salmon to the SJR basin was estimated at approximately 2,800 fish in 2008 (2009b DFG Grandtab Report) and in 2009 slightly increased to approximately 3,600 fish (DFG 2010b). Recent declines in Central Valley Chinook salmon populations in 2008 and 2009 have been largely attributed to poor ocean conditions and have resulted in significant curtailment of west-coast commercial and recreational salmon fishing. Although ocean conditions have played a large roll in the recent declines of fall-run Chinook salmon, it is superimposed on a population that has been declining over a longer time period (Moyle et al. 2008). As shown in Figure 3-2, average fall-run Chinook salmon populations were steadily declining before the onset of poor ocean conditions in the 21st century as shown by the trendline which indicates a declining trend over the last six decades. Poor ocean conditions only exacerbated the negative environmental conditions that fall-run Chinook salmon were already experiencing.

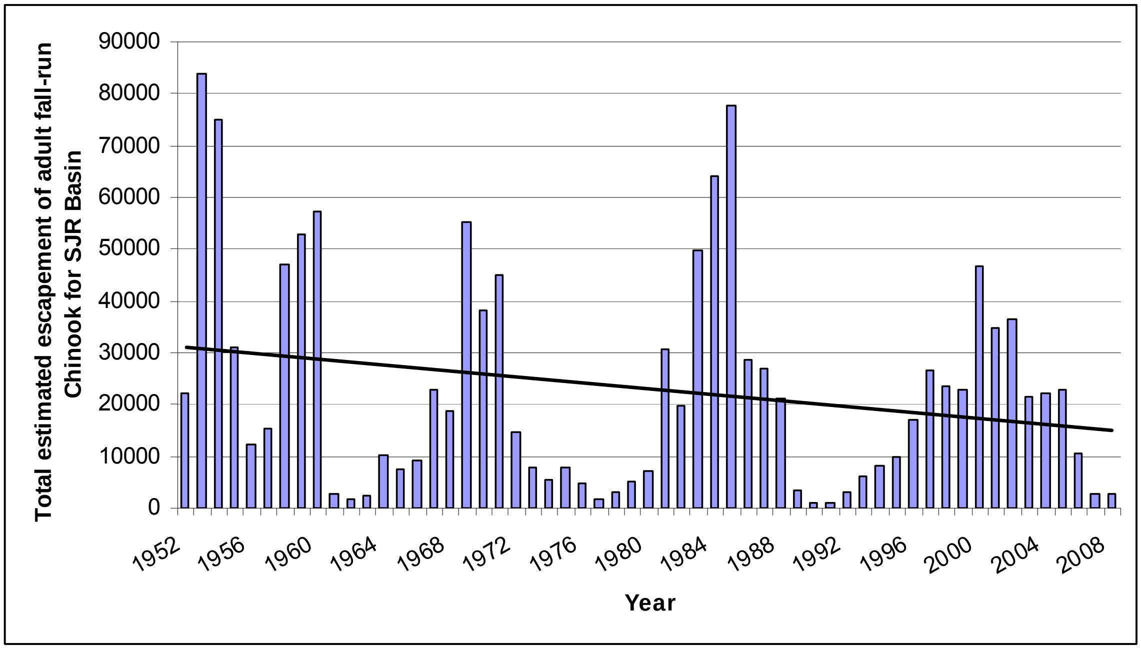


Figure 3-2. Total estimated escapement of adult fall-run Chinook for SJR basin from 1952 to 2008 (Source: DFG 2009b Grandtab)

The classic boom and near bust escapement cycle that SJR basin fall-run Chinook salmon exhibit varies based on water year type and other environmental conditions. Since 1952 there has been a steady decrease in the average number of adults returning to the SJR basin. This can mainly be attributed to the completion of impassable dams and subsequent altered flow and temperature regimes along with other human influences. However, in addition to the steady decline of SJR basin fall-run Chinook salmon, another and potentially more serious decline has emerged in the last two decades. Escapement of naturally produced fish has declined since the 1990s bust, as compared to previous years, and hatchery produced fish have shown a substantial increase, as shown in Figure 3-3. Greene (2009) reports that this increase is most likely a result of overproduction of hatchery fish following low escapement numbers of wild fish in the late 1980s to early 1990s.

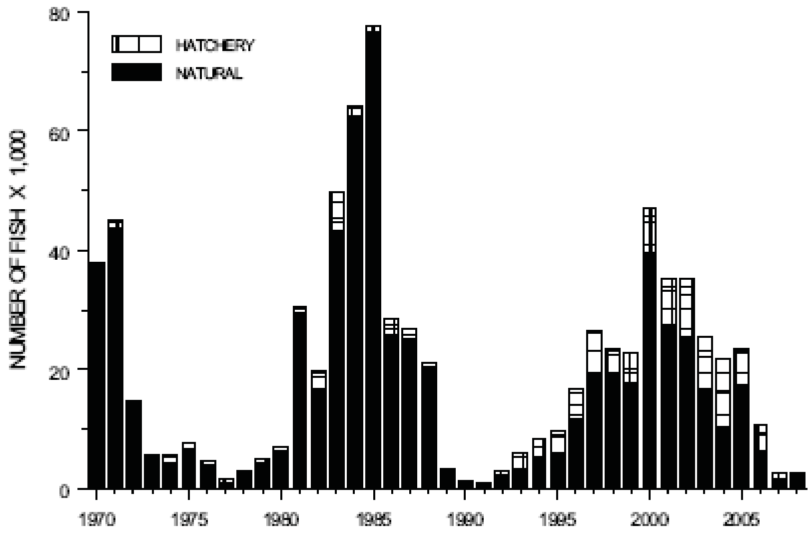


Figure 3-3. Annual natural and hatchery fall-run Chinook escapement to the SJR basin 1970 to 2008 (Source: Greene 2009)

The near bust cycle of the SJR basin fall-run Chinook salmon in the early 1990s, as shown in Figure 3.3, can commonly be described as a "population bottleneck" of the wild SJR Chinook salmon stock. This was quickly followed by overproduction of hatchery produced fish which lead to increased hatchery escapements in following years, which is also represented in Figure 3.3. Instead of supplementing the fall-run Chinook salmon fishery, hatchery managers have inadvertently begun replacing wild stocks with hatchery fish. This has lead to increased hatchery introgression with wild fall-run Chinook salmon stocks. Not only does this undermine the genetic integrity of the wild fall-run Chinook salmon genome, but it also leads to reduced genetic diversity between wild and hatchery fish. Based on the recent population declines and the trend of reduced peak abundance over time leading to reduced population resiliency and genetic diversity, the DFG considers the fall-run Chinook salmon runs in the SJR to be in poor condition, and as a result remains at risk of extinction from a single catastrophic event.

3.3 Winter-Run Steelhead

Oncorhychus mykiss may exhibit either anadromous (steelhead) or freshwater (resident) residency life history types, depending on habitat conditions (NMFS 2009c). Within the anadromous life history type, steelhead are either classified as stream-maturing or ocean-maturing. This classification is based on the state of sexual maturity at the time of freshwater entry and duration of spawning migration. Ocean maturing steelhead are commonly known as winter-run, while stream-maturing steelhead are known as summer-run (NMFS 2009a). Summer-run steelhead may have been present prior to the construction of large dams that separated them from historical spawning and rearing areas (Moyle 2002, NMFS 2009a), but are currently not found in the SJR system. Winter-run steelhead was once widely distributed throughout the Central Valley, and until recently was thought to be extirpated from the SJR system (NMFS 2009c). Today, remnant populations of Central Valley steelhead reside in the major SJR tributaries and the Calaveras River (Zimmerman 2009, Good et al. 2005, McEwan 2001).

3.3.1 Life History

Central Valley steelhead exhibit the most diverse life history strategy of the listed Central Valley anadromous salmonid species (NMFS 2009a). Primary differences between Central Valley fall-run Chinook salmon and Central Valley steelhead are that steelhead: 1) remain in tributaries for at least one year and as many as three years before smolting and outmigration; 2) are iteroparous, capable of spawning more than once before death; and 3) can produce anadromous or non-anadromous life forms (Moyle et al. 2010). Zimmerman et al. (2009) demonstrated this occurrence by performing otolith microchemistry analysis on steelhead in the Central Valley, providing evidence that there is no reproductive barrier between resident and anadromous forms.

Winter-run steelhead are considered “ocean-maturing” steelhead, entering freshwater fully developed and spawning shortly after river entry (NMFS 2009c). Winter-run steelhead typically spend one to three years, but up to as many as five years, in the ocean and spawn upon re-entry to freshwater streams. In the SJR basin, winter-run steelhead populations have been reduced to remnant levels. There is speculation that this is due to less favorable migratory conditions which have resulted in an increased population of the resident form of *O. mykiss*. See Table 3-2 for approximate timing of winter-run steelhead life history phases.

3.3.2 Adult Migration

Winter-run steelhead may remain in the ocean from one to five years, after emigration as one to three year olds, growing rapidly as they feed in the highly productive currents along the continental shelf (USFWS 2001). The majority of winter-run steelhead return to their natal streams and spawn as four or five year olds (NMFS 2009c; USFWS 2001). High flow events help steelhead perceive the scent of their homestream waters in the San Francisco Bay and they begin upstream migration. If water quality parameters and other environmental conditions are not optimal, winter-run steelhead may delay migration to another more suitable year. Optimal immigration and holding temperatures for steelhead have been reported to range from 46°F to 52°F (DFG 1991b as cited by NMFS 2009c). Winter-run steelhead can begin upstream migration beginning as early as July and continue through April, with peaks in upstream migration between October and February (Table 3.3; DOI 2008, Moyle 2002, McBain and Trush 2002).

3.3.3 Spawning and Holding:

Winter-run steelhead enter fresh water with well developed gonads and spawn downstream of impassable dams on the major SJR tributaries and the mainstem SJR, similar to fall-run Chinook salmon (NMFS 2009c). Spawning typically occurs from December through June (Table 3.3; DOI 2008, McBain and Trush 2002), with peaks occurring between January and March (Table 3.3; NMFS 2009a). Winter-run steelhead spawn where cool, well oxygenated water is available year-round (McEwan and Jackson 1996). The preferred water temperature for spawning ranges from 30°F to 52°F (DFG 2000 as cited by NMFS 2009c).

The female winter-run steelhead selects a site with good inter-gravel flow, usually in coarse gravel in the tail of a pool or in a riffle, excavates a redd with her tail, and deposits eggs while an attendant male fertilizes them. Moyle (2002) estimates that adult steelhead generally carry about 2,000 eggs per kilogram of body weight. This translates to an average fecundity of about 3,000 to 4,000 eggs for an average steelhead female (Williams 2006). The actual number of eggs produced is, however, dependent on several variables such as: race, size, age (Leitritz and Lewis 1976), and stressful environmental factors (such as high temperatures, pesticides, and disease).

Unlike Chinook salmon, which are semelparous and spawn only once before dying, steelhead are iteroparous and are capable of spawning more than once before dying (Busby et al. 1996). It is, however, rare for steelhead to spawn more than twice before dying, and most that do so are females (Busby et al. 1996). Iteroparity is more common among southern steelhead populations than northern populations (Busby et al. 1996), and although one-time spawners are still the great majority, Shapovalov and Taft (1954) reported that repeat spawners are relatively numerous (17.2 percent) in California streams. Another dissimilarity between steelhead and Chinook salmon is the duration of courtship and spawning behaviors. Briggs (1953) observed steelhead spawning for from one to two days up to as long as a week (Williams 2006), with average residence time around the redd lasting a few days after fertilization. After fertilization of the redd, the female winter-run steelhead attempt the journey back to the Pacific Ocean to continue maturation in preparation for another spawning year or die along the way.

3.3.4 Egg Development and Emergence

Depending on water temperature, winter-run steelhead eggs may incubate in redds for four weeks to as many as four months before hatching as alevins (NMFS 2009c, McEwan 2001). Winter-run steelhead eggs that incubate at 50°F to 59°F hatch in about four weeks, and fry emerge from the gravel anywhere from four to eight weeks later (Shapovalov and Taft 1954, DFG 1993). Hatching of winter-run steelhead eggs in hatcheries takes about 30 days at 51°F (Leitritz and Lewis 1980 as cited in McEwan 2001). Incubating eggs can reportedly survive at water temperatures ranging from 35.6°F to 59°F (Myrick and Cech 2001), with the highest survival rates at water temperature ranging from 44.6°F to 50.0°F (Myrick and Cech 2001).

Incubation for winter-run steelhead eggs typically occurs between the months of December through June (Table 3.3; DOI 2008, McBain and Trush 2002) with factors such as redd depth, gravel size, siltation, and temperature affecting emergence timing (Shapovalov and Taft 1954). Newly emerged fry usually migrate into shallow (<36 cm), protected areas associated with the stream margin (McEwan and Jackson 1996), or low gradient riffles, and begin actively feeding (USFWS 2001). With increasing size, fry move into higher-velocity, deeper, mid-channel areas, generally in the late summer and fall.

3.3.5 Rearing and Outmigration

Juvenile winter-run steelhead rear in cool, clear, fast flowing permanent freshwater streams and rivers where riffles predominate over pools, for one to three years (one percent spend three years; DFG 2010a). This extended amount of time needed for rearing allows the juvenile to use the freshwater system over a broader suite of months when compared to fall-run juveniles. During this time, some winter-run steelhead may use warm shallow water areas where feeding and growth are possible throughout the winter (NMFS 2009a). These areas, such as floodplain and tidal marsh areas, allow steelhead juveniles to grow faster, which in turn requires a shorter period in freshwater before smoltification occurs (NMFS 2009a, NMFS 2009c).

Some winter-run steelhead may not migrate to the Pacific Ocean (anadromous) at all and remain in rivers (potadromous) or lakes (limnodromous) as resident fish, avoiding

Delta migration completely (Moyle 2002). Populations that have both anadromous and resident forms are likely to have an evolutionary advantage. Resident fish persist when ocean conditions cause poor survival of anadromous forms, and anadromous forms can re-colonize streams in which resident populations have been wiped out by drought or other disasters. Less is known about the migration of juvenile winter-run steelhead in the Central Valley than about juvenile fall-run Chinook salmon, but better information is now becoming available from screw traps that are located in high velocity water that can catch yearlings in significant numbers (Williams 2006). Interpretation of the data, however, is complicated by the large proportion of the population that has adopted a resident life history pattern; making it unclear if winter-run steelhead juveniles captured in the traps are migrating to the ocean (Williams 2006).

Winter-run steelhead juveniles generally begin outmigration anywhere between late December through July, with peaks occurring between March and April (Table 3.3; DOI 2008, McBain and Trush 2002). During their downstream migration, juveniles undergo smoltification, a physiologic transformation enabling them to tolerate the ocean environment and its increased salinity. Winter-run steelhead smoltification has been reported to occur successfully at 44 to 52°F (Myrick and Cech 2001; DOI 2008). Winter-run steelhead life history stages are summarized in Table 3-2 .

Table 3-2. Life History Timing of Central Valley Winter-Run Steelhead

	Upstream Migration Period	Spawning Period	Incubation	Juvenile Outmigration	Rearing Duration
Overall	July to April	December to June	December to June	December to July	1 to 3 Years
Peak	October to February	January to March	30 days	March to April	1 to 2 Years

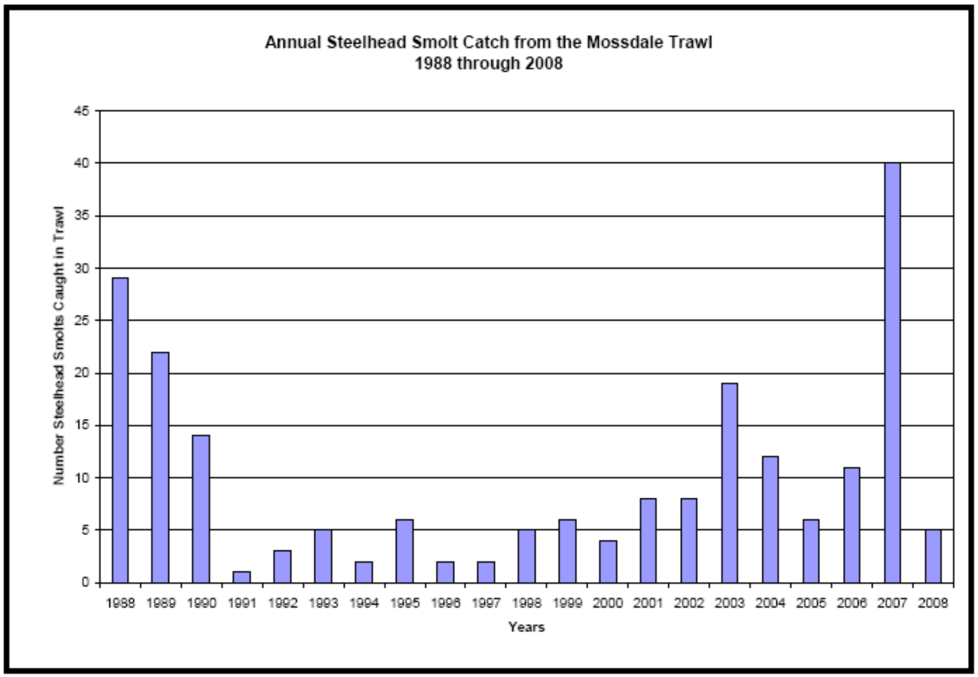
3.3.6 Population Trends

There is little historical documentation regarding winter-run steelhead distribution in the SJR basin, presumably due to the lack of an established steelhead sport fishery (Yoshiyama et al. 1996). Historical populations of winter-run steelhead, however, extended into the headwaters of the SJR and the major SJR tributaries (Moyle 2002). The California Fish and Wildlife Plan of 1965 estimated the combined annual steelhead run size for Central Valley and San Francisco Bay tributaries to be about 40,000 during the 1950s (DFG 1965, as cited in McEwan and Jackson 1996). The spawning population during the mid-1960s for the Central Valley basin was estimated at nearly 27,000 (DFG 1965, as cited in McEwan and Jackson 1996). These numbers were comprised of both wild stocks and hatchery stocks of Central Valley steelhead. In 1996 McEwan and Jackson estimated the annual run size for the Central Valley basin to be less than 10,000 adults by the early 1990s.

Until recently, winter-run steelhead was thought to be extirpated from the SJR and major SJR tributaries. DFG records contain reference to a small population characterized as emigrating smolts that are captured at the DFG Kodiak trawl survey station at Mossdale on the lower SJR each year (EA EST1999). DFG staff prepared catch summaries for juvenile migrant winter-run steelhead on the SJR near Mossdale, which represents migrants from the SJR basin including the major SJR tributaries (NMFS 2009a). Based on trawl recoveries at Mossdale between 1988 and 2002, as well as rotary screw trap efforts on the major SJR tributaries, DFG found that resident rainbow trout do occur in all tributaries as migrants, and that the vast majority of them occur on the Stanislaus River (NMFS 2009a).

On January 5, 2006, NMFS reaffirmed the threatened status of the Central Valley steelhead and applied the DPS policy to the species because the resident and anadromous life forms of *O. mykiss* remain “markedly separated” as a consequence of physical, ecological and behavioral factors, and may therefore warrant delineation as a separate DPS (NMFS 2009c). NMFS concluded that the Central Valley steelhead DPS was in danger of extinction because of habitat degradation and destruction, blockage of freshwater habitats, water allocation problems, the pervasive opportunity for genetic introgression resulting from widespread production of hatchery steelhead, and the potential ecological interaction between introduced stocks and native stocks (NMFS 2009a).

Currently, winter-run steelhead still remain in low numbers on the major SJR tributaries below the major rim dams, as shown by DFG catches on the mainstem SJR near Mossdale (Figure 3-4) and by otolith microchemistry analyses documented by Zimmerman (2009). However, due to the very limited amounts of monitoring in the Central Valley, data is lacking regarding a definitive population size within each tributary for winter-run steelhead. The little data that does exist indicates that the winter-run steelhead population continues to decline (Good et al. 2005) and none of these populations are viable at this time (Lindley et al. 2007). Recent declines are likely due to a combination of declining habitat quality, increased water exports, and land use practices that have reduced the relative capacity of existing winter-run steelhead rearing areas (NMFS 2009c, McEwan 2001).



Annual number of Central Valley steelhead smolts caught while Kodiak trawling at the Mossdale monitoring location on the SJR (Marston 2004, SJRGA 2007, Speegle 2008) (NMFS 2009a).

Figure 3-4. Annual number of Central Valley steelhead smolts

3.4 Fall-Run Chinook Salmon Inflow Needs

Flows on the SJR affect various life stages of fall-run Chinook salmon including: adult migration, adult spawning, egg incubation, juvenile rearing, and juvenile emigration to the ocean. Inflows from the SJR to the Delta have significant effects on SJR basin fall-run Chinook salmon and steelhead during emigration and escapement from and to the SJR basin. Specifically, analyses indicate that the primary limiting factor for SJR fall-run Chinook salmon survival and subsequent abundance is reduced flows during the spring when fry and smolts are completing the rearing phase of their life cycle and migrating from the SJR basin to the Delta (DFG 2005a, Mesick and Marston 2007, Mesick et al. 2008, and Mesick 2009). As such, while SJR flows at other times are also important, the focus of the State Water Board's current review is on inflows to the Delta during the critical spring period of February through June.

3.5 Functions Supported by Spring Flows

Freshwater flows during the late winter and spring period provide several functions that affect juvenile fall-run Chinook salmon survival and abundance as they move downstream through the Delta. Chinook salmon migration patterns are adapted to natural variations in flow conditions (Lytle and Poff 2004). Monitoring shows that both juvenile and adult salmon begin migrating during the rising limb of the hydrograph (DOI 2010). For juveniles, pulse flows appear to be more important than for adults (DOI 2010). Delays in precipitation producing flows may result in delayed emigration which may result in increased susceptibility to in-river mortality from predation and other poor habitat conditions (DFG 2010d).

Juvenile Chinook salmon exhibit different migration and life history strategies adapted to natural variations in flows (Lytle and Poff 2004). Under natural conditions in the SJR basin, flows on the tributaries and the mainstem SJR generally increase in response to snow-melt and precipitation during the spring period, with peak flows occurring during May. These increased flow conditions throughout the late winter to spring period on all of the SJR salmonid producing tributaries (the Merced, Tuolumne, and Stanislaus) are important to maintain Chinook salmon populations with varied genetic and life history strategies in different year types to insure continuation of the species over different hydrologic and other conditions. Depending on several factors including flows, some salmon migrate as fry during early flow events, while others rear in the river for a period and migrate as larger smolts when flows increase later in the season. Fry generally begin migrating in the early spring, with peak smolt outmigration occurring during April and May (USFWS Mossdale Trawl data). In late winter/early spring, increased flows provide improved transport downstream and improved rearing habitat for salmon migrating as fry within a few days of emergence from redds. These early spring flows also provide for increased and improved edge habitat (generally inundated areas with vegetation) and food production for salmon remaining in the river to rear during the early spring. Later in the season, higher inflows function as an environmental cue to trigger migration of smolts and facilitate transport of fish downstream, and improve migration corridor conditions (DOI 2010). Specifically, higher inflows of various magnitudes during the spring support a variety of functions including maintenance of channel habitat and transport of sediment, biota, and nutrients (Junk et al., 1989). Increased turbidity and more rapid flows, may also reduce predation of juvenile Chinook salmon (Gregory 1993; Gregory and Levings 1996, 1998). Higher inflows also provide better water quality conditions by reducing temperatures, increasing dissolved oxygen levels, and reducing contaminant concentrations. NMFS has determined that each of these functions is significantly impaired by current conditions in the SJR basin (NMFS 2009a).

3.6 Analyses of Flow Effects on Fish Survival and Abundance

Studies that examine the relationship between fall-run Chinook salmon population abundances and flows in the SJR basin generally indicate that: 1) additional flow is needed to significantly improve protection of fall-run Chinook salmon; and 2) the primary influence on adult escapement is flow two and a half years earlier during the juvenile rearing and downstream emigration life phase of the currently escaping adult population (AFRP 2005, DFG 2005a, DFG 2010a, Mesick 2008 DOI 2010). These studies also report that the primary limiting factor for tributary abundances are reduced spring flow, and that populations on the tributaries are highly correlated with tributary, Vernalis, and Delta flows (Kjelson et al. 1981, Kjelson and Brandes 1989, AFRP 1995, Baker and Mohardt 2001, Brandes and McLain 2001, Mesick 2001, Mesick and Marston 2007, Mesick 2010 a-d).

Analyses have been conducted for several decades that examine the relationship between SJR fall-run Chinook salmon survival and abundance and flow. Specifically, analyses have also been conducted to: 1) evaluate escapement (the number of adult fish returning to the basin to spawn) versus flow two and a half years earlier when those salmon were rearing and outmigrating from the SJR basin; and 2) to estimate juvenile fall-run Chinook salmon survival at various reaches in the SJR basin and the Delta versus flow. Specific experiments using coded wire tagged (CWT) hatchery smolts released at various locations on the SJR and in the Delta to estimate survival of salmon smolts migrating through the Delta under various circumstances started in 1985. Since 2000, CWT experiments have been conducted pursuant to the VAMP and since 2007, VAMP survival studies have been conducted using acoustic telemetry devices. The VAMP and pre-VAMP CWT studies were similar and involved releasing hatchery fish at various locations on the SJR including: Old River, Jersey Point, Durham Ferry, Mossdale, and Dos Reis (Figure 3-5), and recapturing those fish downstream in the Delta. Under the pre-VAMP studies, fish were released at unspecified flow and export conditions. The 12-year VAMP study was designed to release fish at specified flows during a 31-day period from approximately mid-April through mid-May under specified export conditions in order to evaluate the relative effects of changes in Vernalis flow and SWP and CVP export rates on the survival of SJR salmon smolts passing through the Delta. As part of the original design of VAMP, theHORB (see section 2.5) was also assumed to be in place, although it was recognized that in some years the barrier would not be in place. In recent years, the HORB has not been in place and may be precluded in the future due to concerns related to protection of Delta smelt (SJRTC 2008). Following is a summary of the evaluations conducted to date regarding the relationship between flows and SJR fall-run Chinook salmon survival and abundance related to flow during the spring period.

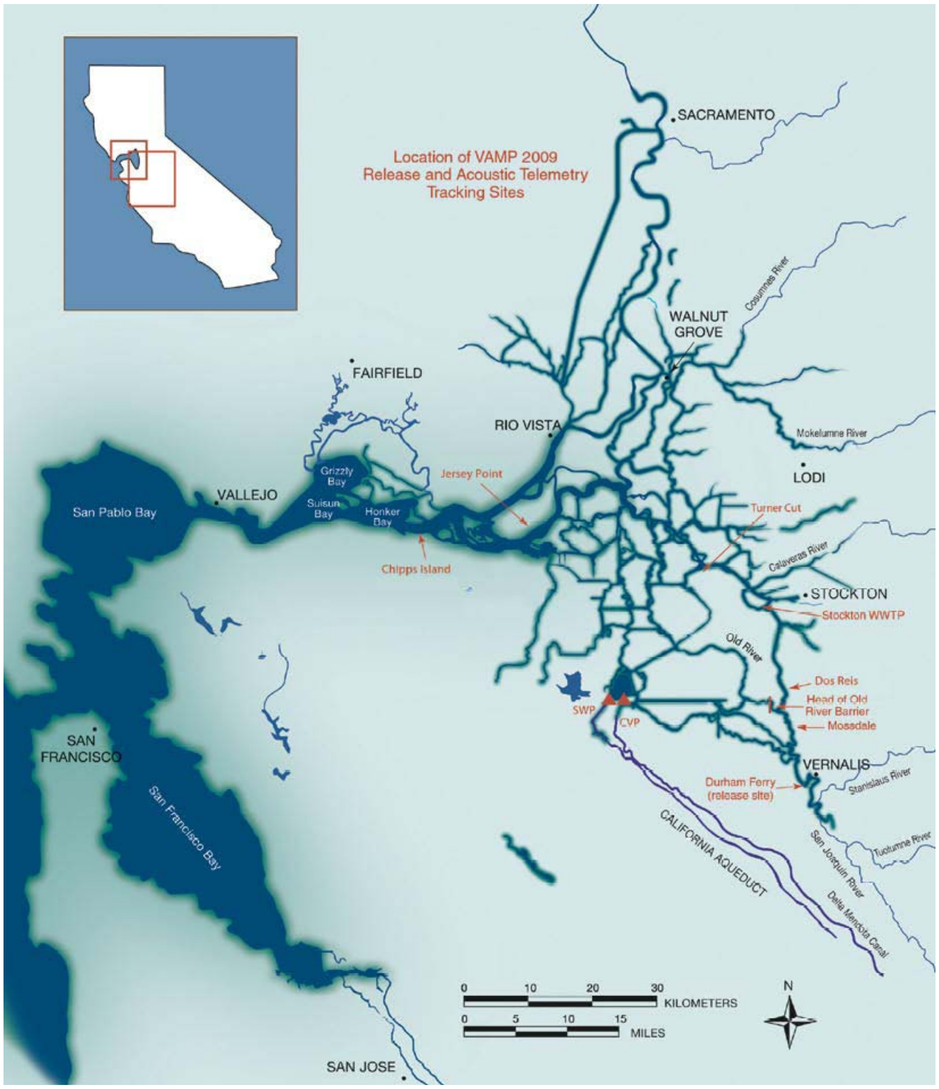


Figure 3-5. Location of VAMP 2009 Release and Acoustic Telemetry Tracking Sites (SJRGA 2010)

Beginning in 1958, Skinner reported that declines in Chinook salmon fisheries in California appear to be associated with the operation of water development projects in California and increases in ocean fishing (Skinner 1958). Specific studies related to the effects of SJR flows on fall-run Chinook salmon date back to the early 1980s. In 1981, based on studies by the Ecological Study Program for the Delta, Kjelson et al. reported on the effects of freshwater inflows on the survival, abundance, and rearing of salmon in the upstream portions of the Delta. Kjelson et al. found that peak catches of salmon fry often follow flow increases associated with storm runoff, suggesting that flow surges influence the number of fry that migrate from spawning grounds into the Delta and increase the rate of migration for fry. Kjelson et al. also found that flows in the upper SJR and Sacramento River during spawning and nursery periods apparently influence the numbers of juvenile Chinook salmon surviving to migrate to the Delta. In addition, observations made in the SJR system between 1957 and 1973 indicate that numbers of Chinook spawners are influenced by the amount of river flow during the nursery and downstream migration period (March to June) two and half years earlier. As a result, Kjelson found that it appears that flow affects juvenile survival, which in turn affects adult abundance (Kjelson 1981). In testimony before the State Water Board in 1987, Kjelson again reported that data indicates that the survival of fall-run salmon smolts migrating from the SJR basin through the Delta increases with flow. Kjelson found that increased flows also appear to increase migration rates, with smolt migration rates more than doubling as inflow increased from 2,000 to 7,000 cfs (USFWS 1987). In a 1989 paper, Kjelson and Brandes once again reported a strong long term correlation (R^2 of 0.82) between flows at Vernalis during the smolt outmigration period of April through June from 1956 to 1984 and resulting SJR basin fall-run Chinook salmon escapement from 1958 to 1986 (a two and a half year lag) (Kjelson and Brandes 1989).

In 1995, the Anadromous Fish Restoration Program[3] *Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California* (Working Paper) reported that declines in adult fall-run Chinook salmon escapement to SJR basin tributaries were attributed to inadequate streamflow in the mainstem SJR and its tributaries. The Working Paper reported that there is a positive relationship between smolt survival and spring flow in the Tuolumne River, and indicated that substantially higher flows are needed for salmon spawning and rearing on the lower Tuolumne River. The Working Paper also reported that escapement of adult Chinook salmon into the Stanislaus River is associated with spring outflow in both the SJR at Vernalis and the Stanislaus River at Ripon, and that the timing, amount, and quality of flow affects the migration and survival of both juvenile and adult Chinook salmon (USFWS 1995).

In 2001 Brandes and McLain reported on the findings of experiments regarding the effects of flows, exports, HORB operations and other factors on the abundance, distribution, and survival of SJR basin juvenile Chinook salmon. Brandes and McLain reported that survival appears greater for smolts that migrate down the mainstem SJR instead of through upper Old River. Brandes and McLain also found a statistically significant relationship between survival and river flow ($R^2 = 0.65$, *p-value* < 0.01). They found that the HORB may have served as a mechanism to increase the flows and that survival is improved via the barrier because of the shorter migration path, but also because it increases the flows down the main-stem SJR (Brandes and McLain 2001).

High net Old and Middle River (OMR) reverse flows can have several negative ecological consequences. First, net OMR reverse flows draw fish, especially the weaker swimming larval and juvenile forms, into the SWP and CVP export facilities. The export facilities have been documented to entrain most species of fish present in the upper estuary (Brown *et al*. 1996). Second, net OMR reverse flows reduce spawning and rearing habitat for native species. Any fish that enters the central or southern Delta has a high probability of being entrained and lost at the pumps (Kimmerer and Nobriga, 2008). Third, net OMR reverse flows have led to a confusing environment for migrating juvenile salmon leaving the SJR basin. Through-Delta exports reduce salinity in the central and southern Delta and as a result juvenile salmon migrate from higher salinity in the SJR to lower salinity in the southern Delta, contrary to the natural historical conditions and their inherited migratory cues. Finally, net OMR reverse flows reduce the natural variability in the Delta by drawing Sacramento River water across and into the

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[3] Representing experts possessing specific technical and biological knowledge of Central Valley drainages and anadromous fish stocks from the Department of Fish and Game, Department of Water Resources, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation and National Marine Fisheries Service (USFWS 1995).

central Delta. Due to the potential impacts of net OMR reverse flows on fish, OMR reverse flow restrictions are included in the USFWS's (Actions 1 through 3) and NMFS's (Action IV.2.3) Biological Opinions for the CVP and SWP, and the DFG Incidental Take Permit (Conditions 5.1 and 5.2) for the protection of delta smelt, salmonids, and longfin smelt, respectively (NMFS 2008, USFWS 2008, DFG 2009c).

In 2001, Baker and Morhardt found that fall-run Chinook salmon smolt survival through the Delta may be influenced to some extent by the magnitude of flows from the SJR, but that the relationship was not well quantified at that time, especially in the range of flows for which such quantification would be most useful. Baker and Morhardt found that there was a clear relationship when high flows were included in the analysis, but at flows below 10,000 cfs there was very little correlation between flows at Vernalis and escapement, and flows at Vernalis and smolt survival. In a 2009 Technical Memorandum regarding the SJR, the National Marine Fisheries Service (NMFS) further expands upon this issue stating that inflows below approximately 5,000 cfs have a high level of variability in the adult escapement returning two and a half years later, indicating that factors other than flow may be responsible for the variable escapement returns. NMFS states that for flows above approximately 5,000 to 6,000 cfs the relationship with escapement begins to take on a linear form and adult escapement increases in relation to flow. NMFS explains that anomalies to the flow relationship (i.e., subsequent low adult returns during high spring flows) can be due to poor ocean conditions upon juvenile entry or low adult returns in the fall prior to the high spring flows. This relationship between April and May flows is illustrated in the following figure (Figure 3-6) extracted from NMFS's technical memorandum (NMFS 2009b).

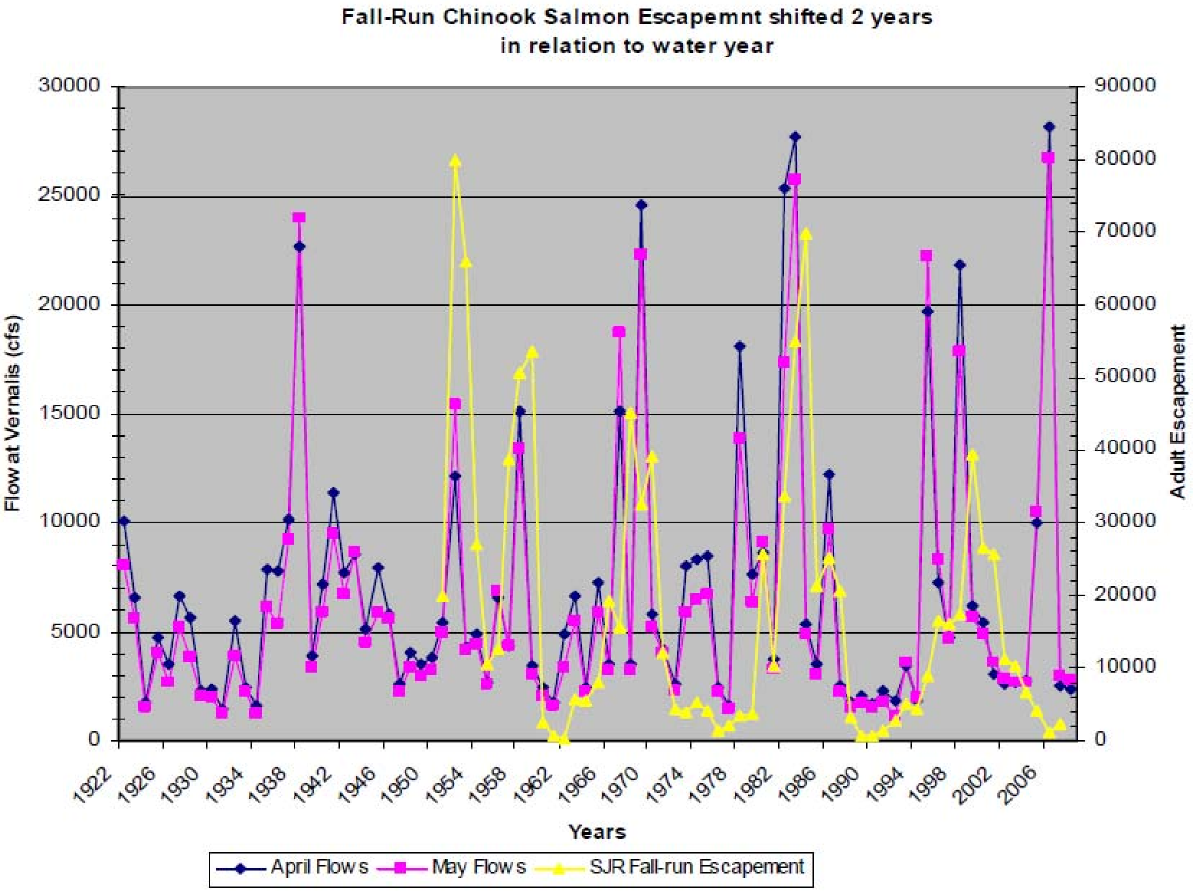

Figure 3-6. Fall-Run Chinook Salmon Escapement Shifted Two Years

In a 2001 paper, Mesick evaluated the factors that potentially limit fall-run Chinook salmon production in the Stanislaus and Tuolumne tributaries to the SJR. Mesick found that recruitment to the Stanislaus River population from 1945 to 1995, and to the Tuolumne River population from 1939 to 1995, were strongly correlated with: springtime flows in the mainstem SJR and the tributaries; the ratio of Delta exports at the SWPand CVP to Vernalis flows; and to a lesser degree, the abundance of spawners (stock); ocean harvest; and anchovy landings[4] Mesick found that correlations with herring landings, November flows during spawning, water temperature at Vernalis, and ocean climate conditions, were not significant. Mesick found that the influence of flow and Delta exports was greatest in the Delta near Stockton, indicating that the survival of smolts migrating in the Delta downstream from Dos Reis to Jersey Point is strongly correlated with flow and to a lesser degree water temperature and Delta exports (Mesick 2001).

In 2008, Newman published a comprehensive evaluation of data from several release-recovery experiments conducted in order to estimate the survival of outmigrating juvenile Chinook salmon and to quantify the effect of various factors on survival. This review included a Bayesian hierarchical model analysis of CWT experiments from the VAMP

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[4] Landings refer to the amount of catch that is brought to land (see http://www.nmfs.noaa.gov/fishwatch/species/anchovy.htm).

(2000-2006) and pre-VAMP data (1996-1999) with both the HORB in and out and SJR at Mossdale flows ranging from 1,400 cfs (1990) to 29,350 (2006) cfs, and exports ranging from 805 cfs (1998) to 10,295 cfs (1989). In this analysis, Newman found that there was a positive association between flow at Dos Reis (with at least a 97.5 percent probability of a positive relationship) and subsequent survival from Dos Reis to Jersey Point. If data from 2003 and later were eliminated from analysis, the strength of the association increased and a positive association between flow in Old River and survival in Old River also appeared. Newman did not find any relationship for the Durham Ferry to Mossdale reach and the Mossdale to Dos Reis reach. In addition, Newman found that the expected probability of surviving to Jersey Point was consistently larger for fish staying in the SJR (passing Dos Reis) than fish entering Old River, but the magnitude of the difference varied slightly between models. Lastly, Newman found that associations between water export levels and survival probabilities were weak to negligible, but that more thorough modeling should be conducted (Newman 2008).

In 2008 Mesick et al. developed a Tuolumne River Management Conceptual Model that includes a limiting factor analysis of Tuolumne River Chinook salmon and rainbow trout populations. The limiting factor analyses suggest that Chinook salmon recruitment, which is the total number of adults in the escapement and harvested in the sport and commercial fisheries in the ocean, is highly correlated with the production of smolt outmigrants in the Tuolumne River, and that winter and spring flows are highly correlated with the number of smolts produced. Mesick et al. reports that other evidence from rotary screw trap studies indicate that many more fry are produced in the Tuolumne River than can be supported with the existing minimum flows, and so, producing more fry by restoring spawning habitat is unlikely to increase adult recruitment. Mesick et al. indicates that low spawner abundances (less than 500 fish) have occurred as a result of extended periods of drought when juvenile survival is reduced as a result of low winter and spring flows and not as a result of high rates of ocean harvest. Mesick et al. also finds that other factors, such as cyclic changes in ocean productivity, Delta export rates, and Microcystis blooms do not explain the trends in the Tuolumne River population. Based on these findings, Mesick et al. concludes that of all the stressors considered, spring flows were most important to the viability of fall-run Chinook salmon and that greater magnitude, duration, and frequency of spring flows are needed to improve survival of smolts through the Tuolumne River and Delta (Mesick et al. 2008).

In 2009, Mesick published a paper on the *High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases*. Mesick reports that fall-run Chinook salmon escapement in the Tuolumne River, has declined from 130,000 salmon during the 1940s to less than 500 salmon during the early 1990s and 2007. Based on this low escapement, the rapid nature of the population declines, and the high mean percentage of hatchery fish in the escapement, Mesick finds that the Tuolumne River's naturally produced fall-run Chinook salmon population has been at a high risk of extinction since 1990. Mesick concludes that the decline in escapement is primarily due to inadequate minimum instream flow releases from La Grange Dam in late winter and spring during the non-flood years. In addition, Mesick finds that since the 1940s, escapement has been correlated with the mean flow at Modesto from February 1 through June 15 two years before escapement when age three salmon were rearing and migrating as juveniles toward the ocean, and that flows at Modesto between March 1 and June 15 explained over 90 percent of the escapement variation. This correlation suggests that escapement has been primarily determined by the rate of juvenile survival, which is primarily determined by the magnitude and duration of late winter and spring flows since the 1940s. Mesick identified two critical flow periods for salmon smolts on the Tuolumne River: winter flows which affect fry survival to the smolt stage; and spring flows which affect the survival of smolts migrating from the river through the Delta. Mesick also reports that other analyses show that spawner abundance, spawning habitat degradation, and the harvest of adult salmon in the ocean have not caused the decline in escapement (Mesick 2009).

In 2010, Mesick used an index of smolt survival made by estimating the total number of CWT salmon that returned to spawn in the inland escapement or were caught in the ocean fisheries divided by the number of juvenile salmon released (Adult Recovery Rate) to compare the relationship between flow, water temperatures, exports and other factors. Mesick's analyses suggest that it is likely that without the HORB, flow cannot substantially reduce the impacts of the poor water quality in the Stockton Deepwater Ship Channel (SDWSC). With the HORB installed, there is a positive association between Delta flow and smolt survival and an inverse correlation between the Adult Recovery Rate and increasing water temperatures at Mossdale (Mesick 2010).

In 2010, an independent scientific review of the VAMP was conducted to evaluate the CWT results from the VAMP studies (2006 and prior). The independent review panel (IRP) found that two distinct statistical analyses support the conclusion that increased flows generally have a positive effect on SJR fall-run Chinook salmon survival. First, the IRP found that data indicate that for flows in excess of about 2,500 to 6,500 cfs, measured at Vernalis for years when the HORB was in place (1994, 1997, 2000-2004), the estimated survival of outmigrating salmon between Mossdale or Durham Ferry and Jersey Point on the mainstem SJR exhibited a strong positive relation with Vernalis flow (Figure 3-7) (see also SJRTC 2008). In addition, there was a positive, though weaker relationship between estimated survival rates from Dos Reis and Jersey Point over a broader range of flows for years with the HORB in place or not (see also SJRTC 2008). Second, the IRP pointed to the broader and more sophisticated Bayesian Hierarchical modeling analyses by Newman (2008) that found a positive influence of SJR flow below Old River on survival rates. The IRP also reported on its own summaries of CWT-based estimates of survival rates from Mossdale (when the HORB has been in place) or Dos Reis to Jersey Point that are consistent with a general increase of mean survival rates with increasing flows measured at Dos Reis. The IRP provided further information concerning the relationship between fall-run Chinook salmon survival and flows within the SJR in and near the SDWSC. In a preliminary analysis of the relationships between flows, residence time, and reach specific survival in 2008 and 2009 (Holbrook et al. 2009, Vogel 2010), the review panel suggests that the SDWSC could be a bottleneck for survival of salmon smolts migrating down the SJR, and that higher flows through the SDWSC could benefit migrating salmon (Hankin et al. 2010).

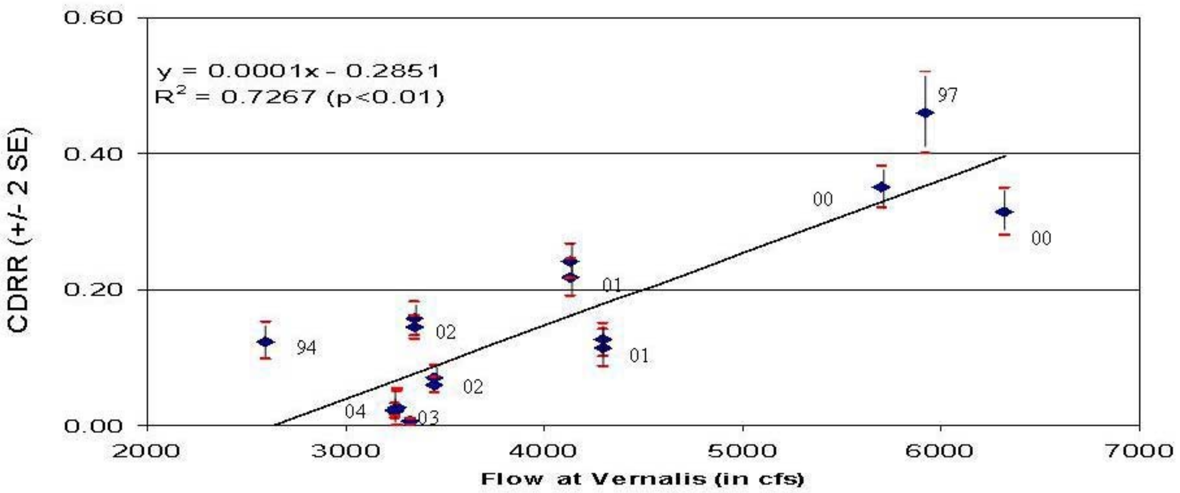


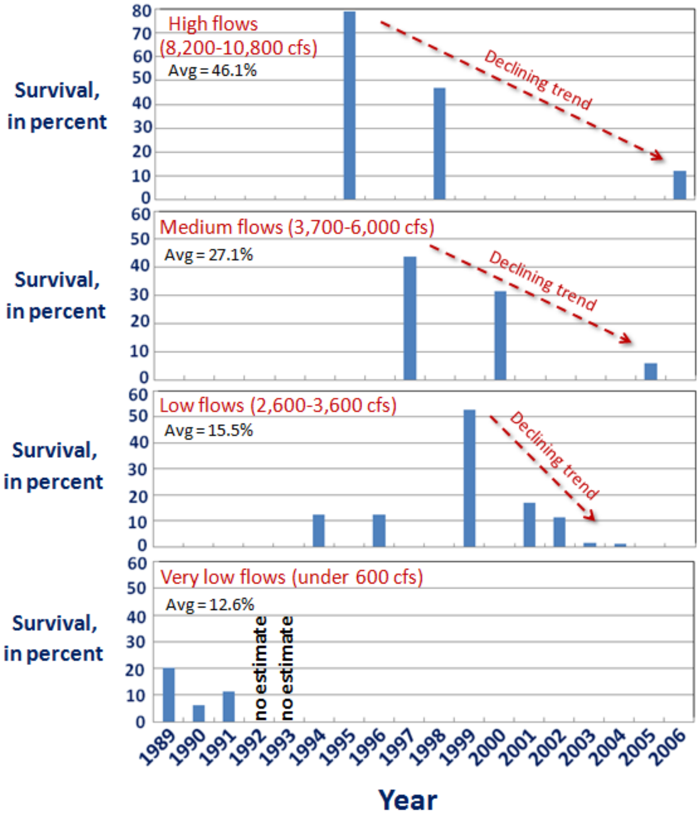
Figure 3-7. Survival of Outmigrating Salmon Versus Vernalis Flow

Combined Differential Recovery Rate (CDRR) (point estimates of survival) plus and minus 2 standard errors using Chipps Island, Antioch and ocean recoveries, for groups released at Mossdale or Durham Ferry and Jersey Point in 1994, 1997, 2000-2004 and average flow at Vernalis in cfs for 10 days starting the day of the Mossdale release or the day after the Durham Ferry release with the HORB in place. Ocean recoveries are not yet available for 2004 releases (SJRGA, 2007 as cited in SJRTC 2008).

The review panel qualified their conclusions regarding the flow versus survival relationships by noting: “only meeting certain flow objectives at Vernalis is unlikely to achieve consistent rates of smolt survival through the Delta over time. The complexities of Delta hydraulics in a strongly tidal environment, and high and likely highly variable impacts of predation, appear to affect survival rates more than the river flow, by itself, and greatly complicate the assessment of effects of flow on survival rates of smolts. And overlaying these complexities is an apparent strong trend toward reduced survival rates at all flows over the past ten years in the Delta” (Hankin et al. 2010).

In their own analysis of the VAMP data, the IRP
(

Figure 3-8) found that survival decreased as flows decreased, and that survival has been decreasing over time within each of four flow groupings (very low, low, moderate, high). Survival estimates from Mossdale or Dos Reis to Jersey Point were just greater than one percent in 2003 and 2004 and the estimate was only about 12 percent in the very high flow year of 2006. This compares to survival estimates that ranged between about 30 and 80 percent in the years 1995 and 1997 to 2000. The IRP points out that the recent survival estimates are significantly lower than the long-term average survival estimate of about 20 percent, which the IRP points out is considered low when compared to the Sacramento River and other estuaries like the Columbia River. The review panel concludes: “the very low recent survival rates seem unlikely to be high enough to support a viable salmon population, even with favorable conditions for ocean survival and upstream migration and spawning success for adults” (Hankin et al.).



CWT smolt survival estimates along the mainstem SJR to Jersey Point for various ranges of flow at Dos Reis. Data are for all releases at Mossdale (with HORB in place) and Dos Reis. For years with multiple releases, the survival estimates were averaged to obtain a single estimate. Data are based on Table 5 from Newman (2008). The analysis assumes that because Mossdale and Dos Reis are only about 5 miles apart, survival from the two locations should be similar when no flow is being diverted into upper Old River (Hankin et al.).

Figure 3-8. Smolt Survival in San Joaquin River

Data from recent VAMP studies using acoustic tagged fish indicate survival remained low during the recent critically dry (2007 and 2008) and dry (2009) water years (survival estimates for the 2010 study are not yet available). In 2007, mean flows during the VAMP period were 3,260 cfs. The lack of two key monitoring stations, receiver malfunctions, and unexplained mortality near Stockton of a sizeable number of test fish reduced the ability to develop survival estimates. The 2008 study was conducted during a period with mean flows of 3,160 cfs, and indicated that fish survival through the Delta ranged from five to six percent. The most recent VAMP annual technical report for 2009 yielded similar results to 2008 during a period with mean flows of 2,260 cfs. Total survival was calculated by combining survival estimates from the Old River route (survival of eight percent) and the SJR route (survival of five percent), and estimated that only six percent of salmon survived through the Delta to Chipps Island. Survival in the Old River and the SJR River, and total survival through the Delta to Chipps Island would be even lower if the detection sites where no salmon were detected (Turner Cut, Middle River, and the interior of Clifton Court Forebay) were incorporated into the survival calculation. In addition, survival estimates may be even lower if data for fish survival into the holding tanks or fish salvage facilities of the SWP and CVP export facilities were incorporated into the calculation (SJRGA 2008, 2009, and 2010).

In addition to the survival studies, in 2009 and 2010, the VAMP experiment included testing of a non-physical barrier at the divergence of the SJR and Old River (the Bio-Acoustic Fish Fence (BAFF)) in order to study the effectiveness of such a device in deterring juvenile fall-run Chinook salmon from migrating down Old River (referred to as the deterrence efficiency) and the effect of the device on the number of fish passing down the SJR (referred to as the protection efficiency). Testing of the BAFF in 2009 was conducted at flows averaging 2,260 cfs with a flow split averaging 75 percent down Old River and 25 percent down the SJR. When the BAFF was off, the amount of tagged salmon smolts remaining in the mainstem SJR (protection efficiency of 25.4 percent) was directly proportional to the amount of flow remaining in the mainstem SJR. With the BAFF on, the protection efficiency increased slightly to 30.8 percent and the deterrence efficiency increased substantially to 81.4 percent. Even though the BAFF was very efficient at deterring salmon that encountered it, the difference between the percentages of salmon remaining in the mainstem SJR was not significant between the BAFF off and BAFF on because predation near the BAFF was also quite high (ranging from 25.2 to 61.6 percent) (Bowen et al. 2009).

During the BAFF study in 2010, flows averaged 5,100 cfs. Similar to 2009 (and 2008; see Holbrook et al. 2009), when the BAFF was off, the amount of tagged salmon smolts remaining in the mainstem SJR (protection efficiency = 25.9 percent) was directly proportional to the amount of flow remaining in the mainstem SJR. However, unlike 2009, the protection efficiency with the BAFF on (protection efficiency of 43.1 percent) was significantly greater than when the BAFF was off (Kruskal-Wallis $X^2 = 8.2835$, $p=0.004$; see Bowen and Bark 2010) resulting in significantly more smolts surviving and continuing down the SJR when the BAFF was on. At the same time, the deterrence efficiency of the BAFF was not nearly as effective as 2009 (23 percent compared to 81.4 percent). In addition, predation rates were much lower in 2010 than 2009, ranging from 2.8 to 20.5 percent for each group of smolts released upstream (Bowen et al. 2010).

Bowen et al. concludes that the inconsistent results between the 2009 and 2010 study may have been a consequence of higher discharges in the experimental period of 2010. These higher discharges in 2010 led to higher velocities through the BAFF, which, in turn, led to a lower deterrence efficiency because the smolts had less time to avoid the BAFF. Additionally, the proportion of smolts eaten near the BAFF decreased as discharge increased. Bowen et al. concludes that the high 2009 predation appears to be a function of the dry conditions and that smolts and predators might have been concentrated into a smaller volume of water than in 2010. Such a concentration would result in higher encounter rates between predators and smolts leading to an increased predation rate. In addition, lower velocities in drier years, such as 2009, may lead to a bioenergetically advantageous situation for large-bodied predators in the open channels near the divergence (Bowen et al. 2010).

3.7 Previous Flow Recommendations

The following discussion describes some of the previous SJR flow recommendations that have been made to improve the survival and abundance of SJR Chinook salmon based on modeling and statistical relationships between flow and survival.

In 2005, DFG identified several statistical relationships between flow at Vernalis and Chinook salmon abundance (DFG 2005a, Table 1). DFG analyses indicate that the most important parameters influencing escapement are spring flow magnitude, duration, and frequency, and that non-flow parameters have little or no relationship to escapement. DFG found that the most highly significant relationship between flow at Vernalis and juvenile production occurs at Mossdale. The relationship between flow and Delta survival to Chipps Island is less significant yet remains positive, suggesting that there are other factors also responsible for through Delta survival. Finally, the relationship between smolts at Chipps Island and returning adults to Chipps Island was not significant, suggesting that perhaps ocean conditions or other factors are responsible for mortality during the adult ocean phase. DFG used these statistical relationships to develop a salmon production model to develop flow recommendations for the SJR for the March 15 through June 15 time period that DFG analyses indicate will achieve doubling of salmon smolts. DFG's flow recommendations at Vernalis range from 7,000 cfs to 15,000 cfs and are recommended to be apportioned between the tributaries based on the average annual runoff for each tributary (DFG 2010a).

The 2005 *Recommended Streamflow Schedules to Meet the AFRP Doubling Goal in the San Joaquin River Basin* includes similar recommendations for achieving doubling of Chinook salmon. The AFRP recommendations are based on salmon production models for each of the three main tributaries (the Merced, Tuolumne, and Stanislaus rivers) that are based on regression analyses of recruits per spawner, and April through May Vernalis Flows. Adjusted R^2 values range from 0.53 to 0.65 for statistically significant positive relationships between production and flow for each tributary. These relationships suggest that increased flows during the spring outmigration period would enhance salmon production. The model combines the above individual recruitment equations to estimate the flows needed at Vernalis during the February through May period to double salmon production in the SJR basin. The flows (Table 2, AFRP 2005) recommended at Vernalis range from 1,744 cfs in February of critically dry years to a maximum of 17,369 cfs in May of wet years and generally increase from February through May to mimic the natural flow regime (natural peak flow in May). Estimates of flows needed on each tributary to double salmon production range from 51 to 97 percent of unimpaired flow; with a greater percentage of unimpaired flow needed in drier years than wet years (AFRP 2005).

To inform the State Water Board's 2010 proceeding to develop flow criteria necessary to protect public trust resources in the Delta, the Bay Institute and Natural Resources Defense Council (TBI/NRDC) conducted a logit analysis to examine the relationship between Vernalis flow and cohort return ratios of SJR Chinook salmon. A logit analysis describes the probability distribution of an independent variable to a dependent variable when there are two different possible results. In this case, the independent variable is Vernalis Flow (log transformed) and the dependant variable is positive or negative population growth, measured as the cohort return ratio (CRR). Where the logit regression-line crosses 0.5 on the y-axis represents the flow level at which positive and negative growth are equally "likely". Based on historical data, flows above that level are more likely to produce positive population growth and flows below that level are less likely to correspond to positive population growth. TBI/NRDC indicates that the advantage of turning CRR into a binary variable (populations increase or decrease) is that it removes any effect of initial absolute population size on the outcome. If you analyze the results with "real" population values or cohort return ratios, small populations behave erratically because small changes in the population size look very big.

Conversely, when populations are large, substantial changes in population size can appear relatively small (TBI/NRDC 2010a,b).

In their logit analysis, TBI/NRDC found that Vernalis average March through June flows of approximately 4,600 cfs corresponded to an equal probability for positive population growth or negative population growth. TBI/NRDC found that average March through June flows of 5,000 cfs or greater resulted in positive population growth in 84 percent of years and flows less than 5,000 cfs resulted in population decline in 66 percent of years. TBI/NRDC found that flows of 6,000 cfs produced a similar response to the 5,000 cfs or greater flows, and flows of 4,000 cfs or lower resulted in significantly reduced population growth in only 37 percent of years. The TBI/NRDC analysis suggests that 5,000 cfs may represent an important minimum flow threshold for salmon survival on the SJR. Based on abundance to prior flow relationships, TBI/NRDC estimates that average March through June inflows of 10,000 cfs are likely to achieve the salmon doubling goal (TBI/NRDC 2010a and b).

Based on the above estimates of flows needed for the protection of juvenile Chinook salmon on the SJR, life history needs of juvenile Chinook salmon, and the science supporting the importance of the natural hydrograph in protecting beneficial uses, in its 2010 report on *Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem*, the State Water Board determined that approximately 60 percent of unimpaired flow during the February through June period would be protective of fish and wildlife beneficial uses in the SJR. State Water Board analyses indicate that 60 percent of unimpaired SJR flow at Vernalis from March through June would achieve flows of 5,000 cfs in over 84 percent of years and flows of 10,000 cfs in approximately 45 percent of years. It should be noted that the State Water Board acknowledged that these flow criteria are not exact, but instead represent the general range of flow conditions that were found to be protective of fish and wildlife beneficial uses when considering flow alone. In addition, these flow criteria do not consider other competing uses of water or tributary specific flow needs for cold water and other purposes (State Water Board 2010).

3.8 Importance of the Natural Flow Regime

This section describes the importance of the natural flow regime in protecting aquatic fish and wildlife beneficial uses. In general, natural flow conditions provide the types of flows needed to support the biological and ecosystem processes needed to protect fish and wildlife beneficial uses. While changes to flows alone are needed to fully restore these ecosystem processes on the SJR, flow is a critical element of that restoration. Using a river's natural flow regime as a foundation for determining ecosystem flow requirements is well supported by the current scientific literature (Poff et al. 1997, Tennant 1976, Orth and Maughan 1981, Marchetti and Moyle 2001, and Mazvimavi et al. 2007). In addition, major regulatory programs in Texas, Florida, Australia and South Africa have developed flow prescriptions based on the natural flow regime in order to enhance or protect aquatic ecosystems (Arthington et al. 1992, Arthington et al. 2004, NRDC 2005, Florida Administrative Code 2010), and the World Bank now uses a framework for ecosystem flows based on the natural quality, quantity, and timing of water flows (Hirji and Davis 2009). Major researchers involved in developing ecologically protective flow prescriptions concur that mimicking the natural flow regime of a river is essential to protecting populations of native aquatic species and promoting natural ecological functions (Sparks 1995, Walker et al. 1995, Richter et al. 1996, Poff et al. 1997, Tharme and King 1998, Bunn and Arthington 2002, Richter et al. 2003, Tharme 2003, Poff et al. 2006, Poff et al. 2007, Brown and Bauer 2009). Poff et al. (1997) describes the natural flow regime as the “master variable” that regulates the ecological integrity of rivers.

In a recent analysis of methods used for establishing environmental flows for the Bay-Delta, Fleenor et al (2010) reported on two methods that use the natural flow regime as a basis for determining flows needed to protect the ecosystem- flows based on the natural flow regime, and flows based on the historical flow regime. These methods attempt to prescribe flows for the protection of the ecosystem as a whole, and use the biological concept that flows similar to the natural (or historical) flow regime will benefit the aquatic species that have evolved with those flows. In a separate review of instream flow science by Petts (2009), he reports the importance of two fundamental principles that should guide the derivation of flow needs: 1) the natural flow regime shapes the evolution of the aquatic biota and ecological process, and 2) every river has a characteristic flow regime and associated biotic community. Petts also finds that flow management should sustain flows that mimic the natural yearly, seasonal, and perhaps daily variability to which aquatic biota have adapted.

Specific ecosystem attributes that a more natural flow regime should improve include: 1) support of native fish communities; 2) support of the natural food web; 3) habitat connectivity; 4) fluvial hydrogeomorphological processes; and 5) improved temperatures. The effects of altered flows on each of these attributes in described below, along with the expected benefits of a more natural flow regime.

3.8.1 Fish Communities

Altered flow regimes have been found to negatively impact fish communities and the aquatic ecosystem (Pringle et al. 2000, Freeman et al. 2001, Bunn and Arthington 2002, Moyle and Mount 2007). This has been found to be the case on the SJR where native fish and other aquatic organisms have been increasingly replaced by non-native species (Brown 2000, Freyer and Healey 2003, Brown and May 2006, Brown and Michniuk 2007, Brown and Bauer 2009). Natural flows generally encourage native fish and other aquatic communities and discourage non-natives. Native communities of fish and other aquatic species are adapted to the natural spatial and temporal variations in river flows under which those species evolved, including extreme events such as floods and droughts (Sparks 1995, Lytle and Poff 2004). On the other hand, permanent or more constant flows created by damming or diverting river flows favor introduced species (Moyle and Mount 2007, Poff et al. 2007). Long-term success (i.e. integration) of an invading species is much more likely in an aquatic system, like the SJR, that has been permanently altered by human activity than in a less disturbed system. Unlike natural systems, systems disturbed by human activity tend to resemble one another over broad geographic areas and favor species that are also favored by humans (Gido and Brown 1999).

Establishing a more natural flow regime should support the various life history adaptations of native fish and aquatic organisms that are synchronized with the natural flow regime (Bunn and Arthington 2002, King et al. 2003, Lytle and Poff 2004). A more natural flow regime that includes more natural tributary inflows would also provide protection of genetically distinct sub populations of aquatic organisms that evolved from individual rivers and their tributaries. Sub populations are important in maintaining genetic diversity and the resilience of aquatic communities. Sub populations exhibit important genetic variability that when preserved allows use of a wider array of environments than without it (McElhany et al. 2000, Moyle 2002, NMFS 2009c). Maintaining the diversity of sub-populations of salmonids on all three tributaries to the SJR has been identified as an important factor for achieving population viability (Moyle 2002).

Historically, each one of the major SJR tributaries (Merced, Tuolumne, and Stanislaus) supported large runs of fall-run Chinook salmon, with the Tuolumne River, on average, supporting the highest spawning escapements among the tributaries (State Water Board 2000). Currently, salmonids use reaches on all three east-side tributaries for spawning habitat including: the 24-mile reach of the Merced River between Crocker-Huffman Dam and the town of Cressy, the 25-mile reach of the Tuolumne River between LaGrange Dam and the town of Waterford, with rearing in the entire lower river (between LaGrange Dam and the confluence with the SJR); and the 23-mile reach in the Stanislaus River between Goodwin Dam and the town of Riverbank for spawning and the entire lower river (between Goodwin Dam and the confluence with the SJR) for rearing (AFRP 1995). Accordingly, providing a more natural flow regime that achieves flows from all tributaries will afford fall-run Chinook salmon with up to 75 miles of protected habitat (the maximum spawning habitat available) as opposed to about 25 miles of habitat on just an individual tributary.

The genetic and life cycle diversity provided by maintaining sub-populations and varied life history timing of juvenile Chinook salmon through achieving a more natural temporal and spatial flow regime would protect the population against both short-term and long-term environmental disturbances. Fish with differing characteristics between populations have different likelihoods of persisting, depending on local environmental conditions. Diversity allows a species to use a wider array of environments than they could without it. Thus, the more diverse a species is, the greater the probability that some individuals will survive and reproduce when presented with environmental variation (Rosenfield, et al. 2010, McElhany et al. 2000). Genetic diversity also provides the raw material for surviving long-term environmental changes. Salmonids regularly face cyclic or directional change in their freshwater, estuarine, and ocean environments due to natural and human causes. Genetic and life-cycle diversity allows them to persist through these changes (McElhany et al. 2000).

Long term conditions in the region are expected to change as global climate change continues. It is difficult to predict what the changes may be, but whatever the change, a more genetically diverse species will more likely adapt to these new conditions. This is particularly important for salmonid species, but this also applies to the aquatic ecosystem as a whole, including the food web and other native warm and cold water fish communities. Similarly, ocean conditions constantly change, and will continue to cycle between more and less favorable conditions. As seen recently in the mid 2000s, poor ocean conditions caused a collapse in the near-shore oceanic food supplies that eventually caused a collapse of the ocean salmon fishery. While, ocean conditions have been blamed for the recent collapse of Central Valley salmon, the overall extent of the collapse was exacerbated by weak salmon runs that have lost much of their genetic variability that would normally allow them greater resilience to poor ocean conditions over multiple years (Lindley et al 2009).

Protecting and enhancing genetic (and life history) variability through a more natural (and variable) flow regime would also protect salmon populations from a significant loss in genetic diversity from the use of hatcheries. Fall-run Chinook salmon and other salmon hatcheries have unintentionally caused a reduction of genetic variability within the species by altering the genetic makeup of native salmon due to interbreeding with stocked strains of salmon. In addition, the greater quantity of hatchery fish within the river system has caused declines in native salmon, and further reduced the genetic viability of wild strains due to predation and competition for spawning grounds, food, and space (Jones and Stokes 2010). A more variable/natural flow regime would maintain and perhaps even enhance the remaining genetic variability of wild stocks and reduce the negative effects of hatcheries on wild populations.

3.8.2 Food Web

Establishing a more natural flow regime should also benefit the natural food web to which native species are adapted. The diversity and abundance of beneficial algae and diatoms (the base of the food web) are higher in unregulated and more natural reference streams than in more perturbed streams (Power et al. 1996). In contrast, the benthic macroinvertebrate community (a key fish food resource) is typically characterized by species-poor communities in regulated river reaches (Munn and Brusven 1991). Additionally, loss of variability in flows, and increasingly stable regulated flows can lead to proliferation of certain nuisance insects such as larval blackflies (De Moor 1986). In regulated rivers of northern California, Wootton et al. (1996) found that seasonal shifting of scouring flows from winter to summer increased the relative abundance of predator-resistant invertebrates that diverted energy away from the natural food web and caused a shift toward predatory fish. In unregulated rivers, high winter flows reduce these predator-resistant insects and favor species that are more palatable to fish (Wooton et al. 1996, Poff et al. 1997).

Altered flows also generally decrease the primary source of nutrients to river systems that support the food web due to reduced riparian and floodplain activation (McBain and Trush 2002, SJRRP 2008). Floodplain inundation associated with the natural flow regime, particularly the ascending and descending limbs of the hydrograph, often provides most of the organic matter that drives aquatic food webs in rivers (Mesick 2009). Sommer et al. (2001) and Opperman (2006) found floodplain habitat promotes rapid growth of juvenile salmon. Properly managed floodplains can have widespread benefits at multiple levels ranging from individual organisms to ecosystems (Junk et al. 1989, Moyle et al. 2007).

3.8.3 Habitat Connectivity

Altered flow regimes decrease habitat connectivity in riverine and deltaic systems which results in a loss of lateral and longitudinal connectivity (Bunn and Arthington 2002). Loss of a natural flow regime and its associated frequent floods has led to a loss of lateral connectivity within remnant seasonal wetlands and riparian areas. This, in turn, has caused a general loss of productivity and a decrease in aquatic habitat quality associated with wetland and riparian communities (Cain et al. 2003, McBain and Trush 2002).

More natural flows on the SJR would increase lateral connectivity by increasing riparian and floodplain activation, thus increasing habitat quality and space, allowing for energy flow between wetland areas and the river, and providing the river and estuary with nutrients and food. Floodplain inundation provides flood peak attenuation and promotes exchange of nutrients, organic matter, organisms, sediment, and energy between the terrestrial and aquatic systems (Cain et al. 2003, Mesick 2009). It also improves juvenile fish survival by improving food availability, providing refuges from predators, and increasing water temperatures in February and March (Jeffres et al. 2008, Mesick 2009). A more natural flow regime on the SJR would increase longitudinal connectivity during times appropriate for aquatic organisms that have adapted to this system, and help create more beneficial migration transport, less hostile rearing conditions (protection from predators), greater net downstream flow, and connectivity with the estuary and near-shore ocean (McBain and Trush 2002, Cain et al. 2003, Kondolf 2006, Poff et al. 2007, Mesick 2009). Increased lateral and longitudinal connectivity also positively affects spatial distribution of organisms by facilitating the movement of organisms and creating important spawning, nursery, and foraging areas for many fish species, including salmon (Bunn and Arthington 2002, Cain et al. 2003, Jeffres et al. 2008, Rosenfield et al. 2010).

3.8.4 Hydrogeomorphological Processes

The altered flow regime has caused the loss of hydrogeomorhological processes related to the movement of water and sediment that are important to the ecosystem (Poff et al.1997). Important benefits that these natural processes provide include increased complexity and diversity of the channel, riparian, and floodplain habitats, and mobilization of the streambed and upstream sediment (Grant 1997). Floods, and their associated sediment transport, are important drivers of the river-riparian system. Small magnitude, frequent floods maintain channel size, shape, and bed texture, while larger, infrequent floods provide beneficial disturbance to both the channel and its adjacent floodplain and riparian corridor. As a result of alterations to natural flows and other factors, channel morphology within the SJR basin is now characterized by significant incision and loss of channel complexity. Of particular concern is the encroachment of vegetation into historic gravel bar habitat that has probably reduced the recruitment, availability, and quality of spawning gravel habitat for Chinook salmon (Cain et al. 2003, McBain and Trush 2009).

A more natural flow regime would generate processes that create a less homogenous channel with structures that are important for fish habitat, such as meanders, pools, riffles, overhanging banks, and gravel substrates of appropriate sizes (Thompson and Larsen 2002, Mount and Moyle 2007). Scour and bed mobilization associated with hydrogeomorhological processes driven by natural flows clean gravel for salmon, benthic macroinvertebrates, and benthic diatoms, and rejuvenates riparian forests (McBain and Trush 2002, Cain et al. 2003, SJRRP 2008). Native fish and other aquatic species have adapted their life cycle to these processes and exploit the diversity of physical habitats these processes create (Poff et al. 1997, Thompson and Larsen 2002, Lytle and Poff 2004). Increasing turbidity events from more natural flows and the associated hydrogeomorhological processes should also decrease predation and provide environmental cues needed to stimulate migration (Jager and Rose 2003, Baxter et al. 2008, Mesick et al. 2008, NMFS 2009a).

3.8.5 Temperature

Dams and reservoirs, and their associated operations, alter the temperature regime of rivers, often to the detriment of cold water species such as salmonids and other aquatic plants and animals that have adapted to colder waters and a variable flow regime

(Richter and Thomas 2007, DFG 2010b). Water stored in reservoirs is warmer at the surface and cooler below the thermocline in deeper waters. The temperature of water within these layers is generally different than the temperature of water entering the reservoir at any given time depending on the season, and is also dissimilar to downstream water temperatures that would occur under natural flow conditions (USACE 1987, Bartholow 2001). Temperature control devices can control the temperature of water released from dams for the protection of downstream fisheries by varying operations of release gates. However, there are no temperature control devices to aid in water temperature management on the east side tributaries, and temperature management can only be achieved directly through flow management (NMFS 2009a). Often, water released from reservoirs is colder in the summer and warmer in the winter compared to water temperatures that would have occurred in the absence of a dam and reservoir (Williams 2006). As a result, species experience additional temperature stress compared to the river's natural flow and temperature regimes.

In addition to the changes in temperature due to reservoir storage and release, reservoirs and diversions also modify the temperature regime of downstream river reaches by diminishing the volume and thermal mass of water. A smaller quantity of water has less thermal mass, and therefore, a decreased ability to absorb temperatures from the surrounding environment (air and solar radiation) without being impacted (USACE 1987). The greatest impact occurs with less flow (less thermal mass) and warmer climate (increased solar radiation), usually in the late spring, summer, and early fall periods (BDCP 2009). During these periods of hot and dry climatic cycles (late spring summer, and early fall) salmonid populations depend on the availability of cold water refugia to oversummer in prior to spawning. The altered flow regime of the SJR has eliminated the cold water refugia upon which salmonid populations depend (US EPA 2001).

The combined effect of storage and dam operations have contributed to increased water temperatures and altered flow regimes that have negatively impacted salmon and other native fishes, encouraged warm-water and non-native fishes, and altered the base of the food web. In addition, undesirable and nuisance algae (e.g. Microsystis), and submerged aquatic vegetation (e.g. Egeria) have established and become widespread through the system due, in part, to the altered temperature and flow regime (Brown and May 2006, Brown and Bauer 2009 Moyle et al. 2010). A more natural flow regime, in particular greater flows in the spring, in combination with reservoir releases that provide temperatures more closely mimicking the natural temperature regimes of the SJR system, would benefit the aquatic ecosystem at multiple levels (food web, fish communities, and cold water salmonids).

3.9 Conclusions

The scientific information discussed above supports the conclusion that a higher and more naturally variable inflow regime from the SJR to the Delta during the spring period (February through June) is needed to protect fish and wildlife beneficial uses, including SJR basin fall-run Chinook salmon. As outlined in the hydrology section, inflows from the SJR basin have been substantially altered from the natural conditions that SJR basin fish and wildlife adapted to. Most notably, flows in the SJR basin have decreased markedly and become less variable as a result of construction and operation of dams. At the same time, naturally produced fall-run Chinook salmon and other native SJR basin fish and wildlife have also experienced significant population declines and as a result may be at a high risk of extinction. The scientific information discussed in this section indicates that higher and more naturally variable flows are needed to protect fall-run Chinook salmon and to support other important ecosystem processes.

While there are many other factors that contribute to impairments to fish and wildlife beneficial uses in the SJR basin, flows remain a critical component in the protection of these beneficial uses. Other factors do not obviate the need for higher and more naturally variable SJR inflow conditions to the Delta to protect fish and wildlife beneficial uses. Instead, there is the need to comprehensively address the various impairments to fish and wildlife beneficial uses in the SJR basin and the Delta. In addition, the State Water Board will address the need for other measures needed to protect SJR basin fish and wildlife beneficial uses in the program of implementation for any revised Bay-Delta Plan.

Estimates of flow needs to protect fish and wildlife beneficial uses are imprecise given the various complicating factors affecting survival and abundance of Chinook salmon, steelhead, and other SJR basin fish and wildlife. Nevertheless, the weight of the scientific evidence indicates that increased and more naturally variable flows are needed to protect fish and wildlife beneficial uses. Given the dynamic and variable environment in which SJR basin fish and wildlife adapted and imperfect human understanding of these factors, developing precise flow objectives that will provide absolute certainty with regard to protection of fish and wildlife beneficial uses is likely not possible. Accordingly, any flow objective will incorporate appropriate adaptive management in order to respond to changing circumstances and improved knowledge.

Given the extremely flattened hydrograph of SJR flows and the various competing demands for water on the SJR, it merits noting that State Water Board must ensure the reasonable protection of fish and wildlife beneficial uses, which may entail consideration of competing beneficial uses of water, including municipal and industrial uses, agricultural uses, and other environmental uses. To assist the State Water Board in determining the amount of water that should be provided to reasonably protect fish and wildlife beneficial uses in the SJR basin, a range of alternative SJR flow objectives will be analyzed. Based on the information discussed above, retaining the spatial and temporal attributes of the natural hydrograph appears to be important in protecting a wide variety of ecosystem processes. The historic practice of developing fixed monthly flow objectives to be met from limited sources has been shown to be less than optimal in protecting fish and wildlife beneficial uses in the SJR basin. Accordingly, to preserve the attributes of the natural hydrograph to which native SJR basin fish and wildlife have adapted, and that are believed to be generally protective of the beneficial uses, each of the alternatives is expressed as a percentage of unimpaired.

In a recent report describing methods for deriving flows needed to protect the Bay-Delta and watershed, Fleenor et al. (2010) suggests that while using unimpaired flows may not indicate precise, or optimum, flow requirements for fish under current conditions, it would, however, provide the general seasonality, magnitude, and duration of flows important for native species (see also Lund et al. 2010). Accordingly, the State Water Board will use and refine this unimpaired flow approach during its water quality control planning and environmental review processes concerning the reasonable protection of fish and wildlife beneficial uses. In addition, the State Water Board will incorporate appropriate measures for adaptive management in any new SJR flow objective in order to respond to new information and changing circumstances.

For illustrative purposes 20, 40, and 60 percent of unimpaired flows from February through June (Figure 3-9) will be used in the following water supply impacts analysis to demonstrate the ability of the analysis to appropriately evaluate the water supply effects of these and other potential alternative SJR flow objectives. In addition to an existing conditions scenario, these illustrative alternatives represent the span of the likely range of alternatives the State Water Board will evaluate in the environmental document supporting any revised SJR flow objectives. In its Delta Flow report (State Water Board 2010), the State Water Board determined that approximately 60 percent of unimpaired flow would be protective of fish and wildlife beneficial uses in the SJR basin. While this number is imprecise, it provides an upper range for evaluating the water supply effects of alternative SJR flow objectives. The intermediate ranges of 20 and 40 percent do not represent any specific flow thresholds but will allow for a broad range of comparison with the 60 percent of unimpaired flow alternative.

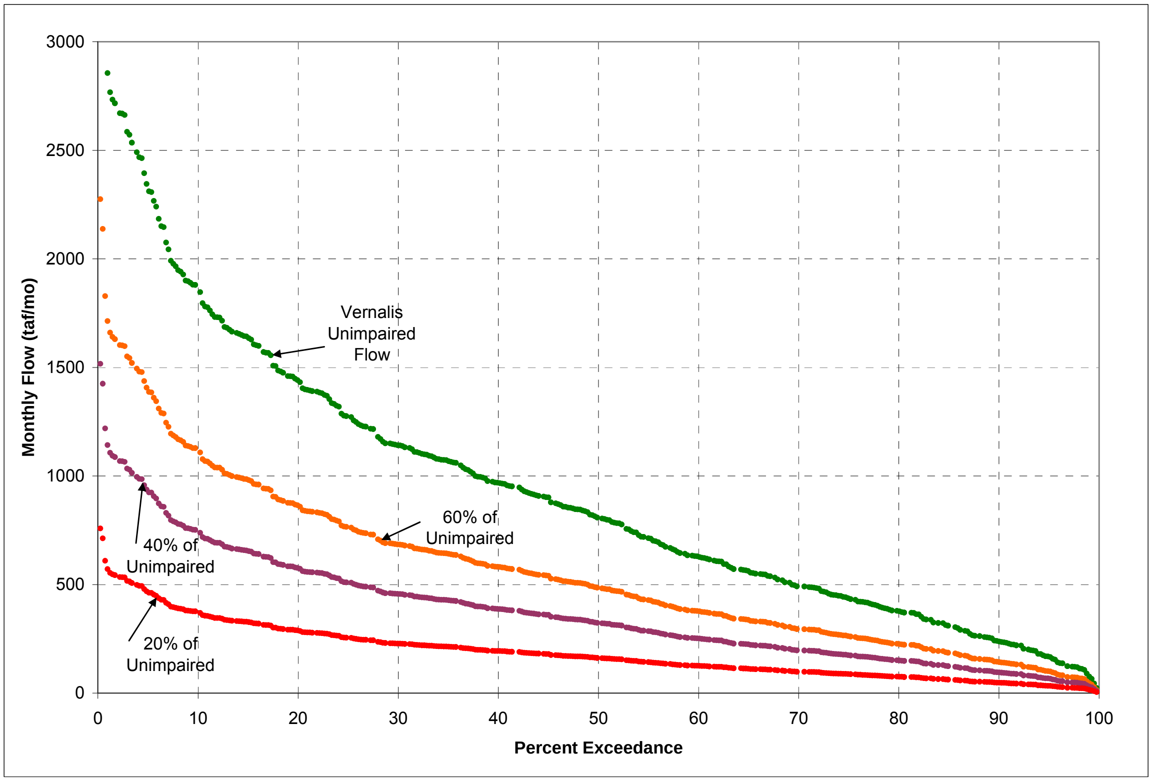


Figure 3-9 Exceedance plot of monthly average SJR unimpaired flows and various percents of unimpaired flow at Vernalis - February thru June for water years 1922 to 2003

4 Southern Delta Salinity

Evaluation of the SJR flow and southern Delta salinity objective alternatives in the SED will include consideration of their potential effects on salinity levels in the southern Delta and any associated impacts on beneficial uses and the environment. This section describes the technical information and analytical methods that will be the basis for these evaluations in the SED.

4.1 Background

The State Water Board established salinity compliance stations within the south Delta at the San Joaquin River at Vernalis (station C-10), the San Joaquin River at Brandt Bridge (station C-6); Old River at Middle River/Union Island (station C-8); and Old River at Tracy Road Bridge (station P-12) as shown in Figure 4-1. The salinity objective at each station is 0.7 millimhos per centimeter (mmhos/cm) electrical conductivity (EC) during the summer irrigation season (April through August) and an objective of 1.0 mmhos/cm EC during the winter irrigation season (September through March). Also shown for reference are the boundaries of the legal Delta and the South Delta Water Agency.

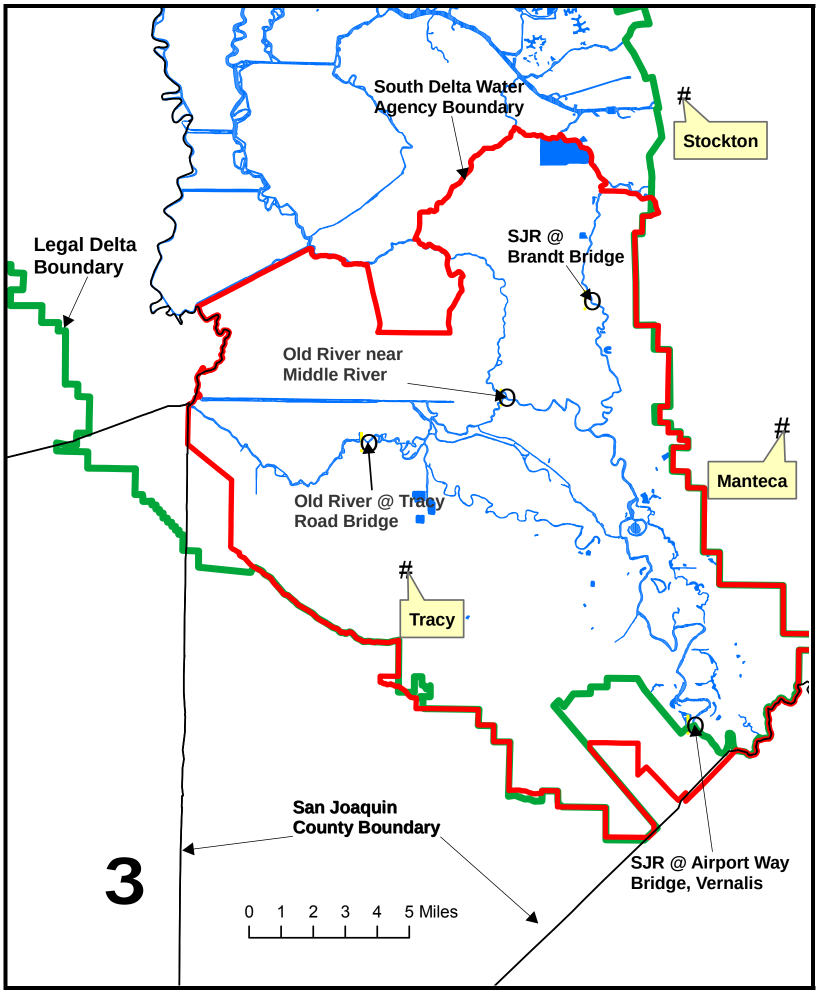


Figure 4-1. Map of southern Delta showing State Water Board salinity compliance stations and boundaries of the legal Delta and South Delta Water Agency.

Salinity objectives at these stations were first established in the 1978 Sacramento-San Joaquin Delta and Suisun Marsh Water Quality Control Plan (1978 Delta Plan). The approach used in developing the objectives involved an initial determination of the water quality needs of significant crops grown in the area, the predominant soil type, and irrigation practices in the area. The State Water Board based the southern Delta EC objectives on the calculated maximum salinity of applied water which sustains 100 percent yields of two important salt sensitive crops grown in the southern Delta (beans and alfalfa) in conditions typical of the southern Delta.

In keeping with the literature on crop response to salinity, numerical values for EC are given in units of deciSiemens per meter (dS/m) wherever possible. This is also numerically equal to millimhos per centimeter (mmho/cm), a now-outmoded unit of measure that was used for decades in agriculture to quantify salinity. EC values are sometimes also presented as microSiemens per centimeter (μS/cm) or micromhos per centimeter (μmho/cm), which are both 1000 times larger than numerical values in units of dS/m.

4.2 Factors Affecting Salinity in the Southern Delta

Salinity levels in the southern Delta are affected primarily by the salinity of water flowing into the southern Delta from the SJR at Vernalis and evapo-concentration of salt diverted from and discharged back into southern Delta channels for agricultural purposes. Additionally, point sources of salt in the southern Delta can have a minimal overall salinity effect. This section discusses the methods to be used in the SED to evaluate the overall and relative magnitude of these sources and processes.

4.2.1 Estimating Southern Delta Salinity Degradation

This section describes the regression analysis used to establish a relationship between salinity at the three interior southern Delta salinity stations and the upstream SJR at Vernalis station. This relationship will be used later in Section 5 to calculate the water supply impact associated with attaining a level of salinity at Vernalis that will in turn meet a particular salinity objective alternative downstream in the southern Delta.

For the purpose of evaluating the impacts of different flow and salinity objective alternatives in the SED (i.e. water quality control planning) the statistical approach described below is a sufficient representation of current changes in salinity conditions between Vernalis and the south Delta. This type of planning analysis only needs a conservative general estimate of this relationship to ensure that a reasonable set of salinity conditions are considered for subsequent impact analysis. This type of analysis does not require the dynamic and higher resolution modeling provided by the California Department of Water Resources (DWR) Delta simulation model (DSM2) or other hydrodynamic and water quality models of the south Delta. Such models are appropriate for more detailed modeling studies of south Delta barrier operations or changes to CVP and SWP operating conditions. In addition, DWR has found that DSM2 underestimates salinity at Old River near Tracy (an important location for this analysis), and has recommended that regression analysis would be appropriate for this type of analysis (DWR, 2007b).

To estimate salinity at these sites, a regression analysis was conducted using salinity data from the DWR California Data Exchange Center (DWR, 2010a). Figure 4-2, Figure

4-3, and Figure 4-4 present the monthly average salinity data for all months from January 1993 to December 2009 for Old River at Tracy (CDEC station = OLD), Old River at Middle River/Union Island (CDEC station = UNI), and SJR at Brandt Bridge (CDEC station = BDT) respectively plotted against corresponding salinity data at Vernalis (CDEC station = VER). The least squares linear regression line for each plot is shown on each plot giving the slope, y-intercept and associated correlation coefficient. The 1:1 line, where salinity at the two locations would be equal, is also shown for reference.

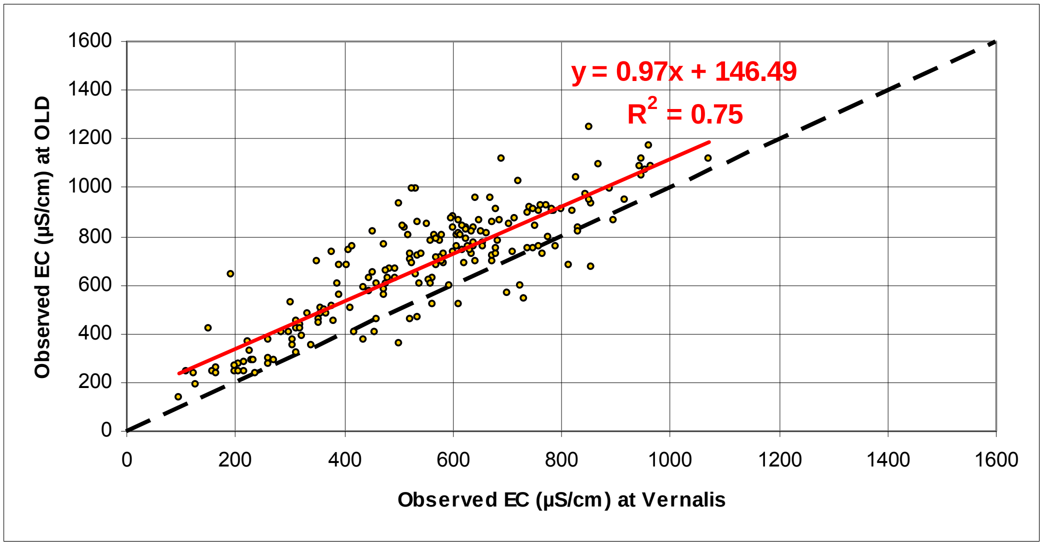


Figure 4-2. Monthly average salinity data from January 1993 to December 2009 for Old River at Tracy (OLD) plotted against corresponding salinity data at SJR at Vernalis

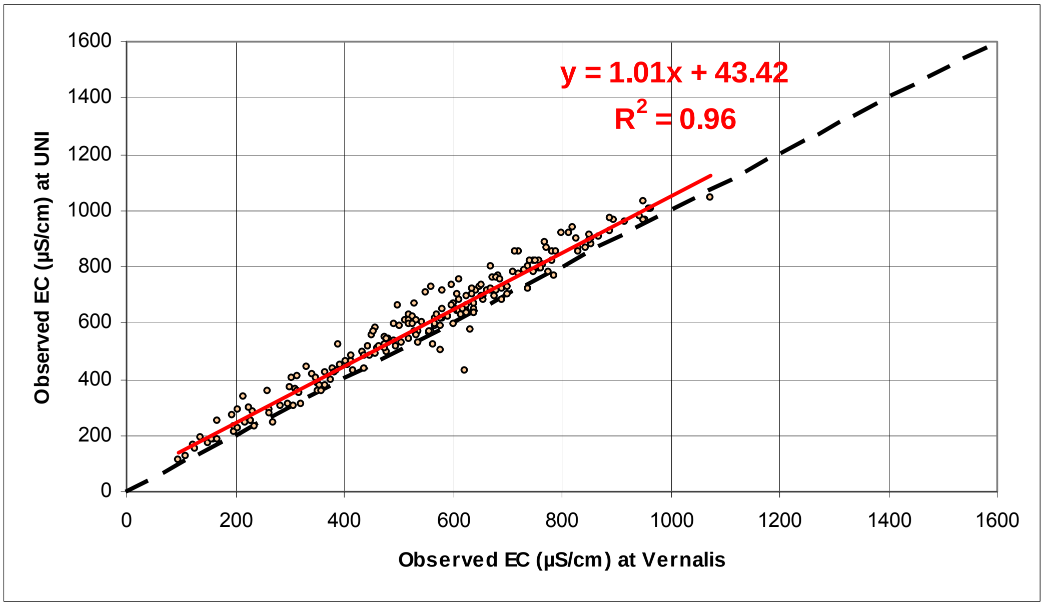


Figure 4-3. Monthly average salinity data from January 1993 to December 2009 for Old River at Middle River/Union Island (UNI) plotted against corresponding salinity data at SJR at Vernalis

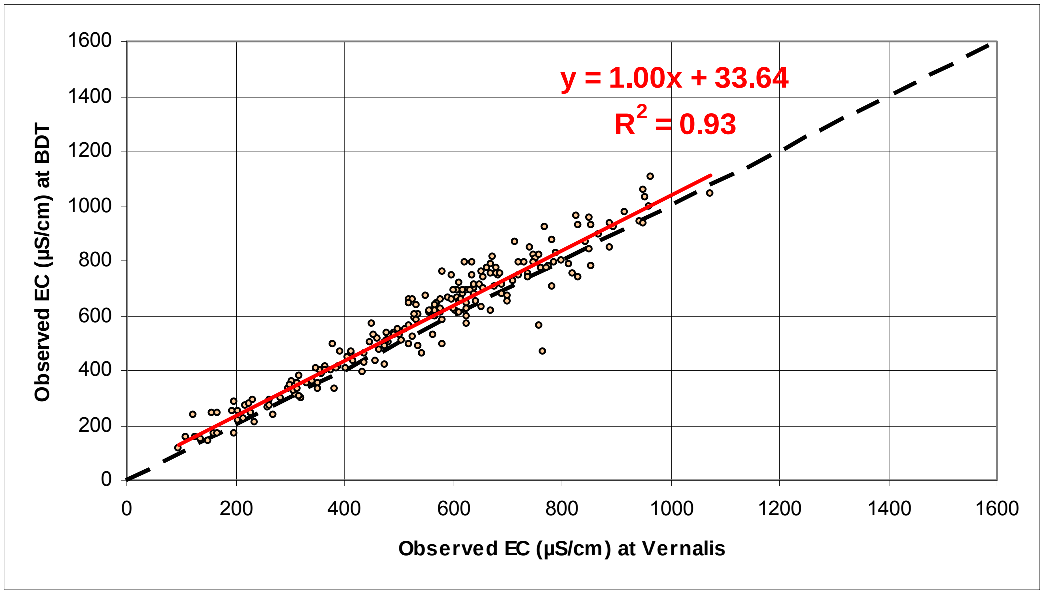


Figure 4-4. Monthly average salinity data from January 1993 to December 2009 for SJR at Brandt Bridge (BDT) plotted against corresponding salinity data at SJR at Vernalis

In general the increase in salinity downstream of Vernalis is greatest at Old River at Tracy. As such, the regression equation from this location represents a reasonable worst-case estimate of salinity conditions in the south Delta for the purpose of estimating water supply impacts in the SJR watershed (discussed later in Section 5). For this purpose two separate regressions were further developed, one for the months of April through August in Figure 4-5 and the other for September through March in Figure 4-6; the former period corresponding to the main growing season. Each figure shows the best-fit regression line and equation for the estimate of the EC at Old River at Tracy as a function of EC at Vernalis. Also shown is the line representing the equation that will provide an estimate of EC at Old River at Tracy which is at or above the actual EC at Old River at Tracy, 85 percent of the time (85 percent prediction line).

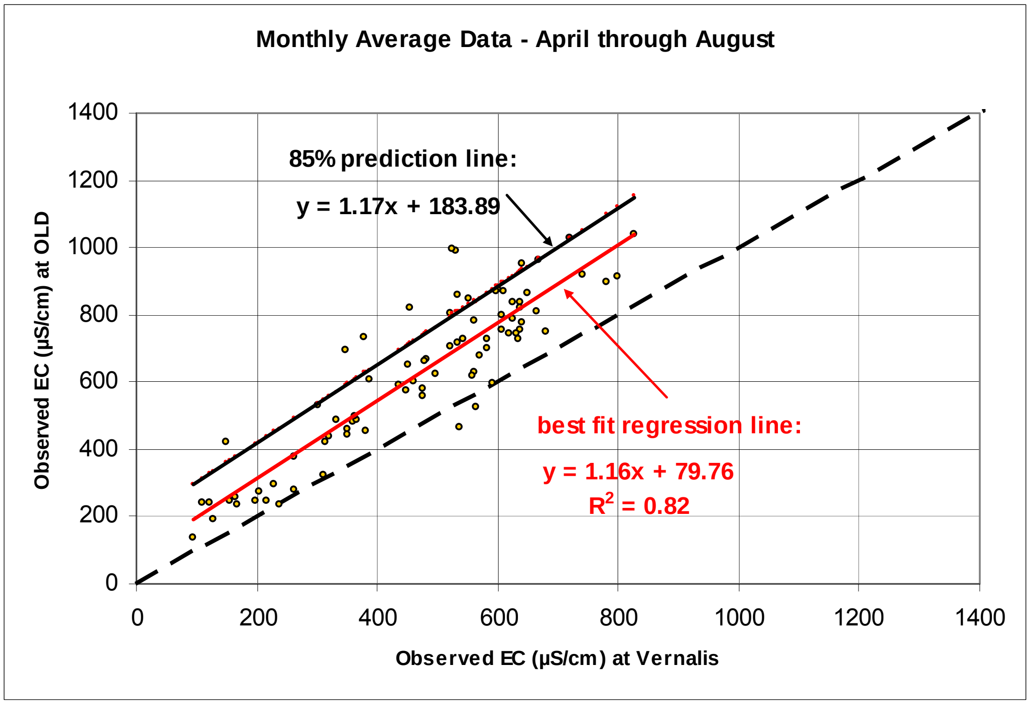


Figure 4-5. Monthly average salinity data for April through August from 1993 through 2009 for Old River at Tracy (OLD) plotted against corresponding salinity data at SJR at Vernalis, with best fit regression and 85 percent prediction lines

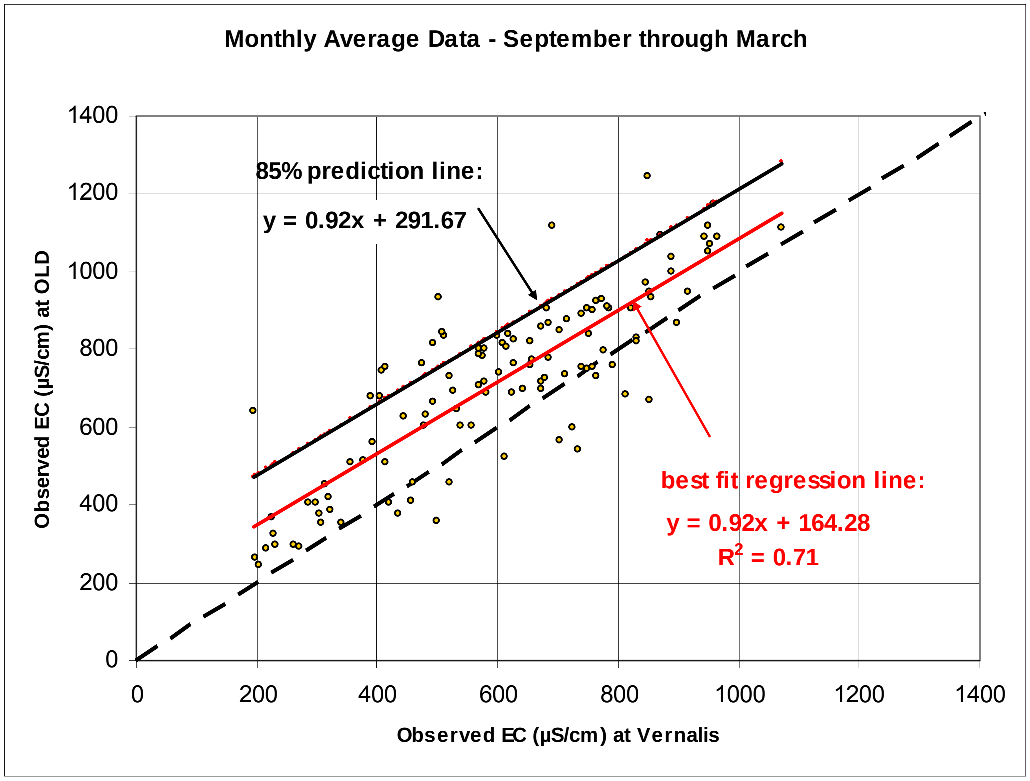


Figure 4-6. Monthly average salinity data for September through March from 1993 through 2009 for Old River at Tracy (OLD) plotted against corresponding salinity data at SJR at Vernalis, with best fit regression and 85 percent prediction lines

Figure 4-7 presents the difference between the estimate of EC at Old River at Tracy using the 85 percent prediction line (and EC at Vernalis as the input variable) and the corresponding observed EC value at Old River at Tracy for two seasons: April through August, and September through March. Rather than monthly, however, these values are calculated as the average of the corresponding seasons. This demonstrates that on a seasonal average basis, the 85 percent prediction line generates an estimate of Old River at Tracy that is greater than the observed value in all but 1 of 17 years presented. Best professional judgment will be used in selecting a percent prediction band that provides an appropriate level of protection against underestimating the level of salinity in the southern Delta, while avoiding overestimates of water supply costs that would be associated with an unnecessarily high percent prediction line.

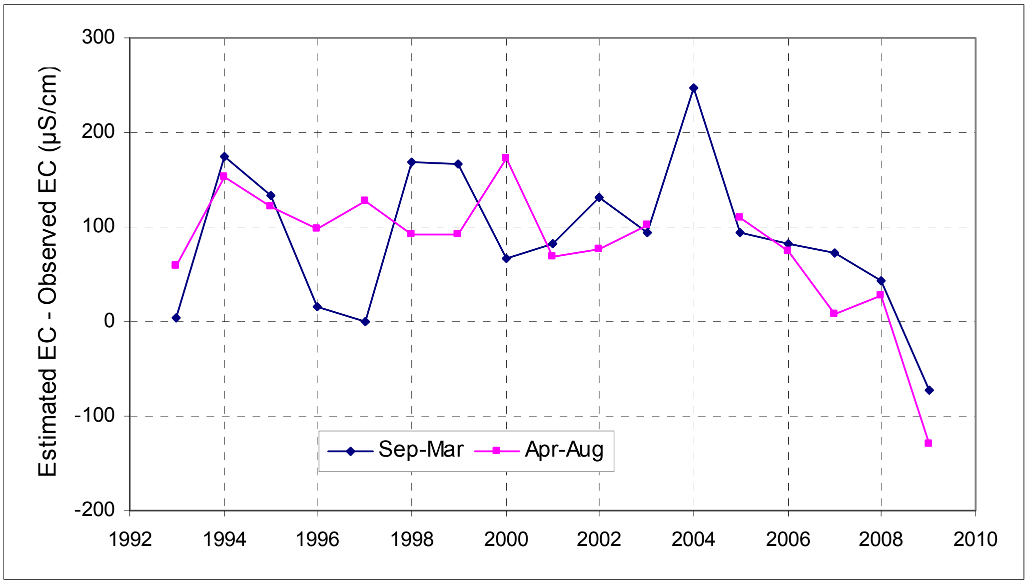


Figure 4-7. Monthly average estimate of EC at Old River at Tracy using the 65 percent prediction band plotted against monthly average observed EC at Old River Tracy for the months of April through August from 1993 through 2009

The equation for the 85 percent prediction line (corresponding to the correct season) will be used in Section 5 for estimating the monthly average salinity needed at Vernalis to meet a particular southern Delta salinity objective alternative for illustrative purposes to demonstrate the method.

4.2.2 Salt Loading from NPDES Discharges in Southern Delta

<u>DWR Modeling Study NPDES Discharges</u>

DSM2 modeling was conducted by a stakeholder group including DWR in 2007 to better understand the salinity impacts of the new and expanded discharges from the City of Tracy and Mountain House Community Services District wastewater treatment plants. The model analysis concluded that the City of Tracy discharge under reasonable worst-case conditions has limited impacts on the salinity problem in the southern Delta as compared to other sources of salinity in the area defined as ambient salinity entering from the San Joaquin River, agricultural activities, and groundwater accretions. Under the assumed ambient EC of 700 µS/cm in August, the affect of the Tracy discharge at 16 million gallons per day (mgd) would increase EC by 11 and 3 µS/cm in August under high and low export pumping scenarios respectively (CVRWQCB, 2007).

Mass Balance Analysis

A simple mass-balance analysis was conducted to further evaluate the relative effect of National Pollutant Discharge Elimination System (NPDES) point sources. This analysis used a combination of observed flow and EC data, and assumptions regarding discharges from the NPDES permitted facilities. As beneficial uses are affected more by longer term salinity averages, this analysis is based on monthly averages to understand the relative importance of major contributing factors, and do not account for dynamic mechanisms that affect short-term and localized fluctuations in EC concentrations.

The analysis compares the permitted maximum salinity loads from the City of Tracy, Deuel Vocational Facility, and Mountain House Community Services District wastewater treatment plants to the salinity load entering at the head of Old River (HOR). Figure 4-8 presents the salt load from HOR in tons/month and the total load from these three point sources as a percentage of the total HOR load for each month from January 1993 to December 2009. This demonstrates that the salt load from point sources in this part of the southern Delta is a small percentage of the salt load entering from upstream.

Salt loads from point sources were derived using the NPDES permitted discharge rates of 16.0 mgd, 0.62 mgd, and 0.54 mgd respectively for the City of Tracy, Deuel Vocational Facility, and Mountain House Community Services District wastewater treatment plants (Central Valley Regional Water Quality Control Board order numbers R5-2007-0036, R5-2008-0164, and R5-2007-0039) and average observed discharge salinities as reported on recent monitoring reports for each facility. Salinity inputs at HOR were derived by assuming the same salinity concentrations as those measured on the SJR at Vernalis, and by calculating flow as the difference between that measured on the SJR at Vernalis and that downstream of the head of Old River (as measured at USGS station #11304810 at the Garwood/Highway 4 bridge immediately upstream of the City of Stockton wastewater treatment plant).

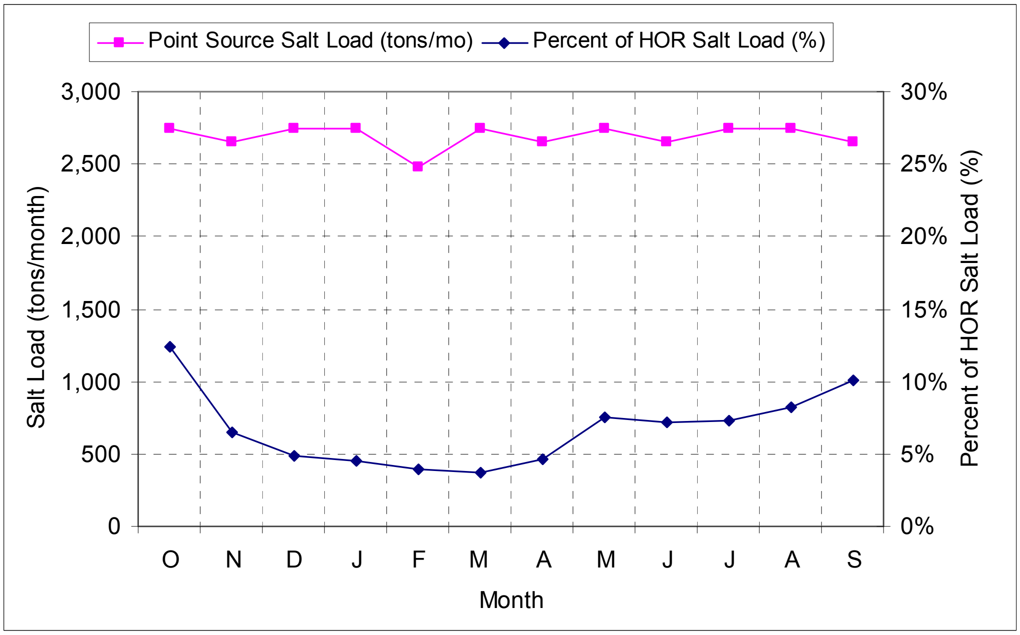


Figure 4-8. Theoretical salinity loading from the City of Tracy, Deuel Vocational Facility and Mountain House wastewater treatment plants stated as total load (tons/month) and as a percent of the load entering the head of Old River

4.3 Effects of Salinity in the Southern Delta

Salinity primarily affects agricultural supply (AGR) and municipal and domestic supply (MUN) beneficial uses in the southern Delta. This section discusses the latest technical information and modeling methodologies relevant to evaluating potential impacts of different salinity objective alternatives on these beneficial uses in the SED.

4.3.1 Effects on Agricultural Supply Beneficial Use

The SED will need to evaluate the impact of different salinity objective alternatives on Agricultural Supply (AGR) beneficial uses in the southern Delta. This evaluation will rely in large part on the conclusions and the modeling methodologies presented in a January, 2010 report by Dr. Glenn Hoffman entitled *Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta* (Hoffman, 2010).

As part of the 2006 *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary* (Bay-Delta Plan) the State Water Board committed to re-evaluate the salinity objectives in the southern Delta. With input from stakeholders, a contract was established with Dr. Glenn Hoffman to review the current scientific literature regarding crop salt tolerance and to assess current conditions in the southern Delta.

After presenting background and a description of soils and crops in the southern Delta, the Hoffman report provides an overview of several factors affecting crop response to salinity, including a discussion of the general state of knowledge and the specific southern Delta situation. The factors considered were:

- Season-long salt tolerance
- Salt tolerance at various growth stages
- Saline-sodic soils
- Bypass flows in shrink-swell soils
- Effective rainfall
- Irrigation methods
- Sprinkling with saline water
- Irrigation efficiency and uniformity
- Crop water uptake distribution
- Climate
- Salt precipitation or dissolution
- Shallow groundwater
- Leaching fraction

In addition to these factors, the report describes and compares the different models that are currently available for estimating soil water salinity in the crop root zone. The report then uses a basic steady-state model to estimate the soil water salinity concentrations and associated effect on the relative yield for three important crops grown in the southern Delta (dry bean, alfalfa, and almond). This modeling methodology uses local historical meteorological conditions and can be applied over a range of irrigation water supply salinity concentrations (i.e. salinity objective alternatives).

This report incorporated considerable input from public and agency stakeholders. In July 2009 Dr. Hoffman issued a draft version of the subject report, which was followed by a presentation of his preliminary findings at a State Water Board public staff workshop in August 2009. Written comments and other input were solicited from stakeholders regarding the draft report, and Dr. Hoffman gave a follow-up presentation in November 2009 to summarize and address the comments received. Based on feedback from these presentations, Dr. Hoffman finalized the subject report, including a comment response appendix.

The main conclusions and recommendations of this report are as follows (in no particular order):

a) Salt sensitive crops of significance in the southern Delta include almond, apricot, dry bean, and walnut, with dry bean being the most sensitive.

b) Based on the last nine years of data, the current level of salinity in the surface waters of the southern Delta appear suitable for all agricultural crops.

c) Neither sodicity nor toxicity should be a concern for irrigated crops; however, based on limited data and known crop tolerances, boron may be a concern.

d) Depth to the water table in much of the southern Delta is at an acceptable depth for crop production.

e) Relatively high leaching fractions are associated with an overall irrigation efficiency of 75 percent for furrow and border irrigation methods predominant in the southern Delta.

f) Data from drains in the western part of the southern Delta suggest leaching fractions are between 0.21 and 0.27, with minimums ranged from 0.11 to 0.22.

g) The field study data supporting the salt tolerance of bean is sparse and over 30 years old. There is also no information on the salt sensitivity of bean and many other crops in early growth stages.

h) Salt dissolution from the soil profile may cause the actual salinity in the root zone to be about 5 percent higher than estimated by the steady-state model, which does not account for dissolution.

i) Steady-state modeling presented in the report, and the results from other transient model studies suggest the water quality standard could be increased up to 0.9 to 1.1 dS/m and be protective of all crops normally grown in the southern Delta under current irrigation practices. During low rainfall years, however, this might lead to yield loss of about 5 percent under certain conditions.

j) Effective rainfall should be included in any modeling of soil water salinity in the southern Delta. Also, the exponential crop water uptake model is recommended as it better matches laboratory data. The 40-30-20-10 model used previously is more conservative, which leads to higher estimates of soil water salinity.

k) In addition to the conclusions above, a number of recommendations were made for further studies in the southern Delta regarding: i) the crop salt tolerance of bean, ii) transient soil salinity modeling, iii) potential for boron toxicity to crops, and iv) leaching fractions associated with current irrigation practices.

4.3.2 Effects on Municipal and Domestic Supply Beneficial Use

The SED will also need to evaluate the impact of different salinity objective alternatives on other beneficial uses in the southern Delta, including Municipal and Domestic Supply (MUN).

Maximum Contaminant Levels (MCL) are components of drinking water standards adopted by either the United States Environmental Protection Agency (USEPA) under the federal Safe Drinking Water Act or by the California Department of Public Health (DPH) under the California Safe Drinking Water Act. California MCLs may be found in chapter 15, division 4 of the title 22 of the California Code of Regulations. Primary MCLs are derived from health-based criteria. The MCL related to salinity is specific conductance, but because specific conductance does not cause health problems, there are no Primary MCLs for specific conductance. However, Secondary MCLs are established on the basis of human welfare considerations (e.g., taste, color, and odor) Drinking water has a Recommended Secondary MCL for specific conductance of 900 uS/cm, with an Upper MCL of 1,600 uS/cm and a Short Term MCL of 2,200 uS/cm. Specific conductance concentrations lower than the Secondary MCL are more desirable to a higher degree of consumers, however, it can be exceeded and is deemed acceptable to approach the Upper MCL if it is neither reasonable nor feasible to provide more suitable waters. In addition, concentrations ranging up to the Short Term MCL are acceptable only for existing community water systems on a temporary basis. (Note: specific conductance is electrical conductivity normalized to a temperature of 25^{O} C).

5 Water Supply Impact Analysis

5.1 Purpose and Approach

The purpose of this section is to describe how the implementation of the proposed alternative SJR flow and southern Delta (SD) salinity objectives in the San Joaquin watershed will be analyzed in the SED. This section describes the analytical approach and modeling tools used to quantify the effects of implementing the objectives. These effects include a conservative estimate of the water supply impacts that in turn can be used to evaluate economic impacts and other impacts in the SED. The analytical steps will be explained and then applied to a range of illustrative alternative flow objectives. This range of alternatives was selected only to demonstrate the applicability of the methodology across this range. The actual alternatives evaluated in the SED may differ.

This analysis compares flow output from a CALSIM II model run representative of current conditions in the San Joaquin watershed against estimates of flow needed to satisfy a particular set of SJR flow and southern Delta salinity objective alternatives, and calculates the amount of additional water needed to attain these objectives. The additional water needed is then compared against CALSIM II estimates of total diversions from the three eastside tributaries (Stanislaus, Tuolumne, and Merced Rivers) and the portion of the SJR between Vernalis and its confluence with the Merced River. Neither this analysis nor the SED will address specifically from where the additional water will be provided within the SJR watershed; instead, the purpose is to demonstrate that water is physically available within the watershed.

5.2 CALSIM II San Joaquin River Model

The CALSIM II San Joaquin River Water Quality Module (CALSIM II) is a computer model developed by the U.S Bureau of Reclamation (USBR) to simulate flow, storage, and use of water in the SJR basin. It is a planning model that imposes a specified level of water resources infrastructure development, land use, water supply contracts, and regulatory requirements over the range of historical meteorological and hydrologic conditions experienced from 1922 to 2003. This assumes future meteorological and hydrologic conditions will be similar to historical. The model then estimates the amount of water available for deliveries, allocates this water based on various priorities, estimates demand and calculates associated return flows. The model assumes fixed annual demands and uses regression analysis to represent flow accretions, depletions and salinity at key locations. It also relies upon historical runoff information and standardized reservoir operating rules for determining carryover storage. Demands not met by surface water deliveries can be supplemented with groundwater pumping, although CALSIM II does not model changing groundwater levels. The CALSIM II model runs on a monthly time step, with monthly average inputs and outputs. (USBR, 2005)

The basis for the water supply impact analysis described in this section will be the CALSIM II “Current (2009) Conditions” model run from the DWR *State Water Project Delivery Reliability Report 2009*. A detailed description of the various hydrology, facilities, regulatory, operations assumptions are provided in Appendix A of that report (DWR, 2010b). This CALSIM II model run includes representation of both the December

2008 U.S. Fish & Wildlife Service and the June 2009 National Marine Fisheries Service biological opinions on the Central Valley Project and the State Water Project.

CALSIM II Flow Estimates at Vernalis

A simple comparison with observed monthly average flow data from the USGS gage #11303500 on the SJR at Vernalis (USGS, 2010) shows CALSIM II provides a reasonable estimate of flow for the SJR at Vernalis. Figure 5-1 shows actual flow data from water years 1984 to 2003 and output from the CALSIM II representation of current conditions assuming hydrology for the same time period. This covers a period during which actual operations in the watershed were relatively similar to those modeled in the CALSIM II representation of current conditions. After 1984 all major eastside dams were completed and filled and their combined effect on flows at Vernalis should be present in the actual data. CALSIM II model output ends with water year 2003.

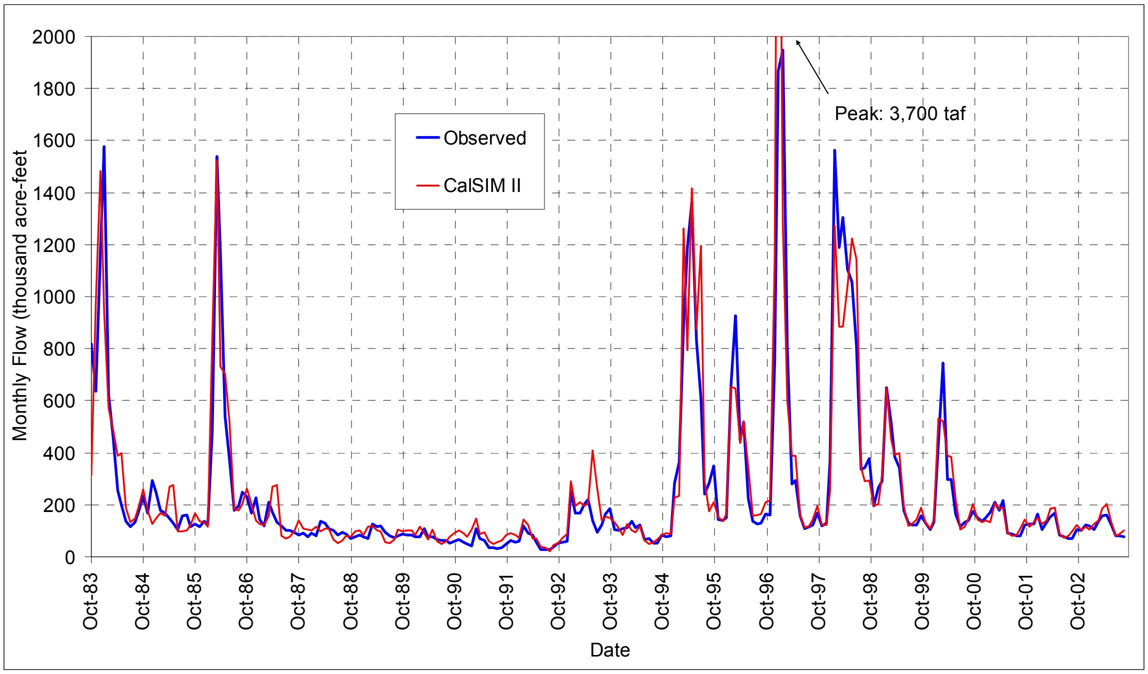


Figure 5-1. Observed monthly average flow from USGS gage #11303500 (SJR near Vernalis) compared to CALSIM II model output for SJR flow at Vernalis

CALSIM II Salinity Estimates at Vernalis

CALSIM II has a water quality module, which provides dynamic estimates of salinity at Vernalis. This module uses a “link-node” approach that assigns salinity values to major inflows to the SJR between Lander Avenue and Vernalis and calculates the resulting salinity at Vernalis using a salt mass balance equation. Inflows from the west side of the SJR are also broken out and calculated as the return flows associated with various surface water diversions and groundwater pumping (MWH, 2004).

In Figure 5-2, monthly average observed salinity data from CDEC at Vernalis (DWR, 2010a) is plotted together with the CALSIM II estimates of salinity at Vernalis for water years 1994 through September 2003. This represents a period commencing shortly after temporary barriers in the southern Delta were regularly installed through to the end of the overlapping CALSIM II period of simulation.

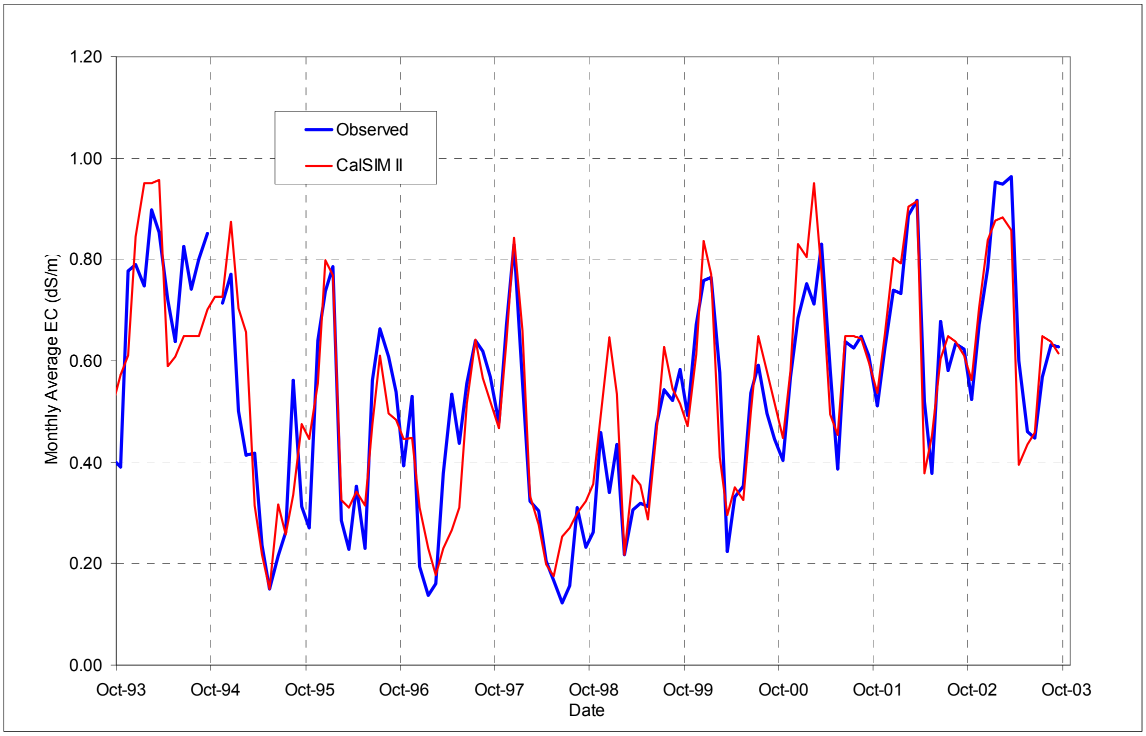


Figure 5-2. Comparison of CALSIM II salinity (dS/m) output at Vernalis to monthly average observed data at the same location for water years 1994 through 2003

5.3 Estimating Additional Flow Needed for Alternatives

This section describes how estimates of additional flow needed to satisfy different SJR flow and southern Delta salinity objective alternatives will be calculated.

5.3.1 SJR Flow Objective Alternatives

As described in Section 3, flow objective alternatives are stated as a minimum percentage of unimpaired flow for the individual months of February through June. The additional annual flow volume needed for a particular SJR flow alternative is the total of the difference in the individual months (February through June) between the desired percentage of unimpaired monthly flow at Vernalis and the CALSIM II estimate of current monthly flows at this same location, but only when CALSIM II flows are less than the desired percent of unimpaired flow.

If the CALSIM II estimate of current flow for a particular month is already greater than the desired percent of unimpaired flow, no flow is added or removed from the annual total. Without re-running the CALSIM II model, it is not possible to estimate what, if any, decreases in flow (i.e. water savings) might be achieved when current flows for a period of time are already greater than the desired alternative. CALSIM II modeling logic might be maintaining such higher flows to satisfy other flow, water quality or other needs, and cannot be determined without re-running the model. To the extent that flows during such periods could be lower after re-running of the CALSIM II model, this assumption for determining additional flow will lead to a conservative (higher) estimate of required flow.

For illustrative purposes Figure 5-3 shows graphically for water years 1978 to 1984, how the additional annual flow volume needed to meet 40 percent unimpaired flow at

Vernalis (at a minimum) is calculated. The following are plotted: a) 40 percent unimpaired flow, b) the CALSIM II estimate of current flows, and c) the difference between b) and a) when the former is greater than the later. The date range was selected for illustrative purposes only to include years when both the desired unimpaired flow percentage and CALSIM II output were greater.

This methodology is demonstrated for all 82 years of CALSIM II simulation in Figure 5-4. This figure presents exceedance plots of CALSIM II monthly flows at Vernalis for the individual months of February through June expressed as a percentage of unimpaired flow at Vernalis, and is overlaid with the same plots modified to meet minimum flow objectives of 20, 40, and 60 percent of unimpaired Vernalis flow. This demonstrates how CALSIM II flows are raised to meet a target flow objective, but remain unchanged when already above that target flow objective.

Neither this analysis, nor the SED will address specifically where the additional flow to meet SJR flow objectives will come from within the San Joaquin River watershed; the analysis will only demonstrate that the additional flows are physically available.

5.3.2 Southern Delta Salinity Objective Alternatives

This section describes the methodology for estimating the amount of additional low-salinity flow from within the watershed that will be needed to meet a particular set of southern Delta salinity objective alternatives. First, the level of salinity at Vernalis needed to meet a particular southern Delta salinity objective alternative will be determined, and then the amount of dilution flow from the low-salinity eastside tributaries (Stanislaus, Merced and Tuolumne) needed to dilute the salinity at Vernalis to this level will be calculated.

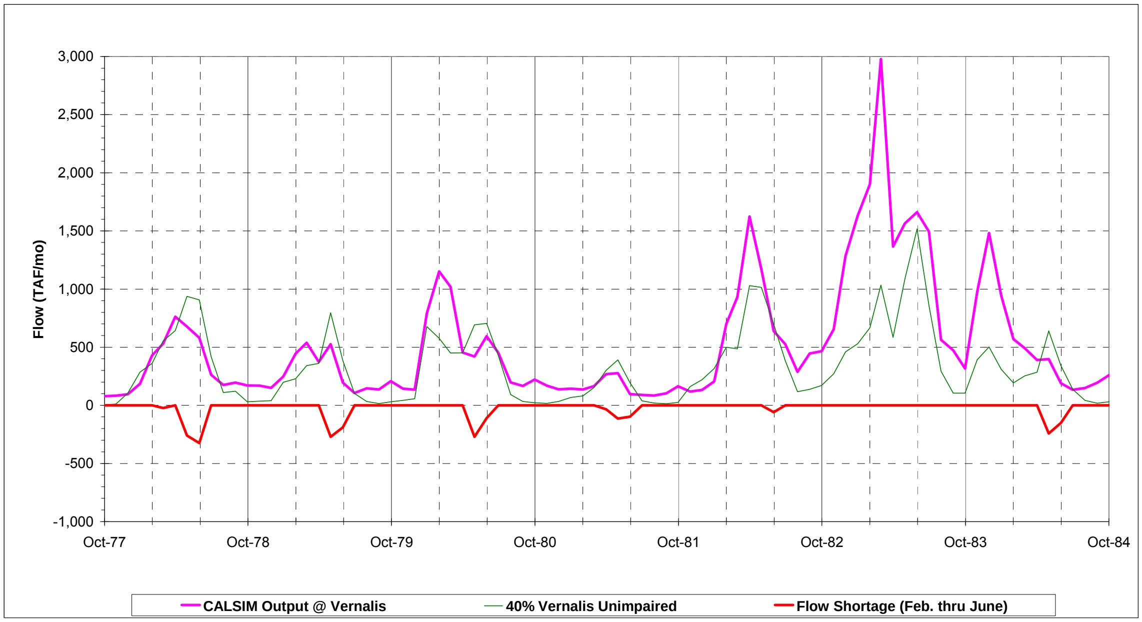


Figure 5-3. Monthly flows on SJR at Vernalis for water years 1978 to 1984 showing a) 40 percent of unimpaired flow, b) CALSIM II estimate of current flows, and c) the difference between b) and a) when the former is greater than the later

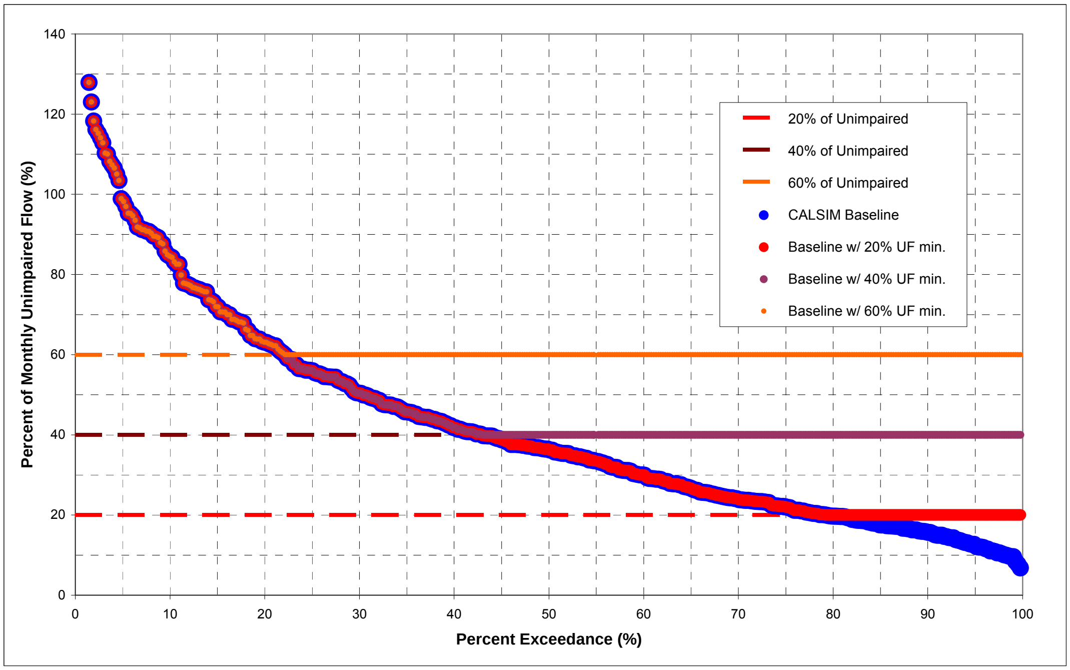


Figure 5-4. Exceedance plots of CALSIM II flows at Vernalis for February through June with those for SJR flow objective alternatives of 20, 40, and 60 percent of unimpaired Vernalis flow (as percentage of unimpaired flow at Vernalis)

The salinity relationship developed in Section 4.2.1 between salinity levels at Vernalis and the southern Delta compliance location on Older River at Tracy Road Bridge (D1641 station P-12) will be used to estimate the needed level of salinity at Vernalis to meet a particular southern Delta salinity objective alternative. This is the southern Delta compliance station which generally has the highest level of salinity increase from Vernalis. This target level of salinity at Vernalis is then compared to the estimate of salinity at Vernalis under current conditions as generated by CALSIM II (see discussion of the CALSIM II salinity estimate in Section 5.2). If the target level of salinity at Vernalis for a particular month is already being met by the estimate of current conditions, then no additional dilution flow is required. If the estimate of current conditions is greater than the target salinity level, then the amount of flow from the low-salinity eastside tributaries (Stanislaus, Merced and Tuoloumne) needed to achieve the target level is calculated by Eqn. 5.1 on a monthly timestep:

$$F_{EC} = \frac{F_V\left(EC_{Vern} - EC_{Target}\right)}{EC_{Target} - EC_{Trib}} \qquad \text{(Eqn. 5.1)}$$

Where:

F_{EC} = additional tributary flow needed to meet EC_{Target}
F_{Vern} = CALSIM II estimated flow at Vernalis
EC_{Trib} = Average CALSIM II estimate of salinity in three eastside tributaries
EC_{Vern} = CALSIM II estimated of salinity at Vernalis
EC_{Target} = target salinity level at Vernalis

Note: Any units for flow or salinity can be used in above equation provided they are used consistently throughout.

The additional flow needed for a particular water year is simply the sum of additional flow needs in all of the months in that water year. This estimate will be further adjusted as described in the next section to account for additional flow that may already be added in a particular month to satisfy a concurrent SJR flow objective.

This way of calculating additional flow to meet southern Delta salinity objectives assumes that the additional flow needs will need to come from sources of low-salinity flow within the SJR watershed (primarily the Stanislaus, Tuolumne, and Merced rivers). Other than this general assumption, neither this analysis, nor the SED will further address specifically the source of low-salinity flows needed to meet southern Delta salinity objectives.

5.3.3 Combined SJR Flow and southern Delta Salinity Objective Alternatives

The total water supply impact for a particular month is estimated by first calculating the additional flow needed to meet SJR flow objectives for that month (as described in Section 5.3.1). Then the additional flow needed to meet the southern Delta salinity objective is calculated for that month (as described in Section 5.3.2), but to the extent that additional flows added to meet the SJR flow objectives will also contribute to satisfying the additional flows needed for the southern Delta salinity objectives, the latter value will be adjusted lower as shown in Eqn 5.2. However, if the additional flow needed to meet the SJR flow objective is greater than the amount needed to meet the salinity objective, then no additional flow for the latter will be required. Eqn. 5.3 provides the total amount of additional flow as needed for a particular month on the SJR at Vernalis to satisfy the combined SJR flow and southern Delta salinity objectives alternative.

$$F_{EC}' = F_{EC} - F_{Flow} \qquad \text{(Eqn. 5.2)}$$

but if: $F_{Flow} > F_{EC}$ then $F_{EC}' = 0$

$$F_{Tot} = F_{Flow} + F_{EC}' \qquad \text{(Eqn. 5.3)}$$

Where:

F_{EC}' = adjusted additional tributary flow needed for salinity objective
F_{EC} = additional tributary flow needed for salinity objectives (per Eqn. 5.1)
F_{Flow} = additional flow needed to meet flow objective (per Section 5.3.1)
F_{Tot} = total additional flow needed for combined flow and salinity objectives

5.4 Water Supply Impact Analysis

This section describes the methodology used to estimate the water supply impact of the additional flows needed to satisfy a particular set of SJR flow and southern Delta salinity objective alternatives. Estimates are then calculated over a range of possible objective alternative combinations to demonstrate how the methodology is applied, resulting in a range of impact estimates. This range of impact estimates is further presented as a percentage of current diversion levels in the SJR watershed. The total annual water supply impact, expressed both as a volume of water and as a percentage of diversions, will be used to inform the economic and other impact analyses in the SED.

5.4.1 Water Supply Impact Calculation

This methodology for estimating water supply impact assumes the additional flow needed to satisfy the objective alternatives in a particular water year will be provided entirely by diversion reductions during the months of February through September in the same water year. As the additional water needs are provided for in the same water year, reservoir levels at the end of each water year are not changed and the storage carryover assumptions contained in the original CALSIM II current conditions model run are preserved. This is conservative to the extent that re-operation of the reservoirs in the CALSIM II model could distribute the effect of diversion reductions over more than the year in which they occurred. For example, peak flow months have shifted in some years from the spring to the fall in the recent period as can be seen in Table 2-6. Figure 2-7c shows a year during which relatively high flows occurred on the Merced River in November. This suggests that some high flow events are occurring in the fall, perhaps to release water from reservoirs to provide storage capacity in anticipation of higher streamflow events. The water supply impacts of additional spring flows could therefore be reduced by re-operating reservoirs. Simplifying assumptions were used in the current analysis for the purpose of developing a conservatively high estimate of water supply impacts associated with proposed flow and salinity objective alternatives. Neither this analysis, nor the SED will address specifically where additional water will come from within the SJR watershed.

To the extent that additional flow needs would come from reductions in diversions, this would likely lead to a proportional decrease in return flows, and lead to efforts by water users to increase the efficiency of their use of these reduced diversions. The estimates of water supply impact for a particular month, therefore, will assume a reduction of return flow proportional to the reduction in diversions, and apply an additional 50 percent reduction to the remainder to account for any increase in efficiency (i.e. further return flow reduction) as shown below:

$$RF_{Red} = \left(\frac{F_{Tot}}{D_{ws}} * RF_{ws} \right) * (1 + 0.5) \qquad \text{(Eqn. 5.4)}$$

Where:
RF_{Red} = total reduction in return flows associated with diversion reductions
D_{ws} = total volume of diversions in the specified portion of the watershed
F_{Tot} = additional flow (i.e. diversion reductions) per Eqn. 5.3
RF_{ws} = total volume of return flows in the specified portion of the watershed

In some cases F_{Tot} is large enough that RF_{Red} can be greater than RF_{ws} for a particular month. As with additional flow needs, however, RF_{Red} is spread out, and in no case does RF_{Red} for the whole water year exceed RF_{ws} for the months of February through September of that same water year, as explained below.

Reduced return flows calculated in the above manner are not an additional flow requirement in the river, but rather an additional water supply impact (i.e. diversion reduction) that would occur in order to maintain a specified flow in the river to counteract the effect of reduced return flows. Over the 82 years of CALSIM II simulation, this adds an average of about 11 percent to the water supply impact in addition to the flow needed to meet the SJR flow and southern Delta salinity objective alternatives.

The total water supply impact for a particular month is the sum of the diversion reductions required to provide additional flow, plus the additional diversion reduction needed to counteract the assumed effect of reduced return flows as follows:

$$WSI = F_{Tot} + RF_{Red} \qquad \text{(Eqn. 5.5)}$$

Where:
WSI = total water supply impact
F_{Tot} = total additional flow requirement as given by Eqn. 5.3
RF_{Red} = total reduction in return flows as given by Eqn. 5.4

The annual water supply impact (i.e. diversion reductions) in a particular water year is the sum of the values as calculated above for all the months in that water year. In some cases *WSI* is greater than all diversions for a particular month, however, (with the exception of a few cases for SJR flow objectives greater than 60 percent minimum unimpaired) *WSI* for a whole water year does not exceed total diversions during the months of February through September for that same water year.

5.4.2 Annual Water Supply Impact Estimates

To demonstrate this methodology, estimates of water supply impacts are calculated for a range of hypothetical objective combinations. For these calculations it is assumed that additional flow needed to meet SJR flow and southern Delta salinity objectives is obtained by reducing CALSIM II modeled diversions downstream of the major dams on the Stanislaus, Tuolumne, and Merced rivers (New Melones Reservoir, New Don Pedro Reservoir, and Lake McClure respectively) and the portion of the SJR between Vernalis and the Merced River. It is also assumed that return flows in this same portion of the SJR watershed will be reduced as described in the previous section. This portion of the SJR watershed was selected for demonstration purposes only. This analysis does not specify from where within the San Joaquin River watershed the additional flow needed for the flow and salinity objectives will come.

CALSIM II model output provides, among other things, monthly average estimates of diversions and return flows from/to the rivers in the SJR watershed over the 82 years of simulated hydrology. All the CALSIM II model nodes and associated diversions and return flows within this portion of the SJR watershed are listed in Table 5-1. This list of diversions and return flows was obtained from the flow balance equations for each of the nodes contained in the CALSIM II input files for this portion of the SJR watershed. The diversions and return flows were further verified by creating a flow balance for each node, including all diversions, return flows, inflows and changes in reservoir storage.

For reference, the total annual diversions for the 82 years of CALSIM II simulation from this portion of the SJR watershed have a median value of 2,235 taf (maximum = 2,567 taf, minimum = 1,351 taf), while total annual return flows have a median of 196 taf (maximum = 214 taf, minimum = 126 taf).

Table 5-1. List of diversions and return flows from all CALSIM II nodes in the portion of the SJR basin including the Stanislaus, Tuolumne, and Merced rivers, and the portion of the SJR between Vernalis and its confluence with the Merced

River	CALSIM II Node No.	CALSIM II Diversion No.	CALSIM II Return Flow No.	Descripton
San Joaquin	620	D620A D620B D620C	R620	Newman - Merced confluence
	630	D630A D630B	R630J R630K R630L R630M R630West	Tuolumne confluence
	636	none	R636A R636B R636C	Maze
	637	D637	R637A R637B R637C R637D	Stanislaus confluence
	639	D639	R639A R639West	Vernalis
Stanislaus	10	none	none	New Melones Reservoir
	76	none	none	Tulloch Reservoir
	520	D520A D520A1 D520B D520C	none	
	528	D528	R528A R528B R528C	
Tuolumne	81	none	none	New Don Pedro Reservoir
	540	D540A D540B	none	
	545	D545	R545A R545B R545C	
Merced	20	none	none	Lake McClure
	561	D561	none	
	562	D562	none	
	564	none	R564A R564B	
	566	D566	R566	

Total Water Volume

Applying the methodology described in Section 5.4.1, the median, and first and third quartile estimates of annual water supply impact (i.e. diversion reductions in thousand acre-feet) generated using the 82 years of CALSIM II simulation for a range of SJR flow objective alternatives from 20 to 60 percent minimum of unimpaired Vernalis flow are presented in Table 5-2. These estimates are presented both with and without concurrently meeting a southern Delta salinity objective of 0.7 dS/m from April to August and 1.0 dS/m from September to March.

Table 5-2. Median, first and third quartile water supply impact (taf/year) for a range of SJR flow objective alternatives, with and without southern Delta salinity objective of 0.7 dS/m from April to August and 1.0 dS/m from September to March

Percent Unimpaired Alternative	Total (taf)			Flow Objective Only (taf)			Add'l for Salinity Objective (taf)		
	Q1	Median	Q3	Q1	Median	Q3	Q1	Median	Q3
60%	1,800	1,480	1,080	1,676	1,311	929	184	162	130
50%	1,300	1,039	763	1,180	923	636	197	168	130
40%	889	680	501	744	478	332	218	179	130
30%	583	428	294	361	237	98	250	184	132
20%	389	287	168	95	22	0	290	204	144

The median is the middle value of the 82 years of annual estimates, and fifty percent of these values fall between the first (Q1) and third (Q3) quartile values. From this table it can be seen that SJR flow objective alternatives have water supply impacts that increase with increased target minimum percentage of unimpaired flow. For a particular southern Delta salinity objective alternative, the associated water cost is slightly decreased when combined with higher SJR flow objective alternatives due to higher flow associated with the latter being able to satisfy some of the flow needs for the former.

The estimates of water supply impact over a range of SJR flow objective alternatives from 20 to 60 percent minimum of unimpaired Vernalis flow are also presented in Table 5-3. These estimates are broken out and averaged by water year type (as defined in D-1641) and presented both with and without concurrently meeting a southern Delta salinity objective alternative of 0.7 dS/m from April to August and 1.0 dS/m from September to March.

Table 5-3. Water supply impact (taf/year) associated with meeting a range of SJR flow objective alternatives, with and without southern Delta salinity objective of 0.7 dS/m from April to August and 1.0 dS/m from September to March

a) combined SJR flow and southern Delta salinity objectives:

Percent Unimpaired Alternative	Water Year Type (average in thousand acre-feet)				
	W	AN	BN	D	C
60%	1,611	1,879	1,669	1,170	1,002
50%	1,024	1,382	1,269	886	806
40%	542	924	905	644	627
30%	243	530	584	465	480
20%	111	256	350	354	399

b) SJR flow objectives only:

Percent Unimpaired Alternative	Water Year Type (average in thousand acre-feet)				
	W	AN	BN	D	C
60%	1,531	1,723	1,496	981	793
50%	944	1,226	1,088	683	584
40%	462	766	709	409	389
30%	162	373	363	194	214
20%	23	83	101	49	69

c) additional for southern Delta salinity objective altenative:

Percent Unimpaired Alternative	Water Year Type (average in thousand acre-feet)				
	W	AN	BN	D	C
60%	80	155	173	189	208
50%	80	155	181	203	223
40%	80	158	197	235	237
30%	81	158	221	271	265
20%	88	172	249	306	329

Percent of Diversions

To put the illustrative alternatives in perspective, the annual water supply impacts for a particular set of SJR flow and southern Delta salinity objective alternatives (calculated per Section 5.4.1) are divided by the total amount of all diversions listed in Table 5-1 for the months of February through September in each water year for the 82 years of CALSIM II simulated hydrology. This provides an additional way of characterizing the water supply impact for subsequent impact analysis in the SED, and verifies the basic assumption of this methodology, namely that additional flow needs can be achieved from diversion reductions.

Rather than dividing the water supply impact by diversions on a monthly basis (which is highly variable), dividing by diversions from February through September provides a better indication of the average impact of diversion reductions over each pre-irrigation and growing season[5]. As mentioned previously, confining water supply impacts to the same water year as the associated additional water needs maintains the storage carryover assumptions contained in the original CALSIM II current conditions model run because reservoir levels at the end of each water year are not affected.

The median, and first and third quartile values calculated in this manner are presented in Table 5-4 for a range of SJR flow objective alternatives ranging from 20 to 60 percent minimum of unimpaired Vernalis flow. These are presented both with the SJR flow objective alternatives alone, and with SJR flow and southern Delta salinity objective alternatives in combination. For reference, the total combined diversions for the months of February through September in each water year for the 82 years of CALSIM II simulation have a median value of 2,081 taf (maximum = 2,407 taf, minimum = 1,219 taf).

Table 5-4. Median, first and third quartile of water supply impact (as percent of total diversions between February and September) for a range of SJR flow objective alternatives, with and without southern Delta salinity objectives

Percent Unimpaired Alternative	Total (%)			Flow Objective Only (%)			Add'l for Salinity Objective (%)		
	Q1	Median	Q3	Q1	Median	Q3	Q1	Median	Q3
60%	88	71	55	83	64	47	10	8	6
50%	66	51	39	56	44	31	10	8	6
40%	46	35	24	37	24	19	11	9	6
30%	31	20	14	18	11	5	12	9	6
20%	19	13	8	5	1	0	14	10	6

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[5] As mentioned previously in Section 5.3.2, the additional flow to meet southern Delta salinity objectives is assumed to come from sources of low-salinity flow within the SJR watershed (primarily the Stanislaus, Tuolumne, and Merced rivers). Dividing this amount by total diversions that include the higher-salinity SJR leads to a slight underestimate of the impact on diversions on the three eastside tributaries. This underestimate is negligible as diversions on the SJR only make up about 10% of the total and is further offset by other conservative assumptions in this analysis.

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