Chapter 2
Hydrology and Water Supply

2.1 Introduction

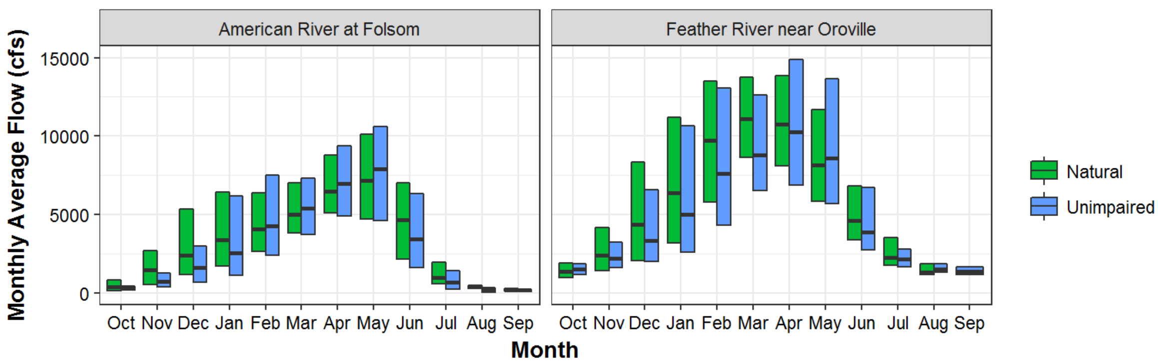
This chapter describes the existing hydrology and water supply conditions in the study area. The discussion of hydrology focuses on the mainstem Sacramento River and its tributaries (Sacramento River watershed), the three eastside tributaries to the Delta (Cosumnes, Mokelumne, and Calaveras Rivers), and the Delta. These regions are referred to in this document as the Sacramento/Delta. Throughout the Sacramento/Delta, current hydrologic conditions are compared with unimpaired conditions to assess changes in the flow regime.

The hydrologic analysis of Delta outflows indicates that diversions and exports have reduced average annual outflow, reduced winter and spring outflow, and reduced seasonal variability. The hydrologic analysis also indicates that water development in regulated tributaries has generally resulted in reduced annual Delta inflow, reduced spring inflow, increased summer inflow, and decreased hydrologic variability. The analysis indicates that tributaries without large reservoirs generally have lower flows in late spring and summer. Finally, the hydrodynamic analysis indicates that SWP and CVP (collectively, the Projects) pumping in the south Delta and associated operations have increased the magnitude and frequency of reverse (upstream) flows on Old and Middle Rivers (OMR) and other alterations in the hydrodynamics of the Delta.

The discussion of water supply (Section 2.8, *Existing Water Supply*) provides an overview of the water supplied to the Sacramento River watershed, Delta eastside tributaries, Delta, San Francisco Bay Area (Bay Area), San Joaquin Valley, Central Coast, and Southern California regions. The water supply discussion describes how much water is supplied to different regions of the state and provides context for what portion of each region's total water supply originates from the Sacramento/Delta. The information in this chapter provides background and supporting information for subsequent chapters.

2.1.1 Natural and Unimpaired Flow

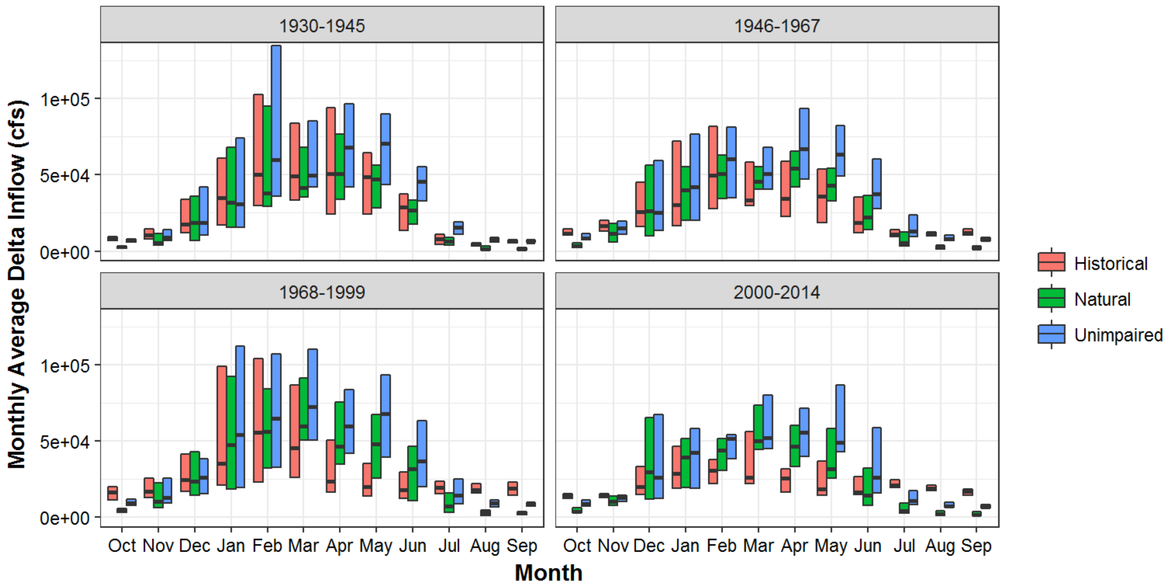
Unimpaired hydrology or *unimpaired flow* represents an index of the total water available to be stored or put to any beneficial use within a watershed under current physical conditions. Stated another way, unimpaired flow represents the flow that would be present in a river or stream under current land use patterns in the absence of diversions, storage, releases from storage, water transfers, or other hydrologic modifications. Unimpaired flow is different than the natural flow that would have occurred absent human development of land and water supply. The use of unimpaired flows as an index is often misunderstood, owing in part to uncertainty regarding the relationship between unimpaired and natural flows and their intended use from a regulatory perspective. In the Bay-Delta watershed, differences between natural flows and unimpaired flows are thought to be relatively small in the upper watersheds where fewer physical modifications to the landscape have occurred and more natural runoff patterns exist (Figure 2.1-1) (DWR 2016a). While unimpaired flows and natural flows may be very similar in these upper watershed areas, flow management must still consider the effects of dams and other physical modifications that block access to historical habitats and alter temperatures and other conditions important to aquatic species. On the valley floor and in the Delta, where the greatest land use changes have occurred, the differences between unimpaired flow and natural flows may be substantial at times (DWR 2016a) but are not known with certainty. Estimating natural flow requires making assumptions about many physical attributes of the pre-development landscape, including the distribution of wetland and riparian vegetation, channel configurations, detention of overbank flows, and groundwater accretions. All of these conditions differ from the current physical condition and land use of the watershed to unknown degrees (DWR 2016a). Recent publications estimate evapotranspiration by natural vegetation (Howes et al. 2015) and its combined effects with other elements of a hypothetical pre-development condition on net Delta outflow (NDO) (Fox et al. 2015) and throughout the Bay-Delta watershed (DWR 2016a). These estimates are produced by routing historical unimpaired flows from the upper watersheds over a hypothetical reconstructed valley floor and Delta (Fox et al. 2015; DWR 2016a), producing estimates of the flow that “would have” occurred over the historical record in the absence of human development. DWR (2016a) concludes that “relative seasonal (i.e., monthly) distributions of unimpaired and natural Delta outflow estimates are not widely different,” but that due to an imperfect scaling and difference in annual magnitude, “unimpaired flow estimates are poor surrogates for natural flow conditions.”



Source: DWR 2016a.
Monthly patterns and magnitudes of natural and unimpaired flows are similar, but not identical.
cfs = cubic feet per second

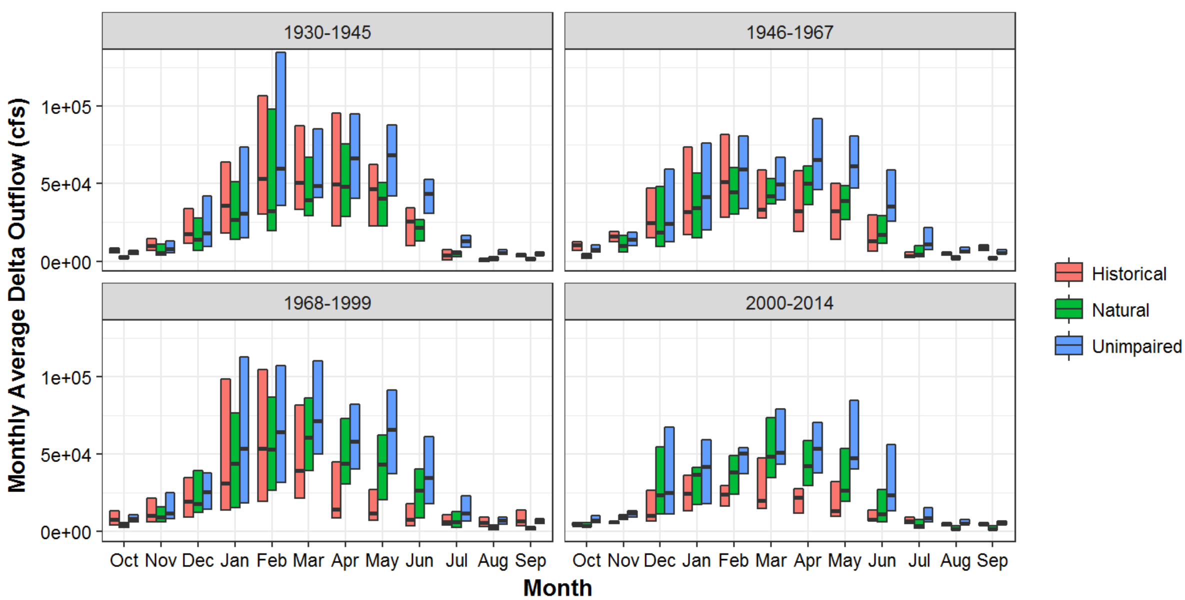
Figure 2.1-1. Quartile Distributions of Natural and Unimpaired Flows at Two Sample Rim Dam Locations, as Estimated by the California Department of Water Resources

To evaluate the potential differences between unimpaired flow and natural flow, the monthly distributions of DWR’s (2016a) estimates of the two, along with estimates of historical flow (also provided by DWR (^DWR 2017a) are compared over time. Figure 2.1-2 and Figure 2.1-3 show these comparisons for Delta inflow and NDO as quartile distributions on a monthly time scale. As with a box and whisker plot, the black horizontal line shows the median, and the box spans the range between the 25th and 75th percentiles; whiskers and outliers are omitted for clarity. The figures show the most significant differences between unimpaired and natural Delta flows during the peak snowmelt season of April through June and generally throughout the drier months, due largely to the assumed presence of significant additional vegetation in the natural flow estimates. The figures also show other significant differences between historical flows and estimates of unimpaired and natural flows, particularly during the wet months of winter and spring, due to water development. This pattern of increasing flow alteration and decreasing Delta outflow will likely continue without additional regulation.



Sources: natural and unimpaired flow estimates: DWR 2016a; historical flow estimates: ^DWR 2017a.
Water supply development has reduced wet season Delta inflow and increased dry season Delta inflow relative to both estimated unimpaired and natural flows over time.
cfs = cubic feet per second

Figure 2.1-2. Quartile Distributions of the California Department of Water Resources Estimates of Historical, Natural, and Unimpaired Delta Inflow



Sources: natural and unimpaired flow estimates: DWR 2016a; historical flow estimates: DWR ^2017a.
Water supply development has reduced wet season Delta outflow relative to both estimated unimpaired and natural flows over time.
cfs = cubic feet per second

Figure 2.1-3. Quartile Distributions of the California Department of Water Resources Estimates of Historical, Natural, and Unimpaired Delta Outflow

Unimpaired flows are used throughout this report in several ways that acknowledge and respect the differences between natural and unimpaired flows. Unimpaired flows are used to help characterize how human uses of water have altered the magnitude, timing, and duration of flows in the watershed under the current physical configuration of the watershed over time. This information can then be evaluated against species declines to help understand how changes in hydrology have contributed to those declines. Impacts from the changes in the physical configuration of the watershed also are discussed. In addition, unimpaired flows are used as an index of water availability to understand and help balance between environmental and other uses as water supplies for all purposes are limited. Unimpaired flows also are used as an approximation of more natural flow conditions protective of native aquatic species. However, as discussed further in Chapters 1, *Executive Summary*, and 5, *Proposed Changes to the Bay-Delta Plan for the Sacramento/Delta*, regulatory requirements based on unimpaired flows acknowledge that native species now inhabit an altered landscape and that adaptive management is needed to allow for sculpting and shaping of those flows to address the realities of that modified landscape. Adaptive management of unimpaired flows can also address changes to the landscape over time due to climate change, habitat restoration, and other factors

2.1.2 Watershed Overview

California has a Mediterranean climate that is characterized by mild, wet winters and dry, hot summers. Eighty-five percent of the annual precipitation falls in winter months. In summer, many parts of the watershed go more than 90 days without any precipitation. California also shows great inter-annual variability in runoff, with Sacramento Valley total annual runoff ranging from an estimated 5.1 million acre-feet (MAF) in water year 1977 to 37.7 MAF in water year 1983 (DWR 2016b). For over 150 years, humans have altered the Sacramento River and its tributaries to reclaim wetlands, tame floods, and provide irrigation during the dry months. Two of the largest water projects in the world, the SWP and the CVP, move water from the Sacramento watershed through the Delta and deliver it to farmers and cities in areas south of the Delta.

The Sacramento River extends from the Modoc Plateau and the southern Cascades near the Oregon border to the San Francisco Bay and Pacific Ocean, draining an area of 27,000 square miles. The Sacramento River has an average annual unimpaired flow of 21 MAF (based on values for water years 1922–2014), which is approximately one-third of the total runoff in California (DWR 2016a). It has more than 20 major salmon-bearing tributaries, a number of other tributaries with intermittent flows that salmon do not inhabit on a sustained basis, a series of flood basins, and is home to an extensive community of fish and wildlife.

Below its source near Mount Shasta, the Sacramento River is impounded by the largest reservoir in California, Shasta Reservoir. Below Shasta, the Sacramento River proceeds southward through a series of leveed river channels bordered by overflow basins and weirs. The capacity of its reaches increases and decreases as it proceeds downstream. Its main tributaries are the Feather River, fed by the Yuba and Bear Rivers, and the American River. At the bottom of the watershed, the Sacramento River meets the San Joaquin River to form the Sacramento-San Joaquin Delta. Below the Delta, the river flows through San Francisco Bay to the Pacific Ocean.

The main hydrologic features of the Sacramento River, its tributaries, the flood basins bordering the streams, the Delta, and the Suisun region are described in this chapter. The descriptions of the tributaries have been organized into the functional hydrological groups shown in the following list and are based on watershed drivers of local hydrology that include elevation, precipitation patterns, geology, surface water origins, groundwater contributions to surface flow, and shared geomorphic history. Some smaller, intermittent tributaries for which there is no, or limited, hydrologic information are not discussed in this report.

- Mainstem Sacramento River
- Tributaries of Mount Lassen
  - Battle Creek, Cow Creek, Bear Creek
- Tributaries of the Chico Monocline
  - Antelope Creek, Deer Creek, Mill Creek, Paynes Creek
- Tributaries of the Klamath Mountains
  - Clear Creek
- Tributaries of the Paleochannels and Tuscan Formation
  - Butte Creek, Big Chico Creek
- Tributaries of the northern Sierra Nevada
  - Feather River, Yuba River, Bear River, American River
- Tributaries of the eastside of the Delta
  - Mokelumne River, Cosumnes River, Calaveras River
- Tributaries of the Northern Coast Range, northern
  - Stony Creek, Cottonwood Creek, Thomes Creek, Elder Creek
- Tributaries of the Northern Coast Range, southern
  - Cache Creek, Putah Creek

The Sacramento River and its major tributaries are shown in Figure 2.1-4. The eastern tributaries from the Calaveras River in the south to the Yuba River in the north are Sierra Nevada streams. The Calaveras, Mokelumne, and Cosumnes Rivers all converge in tidewater as tributaries to the San Joaquin River when it is within the Legal Delta (see Wat. Code, § 12220). The North Fork Feather River is the general dividing line between the Sierra Nevada streams to the south and the Cascade Range streams to the north. Clear Creek is the sole Klamath Range stream that is a tributary to the Sacramento River. The western streams from Cottonwood Creek south to Stony Creek are Northern Inner Coast Range streams while Cache and Putah Creeks, almost twin streams, originate in the Southern Inner Coast Range. Elevation in the Sacramento/Delta varies enormously from east to west and from north to south (Figure 2.1-5). The Coast Ranges produce a significant rain shadow effect on their eastern slope and in the valley by wringing precipitation out of storms approaching from the west, as storms typically do at this latitude. The Golden Gate/Carquinez Straight gap in the Coast Ranges has the effect of focusing storms directly at the watersheds of the American and Feather Rivers. If the approach of the storm front is perpendicular to the slope of the Sierra Nevada, large localized precipitation events occur. However, if the storm strikes a glancing blow, it generates a low-level south-to-north-flowing atmospheric jet stream and turbulent updrafts that distribute the precipitation over a much larger area for a longer period of time (Neiman et al. 2014). These factors are why the amount of precipitation shown in Figure 2.1-6 does not necessarily correspond to the highest areas of the mountain ranges and why the watersheds of the American and Feather Rivers receive so much precipitation. Mount Lassen is an exception to this pattern due to its high elevation and northern location. The Klamath Range is also exceptional as it is far enough north that it receives more frequent storms, which results in more annual precipitation.

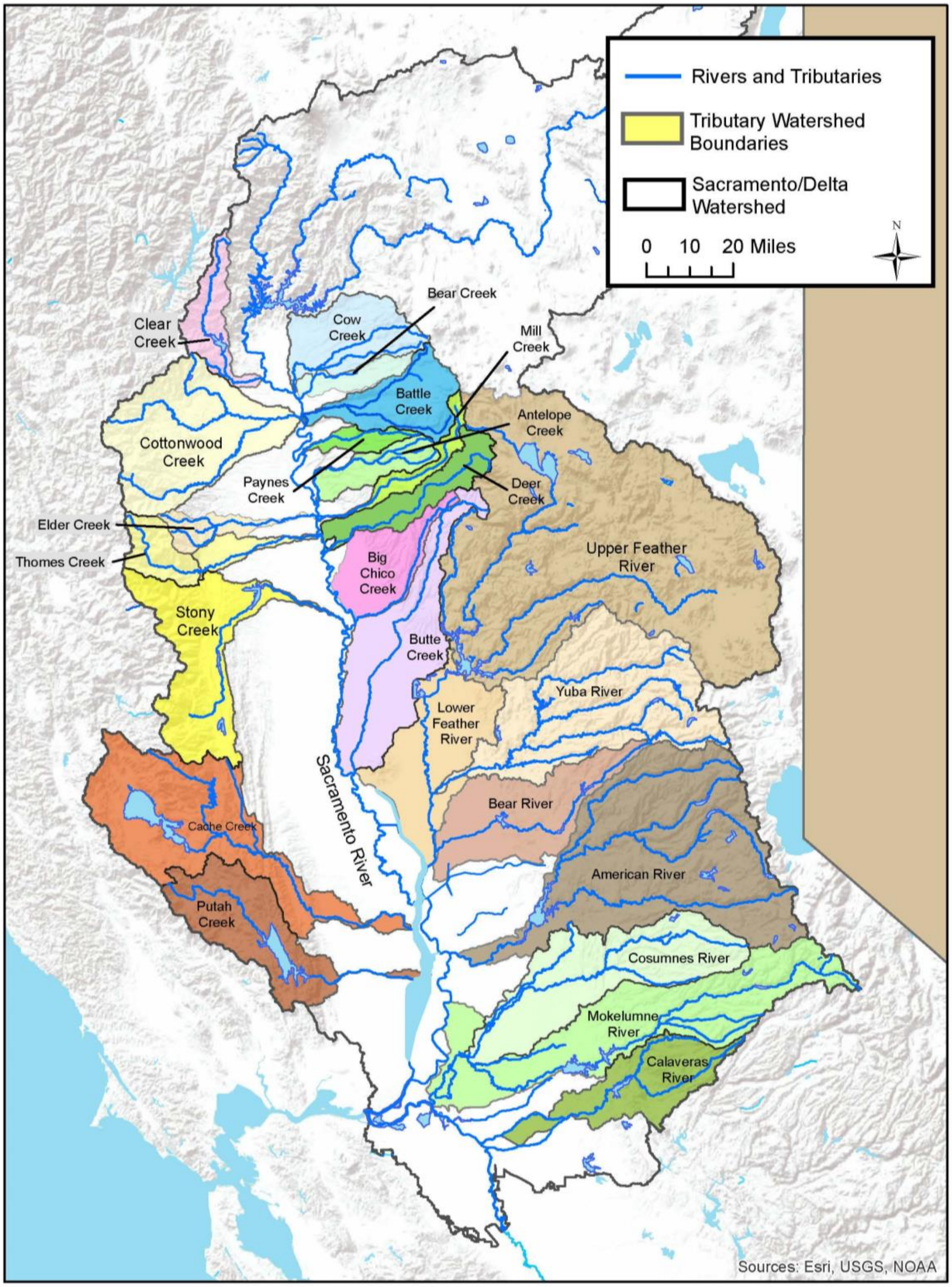


Figure 2.1-4. Major Sacramento/Delta Tributaries and Watersheds

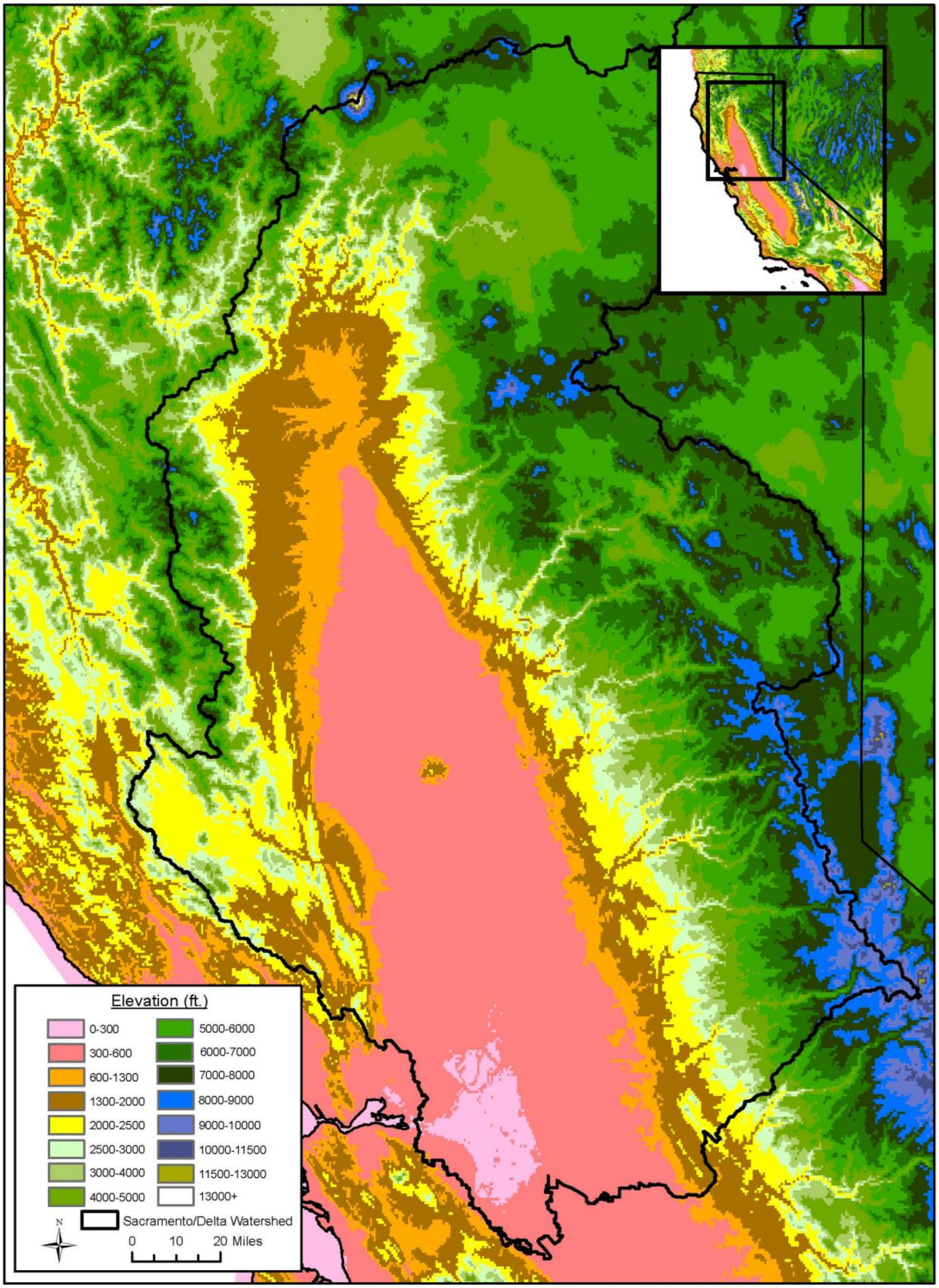


Figure 2.1-5. Elevation Map of Northern California

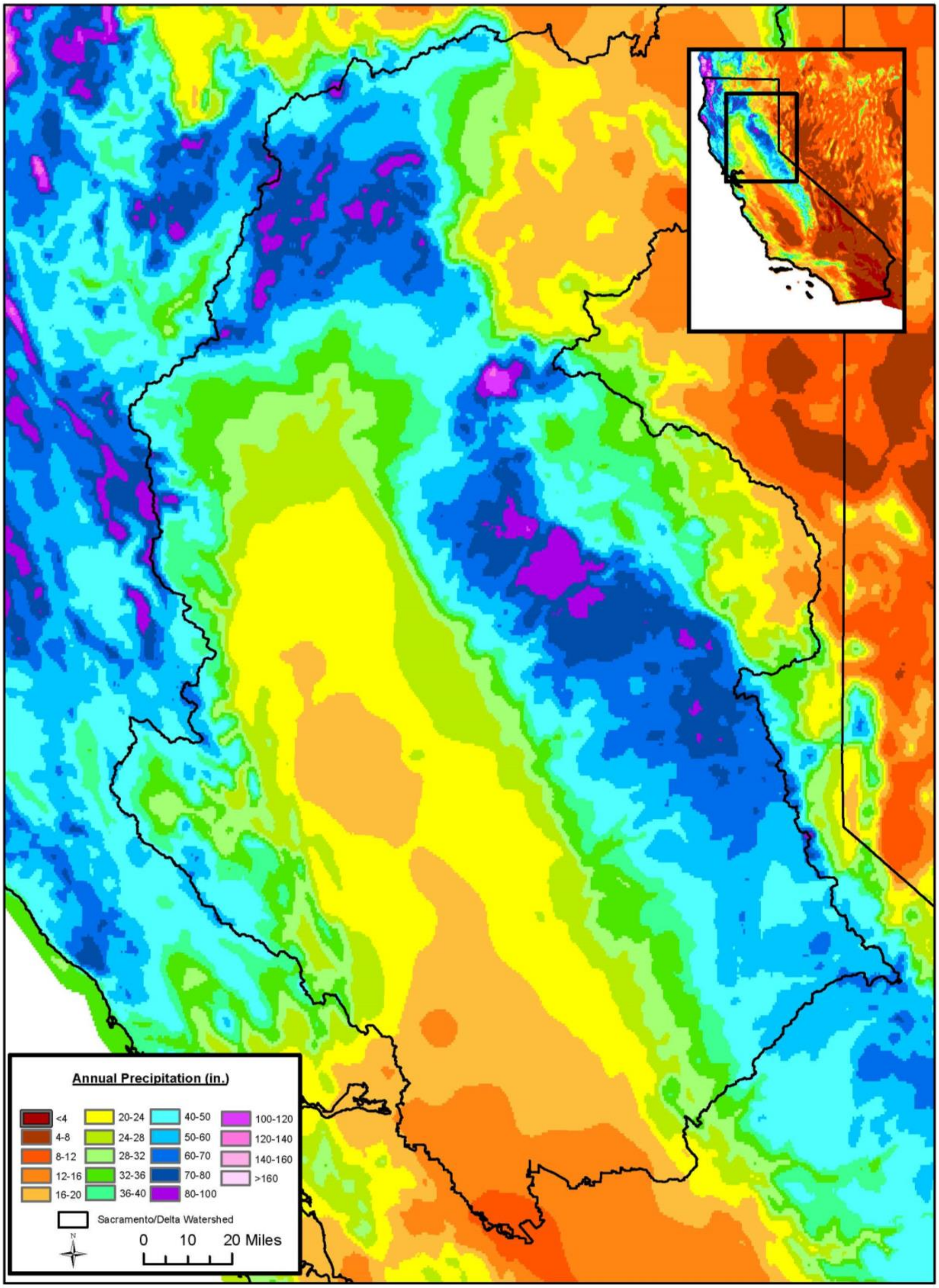
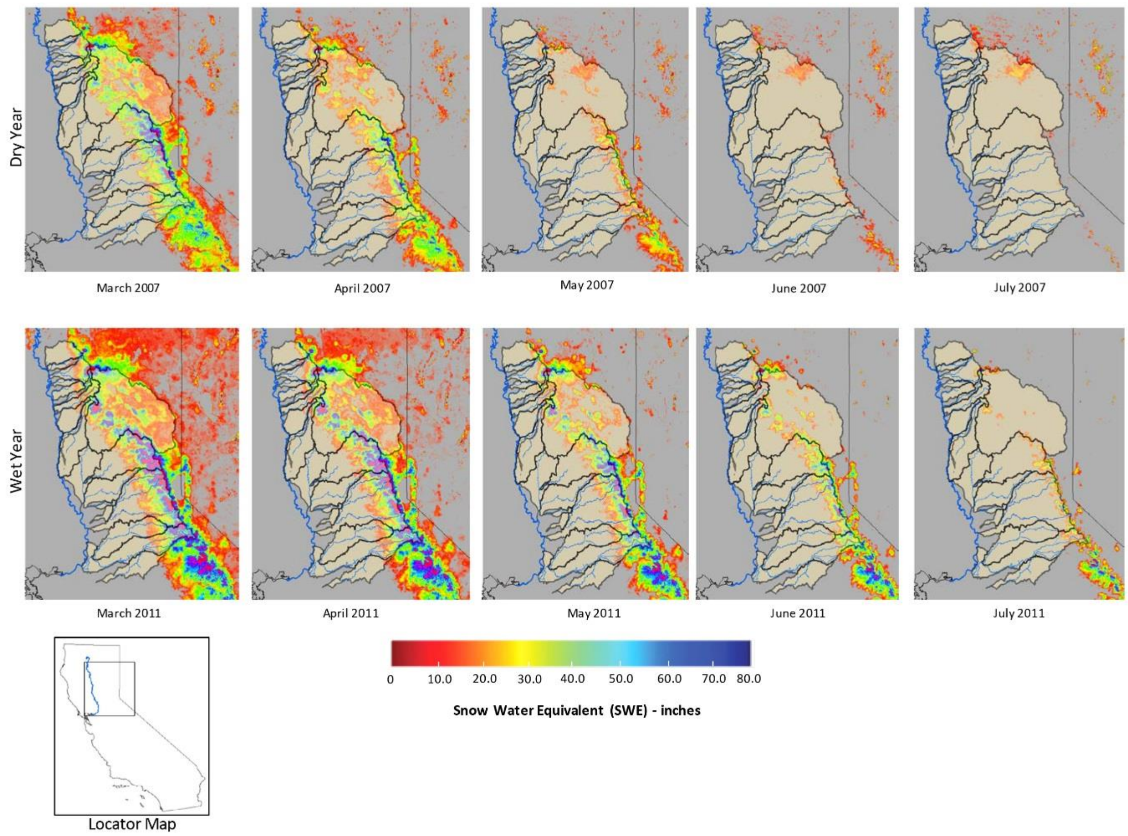


Figure 2.1-6. Annual Precipitation in Northern California

Elevation also affects the form of the precipitation, with higher elevations receiving proportionally more precipitation as snow. This effect is constant for elevations above 7,000 feet but varies by water year type from 7,000 feet down to the 5,500-foot snow line. Figure 2.1-7 illustrates the differences in distribution and extent of the amount of water stored in the snowpack (snow water equivalent) by month during dry and wet years. Additionally, storms originating in the southwest near Hawaii are much warmer than storms approaching from the northwest and, if they produce rain-on-snow events, can generate extremely large flood flows. Ultimately, the amount, form, and temperature of the precipitation determine the hydrological responses of the streams and the ability to capture the runoff above dams.



Source: State Water Resources Control Board, 2016 Data Source: Karl Rittger, http://alexandria.ucsb.edu/lib/ark:/48907/f3gm8581

Figure 2.1-7. Water Year Type Snow Water Equivalents

As the streams leave the foothills, their lowest reaches interact with the many different sedimentary rock formations of the valley (Figure 2.1-8), and the stream channels flowing over those formations have complex groundwater/aquifer and surface water interactions that vary by each stream. Figure 2.1-9 shows the subregions used for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) that has been widely adopted for use in the Central Valley (Brush et al. 2013).

The amount of water flowing into and out of the Sacramento River Valley groundwater basins has fluctuated significantly from year to year, with groundwater levels declining in dry years and recovering in wet years. Moreover, groundwater and surface water interact. Aquifer systems can be recharged through seepage from surface waters such as rivers and streams. *Gaining* streams are portions of stream systems where adjacent groundwater levels are higher than the stream stage, and the groundwater seeps or discharges to the surface waterbody. Conversely, a *losing stream* occurs where groundwater levels are lower than adjacent surface water levels, and water flows from the stream into the aquifer. Streams may contain both gaining stream reaches and losing stream reaches. Average annual stream depletion throughout the Central Valley was approximately 700 thousand acre-feet per year (TAF/yr) from 1989 through 2009 and shows an increasing trend. Assuming 2009 land use conditions, studies estimate stream losses to groundwater will reduce instream flows by an average of 1.3 MAF/yr across the Central Valley over the next several decades (^TNC 2014).

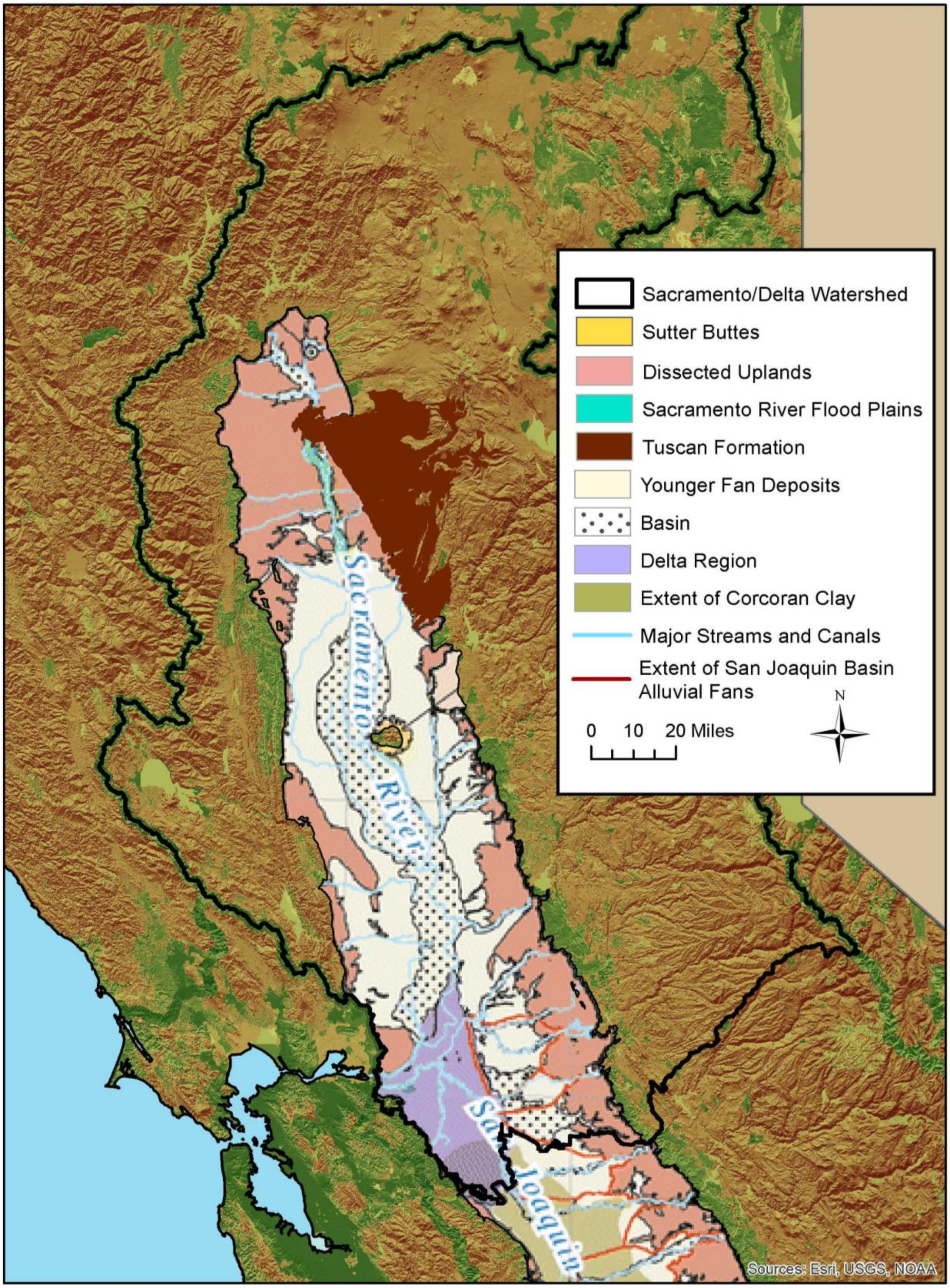


Figure 2.1-8. Generalized Geologic Map of the Valley Floor

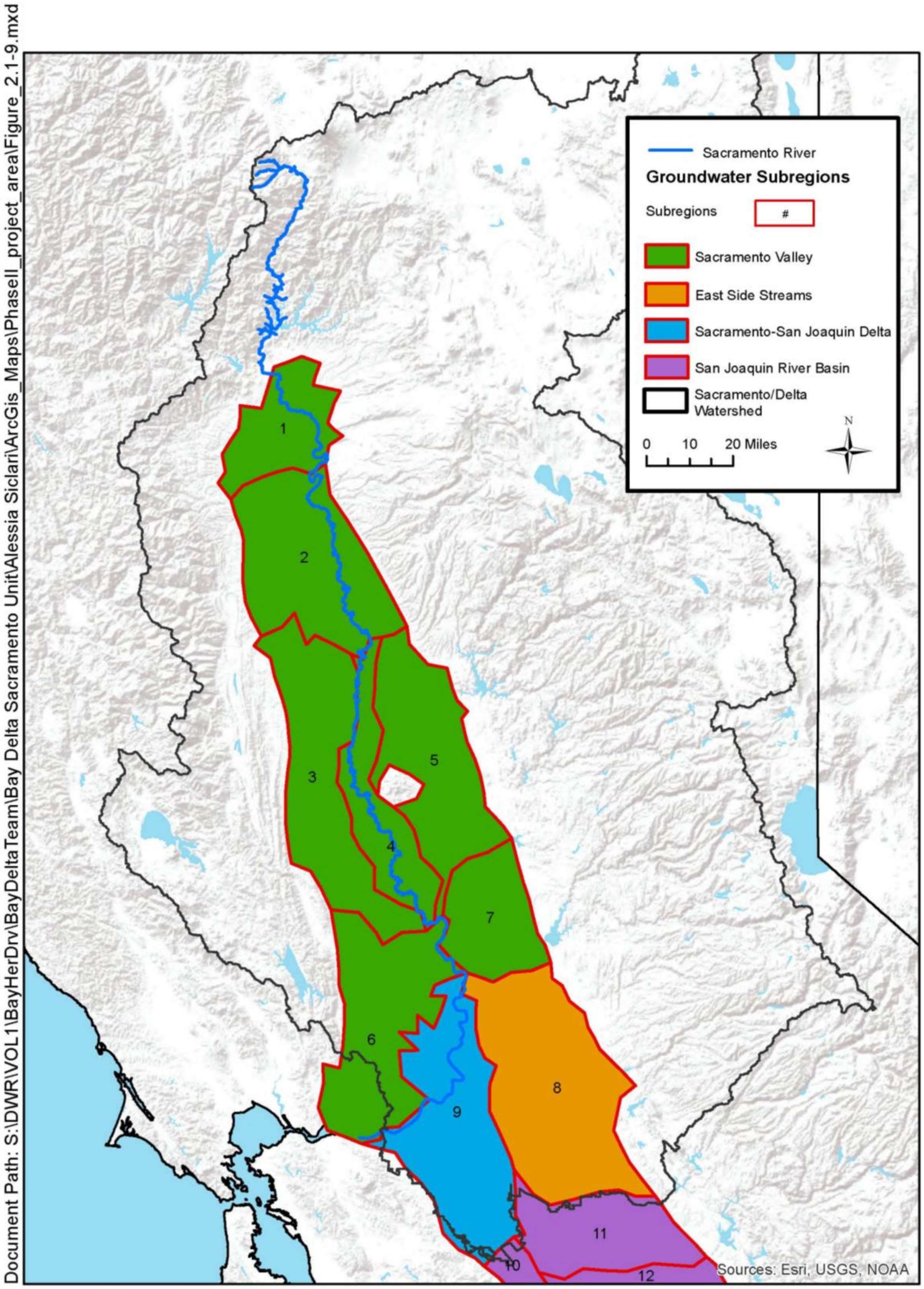


Figure 2.1-9. C2VSim Model Groundwater Subregions

Many of the tributaries in the Sacramento River watershed are extensively developed for hydropower, flood control, agricultural, and urban uses. The consumptive uses (agricultural and urban) are primarily in the valley floor. However, large quantities of water from Shasta, Oroville, and Folsom Reservoirs flow all the way to the Delta and are then exported for use in other watersheds by the CVP, SWP, and other water storage and conveyance facilities. Some non-CVP/SWP tributaries, such as the Yuba River, also move water through the Delta to fulfill water transfer agreements.

Unique characteristics, such as drainage area, and hydrologic alterations like storage are summarized for each tributary in Table 2.1-1; however, two general patterns dominate. In watersheds with reservoirs, winter and spring runoff peaks are now lower and summer flows are now higher and warmer. In watersheds without reservoirs but with substantial land use development, winter and early spring flows typically resemble unimpaired flows, and late spring through fall flows are reduced by direct diversion, mainly for irrigation. The tributary descriptions in this chapter discuss the factors that contribute to their particular hydrographs. Following the tributary descriptions are sections describing the flood basins (Section 2.3), the Sacramento-San Joaquin Delta (Section 2.4), and the Suisun region (Section 2.5).

Results from the Sacramento Water Allocation Model (SacWAM) were used to illustrate the hydrology under current conditions and unimpaired conditions (^SacWAM 2023). SacWAM results presented in this chapter describe the current hydrology of tributaries in the Sacramento River watershed and the Delta eastside tributaries. SacWAM is a peer-reviewed hydrology/system operations model developed by the Stockholm Environment Institute (SEI) and State Water Board to assess potential revisions to instream flow and other requirements in the Bay-Delta Plan. SacWAM is currently one of the most advanced representations of the Sacramento watershed; the model includes 69 reservoirs, 131 demand nodes, complex operations of the SWP and CVP, and an artificial neural network to estimate Delta salinity. SacWAM current conditions simulation is the same as "existing conditions" and "baseline" used throughout this document. More information on the regulatory assumptions for current conditions (baseline) can be found in Section 6.2.1, *Baseline Assumptions*, and Appendix A1, *Sacramento Water Allocation Model Methods and Results*. More information about SacWAM can be found in the SacWAM documentation (^SacWAM 2023).

Many Sacramento/Delta tributaries contain gages that are used to measure streamflows. However, many of the existing streamflow gages are located above the mouth of the tributary and may not represent hydrologic conditions for the entire tributary. Therefore, to better describe the existing impairment of each entire tributary, SacWAM results for current conditions were used in the analysis presented in this chapter. Additionally, unimpaired flows used in this analysis also were estimated using SacWAM, assuming no surface water diversions or reservoir storage except what would occur without infrastructure. More detail about how the unimpaired flows are simulated is described in detail in Appendix A7, *Modeling Approaches Used to Develop Unimpaired Watershed Hydrology*. The box plots in Section 2.2, *Hydrology of the Sacramento River and Major Tributaries* characterize the impairment of each major tributary by comparing the simulated "current conditions" to the "unimpaired flows" to illustrate the general levels of impairment and trends in impairments.

The following analysis provides information on the level of impairment in the mainstem Sacramento River and various tributaries on a monthly, seasonal, and annual basis given different hydrologic conditions (cumulative distributions of the percent of unimpaired flow). These analyses show significant differences in impairment between months, hydrologic conditions, and streams, with generally much greater impairment during drier years when unimpaired flows are already low.

Water Year Type: AN = above normal BN = below normal C = critical D = dry W = wet

Figure 2.1-10 shows simulated impaired flows as a percentage of unimpaired flows for the Sacramento River, its major tributaries, and Delta eastside tributaries ranked by Sacramento Valley water year index value. The Sacramento Valley water year index is an index of total runoff; it is used to determine the Sacramento Valley water year type as implemented in the State Water Board Water Right Decision 1641 (D-1641). The Sacramento Valley water year hydrologic classifications include wet (W), above normal (AN), below normal (BN), dry (D), and critical (C) water years. Sacramento Valley water year index values have ranged from 5.12 MAF in the driest year of 1977, to 37.68 MAF in the wettest year of 1983 (DWR 2016b). Water Year Type: AN = above normal BN = below normal C = critical D = dry W = wet

Figure 2.1-10 also shows the percent of unimpaired flow estimated for each tributary for the January–June period of each year. Darker red colors (percentage values less than 100 percent) indicate a greater reduction in the flow at this location relative to the unimpaired flow, and the darker blue colors (percentage values greater than 100 percent) indicate a greater increase in current conditions flow relative to the unimpaired flow. Percentage values near 100 percent indicate that current conditions are similar to unimpaired flows for the January–June period. Regulated tributaries with large reservoirs, such as the American, Bear, Yuba, and Feather Rivers, have a lower percent of unimpaired flow in the spring in drier years, whereas unregulated tributaries show a higher percent of unimpaired flow in all years.

Table 2.1-1. Summary Information Used in SacWAM for the Major Tributaries to the Sacramento River and the Delta Eastside Tributaries

River	Drainage Area (mi^2)	Mean Annual Runoff (TAF/yr) [a]	Total Storage as Modeled in SacWAM (TAF)	Runoff to Storage Ratio	Average Annual Stream Gain/Loss to GW (TAF/yr) [b]	Hydrologic Regime	Major Reservoirs	Instream Flow Requirements [c]
Cow Creek	430	431	No Major Storage	No Major Storage	-7	Mixed rain and snow- rain dominant-unimpaired	None	None
Battle Creek	357	347	No Major Storage	No Major Storage	9	Mixed rain and snow, significant discharge from springs- rain dominant-hydropower and diversion impacts	None	None
Butte Creek	797	926	No Major Storage	No Major Storage	-31	Mixed rain and snow-interbasin import and diversion impacted during irrigation season	None	None
Antelope Creek	202	100	No Major Storage	No Major Storage	14	Mixed rain and snow- rain dominant-diversion impacts in valley	None	None
Deer Creek	298	228	No Major Storage	No Major Storage	-1	Mixed rain and snow- rain dominant-diversion impacts in valley	None	None
Mill Creek	130	215	No Major Storage	No Major Storage	2	Mixed rain and snow- rain dominant-diversion impacts in valley	None	None
Paynes Creek	93	52	No Major Storage	No Major Storage	9	Rain driven- flashy- diversion impacts in valley	None	None
Clear Creek	249	140	241	0.58	0	Interbasin import dominated- regulated	Whiskeytown Reservoir	Combination of 1960 MOA between DWR and CDFG, (b)2 actions, and 2009 NMFS BiOp
Big Chico Creek	72	101	No Major Storage	No Major Storage	0	Rain driven- flashy- flood control impacts in valley	None	None
Feather River	4,400	4,998	5,131	1.17	-10	Mixed rain and snow- heavily regulated-diversion and flood control impacts in valley	Lake Oroville; Lake Davis; Bucks Lake; Butt Valley; Antelope Reservoir; Frenchman Lake; Lake Almanor; Poe Reservoir; Cresta Reservoir; Rock Creek Reservoir; Belden Reservoir; Little Grass Valley Reservoir; Philbrook-Round Valley Reservoirs; Mountain Meadows Reservoir	1986 MOU between CDFG and DWR (high-flow channel, low-flow channel, and Verona)
Yuba River	1,339	1,654	1,408	1.17	-16	Mixed rain and snow- heavily regulated-diversion and flood control impacts in valley	Englebright Reservoir; New Bullard's Bar Reservoir; Bowman Lake; Scotts Flat Reservoir; Lake Fordyce; Merle Collins Reservoir; Jackson Meadows Reservoir; Lake Spaulding	Lower Yuba River Accord/State Water Board Revised D-1644 (Yuba River near Marysville, Yuba River near Smartville)
Bear River	292	472	176	2.67	-15	Rain dominated- heavily regulated-import/export impacted	Camp Far West Reservoir; Rollins Reservoir; Lake Combie	1994 Settlement Agreement between DWR, South Sutter Water District, and Camp Far West Irrigation District
American River	1,900	2,711	1,759	1.54	-43	Mixed rain and snow- heavily regulated-import/export impacted	Folsom Lake; Lake Natoma; Caples Lake; Loon Lake; Gerle Creek Reservoir; Buck Island; Sly Creek Reservoir; French Meadows; Lake Valley; Stumpy Meadows; Hell Hole; Union Valley Reservoir; Camino Reservoir; Junction Reservoir; Silver Lake; Jenkinson Lake; Chili Bar; Slab Creek; Ice House	Lower American River Flow Management Standard; 1958 WDR-893 (H St.)

River	Drainage Area (mi²)	Mean Annual Runoff (TAF/yr) [a]	Total Storage as Modeled in SacWAM (TAF)	Runoff to Storage Ratio	Average Annual Stream Gain/Loss to GW (TAF/yr) [b]	Hydrologic Regime	Major Reservoirs	Instream Flow Requirements [c]
Mokelumne River	660	744	998	0.74	-47	Mixed rain and snow- snow dominant- heavily regulated- diversion impacted	Pardee Reservoir; Camanche Reservoir; Lower Bear; Salt Springs; Lake Amador	1998 Joint Settlement Agreement and FERC license for the Lower Mokelumne Hydroelectric Project (FERC No. 2916) (below Camanche, below Woodbridge Diversion Dam); 2001 FERC License for the North Fork Mokelumne Project (FERC No. 137) (below PG&E dams, below Electra Powerhouse, below Electra Dam)
Cosumnes River	940	387	41	9.43	-2	Mixed rain and snow- rain dominant- mostly unimpaired- diversion impacts in valley	Jenkinson Reservoir	None
Calaveras River	470	160	317	0.50	-50	Rain driven- regulated- diversion impacts in valley	New Hogan Dam	None
Stony Creek	741	418	245	1.71	-36	Rain driven- regulated- diversion and export impacted	East Park Reservoir; Stony Gorge Reservoir; Black Butte Reservoir	Below Black Butte Reservoir and below Northside Dam
Cottonwood Creek	927	551	No Major Storage	No Major Storage	-9	Rain driven- flashy- mostly unimpaired- import impacts in valley during irrigation season	None	None
Thomes Creek	301	263	No Major Storage	No Major Storage	-20	Rain driven- flashy- unimpaired	None	None
Elder Creek	151	67	No Major Storage	No Major Storage	1	Rain driven- flashy- unimpaired	None	None
Cache Creek	1,139	508	1,456	0.35	1	Rain driven- natural lake buffers extreme events- some regulation on tributaries- flood control and diversion impacts in valley	Clear Lake; Indian Valley Reservoir	None
Putah Creek	710	358	1,602	0.22	-11	Rain driven- regulated- impacted by exports in valley	Lake Berryessa	2000 Putah Creek Accord/Settlement Agreement flow requirements: below Putah Diversion Dam; at I-80 road bridge

BiOp = biological opinion; CDFG = California Department of Fish and Game; DWR = California Department of Water Resources; FERC = Federal Energy Regulatory Commission; GW = groundwater; mi² = square miles; MOA = memorandum of agreement; MOU = memorandum of understanding; NMFS = National Marine Fisheries Service; PG& E = Pacific Gas and Electric Company; TAF/yr = thousand acre-feet per year; WDR = waste discharge requirement.
[a] Estimated using SacWAM Current Conditions results by adding all upstream inflows and rainfall-runoff.
[b] As estimated in SacWAM (^SacWAM 2023).
[c] As estimated in SacWAM (^SacWAM 2023).

Water Year	Water Year Index Value	Water Year Type	Delta Outflow	American River	Bear River	Yuba River	Feather River at Sacramento River	Feather River above Confluence of Yuba River	Sacramento River below Keswick	Sacramento River at Freeport	Mokelumne River	Calaveras River	Cache Creek	Putah Creek	Clear Creek	Stony Creek	Antelope Creek	Mill Creek	Deer Creek	Battle Creek	Big Chico Creek	Cosumnes River	Cottonwood Creek	Cow Creek	Thomes Creek	Paynes Creek	Butte Creek
1977	3.11	C	48%	60%	106%	51%	76%	87%	144%	82%	27%	9%	114%	56%	98%	38%	53%	85%	75%	95%	100%	95%	106%	92%	66%	100%	244%
1931	3.66	C	44%	48%	63%	38%	54%	59%	135%	73%	19%	23%	78%	35%	56%	31%	58%	90%	80%	96%	100%	91%	101%	95%	85%	100%	221%
1924	3.87	C	45%	74%	81%	44%	67%	76%	155%	85%	34%	22%	86%	31%	89%	13%	64%	85%	75%	95%	100%	90%	102%	95%	84%	100%	199%
2015	4.01	C	48%	88%	164%	33%	62%	72%	107%	73%	23%	15%	66%	17%	41%	17%	72%	86%	80%	95%	100%	90%	101%	97%	91%	100%	186%
1992	4.06	C	46%	81%	94%	38%	49%	49%	72%	64%	15%	25%	47%	13%	30%	14%	82%	96%	86%	96%	100%	94%	100%	99%	93%	100%	166%
1934	4.07	C	37%	69%	116%	40%	48%	46%	80%	61%	20%	22%	32%	12%	72%	16%	73%	97%	83%	97%	100%	90%	101%	98%	86%	100%	192%
2014	4.07	C	38%	36%	71%	28%	42%	46%	105%	58%	16%	32%	76%	19%	77%	6%	71%	96%	82%	96%	100%	92%	100%	98%	85%	100%	177%
1991	4.21	C	38%	32%	56%	32%	41%	43%	89%	55%	15%	25%	61%	8%	48%	3%	74%	96%	89%	97%	100%	92%	100%	98%	89%	100%	151%
1933	4.63	C	29%	56%	38%	29%	30%	28%	66%	48%	18%	18%	48%	13%	46%	4%	62%	98%	86%	97%	100%	89%	101%	98%	82%	100%	189%
1988	4.65	C	37%	51%	64%	32%	44%	47%	88%	60%	18%	18%	29%	14%	54%	65%	76%	96%	84%	98%	100%	89%	100%	99%	89%	100%	181%
1990	4.81	C	36%	58%	88%	34%	41%	38%	86%	60%	18%	22%	73%	22%	52%	24%	71%	97%	85%	97%	100%	91%	101%	99%	80%	100%	208%
1994	5.02	C	37%	43%	80%	37%	53%	59%	118%	72%	23%	22%	50%	20%	66%	12%	75%	92%	87%	98%	100%	92%	101%	99%	88%	100%	216%
2008	5.16	C	37%	58%	71%	29%	35%	35%	77%	58%	14%	23%	38%	10%	40%	52%	76%	100%	88%	96%	100%	92%	100%	98%	93%	100%	205%
1929	5.22	C	32%	50%	47%	34%	44%	49%	108%	62%	22%	14%	83%	26%	99%	14%	66%	100%	76%	97%	100%	89%	101%	98%	78%	100%	213%
1976	5.29	C	45%	57%	87%	46%	72%	85%	141%	83%	34%	11%	69%	36%	83%	7%	54%	100%	81%	97%	100%	88%	101%	98%	78%	100%	230%
1932	5.48	D	26%	53%	85%	36%	28%	15%	63%	45%	7%	19%	42%	14%	40%	17%	72%	99%	91%	98%	100%	91%	100%	99%	87%	100%	146%
1939	5.58	D	38%	42%	84%	38%	61%	70%	112%	68%	24%	20%	58%	36%	69%	19%	64%	97%	80%	97%	100%	90%	101%	97%	74%	100%	196%
1947	5.61	D	33%	54%	110%	39%	43%	37%	83%	56%	21%	17%	44%	14%	52%	3%	78%	99%	84%	98%	100%	91%	101%	99%	86%	100%	180%
1961	5.68	D	37%	37%	62%	28%	31%	29%	83%	55%	16%	10%	21%	13%	35%	29%	81%	99%	91%	98%	100%	92%	100%	99%	91%	100%	179%
1926	5.75	D	45%	58%	100%	44%	43%	35%	88%	69%	20%	20%	58%	6%	39%	50%	84%	95%	92%	98%	100%	94%	101%	99%	94%	100%	179%
2001	5.76	D	38%	51%	70%	34%	43%	43%	82%	62%	20%	28%	40%	11%	31%	29%	82%	99%	84%	97%	100%	91%	101%	98%	93%	100%	200%
2009	5.78	D	31%	55%	98%	43%	35%	23%	53%	49%	12%	21%	63%	13%	30%	6%	78%	100%	93%	97%	100%	93%	101%	98%	88%	100%	163%
2013	5.83	D	36%	49%	146%	61%	58%	50%	119%	69%	17%	20%	32%	13%	83%	48%	77%	99%	81%	97%	100%	89%	100%	97%	79%	100%	192%
1987	5.86	D	43%	40%	76%	37%	49%	50%	101%	67%	24%	34%	46%	17%	42%	6%	76%	98%	91%	97%	100%	93%	101%	99%	90%	100%	176%
1930	5.9	D	34%	45%	111%	40%	36%	26%	66%	51%	12%	19%	33%	8%	38%	17%	79%	97%	95%	98%	100%	90%	101%	99%	92%	100%	167%
1949	6.09	D	37%	54%	80%	39%	41%	36%	76%	62%	17%	15%	31%	8%	36%	44%	79%	95%	92%	97%	100%	94%	101%	98%	92%	100%	178%
1989	6.13	D	34%	60%	112%	50%	37%	20%	56%	61%	13%	17%	30%	14%	38%	8%	85%	98%	93%	99%	100%	89%	100%	99%	93%	100%	157%
1955	6.14	D	31%	52%	70%	32%	38%	38%	77%	53%	18%	17%	27%	26%	71%	27%	67%	97%	91%	98%	100%	92%	101%	98%	81%	100%	192%
2007	6.19	D	43%	53%	107%	42%	70%	82%	99%	71%	20%	19%	25%	19%	62%	12%	80%	98%	83%	97%	100%	93%	101%	98%	81%	100%	204%
1960	6.2	D	34%	54%	87%	45%	36%	25%	59%	53%	13%	10%	28%	7%	39%	47%	79%	98%	91%	98%	100%	90%	101%	99%	93%	100%	181%
1981	6.21	D	43%	40%	92%	34%	46%	47%	94%	64%	20%	27%	37%	10%	29%	41%	83%	98%	85%	98%	100%	94%	101%	99%	94%	100%	181%
1944	6.35	D	34%	45%	64%	30%	37%	37%	78%	54%	17%	21%	44%	10%	60%	10%	71%	100%	89%	98%	100%	94%	101%	99%	82%	100%	192%
2002	6.35	D	38%	57%	114%	40%	38%	27%	81%	59%	14%	15%	25%	10%	27%	64%	80%	97%	92%	97%	100%	94%	100%	99%	92%	100%	168%
1925	6.39	D	36%	56%	92%	39%	31%	17%	44%	57%	15%	16%	28%	6%	24%	41%	81%	98%	93%	98%	100%	93%	100%	99%	95%	100%	176%
1964	6.41	D	34%	52%	83%	37%	46%	47%	87%	57%	21%	16%	39%	19%	63%	44%	70%	100%	84%	97%	100%	91%	100%	97%	81%	100%	189%
1985	6.47	D	33%	52%	95%	38%	45%	44%	97%	59%	18%	19%	35%	14%	67%	15%	76%	98%	80%	97%	100%	94%	100%	97%	84%	100%	195%
1950	6.62	BN	35%	61%	107%	48%	33%	16%	58%	51%	26%	13%	37%	8%	58%	22%	75%	100%	96%	98%	100%	94%	101%	99%	91%	100%	165%
1962	6.65	BN	36%	43%	82%	44%	34%	22%	70%	57%	11%	15%	36%	7%	27%	48%	80%	100%	94%	98%	100%	92%	100%	99%	89%	100%	163%
1979	6.67	BN	40%	54%	102%	46%	42%	31%	65%	56%	23%	52%	39%	8%	42%	28%	81%	100%	92%	98%	100%	96%	101%	99%	92%	100%	182%
1959	6.75	BN	49%	41%	94%	40%	59%	66%	93%	69%	20%	22%	39%	10%	33%	46%	84%	100%	88%	97%	100%	92%	100%	99%	92%	100%	183%
1945	6.8	BN	37%	59%	113%	47%	36%	20%	70%	59%	23%	31%	34%	10%	39%	30%	81%	100%	93%	98%	100%	96%	100%	99%	91%	100%	159%
1937	6.87	BN	40%	57%	86%	44%	39%	28%	50%	56%	25%	70%	44%	6%	38%	33%	75%	100%	94%	98%	100%	97%	101%	99%	91%	100%	162%
2012	6.89	BN	45%	52%	102%	50%	56%	53%	83%	66%	19%	21%	38%	9%	40%	11%	81%	99%	91%	98%	100%	95%	101%	99%	88%	100%	154%
1935	6.98	BN	34%	52%	95%	43%	32%	19%	40%	55%	10%	13%	39%	4%	37%	45%	85%	100%	96%	99%	100%	95%	100%	99%	94%	100%	143%
1923	7.06	BN	38%	60%	93%	49%	51%	46%	82%	60%	23%	44%	25%	14%	47%	35%	76%	99%	93%	98%	100%	98%	101%	99%	87%	100%	176%
2010	7.08	BN	40%	55%	88%	41%	29%	15%	68%	56%	23%	18%	33%	6%	20%	59%	81%	100%	98%	99%	100%	94%	100%	99%	96%	100%	159%
1948	7.12	BN	36%	50%	82%	45%	29%	14%	58%	55%	11%	9%	17%	12%	43%	20%	86%	100%	100%	99%	100%	94%	100%	100%	94%	100%	148%
1966	7.16	BN	44%	45%	94%	41%	54%	56%	92%	67%	18%	17%	36%	8%	28%	48%	78%	100%	89%	97%	100%	93%	100%	99%	92%	100%	177%
1968	7.24	BN	54%	54%	124%	47%	67%	73%	92%	73%	19%	34%	55%	7%	34%	57%	85%	100%	92%	98%	100%	94%	100%	99%	94%	100%	172%
1972	7.29	BN	37%	57%	106%	50%	47%	41%	81%	60%	21%	11%	19%	23%	42%	21%	76%	100%	90%	98%	100%	93%	101%	99%	91%	100%	184%
2004	7.51	BN	53%	53%	119%	56%	55%	49%	95%	69%	23%	20%	66%	52%	26%	66%	83%	100%	95%	98%	100%	94%	100%	99%	95%	100%	154%
1946	7.7	BN	40%	59%	112%	56%	53%	46%	70%	60%	26%	26%	71%	19%	38%	53%	74%	100%	91%	98%	100%	98%	100%	99%	88%	100%	172%
1936	7.75	BN	45%	70%	112%	57%	43%	24%	53%	64%	41%	53%	38%	5%	20%	59%	83%	100%	94%	99%	100%	97%	100%	99%	94%	100%	158%

Water Year	Water Year Index Value	Water Year Type	Delta Outflow	American River	Bear River	Yuba River	Feather River at Sacramento River	Feather River above Confluence of Yuba River	Sacramento River below Keswick	Sacramento River at Freeport	Mokelumne River	Calaveras River	Cache Creek	Putah Creek	Clear Creek	Stony Creek	Antelope Creek	Mill Creek	Deer Creek	Battle Creek	Big Chico Creek	Cosumnes River	Cottonwood Creek	Cow Creek	Thomes Creek	Paynes Creek	Butte Creek
1957	7.83	AN	43%	52%	96%	47%	56%	57%	76%	63%	17%	13%	22%	11%	30%	39%	81%	100%	94%	99%	100%	94%	101%	99%	92%	100%	172%
2003	8.21	AN	46%	56%	124%	52%	43%	31%	79%	66%	16%	18%	56%	7%	23%	58%	87%	100%	98%	99%	100%	93%	100%	99%	95%	100%	137%
1928	8.27	AN	52%	67%	121%	62%	65%	60%	82%	68%	30%	26%	31%	7%	24%	60%	85%	100%	93%	98%	100%	96%	100%	99%	94%	100%	149%
2005	8.49	AN	46%	69%	115%	50%	42%	29%	73%	66%	45%	44%	33%	20%	26%	71%	82%	100%	98%	99%	100%	97%	100%	100%	96%	100%	156%
1954	8.51	AN	53%	55%	110%	55%	66%	67%	83%	77%	18%	9%	41%	7%	23%	62%	87%	100%	97%	99%	100%	95%	100%	99%	95%	100%	148%
1993	8.54	AN	46%	65%	114%	55%	43%	29%	49%	71%	26%	36%	59%	5%	20%	77%	87%	100%	100%	99%	100%	96%	100%	100%	97%	100%	142%
1973	8.58	AN	55%	68%	107%	62%	57%	45%	83%	74%	37%	61%	62%	12%	21%	77%	84%	100%	98%	98%	100%	97%	100%	99%	95%	100%	151%
1978	8.65	AN	43%	57%	103%	50%	35%	19%	51%	68%	14%	22%	53%	4%	18%	73%	91%	100%	97%	99%	100%	94%	100%	100%	97%	100%	138%
1940	8.88	AN	54%	69%	111%	53%	52%	44%	74%	75%	27%	29%	50%	4%	22%	64%	91%	99%	97%	99%	100%	97%	100%	100%	97%	100%	143%
2000	8.94	AN	57%	65%	115%	57%	62%	57%	86%	72%	30%	68%	52%	13%	19%	57%	86%	100%	95%	99%	100%	98%	100%	99%	96%	100%	157%
1980	9.04	AN	58%	75%	124%	65%	62%	53%	86%	74%	54%	76%	61%	12%	26%	77%	89%	100%	96%	99%	100%	98%	100%	99%	96%	100%	145%
1951	9.18	AN	55%	67%	123%	67%	70%	64%	77%	73%	39%	62%	48%	8%	35%	55%	83%	100%	94%	98%	100%	99%	100%	99%	94%	100%	153%
1975	9.35	W	53%	60%	98%	55%	67%	71%	80%	72%	28%	54%	59%	24%	23%	70%	84%	100%	98%	99%	100%	97%	100%	99%	95%	100%	155%
1927	9.52	W	54%	72%	120%	62%	55%	43%	79%	72%	28%	32%	67%	4%	22%	71%	84%	100%	97%	99%	100%	96%	100%	99%	95%	100%	150%
1953	9.55	W	55%	61%	119%	53%	65%	68%	81%	69%	19%	10%	55%	6%	28%	65%	82%	100%	100%	99%	100%	95%	100%	100%	95%	100%	138%
1963	9.63	W	55%	70%	132%	62%	67%	64%	81%	76%	42%	14%	52%	4%	30%	69%	89%	100%	95%	99%	100%	97%	100%	100%	95%	100%	148%
1943	9.77	W	57%	74%	124%	63%	72%	71%	75%	75%	51%	81%	64%	16%	30%	61%	88%	100%	97%	99%	100%	99%	100%	100%	95%	100%	148%
1999	9.8	W	57%	69%	114%	60%	70%	71%	81%	73%	44%	60%	67%	28%	24%	58%	82%	100%	97%	98%	100%	98%	100%	99%	93%	100%	147%
1986	9.96	W	62%	80%	123%	73%	66%	56%	90%	74%	56%	79%	65%	45%	24%	82%	90%	100%	97%	99%	100%	99%	100%	99%	97%	100%	140%
1984	10	W	46%	59%	143%	60%	60%	53%	71%	63%	37%	33%	78%	71%	29%	37%	78%	100%	95%	98%	100%	98%	100%	99%	87%	100%	158%
1965	10.15	W	54%	66%	133%	70%	72%	69%	77%	75%	44%	57%	73%	6%	30%	66%	88%	100%	96%	99%	100%	99%	100%	99%	94%	100%	145%
1967	10.2	W	53%	73%	119%	64%	62%	56%	80%	77%	52%	58%	58%	37%	23%	67%	86%	100%	100%	99%	100%	98%	100%	100%	96%	100%	139%
1996	10.26	W	61%	75%	125%	67%	77%	78%	82%	81%	49%	57%	72%	11%	27%	75%	88%	100%	96%	99%	100%	98%	100%	99%	96%	100%	150%
1971	10.37	W	50%	62%	111%	57%	60%	58%	78%	69%	29%	31%	58%	49%	25%	55%	82%	100%	97%	99%	100%	96%	100%	99%	94%	100%	140%
1970	10.4	W	67%	73%	126%	72%	77%	75%	92%	75%	46%	62%	75%	69%	26%	78%	91%	100%	96%	99%	100%	98%	100%	99%	96%	100%	142%
2011	10.54	W	59%	74%	122%	71%	74%	70%	81%	81%	61%	76%	64%	4%	26%	63%	86%	100%	100%	99%	100%	99%	100%	100%	95%	100%	140%
1997	10.82	W	68%	76%	129%	80%	78%	73%	85%	72%	55%	83%	86%	83%	35%	74%	89%	100%	95%	98%	100%	99%	100%	99%	94%	100%	141%
1969	11.05	W	62%	78%	121%	69%	69%	63%	83%	84%	57%	79%	71%	59%	20%	79%	89%	100%	98%	99%	100%	98%	100%	100%	97%	100%	140%
1942	11.27	W	62%	73%	122%	65%	72%	71%	84%	78%	48%	52%	83%	72%	23%	76%	88%	100%	100%	99%	100%	98%	100%	100%	95%	100%	140%
1956	11.38	W	62%	70%	136%	68%	75%	73%	84%	75%	50%	76%	81%	3%	24%	76%	89%	100%	98%	99%	100%	99%	100%	100%	96%	100%	138%
1941	11.47	W	63%	66%	118%	64%	65%	60%	89%	84%	39%	57%	81%	31%	17%	86%	92%	100%	98%	99%	100%	96%	100%	100%	97%	100%	135%
1958	12.16	W	67%	76%	116%	68%	72%	69%	92%	84%	53%	67%	77%	38%	23%	85%	89%	100%	100%	99%	100%	98%	100%	100%	98%	100%	141%
1952	12.38	W	60%	79%	121%	71%	74%	71%	80%	88%	62%	82%	66%	4%	25%	74%	87%	100%	98%	99%	100%	99%	100%	100%	95%	100%	139%
1938	12.62	W	65%	76%	122%	72%	78%	77%	87%	86%	58%	80%	78%	3%	19%	80%	86%	100%	100%	99%	100%	98%	100%	100%	96%	100%	132%
1982	12.76	W	64%	79%	123%	78%	80%	76%	83%	84%	66%	76%	76%	75%	20%	71%	85%	100%	99%	99%	100%	99%	100%	100%	95%	100%	134%
1995	12.89	W	63%	81%	122%	71%	70%	64%	76%	89%	58%	51%	65%	3%	17%	85%	90%	100%	100%	100%	100%	98%	100%	100%	98%	100%	125%
1974	12.99	W	63%	73%	122%	74%	77%	74%	88%	80%	46%	66%	85%	78%	18%	76%	91%	100%	98%	99%	100%	99%	100%	100%	96%	100%	130%
2006	13.2	W	70%	78%	124%	78%	80%	77%	108%	93%	66%	63%	90%	89%	19%	78%	90%	100%	99%	99%	100%	99%	100%	100%	97%	100%	127%
1998	13.31	W	71%	74%	117%	67%	70%	66%	93%	87%	60%	67%	79%	63%	20%	89%	92%	100%	100%	100%	100%	99%	100%	100%	99%	100%	137%
1983	15.29	W	78%	82%	119%	75%	81%	81%	96%	90%	74%	84%	93%	84%	19%	88%	91%	100%	100%	99%	100%	99%	100%	100%	98%	100%	129%
1977	3.11	C	48%	60%	106%	51%	76%	87%	144%	82%	27%	9%	114%	56%	98%	38%	53%	85%	75%	95%	100%	95%	106%	92%	66%	100%	244%

Water Year Type: AN = above normal BN = below normal C = critical D = dry W = wet

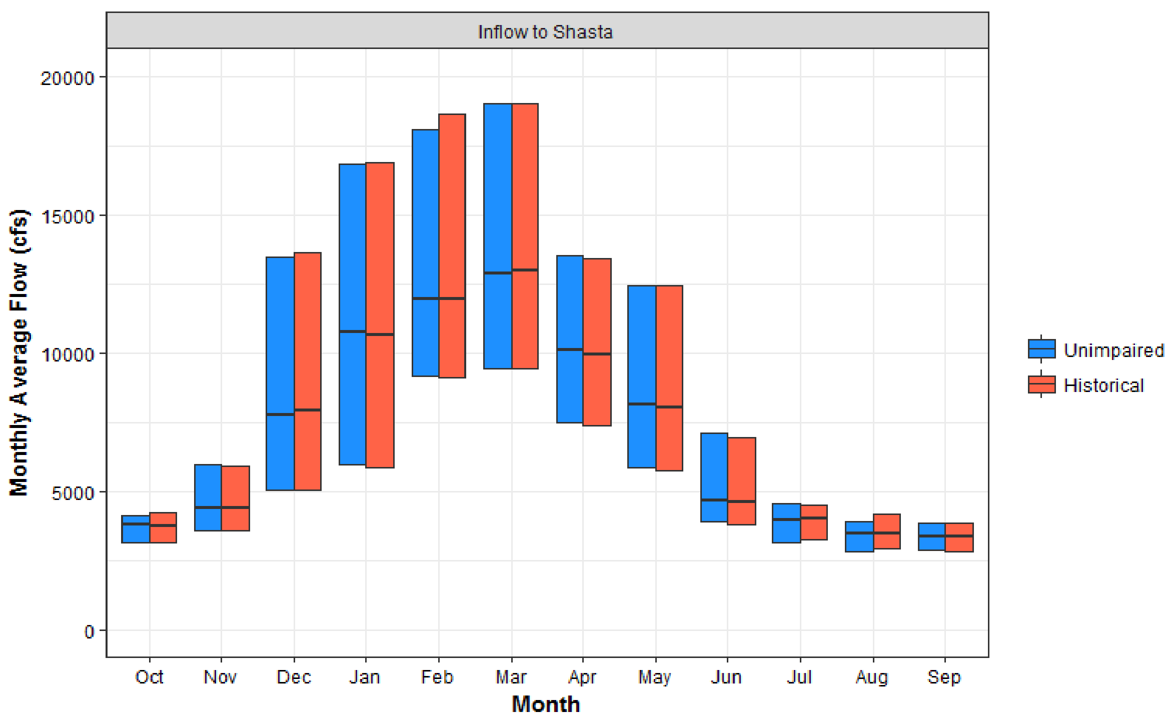
Figure 2.1-10. Simulated Impaired Flows as a Percentage of Unimpaired Flows Ranked by Water Year Index for the Sacramento River, Its Major Tributaries, and Delta Eastside Tributaries for January–June

2.2 Hydrology of the Sacramento River and Major Tributaries

2.2.1 Sacramento River

The Sacramento River is the longest river in the state of California. There are many factors, such as elevation, geology, reservoir operations, flood control structures, and imports to the watershed from the Trinity River system, that affect the Sacramento River's hydrology. The mainstem Sacramento River flows through the Sacramento Valley from Mount Shasta to the Delta.

The Sacramento River watershed above Shasta and Keswick Dams is 6,500 square miles (DWR 2013a). The Pit River and the McCloud River are two major tributaries. The high desert region above Shasta Reservoir produces runoff from winter rains, spring snowmelt, and summer base flows sustained by large springs. Small dams and reservoirs in the upper Pit River watershed seasonally store rainfall and snowmelt for hydropower and agricultural irrigation use through the summer season (Pit River Conservation District 2022; SRWP 2022). While hydropower projects on the Pit and McCloud Rivers may have large effects on local bypass reaches, they have minimal effect on the flow regime of the upper Sacramento River as it enters Shasta Reservoir. Figure 2.2-1 shows historical estimates of Shasta Reservoir inflow and unimpaired inflow, which are very similar, with small differences on a monthly scale.

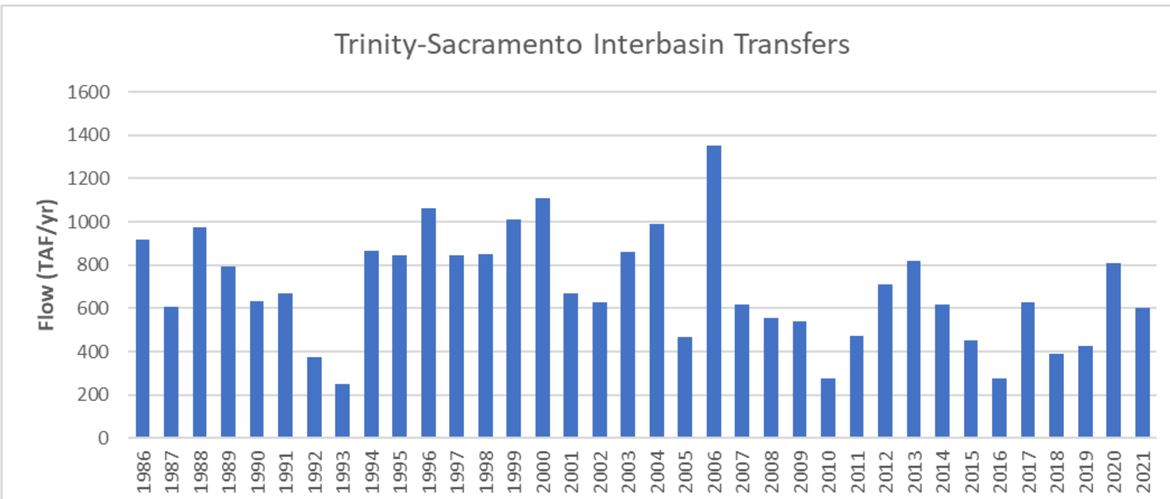


Source: DWR 2018.
cfs = cubic feet per second

Figure 2.2-1. Quartile Distributions of U.S. Bureau of Reclamation Estimates of Historical and Unimpaired Shasta Reservoir Inflow

Shasta Reservoir is the largest reservoir in California, with a capacity of 4.55 MAF. Releases from Shasta Dam are typically made through the Shasta Power Plant and timed for efficient energy production. Nine miles downstream of Shasta Dam is Keswick Reservoir, with a capacity of 28 TAF, that re-regulates the flow from Shasta Powerhouse.

The Sacramento River also receives imports from the Trinity River system through operations of the CVP. Water is transferred to the Sacramento River basin from the Trinity River basin through a system of dams, reservoirs, tunnels, and power plants. Releases from Trinity Dam through the Trinity Power Plant are stored downstream at Lewiston Reservoir, where the water can be diverted to the Sacramento River watershed through the Clear Creek Tunnel to Whiskeytown Lake—where it can then be released to Keswick Reservoir through the Spring Creek Tunnel or to Clear Creek, which enters the Sacramento River downstream of Keswick Reservoir (DWR 2013a). Annual imports from the Trinity River into Keswick Reservoir averaged 694 TAF/yr from water years 1986 through 2021 (Figure 2.2-2).



Source: CDEC 2023.
TAF/yr = thousand acre-feet per year

Figure 2.2-2. Annual Total Observed Imports from the Trinity River to the Sacramento Watershed via the Clear Creek Tunnel for Water Years 1986 through 2021

From Keswick Dam downstream to the city of Redding, the channel is generally straight, stable, and bedrock controlled as it runs across the erosion-resistant metamorphic rock of the Copley Formation (DWR 2013a). From Redding downstream to Red Bluff, the channel continues to be bedrock controlled as it runs across the Tehama and Tuscan Formations, although in a couple of reaches the channel can meander. Here the channel, while stable, is no longer straight but has cut deep and sinuous bends into the Tehama and Tuscan Formations, as well as through basalt flows (WET 1998; DWR 2013a).

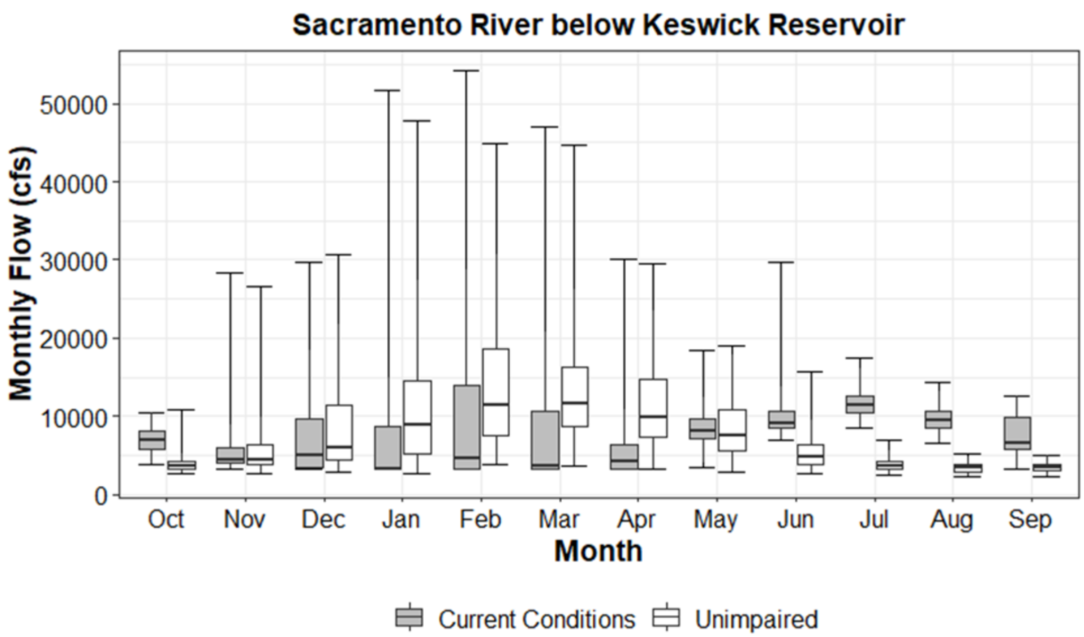
Releases from Keswick Reservoir are generally lower than unimpaired conditions in winter and spring, and higher in summer and fall, as shown in the Sacramento River below Keswick Reservoir box plot (cfs = cubic feet per second

Figure 2.2-3). Box plots in this chapter summarize monthly current simulated hydrologic conditions (gray box) and simulated unimpaired flow (white box) at various locations. Shown in the box plots are maximum and minimum flows (top and bottom whiskers), upper quartile (top of box), median (line within box), and lower quartile (bottom of box) of the flow data.

Releases from Shasta and Keswick Reservoirs are controlled by flood operations, agricultural demands in the Sacramento Valley, stream temperature requirements, and Delta demands (including salinity control and fish and wildlife protection) and for exports to the Central Valley, as well as major urban centers in the Southern California and San Francisco Bay Area regions (Reclamation 2017). Mean annual current flow conditions are higher than mean annual unimpaired flow conditions below Keswick because of imports from the Trinity River. In all but the most extreme years, the Sacramento River below Keswick Reservoir under current conditions is greater than 55 percent of unimpaired flow on average during the January through June period, although monthly flows are often more impaired, with monthly median flows in March and April less than 50 percent of unimpaired flows (Table 2.2-1). In late spring through fall, flows below Keswick Reservoir are generally higher than unimpaired (cfs = cubic feet per second

Figure 2.2-3), due to storage releases for use within the basin, export, and salinity control.

For the Sacramento River, as in other systems dependent on snowpack and snowmelt, the typical components of the unimpaired flow regime generally include fall storm flows, winter storm flows, spring snowmelt, and summer base flows (Kondolf et al. 2001; Cain et al. 2003; Epke 2011; Yarnell et al. 2010; Kondolf et al. 2012; Yarnell et al. 2013). These characteristics are present in the Sacramento Valley streams in nearly all years, with wide temporal variations in magnitude throughout the year and from year to year. These characteristics are illustrated in Figure 2.2-4 for a wet water year (2011) and in Figure 2.2-5 for a critically dry water year (2008), respectively, for the Sacramento River below Keswick Reservoir. Though the overall flow magnitudes may be different, the other characteristics of the flow regimes of the other regulated tributaries are similar. Water diversion and storage have significantly changed the shape of the instream hydrograph. In both water year types shown, fall and winter peak flows are reduced. The recession limb of the spring snowmelt is truncated or absent, and summer base flows are augmented.

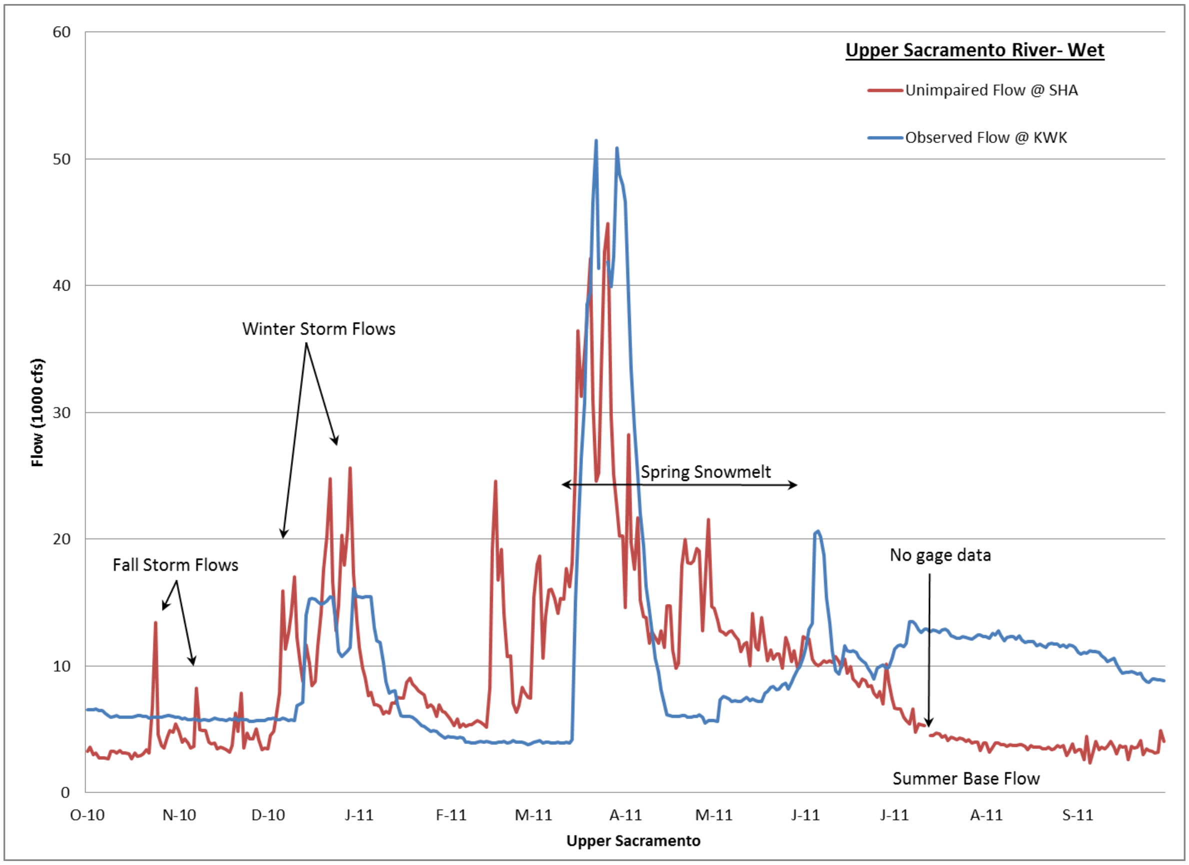


cfs = cubic feet per second

Figure 2.2-3. Sacramento River below Keswick Reservoir Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

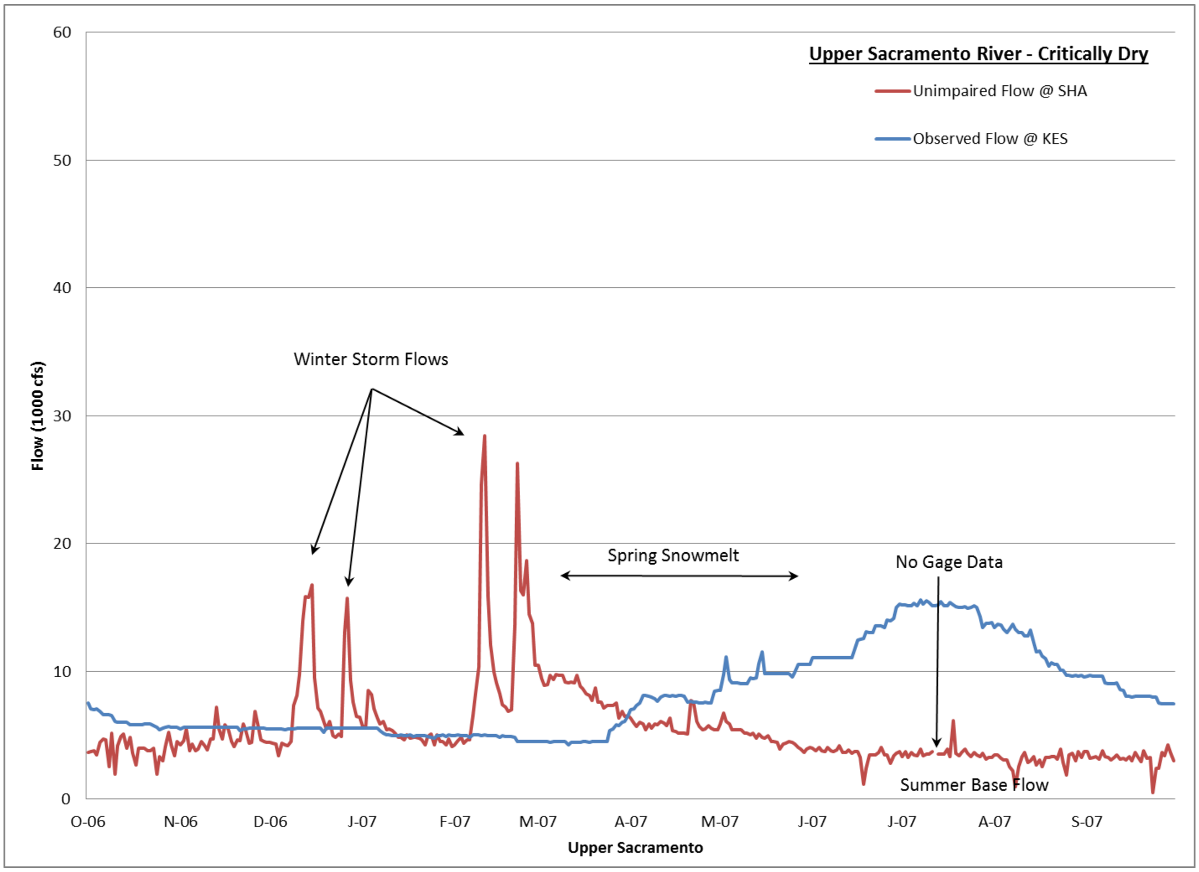
Table 2.2-1. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Sacramento River below Keswick Reservoir

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	91	31	21	11	14	13	16	37	106	176	157	93	40	121	70
10%	133	74	56	37	31	27	28	63	109	214	223	162	58	143	97
20%	146	93	70	43	36	31	34	84	119	241	263	185	71	152	100
30%	160	99	76	51	44	35	40	93	149	271	278	192	77	156	104
40%	177	101	83	58	52	39	44	98	169	308	286	203	80	169	108
50%	184	103	89	63	60	48	48	101	195	326	291	219	82	177	109
60%	195	106	94	67	72	59	56	114	210	342	301	235	84	183	112
70%	200	109	99	85	86	73	63	130	253	360	312	246	88	191	118
80%	206	114	105	91	100	82	72	158	281	387	321	260	93	197	123
90%	225	122	133	106	115	96	93	205	355	407	334	272	107	211	134
100%	300	198	209	178	132	161	161	291	404	489	390	291	155	250	183



Source: CDEC 2023.
cfs = cubic feet per second
KWK = Keswick Reservoir
SHA = Shasta Reservoir
Daily unimpaired flows presented here are produced by the California Department of Water Resources as full natural flows at Shasta Reservoir.

Figure 2.2-4. Daily Hydrograph of the Sacramento River below Keswick Reservoir for Water Year 2011 with Unimpaired Flow and Observed Flow



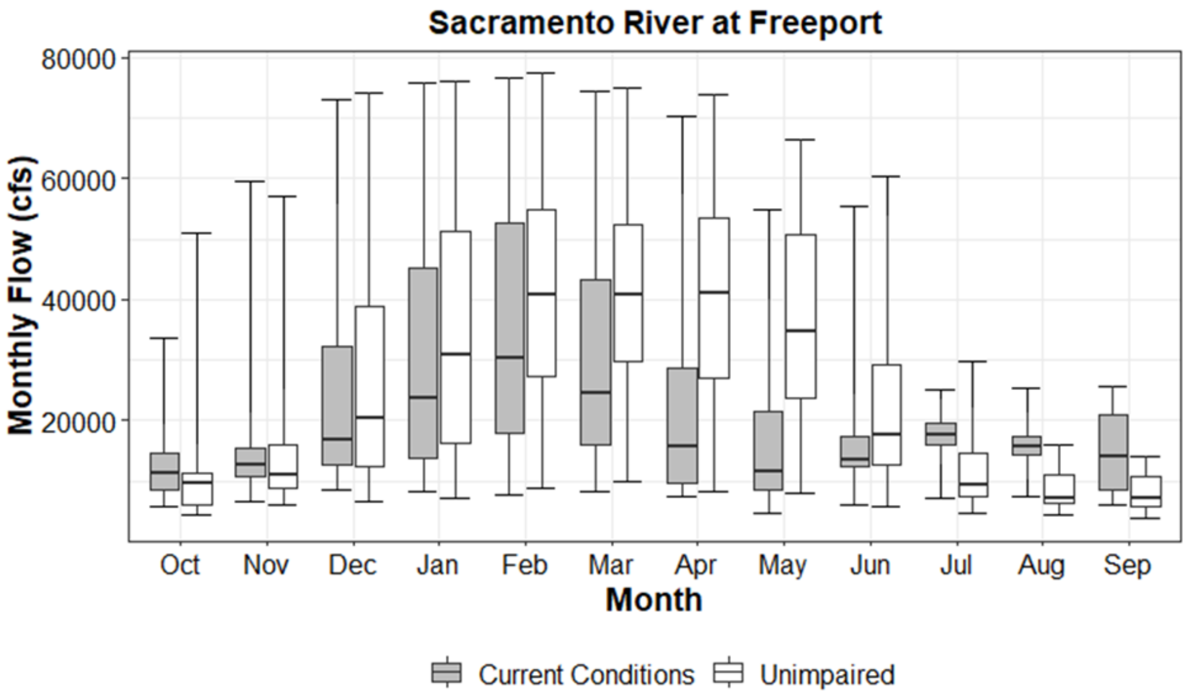
Source: CDEC 2023.
cfs = cubic feet per second
KWK = Keswick Reservoir
SHA = Shasta Reservoir
Daily unimpaired flows presented here are produced by the California Department of Water Resources as full natural flows at Shasta Reservoir.

Figure 2.2-5. Daily Hydrograph of the Sacramento River below Keswick Reservoir for Water Year 2007 with Unimpaired Flow and Observed Flow

Downstream of Red Bluff, the general location of the channel within the Sacramento Valley and its reach-specific geomorphology are controlled by geologic fault systems and river sediment loads that are primarily delivered from westside tributaries (Jones et al. 1972; WET 1998; Schumm et al. 2000; Larsen et al. 2002; DWR 2013a). Between Red Bluff to just above Stony Creek, the Sacramento River has established a wide floodplain and has a sandy and gravelly bottom. From Stony Creek through the Delta to the town of Clarksburg, the channel runs between natural levees and the outboard flood basins (Bryan 1923; Olmsted and Davis 1961; DWR 1994, 2010a, 2010b; ^Whipple et al. 2012).

Downstream of the city of Sacramento, the river enters the Delta where the hydrograph has been modified by diversions, flood basins, and inflows. The flow at Freeport includes all water that has entered the Sacramento River, except Sacramento River water that passes through the Yolo Bypass. At Freeport, the Sacramento River has a greater level of impairment than it does upstream below Keswick Reservoir (cfs = cubic feet per second

Figure 2.2-6). The largest difference between current conditions and unimpaired flows at Freeport are in the months of April and May, where in half of the years, the flows are below 44 percent and 40 percent of unimpaired flows, respectively (Table 2.2-2).



cfs = cubic feet per second

Figure 2.2-6. Sacramento River at Freeport Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-2. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Sacramento River at Freeport

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	66	47	46	52	52	41	29	23	43	66	118	100	45	89	61
10%	96	79	76	67	63	49	32	31	56	89	142	137	55	107	73
20%	116	87	84	74	68	54	35	33	59	110	152	148	57	111	78
30%	123	96	89	77	73	58	37	35	64	127	159	156	60	117	80
40%	130	104	92	81	78	62	39	37	68	149	164	174	64	121	83
50%	137	110	95	88	83	65	44	40	75	164	171	183	68	129	85
60%	142	117	99	93	87	70	49	47	81	187	188	195	72	134	88
70%	148	124	102	97	95	80	56	53	98	208	215	208	73	142	89
80%	152	127	108	99	98	92	67	63	111	227	235	218	76	148	92
90%	158	138	128	105	100	94	83	71	128	245	259	231	84	160	93
100%	181	170	190	144	105	114	95	104	177	289	315	262	93	191	107

2.2.2 Tributaries of Mount Lassen and Volcanic Buttes Region

2.2.2.1 Battle Creek

Battle Creek has a watershed of 357 square miles, most of which is spread among a number of relatively high elevation tributaries (Jones & Stokes 2005; Myers 2012). It has three significant tributaries with headwaters on Mount Lassen (10,500 feet) and two others with headwaters in basins encircled by 7,000-foot peaks. The mainstem, north and south forks, and tributaries run across very complex terrain over volcanic rock of various types and ages (Helley et al. 1981; DWR 1984; Clynne and Muffler 2010).

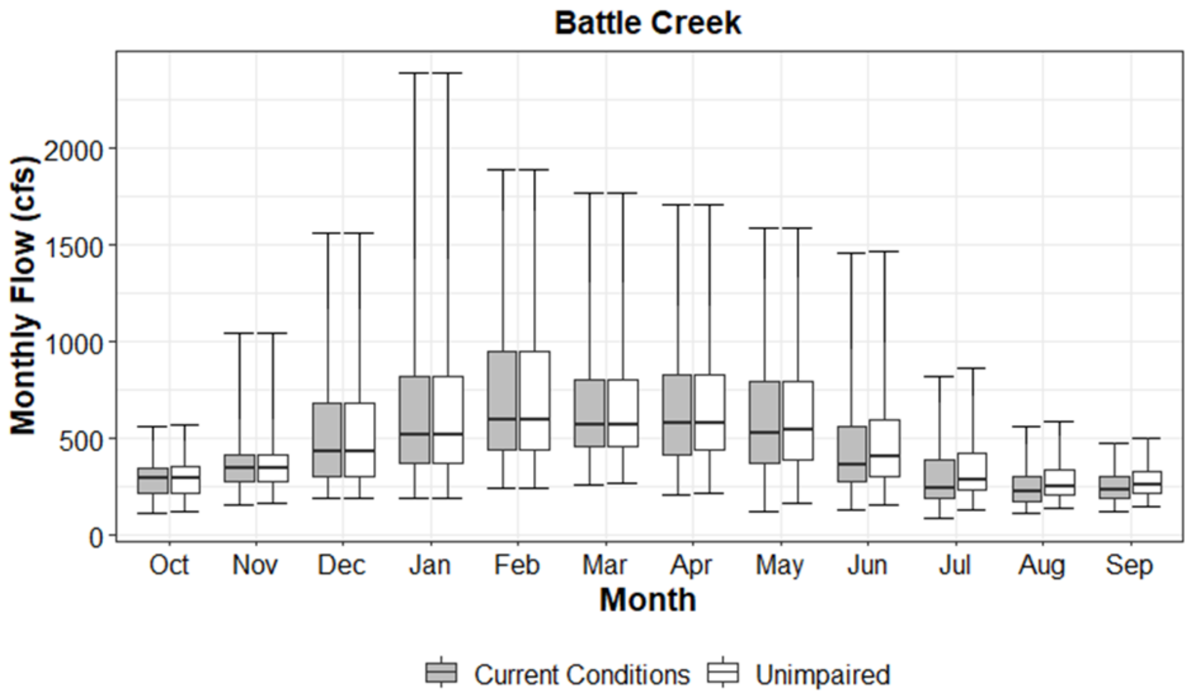
North Fork Battle Creek is especially unique as it has an unusually low precipitation-to-runoff ratio and a number of large cold water springs that discharge at low elevations immediately above impassable fish migration barriers (Jones & Stokes 2005; Myers 2012). The locations of the springs are due to the higher elevation of the watershed, which favors slower and extended infiltration from melting snow compared to infiltration plus rapid runoff from rain.

Because of the high elevation of most of its watershed, Battle Creek has a mixed snow/rainfall runoff regime (Myers 2012). Snow accumulations in the upper watershed store a significant amount of water, dampen large precipitation events, and shift discharge later in spring. Rain-on-snow events are significant in terms of large stream pulse flows, with the largest daily discharge recorded as 35,000 cubic feet per second (cfs) (Reclamation 2001). The numerous springs in the watershed contribute to a high late summer and fall base flow relative to nearby creeks of 250 cfs and to cool stream water temperatures below the springs (Jones & Stokes 2005; Myers 2012) (cfs = cubic feet per second

Figure 2.2-6). Stream groundwater interaction studies generally indicate that most of Battle Creek receives groundwater discharge (DWR 1984). Battle Creek has few diversions for consumptive use but has been developed for hydropower and has an extensive system of small dams, diversions, and canals (Jones & Stokes 2005). Hydropower operations in the Battle Creek watershed primarily affect flows on a sub-monthly timescale; however, cfs = cubic feet per second

Figure 2.2-7 shows that flows in Battle Creek on average are lower than unimpaired flows in the summer months (see also Table 2.2-3). The combination of relatively high base flows, cool water temperatures, and limited diversions for consumptive use has made North Fork and South Fork Battle Creek a focus of potential salmon restoration, with the federal CVP/SWP biological opinion (BiOp) calling for expedited implementation of the Battle Creek Salmon and Steelhead Restoration Project (^NMFS 2009).

Although consumptive water use is considered relatively low in the Battle Creek watershed compared with neighboring creeks, large diversions can occur in the lower watershed. There are two large agricultural diversions in the lower portion of Battle Creek. In addition, the U.S. Fish and Wildlife Service (USFWS) diverts water from lower Battle Creek for Coleman National Fish Hatchery operations. Coleman National Fish Hatchery water use is considered non-consumptive, but hatchery diversions can affect a section of mainstem Battle Creek. Nonetheless, Battle Creek maintains hydrologic connectivity with the Sacramento River on a year-round basis under current conditions (^NMFS 2014b).



cfs = cubic feet per second

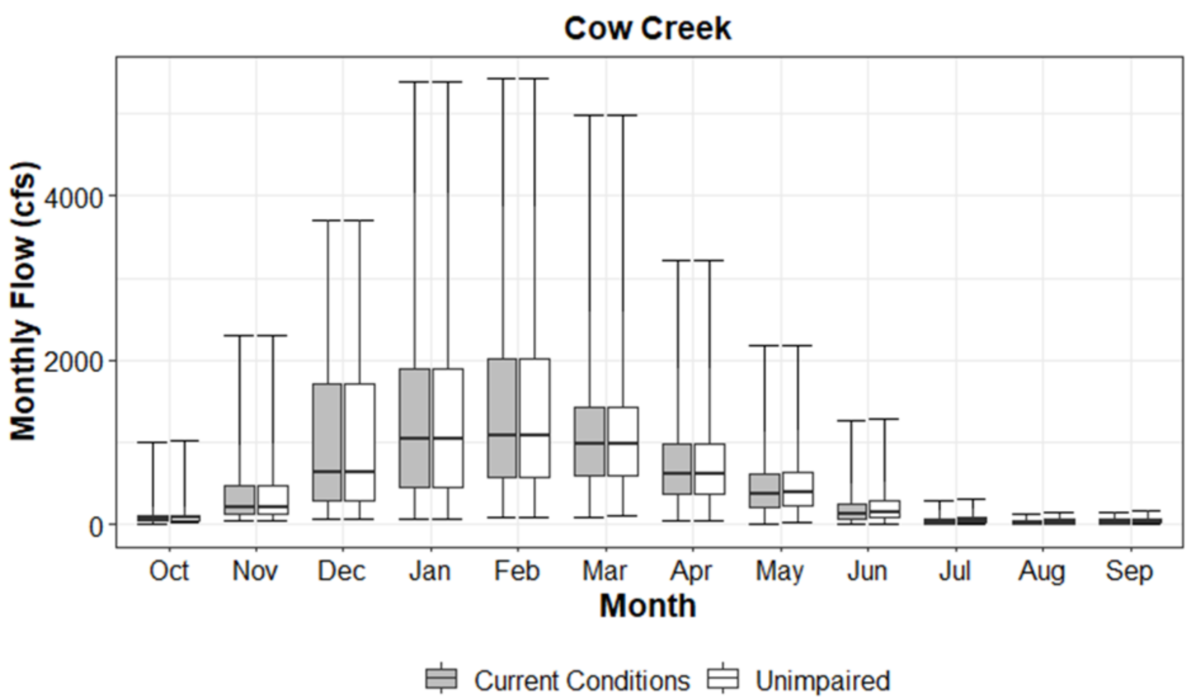
Figure 2.2-7. Battle Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-3. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Battle Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	89	96	100	100	100	94	90	77	76	65	72	81	95	89	94
10%	93	100	100	100	100	100	95	91	86	79	78	87	97	92	95
20%	96	100	100	100	100	100	97	93	89	81	83	88	97	93	96
30%	97	100	100	100	100	100	100	94	90	83	85	90	98	94	96
40%	98	100	100	100	100	100	100	95	92	85	87	90	98	94	97
50%	98	100	100	100	100	100	100	96	92	87	88	92	98	95	97
60%	98	100	100	100	100	100	100	97	93	88	89	92	99	95	97
70%	100	100	100	100	100	100	100	97	94	90	91	93	99	96	98
80%	100	100	100	100	100	100	100	98	96	92	91	94	99	96	98
90%	100	100	100	100	100	100	100	99	97	93	93	97	99	97	98
100%	100	100	100	100	100	100	100	100	99	96	97	100	100	98	99

2.2.2.2 Cow Creek

Cow Creek has a broad watershed of 430 square miles that is almost equally divided into fifths among the mainstem and four essentially coequal tributaries (SHN 2001; Western Shasta Resource Conservation District and Cow Creek Watershed Management Group 2005). Its headwaters reach peaks of up to 6,500 to 7,300 feet in elevation, and the watershed has a mixed snow/rain precipitation regime. Significant rain-on-snow events can occur, with 48,700 cfs being the highest recorded event (SHN 2001). There are no impassable fish migration barriers on the mainstem. The Cow Creek watershed does not contain significant reservoirs, but there are multiple diversions for irrigation uses. Simulated current hydrologic conditions are very similar to unimpaired flows (cfs = cubic feet per second Figure 2.2-9, Table 2.2-4). Streamflow in the lower and middle reaches during summer and fall is typically very low due to diversions for irrigation, recreation, and hydropower (Western Shasta Resource Conservation District and Cow Creek Watershed Management Group 2005; VESTRA Resources 2007). A 1969 decree adjudged all rights to the Cow Creek Stream System other than Clover, Oak Run, and North Cow Creeks (Shasta County Superior Court Decree No. 38577 [August 25, 1969]). Figure 2.2-8. Cow Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows



cfs = cubic feet per second

Figure 2.2-9. Cow Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-4. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Cow Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	42	95	99	100	100	90	86	43	9	7	10	7	92	79	93
10%	84	99	100	100	100	100	96	83	56	15	19	22	98	91	97
20%	88	100	100	100	100	100	97	91	67	19	25	34	98	92	98
30%	91	100	100	100	100	100	100	93	76	22	32	42	99	93	98
40%	94	100	100	100	100	100	100	94	82	34	41	57	99	95	98
50%	95	100	100	100	100	100	100	96	86	47	52	71	99	96	99
60%	97	100	100	100	100	100	100	97	88	59	60	77	99	97	99
70%	99	100	100	100	100	100	100	97	91	72	72	81	99	97	99
80%	100	100	100	100	100	100	100	98	93	76	76	82	100	98	99
90%	100	100	100	100	100	100	100	99	95	81	80	89	100	98	99
100%	100	100	100	100	100	100	100	100	100	163	111	100	100	100	100

2.2.2.3 Bear Creek

Bear Creek lies on the east side of the Sacramento River in Shasta County and has a long and narrow watershed of 157 square miles (SRWP 2010). It is bordered on the north by Cow Creek and on the south by Battle Creek. There are two main forks of Bear Creek: North Fork and South Fork. South Fork Bear Creek has a steeper gradient and a natural barrier to fish passage (Bear Creek Falls). North Fork Bear Creek has a more moderate gradient; Central Valley steelhead have been observed previously in the upper North Fork and in the lower South Fork at the base of Bear Creek Falls (ENPLAN 2006).

Bear Creek descends approximately 6,380 feet in elevation over 40 miles from its headwaters at Latour Butte (elevation 6,740 feet) to its mouth and confluence with the Sacramento River (elevation 360 feet). Based on streamflow gaging conducted by the U.S. Geological Survey (USGS) from 1960 to 1967, the average annual flow for Bear Creek is 82 cfs (SRWP 2010). Peak storm flow can reach 5,000 cfs; in low-rainfall years, lower Bear Creek becomes dry in the late summer season (SRWP 2010). Water may be diverted through direct diversion of water from the creek or its tributaries or pumping of local groundwater. Shallow groundwater, in the form of springs and seeps, plays an important role in sustaining surface flow in Bear Creek and its many smaller tributaries.

Land use within the watershed is largely characterized by timber production in the upper watershed and cattle ranching in the mid-lower watershed (SRWP 2010). Bear Creek provides important spawning and rearing habitat for fall-run salmon and steelhead that migrate from the Sacramento River (McEwen 2012). Unlike Cow Creek, water rights in Bear Creek watershed are not adjudicated; however, approximately 56 appropriative water right holders divert water for domestic use, irrigation, stock watering, power generation, and recreation (SRWP 2010). Because SacWAM does not represent any of the existing diversions from Bear Creek, the current simulated conditions are equal to the unimpaired results; therefore, the box plot and table are not presented.

2.2.3 Tributaries of the Chico Monocline

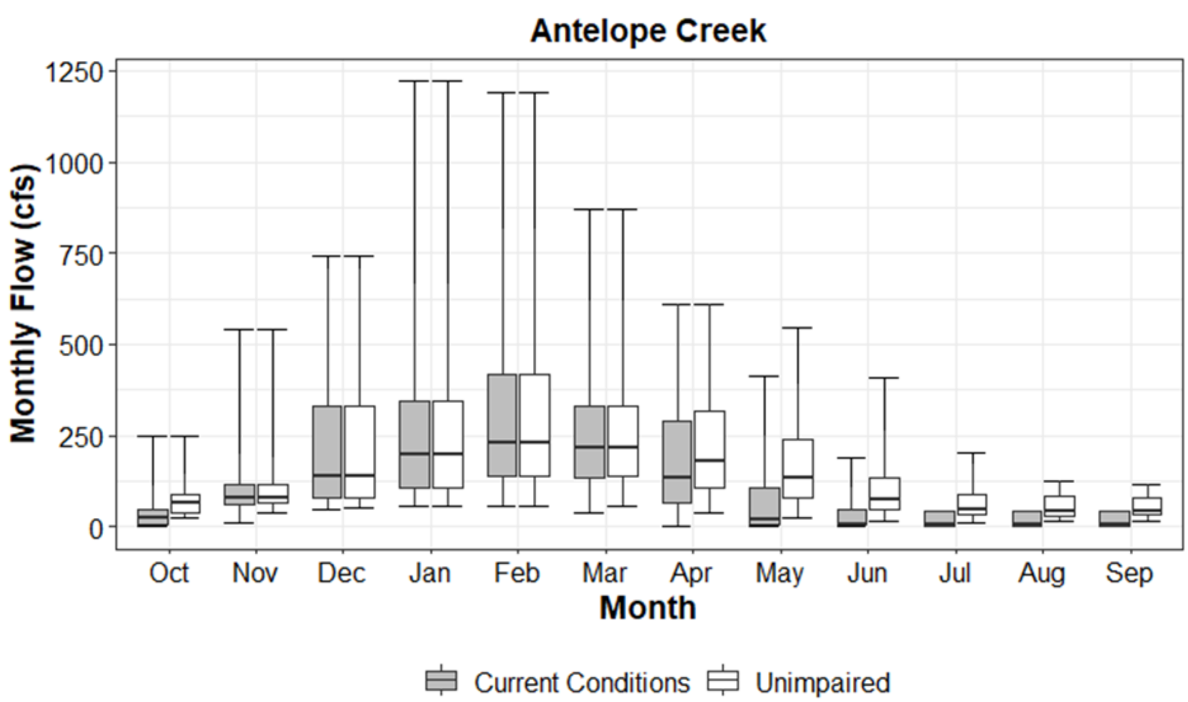
2.2.3.1 Antelope Creek

Antelope Creek has a long and narrow watershed of 202 square miles, of which 123 square miles are above the valley floor (Armentrout et al. 1998; Tehama County Resource Conservation District 2010; Stillwater Sciences 2011, 2015). The three forks of Antelope Creek originate on the west and south slopes of 6,900-foot Mount Turner. Much of the upper watershed is contained within public lands, including both Tehama State Wildlife Area and Lassen National Forest. The lower portion of Antelope Creek splits into a series of four distributaries when it enters the Sacramento Valley floor. Approximately 6 miles of the Sacramento River receive water from Antelope Creek through the series of distributaries that branch off the mainstem Antelope Creek and flow directly into the Sacramento River.

Because of the relatively high elevation of its upper watershed, Antelope Creek has a mixed snow/rainfall runoff regime (Tehama County Resource Conservation District 2010). Snow accumulations in the upper watershed store a significant amount of water, damp large precipitation events, and shift discharge to later in spring. However, rain-on-snow events can create large daily flows, with the largest recorded as 17,200 cfs. The lower elevation portion of the upper watershed receives precipitation primarily as rain, and local runoff is rapid due to the shallow soil and impervious surface of the Tuscan Formation that underlies this portion of the watershed. The numerous springs discharging from the canyon walls of the upper watershed also contribute to summer base flow and lower water temperatures (Armentrout et al. 1998) (cfs = cubic feet per second Figure 2.2-10).

There are few diversions in the upper watershed, but immediately downstream of the mouth of its canyon, Edwards Ranch and Los Molinos Mutual Water Company divert water at Edwards Diversion Dam (Tehama County Resource Conservation District 2010; Stillwater Sciences 2011, 2015). There are several other smaller diversions in the Antelope Creek watershed. Stream/groundwater interactions on Antelope Creek have not been well studied, but results from C2VSIM and SacWAM show that it is a gaining reach (^SacWAM 2023).

The upper limits of anadromy are located approximately 2 to 3 miles above the confluences of each of the three forks on Antelope Creek (Armentrout et al. 1998). Flow-related constraints on fisheries include low summer flows from the canyon mouth to the Sacramento River and numerous beaver dams with the potential to cause stranding and impair migration (Stillwater Sciences 2011, 2015). Diversions during the spring through fall irrigation season can result in low summer streamflows (cfs = cubic feet per second Figure 2.2-10, Table 2.2-5). However, the Antelope Creek watershed lacks a major storage reservoir, and streamflows remain relatively unimpaired during winter months.



cfs = cubic feet per second

Figure 2.2-10. Antelope Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-5. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Antelope Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	0	24	98	100	80	56	0	0	0	0	0	0	53	28	42
10%	0	98	99	100	100	96	11	0	0	0	0	0	71	55	68
20%	11	99	99	100	100	100	53	5	8	10	11	11	75	58	72
30%	15	99	100	100	100	100	66	6	9	12	13	12	78	61	74
40%	19	99	100	100	100	100	71	7	12	15	15	15	80	65	77
50%	45	100	100	100	100	100	76	16	14	16	18	18	82	69	79
60%	50	100	100	100	100	100	85	27	26	26	36	39	84	73	81
70%	51	100	100	100	100	100	90	39	32	41	45	45	86	75	82
80%	55	100	100	100	100	100	93	59	38	44	48	47	88	79	84
90%	66	100	100	100	100	100	100	63	41	47	50	51	90	84	87
100%	100	100	100	100	100	100	100	79	53	51	53	54	92	86	90

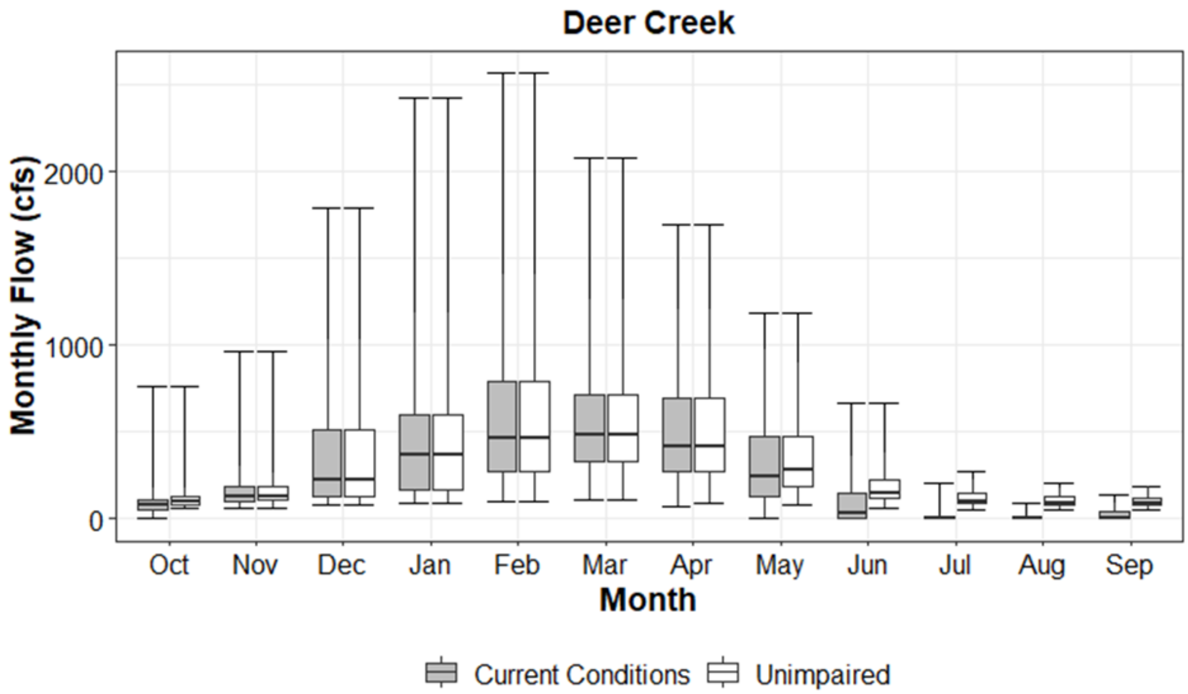
2.2.3.2 Deer Creek

Deer Creek has a watershed area of 298 square miles (including the valley reach) (Armentrout et al. 1998; Tompkins and Kondolf 2007). The creek originates from a number of tributaries flowing from the Mill Creek Plateau, the Lost Creek Plateau, and a number of individual peaks, including Butt Mountain, at an elevation of over 7,000 feet. Because of the relatively high elevation of its upper watershed, Deer Creek has a mixed snow/rainfall runoff regime (Armentrout et al. 1998; Tompkins and Kondolf 2007). Snow accumulations and the large area of the meadow system in the upper watershed store a significant amount of water, dampen large precipitation events, and shift discharge later in spring. However, rain-on-snow events can create large daily flows, with the largest recorded as 24,000 cfs (Tompkins and Kondolf 2007). The lower elevation areas of the upper watershed receive precipitation primarily as rain, and local runoff is rapid due to the shallow soil and impervious surface of the Tuscan Formation.

The upper Deer Creek watershed is located primarily on public lands, including lands managed by Lassen National Forest. There are few diversions in the upper Deer Creek watershed, but significant diversions can occur in the lower watershed. The late spring and summer hydrology of the valley floor section of Deer Creek has been extensively modified by three diversion dams: Stanford Vina Ranch Diversion Dam, Cone-Kimball Diversion Dam, and the Deer Creek Irrigation District Diversion Dam (Tompkins and Kondolf 2007). Major diverters in the lower watershed include Stanford Vina Ranch Irrigation Company and Deer Creek Irrigation District. A 1923 superior court adjudication divided 100 percent of Deer Creek's natural flows, with approximately 66 percent allocated to the Stanford Vina Ranch Irrigation Company, 33 percent allocated to the Deer Creek Irrigation District, and 1 percent to a third holder (Tehama County Superior Court Decree No. 4189, 1923). A flood control levee system also constrains and diverts flood flows up to peak flows of approximately 16,000 cfs (Tompkins and Kondolf 2007).

Studies have shown that minimal streamflow is lost to shallow aquifers on the lower portion of Deer Creek (Brown and Caldwell 2013; DWR 2004, 2009). Only 1 TAF/yr on average is estimated to be lost on Deer Creek to groundwater in the current conditions simulation in SacWAM.

Fish migration is blocked at Upper Deer Creek Falls (Armentrout et al. 1998). Fishery constraints are restricted to the valley floor reach and include diversion dams that impede or block passage, elevated water temperatures, and low flows in late spring and summer (Armentrout et al. 1998). Diversions primarily affect the instream flows on Deer Creek in summer months when the unimpaired flows are already very low. Deer Creek has essentially no water in summer months in many years. However, the Deer Creek watershed lacks a major storage reservoir, and flows are generally less impaired during winter months (cfs = cubic feet per second Figure 2.2-11, Table 2.2-6).



cfs = cubic feet per second

Figure 2.2-11. Deer Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-6. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Deer Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	0	82	100	100	100	100	55	0	0	0	0	0	75	38	64
10%	33	100	100	100	100	100	100	12	0	0	0	0	82	50	76
20%	49	100	100	100	100	100	100	53	0	1	1	1	86	53	79
30%	63	100	100	100	100	100	100	68	0	1	1	1	91	59	82
40%	72	100	100	100	100	100	100	79	7	1	2	2	92	62	84
50%	80	100	100	100	100	100	100	89	22	2	2	8	94	64	87
60%	89	100	100	100	100	100	100	100	38	5	6	18	95	67	89
70%	97	100	100	100	100	100	100	100	59	6	7	35	97	71	90
80%	100	100	100	100	100	100	100	100	73	8	8	41	98	76	92
90%	100	100	100	100	100	100	100	100	95	27	12	50	100	82	94
100%	100	100	100	100	100	100	100	100	100	87	54	100	100	88	97

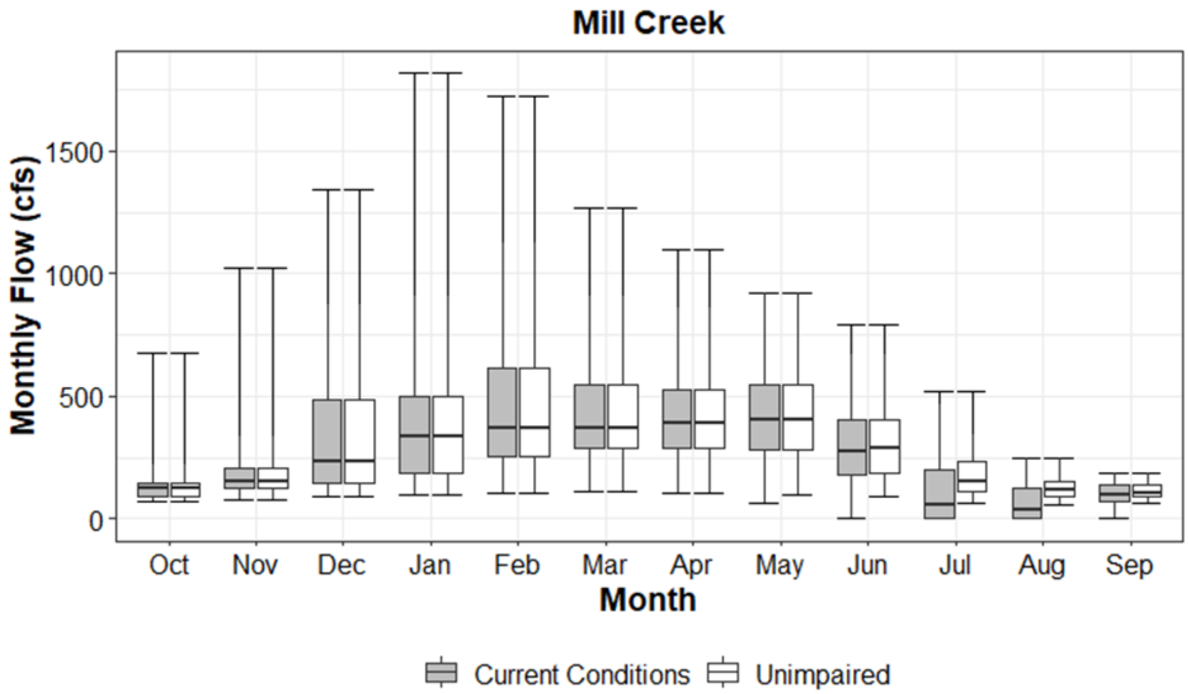
2.2.3.3 Mill Creek

Mill Creek has a watershed area of approximately 130 square miles (Armentrout et al. 1998; Kondolf et al. 2001). Its watershed is very narrow and elongated and originates on the upper slopes of Mount Lassen (10,500 feet), flows southward to the Mill Creek Plateau, and soon afterward bends to the southwest toward the Sacramento Valley (Armentrout et al. 1998; Kondolf et al. 2001; CDFW 2014). Mill Creek runs in its deep canyon and has no significant tributaries (Armentrout et al. 1998; Kondolf et al. 2001; Clynne and Muffler 2010; ^DWR 2014a; Muffler and Clynne 2015).

Mill Creek has a mixed snow/rainfall runoff regime where snow accumulations on the sides of the high elevation peaks in the upper watershed store a significant amount of water, dampen large precipitation events, and shift discharge later in spring (Armentrout et al. 1998; Kondolf et al. 2001). However, rain-on-snow events can create large daily flows, with the largest recorded as 36,400 cfs (Kondolf et al. 2001). The lower elevation areas of the upper watershed receive precipitation primarily as rain, and local runoff is rapid due to the shallow soil and impervious surface of the Tuscan Formation. A significant amount of summer and fall base flow originates from hydrothermal springs on Brokeoff Mountain, Bumpass Mountain, and Diamond Peak (Armentrout et al. 1998; Clynne and Muffler 2010; Muffler and Clynne 2015).

Much of the upper Mill Creek watershed is located on public lands. The upper Mill Creek watershed contains few diversions, but significant diversions can occur in the lower watershed. A 1920 Mill Creek adjudication apportioned all flows in Mill Creek up to 203 cfs (Tehama County Superior Court Decree No. 3811, 1920). In the valley portion of the Mill Creek watershed, streamflows can be affected by two diversion dams: Upper Diversion Dam and Ward Diversion Dam (Armentrout et al. 1998; CDFW 2014; Tehama Environmental Solutions 2015). Diversions from those dams significantly affect late spring, summer, and fall flows; but those impacts are partially mitigated through surface water transfer and groundwater conjunctive use agreements (USDOI 2002; LMMWC 2007) (cfs = cubic feet per second Figure 2.2-11). A stream and groundwater interaction study for Mill Creek found that interactions were very small (Brown and Caldwell 2013). SacWAM estimates that 2 TAF/yr on average is gained on Mill Creek from groundwater in the current conditions simulation.

The upper limit of anadromy on Mill Creek is located 48 miles above the Sacramento River near the Little Mill Creek confluence (Armentrout et al. 1998). The Mill Creek watershed lacks a major storage reservoir, and the primary impairments for anadromous fish in the Mill Creek watershed are low late spring, summer, and fall flows (cfs = cubic feet per second Figure 2.2-12, Table 2.2-7) and related temperature issues (Armentrout et al. 1998; USDOI 2002; LMMWC 2007).



cfs = cubic feet per second

Figure 2.2-12. Mill Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-7. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Mill Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	93	100	100	100	100	100	100	50	0	0	0	0	85	52	75
10%	100	100	100	100	100	100	100	100	69	0	0	34	96	66	87
20%	100	100	100	100	100	100	100	100	82	2	2	64	98	72	90
30%	100	100	100	100	100	100	100	100	93	10	4	81	99	74	91
40%	100	100	100	100	100	100	100	100	100	20	16	91	100	76	93
50%	100	100	100	100	100	100	100	100	100	45	35	100	100	82	94
60%	100	100	100	100	100	100	100	100	100	64	51	100	100	88	96
70%	100	100	100	100	100	100	100	100	100	83	71	100	100	92	98
80%	100	100	100	100	100	100	100	100	100	100	84	100	100	97	99
90%	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
100%	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

2.2.3.4 Paynes Creek

Paynes Creek has a watershed area of 93 square miles (Tehama County Resource Conservation District 2010), with its origin at an elevation of approximately 5,300 feet. The upper watershed of Paynes Creek receives precipitation primarily as rain, and runoff is rapid due to the shallow soil and impervious surface of the Tuscan Formation that underlies this portion of the watershed. A peak daily flow of 10,600 cfs has been recorded. Flows during summer are typically low, and the stream can become intermittent (Tehama County Resource Conservation District 2010). There are no dams on Paynes Creek, but several small diversions reduce spring and summer flows (Tehama County Resource Conservation District 2010; ^NMFS 2014b).

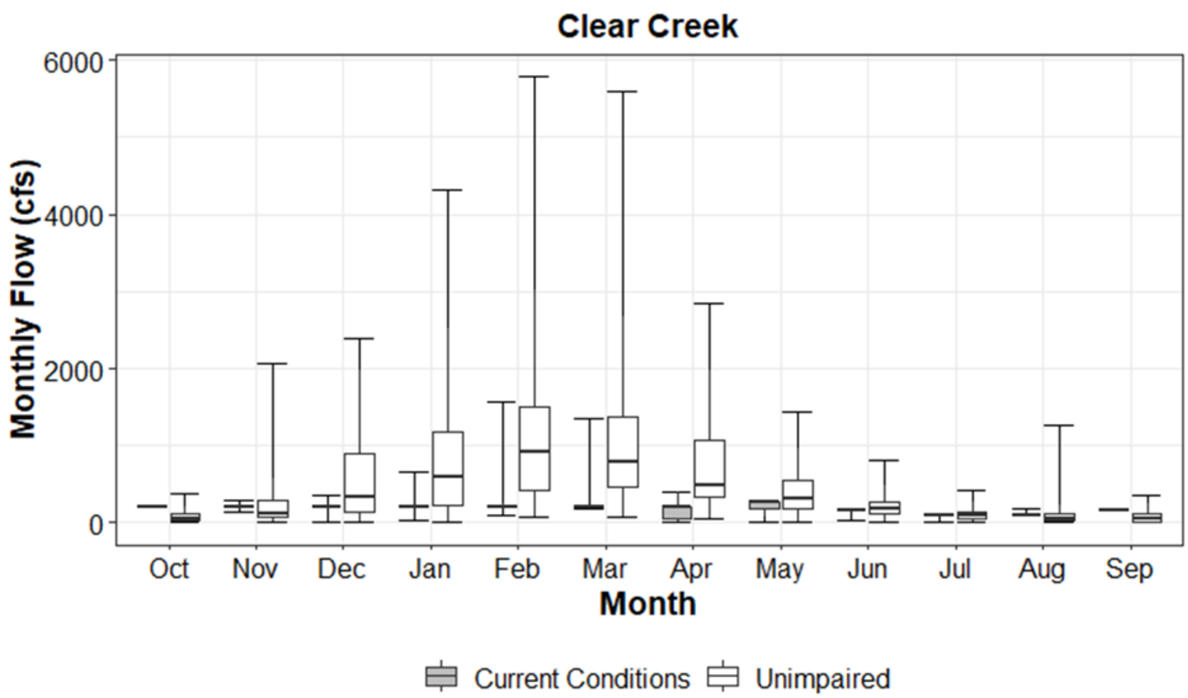
SacWAM does not include any diversions from Paynes Creek. Because the current simulated conditions and the unimpaired results are the same, a box plot and cumulative distribution table are not presented.

2.2.4 Tributaries of the Klamath Mountains

2.2.4.1 Clear Creek

Clear Creek has a watershed area of approximately 249 square miles, but only 49 square miles and 16 river miles are located below the Whiskeytown Dam, a major storage reservoir. As a result, reservoir operations completely dominate the hydrology of lower Clear Creek (Western Shasta Resource Conservation District 1996). Above Whiskeytown Reservoir, numerous small tributaries drain from the Trinity Mountains at maximum elevations of 6,200 feet (Tetra Tech 1998). Occasionally there are large winter peak flow events, and snow can remain on the peaks through June.

Trinity River flows are imported to the Sacramento River watershed through the Clear Creek Tunnel to Whiskeytown Reservoir. All of the water diverted from the Trinity River, in addition to a portion of Clear Creek flows, is diverted to the Keswick Reservoir on the Sacramento River via the Spring Creek Tunnel and Powerhouse. SacWAM results show that approximately 38 percent of the volume of water in the Whiskeytown Reservoir is from upper Clear Creek, and the other 62 percent is imported from the Trinity River. About 12 percent of the stored water is released into lower Clear Creek; the remaining 88 percent is diverted to the Spring Creek Powerhouse and discharged into Keswick Reservoir, which reduces the flow in Clear Creek in spring (cfs = cubic feet per second, Table 2.2-8). Flows in Clear Creek are often higher than unimpaired flows in summer and fall due to an instream flow requirement at Igo designed to protect native fisheries during hot summer months.



cfs = cubic feet per second

Figure 2.2-13. Clear Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-8. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Clear Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	54	14	14	14	14	14	14	14	19	15	14	42	17	24	20
10%	117	31	16	15	15	14	14	15	37	47	60	87	20	46	28
20%	136	59	21	15	15	15	14	34	53	55	75	118	23	57	30
30%	190	86	31	22	16	18	14	43	60	74	117	155	25	69	34
40%	272	132	41	26	19	21	14	51	66	89	173	272	27	78	37
50%	328	172	64	36	23	26	16	56	72	101	214	367	30	89	45
60%	417	189	84	55	33	34	18	68	87	153	325	618	37	112	53
70%	523	260	95	75	44	40	24	79	100	215	459	948	40	160	60
80%	727	343	100	101	60	53	28	110	147	286	812	AZ	50	252	70
90%	AZ	559	231	141	95	75	34	136	228	981	AZ	AZ	67	351	100
100%	AZ	AZ	425	AZ	220	280	95	278	AZ	AZ	AZ	AZ	99	1,151	178

"AZ" indicates that the unimpaired flow is approaching zero and is very low.

2.2.5 Tributaries of the Paleochannels and Tuscan Formation

2.2.5.1 Butte Creek

The Butte Creek watershed encompasses approximately 797 square miles in portions of Tehama, Glenn, Colusa, and Sutter Counties. Butte Creek originates at an elevation of about 7,000 feet where a number of small tributaries converge in the Jonesville basin of the Lassen National Forest on the western slope of the Sierra Nevada (Butte Creek Watershed Conservancy 2007). Butte Creek transitions from the upper watershed area of the Butte Meadows approximately 25 miles through a steep canyon to the point where it enters the valley floor near Chico. During the irrigation season, Butte Creek discharges through the Butte Slough outfall gates at the western side of the Sutter Buttes, but otherwise it drains southward into Butte Slough in the Sutter Bypass, passes through large areas of irrigated agriculture, and then through Sacramento Slough into the Sacramento River (Butte Creek Watershed Project 1998).

Because of the relatively high elevation of its upper watershed, Butte Creek has a mixed snow/rainfall runoff regime. Snow accumulations in the upper watershed store a significant amount of water, dampen large precipitation events, and shift discharge later in spring. The lower elevation portion of the upper watershed receives precipitation primarily as rain, and local runoff is rapid due to the shallow soil and impervious surface of the Tuscan Formation that underlies this portion of the watershed. There are infrequent rain-on-snow events that have generated daily flows of up to 26,600 cfs, and minimum wet season flows during drought are approximately 500 cfs. (Butte Creek Watershed Project 1998.)

The hydrology of Butte Creek has been extensively modified and developed. In the upper watershed A number of dams, hydropower projects, and diversions in the upper watershed, including water imported from the Feather River watershed via the Toadtown Canal and SWP Oroville-Thermalito Complex, significantly alter the timing, magnitude, and temperature of flows. On the valley floor, a complex system of levees, canals, and diversions for irrigation utilize water diverted from both the Butte Creek watershed and Thermalito Afterbay. (Butte Creek Watershed Project 1998; Williams et al. 2002).

Sacramento River flood flows often completely overtop the valley floor reach of Butte Creek in the Butte and Sutter basins. These combined flows start in the upper two-thirds of the Butte basin and drain into the wide upper end of the Butte Sink area, the southernmost section and remaining one-quarter of Butte basin. The combined flows enter Butte Sink at the 60-foot elevation contour near the Moulton Weir (Bryan 1923), converge southward, and wrap around the west side of the Sutter Buttes. Butte Sink is bounded to the west by the 30-foot-high natural levee of the Sacramento River, which forces Butte Creek to the southeast, and is bounded to the east by the Sutter Buttes. The naturally incised channel of Butte Creek, while sometimes immersed deeply by basin and sink flood flows, persists as a defined channel that discharges into Butte Slough, which drains into the Sutter basin (USGS 1913; Bryan 1923; Carpenter et al. 1926; Olmsted and Davis 1961; DWR 2012).

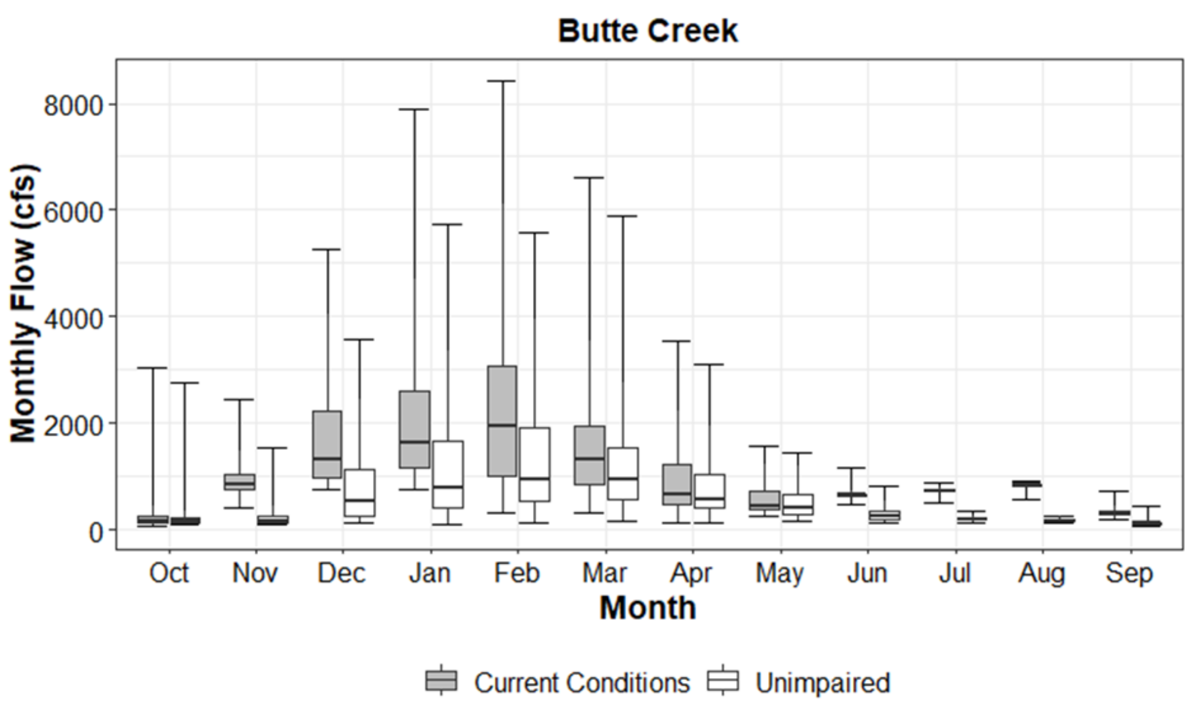
Sacramento River flows can enter the Butte basin through six locations (DWR 2010a, 2010b, 2012). When flows in the Sacramento River exceed 30,000 cfs, flood waters flow over the Colusa Weir (70,000 cfs designed capacity) into the main section of the Butte Sink (DWR 2010a, 2012). Normally, the Colusa Weir does not overtop until after the Tisdale Weir is also spilling, when Sacramento River flow is greater than about 23,000 cfs, except for flood events that are characterized by a rapid rise in Sacramento River stage (CDFW 2017; USGS 2017). When flows in the Sacramento River exceed

70,000 cfs, flood waters flow into the upper end of the Butte Sink over the Moulton Weir (25,000 cfs designed capacity) (DWR 2010a, 2012). When flows in the Sacramento River exceed 100,000 cfs, water can pass into the basin at its upper end through the M&T and Parrot Plug flow relief structures, the Three-Bs overflow area, and an emergency overflow roadway (Goose Lake Flood Relief Structure) (DWR 2010a, 2012).

The valley floor reach is known to lose surface water to groundwater recharge where it traverses the Chico alluvial fan, but the amount of that loss has not been determined by site-specific studies (Moran et al. 2005). SacWAM estimates the stream loss to groundwater to be -31 TAF/yr, on average, from Butte Creek (^SacWAM 2023).

The Quartz Bowl Falls, about 1 mile below the DeSabla Powerhouse, is a natural barrier that can block fish passage under most hydrologic conditions (Butte Creek Watershed Project 1998). Salmon and steelhead cannot regularly access Butte Creek upstream of the Quartz Bowl Falls but have been observed upstream in several instances when spring flows were greater than 2,000 cfs (Ward and Moberg 2004; DWR 2005). Low flows and high water temperatures during summer, imported water obscuring migratory cues from natal stream water, and the lack of a defined channel from the lower Butte basin to the Sacramento River are the primary fishery-related issues.

Compared to other Sacramento/Delta tributaries, Butte Creek exhibits a unique hydrologic pattern in that streamflows under current conditions are higher than streamflows under unimpaired flow conditions because of the imported water from the Feather River watershed (cfs = cubic feet per second Figure 2.2-14, Table 2.2-9).



cfs = cubic feet per second

Figure 2.2-14. Butte Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-9. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Butte Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	41	158	133	134	133	112	99	93	139	212	250	160	125	171	141
10%	68	260	160	146	146	120	106	102	160	289	375	182	138	198	155
20%	76	320	176	157	151	127	111	105	183	310	440	222	140	223	162
30%	84	402	197	179	160	132	112	108	212	341	456	238	147	251	173
40%	92	435	217	193	168	136	114	112	231	360	477	248	151	273	181
50%	97	504	260	204	173	138	115	115	247	377	492	255	158	301	190
60%	105	528	313	229	180	144	117	118	263	394	509	259	169	320	201
70%	113	578	351	268	193	148	119	128	289	405	524	263	178	344	214
80%	120	595	433	312	210	158	122	136	317	423	538	275	185	359	228
90%	130	635	560	431	242	176	126	156	348	448	562	293	198	385	245
100%	159	732	686	804	357	206	136	176	458	498	630	347	244	440	299

2.2.5.2 Big Chico Creek

Big Chico Creek originates from surface runoff and springs from Colby Mountain; the creek has a 72-square-mile watershed in the foothills (Big Chico Creek Watershed Alliance 2014) and a combined valley/foothill watershed of 359 square miles. Because of Colby Mountain's relatively low maximum elevation of 5,400 feet, most of the precipitation falls as rain; but colder winter storms often produce significant amounts of snow that can persist in the shade of the mountain's mixed coniferous forest, reducing the peak storm runoff and increasing the duration of winter flows. Rainfall is the dominant source of precipitation over most of the watershed, and runoff is rapid due to the shallow soil and impervious surface of the Tuscan Formation that underlies the entire upland area of the watershed. Big Chico Creek has two significant tributaries: Mud and Rock Creeks, which originate in the foothills at elevations below 4,000 feet. Their watersheds also are underlain by the Tuscan Formation, and runoff is rapid.

There are no large reservoirs or diversions in the upland reaches of Big Chico Creek or its tributaries (Big Chico Creek Watershed Alliance 2014). At the lower end of Butte Meadows at an elevation of 4,400 feet, a small dam creates a swimming pond. Big Chico Creek is free flowing from Butte Meadows to the Five Mile Dam, a flood control structure that diverts winter flood flows into the Lindo Flood Control Channel. Those flows and the flows of the Sycamore Diversion Canal rejoin Big Chico Creek 2.5 miles upstream of its confluence with the Sacramento River. Mud and Rock Creeks join Big Chico Creek below the Lindo Flood Control Channel confluence. Below Five Mile Dam, One Mile Dam (an inflatable dam and fish ladder complex located within the City of Chico) is operated during the warm season to create a swimming pond within the channel of Big Chico Creek.

There are a number of small water diversions from Big Chico Creek and its tributaries. However, the hydrology of Big Chico Creek has not been significantly impaired on a monthly timescale by upstream diversions. Big Chico Creek maintains a summer base flow of 20 to 25 cfs in its reach across the valley floor to the Sacramento River, while its tributaries become dry before reaching the valley floor.

The valley floor reach is known to lose surface water to groundwater recharge where the reach and the Lindo Flood Control Channel traverse the Chico alluvial fan, but the amount of that loss has not been determined by site-specific studies (Moran et al. 2005).

The upper limit of anadromy is a waterfall above the Higgins Hole at river mile (RM) 24 on Big Chico Creek. Higgins Hole and a number of other holes immediately downstream generally provide excellent over-summer holding habitat for spring-run Chinook salmon (Big Chico Creek Watershed Alliance 2014). The reach from the Sacramento River to just upstream of the Lindo Flood Control Channel provides good rearing habitat. Juveniles sometimes are stranded in the Lindo Flood Control Channel when flood flows drop rapidly. The primary impairments for anadromous fish in the Big Chico Creek watershed are low late-spring and summer flows and deficiencies of the Iron Canyon Fish Ladder, a series of weirs intended to allow fish to bypass a natural waterfall near RM 13.

SacWAM does not include any diversions from Big Chico Creek in the model. Because the simulated current conditions and the unimpaired flows are the same, a box plot and cumulative distribution table are not presented.

2.2.6 Tributaries of the Northern Sierra Nevada

2.2.6.1 Feather River

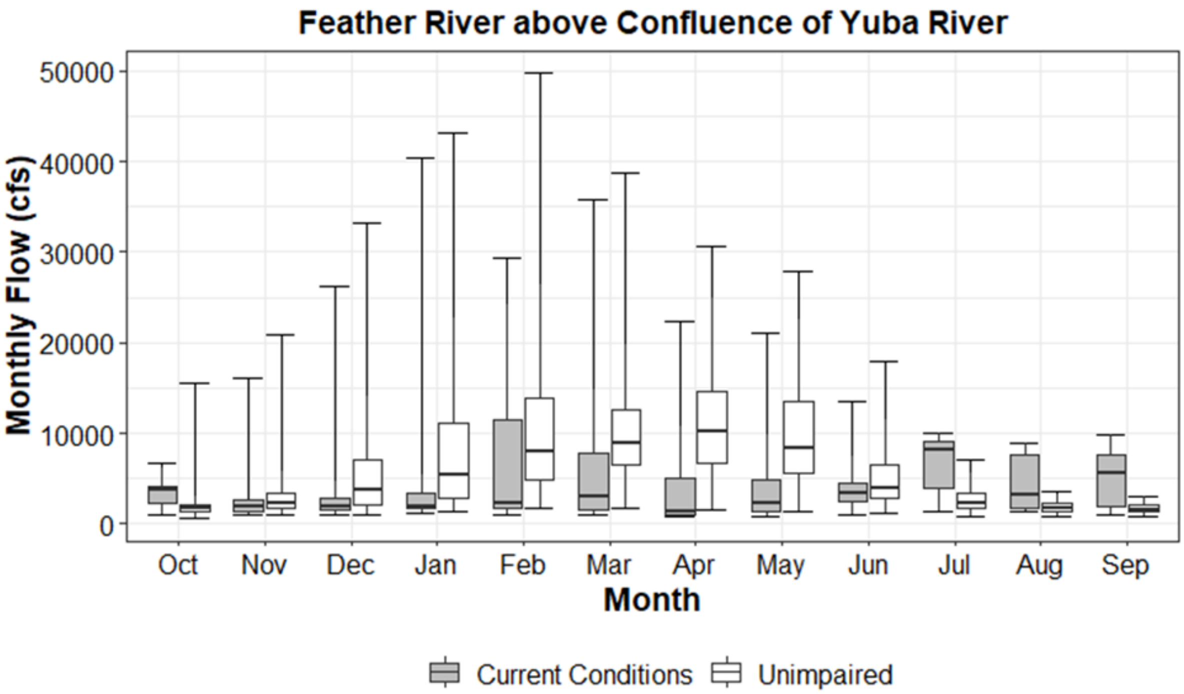
The Feather River has a watershed of 4,400 square miles, including 3,600 square miles above Lake Oroville and the remainder below—not counting the watersheds of the Yuba and Bear Rivers and other foothill tributaries (Koczot et al. 2005; SRWP 2010). The Feather River watershed reaches an elevation of 10,400 feet on Mount Lassen, although most of its headwaters in the Sierra Nevada and Diamond Mountains are below 7,000 feet (Koczot et al. 2005).

Above Lake Oroville, the Feather River has four main forks: the West Branch, the North Fork, the Middle Fork, and the South Fork. Additionally, the North Fork often is considered to have an Upper North Fork (upstream of Lake Almanor [1.3 MAF capacity]) and an East Branch. The four river forks and two branches of the North Fork provide an average annual inflow to Lake Oroville (3.54 MAF capacity) of 4.54 MAF.

The Feather River watershed contains several hydropower projects. Pacific Gas and Electric Company (PG&E) diverts approximately 45 TAF from the West Branch through the Toadtown Canal to Butte Creek. The South Feather Power Project diverts approximately 85 TAF/yr from Slate Creek (tributary of the North Yuba River) into the Feather River watershed. Additionally, Sierra Valley on the Middle Fork and Indian Valley on the East Branch contain large areas of irrigated agriculture for forage and hay (Koczot et al. 2005; George et al. 2007).

Because of the generally low elevation of the ranges and because approximately 60 percent of the watershed lies below the 5,500-foot snow line, the type of precipitation is sensitive to temperature, frequently with rain-on-snow during the day and snow at night (Koczot et al. 2005). The Feather River watershed is responsive to large rain-on-snow events; during February 1986, instantaneous inflow to Lake Oroville reached 266,000 cfs (USGS 2013). The timing of peak monthly inflow into Lake Oroville varies from March through May according to the phase of the Pacific Decadal Oscillation, a recurring pattern of ocean-atmosphere climate variability, and hydropower operations (Koczot et al. 2005).

Oroville Dam is an impassable fish barrier; the loss of habitat upstream of Oroville Dam represents a major impact on fisheries, although spawning habitat restoration actions are being implemented in the lower Feather River (^DWR 2007). Flows in the lower Feather River are highly dependent on releases from Oroville Dam and diversions from Thermalito Afterbay. Additional diversions for agriculture by water rights holders as well as SWP contractors reduce instream flows above the confluence with the Yuba River. The large effect of SWP operations on the Feather River is shown in cfs = cubic feet per second Figure 2.2-15 and Table 2.2-10, where under current conditions winter and spring flows are greatly reduced and summer flows are much higher than unimpaired flows. The January through June impairment of the Feather River above the confluence with the Yuba River ranges between 14 and 87 percent, and the impaired flow is less than 50 percent of the estimated unimpaired flow from January through June for more than half of the years modeled (Table 2.2-10).



cfs = cubic feet per second

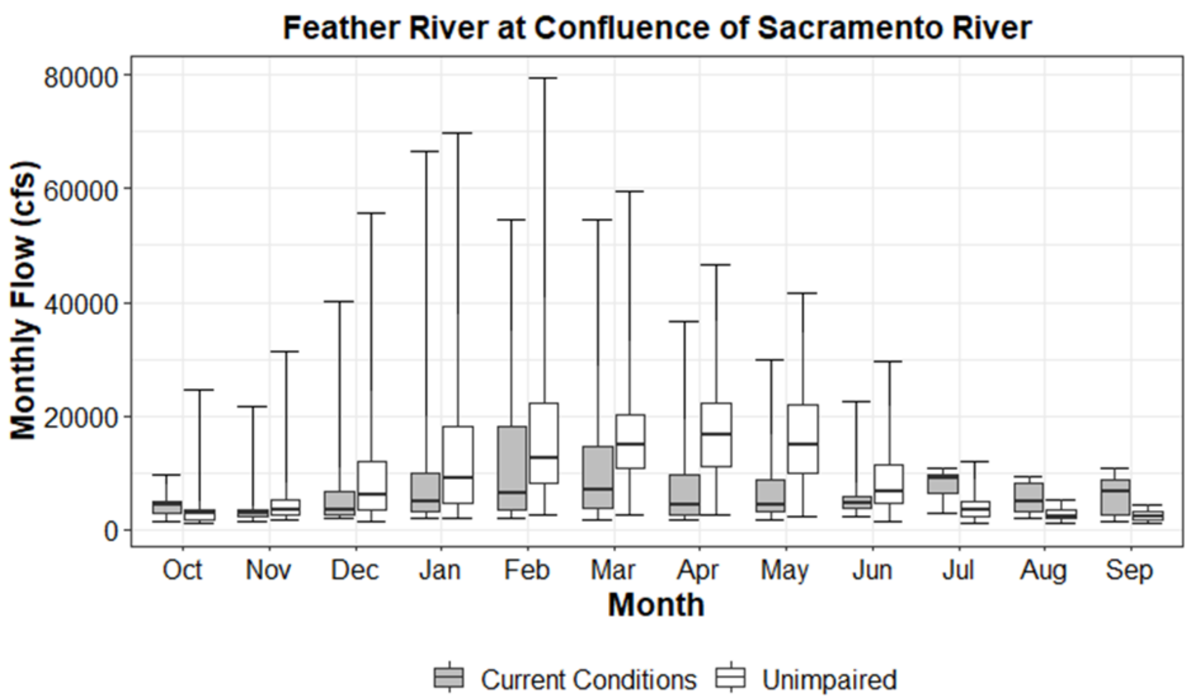
Figure 2.2-15. Feather River above Confluence with the Yuba River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-10. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Feather River above Confluence with Yuba River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	20	7	14	13	13	7	5	8	13	36	45	68	14	46	33
10%	83	39	22	22	19	16	9	14	32	69	55	96	22	73	56
20%	120	49	34	29	27	19	11	20	42	165	64	162	29	105	64
30%	154	58	43	38	30	25	13	25	59	228	101	191	38	130	68
40%	188	70	53	43	40	33	16	31	65	264	206	226	46	150	70
50%	203	81	61	50	48	48	19	36	74	318	243	280	50	163	75
60%	221	93	70	62	60	60	28	45	81	367	331	359	57	190	83
70%	247	102	80	78	82	70	40	53	112	396	383	404	65	214	89
80%	260	122	101	92	92	83	52	61	133	478	502	435	71	234	95
90%	294	141	133	101	98	92	66	74	197	537	599	478	75	264	103
100%	435	217	346	167	143	109	112	230	336	777	1,009	577	87	331	140

Groundwater interactions are complex along the lower Feather River as they respond to droughts, seasonal groundwater pumping, seepage from Thermalito Reservoir, local expression of the underlying geologic formations, and flows from the river channel through underlying paleochannels of the Feather River (Busacca et al. 1989; Baker and Pavlik 1990; Blair et al. 1992; CDM 2008; Springhorn 2008; Wood Rodgers 2012). In SacWAM under current conditions, stream losses to groundwater are estimated to be -10 TAF/yr on average. In some years, however, losses are over -100 TAF/yr and in other years, the lower Feather River gains over 200 TAF/yr from groundwater. (^SacWAM 2023).

Below inflows from the Yuba and Bear Rivers, the much larger Feather River (cfs = cubic feet per second Figure 2.2-16) meanders for 12 miles where two minor agricultural diversions exist before meeting with the Sacramento River. The Yuba and Bear Rivers add additional flow in spring to the Feather River, often increasing the combined percent of unimpaired flow reaching the Sacramento River. Above the confluence with the Sacramento River, the January through June current conditions as a percentage of unimpaired flow range from 28 to 81 percent and are less than 54 percent in half of the years. Monthly average impaired flows during fall, winter, and spring are significantly lower in some years, with flows as low as 16 percent of unimpaired in April and May under current conditions (Table 2.2-11).



cfs = cubic feet per second

Figure 2.2-16. Feather River at Confluence with the Sacramento River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-11. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Feather River with Confluence of Sacramento River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	38	22	22	25	25	22	16	17	29	54	78	75	28	62	41
10%	89	40	39	41	37	29	18	23	41	73	89	127	35	78	58
20%	104	51	46	46	41	33	22	26	49	140	99	154	39	96	61
30%	124	60	50	52	46	37	24	29	56	181	115	177	43	115	67
40%	147	72	55	60	50	43	26	32	62	207	182	212	47	126	71
50%	159	82	66	67	59	55	28	36	67	245	221	244	54	139	73
60%	169	90	73	76	69	66	35	42	76	271	262	286	60	153	76
70%	181	100	78	84	85	74	46	50	90	298	301	322	66	166	81
80%	193	111	95	96	91	81	52	56	105	359	387	350	70	186	85
90%	220	121	110	102	97	91	65	63	152	401	461	376	75	206	90
100%	342	171	246	134	116	111	79	155	237	541	653	442	81	270	113

2.2.6.2 Yuba River

The Yuba River has a watershed of 1,339 square miles and runs to its confluence with the Feather River from an elevation of 8,600 feet at the crest of the Sierra Nevada (HDR and SWRI 2007). The Yuba River has three forks with the following watershed areas: North Fork, 490 square miles; Middle Fork, 210 square miles; and South Fork, 350 square miles (UYRSPST 2007). The Yuba River watershed is responsive to rain-on-snow events; during the January 1997 rain-on-snow event, instantaneous flow at Marysville reached 180,000 cfs (Entrix 2003). Historically, prior to the construction of New Bullards Bar and Englebright Dams, peak monthly runoff was generated by snowmelt during April and May (Pasternack 2009). Flows in the lower Yuba River during the July to January low-flow season appear to have increased since construction of the dams (Pasternack 2009), but streamflow gage records began only after most of the high elevation dams had been constructed.

North Fork Yuba River and Middle Fork Yuba River join in the foothills just below New Bullards Bar Reservoir; a few miles more downstream, they are joined by South Fork Yuba River, which then flows into the relatively small Englebright Lake (70 TAF). The Yuba River watershed can be naturally divided into three sections. The upper sections of each of the three forks run through a series of glaciated basins at elevations ranging from 5,500 to 7,000 feet (James et al. 2002; James 2003; NID 2011). Between the glaciated basins and the toe of the foothills just below Englebright Reservoir, the three forks and mainstem run through deep and narrow parallel canyons with relatively steep gradients (NID 2011). Below the foothills, the Yuba River flows through a valley section to its confluence with the Feather River.

The Yuba River has been extensively developed for hydropower generation and water supply. Development in the upper watersheds of North, Middle, and South Fork Yuba River and Deer Creek include parts of the South Feather Water and Power Agency's South Feather Hydroelectric Project (FERC No. 2088), Yuba County Water Agency's Yuba River Development Project (FERC No. 2246), Nevada Irrigation District's Yuba-Bear Hydroelectric Project (FERC No. 2266), PG&E's Drum-Spaulding Project (FERC No. 2310), and U.S. Army Corps of Engineers' (USACE) Englebright and Daguerre Point Dams (^SacWAM 2023). The many hydropower reservoirs and diversions in the upper watershed affect the timing of inflows to New Bullards Bar and Englebright Reservoirs. Additionally, there are major transfers of water out of the watershed. The Slate Creek Diversion (discussed in Section 2.2.6.1, *Feather River*) diverts on average about 80 TAF/yr from North Fork Yuba River into the Feather River watershed. The South Yuba Canal and the Drum Canal divert on average about 430 TAF/yr from the South Fork Yuba River at Lake Spaulding to the Deer Creek and Bear River watersheds.

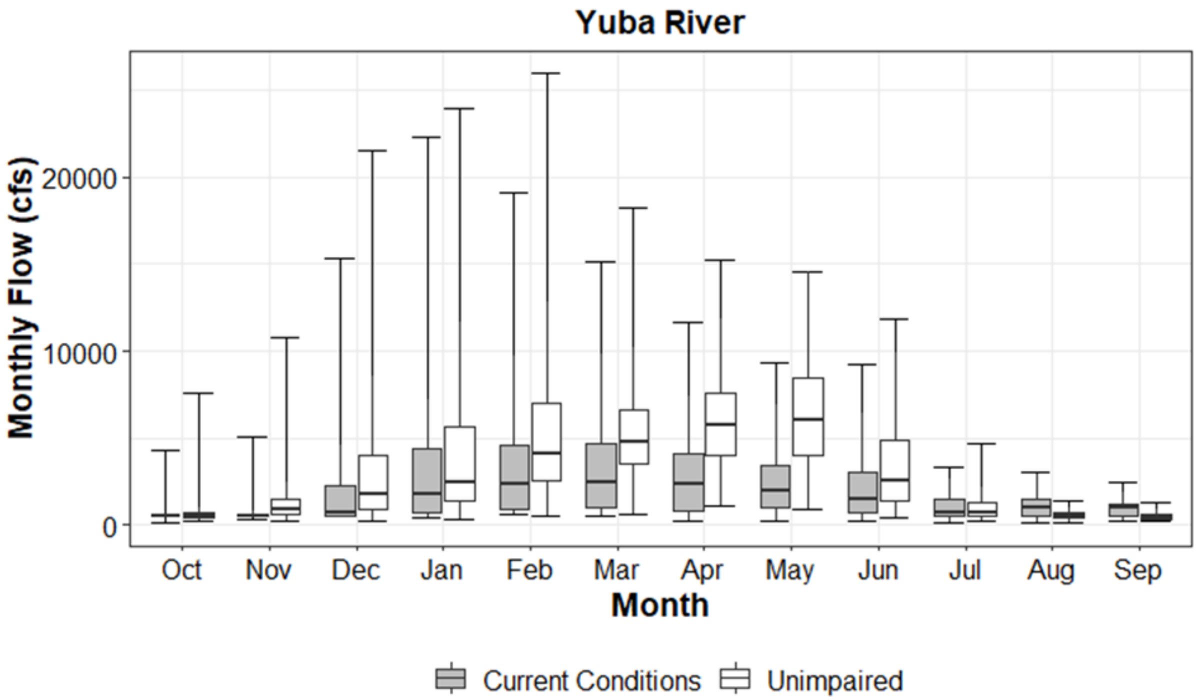
As part of the Yuba River Development Project, Yuba County Water Agency delivers water to its member units at Daguerre Point Dam, located at RM 11. Water is diverted to irrigate lands both north and south of the river. Additionally, Browns Valley Irrigation District diverts water at its pumping plant approximately 2 miles upstream at RM 13.

Dry Creek joins the Yuba River from the north, approximately 2 miles upstream from Daguerre Point Dam. Flows in Dry Creek are regulated by Browns Valley Irrigation District's operation of Merle Collins Reservoir and Virginia Ranch Dam. The district supplements Yuba River water with diversions below Merle Collins Reservoir.

New Bullards Bar Reservoir on the North Fork is by far the largest reservoir in the Yuba River watershed, with storage capacity of about 960 TAF. While reservoirs on the Middle Fork are smaller, Middle Fork water can be transferred to either the North Fork via Yuba County Water Agency's Our House Diversion Dam or Log Cabin Diversion Dam, or to the South Fork via Nevada Irrigation District's Milton Reservoir. Similarly, reservoirs on South Fork Yuba River are relatively small, but South Fork water can be transferred to the Bear River at Lake Spaulding. As a result, winter and spring flows on the lower Yuba River may be dominated by unregulated South Fork flow downstream of Lake Spaulding; Middle Fork flow that could not be transferred to the other forks; or flow from Deer and Dry Creeks, which are tributaries to the lower Yuba River. However, North Fork flows may dominate flows in the lower Yuba River when flood releases are made from New Bullards Bar Reservoir.

Englebright Dam blocks fish passage on the Yuba River; the major impacts on fisheries are primarily due to the loss of spawning habitat above Englebright Dam and the other dams. There have been a number of operations agreements to maintain flow and water temperature below Englebright Dam and provide spawning habitat restoration actions in the lower Yuba River (Pasternack 2009; NID 2011; USACE 2013, 2014). Plans for fish passage above Englebright Reservoir and New Bullards Bar Reservoir are being discussed as part of the BiOp for continued operation of Englebright Reservoir and Daguerre Point Dam and the multiple FERC projects going through relicensing in the Yuba River watershed (DWR 2016c).

Groundwater interactions are complex along the lower Yuba River as they respond to droughts, seasonal groundwater pumping, and movement of stream water into and out of the large deposits of hydraulic mining sediment (Entrix 2003). However, despite those complexities, flow in the lower Yuba River is dominated by the operations of New Bullards Bar Reservoir and diversions at Daguerre Point Dam. Reservoir storage and diversions on the Yuba River have greatly reduced flows on the lower Yuba River during spring months, reduced winter peak flows, and reduced the variability in monthly flows (cfs = cubic feet per second Figure 2.2-17). The January–June Yuba River impaired flow as a percentage of unimpaired flow ranges from 28 to 71 percent and is less than 50 percent in half of the years. Flows in all months, except September, also are significantly reduced in some years but generally are reduced in the wet season and increased in the dry season (Table 2.2-12).



cfs = cubic feet per second

Figure 2.2-17. Yuba River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

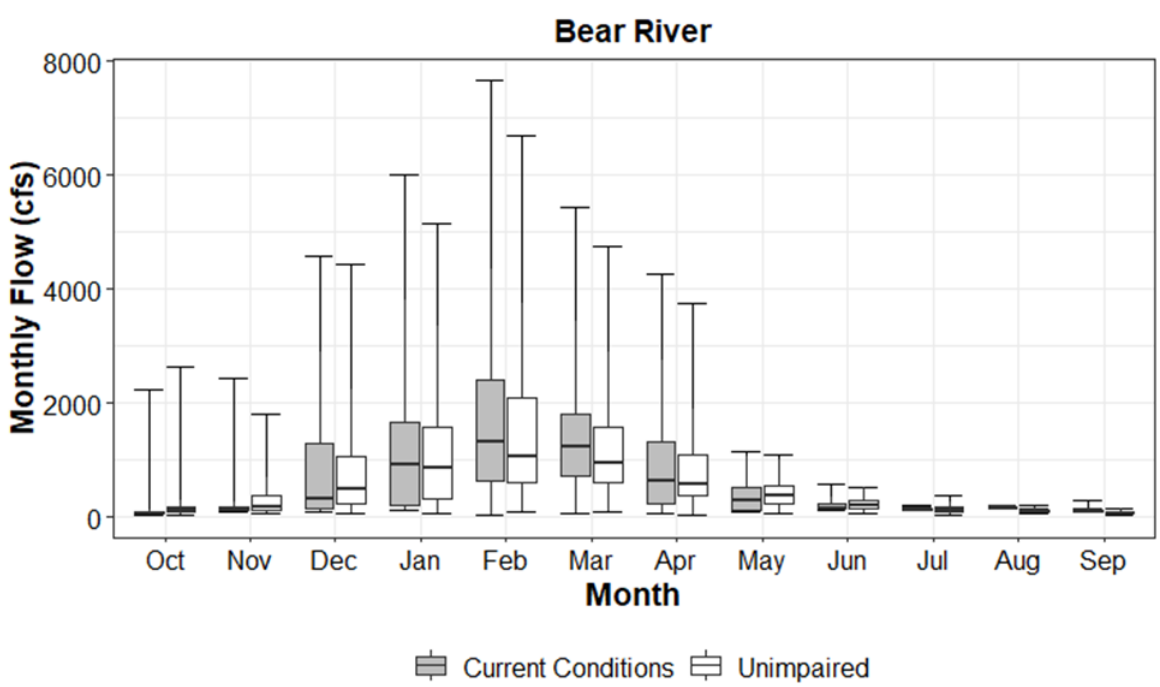
Table 2.2-12. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Yuba River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	32	20	17	18	23	24	14	16	17	32	51	65	28	43	37
10%	58	36	36	39	37	27	20	22	35	80	120	120	34	69	44
20%	68	44	42	52	44	34	22	29	47	90	134	144	38	74	47
30%	76	47	52	59	50	38	26	32	55	95	144	162	41	80	51
40%	83	53	55	67	54	42	32	36	59	101	158	182	45	86	53
50%	93	65	62	73	58	52	38	38	63	107	197	196	50	92	56
60%	99	75	67	85	63	56	44	40	66	115	212	211	55	94	61
70%	106	84	71	89	69	75	49	45	68	121	227	229	60	102	66
80%	118	98	76	98	85	83	53	49	74	131	240	237	65	113	70
90%	140	117	87	110	96	88	62	55	81	145	277	256	71	125	73
100%	228	211	209	170	142	107	76	71	119	229	411	332	80	153	77

2.2.6.3 Bear River

The Bear River has a watershed of 292 square miles and runs from an elevation of 5,500 feet in the Sierra Nevada to its confluence with the Feather River. The Bear River can be divided into an upper section above Rollins Reservoir, a middle section above Camp Far West Reservoir, and a lower section in the Sacramento Valley from Camp Far West Reservoir to the Feather River confluence (James 1989).

The hydrology of the Bear River has been extensively altered through a complex series of power diversion and storage dams, exports and imports of water to and from adjacent watersheds, and the filling and subsequent incision of the hydraulic mining sediment in the channel (SWRCB 1955; James 1989; NID 2008, 2010, 2011; ^NMFS 2014b). The Bear River watershed receives imported water from the Yuba River and North Fork American River through PG&E's Drum-Spaulding Project and Nevada Irrigation District's Yuba-Bear Hydroelectric Project. The Bear River watershed upstream of Camp Far West Reservoir also includes storage and diversion facilities owned and operated by Nevada Irrigation District, Placer County Water Agency (PCWA), and PG&E. Water is released from Camp Far West Reservoir for power generation, irrigation, and to meet downstream flow requirements. South Sutter Water District operates a diversion dam at RM 17, approximately 1 mile downstream from Camp Far West Dam, to irrigate lands served by Camp Far West Irrigation District and South Sutter Water District. Low minimum flow releases from Camp Far West Reservoir during most of the year are the largest impact on anadromous fish in the river (^NMFS 2014b). Because of imported water from the Yuba watershed, current flows are greater than 110 percent of the unimpaired conditions in half of the years from January through June (cfs = cubic feet per second Figure 2.2-18, Table 2.2-13).



cfs = cubic feet per second

Figure 2.2-18. Bear River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-13. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Bear River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	23	28	32	35	24	25	28	29	45	39	81	50	38	51	59
10%	37	39	46	55	56	81	45	47	61	60	108	76	71	70	82
20%	42	50	53	66	79	92	58	58	66	65	120	95	85	79	87
30%	49	59	66	75	97	101	76	68	72	82	134	108	94	88	96
40%	55	68	70	94	114	107	91	77	83	91	144	125	101	94	101
50%	61	74	82	107	121	115	101	83	93	102	160	135	110	101	105
60%	70	83	103	116	125	120	114	90	98	111	172	151	114	105	109
70%	75	99	116	122	131	126	121	95	103	128	187	176	119	109	114
80%	83	121	127	128	140	136	132	104	115	150	220	207	122	115	117
90%	100	145	165	148	155	151	147	108	134	174	256	263	124	128	121
100%	180	388	198	196	214	264	267	200	250	303	293	485	164	160	134

2.2.6.4 American River

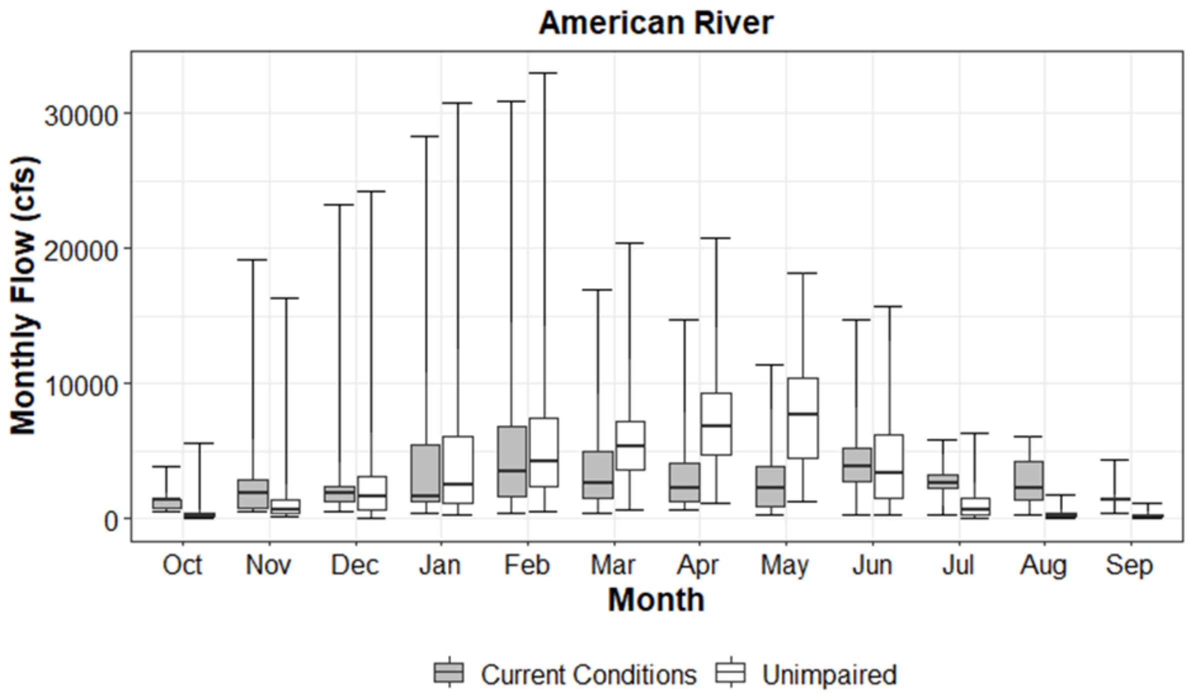
The American River has a watershed of 1,900 square miles that ranges in elevation from 23 to more than 10,000 feet (^USFWS 1995). In the lower foothills, the river branches into the North, Middle, and South Forks. Additionally, the South and Middle Forks have significant tributaries, including Silver Creek and the Rubicon River, respectively (PCWA 2007; FERC 2008; NID 2008). The American River watershed is very responsive to rain-on-snow events. A significant area of the watershed is located at moderate elevations, where storms are most likely to produce intense precipitation (Dettinger 2005). During the January 1997 rain-on-snow event, instantaneous inflow to Folsom Reservoir reached 253,000 cfs (NOAA 2016).

There are a large number of diversions in the watershed, 13 major reservoirs, and imports of water, as well as transfers between the three forks (^USFWS 1995; PCWA 2007; FERC 2008; NID 2008, 2011). There are several hydropower projects in the American River watershed. Some projects in the upper watershed include portions of PG&E's Drum-Spaulding Project PCWA's Middle Fork American Project, Sacramento Municipal Utility District's (SMUD) Upper American River Project, and El Dorado Irrigation District's South Fork American River Project. Diversions for water supply in the upper watershed include those from Pilot Creek to Georgetown Public Utilities District, PCWA's diversion at the Auburn Dam site, and El Dorado Irrigation District's diversion from the El Dorado Canal. (^SacWAM 2023.) Hydropower reservoirs, diversions, and inter-basin transfers upstream of Folsom Reservoir reduce the inflow to Folsom Reservoir during spring and increase the inflow during summer. Two transfers of water provide imports to the American River watershed: one via the South Canal from the Bear River, which transfers about 100 TAF/yr on average; and one from Sly Park Creek, a tributary of the Cosumnes River, of approximately 11 TAF/yr. There are two main diversions above Folsom Reservoir to PCWA and El Dorado Irrigation District.

There are no significant agricultural diversions from Folsom Reservoir and the lower American River. There are, however, four municipalities that divert water from Folsom Reservoir (City of Roseville, San Juan Water District, City of Folsom, and El Dorado Irrigation District). Additionally, Aerojet, Folsom State Prison, and California Department of Parks and Recreation receive water from Folsom Reservoir. As part of the CVP, water is diverted from Lake Natoma into the Folsom South Canal. The canal delivers water to Golden State Water Company and SMUD's Rancho Seco Power Plant. In the past, the CVP has delivered water to agricultural districts in the Cosumnes River watershed. On the lower American River, there are diversions to Carmichael Water District and the City of Sacramento.

Folsom Reservoir is operated for flood control, urban uses within the basin, Delta salinity control, and agricultural uses south of the Delta. How each of these uses control releases can be complex; however, flows on the lower American River are lower in spring and higher in summer when compared to unimpaired conditions (cfs = cubic feet per second Figure 2.2-19). Table 2.2-14 shows that current conditions are less than 50 percent of unimpaired flow at the mouth of the American River nearly 70 percent of the time in April and 80 percent of the time in May. January through June flows range from 32 to 88 percent of unimpaired flows.

Groundwater interactions north of the current channel are dominated by groundwater pumping in the Mehrten and Laguna Formations (DWR 1974), and the lower American River is now considered to be a losing reach (DWR 2013a). In SacWAM under current conditions, the lower American River is assumed to lose about -43 TAF/yr on average.



cfs = cubic feet per second

Figure 2.2-19. American River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-14. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in American River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	68	24	17	18	16	16	15	11	38	91	145	193	32	87	55
10%	167	73	37	34	53	29	19	19	82	124	527	405	45	144	73
20%	229	115	90	65	65	41	22	22	85	141	600	448	52	169	83
30%	266	151	98	77	77	45	27	25	87	157	711	544	54	193	86
40%	329	184	101	85	91	53	33	29	89	239	797	703	56	209	87
50%	374	233	106	91	94	59	38	32	92	308	888	829	59	242	89
60%	404	307	116	94	98	65	44	35	97	420	963	951	62	318	91
70%	438	390	187	98	100	69	49	39	122	515	1159	1046	69	373	92
80%	558	465	275	138	102	75	55	50	145	657	1414	1263	73	447	95
90%	725	603	376	177	106	81	60	56	207	1065	AZ	AZ	76	548	98
100%	AZ	1213	640	1391	161	96	148	110	444	AZ	AZ	AZ	88	809	148

"AZ" indicates that the unimpaired flow is approaching zero and is very low.

2.2.7 Delta Eastside Tributaries

The Delta eastside tributaries drain directly to the eastern side of the Delta. Three rivers with very different hydrological responses comprise this grouping: the Mokelumne, Calaveras, and Cosumnes Rivers. The Mokelumne and Calaveras Rivers are within the San Joaquin fluvial fan system and join the San Joaquin River north of Vernalis, which marks the southernmost boundary of the Legal Delta on the San Joaquin River. The Cosumnes River occupies a small geological and hydrological gap between that system and the northern Sierra Nevada tributaries. Because the Delta eastside tributaries drain into the Delta, they are part of the Sacramento/Delta and therefore are covered in this Staff Report.

2.2.7.1 Mokelumne River

The Mokelumne River watershed is 660 square miles and extends from 10,400 feet in the Sierra Nevada to sea level at its confluence with the San Joaquin River in the Delta (RMC 2006, 2007). The watershed is generally divided into an upper section with three large forks, a middle section with Pardee and Camanche Reservoirs and no significant tributaries, and a lower section that connects to the San Joaquin River and receives inflow from the Cosumnes River and Dry Creek. The hydrology of the Mokelumne River is dominated by the flows of the North Fork into Pardee and releases from Camanche Reservoir into the lower Mokelumne River.

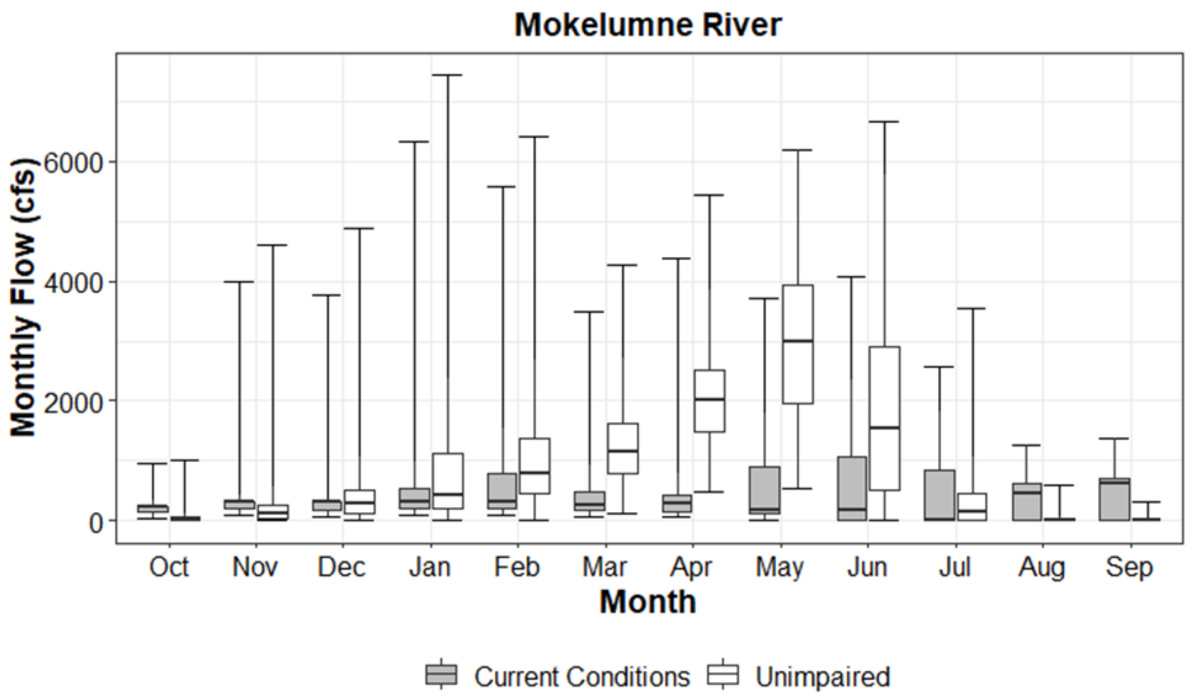
The North Fork Mokelumne River, with a watershed of 370 square miles, is the largest tributary and produces 85 percent of the river's flow (RMC 2006). Because of the high elevation of its catchment, much of the North Fork's flow originates from melting snowpack which, while reduced and truncated by power-generating dams (Ahearn et al. 2005), sustains high flows into Pardee and Camanche Reservoirs through July in wet years and through May in dry years (Piper et al. 1939; RMC 2006, 2007). PG&E operates the Mokelumne River Project (FERC Project No. 137) in the North Fork Mokelumne River watershed. The Middle and South Forks of the Mokelumne River remain largely undeveloped.

Pardee and Camanche Reservoirs, located on the mainstem Mokelumne River, are operated by East Bay Municipal Utility District (EBMUD) with the purposes of flood control, urban uses, and hydropower generation. EBMUD diverts an average of approximately 200 TAF/yr from Pardee Reservoir to its service area in the Bay Area through the Mokelumne Aqueduct.

Below Camanche Reservoir, the lower Mokelumne River winds through a pattern of incised channels. Water right holders on the lower Mokelumne River below Camanche Dam include North San Joaquin Water Conservation District, Woodbridge Irrigation District, and comparatively smaller riparian and appropriative water right holders. There are many diversions on the Mokelumne River for agricultural uses, the largest being at Woodbridge Diversion Dam.

Current simulated flow conditions on the Mokelumne River above the confluence with the Cosumnes River are much lower for all months except the late summer and fall when compared with the unimpaired simulation (cfs = cubic feet per second Figure 2.2-20). The unimpaired flow approaches or reaches zero frequently in late summer through early fall, indicating that dry season base flows are naturally low in the Mokelumne River (cfs = cubic feet per second Figure 2.2-20, Table 2.2-15). Reservoir operations and diversions on the Mokelumne River have reduced the simulated current flows to below 23 percent of the unimpaired January through June flows in 50 percent of the years.

The FERC license modification process for the lower Mokelumne River identified negative fishery effects from insufficient flow, insufficient habitat, migration barriers, and predatory fish. In 1996, EBMUD, USFWS, and CDFW entered into a Joint Settlement Agreement. Under the Joint Settlement Agreement, EBMUD assumed responsibility for a range of streamflow, reservoir cold water pool, habitat restoration, and predator control responsibilities (EBMUD et al. 1996).



cfs = cubic feet per second

Figure 2.2-20. Mokelumne River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-15. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Mokelumne River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	85	13	12	6	9	3	4	0	0	0	0	33	7	25	16
10%	226	68	45	35	25	15	6	0	0	0	0	1,181	14	107	23
20%	406	91	60	45	34	20	8	6	0	1	107	AZ	17	128	28
30%	683	108	70	64	45	24	10	6	1	3	544	AZ	19	156	32
40%	1206	177	88	77	56	28	12	7	8	80	1,216	AZ	20	175	35
50%	AZ	241	102	88	63	33	14	8	18	149	AZ	AZ	23	209	41
60%	AZ	357	133	98	71	37	16	10	34	183	AZ	AZ	27	278	48
70%	AZ	488	168	110	82	44	20	20	40	228	AZ	AZ	37	305	59
80%	AZ	685	278	147	89	56	30	33	45	330	AZ	AZ	46	386	64
90%	AZ	1,101	504	256	113	66	51	51	49	AZ	AZ	AZ	56	750	69
100%	AZ	AZ	AZ	AZ	AZ	165	80	75	AZ	AZ	AZ	AZ	74	AZ	83

"AZ" indicates that the unimpaired flow is approaching zero and is very low.

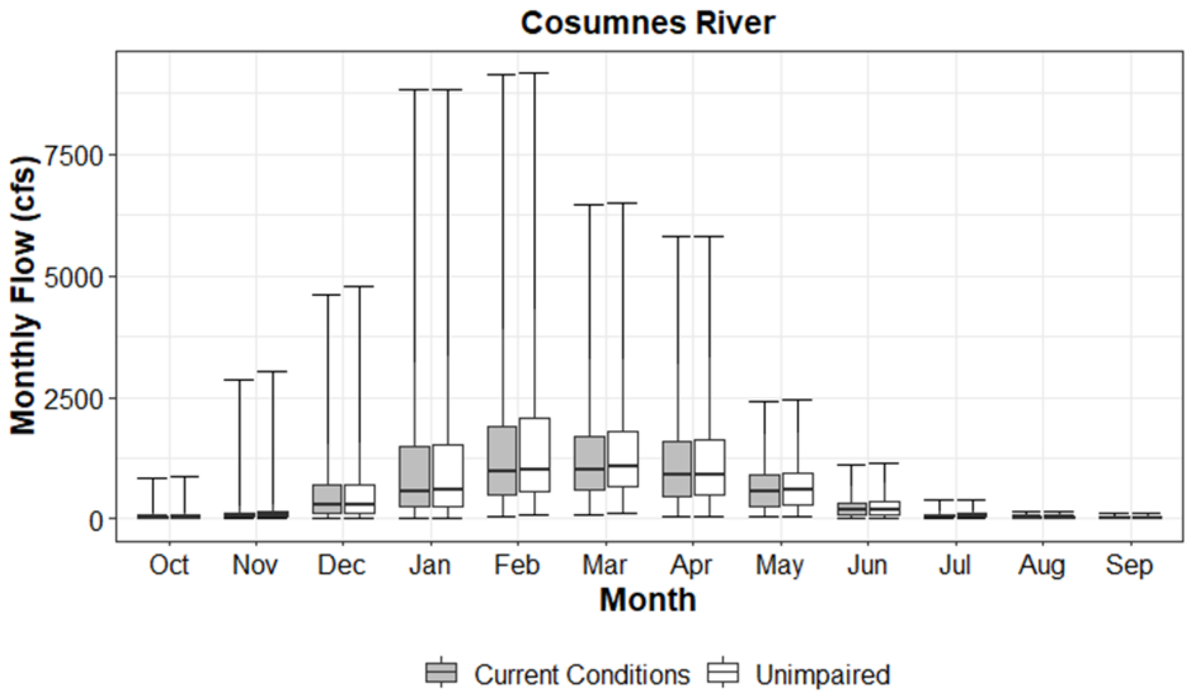
2.2.7.2 Cosumnes River

The Cosumnes River watershed is 940 square miles that extends from an elevation of 7,500 feet in the Sierra Nevada to a few feet above sea level at its confluence near the mouth of the Mokelumne River (Robertson-Bryan 2006a). There are three main tributaries to the Cosumnes River—the North, Middle, and South Forks—that all converge in the foothills immediately above the Central Valley.

The watershed of the Cosumnes River is unique among those of the Sierra Nevada as there are no major dams on its mainstem and only one significant dam (Sly Park [41 TAF]; 5 percent of average total flow that is exported to the American River watershed) on an upstream tributary; therefore, it retains a relatively natural hydrograph for wet season flows (Mount et al. 2001; Robertson-Bryan 2006a) (cfs = cubic feet per second Figure 2.2-21). Diverters in the Cosumnes River watershed include El Dorado Irrigation District, which diverts water primarily for irrigation, and Rancho Murieta Community Services District, which diverts water primarily for municipal uses. Additional diversions, including diversions for domestic and stock watering uses, also occur in the Cosumnes River watershed. In contrast to the Mokelumne River, while the headwaters of the Cosumnes River receives similar mean annual precipitation, the elevation of the headwaters is lower (between 5,000 and 7,000 feet). Any precipitation that falls as snow in the Cosumnes River watershed generally melts during the wet season and does not produce high flows during late spring and summer (DWR 1974; Booth et al. 2006; Ahearn et al. 2004, 2005; Epke 2011). Rain-on-snow events can occur, and the largest recorded maximum flow was 93,000 cfs in January 1997 (USGS 1999). Other than some minor diversions on the lower Cosumnes River and operations of Jenkinson Lake by El Dorado Irrigation District, the current conditions are very similar to the unimpaired conditions shown in cfs = cubic feet per second Figure 2.2-21 and Table 2.2-16.

Historically, groundwater discharge maintained several large perennial ponds in the lowest reach on the valley floor (USGS 1908, 1910; Shlemon et al. 2000). More recently, groundwater approaches the surface in this same area but does not discharge into the channel (Mount et al. 2001; Fleckenstein et al. 2006; Meirovitz 2010). Previous groundwater modeling studies have shown uncertainty in stream-aquifer interactions on the lower Cosumnes River, which range from losing up to 85 TAF/yr (Mount et al. 2001) to 2 TAF/yr (Brush et al. 2013). SacWAM results, based on the model of Brush et al. (2013), show very little stream–aquifer interaction on the lower Cosumnes River under current conditions.

The upper limit of anadromy on the Cosumnes River is Latrobe Falls, located in the foothills just above the valley floor (Moyle et al. 2003). Lowered local and regional water tables causing intermittent flows in the valley floor reach, in combination with loss of tidal marsh spawning and rearing habitat, have affected fisheries. In 2005, a fisheries enhancement study determined the feasibility and water cost of enhancing natural fall flows in the valley floor reach by pre-wetting the streambed (Robertson-Bryan 2006b). The study began in October 2005; a wetting front was established and reached tide water by the end of November 2005 at a water cost of less than 1,000 acre-feet (AF). An intentional levee breach to restore floodplain habitat along a portion of the channel immediately above tide water was successful for some native fish species (Crain et al. 2004).



cfs = cubic feet per second

Figure 2.2-21. Cosumnes River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-16. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Cosumnes River

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	23	68	79	78	83	85	82	86	80	84	78	65	88	85	88
10%	72	80	88	89	89	88	87	87	87	91	88	84	90	91	91
20%	83	83	91	91	91	90	88	88	88	92	91	90	92	93	92
30%	88	85	92	92	91	92	93	90	89	93	96	95	93	93	93
40%	90	88	94	94	92	93	96	93	90	94	100	99	94	94	94
50%	92	89	94	95	94	96	97	95	91	96	105	103	94	95	95
60%	94	90	95	95	96	99	98	96	92	98	110	106	96	96	96
70%	97	91	96	97	98	99	98	96	94	101	115	111	97	96	97
80%	98	92	97	98	99	100	99	97	96	104	119	118	98	98	97
90%	105	94	98	100	100	100	99	98	100	113	136	130	99	100	98
100%	124	111	101	102	100	100	100	99	125	147	174	219	99	104	99

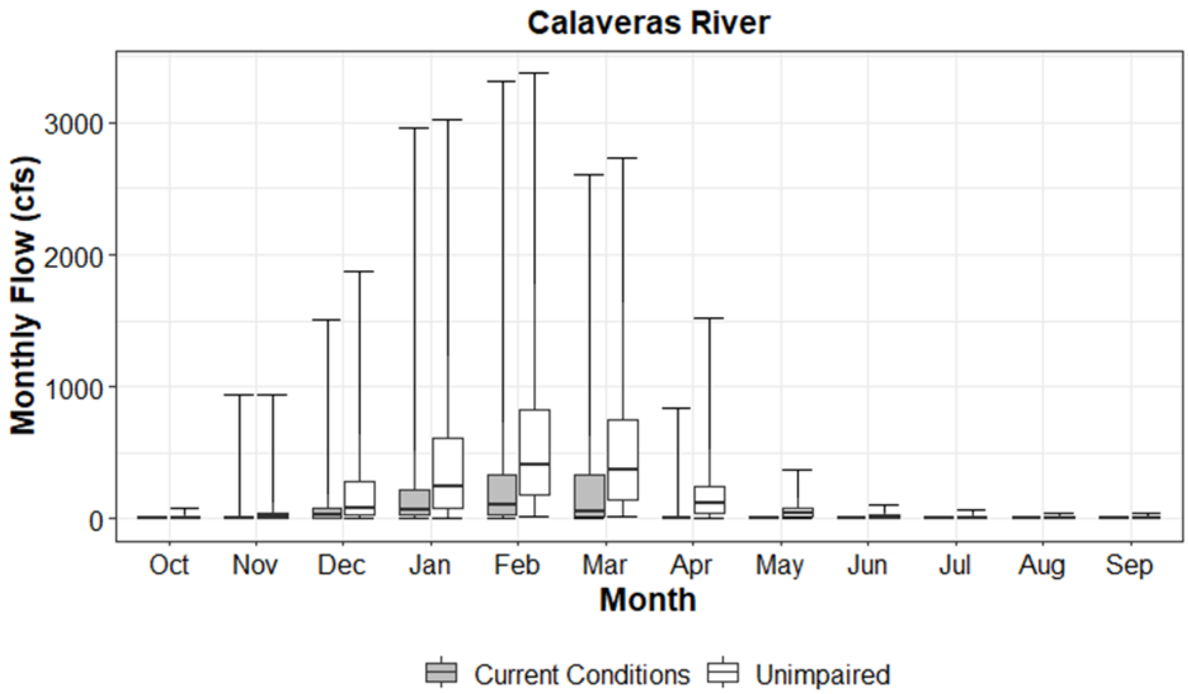
2.2.7.3 Calaveras River

The watershed of the Calaveras River extends from elevations of up to 6,000 feet to sea level, is 470 square miles, and produces an average runoff of 157 TAF at the New Hogan Reservoir. The hydrology of the watershed of the Calaveras River is considered entirely rain-fed, and inflow to New Hogan Reservoir drops to base levels in April (DWR 2007a) (cfs = cubic feet per second Figure 2.2-22).

New Hogan Reservoir has a capacity of approximately twice the mean annual runoff of the watershed, and spills tend to occur only in wet years to maintain storage capacity for flood control. Water from New Hogan Reservoir is used for irrigation and municipal purposes with the water right permit held by Reclamation. In 1970, Stockton East Water District (SEWD) and the Calaveras County Water District contracted with Reclamation for the project's entire water supply. In 1978, SEWD began to divert water at Bellota Weir, downstream of New Hogan Reservoir, further altering hydrologic patterns in the lower Calaveras River system. (DWR 2007a.) SEWD and the Calaveras County Water District are the largest diverters in the watershed. The Calaveras River provides water for agricultural and municipal uses in San Joaquin and Calaveras Counties (^NMFS 2014b). At Bellota Weir, the Calaveras River splits into two channels on the alluvial fan, with the primary channel (Mormon Slough) to the south and Old Calaveras River to the north. Outside of the April to October irrigation season, Mormon Slough and the Old Calaveras River downstream of the headworks may have little to no flow due to reduced releases from the reservoir and diversion into the SEWD municipal diversion at Bellota Weir (DWR 2007a).

Except for infrequent flood spills, the Calaveras River often dries up before it connects to the San Joaquin River, as shown by zeros in Table 2.2-17 and in cfs = cubic feet per second Figure 2.2-22. In the unimpaired simulation, river flows peak in January or February and become very low between April and October of most years (cfs = cubic feet per second Figure 2.2-22). In January through June, the current conditions for the Calaveras River are less than 25 percent of the unimpaired conditions in half of the years.

Moreover, the large number of migration barriers in the lower watershed, lack of attraction flows, rapid dewatering in the Old Calaveras River and Mormon Slough channels, and lack of connecting flow from the San Joaquin River to the reach between the Bellota Weir and the New Hogan Dam affect fisheries (DWR 2007a).



cfs = cubic feet per second

Figure 2.2-22. Calaveras River Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-17. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Calaveras River

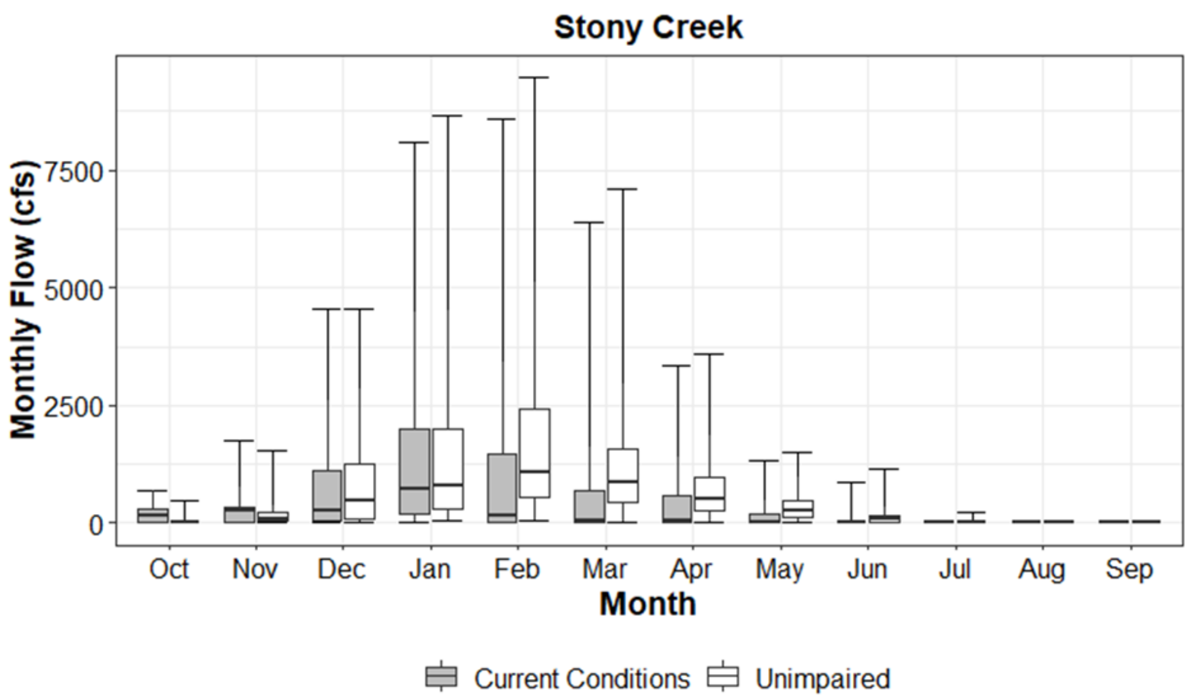
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan-Jun	Jul-Dec	Annual Total
0%	0	0	0	0	0	0	0	0	0	0	0	0	9	0	7
10%	0	0	0	19	9	0	0	0	0	0	0	0	13	3	13
20%	0	1	12	22	16	5	0	0	1	0	0	0	16	6	16
30%	1	1	18	25	18	9	0	0	1	1	0	1	19	11	19
40%	1	2	21	29	23	14	0	0	1	1	0	2	21	14	21
50%	2	3	25	35	25	17	0	0	2	2	1	5	25	18	26
60%	3	8	28	39	29	24	1	1	2	3	2	9	32	21	32
70%	5	13	35	45	42	36	1	1	3	5	3	18	52	27	51
80%	8	19	48	61	70	69	2	1	9	11	6	39	61	36	60
90%	35	52	71	80	86	89	7	3	45	28	41	71	76	56	74
100%	AZ	AZ	177	116	107	101	56	109	131	65	89	139	84	380	85

“AZ” indicates that the unimpaired flow is approaching zero and is very low.

2.2.8 Tributaries of the Northern Coast Range, Northern

2.2.8.1 Stony Creek

Stony Creek has a watershed of 741 square miles with a mean annual flow of about 425 TAF/yr. It has three reservoirs operated for flood control and agricultural irrigation. Reclamation operates two reservoirs: East Park Reservoir (51 TAF) and Stony Gorge Reservoir (48 TAF) as part of the Orland Project. The main elements of the project include East Park Dam, Stony Gorge Dam, Rainbow Diversion Dam and East Park Feeder Canal, South Diversion Intake and South Canal, and Northside Diversion Dam and North Canal. Black Butte Dam, constructed by USACE, is an authorized facility of the CVP. The CVP and the Orland Project are separate projects with separate water rights (^SacWAM 2023). Black Butte Reservoir (160 TAF) is the lowest reservoir and is managed November through March for flood control and April through October for irrigation. Prior to construction of Black Butte Dam, daily flood flows exceeded 30,000 cfs about every 5 years, with maximum flows of more than 80,000 cfs (H. T. Harvey and Associates 2007). Orland Project operations have greatly reduced flows and variability on Stony Creek (cfs = cubic feet per second Figure 2.2-23). For example, during March, current conditions flows are less than 50 percent of unimpaired flows in half of the modeled years (Table 2.2-18).



cfs = cubic feet per second

Figure 2.2-23. Stony Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-18. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Stony Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan-Jun	Jul-Dec	Annual Total
0%	0	7	12	14	0	0	0	0	0	0	0	0	3	14	5
10%	171	43	27	45	4	0	0	0	0	1	1	1	11	31	22
20%	1,119	95	55	69	5	0	0	0	0	1	647	1	17	75	44
30%	AZ	112	71	78	7	0	0	0	0	1	AZ	1	29	101	52
40%	AZ	138	77	84	13	0	1	1	1	5	AZ	2	41	108	63
50%	AZ	196	85	94	19	8	16	3	1	27	AZ	3	50	116	70
60%	AZ	310	91	97	42	25	45	20	2	AZ	AZ	3	59	131	75
70%	AZ	379	95	99	56	41	61	41	3	AZ	AZ	7	65	180	77
80%	AZ	496	97	99	69	58	74	64	14	AZ	AZ	52	74	280	82
90%	AZ	595	99	99	77	69	85	73	AZ	AZ	AZ	AZ	78	425	85
100%	AZ	AZ	110	100	91	90	AZ	AZ	AZ	AZ	AZ	AZ	89	736	114

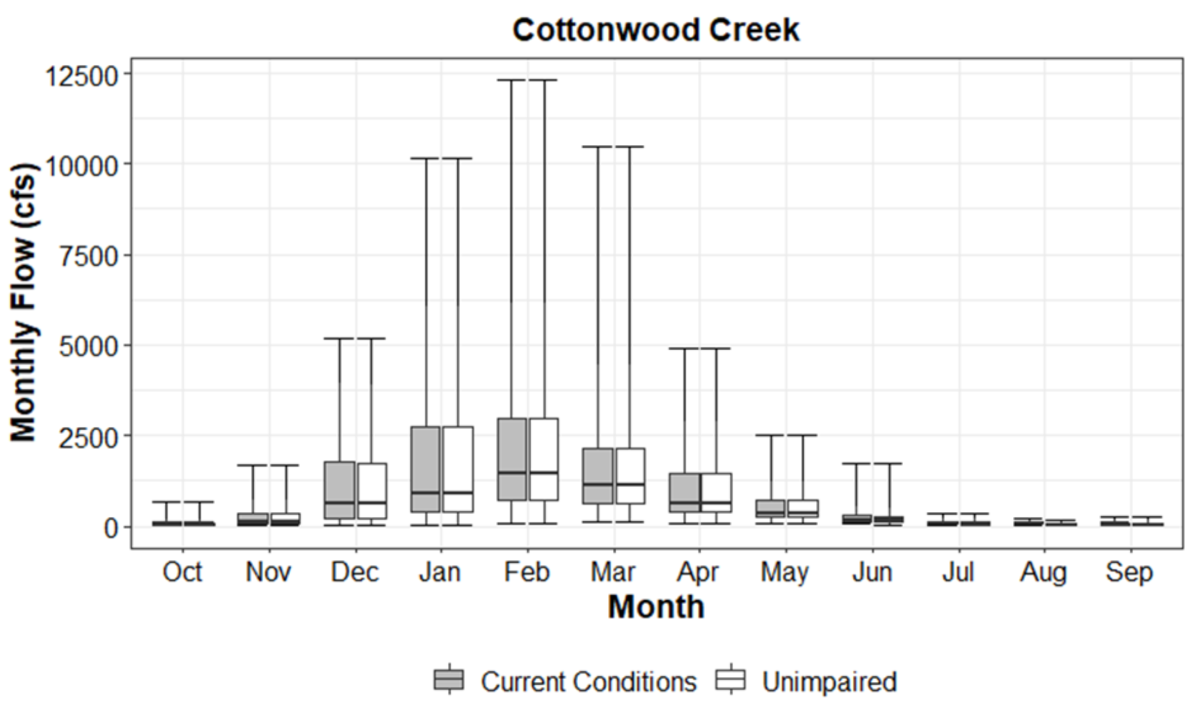
“AZ” indicates that the unimpaired flow is approaching zero and is very low.

2.2.8.2 Cottonwood Creek

Cottonwood Creek has a watershed of 927 square miles, with three forks whose headwaters are in the Northern Coast Range (8,000 feet) and the southernmost peaks of the Klamath Range (CH2M Hill 2002; Graham Matthews and Associates 2003). The hydrology of the watershed is extremely variable, with a peak recorded flow of 86,000 cfs and annual flow volumes that range from 68,000 AF to 2 MAF (CH2M Hill 2002; Graham Matthews and Associates 2003). Cottonwood Creek, like all of the larger creeks with headwaters in the Northern Coast Range, produces large amounts of gravel, sand, and sediment during floods.

Late-fall flows are low and variable but generally are around 60 cfs. Cottonwood Creek is unique in that 18 miles of its lowest section run within a 1-mile-wide, alluvium-filled trench to its confluence with the Sacramento River. There is one small 4,800-AF reservoir, Rainbow Lake, on the North Fork; otherwise, Cottonwood Creek is unregulated. Therefore, current conditions and unimpaired simulations are very similar (cfs = cubic feet per second Figure 2.2-24).

Results from SacWAM show that Cottonwood Creek loses 9 TAF/yr on average to groundwater under current conditions; however, previous studies showed that historically it was a gaining reach under dry conditions (Blodgett et al. 1992). The Anderson-Cottonwood Irrigation District imports approximately 18,000 AF of Sacramento River water to the watershed for irrigation that through losses and return flows contributes significantly to summer base flows (Blodgett et al. 1992) (Table 2.2-19). Because water demand is relatively low, current conditions are similar to unimpaired flow conditions during most months and under most hydrology.



cfs = cubic feet per second

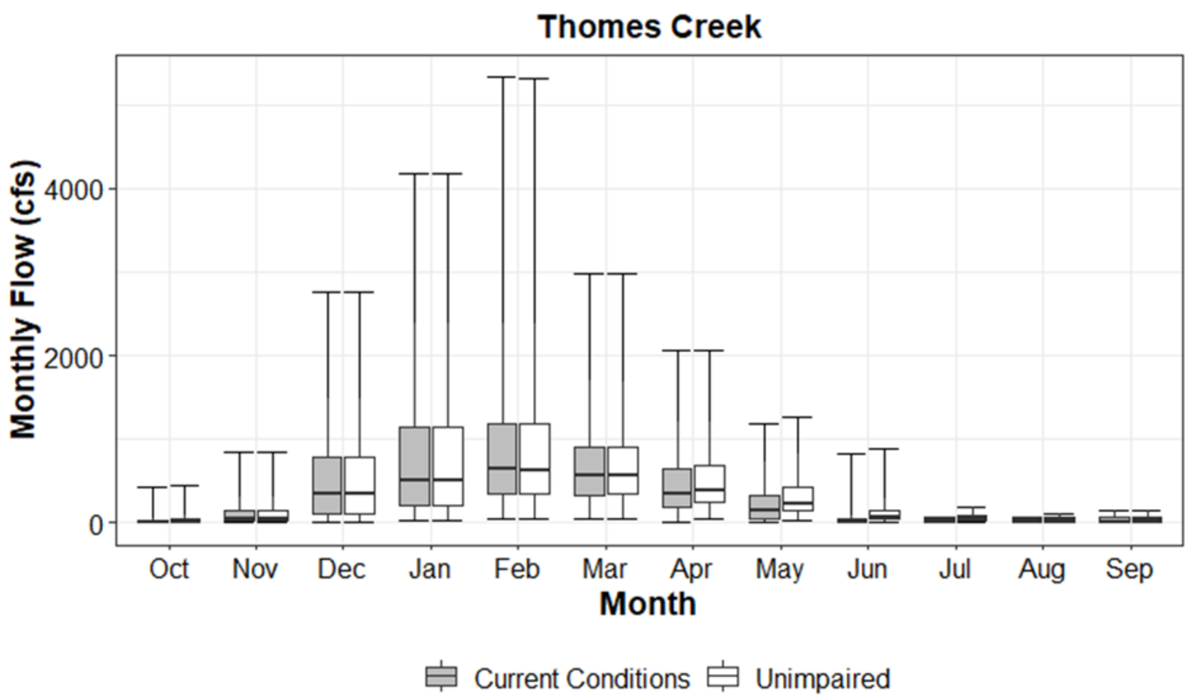
Figure 2.2-24. Cottonwood Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-19. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Cottonwood Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	83	100	100	100	100	98	82	88	100	103	102	100	100	101	100
10%	99	100	100	100	100	100	97	100	102	105	120	103	100	102	100
20%	100	100	100	100	100	100	98	101	103	108	129	109	100	102	101
30%	101	100	100	100	100	100	99	101	103	110	131	116	100	103	101
40%	102	100	100	100	100	100	100	101	104	120	144	120	100	104	101
50%	104	100	100	100	100	100	100	102	105	129	156	128	100	106	101
60%	105	100	101	100	100	100	100	102	106	135	166	137	100	108	102
70%	109	101	101	100	100	100	100	103	107	152	178	161	101	111	102
80%	115	101	101	101	100	100	100	103	109	169	205	184	101	114	102
90%	125	102	102	101	101	100	100	105	111	194	229	213	101	123	104
100%	245	107	104	103	101	106	103	109	250	513	426	387	106	142	115

2.2.8.3 Thomes Creek

Thomes Creek has a watershed area of 301 square miles that drains from the Inner Northern Coast Range at an elevation of 6,600 feet (VESTRA Resources 2006; Tehama County Flood Control and Water Conservation District 2012). Thomes Creek has an extremely variable hydrology, with a maximum daily recorded flow of 37,800 cfs and very low late-summer flows of approximately 6 cfs that can fall to zero in dry years. Thomes Creek, like all of the larger creeks with headwaters in the Northern Coast Range, produces large amounts of gravel, sand, and sediment during floods. After leaving the foothills, it flows 25 miles through a narrow alluvial valley cut into relatively impermeable Tehama and Red Bluff Formations to the Sacramento River (Tehama County Flood Control and Water Conservation District 2012). There are no significant dams on the watershed and only a few relatively small surface diversions. The current conditions simulation shows very similar hydrology when compared with the unimpaired flows in winter months (cfs = cubic feet per second Figure 2.2-25, Table 2.2-20). Diversions during summer months reduce flows compared with unimpaired conditions. About 88 percent of the water used in the region is obtained from groundwater for irrigated agriculture (VESTRA Resources 2006).



cfs = cubic feet per second

Figure 2.2-25. Thomes Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-20. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Thomes Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	11	32	81	98	77	60	6	7	6	24	39	35	66	66	67
10%	32	90	99	100	100	86	65	20	8	38	64	68	82	80	85
20%	40	96	100	100	100	93	75	30	10	47	81	83	87	86	89
30%	50	97	100	100	100	96	82	40	12	58	84	89	90	90	91
40%	55	98	101	100	100	97	85	51	14	61	87	91	92	93	93
50%	57	99	101	101	100	100	91	63	18	65	90	92	93	95	94
60%	62	100	101	101	101	100	94	75	25	70	91	94	94	96	95
70%	68	100	101	101	101	100	96	77	30	73	93	95	95	97	95
80%	75	101	102	102	101	100	97	86	47	77	96	98	96	98	96
90%	91	102	103	102	101	100	100	89	59	84	100	104	97	99	97
100%	136	103	105	106	103	101	100	96	91	104	108	107	99	100	98

2.2.8.4 Elder Creek

Elder Creek has a watershed area of 151 square miles that drains from the Inner Northern Coast Range at a peak elevation of 5,500 feet (VESTRA Resources 2006; Tehama County Flood Control and Water Conservation District 2012). Elder Creek has an extremely variable hydrology, with a maximum daily recorded flow of 17,700 cfs and very low late-summer base flows that frequently fall to zero. After leaving the foothills, its channel flows 20 miles through a narrow alluvial valley cut into relatively impermeable Tehama and Red Bluff Formations to the Sacramento River (Tehama County Flood Control and Water Conservation District 2012). There are no significant dams on the watershed and only a few small surface diversions. Because SacWAM does not include any diversions from Elder Creek, the current simulated conditions are equal to the unimpaired results. Therefore, a box plot and cumulative distribution table are not presented.

2.2.9 Tributaries of the Northern Coast Range, Southern

2.2.9.1 Cache Creek

Cache Creek has a watershed area of 1,139 square miles, including 1,044 square miles in the southern portion of the Interior Coast Range (Yolo County 2006; WRAYC 2007). Cache Creek has a north fork and a south fork. The South Fork headwaters flow from elevations of 4,000 feet and accumulate in Clear Lake, a large, shallow, natural lake, before flowing through a narrow canyon to the Sacramento Valley. The volume of the lake and the small natural outlet from Clear Lake significantly reduce the magnitude of peak flows into the canyon downstream (WRAYC 2007). The North Fork headwaters are at slightly lower elevations but also run through a narrow canyon. The river canyon opens into the Capay Valley immediately above the Sacramento Valley. Cache Creek, like all of the larger creeks with headwaters in the Northern Coast Range, produces large amounts of gravel, sand, and sediment during floods.

In its natural state, the lower reach of Cache Creek flowed as a wide braided stream from the mouth of Capay Valley to the Yolo basin, where its waters mixed with waters from overflow from the Sacramento River, Willow Slough, and Putah Creek and the combined flow drained southward to the confluence of the Yolo basin with the Sacramento River (WRAYC 2007). Historically, when flows exceeded approximately 20,000 cfs at the mouth of the Capay Valley, the excess flow would overtop the low natural levees and flood the Hungry Hollow basin to the north and the much larger Cache-Putah basins to the south. Because of these overflows to flood basins, there are no records of flows exceeding 20,000 cfs in Cache Creek prior to its regulation by dams (WRAYC 2007), but peak flows likely exceeded 80,000 cfs. Overbank flood basin flows in the Cache-Putah basin merged with overbank flood flows from Putah Creek and flowed through Willow Slough into the Yolo basin. The Sacramento Valley section of Cache Creek has been extensively modified by instream gravel mining, flood levees at its lower end with designed capacities of 36,800 cfs, and a sediment settling basin immediately adjacent to the Yolo basin.

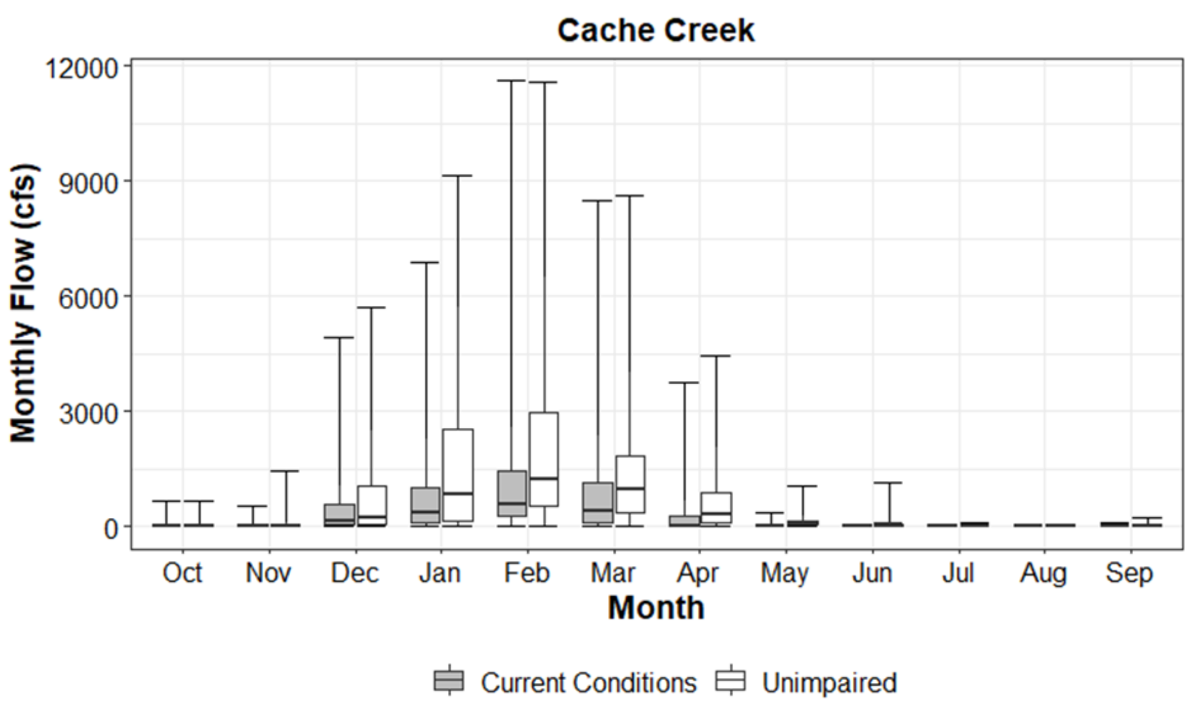
There are three significant dams on Cache Creek: the Clear Lake Impoundment Dam, Indian Valley Reservoir, and Capay Diversion Dam. The Clear Lake Impoundment Dam is located immediately below the outlet from Clear Lake and regulates outflows from Clear Lake but does not significantly affect lake carryover capacity. Clear Lake loses nearly 200 TAF/yr on average to evaporation under current conditions as estimated in SacWAM (^SacWAM 2023). Both irrigation releases and flood releases are regulated under the Solano and Bemmerly decrees. Indian Valley Reservoir on the

North Fork has a capacity of 301 TAF and is used for irrigation storage and flood control. The Capay Diversion Dam at the mouth of Capay Valley is a 15-foot-high structure that can be raised an additional 5 feet with an inflatable bladder. The diverted water supports agriculture in the basins on either side of Cache Creek.

Cache Creek has been severely impaired by upstream diversions and storage; under current conditions, streamflows tend to be much lower than unimpaired flows, especially in spring (cfs = cubic feet per second Figure 2.2-26, Table 2.2-21). In about 10 percent of the years, January through June current conditions are more than 80 percent unimpaired flows; but in half of the years, the current conditions are less than 53 percent of unimpaired flows during the January through June period.

Downstream of Capay Dam, Cache Creek loses surface water to the ground until Dunnigan Hills, where it is briefly a gaining reach before becoming a losing reach again all the way to the Yolo basin (Yolo County 2006). Current condition simulations estimate an average 1 TAF/yr of streamflow is lost to groundwater from Cache Creek (^SacWAM 2023).

Clear Lake is the dominant feature within the Cache Creek watershed. Releases from the lake for agricultural water supply are supplemented by releases from Indian Valley Reservoir located on North Fork Cache Creek. Irrigated agriculture is the primary demand for water in the watershed, although there are a large number of domestic and stock watering diversions.



cfs = cubic feet per second

Figure 2.2-26. Cache Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-21. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Cache Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	11	21	13	12	12	2	5	6	3	14	22	9	17	22	20
10%	59	52	33	27	23	18	9	15	36	36	57	44	28	37	36
20%	70	68	44	36	32	26	13	23	49	47	81	66	33	49	39
30%	85	81	53	45	38	30	17	28	57	59	88	82	39	57	42
40%	93	89	69	53	48	42	21	35	68	73	98	93	44	74	48
50%	95	100	78	64	64	57	29	41	83	89	110	105	53	79	54
60%	104	112	91	76	74	75	41	47	90	98	125	116	59	86	60
70%	111	120	99	83	84	82	49	55	95	111	141	132	66	96	63
80%	121	154	105	89	89	87	67	64	101	120	154	142	73	104	70
90%	128	170	113	105	100	95	85	87	111	132	162	159	80	112	77
100%	208	572	143	268	134	120	104	118	140	157	189	232	114	131	115

2.2.9.2 Putah Creek

Putah Creek has a watershed area of 710 square miles, with 600 square miles occurring in the southern portion of the Interior Coast Range (WRAYC 2007). The headwaters of the Putah Creek watershed are at elevations of about 4,800 in the Mayacamas Mountains, and its various tributaries flow through a series of small valleys and narrow canyons to Monticello Dam, located west of the town of Winters.

Putah Creek, like all of the larger creeks with headwaters in the Northern Coast Range, produces large amounts of gravel, sand, and sediment during floods; but all are trapped behind Monticello Dam. At the mouth of its last canyon, Putah Creek flows over its large alluvial fan as it enters the Sacramento Valley. Historically, from the lower edge of the alluvial fan, Putah Creek flowed between low natural levees with occasional breaches leading to intermittent sloughs that drained either northward into the Cache-Putah basin or southward across the Putah Plains. The main channel flowed through what is now the city of Davis and emptied into a section of the Yolo basin known as the Putah Sink. where its waters mixed with waters from overflow from the Sacramento River, Willow Slough, and Cache Creek, and the combined flow drained southward to the confluence of the Yolo basin with the Sacramento River (EDAW 2005; WRAYC 2007). Flood control modifications to the channels near the city of Davis isolated the main channel to the Yolo basin and forced Putah Creek to flow through a bypass channel with constructed levees from the city of Davis to the Yolo basin.

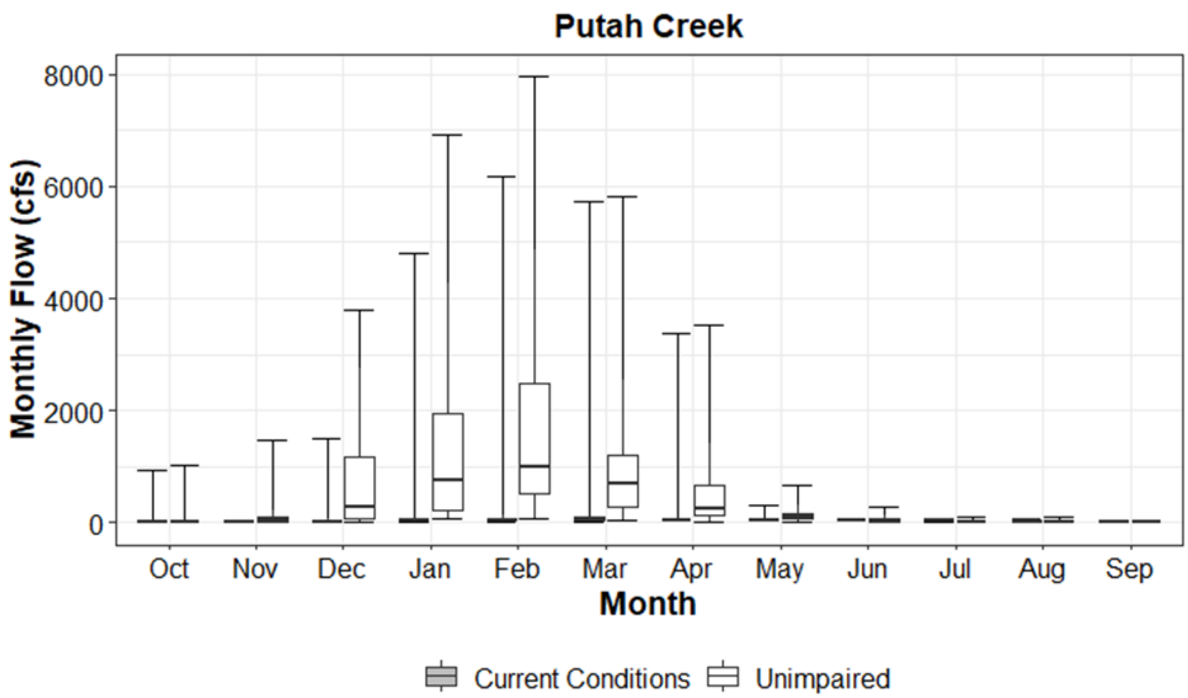
The Solano Project was constructed by Reclamation to provide irrigation water to approximately 96,000 acres of land in Solano County. The project also furnishes municipal and irrigation water to the major cities of Solano County. Project facilities include Lake Berryessa and Monticello Dam, Putah Diversion Dam, Putah South Canal and canal distribution system, and a small terminal reservoir (Solano County WA 2011).

Monticello Dam forms Lake Berryessa, located in the upper end of the last canyon before the Sacramento Valley, with a capacity of 1.6 MAF. The maximum recorded flood prior to the dam was 81,000 cfs and predicted 100-year flood events post-dam are 32,000 cfs (WRAYC 2007). The Putah Creek Diversion Dam, 29 feet high, is located at the end of the canyon and diverts water south into Solano County via Putah South Canal (Redmond 2000). The 2000 Putah Creek Accord identifies minimum instream flows for lower Putah Creek below Putah Diversion Dam. The minimum flow requirements below the dam under the water right license have been supplemented with flows designed to maintain salmonids in the lower section of Putah Creek under the Putah Creek Accord (EDAW 2005).

Simulated current conditions below Putah Diversion Dam are much lower than the unimpaired flows throughout the spring, with variability of flow conditions greatly reduced (cfs = cubic feet per second Figure 2.2-27). Putah Creek goes dry under unimpaired conditions from July through October in about 30 percent of the years (Table 2.2-22). In more than half of the years, current conditions are less than 14 percent of unimpaired flows from January through June.

Groundwater pumping for agriculture and municipal uses has lowered the regional groundwater table, but historically Putah Creek was a losing stream from the top of its alluvial fan to the Yolo Bypass except for the short reach that crosses the Plainfield Ridge (Bryan 1923; Thomasson et al. 1960). Current stream losses to groundwater average 11 TAF/yr (^SacWAM 2023). Small numbers of anadromous fish have returned to Putah Creek in response to the flow releases of the Putah Creek

Accord and extensive restoration efforts (EDAW 2005). In 2015, 500 fall-run Chinook salmon spawned in lower Putah Creek (Shaw 2015).



cfs = cubic feet per second

Figure 2.2-27. Putah Creek Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.2-22. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Putah Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	28	1	2	1	1	2	2	8	16	32	29	32	3	5	4
10%	49	5	2	2	2	4	6	14	37	81	211	109	4	7	6
20%	100	11	3	3	3	6	10	20	47	129	362	200	7	10	9
30%	200	22	4	4	3	8	16	27	70	224	622	316	8	14	11
40%	325	30	7	5	4	10	22	34	88	432	1028	532	10	21	13
50%	478	46	9	6	5	18	26	39	103	635	AZ	681	13	35	15
60%	AZ	80	13	11	6	28	32	48	146	1109	AZ	AZ	14	47	18
70%	AZ	118	30	15	9	36	46	67	246	AZ	AZ	AZ	20	68	25
80%	AZ	166	57	23	21	59	66	103	362	AZ	AZ	AZ	33	136	33
90%	AZ	290	80	37	77	88	89	129	762	AZ	AZ	AZ	59	201	54
100%	AZ	AZ	614	87	98	109	337	AZ	AZ	AZ	AZ	AZ	89	AZ	75

"AZ" indicates that the unimpaired flow is approaching zero and is very low.

2.3 Flood Basins

Land development over the past century in the Sacramento Valley was made possible by "reclaiming the inland sea" through a complex system of dams and reservoirs, levees, weirs, bypasses, and other flood control features constructed piecemeal over the last more than 100 years that protect urban and rural areas from flooding (^DWR 2017b) (Figure 2.3-1). Beginning just above Stony Creek near Hamilton City and continuing to Rio Vista in the Delta, the Sacramento River runs between natural banks and artificial levees that can be relieved during high flows by diversion of floodwaters into a series of flood basins adjacent to the river channel that are critical elements of the flood control system (Bryan 1923; Olmsted and Davis 1961; DWR 1994, 2010a, 2010b; ^Whipple et al. 2012). These six flood basins, in order from upper to lower, are Butte, Colusa, Sutter, Yolo, American, and Sacramento.

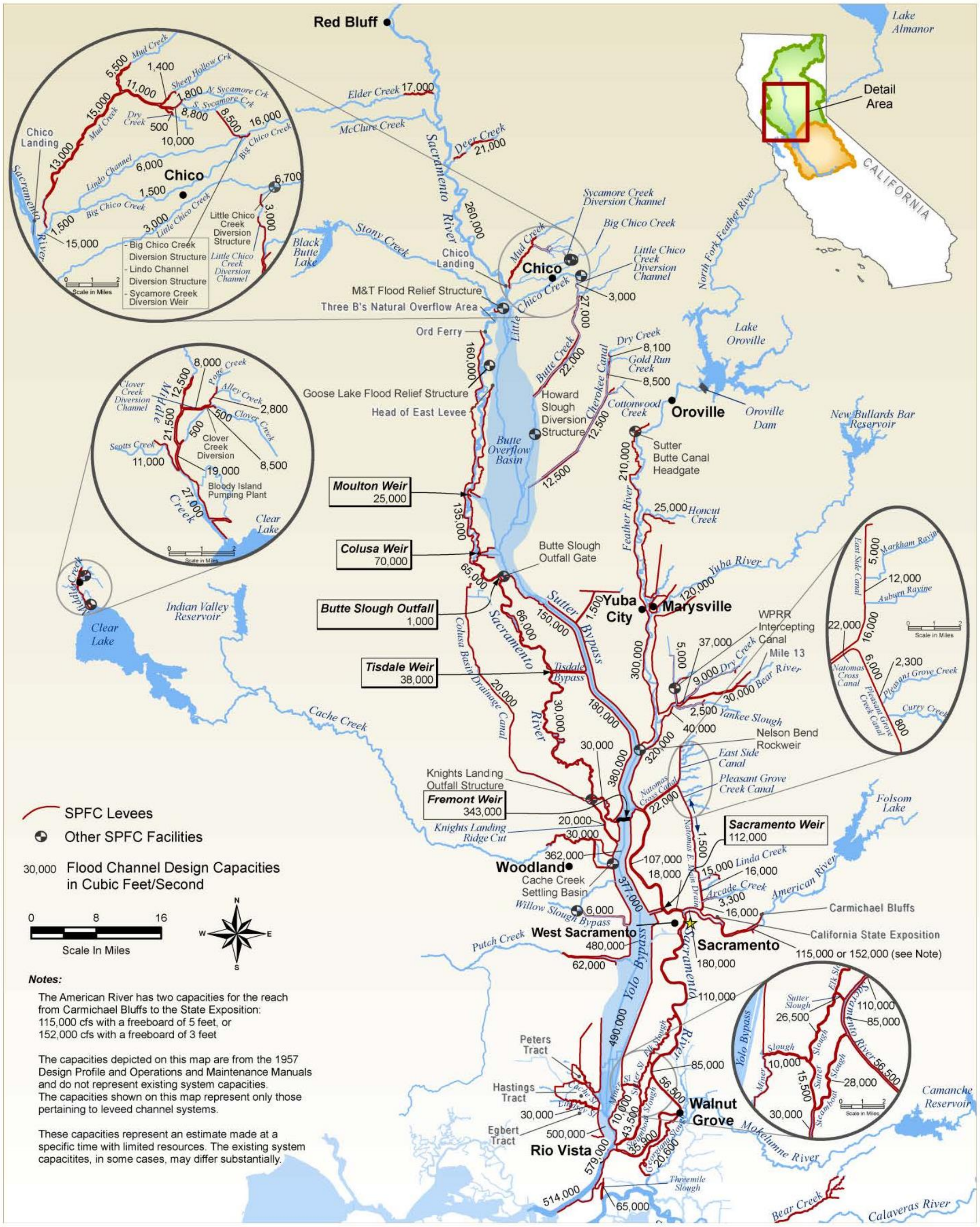
Because the flow of the Sacramento River is highly variable and can range from approximately 3,000 cfs in summer during droughts to 500,000 cfs during floods, the flood basins function both as short-term storage reservoirs and as safety valves that can channel the majority of Sacramento River flows away from the mainstem during floods. Additionally, the lower halves of the Yolo and Sacramento basins are tidal and experience two high and two low tides each day, with greater and then lesser tidal ranges over the 14-day spring/neap tidal cycle. At their upstream ends, the levees along the Sacramento River are broad and low, 3 to 5 miles apart and cut by active meandering channels. Each cut was relatively permanent and discharged channel water into the Butte and Colusa flood basins at flows significantly below flood stage. The frequency of the levee cuts decreased downstream near the town of Colusa.

Functionally, flood basins differ from floodplains because they drain more slowly and may contain areas of permanent open water. The upper flood basins of the Sacramento River have greater slopes than the lower and tend to drain more rapidly. The flood waters transport sediment to the basins and small clay-size particles of sediment remain suspended longer while the coarser sediment remains in or adjacent to the Sacramento River. The relatively slow-moving water of the basins traps the slowly sinking clay particles and causes the bottoms and sides of the basins to be lined with clay soils. Percolation of flood basin water to groundwater is blocked by those extensive impermeable clay soils.

The precise boundaries of the transitions from flood basins upward onto the lower floodplains of the tributaries are difficult to determine as the change in elevation is gradual and the depth and duration of flood waters highly variable. However, the consistently longer inundation of the deeper sections of the flood basins produces vegetation and habitat types that are distinct from those of the floodplains.

The natural hydrology of the basins has been extensively altered. A flood control system of levees and weirs along the Sacramento River adjacent to the flood basins and bypass floodways runs through the Sutter and Yolo basins (DWR 2010a, 2010b, 2012). The State Plan of Flood Control (SPFC) denotes those state- and federally authorized projects in this complex system for which the Central Valley Flood Protection Board or DWR has provided assurances of cooperation to the federal government; the plan includes facilities, lands, programs, conditions, and modes of operation and maintenance, including for many of the levees and weirs. However, not all flood protection facilities in the Sacramento Valley are part of the state-federal system (DWR 2010a).

All the basins are extensively modified by reclamation actions and are farmed with irrigation-intensive crops such as rice, alfalfa, row crops, and orchards. Additionally, each basin has areas permanently set aside as habitat for waterfowl with nearby agricultural lands providing incidental habitat during the cropping season and managed habitat during fall and winter (Garone 2011).



Source: DWR 2017b.
SPFC = State Plan of Flood Control

Figure 2.3-1**. Flood Control Facilities in the Sacramento River, Sutter and Yolo Bypasses, and Major Tributaries in the Sacramento River Basin**

2.3.1 Butte Flood Basin

The Butte flood basin combines attributes of both a flood basin and a floodplain; Holmes and Nelson (1916) describe the area as a semibasin, and Olmsted and Davis (1961) uniquely describe it as the Butte Creek Lowland. Olmsted and Davis (1961) note that its slope of 2 feet per mile is greater than any of the other flood basins, and Bryan (1923) describes it as a vast sheet of slowly moving water when in flood stage. The transit time of flood waters through the Butte basin is 2 days (DWR 2012).

Flood flows from the upper two-thirds of the basin merge and drain into the wide upper end of the Butte Sink area, which is the southernmost section and remaining one-quarter of the basin. The combined flows enter Butte Sink at the 60-foot elevation contour near the Moulton Weir (Bryan 1923), converge southward, and wrap around the west side of the Sutter Buttes. Butte Sink is bounded to the west by the 30-foot-high levee of the Sacramento River, which forces Butte Creek to the southeast, and is bounded to the east by the Sutter Buttes. The naturally incised channel of Butte Creek, while sometimes immersed deeply by basin and sink flood flows, persists as a defined channel that discharges into Butte Slough, which drains into the Sutter basin (USGS 1913; Bryan 1923; Carpenter et al. 1926; Olmsted and Davis 1961; DWR 2012).

The vegetation of the Butte basin outside of the Butte Sink was rapidly converted to extensive agriculture when California became a state and, as late as 1912, agriculture within the Butte basin was primarily grazing and areas of dry-farmed grain (Strahorn et al. 1911). Commercial rice production began on 1,400 acres in the same area in 1912 (Robertson 1917; Adams 1920; Dunshee 1928) and expanded to almost 95,000 acres by 1920 (California Department of Public Works 1923). To irrigate the rapidly growing acreage of rice fields, water was diverted from the Feather River and run down existing sloughs and transferred to lateral canals to irrigate rice fields west and northwest of Biggs and Gridley, as well as the area of eastern Colusa County that lies within the Butte basin; and rice field drainage water was released into natural channels running to the Butte Sink (USGS 1912; State Water Commission 1917; Carpenter et al. 1926).

Butte basin is unique among the basins because flood waters are not specifically directed within the basin through engineered structures, such as bypasses, drains, or systems of levees (Garone 2011; DWR 2012). When the Butte basin is full, it holds approximately 1 MAF of water, which enters the basin from the Sacramento River through six locations (DWR 2010a, 2010b, 2012). When flows in the Sacramento River exceed 30,000 cfs, flood waters flow over the Colusa Weir into the main section of the Butte Sink, which has a designed capacity of 70,000 cfs (DWR 2010a, 2012). When flows in the Sacramento River exceed 60,000 cfs, flood waters flow into the upper end of the Butte Sink over the Moulton Weir, a SPFC facility maintained by DWR with a designed capacity of 25,000 cfs (DWR 2010a, 2012). When flows in the Sacramento River exceed 100,000 cfs, water can pass into the basin at its upper end through the M&T and Parrot Plug flow relief structures, the Three-Bs overflow area, and an emergency overflow roadway (DWR 2010a, 2012). The Butte Slough outfall gates, also part of the SPFC, are at the lower end of the Butte Sink and direct low flows within the basin and irrigation flows back into the Sacramento River but are otherwise closed.

2.3.2 Colusa Flood Basin

The Colusa flood basin is an irregular 50-mile-long trough lying between the coalesced, clay-soil alluvial fans of the small creeks flowing eastward from the Northern Coast Range and the western natural levee of the Sacramento River. Lengthwise, it extends from the border of Glenn and Colusa

Counties to the Knights Landing Ridge and consists of two functionally distinct subbasins located above and below the alluvial ridge of Upper Sycamore Slough (Bryan 1923; Olmsted and Davis 1961).

Historically, flood waters entered the Colusa basin at its upper end between the towns of Princeton and Glenn when flows in the Sacramento River exceeded summer base flows, along its entire western margin when creeks such as Willow Creek flowed eastward out of the Northern Coast Range, and through levee breaks immediately above and below the town of Colusa (California Department of Engineering 1914; McComish and Lambert 1918; DWR 1964; ^Kelley 1989). Flood water in the upper subbasin drains relatively rapidly through a generally smooth and slightly concave trough, while flows through the lower subbasin historically drained through the defined channel of lower Sycamore Slough but backed up at the Knights Landing Ridge. Historically, in the lower subbasin, several permanent breaches in the natural levee of the Sacramento River, upper Sycamore Slough being the largest, discharged flood flows into the Colusa basin when the Sacramento River was at flood stage (Mann et al. 1911; State Water Commission 1917; Bryan 1923). As noted in the Butte basin discussion, at the highest Sacramento Valley flood flows, the combined Butte basin flows consisting of the local streams, the sloughs draining the cuts in the Sacramento River levee, and the Feather River flood water pouring into the Butte basin sometimes overtopped the Sacramento River levees and forced flood waters westward into the Colusa basin (California Department of Engineering 1914).

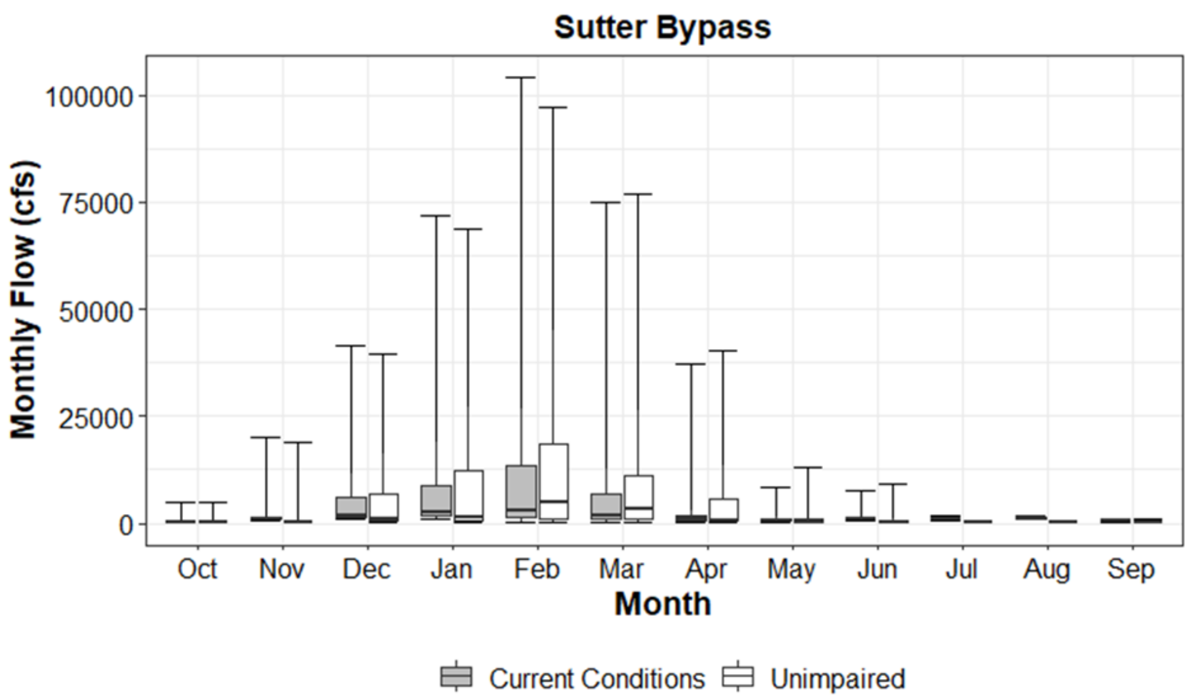
Rice farming began in the Colusa basin 2 years later than in the Butte basin. Commercial rice production of 147 acres began in the Colusa basin in 1914 (McComish and Lambert 1918) and rapidly expanded to 170,000 acres by 1920 (California Department of Public Works 1923).

Flood protection in the Colusa basin is designed to prevent flooding by the Sacramento River, to reduce winter and spring flooding from the creeks flowing eastward from the Northern Coast Range, and to provide drainage for large amounts of summer and fall rice irrigation water (State Water Commission 1917; DWR 1964). A levee system was constructed along the Sacramento River from the Stony Creek alluvial fan to the Knights Landing Ridge Cut that prevents flooding of the Colusa basin by the Sacramento River (DWR 1964, 2010a, 2012). Along the west side of the basin, a back levee with an upslope drain constructed in the borrow pit of the levee conveys winter flows from the Northern Coast Range tributaries and summer flows from rice fields south through the basin, through the Knights Landing Ridge Cut, and into the Yolo basin (DWR 1964, 2010a). Before the Knight's Landing Ridge Cut was dredged, natural flows in Colusa basin drained back into the Sacramento River through the lower end of Sycamore Slough. However, because the Sacramento River was typically at a high stage during the spring, the water ponded above the Knights Landing Ridge could not drain, which caused prolonged flooding in the lower end of the lower subbasin (DWR 1964). The Colusa Drain and the Knights Landing Ridge Cut have a design capacity of 20,000 cfs (DWR 2010b, 2012). At low Sacramento River flows, the basin can drain into the Sacramento River through the Sycamore Slough outfall gates (DWR 2012).

2.3.3 Sutter Flood Basin

The Sutter basin runs 30 miles, generally north to south, from Butte Slough at the southern edge of the Sutter Buttes to Verona on the Sacramento River. It lies between the natural levees of the Sacramento River to the west and the natural levees of the Feather River to the east (Singer et al. 2008; Singer and Aalto 2009; DWR 2012). Today and historically, the majority of its flood waters originate from Butte Slough (Bryan 1923; Singer et al. 2008; Singer and Aalto 2009; DWR 2012; ^Kelley 1989). Historically, the Sutter basin also received flood waters through permanent breaks in the levee of the Sacramento River (e.g., the Cole Grove Point break, which is north of Kirkville), from overflows of the Feather River through permanent breaks in its levee (e.g., Gilsizer Slough), and from periodic overflow near the confluence of the Feather and Sacramento Rivers (Bryan 1923).

The conversion of the wetlands in the Sutter basin to agriculture was slower than the conversions in the Butte and Colusa basins because the Sutter basin was the main floodway of the Sacramento River. Early attempts to prevent flooding in the basin by the Park's Dam initiated what are known as the levee wars and eventually resulted in construction of a series of flood bypasses (^Kelley 1989; Singer et al. 2008; Singer and Aalto 2009). The Sutter Bypass was established to convey flood flows down the central portion of the basin (cfs = cubic feet per second Figure 2.3-2 and Table 2.3-1). The Sutter Bypass receives flows from Butte Slough (150,000 cfs), the Tisdale Weir (38,000 cfs), and the Feather River (300,000 cfs); the bypass has a designed flow of 416,500 cfs in the section that joins the Sacramento River (DWR 2010a, 2010b, 2012).



cfs = cubic feet per second

Figure 2.3-2. Sutter Bypass Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.3-1. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Sutter Bypass

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	34	38	42	34	23	15	10	11	68	170	222	124	36	58	56
10%	54	228	94	54	51	30	24	34	144	243	293	181	60	112	72
20%	59	328	104	79	65	50	39	69	161	274	321	204	74	125	88
30%	61	384	113	95	83	60	56	79	191	295	348	216	82	164	92
40%	63	444	176	103	99	80	77	92	218	306	374	223	86	232	96
50%	69	485	234	147	109	102	89	113	236	319	397	230	89	261	99
60%	80	527	273	206	129	115	102	121	267	345	409	239	92	284	109
70%	103	561	302	239	151	137	119	135	288	351	420	255	98	304	118
80%	114	588	391	281	188	148	124	143	299	362	428	277	141	318	161
90%	123	621	501	404	222	169	136	163	324	373	453	317	190	343	225
100%	152	728	603	678	355	187	161	231	1246	440	524	381	232	408	277

2.3.4 American Flood Basin

The American flood basin is a small basin that lies immediately east of the confluence of the Feather and Sacramento Rivers, is immediately north of the American River, and historically received the flows of the Feather River and the tributaries of the Sierra Nevada foothills (Bryan 1923; DWR 2012). The basin lies between the plains of the foothills and the levees of the bounding rivers (Olmsted and Davis 1961). Historically, the basin drained to the Sacramento River through a number of deep sloughs (Bryan 1923). Currently, the basin is drained by a network of creeks and canals that merge into the Natomas Cross Canal, which has a capacity of 22,000 cfs and which discharges into the Sacramento River (DWR 2010a, 2012). The tributaries of the American basin include, from north to south, Coon Creek, Auburn Ravine, and the Dry Creek system, including Secret and Miners Ravines. While Coon Creek and Auburn Ravine enter the Sacramento River via the Natomas Cross Canal, the Dry Creek system does so via the Natomas East Main Drainage Canal, which enters the Sacramento River via Bannon Slough.

2.3.5 Yolo Flood Basin

The Yolo Bypass is the last large floodplain with a direct connection to the Delta. The bypass is a 57,000-acre flood conveyance system created to divert Sacramento River water around the city of Sacramento during flood conditions. The Yolo basin is 40 miles long and runs north to south along the west bank of the Sacramento River from the Knights Landing Ridge to the town of Clarksburg, where it continues south immediately west of the river's secondary channel (Elk/Sutter/Steamboat Slough) to the confluence with Cache Slough (Bryan 1923; ^Whipple et al. 2012). The western edge of the basin transitions into the broad alluvial fans of Cache and Putah Creeks (Bryan 1923; Graymer et al. 2002; ^Whipple et al. 2012).

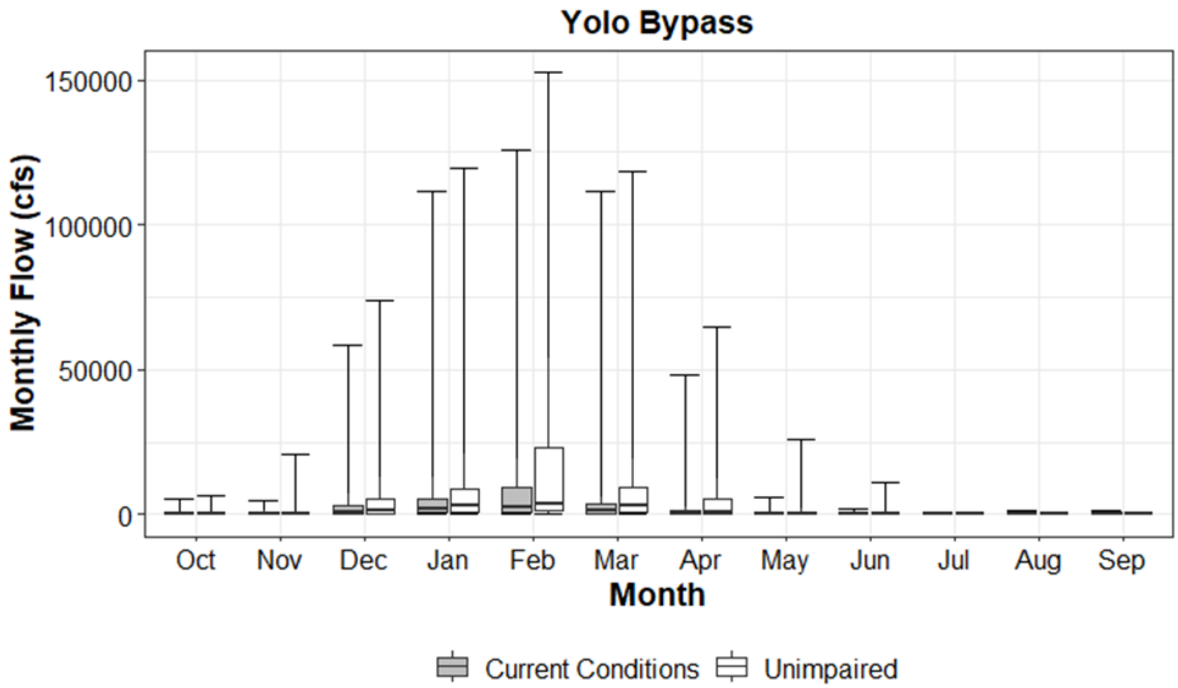
Historically, the Yolo basin filled when the combined flows of the Sacramento, Feather, and American Rivers overtopped the natural levee of the Sacramento River and when the Northern Coast Range streams, principally Cache and Putah Creeks, flooded (Bryan 1923; WRAYC 2005). The main upstream entry point for flood water into the current managed bypass is at Fremont Weir. The 343,000-cfs capacity weir is a passive cement structure that begins to spill into the bypass when Sacramento River flows at Verona exceed 55,000 cfs (^Sommer et al. 2001; DWR 2010a, 2010b, 2012). Overtopping events that lead to at least 2 weeks of downstream floodplain inundation occur in only about 40 percent of years (DWR 2012). Water also enters the Yolo Bypass from the Sacramento Weir and from Putah and Cache Creeks. The Sacramento Weir is another operable weir near the town of Sacramento that discharges into the Yolo Bypass, with a design capacity of 112,000 cfs (DWR 2010a, 2010b, 2012).

All these sources join the Toe Drain, a perennial channel on the east side of the bypass that discharges back to Cache Slough and the Delta several miles above Rio Vista. The Toe Drain begins to spill onto the floodplain when flows exceed 3,500 cfs at the Lisbon Weir (^Feyrer et al. 2006b). Some portion of the Yolo Bypass typically floods in about 60 percent of years, with peak inundation occurring between January and March (DWR 2012; ^Feyrer et al. 2006a; ^Sommer et al. 2001).

In contrast to the upstream basins, the Yolo basin is tidally influenced, and the higher high tide of spring tides extends to just above the sink of Putah Creek (Bryan 1923; Jones & Stokes 2001; ^Whipple et al. 2012).

As was the case with the Butte and Colusa basins, rice was the first crop grown on the clay soils of the Yolo basin's floor and sides; 14,210 acres were grown in the upper portion of the basin by 1920 (California Department of Public Works 1923). Rice was not grown in the lower section of the basin because of that section's cooler summer temperatures due to its proximity to the Delta's marine-influenced climate (Jones & Stokes 2001). As with the other basins, agricultural fields are not only used by wildlife during the cropping season, but they also often have a substantial role in supporting waterfowl in late fall and during the wet season (^CDFG 2008a). Additionally, both the upper and lower sections of the basin support spawning habitat for floodplain-adapted fish, such as Sacramento splittail, and provide valuable rearing habitat for Chinook salmon and steelhead (^Sommer et al. 2005; ^Feyrer et al. 2006a, 2006b; ^CDFG 2008a; Sommer et al. 2014).

Within the Yolo Bypass, a network of drainage canals conveys flows from the Northern Coast Range creeks, Delta waters, agricultural drainage, and irrigation water (Jones & Stokes 2001; NHC 2012). The primary north-to-south conduits along the Yolo Bypass are the Tule Canal/Toe Drain on the east side and the Conway Canal on the west side (Jones & Stokes 2001). The Lisbon Weir spans the Toe Drain approximately 8.5 miles south of the Sacramento Weir (Jones & Stokes 2001). The top of the weir is 2.5 feet above mean sea level, the tops of the banks of the Toe Drain are 8.5 feet above mean sea level, and the higher high tides during each spring tide cycle range to approximately 4.5 feet above mean sea level. The maximum design capacity of the upper end of the bypass is 377,000 cfs and is 490,000 cfs where it discharges into the Delta (DWR 2010a, 2010b). Under current conditions, outflow from the Yolo Bypass is lower than unimpaired simulations, especially during winter and spring months due to less frequent weir spills and less inflow from Cache and Putah Creeks (cfs = cubic feet per second Figure 2.3-3 and Table 2.3-2). Yolo Bypass outflows under simulated current conditions and unimpaired conditions have maximum monthly flows of over 100,000 cfs for January through March.



cfs = cubic feet per second

Figure 2.3-3. Yolo Bypass Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.3-2. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Yolo Bypass

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	14	7	24	18	11	6	4	2	15	15	17	19	11	25	17
10%	24	41	31	32	22	19	9	9	79	18	24	31	28	41	34
20%	31	65	38	36	28	29	15	21	99	23	31	65	38	52	44
30%	58	83	45	47	34	37	19	48	120	33	46	100	47	63	52
40%	85	107	56	52	51	45	35	66	144	41	65	157	58	77	62
50%	99	129	70	64	72	50	41	80	176	48	91	229	67	87	67
60%	141	190	76	73	84	57	56	95	188	61	123	268	71	98	73
70%	171	252	83	87	96	68	67	113	214	79	153	686	75	124	77
80%	186	315	111	93	103	76	76	131	346	97	215	927	79	167	81
90%	232	479	181	110	115	94	108	193	524	200	709	AZ	87	218	92
100%	706	1,381	1,071	344	406	200	259	576	884	699	AZ	AZ	114	352	163

"AZ" indicates that the unimpaired flow is approaching zero and is very low.

2.3.6 Sacramento Flood Basin

The Sacramento basin is approximately 20 miles long and extends from near the current southern border of the city of Sacramento to just beyond the southern end of Snodgrass Slough, near the north and south Delta forks of the Mokelumne River (^Whipple et al. 2012).

The SPFC levee runs along the east bank of the Sacramento River, which has a capacity of 56,500 cfs in this area (DWR 2010a). However, the basin discharges through the Mokelumne River into the San Joaquin River and not into the Sacramento River. A discontinuous series of levees direct flow through Sutter and Snodgrass Sloughs to the Mokelumne River and constrain flows within the Cosumnes and Mokelumne Rivers (DWR 2010a). These levees have been breached by large floods and have been intentionally breached to restore floodplain habitat (Swenson et al. 2003).

2.4 Sacramento-San Joaquin Delta

The Delta is the region where channels of the Sacramento and San Joaquin Rivers meet and mix with saline water from the Pacific Ocean. The *Legal Delta* is a geographic boundary of the region that encompasses 1,150 square miles roughly between the city of Sacramento to the north, Stockton to the east, Tracy to the south, and Pittsburg to the west. There are over 1,000 miles of levees lining hundreds of miles of Delta watercourses (DWR 2010a) (Figure 2.4-1). While not part of the Legal Delta, Suisun Marsh is an important ecological area closely associated with the Delta. It is the marshland located north of Suisun and Honker Bays, west of Pittsburg.

Historically, the Delta contained innumerable channels of various sizes, but only a few of the largest channels remain and many of those have been altered by meander cuts and dredging to make navigation more efficient (^Whipple et al. 2012). The largest sources of fresh water to the Delta are the Sacramento River and Yolo Bypass to the north, the Mokelumne and Calaveras Rivers to the east, and the San Joaquin River to the south. An additional and essentially unlimited source of saline water to the Delta is the Pacific Ocean and its daily and seasonal tidal cycles that propagate up Suisun Bay and influence the entire Delta.

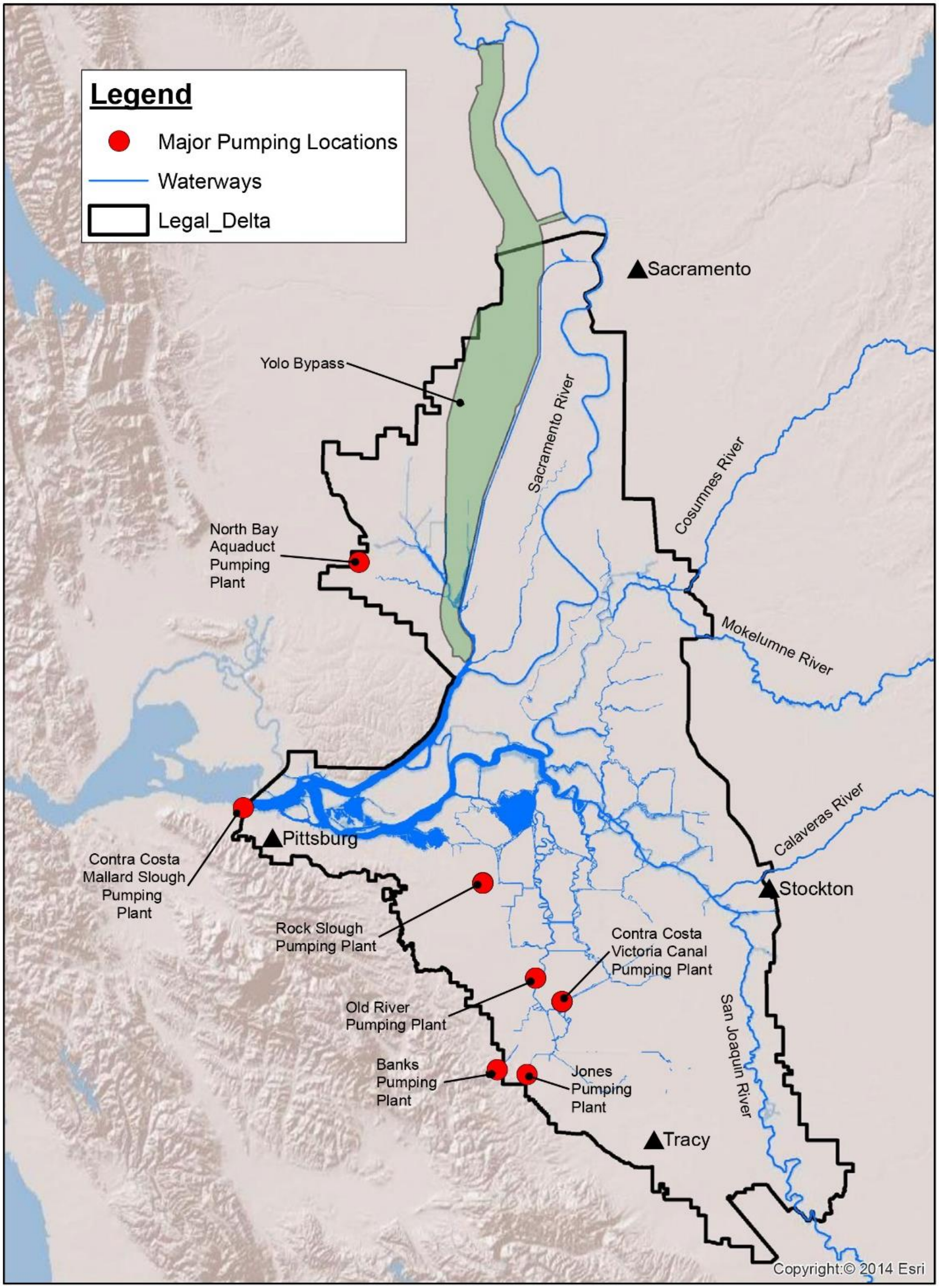


Figure 2.4-1. Generalized Delta Map

The natural geomorphology of the Delta and Suisun Marsh has been greatly altered by anthropogenic changes in sediment supply; flood control projects, including levee building and draining; mosquito ditches in Suisun Marsh; and large dam and diversion projects throughout the watershed. Levees and various land uses have reduced the depth of peat soils within the confines of the levees to depths of -24 feet (-7.25 meters) (Drexler et al. 2009), which creates an enormous volume of space that, in the event of a levee break, would bring saline and brackish water from the west further into the Delta (^Mount and Twiss 2005).

There are many agricultural diversions directly from the channels of the Delta (DWR 2010a). Additionally, there are large diversions and pumping plants for distant municipal, industrial, and agricultural uses (DWR 2010a). While these diversions are managed to satisfy multiple objectives, they influence flow through the Delta and can have consequences such as entrainment loss and increased predation to imperiled native fish species. Agricultural diversions and pumped exports remove phytoplankton biomass and reduce the Delta's carrying capacity for consumers in this low-productivity ecosystem where food limitation is pervasive across trophic levels (^Monsen et al. 2007).

In the north, the Freeport Regional Water Authority diverts from the Sacramento River at Freeport, and the North Bay Aqueduct and the City of Vallejo Pipeline divert water from sloughs at the lower end of the Yolo Bypass. In the east, the City of Stockton diverts from the mainstem of the San Joaquin River near Medford Island. In the southwest, the CVP, SWP, Contra Costa Water District (CCWD), East Contra Costa Irrigation District, and Byron-Bethany Irrigation District divert from the Old River channel of the San Joaquin River and other southern Delta channels. The Sacramento River is a major source of the fresh water in the Old River channel which is pulled upstream through Georgiana Slough and the Delta Cross Channel (DCC) gates (DWR 2010a).

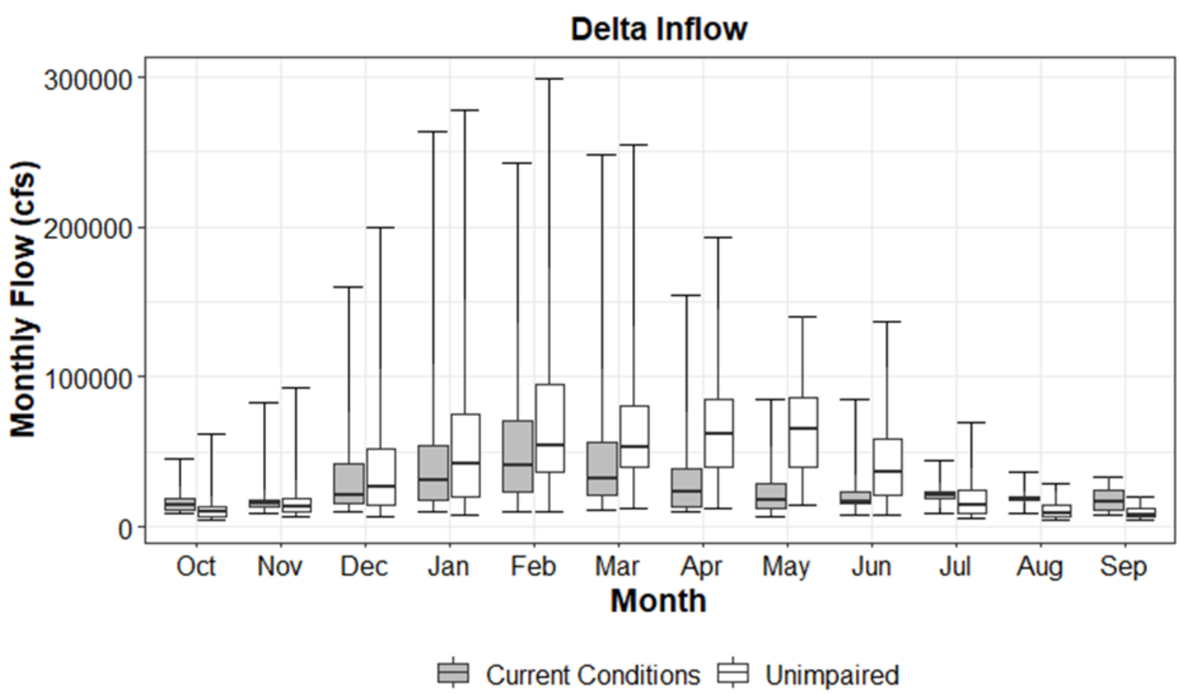
2.4.1 Delta Inflows

Despite its name, the Delta is not simply the merging of two river deltas but rather an elongated complex network of deltas and flood basins. Based on SacWAM unimpaired flow estimates, the Sacramento River is the largest source of flows and contributes an average of 62 percent of inflows to the Delta; the Yolo Bypass contributes about 12 percent; the eastside tributaries, including the Mokelumne River, contribute about 5 percent; and the San Joaquin River contributes about 21 percent.

Currently, during flood stages, approximately 82 percent of flows from the Sacramento River pass through the Yolo Bypass (Roos 2006). The flood stage flows can have many sources, including direct flows from tributaries such as the Feather and American Rivers, as well as through a system of passive and active weirs (James and Singer 2008; Singer et al. 2008; Singer and Aalto 2009; DWR 2010a, 2012). The San Joaquin River discharges into a broad network of sloughs and channels, and the Mokelumne River delta merges with the San Joaquin River delta on the eastern side of the Delta. On the southwest side of the Delta, the Marsh Creek delta merges with the San Joaquin River delta.

Under pre-development conditions, inflows from both the Sacramento and San Joaquin Rivers were much lower July through November compared to December through June (^TBI 1998). This difference was more dramatic in the San Joaquin River. The San Joaquin River has an upper watershed consisting of impermeable granitic rock. In contrast, the upper watershed of the Sacramento River is composed of permeable volcanic rock. As a result, groundwater discharge from this volcanic system historically maintained a summer base flow of approximately 4,000 cfs at Red Bluff and about 800 cfs in the Feather River, without which the Sacramento River would have nearly dried up during fall (^TBI 1998). Water diversions in the San Joaquin Valley began earlier than those in the Sacramento Valley; by 1870, flows of the San Joaquin River were significantly reduced (California Department of Public Works 1931; Jackson and Patterson 1977). Sacramento River diversions, particularly those in late spring and summer for rice irrigation, increased dramatically from 1912 to 1929; and the combination of significant drought periods and increased diversion during the annual low-flow period resulted in an unprecedented salinity intrusion into the Delta in fall 1918 (California Department of Public Works 1931; Jackson and Patterson 1977; ^TBI 1998). The economic impacts of these diversion-caused saltwater intrusions ultimately led to creation of the CVP and construction of dams for the release of freshwater flow to prevent salinity intrusion (Jackson and Patterson 1977). Construction of dams and diversions on all major rivers contributing to the Delta between the 1930s and 1960s resulted in substantial changes to Delta inflows (cfs = cubic feet per second Figure 2.4-2, Table 2.4-1). Winter flood peaks and spring snowmelt runoff from Delta tributaries have been greatly reduced by upstream storage and replaced by increased flows in summer and early fall, compared to pre-Project hydrology (^Kimmerer 2002a, 2004).

Table 2.4-1 and cfs = cubic feet per second Figure 2.4-2 show the large effects of water development upstream of the Delta. Current conditions in the January–June period are less variable than unimpaired conditions, and inflows are less than 60 percent of unimpaired flows in half of the years. The months of April and May are the most extreme, where current Delta inflow is less than half of unimpaired flows in more than 70 percent of the years. Table 2.4-2 shows that Delta inflows from the San Joaquin River are the most impaired, followed by Delta eastside tributaries, with the Sacramento River as the least impaired contribution to Delta inflow.



cfs = cubic feet per second

Figure 2.4-2. Delta Inflow Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

Table 2.4-1. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow for Delta Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	73	51	48	51	50	41	26	19	25	57	119	100	38	79	51
10%	117	79	70	64	61	48	31	26	37	68	135	156	47	93	63
20%	131	86	77	70	64	50	33	28	42	81	147	162	51	101	67
30%	144	94	80	75	67	55	35	30	44	96	154	174	53	107	71
40%	151	108	84	78	72	59	40	32	48	114	162	186	55	117	73
50%	159	117	91	80	77	64	41	34	54	133	174	194	60	125	74
60%	163	124	96	86	81	65	44	37	59	146	186	208	63	133	77
70%	167	131	101	92	87	71	49	43	66	163	212	219	66	141	79
80%	177	141	117	95	91	80	55	47	81	202	224	231	70	153	80
90%	187	150	135	108	96	87	66	51	101	219	249	243	74	164	86
100%	218	187	191	142	116	112	80	75	151	244	292	277	85	195	105

Table 2.4-2. Median Current Conditions as Percent of Unimpaired Flow for Delta Inflow by Major Tributary

	Median Jan–June	Median July–December	Median Annual
Yolo Bypass	67	87	67
Sacramento at Freeport	68	129	85
San Joaquin at Vernalis	32	99	41
Eastside Tributaries	45	144	58

2.4.2 Delta Hydrodynamics

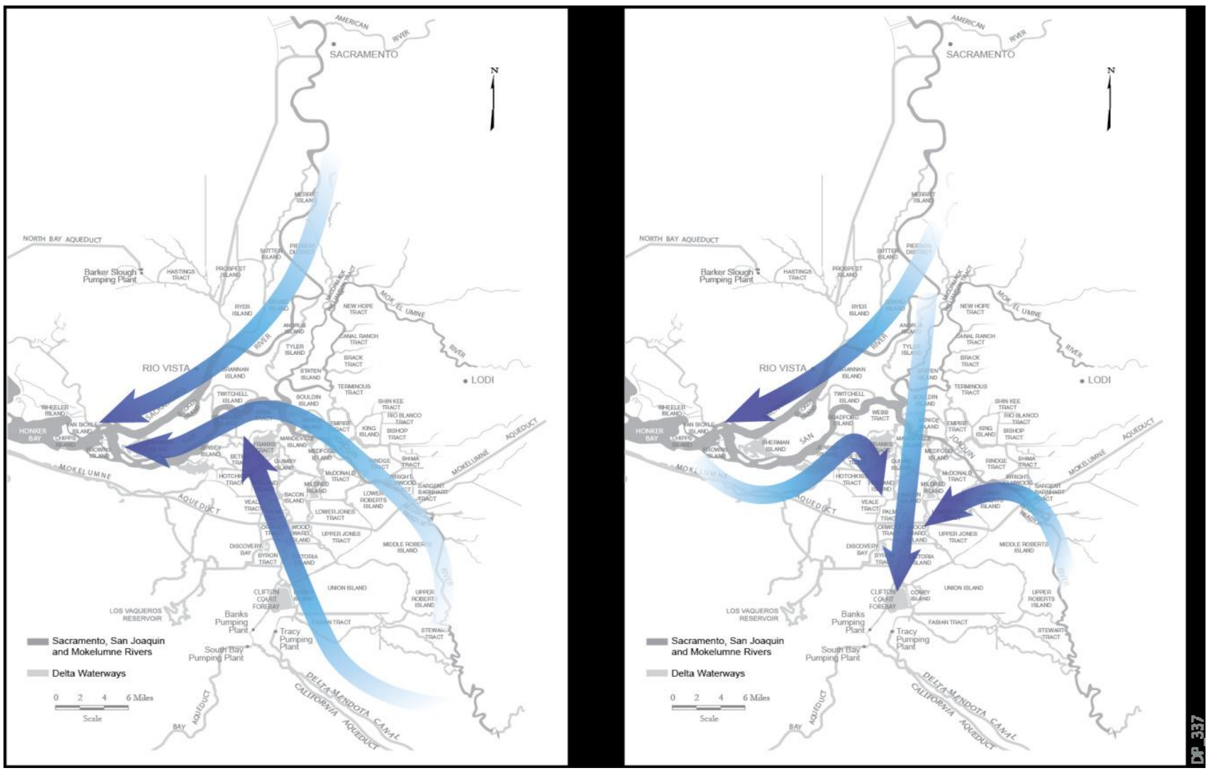
Human management of water and changes to the physical structure of the Delta have significantly changed the timing, magnitude, and flow paths through the Delta, with adverse effects on fish and wildlife. During the summer–fall dry season, the Delta channels essentially serve as a conveyance system for moving water from reservoirs in the north to the CVP and SWP export facilities (operated jointly under the Coordinated Operations Agreement) as well as the smaller CCWD facility, for subsequent delivery to farms and cities in the San Joaquin Valley, southern California, and/or other areas outside the watershed (^Kimmerer 2002a).

The CVP Delta facilities consist of the C. W. "Bill" Jones (Jones) Pumping Plant (formerly Tracy Pumping Plant), Tracy Fish Collection Facility, and Delta-Mendota Canal (DMC). Along with these facilities, Reclamation directs the operation of the DCC to improve the transfer of water from the Sacramento River to the pumping plant (Reclamation 2009). The design capacity of the Jones Pumping Plant is 4,600 cfs. Until 2012, a variety of factors, including subsidence in the DMC, limited the maximum pumping rate to approximately 4,200 cfs. In April 2012, a shared federal-state water system intertie (two 108-inch-diameter pipes) was completed between the SWP and the CVP. The intertie allows up to 900 cfs of conveyed water to gravity flow from the California Aqueduct to the DMC and 467 cfs of conveyed water to be pumped uphill from the DMC to the California Aqueduct (Reclamation 2022). Operation of the intertie is expected to have some effects on the tidal elevations at the DMC intake and smaller effects on tidal elevations, flows, and velocities in south Delta channels (Reclamation 2009). Water is pumped by the Jones Pumping Plant into the DMC for delivery to CVP contractors in the Central Valley or storage in San Luis Reservoir, a shared CVP and SWP facility.

The SWP Delta facilities consist of the Harvey O. Banks Pumping Plant, Clifton Court Forebay (CCF), California Aqueduct, and Barker Slough Pumping Plant for export through the North Bay Aqueduct (Reclamation 2009). The installed capacity of the Banks Pumping Plant is 10,300 cfs. However, a USACE permit limited diversions into CCF at the historical maximum daily average rate of 6,680 cfs (USACE 1981). When San Joaquin River flow at Vernalis exceeds 1,000 cfs during the period from mid-December to mid-March, the diversion into CCF may be increased by one-third of the Vernalis flow (USACE 1981). Banks Pumping Plant is operated to minimize the impact on power loads on the California electrical grid to the extent practical, using CCF as a holding reservoir and running all available pumps at night and a reduced number during the higher energy demand hours—even when the CCF is admitting the maximum permitted inflow. Banks Pumping Plant is almost always operated to the maximum extent possible, subject to the limitation of water quality, Delta standards, and other variables, until all needs are satisfied and all storage south of Delta is full (^USDOI 2008). Water is pumped by the Banks Pumping Plant for delivery to SWP contractors in the San Joaquin

Valley and southern California, and for storage in San Luis Reservoir and multiple terminal and local reservoirs—the largest and newest being Diamond Valley Lake in Riverside County, which was completed in 2003, with a capacity of 800 TAF.

Habitat conditions in the Delta are driven by the rise and fall of the tides, which results in upstream and downstream movement of large volumes of water and produces flows and velocities that are generally much greater than what is associated with net flows. However, net flows also play a role in the ecosystem. Export operations combined with changes in channel geometry, gates, and barriers and have greatly altered the natural direction of net flow in the Delta with effects on water quality, fish migration, and habitat suitability (DSC 2012). Historically, the natural flow of fresh water through the Delta generally was from the Sacramento River, San Joaquin River, and eastside tributaries westward toward San Francisco Bay. Currently, net flow generally is from the Sacramento River southward toward the export pumps, except during high-flow events (Figure 2.4-3). The San Joaquin River's small relative flow contribution combined with high export pumping rates has caused reverse flows in the southern Delta and reduced outflow from the Delta into the San Francisco Bay.



Source: DSC 2012.
The left panel depicts the tidally averaged flow direction in the absence of export pumping. The right panel depicts reversal of tidally averaged flows that occurs during times of high exports (pumping) and low inflows to the Delta.

Figure 2.4-3. Flow Direction in the South Delta showing the natural east-to-west flow pattern in the pane on the left and a typical summer flow pattern under current conditions on the right

Delta gates and diversions can substantially redirect tidal and river flows, creating net flow patterns and salinity and turbidity distributions that did not occur prior to development. Barriers are used in the Delta to control water quality in various locations in the Delta by changing the hydrodynamics.

2.4.3 Delta Barriers

Hydrodynamics in the south Delta is affected by four seasonal rock barriers installed to improve water levels for agricultural diverters and to reduce entrainment of native fish. The south Delta Temporary Barriers Project includes three agricultural barriers: at Old River near Tracy (ORT), at Middle River (MR) near its confluence with Victoria and North Canals, and on Grant Line Canal; and one fisheries barrier: the Head of Old River Barrier (HORB) (NMFS 2012).

The three agricultural barriers are installed seasonally from April 15 to September 30 on ORT, MR, and Grant Line Canal. The tops of the barriers are below the mean high tide level, allowing flow to enter on the flood tide but restricting it from exiting on the ebb tide. This trapped water provides sufficient draft for agricultural pumps in the south Delta to operate without interruption but also blocks the natural flow and circulation patterns of these streams (^NMFS 2009 BiOp).

Prior to issuance of the 2019 BiOps, the HORB historically was installed in spring to keep migrating San Joaquin Chinook salmon in the main San Joaquin River channel and away from the pumps and predators in the interior Delta and again in fall to improve low dissolved oxygen conditions in the Stockton Deep Water Ship Channel by increasing flow (NMFS 2012). The barrier was fitted with culverts to allow a minimum of approximately 500 cfs to flow into Old River. The HORB was installed in mid-September, at the discretion of CDFW, and was completely removed by November 30. Throughout this period, the barrier was notched to allow for upstream passage of adult salmon and steelhead (NMFS 2012). Unlike the agricultural barriers, the HORB was not submerged at high tide. Whether the HORB will continue to be installed in the future is uncertain and is being discussed in the ongoing reconsultation process between the Reclamation and the National Marine Fisheries Service.

Installation of the south Delta agricultural barriers reduces tidal exchange in the south Delta. The barriers create a delay in the tidal signal and a difference in elevation between the channels upstream and downstream of the barriers. Installation of the HORB reduces net flows into Old River (NMFS 2012). There is evidence that the presence of the HORB magnifies reverse flows in OMR, thus increasing entrainment of Delta smelt (^NMFS 2009a). This can occur when water that is blocked by the HORB from entering Old River proceeds down the San Joaquin River and then is drawn into OMR toward the CVP and SWP diversion points.

Areas of null flows (flows with no net upstream or downstream motion) can occur in the interior sections of the south Delta channels. Null flows become more common when south Delta irrigation demands are high and inflow from the San Joaquin River is low (e.g., when the HORB is in place). The flow patterns in the interior of the south Delta under these conditions create a “hydraulic trap” for particles (or fish) moving with the river’s flow. These null flow areas are also associated with low dissolved oxygen and poor water quality (NMFS 2012).

2.4.4 Delta Cross Channel Gate Operations

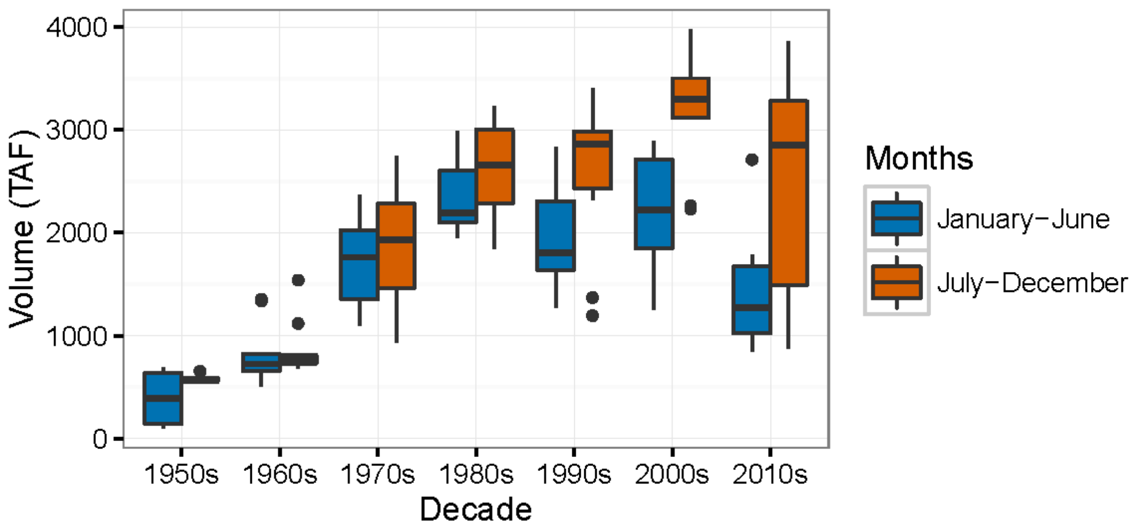
The DCC is a controlled diversion built in 1951, located in Walnut Grove and operated and maintained by the San Luis Delta-Mendota Water Authority at the direction of Reclamation. The gates have a physical capacity of 3,500 cfs and can divert a significant portion of Sacramento River flows into the eastern Delta (^SWRCB 2010). Flows are controlled by gates that are normally kept open to maintain cross-Delta flows. The DCC gates are closed in late summer and autumn to facilitate salmon emigration (^Monsen et al. 2007). The DCC significantly affects Delta hydrodynamics by sending Sacramento River water into Snodgrass Slough and the North Fork

Mokelumne River and then to the interior Delta (Reclamation 2006). This diversion significantly improves water quality in the southern Delta and at the export pumps but also increases the probability of entrainment of juvenile salmon migrating past its gates into the interior Delta, resulting in lower survival. When the gates are open, 40 to 50 percent of the Sacramento River flow enters the interior Delta through the DCC and Georgiana Slough. When the gates are closed, only 15 to 20 percent of the Sacramento River flow enters the interior Delta (^Low et al. 2006). The gates are closed during migration periods to protect Chinook salmon and at high flows to prevent flooding (Reclamation 2006). The effect of the DCC on fish is discussed in more detail in Section 3.4.5, *Flow Effects on Salmonids*.

Closure of the DCC gates alters circulation in the north Delta by directing more Sacramento River water down its mainstem and away from the central Delta. This closure results in less fresh water available to prevent salinity intrusion on the San Joaquin River stem of the Delta. While salinity would decrease at Emmaton on the Sacramento River, salinity would increase on the San Joaquin River at Jersey Point (^Monsen et al. 2007).

2.4.5 South Delta Exports and Old and Middle River Reverse Flows

Exports from the south Delta include SWP's Banks Pumping Plant, CVP's Jones Pumping Plant, and CCWD's Victoria Canal and Old River Pumping Plants. The combined capacity of the CVP and SWP south Delta pumping plants is about 15,000 cfs, with median and maximum daily combined diversions between water year 2000 and 2020 of 6,618 and 14,650 cfs, respectively (Dayflow). The combined capacity of CCWD south Delta intakes is about 500 cfs, with median and maximum daily combined diversions for the same period of 140 and 460 cfs, respectively (Dayflow). Exports from south Delta channels can greatly reduce Delta outflow and alter Delta hydrodynamics by drawing water from the central Delta toward the export facilities in the south Delta. South Delta exports have increased since the late 1950s when Jones Pumping Plant was developed. The highest pumping rates were in the years 2000 through 2009 after the adoption of D-1641, particularly in summer and fall (Figure 2.4-4). From 2010 through 2015, south Delta exports have been reduced by implementation of the BiOps to protect endangered species (^NMFS 2009 BiOp; ^USDOI 2008) and reduced available water for export due to drought conditions.

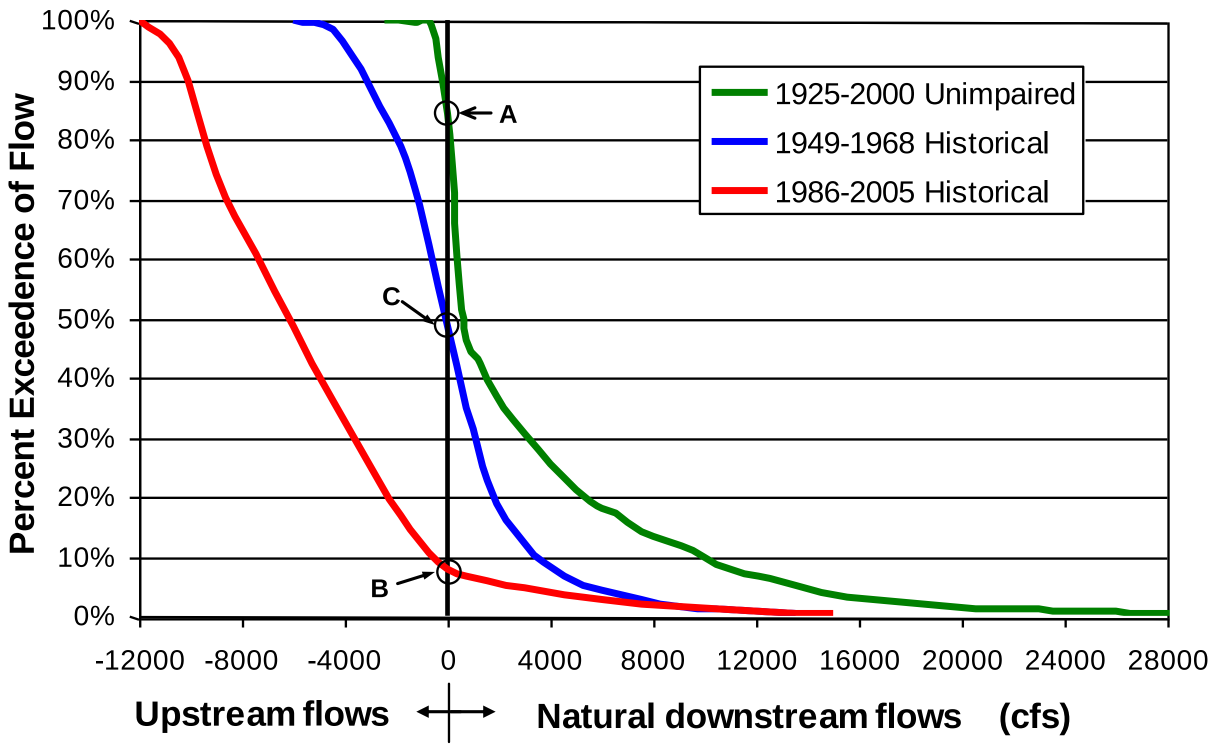


Source: Dayflow DWR 2017a
The year shown on the x-axis represents the start year of the decade, for example “2000s” represents 2000–2009 and “2010s” represents 2010–2015.
TAF = thousand acre-feet

Figure 2.4-4. Total Seasonal SWP and CVP South Delta Exports by Decade

The most prominent example of changes in net flow direction in the Delta occurs in the Old River and Middle River channels of the San Joaquin River. ^Fleenor et al. (2010) documented the change in both the magnitude and frequency of net OMR reverse flows as water development occurred in the Delta (Figure 2.4-5). The disparity between pumping rates and the streamflow in the San Joaquin River creates net reverse flows (water flowing upstream) on the Old and Middle Rivers. The magnitude of these net reverse flows can at times be as great as 12,000 cfs flowing from the central Delta toward the export pumps. These reverse flows can entrain fish into the pumps, confuse migratory cues that juvenile salmonids use to navigate toward the ocean, and affect water quality in the Delta (Jassby 2005; ^Kimmerer 2008).

The 1925 through 2000 unimpaired line in Figure 2.4-5 represents 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 modern water development (Figure 2.4-5, Point A). The magnitude of natural net OMR reverse flows was seldom more negative than a couple of thousand cfs. In contrast, between 1986 and 2005, net OMR reverse flows had become more frequent than 90 percent of the time (Figure 2.4-5, Point B).



Source: ^Fleenor et al. 2010.
cfs = cubic feet per second

Figure 2.4-5. Cumulative Probability of OMR Flows

OMR flows are monitored by USGS at two sites using rated velocity meters combined with stage to estimate discharge every 15 minutes. Tidal influences are digitally filtered out, which results in a measured net OMR flow. The tidal filter uses past and future measurements, which imposes a delay of 35 hours until the net flow data are available to operators, enforcement agencies, and the public. The net OMR flow measured by USGS has been criticized as being a poor compliance index and difficult to operate to because of the time delay and frequent missing or erroneous data (CCWD 2012).

Starting in early 2014, Reclamation and DWR, with concurrence from the National Marine Fisheries Service and USFWS, began a 1-year demonstration project, which was later extended, to test the ability to manage OMR flows through a numerical index developed by the Metropolitan Water District of Southern California (MWD). During the project duration, the SWP and CVP monitor and compare both the USGS tidally filtered OMR measurements and the index values. The index is intended to be equally protective of fish and more predictable to operate to (^Reclamation 2014; NMFS 2014).

2.4.6 Delta Outflow and X2

The amount of water leaving the Delta and entering San Francisco Bay is known as *Delta outflow*. As with the Sacramento River and the Delta eastside tributaries, the annual Delta outflow has a large range, from under 5 MAF/yr to over 50 MAF/yr, with an average of about 15 MAF/yr (Appendix A1, *Sacramento Water Allocation Model Methods and Results*). Delta outflow affects salinity throughout the Delta and the wildlife habitat defined by the low salinity zone (LSZ).

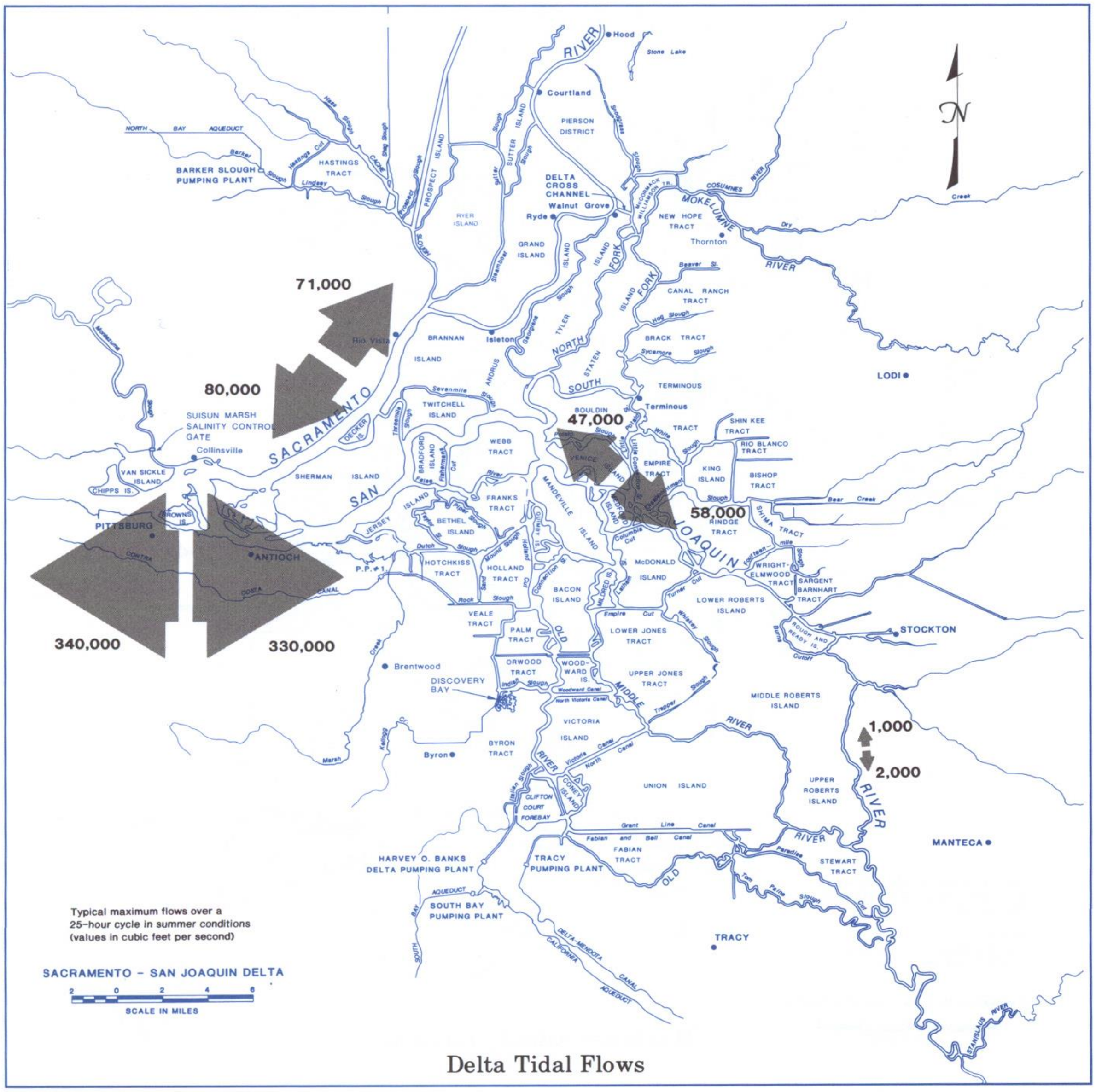
Two commonly used metrics of flow magnitude through the Delta are outflow and X2. *Outflow* is expressed as a net flow from the Delta to San Francisco Bay with the tidal signal removed. *X2* is defined as the horizontal distance in kilometers up the axis of the estuary from the Golden Gate Bridge to where the tidally averaged near-bottom salinity is 2 practical salinity units (^Jassby et al. 1995). Delta outflow and the position of X2 are closely and inversely related, with a time lag of about 2 weeks (^Jassby et al. 1995; ^Kimmerer 2004), the lag being inversely dependent on the magnitude of Delta outflow.

Tides are driven by gravitational pull by the sun and the moon, air pressure, and wind currents. The flow driven by the tides is greatest closer to the ocean. Summer tidal flows can reach up to 340,000 cfs at the mouth of the estuary near Pittsburg and are weaker upstream on the Sacramento and San Joaquin Rivers (Figure 2.4-6). Large tidal exchanges below the confluence of the Sacramento and the San Joaquin Rivers make it difficult to measure flow through the large channels. Recently, USGS installed monitoring stations to measure Delta outflow; however, they are subject to frequent outages, imprecision, and error. To better account for hydrology within the Delta in the absence of accurate measured data, mass-balance models such as Dayflow have been developed to estimate interior Delta flows and NDO.

Dayflow is a model developed by DWR in 1978 as an accounting tool for water in the Delta. State Water Board Water Rights Decision D-1485 set Delta outflow standards; however, the technology to gage the large flow exchange at the mouth of the Delta was not available. Dayflow was developed to provide an estimate of outflow and to gain estimates of historical Delta outflow. Dayflow calculates the daily average net Delta outflow index (NDOI) based on precipitation gages, inflow gages, Delta exports, channel depletions, and agricultural consumptive uses. In addition to NDOI, Dayflow provides estimates of net flow through the DCC and Georgiana Slough, net flow at Jersey Point (QWEST), and X2.

Studies have shown that NDOI is an inaccurate measure of Delta outflow during certain times of the year and particularly at times of low Delta outflow. During these times, measured salinity values can be used to estimate Delta outflow using historical relationships between salinity and outflow (Brown and Huber 2015; DWR 2016d). Discrepancies between salinity values and NDOI may be indicative of errors in the NDOI terms, particularly Delta consumptive use.

DWR, UC Davis, and others have been working to improve the estimates of in-Delta consumptive uses and channel depletion, which will improve the estimates of Delta outflow and ultimately hydrodynamics and the LSZ (Medellín-Azuara et al. 2016). One of these new tools is Delta Evapotranspiration of Applied Water (DETAW). Remote sensing techniques have the potential to improve the accuracy of these tools; however, the new methods are still under development and may require significant resources to be applied to the entire Delta. Current Dayflow estimates tend to underestimate Delta consumptive uses in summer, which affects outflow and LSZ estimates when compared to newer estimates using DETAW (DWR 2016d). The future release of DETAW and other models hopefully will more accurately estimate Delta uses and improve estimates of Delta salinity, outflow, and hydrodynamics.



Source: DWR 1995.

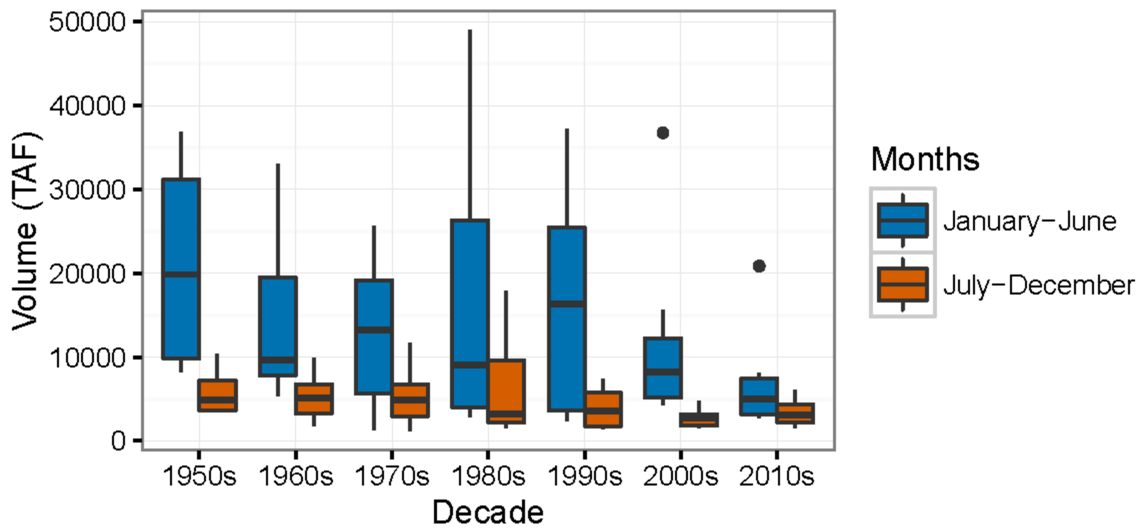
Figure 2.4-6. Delta Tidal Flows over a 25-Hour Cycle in Summer Conditions (values in cubic feet per second)

USGS has installed a monitoring station network that now allows for a comparison between direct estimates of NDO and Dayflow NDOI; however, because of the large tidal fluctuations, the measured net flow is prone to errors (DWR 2016d). In the absence of measurement error or error in the estimates of the NDOI components, NDO and NDOI would be similar except for differences caused by the spring–neap tidal cycle, which causes the Delta to fill and drain over a 2-week period. At times of very low Delta outflow, the filling and draining of the Delta associated with the spring–neap tidal cycle can cause negative NDO. When NDO is very low, errors in the components of the Dayflow estimate of NDOI and the spring–neap filling and draining of the Delta can cause a relatively large discrepancy between NDOI and actual NDO (DWR 2012). The State Water Board conducted a peer review through the Delta Stewardship Council Delta Science Program of the issues as summarized by DWR (2016d) to provide recommendations on improvements to Delta outflow estimates. The peer review report (Fleenor et al. 2016) was received in fall 2016 and will be used to inform the future implementation of regulatory requirements for Delta outflow.

The combined effects of water exports and upstream diversions have contributed to reduce the average annual net outflow from the Delta by 33 percent and 48 percent during the 1948 through 1968 and 1986 through 2005 periods, respectively, compared with unimpaired conditions (^Fleenor et al. 2010). Dayflow data also show a trend for decreasing Delta outflow through time. Since the 1990s, there has been a reduction in spring outflow and a reduction in the variability of Delta outflow throughout the year (Figure 2.4-7) due largely to the combined effects of exports, diversions, and variable hydrology.

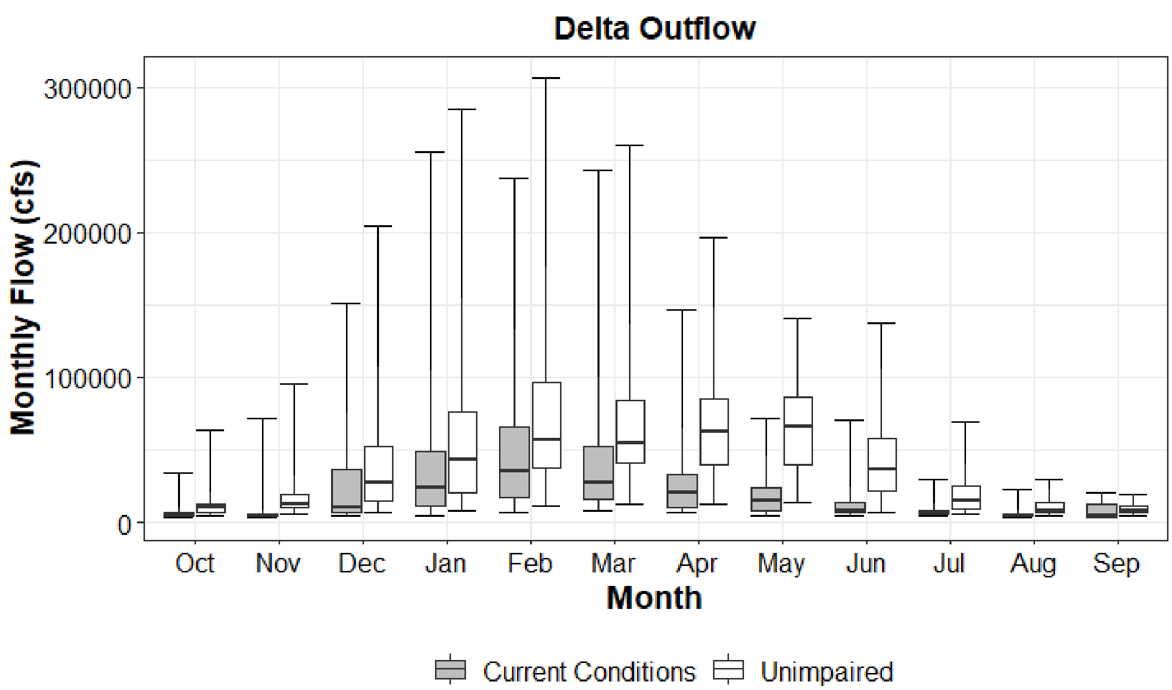
SacWAM results for unimpaired and current conditions indicate the degree and variability of impairment of total Delta outflow by month (Table 2.4-3, cfs = cubic feet per second Figure 2.4-8). The San Joaquin River watershed is not part of the SacWAM model. Instead, San Joaquin River inflow to the Delta is a model input. For the SacWAM simulation of unimpaired conditions, the Vernalis inflow values came from DWR as outlined in the fourth edition unimpaired flows report (DWR 2007b). For the SacWAM simulation of current impaired conditions, the Vernalis inflow values were those simulated by CalSim 3.0 to represent current conditions (see Chapter 6, *Changes in Hydrology and Water Supply*, and Appendix A1, *Sacramento Water Allocation Model Methods and Results*).

May and June show the largest impairment; in 80 percent of those months, Delta outflow is less than 44 percent and 46 percent of the unimpaired flow, respectively (Table 2.4-3). For simulated current conditions, Delta outflow is much lower in spring and frequently higher in September compared with unimpaired Delta outflow, and variability is reduced in all months except September (cfs = cubic feet per second Figure 2.4-8). Table 2.4-4 shows the contributing sources of unimpaired Delta outflow by season. The Sacramento River at Freeport contributes 61 percent of the outflow in winter-spring, and 77 percent in the summer-fall. The other major annual average contributions to Delta outflow originate from the Feather, American, and San Joaquin River watersheds (25 percent, 9 percent, and 21 percent, respectively).



Source: Dayflow DWR 2017a
The year shown on the x-axis represents the start year of the decade, for example "2000s" represents 2000–2009 and "2010s" represents 2010–2015.
TAF = thousand acre-feet

Figure 2.4-7. Seasonal Net Delta Outflow Index by Decade



cfs = cubic feet per second

Figure 2.4-8. Delta Outflow Simulated Current Conditions (gray) and Unimpaired (white) Monthly Flows

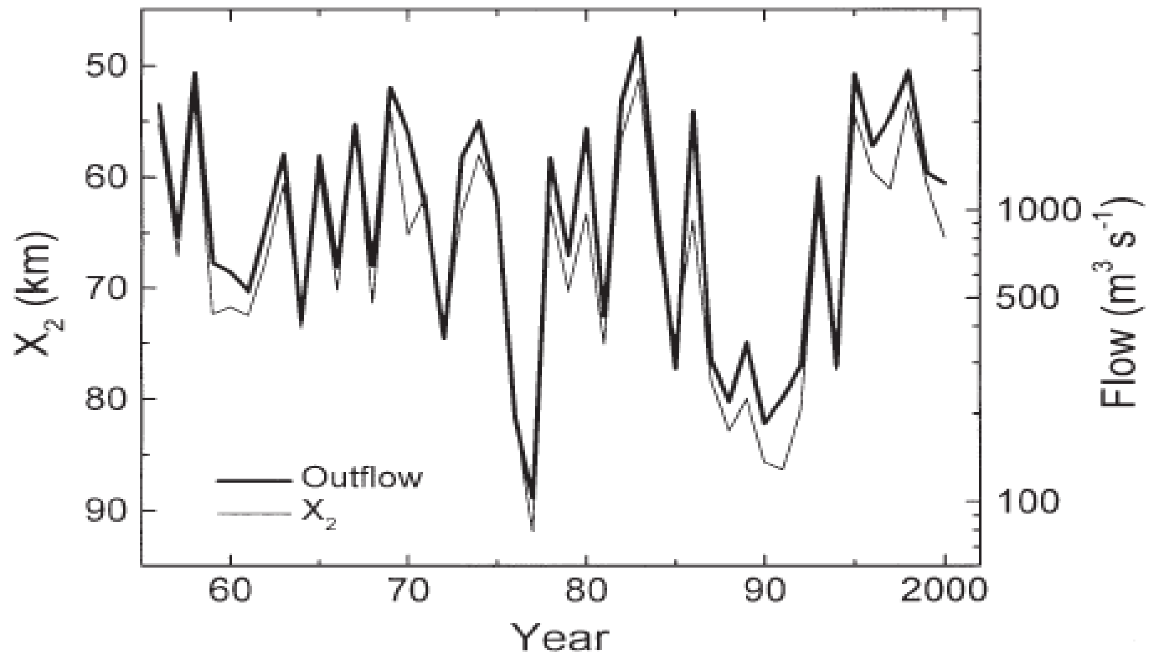
Table 2.4-3. Cumulative Distribution of Current Conditions as Percent of Unimpaired Flow in Delta Outflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan–Jun	Jul–Dec	Annual Total
0%	29	18	27	26	37	26	20	15	15	22	29	33	26	39	30
10%	42	27	35	42	44	35	23	18	20	28	35	48	34	44	37
20%	50	33	38	49	46	38	27	21	22	33	42	50	36	47	39
30%	52	35	40	53	49	42	30	22	24	37	48	58	38	49	41
40%	58	39	44	56	53	45	32	23	26	41	53	62	42	51	44
50%	62	41	49	59	56	49	35	25	30	46	57	70	45	53	47
60%	65	44	58	64	63	54	38	27	33	51	60	79	48	57	52
70%	68	47	64	68	71	59	41	32	38	56	65	94	54	58	55
80%	71	50	70	76	79	69	49	37	43	63	72	104	58	61	59
90%	76	58	78	84	86	76	57	43	52	72	79	115	63	65	62
100%	96	85	107	119	102	93	75	54	76	102	101	138	78	84	76

Table 2.4-4. Simulated Unimpaired Contributions to Total Delta Outflow from Various Locations in the Plan Area (percent of Delta outflow)

Location	Jan–Jun	Jul–Dec	Annual Total
Sacramento River below Keswick	17	26.3	19.1
Sacramento River at Freeport	57.1	71.6	60.4
Cow Creek at confluence with Sacramento River	1.4	1.5	1.5
Battle Creek at confluence with Sacramento River	1	1.9	1.2
Butte Creek near Durham	1.4	1.6	1.5
Antelope Creek at confluence with Sacramento River	0.4	0.5	0.4
Deer Creek	0.7	0.9	0.8
Mill Creek	0.7	1	0.7
Paynes Creek	0.2	0.2	0.2
Clear Creek	1.1	1	1.1
Big Chico Creek	0.3	0.3	0.3
Feather River at confluence with Sacramento River	23.9	24.7	24.1
Feather River above confluence with Yuba River	14.8	16.1	15.1
Yuba River	8.1	6.9	7.9
Bear River at confluence with Feather River	1.4	1.5	1.4
American River at confluence with Sacramento River	9.5	6.1	8.7
Mokelumne River above confluence with Cosumnes River	2.7	1.2	2.4
Cosumnes River at confluence with Mokelumne River	1.7	1	1.5
Calaveras River	0.5	0.3	0.5
Stony Creek	1.5	1	1.4
Cottonwood Creek	1.9	1.6	1.9
Thomes Creek	0.9	0.8	0.9
Elder Creek	0.2	0.2	0.2
Cache Creek	1.6	0.9	1.5
Putah Creek	1.2	0.8	1.1
Sutter Bypass outflow	10.3	6.4	9.4
Yolo Bypass	13.1	7.5	11.9
San Joaquin River at Vernalis	22.1	15.1	20.5
Delta outflow	100	100	100

Delta outflow and X2 are closely and inversely related. Higher Delta outflows push saline waters from the Pacific further toward the Golden Gate Bridge, thereby reducing the value of X2, which scales as the logarithm of NDO. However, because antecedent conditions are also important, especially at times when there is a large variability in daily outflow, the relationship between current outflow and X2 weakens (Monismith et. al. 2002). On a monthly time step, the relationship between outflow and X2 is quite clear, as shown in Figure 2.4-9.



Sources: ^Jassby et al. 1995, ^Kimmerer 2002b.
Flow data from California Department of Water Resources; X2 calculated as in ^Jassby et al. (1995).
km = kilometers
m^3s^{-1} = cubic meter per second

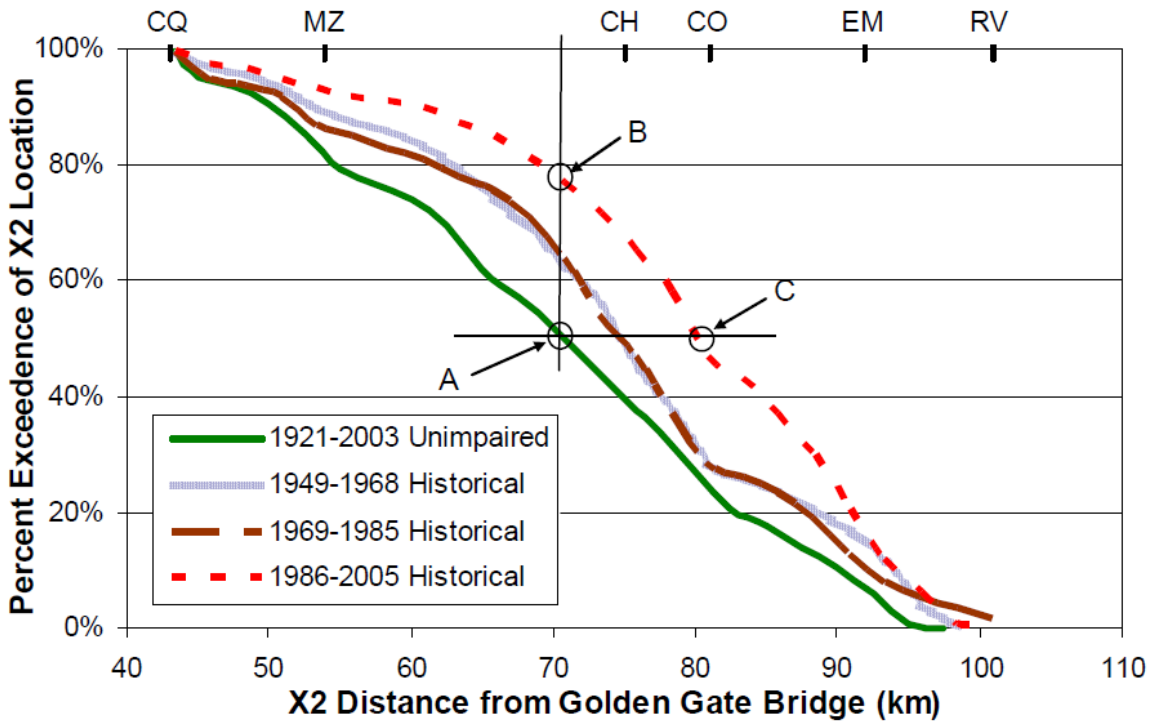
Figure 2.4-9. Time Series of X2 (thin line, left axis, scale reversed) and Outflow (heavy line, right axis, log scale), Annual Averages for January to June

Hydrodynamic simulations conducted by ^Fleenor et al. (2010) indicate that the position of X2 has been skewed eastward in the recent past, compared with pre-development conditions and earlier impaired periods, and that the variability of salinity in the western Delta and Suisun Bay has been significantly reduced (Figure 2.4-10).

Figure 2.4-10 shows the cumulative probability distributions of simulated daily X2 locations for unimpaired flows (green solid line) and three historical periods: 1949 through 1968 (light solid blue line), 1969 through 1985 (long-dashed brown line), and 1986 through 2005 (short-dashed red line), illustrating progressive reduction in salinity variability from unimpaired conditions.[1] Paired letters indicate geographical landmarks: CQ = Carquinez Bridge; MZ = Martinez Bridge; CH = Chipps Island; CO = Collinsville; EM = Emmaton; and RV = Rio Vista. The higher X2 values shown in Figure 2.4-10 (refer to Point B) indicate that the LSZ is farther upstream for a more prolonged period of time. Point B demonstrates that, from 1986 to 2005, the position of X2 was located upstream of 71 km nearly 80 percent of the time, compared with unimpaired flows that were equally likely to place X2 upstream or downstream of the 71-km location (50 percent probability). (^Fleenor et al. 2010.)

Historically, X2 exhibited a wide seasonal range tracking the unimpaired Delta outflows; however, seasonal variation in X2 range has been reduced by nearly 40 percent compared with pre-dam conditions (TBI 2003).

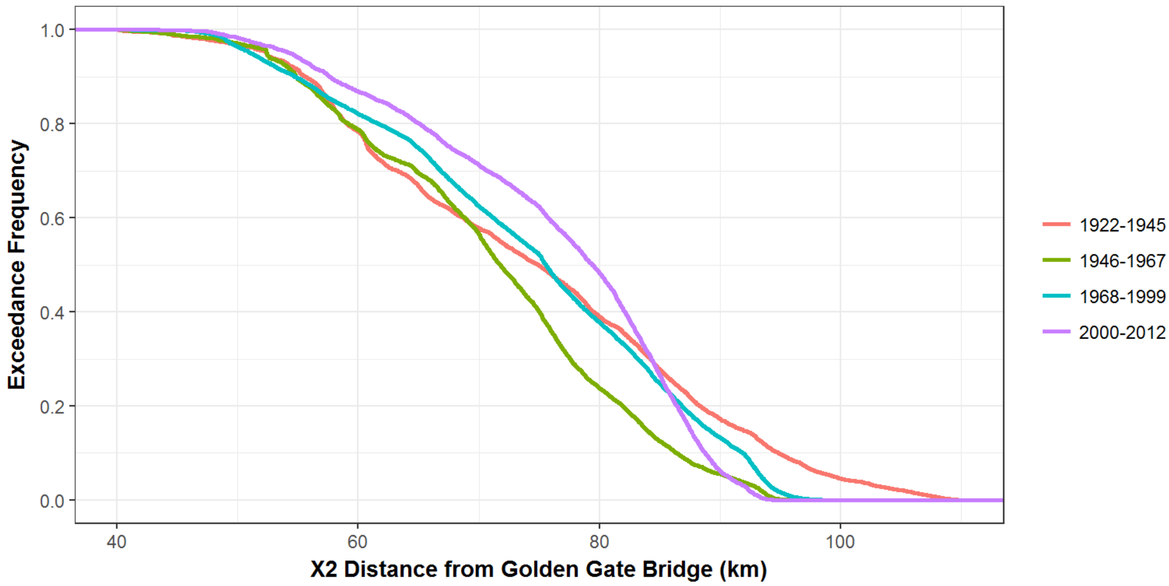
[1] Daily unimpaired flows shown here are estimated using DWR's previous method of estimating unimpaired flows described in *California Central Valley Unimpaired Flow Data*, Fourth Edition (DWR 2007b).



Source: ^Fleenor et al. 2010.
CH = Chipps Island; CO = Collinsville; CQ = Carquinez Bridge; EM = Emmaton; MZ = Martinez Bridge; RV = Rio Vista; km = kilometers

Figure 2.4-10. Cumulative Probability of Daily X2 Locations

Hutton et al. (2015) estimated X2 position based on salinity measurements for 1922 through 2012. This analysis evaluated trends through time by month, as opposed to the analysis in this section that combined results for all months (^Fleenor et al. 2010). As might be expected based on increases through time in the storage and release of water, analysis for the entire 91 years showed increases in X2 through time (i.e., more saltwater intrusion) during the period when water is most typically stored (November–June) and decreases in X2 (i.e., less saltwater intrusion) during dry months when water is typically released from storage (August and September). Comparison of X2 position during pre-SWP/CVP water years (1922–1967) and post-SWP/CVP water years (1968–2012) showed the largest monthly differences occurring during critical water years, when reservoir storage and release have a greater effect on hydrology. Figure 2.4-11 was produced from the Hutton et al. (2015) daily X2 position data and resembles Figure 2.4-10 in most salient features. Inclusion of the 1922–1945 period highlights one of the problems that occurred in the watershed after the diking and draining of the Delta and development but before completion of upstream storage projects, including Shasta Reservoir. During dry months, and in particular during severe droughts, salinity intruded deep into the Delta, as shown in the red line in Figure 2.4-11. Such severe salinity intrusions were likely much rarer prior to the widening and deepening of Delta channels (^Whipple et al. 2012). In the period since 1945, X2 positions have reduced in variability due in part to a greater ability to repel salinity during dry conditions but generally have skewed upstream under all but the driest conditions, as shown in both Figure 2.4-10 and Figure 2.4-11.

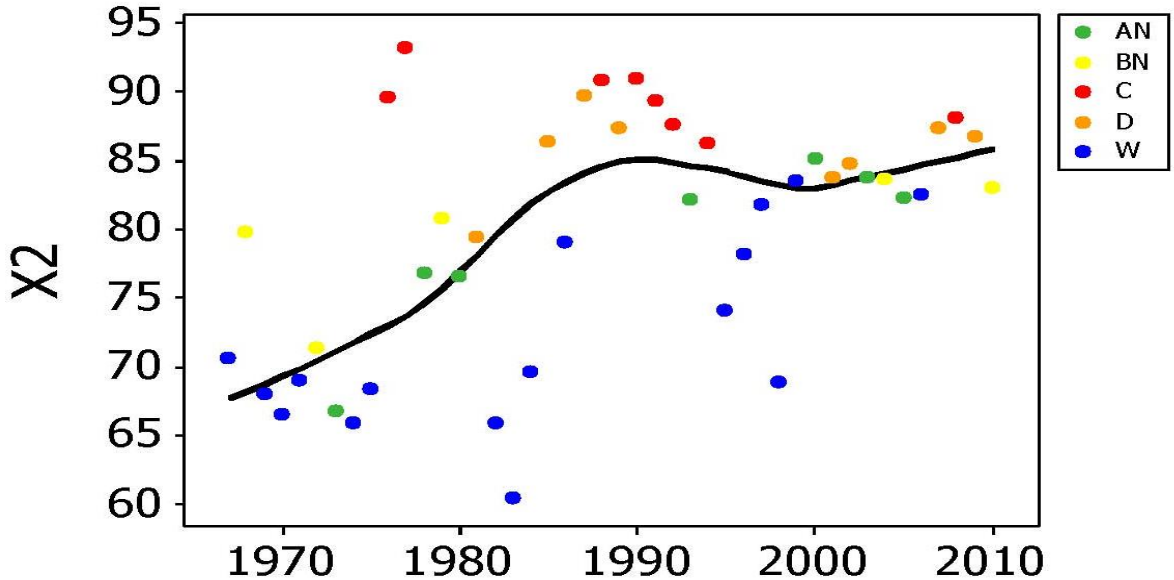


Source: Hutton et al. 2015.

Data are divided into four historical periods: prior to completion of Shasta Reservoir (1922–1945), prior to completion of Oroville Reservoir (1946–1967), prior to adoption of Water Right Decision 1641 (1968–1999), and following adoption of Water Right Decision 1641 (2000–2012). Data shown are the Sacramento River daily X2 positions.
km = kilometers

Figure 2.4-11. Exceedance Frequency Distribution of Daily X2 Positions

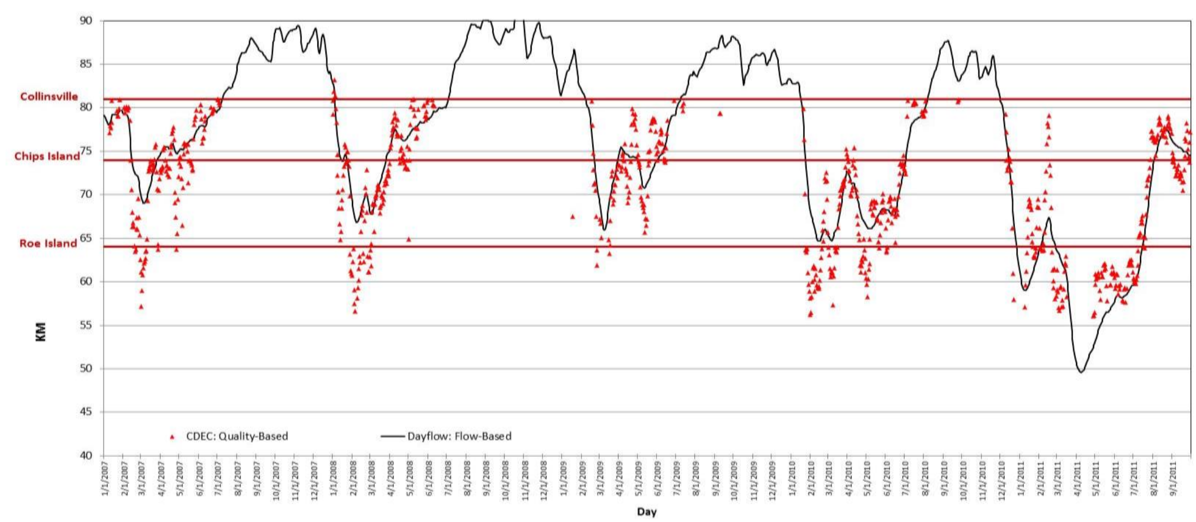
Although X2 originally was conceived of as a regulatory parameter for the winter–spring period (^Jassby et al. 1995), more recent research has suggested that the position of X2 in fall may affect Delta smelt populations (see Chapter 3, *Scientific Knowledge to Inform Fish and Wildlife Flow Recommendations*). Work by USFWS (2011) has shown that, since 1967, fall X2 has increased and variability has decreased through time (Figure 2.4-12). This increase in fall X2 in water years during SWP and CVP operations (1968–2012) was corroborated in work by Hutton et al. (2015) that showed increases in X2 from September through December. However, Hutton et al. (2015) work showed that during pre-SWP/CVP water years (1922–1967), there was a trend of decreasing X2 from August through December.



Source: USFWS 2011.
Water year types: AN = above normal; BN = below normal; C = critical; D = dry; w = wet
Water year types represent the preceding spring. A locally estimated scatterplot smoothing is fitted to the data.

Figure 2.4-12. Time Series of Fall X2 since 1967

The Dayflow methodology often is used to estimate X2 based on outflow for operational and management decisions. Dayflow's X2 estimate is based on a 20-year-old autoregressive equation, which produces significant discrepancies from measured values recorded by the California Data Exchange Center (CDEC) (Figure 2.4-13) (Mueller-Solger 2012). Various alternative approaches have been described for improving the method for calculating daily X2 (Monismith et al. 2002; Huber and Brown 2014; ^MacWilliams et al. 2015; Hutton et al. 2015; Rath et al. 2016).



Source: Bourez 2012.
CDEC = California Data Exchange Center
km = kilometers

Figure 2.4-13. Dayflow Flow-Based Estimation of X2 and California Data Exchange Center Water-Quality Based X2 Values

2.5 Suisun Region

Functionally, Suisun Marsh is similar to the larger Delta in having a delta (Green Valley Creek/Suisun Creek/Cordelia Slough) embedded within a tidal marsh. Suisun Marsh differs from the larger Delta because it lies between the Delta and the San Francisco Bay Estuary. While Sacramento-San Joaquin River flows have a significant effect on flow and salinity gradients in the Suisun region, localized factors can have large effects on flows and salinity gradients within the marsh. The vegetation of brackish tidal marsh wetlands and non-tidal managed wetlands are biological expressions of those gradients, and the wetlands and sloughs are particularly important habitat.

Suisun Creek and Green Valley Creek are regulated by dams and have an estimated combined average annual runoff of 16,420 AF (Jones & Stokes Associates and EDAW 1975). Summer base flow in both creeks is currently <1 cfs (RMA 2009). In addition to the discharge of the two creeks, the Fairfield-Suisun Sewer District Treatment Plant discharges approximately 20 cfs of treated wastewater into Boynton Slough during the dry season and significantly more during the wet season (San Francisco Bay Water Board 2009, 2014). Boynton Slough drains into the upper reach of Suisun Slough. Natural flows for other creeks in the Suisun region have not been reported, and those creeks flow through developed areas that have significant treated wastewater or irrigation base flows during summer.

Tides in the San Francisco Bay Estuary and in the Suisun region are mixed semi-diurnal (two dissimilar high tides and two dissimilar low tides each day) (Malamud-Roam 2000; RMA 2009), and present day tidal flows in the main channel range from approximately 300,000 cfs at the eastern end to approximately 600,000 cfs at the western end (Siegel et al. 2010; Enright 2014). The cycling of the tides affects the tidal marsh ecosystem by flooding some areas only during the highest of the two daily high tides and some areas only during the period of the highest tides each month, affecting the temperature and salinity of water in adjacent tidal channels and soil salinity in the tidal marsh. Those factors in turn control the distribution of plants and animals on the marsh plains and channels.

The Bay-Delta Plan contains salinity objectives for the Suisun region. The Suisun Marsh Salinity Control Gates are operated to assist in meeting those objectives and have been shown to be very effective at conveying relatively fresh water from Collinsville downstream in Montezuma Slough and through Hunter Cut into Suisun Slough (Enright 2008). The net flow during fall can be approximately 2,800 cfs through the gates at times when the Delta Outflow Index ranges from 2,000 to 8,000 cfs (Enright 2008). Operation of the gates has a significant freshening effect on high and low tide salinity at the Suisun Slough salinity compliance point (S-42) and at high tide at the Chadbourne Slough compliance site (S-21) (Enright 2008). Operation of the gates has significant effects on tidal dynamics, ranging from damping to increasing the range of tides. Additionally, operation of the gates during fall causes increases in salinity in the Delta, resulting in a 3-km upstream shift in X2 (Enright 2008).

2.6 Climate Change and Drought

Many studies indicate that the next 94 years will likely be very different than the 94 years analyzed above (Null et. al. 2010; Milly et al. 2008; Barnett et al. 2008; Null and Viers 2013), but exactly how the hydrology of the Sacramento/Delta watershed will be affected by climate change is uncertain. California will likely experience more extreme winter floods and longer, more severe droughts in years to come. Air and water temperatures will likely be higher, and evapotranspiration will be greater. The amount of precipitation that falls as snow in the mountains will decrease, and sea level rise will likely affect salinity intrusion in the Delta. The potential effects of climate change are discussed in more detail in Section 4.6, *Climate Change*.

Climate change has increased the probability of temperature and precipitation conditions that historically have led to drought in California (Diffenbaugh et al. 2015). The Bay-Delta hydrology historically has been defined by extreme events, ranging from large winter and spring floods to multi-year droughts. The 2012 to 2016 drought was one of the most severe in California within the past century (CNRA 2021). From water year 2012 through 2016, runoff into the Delta was below normal, with 3 very dry years in a row (2013–2015). Other droughts also have occurred within the SacWAM period of simulation (water years 1922–2015), including in 1929–1934, 1976–1977, and 1987–1992. Modeling data for these drought periods are included in the analysis throughout this chapter.

Droughts are expected to occur in the future, and an additional drought occurred in California during 2020 to 2022. The 2020 to 2022 drought period was severe; however, it was like previous droughts throughout the 94-year analysis in both severity and duration. The average Sacramento Valley annual runoff estimated by DWR for 2020 to 2022 was 9.0 MAF, slightly lower than the next most recent drought in 2012 to 2016 in which the average runoff was 11.6 MAF (Table 2.6-1). The 1976 to 1977 drought was short and severe even when compared with the 2020 to 2022 drought.

Table 2.6-1. Sacramento Valley Unimpaired Runoff

Period (Water Years)	Average Annual Runoff (MAF)
2020–2022	9.0
2012–2016	11.6
1987–1992	10.0
1976–1977	6.7
1929–1934	9.8

Sources: DWR 2016b, DWR 2023.
MAF = million acre-feet

2.7 Existing and Future Water Rights in the Sacramento/Delta Watershed

A *water right* is legal permission to use a reasonable amount of water for a beneficial use such as domestic, irrigation, power, municipal, mining, industrial, fish and wildlife preservation and enhancement, aquaculture, recreational, stock watering, water quality, frost protection, or heat control (Cal. Code Regs., tit. 23, §§ 659–672). In California, the two main categories of surface water rights constitute the majority of diversions: appropriative water rights and riparian water rights.

A *riparian water right* generally provides a right to use the natural flow of a waterbody on riparian land, which is land that touches a lake, river, stream, or creek. Riparian land must be in the same watershed as the water source, and the diverted water must drain back to the source watershed. Riparian rights remain with the property when it changes hands, although parcels severed from the adjacent water source generally lose their right to the water. Riparian rights may be used to divert the natural flow of a stream but may not be used to store water for later use or to divert water that originates in a different watershed, water previously stored by others, return flows from use of groundwater, or other water foreign to the natural stream system. Riparian rights are not lost by non-use.

An *appropriative water right* is generally needed for water that is diverted for use on non-riparian land or to store water for use when it would not be available under natural conditions. An appropriative right holder can use natural flow and non-natural flows, like imported water from other watersheds or irrigation return flows. Prior to 1914, appropriative water rights were acquired by putting water to beneficial use. An appropriative water right that was acquired before 1914 is called a *pre-1914 appropriative water right*. Appropriative water rights obtained after 1914 require a water right permit and, subsequently, a license issued by the State Water Board or its predecessors. Since 1989, water right registrations have been available for expedited acquisition of appropriative water rights for certain small projects (Wat. Code, §§ 1228–1229). For appropriative water rights, seniority is based on a first-in-time concept whereby earlier users of water are more senior to those have put water to use more recently.

When the amount of water available in a surface water source is not sufficient to support the needs of existing water right holders, junior appropriators must cease diversion in favor of more senior rights. In times of shortage, appropriative users must reduce diversions, starting with the most junior user in the watershed, followed by the senior users. Riparian rights generally have a senior (higher relative priority) right to natural flows as against appropriative water rights, and water must be available to fulfill the needs of all riparian right holders before an appropriator may divert. Riparian diverters usually are the last to reduce diversions during shortage; if there is not enough water to satisfy all of the riparian demand, all riparian users must reduce their diversions in a correlative fashion.

Both appropriative and riparian water rights have other associated limitations and stipulations not discussed here.

Currently, all diverters whose diversion and use are not reported by a watermaster are required to submit annual reports of water diversion and use (annual reports) to the State Water Board electronically through the Electronic Water Right Information Management System (eWRIMS) Report Management System (RMS). The eWRIMS database system contains information for various water right types, including riparian and appropriative water rights. Within the eWRIMS database system, post-1914 appropriative water rights are categorized as “Appropriative”; other claims of right, which mainly consist of pre-1914 appropriative and riparian claims, are categorized as “Statements of Diversion and Use.” The eWRIMS database system also includes information for other minor water right types, such as water right registrations.

The annual reports are mandatory filings that document water diversions and uses made during each month of the previous calendar year, including monthly direct diversion volumes, monthly diversion to storage volumes, and monthly water use volumes. A separate annual report of water diversion and use is required for each water right each year; therefore, a diverter may be required to submit more than one annual report if they hold or claim more than one right. Diversion data contained within annual reports is self-reported and is not systematically verified for accuracy upon submittal. Water right holders and claimants that divert water under Statements of Diversion and Use also provide information about the water right claim type (e.g., riparian, pre-1914 appropriative) in annual reports.

This section presents a water right demand data summary for the Sacramento/Delta watershed using information from a demand dataset developed as a component of the State Water Board's Water Unavailability Methodology for the Delta watershed (Water Unavailability Methodology). The Water Unavailability Methodology identifies when supply and demand data indicate that water is unavailable for diversion by water right holders at their priorities of right; it is used to support issuance of curtailment orders to water right holders and claimants in the Delta watershed pursuant to an emergency curtailment and reporting regulation. 2018 and 2019 diversion data contained within annual reports form the basis for estimates of water demand used in the Water Unavailability Methodology and summarized in this section.

As discussed in the Water Unavailability Methodology summary report (SWRCB 2023), an internal review and quality control effort was conducted as part of the water right demand data summary. Technical Appendix B of the Water Unavailability Methodology (SWRCB 2022) summarizes (1) the process used to select water right records in the Delta watershed; (2) the quality control process used to review diversion data submitted by water right holders and claimants and address diversion data reporting inaccuracies; and (3) demand dataset updates and formatting.

A review of the water right records in the Sacramento/Delta watershed included in the demand dataset shows that the total volume of water authorized for diversion in the Sacramento/Delta watershed exceeds the total average unimpaired outflow from the Bay-Delta watershed. The total average unimpaired outflow from the Bay-Delta watershed is about 28.5 MAF/yr. The face value, or total volume of water authorized for diversion, of the active consumptive post-1914 appropriative water right records in the Sacramento/Delta watershed is approximately 159 MAF/yr (Table 2.7-1a), which is over five times the total annual average unimpaired outflow for the entire Bay-Delta watershed. This total face value amount excludes statements of diversion and use (including riparian and pre-1914 appropriative claims), which are not assigned a face value amount but account for many of the water right records in the Sacramento/Delta watershed. While there are some reasons for large discrepancies between the total face value and supply available, such as the addition of return flows, duplicative claims for a single use, and face values that tend to exceed actual water demand (e.g., once reservoirs are filled they can maintain a significant amount of storage from year to year), the fact remains that under existing water right records, a large volume of water is authorized for diversion in the Bay-Delta watershed, and there is the potential for future development to increase the diversion and reduce Delta outflow.

There are thousands of active diversions in the Sacramento/Delta watershed. As shown in Tables 2.7-1a through 2.7-1c, there are approximately 14,300 active water right records in the Sacramento/Delta watershed, including approximately 5,210 post-1914 appropriative, 6,450 pre-1914 appropriative and riparian, and 2,640 water right registration records. All demand values presented in Tables 2.7-1a through 2.7-1c are rounded to the nearest 10 TAF, and all water right record counts are rounded to the nearest 10.

Post-1914 appropriative water right records (Table 2.7-1a) make up fewer than half of the total number of water right records but account for the majority of the water diverted, due in large part because the SWP and CVP (Project) diversions generally occur under post-1914 appropriative water rights. (Some water right records contain multiple points of diversion. Approximately 20 post-1914 appropriative water right records owned by DWR or Reclamation and identified in D-1641 have points of diversion that span both the Sacramento River watershed and Delta regions. For the purposes of the summary data shown in this chapter, these records and their associated face values and reported diversions are included under the Project water rights category in Table 2.7-1a. Additionally, non-Project water rights with multiple points of diversion and that report at least one of these points of diversion in the Delta, are included in the summary of water rights in the Legal Delta.)

Based on the water right summary information shown in Tables 2.7-1a through 2.7-1c, water right face values tend to exceed actual diversions, and certain diversion categories account for most of the water diverted in the Sacramento/Delta watershed. Overall, the total water right face value of approximately 159 MAF for the post-1914 appropriative water right records far exceeds the total reported diversion of approximately 10.6 MAF in 2018 and 14.3 MAF in 2019 under these records. Statements of diversion and use, including pre-1914 appropriative and riparian water right records, are identified in Table 2.7-1b and do not have assigned face values, but the reported total diversion of approximately 4.5 MAF in 2018 and 4.9 MAF in 2019 is less than the total diversion volumes reported under the appropriative water right records.

There are also many stockponds, water right registrations, and other small diversions in the Sacramento/Delta watershed. The Water Unavailability Methodology assumes that minor water right types, such as stockponds and water right registrations, constitute a negligible demand. Accordingly, all demands for these records have been set to zero in the demand dataset. However, Table 2.7-1c shows that there are approximately 2,350 of these records in the Sacramento River watershed, 290 in the Delta eastside tributaries, and less than 10 in the Delta.

Table 2.7-1a. Summary of Active Water Right Records in the Sacramento/Delta Watershed: Post-1914 Appropriative Water Rights

Region	Number of Unique Water Right Records	Total Face Value (TAF)	Total 2018 Reported Diversion (TAF)	Total 2019 Reported Diversion (TAF)
Sacramento River watershed [a]	3,670	109,100	3,270	4,820
Delta eastside tributaries [b]	1,210	5,630	620	700
Delta [c]	310	2,960	330	590
Project [d]	20	41,610	6,420	8,190
Total	5,210	159,300	10,640	14,300

TAF = thousand acre-feet

[a] The Sacramento River watershed includes the entire HUC4 Sacramento River watershed, excluding portions of the HUC4 Sacramento River watershed within the boundaries of the Legal Delta. Water rights with points of diversion within both the HUC4 Sacramento River watershed and the Legal Delta are not included.

[b] Delta eastside tributaries includes the HUC8 Calaveras, Cosumnes, and Mokelumne watersheds, excluding any portions of these watersheds within the boundaries of the Legal Delta. Water rights with points of diversion within both the Delta eastside tributaries region and the Legal Delta are not included.

[c] Delta is the Legal Delta. Non-Project water rights with points of diversion within both the Sacramento River watershed or Delta eastside tributaries and the Legal Delta are included in these data.

[d] Project water rights are California Department of Water Resources or U.S. Bureau of Reclamation water rights identified in Water Right Decision 1641 that authorize diversion of natural flow in the Sacramento River watershed and Legal Delta (i.e., not including Trinity, Friant, and New Melones water rights).

Table 2.7-1b. Summary of Active Water Right Records in the Sacramento/Delta Watershed: Statements of Diversion and Use

Region	Number of Unique Water Right Records	Total 2018 Reported Diversion (TAF)	Total 2019 Reported Diversion (TAF)
Sacramento River watershed	3,630	3,260	3,620
Delta eastside tributaries	480	70	80
Delta	2,340	1,200	1,170
Total	6,450	4,530	4,870

TAF = thousand acre-feet

Table 2.7-1c. Summary of Active Water Right Records in the Sacramento/Delta Watershed: Minor Water Right Types

Region	Number of Unique Water Right Records	Total Face Value (TAF)
Sacramento River watershed	2,350	10
Delta eastside tributaries	290	>10
Delta	>10	>10
Total	2,640	10

TAF = thousand acre-feet

Although there are thousands of diversions in the Sacramento/Delta watershed, a relatively small number of diverters, including DWR and Reclamation, account for most of the total face value of the water right records in the Sacramento/Delta watershed. DWR and Reclamation collectively have a total of approximately 170 active water rights and claims, as summarized in Table 2.7-2. These records include the approximately 20 Project water rights identified in Table 2.7-1a, and other DWR and Reclamation water rights and claims. The majority of total reported diversion amounts are associated with CVP and SWP (Project) diversions and uses but also include some other non-Project diversions; for example, Reclamation has several water right records associated with the Orland Project on Stony Creek. The combined face value of the rights held by DWR and Reclamation is approximately 93 MAF in the Sacramento River watershed and Legal Delta, which greatly exceeds the total reported volume of water diverted under the DWR and Reclamation water right records in 2018 and 2019.

Table 2.7-2. Summary of California Department of Water Resources and U.S. Bureau of Reclamation Water Right Records in the Sacramento/Delta Watershed

Primary Owner	Number of Unique Water Right Records	Total Face Value (TAF)	Total 2018 Reported Diversion (TAF)	Total 2019 Reported Diversion (TAF)
California Department of Water Resources	130	30,770	2,170	4,690
U.S. Bureau of Reclamation	40	63,760	4,480	3,850

TAF = thousand acre-feet

At the regional level, most of the active water right records divert relatively small (less than 1 TAF) of water. A relatively small number of active water right records accounts for most of the total volume of water diverted in the Sacramento/Delta watershed. Table 2.7-3a and 2.7-3b provide a summary of 2018 and 2019 reported diversions in the Sacramento/Delta watershed by diversion volume, based on four diversion volume categories: (1) 0–1 TAF; (2) 1–10 TAF; (3) 10–100 TAF; and (4) volume greater than 100 TAF. Minor water right types as defined above are excluded from Table 2.7-3a and 2.7-3b. These tables show that most of the water diverted in the Sacramento/Delta watershed in 2018 and 2019 was diverted under approximately 20 water right records, which include some DWR and Reclamation diversions as well as diversions by other water users such as Yuba County Water Agency, EBMUD, and Solano County Water Agency. Conversely, most (over 11,000) water right records reported diversions of 1 TAF or less during 2018 and 2019.

Table 2.7-3a. Summary of 2018 Reported Diversions by Volume for Water Right Records in the Sacramento/Delta Watershed

2018 Reported Diversion Volume Category	Number of Active Water Right Records	Total 2018 Reported Diversion (TAF)
0–1 TAF	11,030	950
1–10 TAF	720	1,870
10–100 TAF	130	3,420
>100 TAF	20	5,410

TAF = thousand acre-feet

Table 2.7-3b. Summary of 2019 Reported Diversions by Volume for Water Right Records in the Sacramento/Delta Watershed

2019 Reported Diversion Volume Category	Number of Active Water Right Records	Total 2019 Reported Diversion (TAF)
0–1 TAF	11,020	990
1–10 TAF	710	1,860
10–100 TAF	130	3,750
>100 TAF	20	5,980

TAF = thousand acre-feet

The Bay-Delta Plan establishes water quality control measures and flow requirements needed to provide reasonable protection of beneficial uses in the watershed, including fish and wildlife beneficial uses. Responsibility for meeting the existing Bay-Delta Plan objectives falls primarily on only two water right holders in the watershed: DWR and Reclamation for the SWP and CVP, respectively. Many other diverters do not have specific requirements to provide bypass flows or to contribute to the existing Bay-Delta Plan objectives, such as the existing Delta outflow requirements.

Specific issues that arose during multiple recent drought years with the current requirements illustrate that issues will be exacerbated with climate change and additional water development. Under D-1641, DWR and Reclamation assumed responsibility for meeting existing Delta outflow and salinity objectives and subsequently submitted Temporary Urgency Change Petitions (TUCP) to the State Water Board requesting modification of these obligations during drought and drought recovery periods. The purpose of these TUCP requests was in large part to provide for maintaining reservoir storage supplies for salinity control, minimal water supplies, and temperature management for the protection of the fishery. Exhaustion of these supplies is exacerbated during drought conditions due to the focused responsibility of DWR and Reclamation to meet these requirements rather than those obligations being distributed broadly over the watershed. The State Water Board has approved multiple TUCPs in recent years related to the Projects' D-1641 requirements, including TUCPs submitted by the Projects in 2014, 2015, 2016, 2021, 2022, and 2023 (petitions also were submitted in 2008/2009). California law identifies TUCPs as limited to urgencies that cannot otherwise be avoided through the exercise of due diligence (Wat. Code, § 1435, subd. (c)). It is foreseeable that the State Water Board may receive and could approve TUCPs during future drought and drought recovery periods.

At times, DWR and Reclamation meet the flow and water quality objectives by bypassing flows, releasing previously stored water, or reducing Delta diversions. When natural and abandoned flows are inadequate to meet Delta flow and water quality requirements, diversions by other water users also can result in the need for the Projects to release previously stored water to meet water quality requirements. During drought conditions, these quantities of water can be significant and can deplete reservoir storage supplies needed for multiple purposes, including meeting water quality and temperature requirements later in the same year or in the following year.

To protect previously stored Project water and to prevent water users from diverting natural flows contributing to Delta flow and water quality requirements, the State Water Board has included Term 91 in the permits and licenses of the most junior water diverters in the Delta watershed. Term 91 enables the State Water Board to curtail water diversions when the Projects are required to release previously stored water to meet Delta flow and water quality requirements and other in-basin (within the Delta watershed) non-Project demands, referred to as *supplemental Project water*. Term 91 effectively prevents water right holders subject to the term from diverting the Projects' stored water and makes those users partially responsible for bypassing natural and abandoned flows needed to meet Delta flow-dependent water quality objectives. However, Term 91 currently applies to only a very small number (115) of the water rights and claims of right in the Delta watershed, which significantly limits the effectiveness of these curtailments.

Table 2.7-4 summarizes the estimated supplemental Project water that the Projects released from storage to meet D-1641 requirements each year for the period of 2000 to 2022.[2]

Table 2.7-4. SWP and CVP Supplemental Project Water Releases from 2000 to 2022

Water Year	Sacramento 40-30-30 Water Year Type	San Joaquin 60-20-20 Water Year Type	Term 91 Supplemental Project Water (AF, Total) [a]
2000	AN	AN	731,800
2001	D	D	1,368,500
2002	D	D	1,218,800
2003	AN	BN	741,700
2004	BN	D	1,332,900
2005	AN	W	229,100
2006	W	W	269,600
2007	D	C	1,812,500
2008	C	C	1,611,800
2009	D	BN	1,423,000
2010	BN	AN	416,800
2011	W	W	94,400
2012	BN	D	1,924,000
2013	D	C	2,393,700

[2] This includes imports from the Trinity River system.

Water Year	Sacramento 40-30-30 Water Year Type	San Joaquin 60-20-20 Water Year Type	Term 91 Supplemental Project Water (AF, Total) [a]
2014	C	C	2,408,000
2015	C	C	2,465,400
2016	BN	D	1,772,100
2017	W	W	0
2018	BN	BN	1,687,300
2019	W	W	1,125,300
2020	D	D	1,935,600
2021	C	C	2,225,300
2022	C	C	1,184,600

Source: Reclamation 2023.
Water year type: AN = above normal; BN = below normal; C = critical; D = dry; W = wet.
AF = acre-feet
[a] Supplemental Project water can be calculated in different ways. The supplemental Project water identified here is a number calculated daily by the U.S. Bureau of Reclamation according to an equation in State Water Board Order Water Right 81-15. The published data were aggregated and adjusted downward for excess conditions when more water is released from storage than is needed for exports + in-basin demands + Delta water quality and outflow requirements.

Existing flows include unprotected Delta outflows that are not currently regulatorily required and as such could be diminished in the future as a result of (1) exercising existing water rights more fully, since many water rights are not currently fully exercised; or (2) new water rights in the absence of additional regulatory requirements. Currently, a large volume of water is reserved for future use under unassigned state filed water rights. To provide for growth and development in areas that were not yet built out in the Bay-Delta watershed and other areas of the state, soon after post-1914 appropriative water rights were established, the legislature enacted Water Code section 10500 that sets aside reservations of post-1914 water rights (referred to as *state filed water rights* or *state filings*) for future assignment. These state filings maintain the water right priority of the date they were established, which date back to as early as 1927. In addition, multiple pending water right applications in the Bay-Delta watershed for new appropriations of water could place further demands on flows from the watershed if approved in the future. Overall, in the Sacramento/Delta watershed, there are currently approximately 130 pending appropriative water right applications and approximately 70 unassigned state filings with a total face value of over 10 MAF. Given these potential future demands and limited existing flow requirements in the Bay-Delta watershed, Sacramento/Delta inflows and Delta outflows could be diminished in the future as a result of additional diversions and water demands in the absence of additional regulatory flow requirements.

2.8 Existing Water Supply

Many of California's communities and much of its vast economy and agricultural industry are dependent on a complex water distribution infrastructure that stores, manages, and transports water from its original sources in the Bay-Delta watershed to the locations where it is eventually used throughout the state. The Delta and many of the tributaries in its watershed have been extensively developed for agricultural and urban water supply, as well as hydropower generation and flood control. The physical infrastructure and the effects of these operations on hydrology and hydrodynamics are generally described in Sections 2.2, *Hydrology of the Sacramento River and Major Tributaries*, 2.3, *Flood Basins*, and 2.4, *Sacramento-San Joaquin Delta*. This section discusses existing water supply and the water sources relied upon for agricultural, municipal,[3] and wildlife refuge beneficial uses.[4] The term *water supply* is used throughout this report to describe water that is supplied for beneficial uses (e.g., agricultural use, municipal use).

The Sacramento River watershed, Delta eastside tributaries, and Delta regions are collectively referred to as the *plan area, Sacramento/Delta watershed* or *Sacramento/Delta*. Surface water from the Sacramento/Delta (referred to as *Sacramento/Delta supply*) is supplied to users within the plan area, as well as to users in several other regions in California. Therefore, a larger *study area* is also defined to provide context for total water supplies. Figures 2.8-1a and 2.8-1b shows the location of the plan area and study area in California. As shown in Figure 2.8-1a, the study area is divided into seven geographic regions based on geography and water supply, including the Sacramento River watershed, Delta eastside tributaries, Delta, San Joaquin Valley, San Francisco Bay Area, Central Coast, and Southern California. Only a portion of the water supplied to each of the regions is derived from surface water from the Sacramento/Delta watershed.

The study area regions generally correspond to the hydrologic regions defined in the California Water Plan or are aggregations of hydrologic regions, differing where appropriate. Figure 2.8-1b shows the location of the study area geographic regions and the DWR hydrologic regions identified in the California Water Plan for comparison purposes. The study area includes the entire Sacramento/Delta watershed as well as the other areas that receive Sacramento/Delta supplies, such as the SWP and CVP service areas, and other services areas (e.g., EBMUD service area in the San Francisco Bay Area) that receive Sacramento/Delta supplies. (Refer to Figures 2.8-3a, 2.8-3b, and 2.8-3c for these service areas and major SWP, CVP, and other conveyances further discussed in sections below).

SacWAM estimates that the total annual Sacramento/Delta supply to users in the study area ranges from approximately 7.4 to 14.8 MAF depending on hydrology, with an average of about 11.9 MAF. In addition to Sacramento/Delta supplies, existing water supplies can include *other water supplies*, such as supplies derived from surface water sources outside of the Sacramento/Delta watershed, groundwater, groundwater banking (also referred to as groundwater storage and recovery), recycled water, water transfers, water conservation measures, and desalination. Municipal and agricultural water planning documents refer to this mixture of water supplies as a *water supply portfolio*. Over time, the amount of other water supplies in many local and regional water supply portfolios has expanded in response to limited surface water supplies and increasing water demands due to many factors. These other water supplies are discussed in more detail in Chapter 6, *Changes in Hydrology and Water Supply*. Some potential water supplies involve construction of future projects such as desalinization plants and new or modified reservoirs.

As explained above, the study area is divided into seven regions based on geography and water supply (Figure 2.8-1b). The study area regions generally correspond to the hydrologic regions defined in DWR's California Water Plan or are aggregations of hydrologic regions, differing where appropriate for the current analysis. There is no regulatory significance to the study area regions designated in this Staff Report, and information presented in this document occasionally spans regional boundaries. In these cases, information generally is presented where it best aligns with

[3] For the purposes of this document, a reference to *municipal use* includes domestic and industrial uses unless otherwise specified. The terms *urban* and *municipal and industrial (M&I)* are also sometimes used in this document to generally reference municipal water supplies.

[4] The term *water supply* used in this report refers to water delivered to users and does not include transmission losses from major canals and aqueducts.

geographic boundaries. For example, several counties span portions of multiple study area geographic regions, and county-level data generally are presented in context of the region with which the county best aligns geographically.

The following sections describe the existing water supply in each study area geographic region based on historical water deliveries data and estimates of Sacramento/Delta supply from SacWAM results. The historical water deliveries data convey the overall magnitude of the average water supply available to each region and sector (i.e., agriculture, municipal, managed wetland uses) and are summarized in Table 2.8-1 and Table 2.8-2. These data are based on evaluation of historical water deliveries data from DWR's 2018 California Water Plan and other sources. The methods used to obtain the historical water deliveries data estimates are described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data*. Overall, the historical water deliveries data indicate that the average annual total surface water and other water supply to the study area was approximately 24 MAF, and the average annual total groundwater supply was approximately 17 MAF, for an annual average total of approximately 41 MAF for the period of 2005–2015 (Table 2.8-1 and Table 2.8-2).

SacWAM estimates of Sacramento/Delta surface water supply to the study regions is provided in Table 2.8-3. SacWAM results are provided for surface water supplies for the Sacramento/Delta watershed. Results also are provided for Sacramento/Delta supply to the other study area geographic regions, which include the Bay Area, San Joaquin Valley, Central Coast, and Southern California regions. Sacramento/Delta supplies to these regions were estimated using SacWAM results and additional information regarding to which sectors (agriculture or municipal suppliers) the water ultimately is delivered. This process is described in Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

Although both SacWAM and historical water deliveries data provide useful information on regional water supplies, these data are derived from different sources, and any comparison of data from the two sources should be done cautiously. Comparisons of the historical water deliveries data and SacWAM results are provided throughout this report to generally show the proportion of Sacramento/Delta supply for any given region relative to the total water supply for that region. This is a reasonable use of the data from the two sources. In the sections that follow, the historical water deliveries data estimates are provided for total, groundwater, and surface water and other supplies; and SacWAM estimates are provided for Sacramento/Delta surface water supply for each geographic region. *Surface water and other water supplies* is used to describe the existing water supply estimated from historical water deliveries data, recognizing that surface water as well as recycled water and other non-groundwater supplies are included in these estimates. The existing water supply estimated from historical water deliveries data includes estimates of managed wetlands supply, which includes water supply to refuges and some rice fields managed for multiple uses. SacWAM includes estimates of supply to state and federal refuges and includes supply to rice production as agricultural supply.

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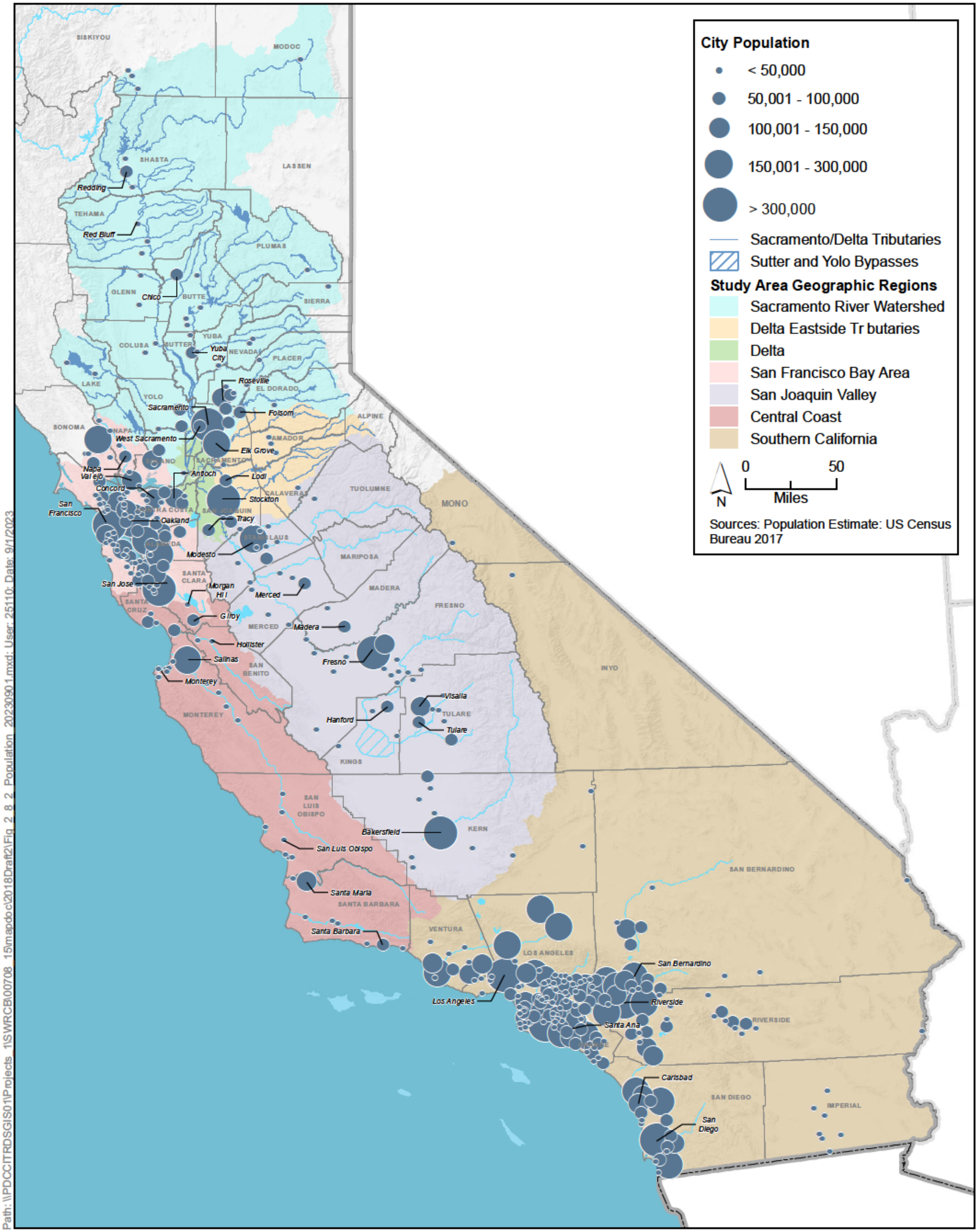
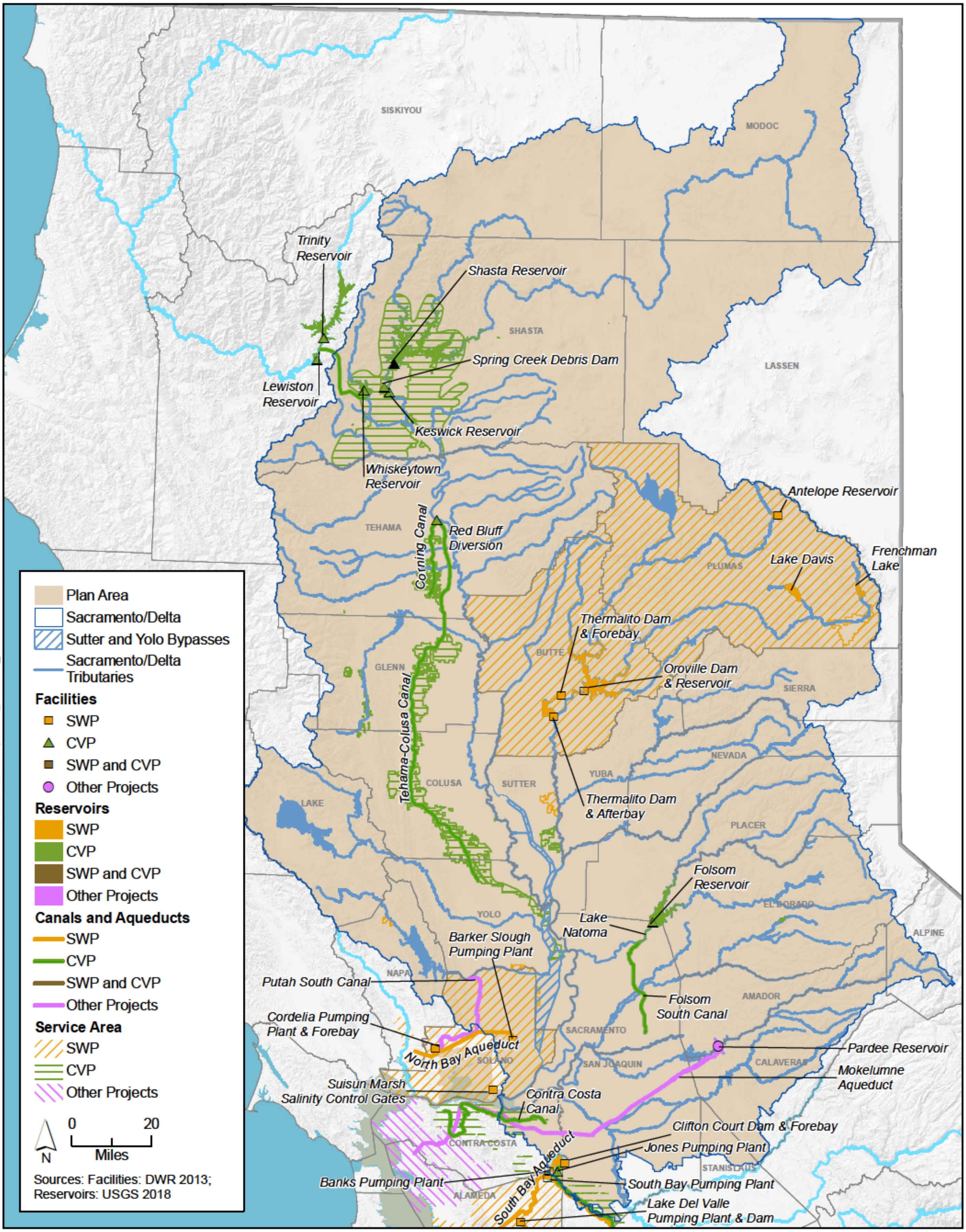
Figure 2.8-1a
Plan Area and Study Area Geographic Regions

Figure 2.8-1b
Study Area Geographic Regions and DWR Hydrologic Regions



Path: \\PDCCITRDSGIS01\Projects_1\SWRCB\00708_15\mapdoc\2018Draft2\Fig_2_8_2_Population_20230901.mxd; User: 25110; Date: 9/1/2023

Figure 2.8-2
Population Centers in the Study Area



Path: \\PDCCITRDSGIS01\Projects_1\SWRCB\00708_15\mapdoc\2018Draft2\Fig_2_8_3a_Conveyances_northern_20230818.mxd; User: 25110; Date: 8/18/2023

Figure 2.8-3a
Conveyances and Facilities (northern)

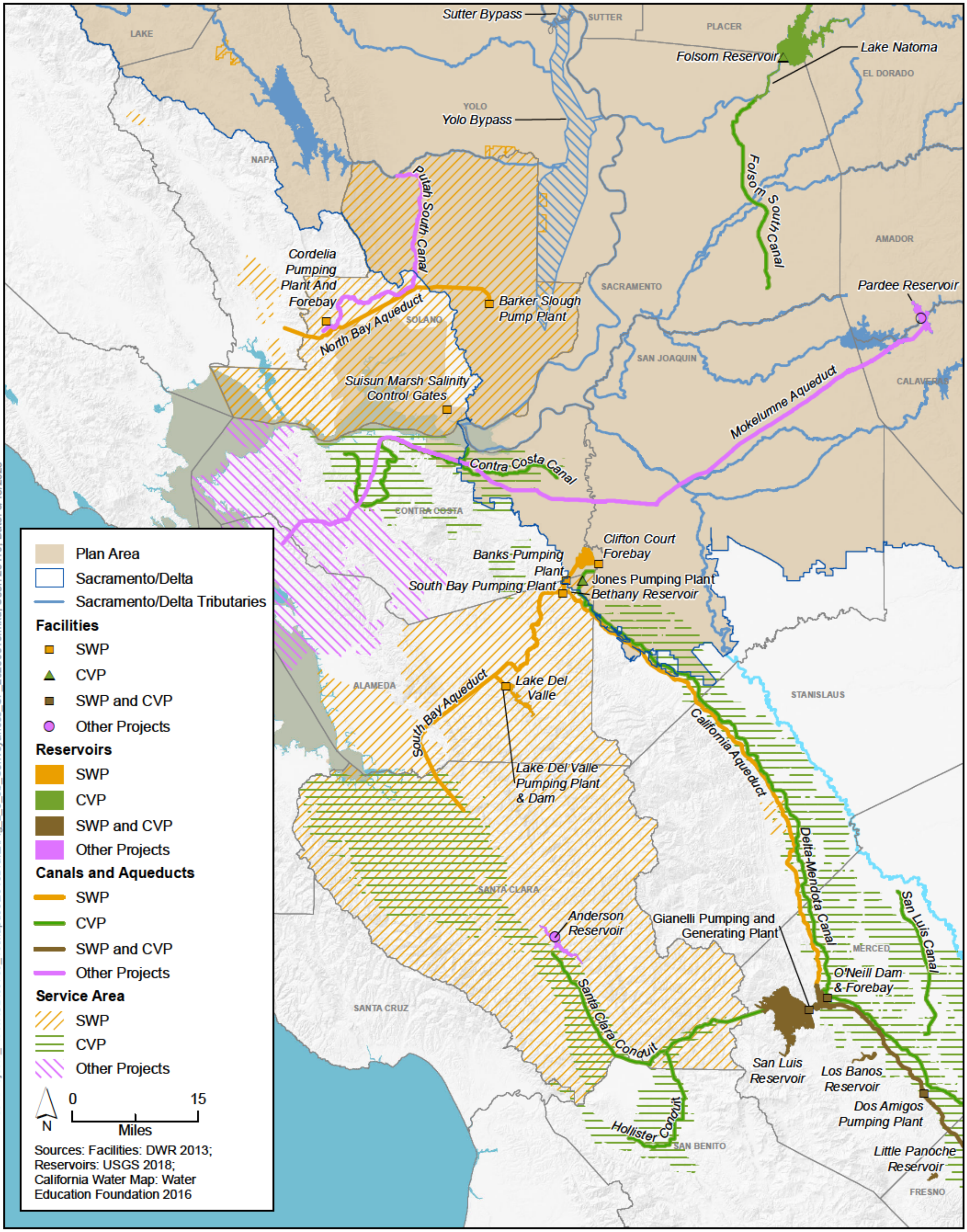


Figure 2.8-3b
Conveyances and Facilities (San Francisco Bay Area)

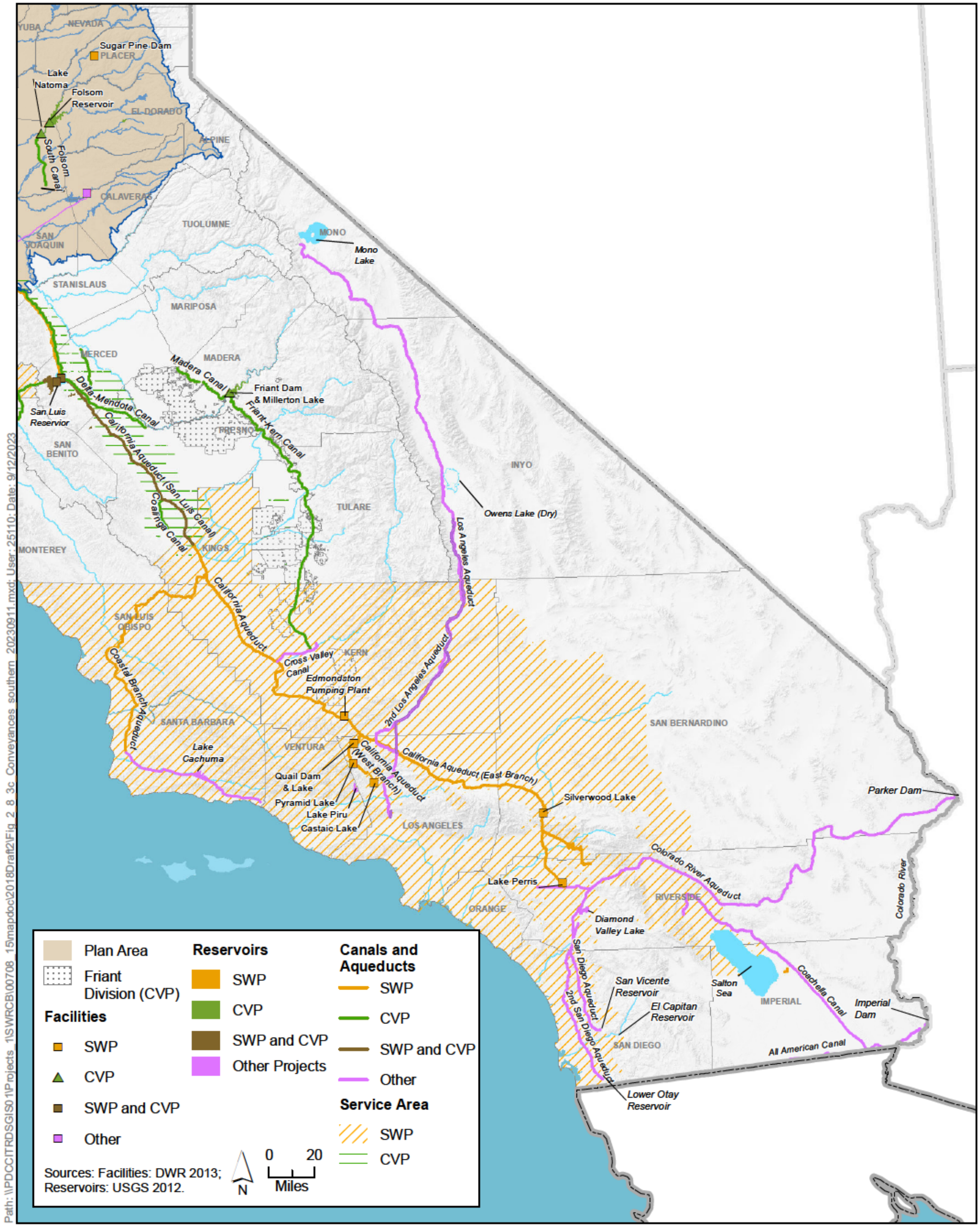


Figure 2.8-3c
Conveyances and Facilities (southern)

Table 2.8-1. Estimated Average Annual Total Surface Water and Other Water Supplies by Geographic Region and Sector (thousand acre-feet)

Geographic Region	Agriculture	Municipal	Managed Wetlands	Total
Sacramento River watershed	4,501	439	431	5,371
Delta eastside tributaries	279	102	8	389
Delta	1,151	96	48	1,294
San Francisco Bay Area	57	905	26	987
San Joaquin Valley	7,769	231	330	8,330
Central Coast	87	83	<1	170
Southern California	4,071	2,928	68	7,067

Values presented in this table are average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data*.

Table 2.8-2. Estimated Average Annual Groundwater Supply by Geographic Region and Sector (thousand acre-feet)

Geographic Region	Agriculture	Municipal	Managed Wetlands	Total
Sacramento River watershed	2,272	387	20	2,679
Delta eastside tributaries	545	53	<1	597
Delta	34	40	0	74
San Francisco Bay Area	80	184	0	264
San Joaquin Valley	9,034	823	251	10,107
Central Coast	968	196	0	1,164
Southern California	792	1,590	<1	2,382

Values presented in this table are average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data*.

Table 2.8-3. Simulated Average Annual Sacramento/Delta Surface Water Supply by Geographic Region and Sector (thousand acre-feet)

Geographic Region	Agriculture	Municipal	Refuge	Total
Sacramento River watershed	4,641	480	199	5,320
Delta eastside tributaries	124	81	0	205
Delta	1,136	18	0	1,154
San Francisco Bay Area	27	670	0	698
Central Coast	37	49	0	86
San Joaquin Valley	2,422	99	298	2,819
Southern California	14	1,661	0	1,675

Values presented in this table are simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results* and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use.*

The water supply summaries in Table 2.8-1 and Table 2.8-2 demonstrate regional differences in water supply portfolios. The water supply in some regions, such as the San Joaquin Valley, is used primarily for agricultural purposes, while the water supply in other regions, such as the San Francisco Bay Area, is used primarily for municipal purposes. Some regions, such as the Central

Coast, depend primarily on groundwater, while other regions, such as the San Francisco Bay Area, depend primarily on surface water supplies. Regional water supply portfolios and water uses are further described in Sections 2.8.1 through 2.8.7. These characterizations of the geographic regions in the study area are based on historical water deliveries data (2005–2015 average annual values) and SacWAM results, as available.

The following regional descriptions also discuss residential per capita water use and provide residential gallons per capita per day (R-GPCD) water use values for each of the geographic regions based on an analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). The R-GPCD was calculated by partitioning the urban water suppliers and associated reporting data amongst the study area geographic regions using a spatial query. The R-GPCD value was then calculated for each month as the combined total reported monthly potable water production for all urban water suppliers in the region, divided by the total population served by all the urban water suppliers in the region. Only large urban water suppliers, which include water providers that produce 3,000 acre-feet per year (AF/yr) of water or serve 3,000 or more service connections, are required to submit urban water supplier monthly reports. Therefore, per capita water use from small urban water suppliers and domestic sources are not included in these calculations.

The following regional descriptions also provide information on recycled water use drawn from county-level data reported in the Municipal Wastewater Recycling Survey (SWRCB 2015, Table 4) and other sources as available. Because some counties span multiple regions, county-level data were divided among regions based on a geographic information system analysis of the overlap of the land area of each county with the regions. Estimates of municipal water use efficiency were obtained by using data reported to the State Water Board pursuant to emergency water conservation regulations to estimate water use efficiency as a population-weighted average of the available data (SWRCB 2018).

2.8.1 Sacramento River Watershed

The Sacramento River watershed includes the Sacramento River and its tributaries. This region is bounded by the Sierra Nevada on the east, the Coast Ranges on the west, the Cascade and Trinity Mountains on the north, and the Bay-Delta on the south. This region closely resembles the Sacramento River Hydrologic Region as described in the California Water Plan but does not include the portion of the Delta that overlies the Sacramento River hydrologic region (Figure 2.8-1a). In 2018, the Sacramento River watershed supported approximately 1.8 million acres of irrigated agriculture, mostly on the valley floor (^Land IQ 2021) (see Figure 7.4-4a in Section 7.4, *Agriculture and Forest Resources*). The 2016 population estimate of the Sacramento River watershed was approximately 2.9 million people (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*). The most populous cities in the region are Sacramento, Elk Grove, and Roseville; these and other population centers in the study area are depicted in Figure 2.8-2. The City of West Sacramento spans the boundary between the Sacramento River watershed and Delta and, for the purposes of this report, is included in the Sacramento River watershed.

Water users in the Sacramento River watershed rely on groundwater and surface water sources. The region's surface water supplies include CVP deliveries, SWP deliveries, and other local surface water sources—primarily from within the Sacramento River watershed, with some water imported from the Trinity River.

Historical water deliveries data indicate that the average annual total water supply in the Sacramento River watershed during 2005–2015 was approximately 8,050 TAF, with over 80 percent (6,773 TAF) going to agricultural uses (Table 2.8-4). SacWAM estimates average annual wetland/refuge supplies of 199 TAF, while the historical water deliveries data indicate that managed wetland supplies are approximately double this value. This reflects SacWAM's narrower definition of refuge supplies, which includes supplies to national wildlife refuges, national wildlife management areas, and state wildlife areas but does not include private managed wetlands associated primarily with rice agriculture (SWRCB 2017). In contrast, the historical water deliveries data for managed wetlands supply include agricultural supplies that provide wetland habitat (^2013 Water Plan V1). Out of the region's total water supply, approximately 5,320 TAF is derived from Sacramento/Delta surface water supplies as estimated by SacWAM (Table 2.8-4).

Table 2.8-4. Average Annual Sacramento River Watershed Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	4,501	2,272	6,773	4,641
Municipal	439	387	826	480
Wetland/Refuge	431	20	451	199
All Sectors	5,371	2,679	8,050	5,320

[a] Average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data.*
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

The Sacramento metropolitan area is the largest metropolitan area in the region. It relies primarily on surface water supplies to meet municipal demand and is served by more than 20 water purveyors. The City of Sacramento receives approximately 80–90 percent of its total water supply from surface water sources, and the City of Folsom receives all of its water supply from Folsom Lake (^2013 Water Plan V1). Several other metropolitan area purveyors in this region receive CVP water originating in the American River watershed. Many other municipal water users in the region depend on groundwater for municipal water supplies. Some areas, such as the Colusa basin planning area, rely entirely on groundwater for municipal water supplies (^2013 Water Plan V1).

The Sacramento River watershed has approximately 500 community drinking water systems. A *community water system* is a public water system that supplies water to the same population year-round. Over 80 percent of these community drinking water systems are considered small and serve fewer than 3,300 people; most small water systems serve fewer than 500 people. In contrast, medium and large water systems account for less than 20 percent of the region's drinking water systems; however, these medium and large systems deliver drinking water to over 90 percent of the region's population. (^2013 Water Plan V1)

There are multiple economically disadvantaged communities in the Sacramento River watershed. Almost all the region's counties contain at least one economically disadvantaged community. Economically disadvantaged communities account for more than 50 percent of all communities in Butte, Colusa, Glenn, Lake, Modoc, Nevada, Plumas, Shasta, Siskiyou, Tehama, and Yuba Counties (^2013 Water Plan V1).

Residential per capita water use in the Sacramento River watershed is higher than in more heavily urbanized regions of the state, with overall use ranging from 226 R-GPCD in 2013 to 161 R-GPCD in 2015 based on analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). Some recycled water also is used in the Sacramento River watershed for landscape irrigation and other purposes. The California Water Plan reports that recycled water is used in the American River Basin Integrated Regional Water Management effort. The Sacramento Regional County Sanitation District reports that more than 3.4 billion gallons (about 10 TAF) of recycled water has been used for landscape irrigation in Elk Grove neighborhoods since 2003 (Regional San 2014). According to county-level data reported in the Municipal Wastewater Recycling Survey (SWRCB 2015), approximately 21.5 TAF of recycled water is used each year in the Sacramento River watershed.

The CVP and SWP are the largest distributers of water in the Sacramento River watershed, which together deliver about 63 percent of the total surface water to this region as estimated by SacWAM. Several different types of CVP contracts provide for different allocations based on the available annual supply. Similarly, different types of SWP contracts provide for different allocations based on hydrology. The sections that follow describe CVP and SWP deliveries to contractors in the Sacramento River watershed. Figure 2.8-3a shows the CVP and SWP conveyance systems in these areas.

2.8.1.1 Central Valley Project Deliveries

Major CVP reservoirs in the Sacramento River watershed include Shasta Reservoir on the Sacramento River and Folsom Reservoir on the American River. In addition, Whiskeytown Reservoir on Clear Creek receives CVP water imported from the Trinity River. The CVP delivers water to several categories of north-of-Delta contractors: (1) Sacramento River settlement contractors; (2) agricultural water service contractors; (3) municipal and industrial (M&I) water service contractors; and (4) wildlife refuge contractors. In total, these CVP north-of-Delta water users have a maximum contract allocation of approximately 2.9 MAF of water (Reclamation 2016). However, actual delivery amounts are often lower than the maximum contract totals. According to SacWAM results, average CVP deliveries are about 2.5 MAF/yr to these water contractors. Nearly all the north-of-Delta CVP deliveries are to users in the Sacramento River watershed; however, there are north-of-Delta M&I contractors in the Bay Area. (CVP deliveries to Bay Area contractors is discussed in Section 2.8.4, *San Francisco Bay Area*.)

The majority of the CVP water is allocated to Sacramento River settlement contractors who hold maximum contract amounts totaling approximately 2.1 MAF/yr (Reclamation 2016). The approximately 140 Sacramento River settlement contractors receive supply from natural flow, storage regulated at Shasta Dam, and Trinity River imports. According to SacWAM, settlement contractors on average receive approximately 1.8 MAF/yr of surface water supplies, including water diverted directly from the Sacramento River. The majority of water is for agricultural uses (^2013 Water Plan V1).

North-of-Delta agricultural water service contractors receive water supply from the same sources as the Sacramento River settlement contractors. SacWAM estimates annual deliveries to north-of-Delta agricultural contractors average about 300 TAF/yr of the total maximum contract amount of about 460 TAF/yr, also primarily for agricultural uses.

North-of-Delta M&I water service contractors are located primarily in the American River basin, with a small portion delivered to the Bay Area via the Mokelumne Aqueduct and the Contra Costa

Canal. The CVP American River Division users hold contracts for deliveries from Folsom Dam and Reservoir, Folsom South Canal, and the Upper American River for municipal water supply purposes. According to SacWAM, existing CVP north-of-Delta M&I deliveries are estimated at about 84 TAF/yr, substantially lower than the contract amount of 384 TAF because of water availability and because many contractors in the American River Division have not yet developed demand for full contract supplies.

Five Central Valley Project Improvement Act (CVPIA) wildlife refuges are located in the Sacramento River watershed: Sacramento National Wildlife Refuge, Delevan National Wildlife Refuge, Colusa National Wildlife Refuge, Sutter National Wildlife Refuge, and Gray Lodge State Wildlife Area. All five of these refuges have entered into CVP water supply contracts with Reclamation; however, infrastructure limitations hinder Reclamation's ability to deliver the full amount of water to several refuges, including Sutter National Wildlife Refuge and Gray Lodge State Wildlife Area. (See Section 7.6.1, *Terrestrial Biological Resources*, for further discussion.) North-of-Delta CVPIA refuges have contract allocations of 151 TAF/yr (Reclamation 2016). SacWAM estimates average surface water deliveries to Sacramento River watershed wildlife refuges of about 132 TAF/yr (see Appendix A1, *Sacramento Water Allocation Model Methods and Results*).

2.8.1.2 State Water Project Deliveries

SWP reservoirs in the Sacramento River watershed are Oroville Reservoir, Thermalito Afterbay, Antelope Reservoir, Lake Davis, and Frenchman Reservoir, which are within in the Feather River watershed. The SWP delivers water to two different types of users: senior water rights holders and claimants, and long-term water supply contract holders also known as *Table A contractors*.

The largest category of SWP water deliveries north of the Delta are to the water rights holders and claimants in the Feather River service area (FRSA). These users include senior water right holders and claimants that receive their full allocation in all but very critically dry years based on inflow to Oroville Reservoir. SacWAM estimates deliveries to the Feather River service area to be about 900 TAF/yr. In addition to the FRSA contractors, the SWP delivers a small amount water to Table A contractors in the Sacramento River watershed; however, most of the Table A deliveries are to water users outside of the Sacramento/Delta watershed.

2.8.1.3 Local Projects

In addition to the CVP and SWP, many local water projects store and deliver water for agricultural and municipal uses in the Sacramento River watershed. These local projects include the Upper American River Project, the Orland Project, the Yuba River Development Project, and the Solano Project. There are many smaller projects in the Sacramento River watershed, such as those developed by PCWA, Nevada Irrigation District, El Dorado Irrigation District, South Sutter Water District, as well as other water districts and individuals that divert water for beneficial uses under water rights and claims. The City of Sacramento stores water in many reservoirs in the upper American River drainage and diverts about 140 TAF/yr for urban uses in the Sacramento area as estimated by SacWAM. The Orland Project on Stony Creek, one of Reclamation's earliest projects in the state, diverts about 80 TAF/yr from East Park and Stony Gorge Reservoirs for agricultural uses as estimated by SacWAM. The Yuba River Development Project is owned and operated by Yuba County Water Agency. The Yuba River Development Project diverts about 300 TAF/yr primarily for agricultural uses as estimated by SacWAM. The Solano Project is a Reclamation project on Putah Creek that includes Lake Berryessa, Putah Diversion Dam, and Putah South Canal. SacWAM estimates that Solano Project diversions average 200 TAF/yr to agricultural and municipal uses in Solano County.

2.8.2 Delta Eastside Tributaries

The Delta eastside tributaries region occupies the region east of the Delta, and comprises the watersheds of the Cosumnes, Mokelumne, and Calaveras Rivers (Figure 2.8-1a). The region is bounded by the Sacramento River watershed on the north, the Sierra Nevada on the east, the San Joaquin Valley on the south, and the Delta on the west. This region encompasses the northern portion of the San Joaquin Valley Hydrologic Region as described in the California Water Plan but does not include the portion of the Delta that overlies the San Joaquin Valley Hydrologic Region (Figure 2.8-1a). In 2018, the Delta eastside tributaries region supported approximately 304,500 acres of irrigated agriculture (^Land IQ 2021) (see Figure 7.4-4a in Section 7.4, *Agriculture and Forest Resources*). The 2016 population estimate of the Delta eastside tributaries region was approximately 452,000 people (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*). The most populous communities in this region are Stockton and Lodi; Figure 2.8-2 depicts these and other population centers in the study area. Stockton spans the Delta eastside tributaries region and Delta and is included in this region for convenience.

Historical water deliveries data indicate that total average annual water supply to the Delta eastside tributaries region during 2005–2015 averaged approximately 986 TAF, with approximately 597 TAF from groundwater. Of the region's total supply, approximately 824 TAF was for agricultural uses, 154 TAF for municipal uses, and 8 TAF for managed wetlands (Table 2.8-5).

Table 2.8-5. Average Annual Delta Eastside Tributaries Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	279	545	824	124
Municipal	102	53	154	81
Wetland/Refuge	8	<1	8	0
All Sectors	389	597	986	205

[a] Average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data*.
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use.*

SacWAM estimates that average annual Sacramento/Delta surface water supplies to the region are about 205 TAF (Table 2.8-5). SacWAM estimates that approximately 98 TAF of the total average annual supply is surface water delivered from the Stanislaus River, primarily to agricultural uses in SEWD. Surface water sources in the region include the Mokelumne, Calaveras, and Cosumnes Rivers, as well as smaller creeks that flow into the east side of the Delta.

The City of Stockton is the largest urban water user in the Delta eastside tributaries region; the city has a diversified portfolio of local supplies that includes purchases from neighboring water districts, such as Stanislaus River water from SEWD, diversion from the Delta, and groundwater. The upper watersheds of the Delta eastside tributaries are sparsely populated and relatively undeveloped. Jenkinson Lake on the Cosumnes River is operated by the El Dorado Irrigation District. The district transfers about 17 TAF/yr from the lake for use in the American basin. Small communities have developed water distribution systems in the upper Mokelumne River watershed that supply more than 10 TAF/yr. These include the Amador Water Agency, Calaveras County Water District, and Calaveras Public Utility District (SWRCB 2019).

The Cosumnes River Preserve spans 46,000 acres of the river's riparian corridor in the lower southwestern reach of the watershed. The lower Mokelumne River and Calaveras River watersheds include portions of the Stockton metropolitan area and the city of Lodi. Other major users of Sacramento/Delta water in this region include Woodbridge Irrigation District, which diverts from the Mokelumne River to agricultural and municipal uses, and SEWD, which supplies water from the Calaveras River and other sources to agricultural and municipal uses.

Residential per capita water use in the Delta eastside tributaries region is moderate relative to other areas of the state, with overall use ranging from 170 R-GPCD in 2013 to 125 R-GPCD in 2015, based on analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). Approximately 4.2 TAF of recycled water is used in the region (SWRCB 2015). Amador County uses approximately 863 AF/yr of recycled water for golf course and cattle grazing. Calaveras County Water District uses recycled water to irrigate golf courses and plans to expand its use of recycled water to include agricultural uses and other public activities (RMC 2013).

EBMUD operates the Pardee and Camanche Reservoirs on the Mokelumne River and supplies water to the EBMUD service area in the Bay Area, delivered through the Mokelumne Aqueduct. Supplies to EBMUD are discussed in Section 2.8.4.

2.8.3 Delta

The Delta region spans approximately 1,150 square miles of tidally influenced land near the confluence of the Sacramento and San Joaquin Rivers. This region primarily contains agricultural uses; in 2018, the Delta supported approximately 373,000 acres of irrigated agriculture (^Land IQ 2021) (see Figure 7.4-4a in Section 7.4, *Agriculture and Forest Resources*). In addition, there are several communities in the Delta, including Tracy, Antioch, Rio Vista, Bethel Island, Clarksburg, Courtland, Freeport, Hood, Isleton, Knightsen, Ryde, Locke, and Walnut Grove (^2013 Water Plan V1) (Figure 2.8-2). The 2016 population estimate of the Delta region was approximately 774,000 people (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*).

Suisun Marsh is described in Section 2.8.4, *San Francisco Bay Area*.

2.8.3.1 Local Water Supply

The total water supplied to the Delta is difficult to estimate because most of the water is obtained through local diversions, and some water comes from naturally occurring seepage from Delta channels to low-lying areas. Many studies have evaluated the Delta's consumptive water use and have reported disparate estimates. The State Water Board's Office of the Delta Watermaster funded a project to compare methods used to estimate crop water use in the Delta to improve the estimates of water supplied to agriculture in the Delta (Medellín-Azuara et. al. 2016).

In SacWAM, most of the Delta demand is assumed from DWR's Delta depletion estimates, which average about 1.2 MAF/yr. Additionally, the Delta region includes users such as Byron Bethany Irrigation District, Westside Irrigation District, Banta-Carbona Irrigation District, and the Cities of

Antioch and Tracy. SacWAM assumes that groundwater does not provide a local water source within the Delta.

Historical water deliveries data indicate that the total average annual water supply to the Delta during 2005–2015 was approximately 1,368 TAF, with 1,185 TAF for agricultural uses, 136 TAF for municipal uses, and 48 TAF for managed wetlands. Groundwater accounted for only 74 TAF of the region's total water supply (Table 2.8-6).

Table 2.8-6. Average Annual Delta Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	1,151	34	1,185	1,136
Municipal	96	40	136	18
Wetland/Refuge	48	0	48	0
All Sectors	1,294	74	1,368	1,154

[a] Average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data*.
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

The North Delta Water Agency (NDWA), Central Delta Water Agency (CDWA), and South Delta Water Agency were formed to enter into agreements with Reclamation and DWR to ensure maintenance of agricultural water quality at various locations in the Delta (^2013 Water Plan V1). NDWA, the largest of the three Delta water agencies, entered into a contract with DWR in 1981 to ensure that the SWP is operated in a manner that would not harm NDWA's water supply or quality. Neither CDWA nor SDWA has entered into a contract with Reclamation or DWR.

The largest communities in the Delta region are Tracy and Antioch, which together receive an average of 18 TAF of surface water as estimated by SacWAM (Table 2.8-6). Tracy has a diversified portfolio of local supplies that include purchases of Stanislaus River water from South San Joaquin Irrigation District, and groundwater. Antioch diverts water through two pumping plants in the southern Delta and receives water from CCWD. The other small communities in the Delta primarily divert directly from neighboring Delta channels and pump groundwater. The City of Stockton is included in the Delta eastside tributaries region, although a portion of the city is located in the Delta (Figure 2.8-2).

Residential per capita water use in the Delta is moderate relative to other regions of the state, with overall use ranging from 184 R-GPCD in 2013 to 134 R-GPCD in 2015, based on analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). Approximately 10.4 TAF of recycled water is used each year in the Delta (SWRCB 2015), primarily for agricultural irrigation or for wetlands and natural systems.

2.8.3.2 Sacramento/Delta Supply Diversions to Other Regions

The Bay Area, San Joaquin Valley, Central Coast, and Southern California regions all receive Sacramento/Delta water supplies exported from the Sacramento/Delta watershed (Figure 2.8-3a and Figure 2.8-3b).

CVP facilities in the Delta consist of the Jones Pumping Plant and the DMC. The DMC is approximately 117 miles in length to O'Neill Forebay and San Luis Reservoir. From San Luis

Reservoir, the DMC transports water east to the Mendota Pool on the San Joaquin River, approximately 30 miles west of Fresno. CVP water conveyed through the DMC is released into the San Joaquin River at the Mendota Pool to replace the exchange contractors' entitlements, which are diverted at Friant Dam. The CVP also provides water to wildlife refuges in the San Joaquin Valley.

SWP facilities in the Delta consist of the Banks Pumping Plant, CCF, the California Aqueduct, and Barker Slough Pumping Plant for export through the North Bay Aqueduct (Reclamation 2009). The South Bay Aqueduct branches off the California Aqueduct and conveys water to the Bay Area region. The California Aqueduct follows the west side of the San Joaquin Valley to O'Neill Forebay and San Luis Reservoir, and continues south, where it ultimately splits into three terminus branches. The Coastal Branch delivers water to San Luis Obispo and Santa Barbara Counties, the West Branch ends in Los Angeles Department of Water and Power's Castaic Reservoir, and the East Branch ends in Lake Silverwood in San Bernardino County.

San Luis Reservoir is located in the San Joaquin Valley and provides about 2 MAF of storage for both the CVP and SWP. The CVP and SWP contain roughly equal shares of San Luis Reservoir storage. SWP water released from storage in San Luis Reservoir flows south to SWP delivery locations in the San Joaquin Valley and Southern California. Reclamation stores water in San Luis Reservoir for subsequent delivery to west-side agricultural contractors and to exchange contractors from Mendota Pool. In addition, the CVP's San Felipe Division diverts water to the west from San Luis Reservoir via Pacheco Tunnel and subsequent conduits to deliver water to the Central Coast and Bay Area region.

CCWD diverts water from multiple intakes in the Delta to its service area in the Bay Area region. Further information on CCWD infrastructure is provided in Section 2.8.4, *San Francisco Bay Area*.

2.8.4 San Francisco Bay Area

The Bay Area region includes San Francisco County and portions of Marin, Sonoma, Napa, Solano, San Mateo, Santa Clara, Contra Costa, and Alameda Counties. The region surrounds San Francisco Bay, extends from the ocean to the Delta, and includes Suisun Marsh. This region closely resembles the San Francisco Bay Hydrologic Region as described in the California Water Plan (Figure 2.8-1a). Historical water deliveries data indicate that the total average annual water supply to the Bay Area during 2005–2015 was approximately 1,251 TAF, including an average annual groundwater supply for this period of 264 TAF (Table 2.8-7). Of the region's total water supply, approximately 1,089 TAF was supplied for municipal uses, 137 TAF for agricultural uses, and 26 TAF for managed wetland uses.

Table 2.8-7. Average Annual San Francisco Bay Area Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	57	80	137	27
Municipal	905	184	1,089	670
Wetland/Refuge	26	0	26	0
All Sectors	987	264	1,251	698

[a] Average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data*.
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

The Bay Area uses water supply from several sources, including local surface water and groundwater as well as multiple sources of imported surface water supplies. Sacramento/Delta water supply accounts for approximately half of the total water supply to the Bay Area, with a SacWAM annual average of 698 TAF to the region—about 95 percent of which goes to municipal uses. The only Bay Area region agricultural use modeled in SacWAM includes approximately 8,000 acres of irrigated agriculture near Fairfield that receives surface water from the Putah South Canal, as well as local groundwater. Additional agricultural use in the Livermore Valley is accounted for as retail deliveries from Alameda County Flood Control and Water Conservation District (FC&WCD) (Zone 7 WD), an SWP contractor on the South Bay Aqueduct. There are other water supply sources in the Bay Area, such as imported water from Hetch Hetchy Reservoir, located on the Tuolumne River.

Water from the Sacramento/Delta is supplied to the Bay Area in several ways. SWP contract water is carried via the North Bay Aqueduct (Solano County Water Agency and Napa County FC&WCD) and South Bay Aqueduct (Alameda County WD, Zone 7 WD, and Valley Water). CVP water for municipal use arrives via the Pacheco Conduit and the Contra Costa Canal. Putah South Canal provides stored Reclamation water from Lake Berryessa. Additional diversions from the western Delta serve EBMUD and Antioch. EBMUD and the San Francisco Public Utilities Commission import approximately 38 percent of the region's average annual water supply from the Mokelumne River (201 TAF) and Tuolumne River (250 TAF), respectively (^DWR 2014). In total, approximately 28 percent of the region's total supply is imported via the CVP and SWP, approximately 31 percent is provided from local groundwater and surface water, and approximately 3 percent is provided from other sources (e.g., harvested rainwater, recycled water) (^DWR 2014). SacWAM estimates total SWP deliveries to the Bay Area of 198 TAF/yr on average and deliveries from the CVP San Felipe Unit to the Bay Area of 109 TAF/yr on average.

Approximately 21 percent of the Bay Area's land is used for agricultural purposes, primarily in Napa Valley and Santa Clara Valley (^DWR 2014). The historical water deliveries data show that, for the 2005–2015 period, groundwater met approximately 70 percent (80 TAF/yr) of the region's agricultural water supply. In 2018, the Bay Area supported approximately 115,000 acres of irrigated agriculture (^Land IQ 2021) (see Figure 7.4-4a in Section 7.4, *Agriculture and Forest Resources*). Although agricultural production continues to occur in the Bay Area, irrigated acreage has decreased over the past several decades. Urbanization has reduced agricultural acreage in the Santa Clara Valley from more than 125,000 acres in the 1940s to fewer than 18,000 acres today, and Marin County has only about 3,700 irrigated acres remaining (^SCCACO 2014; ^SCCDA 1949, 1960; ^Marin

County Department of Agriculture 2016; USDA 2017). Napa and Sonoma Counties have increased agricultural acreage in recent years, primarily through vineyards.

Approximately 17 percent of Californians reside in the Bay Area, which is the second most populous hydrologic region in California. The 2016 population of the Bay Area was approximately 7.0 million people (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*). Water is supplied to Bay Area municipal uses by approximately 190 water service providers. Approximately 95 percent of the population is served by medium and large drinking water systems that serve more than 3,300 people. The remaining 5 percent of the population is served by small drinking water systems serving fewer than 3,300 people (^DWR 2014).

Although the median household income in each Bay Area county is well above the economically disadvantaged community income threshold for California, economically disadvantaged communities exist in all Bay Area counties. Most of these economically disadvantaged communities are located in Alameda and Contra Costa Counties (^DWR 2014).

Recent estimates of water recycling in the Bay Area indicate that recycling and efficiencies are increasing compared with previous estimates presented in the California Water Plan. Per-capita residential water use in the Bay Area is relatively low due to high water rates, cool climate, and small lot sizes. Residential per capita water use in the Bay Area during recent years ranged from 129 R-GPCD in 2013 to 99 R-GPCD in 2015, based on analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). In 2015, the region's recycled water use included approximately 19 TAF for landscape irrigation and golf courses, 5 TAF for wetlands, more than 13 TAF for industrial uses and geothermal energy production, and more than 12 TAF for agricultural irrigation—for a total of 65 TAF of recycled water use (SWRCB 2015).

The CVP San Felipe Division provides Sacramento/Delta water supply to Valley Water and San Benito County Water District from San Luis Reservoir via Pacheco Tunnel. The CVP San Felipe Division deliveries to the Bay Area average 146 TAF/yr as estimated by SacWAM. Valley Water provides water to Silicon Valley local municipalities and private retailers, which deliver drinking water to approximately 2 million people in Campbell, Cupertino, Gilroy, Los Altos, Los Altos Hills, Los Gatos, Milpitas, Monte Sereno, Morgan Hill, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, and Sunnyvale (SCVWD 2017). Valley Water also receives SWP deliveries via the South Bay Aqueduct.

The North Bay Aqueduct delivers about 57 TAF/yr of SWP water, as estimated by SacWAM, to the Solano County Water Agency and Napa County FC&WCD. These contractors have supply agreements with the cities of Benicia, Fairfield, Vallejo, and smaller communities in Napa County. The cities of Calistoga, Napa, St. Helena, and American Canyon and the town of Yountville receive SWP water from an extension of the North Bay Aqueduct. SWP water also is delivered via the South Bay Aqueduct to the Alameda County Flood Control and Water Conservation District (Zone 7), Alameda County Water District, and Valley Water. Maximum Table A contract amounts for SWP contractors in the South Bay Area total approximately 223 TAF/yr. Existing South Bay Aqueduct deliveries are about 141 TAF/yr on average as estimated by SacWAM.

Several North Bay communities, including Fairfield, Suisun City, Benicia, Vallejo, Travis Air Force Base, and communities in Napa County receive supplies from Putah South Canal, a component of the Solano Project. Average deliveries from Putah South Canal to the Bay Area are 25 TAF/yr for agricultural uses and 33 TAF/yr for municipal uses as estimated by SacWAM.

CCWD supplies water to approximately 500,000 people, primarily in eastern Contra Costa County for municipal use. CCWD's service area includes the cities of Antioch, Bay Point, Clayton, Clyde, Concord, Oakley, Pittsburg, and Port Costa, as well as portions of Brentwood, Martinez, Pleasant Hill, and Walnut Creek (CCWD 2017). CCWD operates the Los Vaqueros Reservoir and Delta intakes at Rock Slough, Old River, Victoria Canal, and Mallard Slough under multiple appropriative water rights and under a CVP contract (Reclamation 2016). Los Vaqueros Reservoir (capacity 160 TAF) is filled from district intakes on the Old River and Victoria Canal (^SacWAM 2023). The 48-mile Contra Costa Canal originates at Rock Slough, receives water from all CCWD sources, and ends near the Bollman Water Treatment Plant just outside Concord. It diverts an average of 75 TAF/yr as estimated by SacWAM.

EBMUD provides water to approximately 1.4 million Bay Area residents, including several major cities such as Oakland and Berkeley. EBMUD relies on imported water from the Mokelumne River watershed as its primary source of water. EBMUD transports water from Pardee Reservoir to EBMUD facilities in Walnut Creek via three 82-mile-long pipelines. Together, the Mokelumne aqueducts deliver about 211 TAF/yr as estimated by SacWAM. EBMUD also has access to local surface water supplies, which provide an average of 15 to 25 million gallons per day (approximately 20–33 TAF/yr) during normal hydrologic years, but these local supplies provide very little water during dry years. EBMUD also receives water from the Sacramento River during drier years and has a contract for CVP water that can be delivered through the Folsom South Canal from the American River. The CVP contract provides for delivery of up to 133 TAF for a single year, not to exceed 165 TAF for three consecutive qualifying years (EBMUD 2015).

2.8.5 San Joaquin Valley

The San Joaquin Valley region occupies the southern half of the Central Valley of California. It is bounded by the Sierra Nevada on the east, the Tehachapi Mountains on the south and southeast, the San Emigdio Mountains on the south and southwest, and the Southern Coast Ranges on the west. The Delta eastside tributaries and Delta regions form the northern boundary. The region combines the San Joaquin River and Tulare Lake Hydrologic Regions of the California Water Plan, excluding portions of the San Joaquin Hydrologic Region located in the Delta and Delta eastside tributaries regions. The San Joaquin River, along with its northern tributaries, is the largest river draining the region, with headwaters in the Sierra Nevada. In most water years, the rivers south of the San Joaquin River with watersheds in the Sierra Nevada (e.g., Kings, Kaweah, Tule, Kern Rivers) discharge onto the valley floor or into the ephemeral Kern, Buena Vista, and Tulare lakebeds. During wet periods, discharges from one or more of these rivers can reach these lakebeds, causing them to overflow and convey water northward to the San Joaquin River. Most of the water from these rivers is diverted for agricultural irrigation and for groundwater recharge (e.g., Kern Water Bank). Ephemeral streams that drain the Tehachapi and San Emigdio Mountains and the Southern Coast Ranges discharge to valley lowlands.

The San Joaquin Valley is the largest agricultural region in California. In 2018, the San Joaquin Valley supported approximately 4 million acres of irrigated agriculture (^Land IQ 2021) (see Figure 7.4-4b in Section 7.4, *Agriculture and Forest Resources*). The population in the San Joaquin Valley region in 2016 was approximately 3.6 million people (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*). There are 14 CVPIA wildlife refuge units in the San Joaquin Valley, including 11 that receive Sacramento/Delta supplies.

The sources of water supply for the San Joaquin Valley include the San Joaquin River and other local surface water supplies, groundwater, and imported water from the Sacramento/Delta watershed via the CVP and SWP.

Historical water deliveries data indicate that the average annual total water supply to the San Joaquin Valley during 2005–2015 was approximately 18,437 TAF, of which approximately 16,803 TAF was for agricultural uses, 1,053 TMAF was for municipal uses, and 581 TAF was for managed wetlands (Table 2.8-8). Approximately 2,819 TAF (15 percent) of total average annual supply to the region is Sacramento/Delta water supplied by the CVP and SWP as estimated by SacWAM.

Table 2.8-8. Average Annual San Joaquin Valley Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	7,769	9,034	16,803	2,422
Municipal	231	823	1,053	99
Wetland/Refuge	330	251	581	298
All Sectors	8,330	10,107	18,437	2,819

[a] Average annual estimates for 2005-2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data.*
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

Historical water deliveries data for the 2005–2015 period indicate that groundwater supplied an annual average of 10,107 TAF to the San Joaquin Valley region (Table 2.8-8), including approximately 9,034 TAF for agricultural uses, 823 TAF for municipal uses, and 251 TAF for managed wetlands uses.

Local surface water supplies in the San Joaquin Valley include the Tule, Kaweah, Kings, San Joaquin, Merced, Tuolumne, and Stanislaus Rivers, as well as other smaller creeks. Several agricultural and municipal users in the San Joaquin Valley receive water supply from Modesto, Merced, Oakdale, South San Joaquin, Madera, Turlock, and Kern County Irrigation Districts. The San Joaquin Valley has approximately 793 community drinking water systems (^DWR 2014). The majority (over 80 percent) of these community water systems are considered small and serve fewer than 3,300 people. Although medium and large community drinking water systems account for less than 20 percent of the region's drinking water systems, medium and large community drinking water systems serve over 90 percent of the region's population. In the San Joaquin Valley, many rural homes maintain domestic wells, which tend to be shallower than agricultural wells (^DWR 2014).

Numerous economically disadvantaged communities exist in the San Joaquin Valley. Several of the region's most populous cities are economically disadvantaged communities, such as Fresno, Merced, Madera, and Tulare (^DWR 2014).

Residential per capita water use in the San Joaquin Valley is high relative to other regions of the state, with overall rates ranging from 239 R-GPCD in 2013 to 182 R-GPCD in 2015, based on analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). Approximately 97 TAF of recycled water is used in the San Joaquin Valley each year, primarily for agricultural irrigation (SWRCB 2015).

2.8.5.1 Central Valley Project Deliveries

The CVP delivers water throughout the San Joaquin Valley from the San Joaquin River, the Stanislaus River, and the Sacramento/Delta. Friant Dam on the San Joaquin River provides supplies for Friant Water service area contractors, and the Delta and San Luis Reservoir provide water for CVP south-of-Delta water service contractors and exchange contractors.

The CVP also delivers water to Oakdale Irrigation District and South San Joaquin Irrigation District. These districts jointly store up to 600 TAF of inflow to New Melones Reservoir under an agreement with Reclamation (Reclamation, OID, and SSJID 1988; Reclamation 2017b). Stanislaus River water does not originate in the Sacramento River watershed or Delta and is not included in Sacramento/Delta supply.

Millerton Reservoir, located behind Friant Dam on the San Joaquin River, has a 520-TAF capacity. Water from Millerton Reservoir is delivered to the Madera region via the Madera Canal and to the Tulare Lake region via the Friant-Kern Canal. The CVP employs a Class I/Class II contracting system for the Friant Division. Class I is commonly referred to as the *firm yield* of the project and is the first 800 TAF; however, there are many years when the project does not yield all Class I water. Class II water is the next 1.4 MAF that develops from the project. Class II water is available only after all the Class I water has been made available and, in an average year, is about an additional 600 TAF to promote groundwater conjunctive use.

Several pre-1914 appropriative/riparian water right claimants from the San Joaquin and Kings Rivers have entered into settlement-type contracts known as *exchange contracts* related to development of the Friant Project by Reclamation. These water users are referred to as *exchange contractors*. In most years, the exchange contractors receive replacement supplies exported from the Delta in exchange for use of water from the San Joaquin River under the exchange contractors' underlying rights. In normal years, Reclamation guarantees the exchange contractors 100 percent of their contractual water allotment (840 TAF); in very dry years, the exchange contractors receive 77 percent (650 TAF). If Reclamation is unable to provide the agreed-upon amount, the exchange contractors can exercise their senior water right claims to divert water from the San Joaquin River, potentially reducing the supply to other water users that receive water supplies from the CVP Friant Unit.

Reclamation also provides water for agricultural uses on the west side of the San Joaquin Valley that is exported from the Delta. The portion of water stored by the CVP in San Luis Reservoir is delivered via the San Luis Canal to serve south-of-Delta contractors, including Westlands Water District. It is delivered via the DMC to serve CVP contractors on the west side of the San Joaquin Valley. SacWAM estimates that the total CVP San Joaquin Valley deliveries from the Sacramento/Delta are about 2.2 MAF/yr, which includes deliveries to wildlife refuges and exchange contractors.

SacWAM estimates that Sacramento/Delta supplies to CVPIA wildlife refuges in the San Joaquin Valley average about 298 TAF/yr. Most CVPIA wildlife refuges in the San Joaquin Valley receive some Sacramento/Delta water supply. (See Section 7.6.1, *Terrestrial Biological Resources*, for additional information on San Joaquin Valley wildlife refuges.)

2.8.5.2 State Water Project Deliveries

The SWP delivers water from the Sacramento/Delta via the California Aqueduct to contractors in the San Joaquin Valley. These users are primarily agricultural contractors in the Tulare Lake area. SacWAM estimates that SWP delivers about 721 TAF/yr on average to the San Joaquin Valley. Kern

County Water Agency has the largest contract amount of approximately 983 TAF/yr of Table A water. The Kern Water Bank Authority owns and operates the Kern Water Bank, a groundwater banking project located on approximately 20,000 acres in Kern County, which stores SWP deliveries to the Kern County area.

2.8.6 Central Coast

The Central Coast region spans approximately 11,300 square miles in central California. The region includes all of Santa Cruz, Monterey, San Luis Obispo, and Santa Barbara Counties; most of San Benito County; and parts of San Mateo, Santa Clara, and Ventura Counties (Figure 2.8-1a). Major drainages in the Central Coast region include the Salinas, Cuyama, Santa Ynez, Santa Maria, San Antonio, San Lorenzo, San Benito, Pajaro, Nacimiento, Carmel, and Big Sur Rivers. This region closely resembles the Central Coast Hydrologic Region as described in the California Water Plan (Figure 2.8-1a). Historical water deliveries data indicate that total average annual water supply to the Central Coast region during 2005–2015 averaged 1,334 TAF, including approximately 1,055 TAF/yr for agricultural uses, 279 TAF/yr for municipal uses, and less than 1 TAF/yr for managed wetlands. SacWAM modeling indicates that Sacramento/Delta water makes up about 6 percent of total water supply in the Central Coast but accounts for approximately half of the region's surface water supply (Table 2.8-9).

Table 2.8-9. Average Annual Central Coast Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	87	968	1,055	37
Municipal	83	196	279	49
Wetland/Refuge	<1	0	<1	0
All Sectors	170	1,164	1,334	86

[a] Average annual estimates for 2005-2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data.*
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

The Central Coast is heavily reliant on groundwater for its water supply. Based on historical deliveries data, for the 2005–2015 period, groundwater supplies accounted for an annual average of 1,164 TAF of the region's total water supply, which included 968 TAF for agricultural water uses and 196 TAF for municipal water uses (Table 2.8-9). Groundwater supplies accounted for nearly 100 percent of the region's rural domestic water uses and nearly 100 percent of the potable water supply in the Salinas Valley. Other sources of water to the Central Coast include imported Sacramento/Delta supplies and local surface water supplies (^DWR 2014).

The SWP provides Sacramento/Delta water supply to San Luis Obispo and Santa Barbara Counties via the Coastal Branch Aqueduct, which diverges from the California Aqueduct. SWP contractors in the Central Coast region include San Luis Obispo County FC&WCD and Santa Barbara County FC&WCD. According to SacWAM, SWP deliveries to the Central Coast for primarily municipal uses average 49 TAF/yr. CVP's San Felipe Division also provides imported water to the Central Coast from San Luis Reservoir. Most of the CVP San Felipe Division water is used for municipal purposes in the South Bay and is accounted for and discussed above in Section 2.8.4, *San Francisco Bay Area*.

Approximately 37 TAF/yr of the Sacramento/Delta water supplied through the CVP San Felipe Division is used in the Central Coast; this water is used for agricultural irrigation.

Water users in the Central Coast receive surface water supplies from several local water projects, such as Reclamation's Santa Maria Project, Reclamation's Cachuma Project, and Monterey County Water Resources Agency's Nacimiento Project. Reclamation's Santa Maria Project includes Twitchell Dam and Reservoir on the Cuyama River. Reclamation's Cachuma Project provides the main source of water for southern Santa Barbara County and includes Cachuma Reservoir on the Santa Ynez River, as well as other reservoirs, tunnels, and conveyances. Cachuma Reservoir stores Santa Ynez River water and receives supplemental SWP water. Monterey County Water Resources Agency's Nacimiento Project in San Luis Obispo County includes Nacimiento dam and reservoir on the Nacimiento River. San Luis Obispo County receives an annual water delivery of up to 17.5 TAF from Lake Nacimiento (^DWR 2014).

Agricultural production is an important component of the region's economy. Major agricultural centers in the Central Coast include Gilroy, Hollister, Pajaro Valley, Watsonville, Salinas Valley, Paso Robles, San Luis Obispo, Santa Maria, Lompoc, Solvang, and Guadalupe. In 2018, the Central Coast region supported approximately 526,000 acres of irrigated agriculture (^Land IQ 2021; Figures 7.4-4a and 7.4-4b in Section 7.4, *Agriculture and Forest Resources*). Major agricultural products include strawberries, lettuce, and wine grapes (^DWR 2014).

The population in the Central Coast region in 2016 was approximately 1.5 million people (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*). Average annual water supply estimates using historical water deliveries data indicate that the average annual total municipal water supply to the Central Coast region during 2005–2015 was approximately 280 TAF, of which approximately 280 TAF was supplied by groundwater (Table 2.8-9). Major population centers are Santa Barbara, Santa Maria, San Luis Obispo, Gilroy, Hollister, Morgan Hill, Salinas, and Monterey. The Central Coast region contains numerous economically disadvantaged communities, many of them small agricultural communities that support agricultural production workers. The Central Coast has one of the highest percentages of population living in poverty (^DWR 2014).

There are an estimated 400 community drinking water systems in the Central Coast. More than 80 percent of these community drinking water systems are small, serving fewer than 3,300 people, and most serve fewer than 500 people. Medium and large community drinking water systems account for less than 20 percent of the region's community drinking water systems but supply over 90 percent of the region's population (^DWR 2014).

Residential per capita water use in the Central Coast region is lower relative to other regions of the state, with overall use ranging from 135 R-GPCD in 2013 to 99 R-GPCD in 2016, based on an analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). Recycled water use accounts for approximately 34 TAF/yr (SWRCB 2015). The Monterey Regional Water Pollution Control Agency supplies over half of the region's recycled water. Eighty percent of the region's recycled water use is for agricultural irrigation purposes; recycled water also is used for landscape and golf course irrigation. The Central Coast region also contains several desalination facilities (^DWR 2014).

2.8.7 Southern California

Southern California encompasses the southernmost portion of California, north of Mexico, and southeast of the San Joaquin Valley. This region combines the South Coast, South Lahontan, and Colorado River Hydrologic Regions described in the California Water Plan (Figure 2.8-1a). Southern California is the most populous region in California and one of the state's driest regions. Southern California includes major population centers such as the metropolitan Los Angeles, San Diego, and Santa Ana planning areas, where the majority of Southern California's population resides. In addition, Southern California includes areas east of the coast, further inland, that generally are more sparsely populated and semi-arid to arid in climate. The Southern California region had approximately 22.2 million people in 2016 (^U.S. Census Bureau 2017) (see Table 8.2-2 in Chapter 8, *Economic Analysis and Other Considerations*).

Historical water deliveries data indicate that the total average annual water supply in Southern California during 2005–2015 was approximately 9,449 TAF (Table 2.8-10), including approximately 4,518 TAF for municipal uses, approximately 4,863 TAF for agricultural uses, and 68 TAF for managed wetlands. For the same period, approximately 2,382 TAF of Southern California's total annual water supply was from groundwater sources, of which approximately 1,590 TAF was for municipal uses and 792 TAF for agricultural uses (Table 2.8-10). Approximately 1,675 TAF, or 18 percent, of the average annual water supply to Southern California is Sacramento/Delta water (Table 2.8-10).

Table 2.8-10. Average Annual Southern California Water Supply Estimates (thousand acre-feet)

	Surface Water and Other Sources [a]	Groundwater [a]	Total [a]	Sacramento/Delta Surface Water Supply [b]
Agriculture	4,071	792	4,863	14
Municipal	2,928	1,590	4,518	1,661
Wetland/Refuge	68	<1	68	0
All Sectors	7,067	2,382	9,449	1,675

[a] Average annual estimates for 2005–2015 using methods described in Appendix A1b, *Methodology for Estimating Existing Water Supply from Historical Water Deliveries Data.*
[b] Simulated average annual water supply values from SacWAM results. Methods are described in Appendix A1, *Sacramento Water Allocation Model Methods and Results*, and Appendix A1a, *Methods for Estimating Regional Sacramento/Delta Surface Water Supply for Agricultural and Municipal Use*.

The primary uses of water vary spatially in Southern California. In the densely populated South Coast area, water supplies are used primarily for municipal uses, while a larger portion of the total water supplies are used for agricultural uses in inland areas (^DWR 2014). In 2018, Southern California supported approximately 728,000 acres of irrigated agriculture (^Land IQ 2021) (see Figure 7.4-4b in Section 7.4, *Agriculture and Forest Resources*). The Imperial Valley is the most productive agricultural area in southern California and contains a large portion of the region's total crop acreage. Major crop types in the Imperial Valley include livestock forage and field crops, such as alfalfa. Coachella Valley is also an important local agricultural region where orchards are the predominant crop type (^DWR 2014).

Southern California water sources include imported supplies from several sources, local surface water supplies and groundwater, as well as some recycled and desalinated water supplies. Sources of imported supplies to Southern California include the Colorado River, the Sacramento/Delta watershed via the SWP, and the Owens Valley/Mono Basin in the Eastern Sierra. In addition, water conservation and water use efficiency practices have been emphasized in the South Coast Hydrologic Region, and total water use in this populous region of Southern California has not increased as substantially as would be expected from the region's population growth (^DWR 2014).

Sacramento/Delta supply is conveyed to Southern California SWP contractors through the California Aqueduct. The water is lifted at several pumping plants over the Tehachapi Mountains, including at the A. D. Edmonston Pumping Plant, the highest lift pumping plant in the United States. The California Aqueduct splits into two branches after crossing the Tehachapi Mountains: the West Branch and the East Branch. The West Branch delivers water to Lake Castaic and provides water to western Los Angeles County and vicinity. The East Branch delivers water to the Antelope Valley, San Bernardino/Riverside areas, and eventually to Lake Perris near Hemet. The East Branch and West Branch Aqueducts supply 13 SWP contractors, including MWD, a regional wholesaler that provides water to 19 million southern California residents. Southern California Table A contracts total approximately 2.6 MAF/yr. MWD holds the largest of these contracts at approximately 1.9 MAF/yr. Actual SWP deliveries to Southern California SWP contractors vary and are typically lower than maximum contract allocations. Total SWP deliveries to Southern California are about 1.7 MAF/yr on average as estimated by SacWAM, and the majority of these SWP deliveries are used in the South Coast area.

Coachella Valley Water District and Desert Water Agency in eastern San Bernardino County have an exchange agreement with MWD regarding SWP supplies. Facilities do not currently exist to deliver SWP supplies to SWP contractors in the Coachella Valley. Under the agreement, MWD receives the two agencies' annual allocations through SWP facilities. In exchange, MWD releases its water to meet the Coachella Valley Water District and Desert Water Agency SWP allocations into the Whitewater River via the Colorado River Aqueduct. SWP deliveries are used to recharge local groundwater basins (^DWR 2014).

Other imported surface water supplies in the Southern California region include the Colorado River and the Owens Valley/Mono Basin. The Colorado River provides a substantial source of imported surface water to southern California. Colorado River water is delivered to southern California via the Colorado River Aqueduct and the All American Canal. Southern California water users receive approximately 4.26 MAF/yr of imports from the Colorado River (^DWR 2014). The City of Los Angeles also receives imported water from Owens Valley/Mono Basin through the 223-mile Los Angeles Aqueduct.

Historical water deliveries data indicate that groundwater supplies account for another large part of Southern California's water supply portfolio and provided an annual average of 2.38 MAF of Southern California's total supply for the period of 2005 to 2015 (Table 2.8-10). Groundwater makes up most of the supply for agricultural uses in the Owens-Mono, Antelope Valley, and Mojave River areas. Groundwater supplies make up more than half of municipal supplies in areas such as Coachella and Imperial Valleys. Some groundwater basins are in overdraft conditions due to decades of pumping, especially in the eastern portion of Southern California (^DWR 2014).

Residential per capita water use in Southern California is low relative to other regions of the state, with overall use ranging from 156 R-GPCD in 2013 to 128 R-GPCD in 2016, based on an analysis of data from the State Water Board's Urban Water Supplier Monthly Reports Dataset (SWRCB 2018). Numerous water suppliers in Southern California currently implement water use efficiency programs, water recycling programs, groundwater desalination facilities, and seawater desalination facilities to meet a portion of their water supply needs. Water recycling has been used successfully in Southern California since the 1960s, and recycled water provides approximately 482 TAF/yr of water (4 percent of Southern California's total applied water), primarily in the South Coast region (SWRCB 2015). Seawater desalination projects meet a small portion of the region's water demand, including the Carlsbad Desalination Plant, which opened in December 2015. More projects are in the planning stages (^DWR 2014; Carlsbad Desalination Project 2017). In the densely populated South Coast area, many water suppliers have implemented water use efficiency programs, such as rebates for high-efficiency appliances, and many agencies have implemented tiered or seasonal water supply rate structures (^DWR 2014).

Southern California has more than 700 community drinking water systems. Approximately 40 percent of the region's community drinking water systems are medium or large (serving over 3,300 people) and deliver drinking water to over 95 percent of Southern California residents. Many communities in Southern California are considered economically disadvantaged communities, including multiple communities in the densely populated South Coast as well as inland communities. (^DWR 2014).

2.9 Conclusions

Current hydrologic conditions in the Sacramento River watershed are very different than simulated unimpaired hydrologic conditions because of the development of this source as a water supply. The Sacramento River has been termed "the hardest working river in the state" because of the many beneficial uses it provides (LA Times 1989). It provides drinking water for millions of people throughout the state, and it is the primary supply for agriculture throughout the Central Valley. In general, this water supply development has reduced winter and spring flows and increased summer flows while reducing the hydrologic variability for regulated tributaries. In unregulated tributaries, hydrologic development has reduced flows during the irrigation season, resulting in low, warm flows, particularly in summer.

Regulated tributaries show the largest difference between current conditions and unimpaired conditions in January through June. These differences are largest for tributaries such as the Mokelumne River, Putah Creek, and Cache Creek, where flows are less than 28 percent, 14 percent, and 53 percent of unimpaired flow in half of the years, respectively. Project (CVP and SWP) tributaries such as Clear Creek and the Feather and American Rivers have higher flows than other tributaries most of the years; however, during dry years, Project tributaries still show a large decrease in flows. For example, Clear Creek and the Feather and American Rivers are below 20 percent, 32 percent, and 39 percent of unimpaired flow in 10 percent of the years, respectively.

Current water management has increased the stability of the Delta's annual inflows and salinity. Annual incursions of saline water into the Delta still occur each summer but have been substantially muted compared to their historical levels by the release of summer water from the reservoirs (Herbold and Moyle 1989). Simulated Delta outflow under current conditions is less than 44 percent of unimpaired Delta outflow during January through June in half of the years, with the greatest impairment generally occurring during April through June. In contrast to the reduced saline intrusion during summer, these reductions in outflow during January through June are associated with an increase in X2 and salinity intrusion.

The State Water Board is considering amendments to the Bay-Delta Plan focused on the Sacramento River and its tributaries, Delta eastside tributaries (the Cosumnes, Mokelumne, and Calaveras Rivers), Delta outflows, and interior Delta flows in order to reasonably protect fish and wildlife beneficial uses (referred to as the *Sacramento/Delta update to the Bay-Delta Plan*). The

Sacramento/Delta update to the Bay-Delta Plan is discussed in detail in subsequent chapters and can be considered a restoration project to benefit the Bay-Delta watershed ecosystem over time. This will result in additional instream flows within the Sacramento/Delta watershed, which will reduce the amount of Sacramento/Delta water supply available for consumptive use. Providing additional water to benefit the Bay-Delta watershed ecosystem will be challenging for various sectors that have come to rely on this water, especially considering climate change and other factors. Water from the Sacramento/Delta is delivered to and used in the Sacramento River watershed, Delta eastside tributaries, Delta, San Francisco Bay Area, San Joaquin Valley, Central Coast, and Southern California regions; however, as discussed in Section 2.8, *Existing Water Supply*, this supply makes up only a portion of the total water supply portfolio in these regions. The decision on how to move forward to protect such a significant resource requires careful consideration, including the location and context of total water supplies available.

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