Appendix C

Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives

State Water Resources Control Board
California Environmental Protection Agency

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

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

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California Environmental Protection Agency

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

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Acronyms and Abbreviations

2006 Bay-Delta Plan; Plan	2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary
AFRP	Anadromous Fish Restoration Program
AGR	agricultural supply
BAFF	Bio-Acoustic Fish Fence
BO	biological opinions
Bureau	U.S. Bureau of Reclamation
CALSIM II	CALSIM II San Joaquin River Water Quality Module
CDEC	California Data Exchange Center
Central Valley Water Board	Central Valley Regional Water Quality Control Board
COG	coordinated operations group
CRR	cohort return ratio
CSPA	California Sportfishing Protection Alliance
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWIN	California Water Impact Network
CWT	coded wire tagged
DPH	California Department of Public Health
DPS	Distinct Population Segment
dS/m	deciSiemens per meter
DSM2	Delta simulation model
DSOD	Division of Safety of Dams
DWR	California Department of Water Resources
DWSC	Stockton Deepwater Ship Channel
EC	electrical conductivity
ESA	Endangered Species Act
ESUs	Evolutionary Significant Units
FERC	Federal Energy Regulatory Commission
HOR	head of Old River
HORB	HOR barrier
IPO	Interim Plan of Operations
IRP	independent review panel
MAF	million acre-feet
MCL	Maximum Contaminant Levels
mgd	million gallons per day
MID	Modesto Irrigation District

mmhos/cm	millimhos per centimeter
MUN	Municipal and Domestic Supply
NPDES	National Pollutant Discharge Elimination System
NRDC	Natural Resources Defense Council
OMR reverse flows	Old and Middle River reverse flows
RM	river mile
RPA	Reasonable and Prudent Alternative
SED	Substitute Environmental Document
SJR	San Joaquin River
SJRA	San Joaquin River Agreement
SJRGA	San Joaquin River Group Authority
State Water Board or Board	State Water Resources Control Board
SWP	State Water Project
TBI	The Bay Institute
TDS	total dissolved solids
TNC	The Nature Conservancy
USBR	United States Bureau of Reclamation
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
VAMP	Vernalis Adaptive Management Plan
WAP	Water Acquisition Program
WSE	water supply effects
μmho/cm	micromhos per centimeter
μS/cm	microSiemens per centimeter

1 Introduction

The State Water Resources Control Board (State Water Board) is in the process of reviewing the San Joaquin River (SJR) flow objectives for the protection of fish and wildlife beneficial uses, water quality objectives for the protection of southern delta agricultural beneficial uses, and the program of implementation for those objectives contained in the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (2006 Bay-Delta Plan). Figure 1.1 displays the project area corresponding to SJR flow objectives and program of implementation and Figure 1.2 displays the project area for the southern Delta water quality objectives and program of implementation.

The information and analytical tools described in this report (referred to hereafter as Draft Technical Report or Technical Report) are intended to provide the State Water Board with the scientific information and tools needed to consider potential changes to these objectives and their associated program of implementation. In this quasi-legislative process, State Water Board staff will propose amendments to the SJR flow objectives for the protection of fish and wildlife beneficial uses, southern Delta water quality objectives for the protection of agricultural beneficial uses, and the program of implementation contained in the 2006 Bay-Delta Plan. Also, the environmental impacts of these amendments will be evaluated in a Substitute Environmental Document (SED) in compliance with the California Environmental Quality Act. Any changes to water rights consistent with the revised program of implementation will be considered in a subsequent adjudicative proceeding.

The State Water Board released the first draft of the Technical Report on October 29, 2010. In order to receive comments and other technical information related to that draft, the State Water Board solicited public comments and held a public workshop on January 6 and 7, 2011. The purpose of the public workshop was to determine whether: 1) the information and analytical tools described in the Draft Technical Report are sufficient to inform the State Water Board's decision-making to establish SJR flow and southern Delta salinity objectives and a program of implementation to achieve these objectives; and 2) the State Water Board should consider additional information or tools to evaluate and establish SJR flow and southern Delta salinity objectives, and a program of implementation to achieve these objectives. The State Water Board received 21 comment letters on the Draft Technical Report which are available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/comments120610.shtml.

The public workshop was organized into a series of panel discussions by technical experts concerning the following topics: 1) hydrologic analysis of the SJR basin; 2) scientific basis for developing alternative SJR flow objectives and a program of implementation; 3) scientific basis for developing alternative southern Delta water quality objectives and a program of implementation; and 4) water supply impacts of potential alternative SJR flow and southern Delta water quality objectives. The written comments and verbal comments made at the workshop raised a number of issues concerning the Draft Technical Report.

As a result of those comments, several edits were made and a revised draft was issued in October, 2011, which also included draft basin plan amendment language as Appendix A. That version of the Technical Report was submitted for independent scientific peer review in October of 2011. The peer review comments, in addition to other information concerning the peer review process, are available on the State Water Board's website at: http://www.waterboards.ca.gov/water_issues/programs/peer_review/sanjoaquin_river_flow.shtl

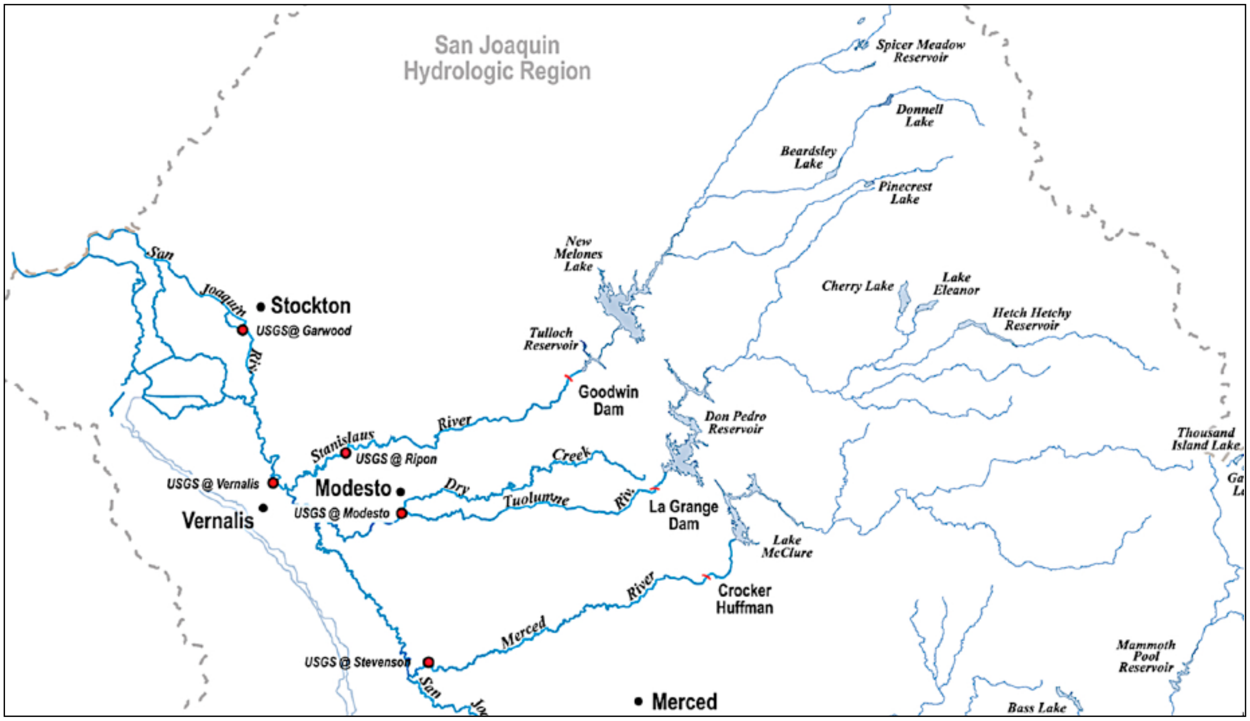

Figure 1.1. Project Area: SJR Flow Objectives

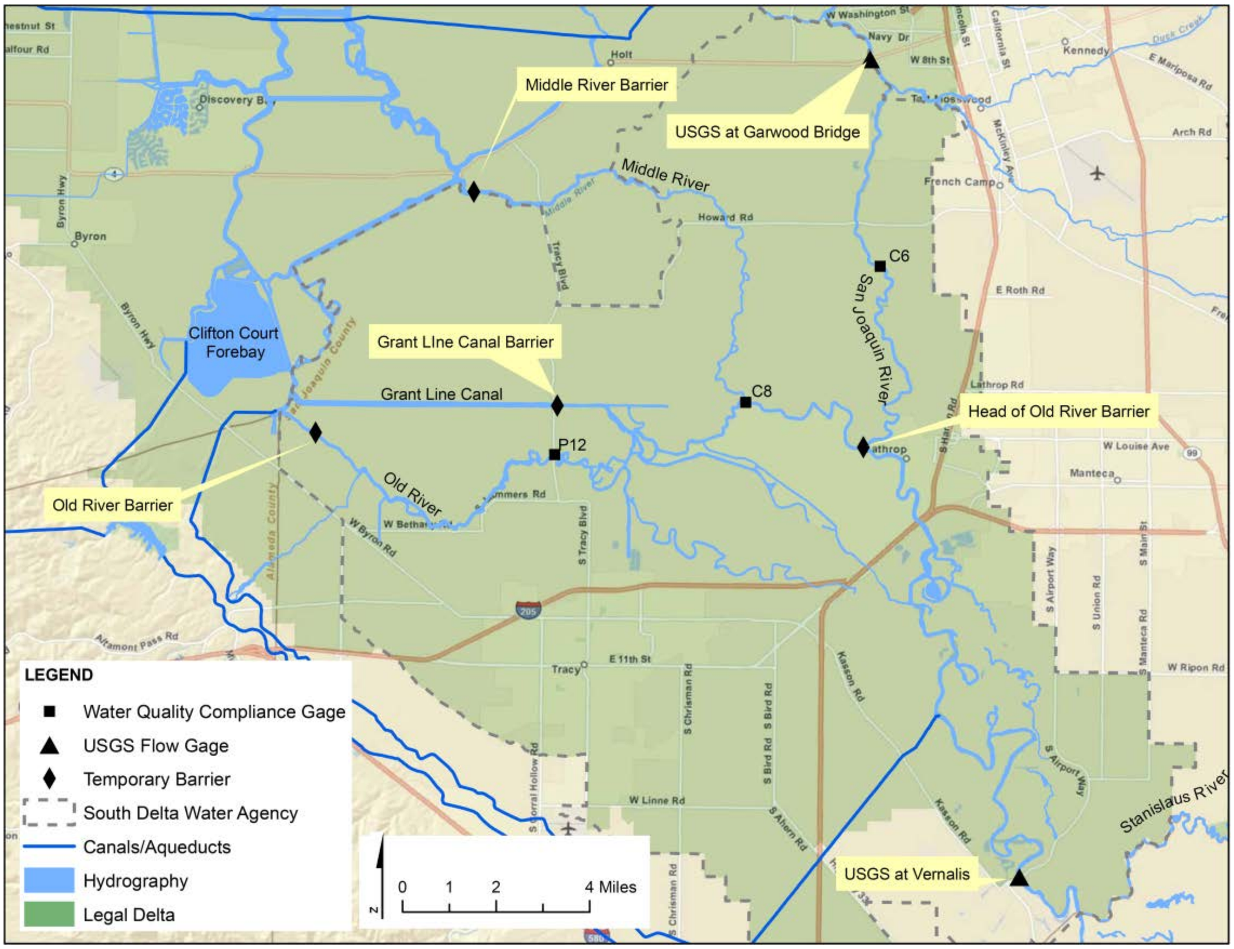

Figure 1.2. Project Area: Southern Delta Salinity Objectives, Showing Agricultural Barriers, Water Quality Compliance Stations, and Major Flow Gages

This February 2012 version of the Technical Report has been revised to address peer review comments. Not all of peer-review comments required a change in the Technical Report, but all will be addressed in a separate response to comments document. The Final Technical Report, response to comments document, and peer review findings will be included in the SED as an Appendix. Any impacts associated with the flow alternatives that are described in the Final Technical Report will be discussed in more detail in the impacts section of the appropriate resource chapter of the SED.

The following is a brief summary of the information presented in the subsequent sections of this report.

Section two provides an analysis of the flow regime within the SJR basin. The purpose of this hydrologic analysis is to describe how the magnitude, frequency, duration, timing, and rate of change of flows in the SJR and its major tributaries have been altered within the project area.

This analysis is accomplished through a comparison of observed flows against unimpaired[1] flows for each of the major tributaries in the project area (i.e., Stanislaus, Tuolumne, and Merced Rivers).

Section three provides the scientific basis for developing SJR flow objectives for the protection of fish and wildlife beneficial uses and a program of implementation to achieve those objectives. This section includes life history information and population variations for SJR fall-run Chinook salmon and Central Valley Steelhead, and flow needs for the reasonable protection of fish and wildlife beneficial uses in each of the major tributaries. Specific support for developing alternative SJR flow objectives focuses on the importance of the flow regime to aquatic ecosystem processes and species. Specifically, the Technical Report focuses on the flows needed to support and maintain the natural production of SJR fall-run Chinook salmon, identifying juvenile rearing in the tributary streams and migration through the Delta as the most critical life history stages. Flow alternatives, expressed as percentages of unimpaired flow in the juvenile rearing and migration months of February to June, represent the range of alternatives that will be further developed in the SED.

Section four provides the scientific basis for developing water quality objectives and a program of implementation to protect agricultural beneficial uses in the southern Delta, including the factors and sources that affect salinity concentrations and salt loads (mass of salt in the river), and the effects of salinity on crops. Information is provided on tools that can be used to: estimate salinity in the SJR at Vernalis and in the southern Delta; quantify the contribution of salinity from National Pollutant Discharge Elimination System (NPDES) discharges; model salinity effects on crop salt tolerance; and evaluate threshold levels for salinity impacts on the Municipal and Domestic Supply (MUN) beneficial uses.

Section five describes the tools and methods that will be used in the SED to analyze the effect of flow and southern Delta water quality alternatives on water supplies in the SJR watershed. A range of SJR and tributary flow requirement alternatives was selected to demonstrate applicability of the data, methods, and tools for analyzing the associated effects. The range of alternatives presented in this section is based on minimum flow requirements of 20%, 40%, and 60% of unimpaired flow from the SJR tributaries during the months of February through June. The range of SJR flow and southern Delta water quality alternatives will be further refined in the SED. The potential environmental, economic, water supply, and related impacts of the various alternatives will then be analyzed and disclosed prior to any determination concerning changes to the existing SJR flow and southern Delta water quality objectives and associated programs of implementation.

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[1] Unimpaired flow is a modeled flow generally based on historical gage data with factors applied to primarily remove the effects of dams and diversions within the watersheds. It differs from full natural flow in that the modeled unimpaired flow does not remove changes that have occurred such as channelization and levees, loss of floodplains and wetlands, deforestation, and urbanization.

2 Hydrologic Analysis of San Joaquin River Basin

Construction of storage infrastructure (dams) and diversions have vastly altered the natural flow regime of the San Joaquin River (SJR) and its major tributaries (McBain and Trush 2000; Kondolf et al. 2001; Cain et. al 2003; Brown and Bauer 2009). The purpose of this hydrologic analysis is to describe how the magnitude, frequency, duration, timing, and rate of change of the flows in the SJR and its major tributaries have been altered within the project area. This analysis is accomplished by comparing observed flows against unimpaired flows for each of these rivers. As described in Section 2.2.2, unimpaired flows are estimated on a monthly basis for water years 1922 to 2003 by DWR, and for the purpose of this analysis, are considered to adequately portray the natural flow regime.

The SED identifies the Lower San Joaquin River (LSJR) as the portion of the SJR downstream of the Merced River confluence. The Stanislaus, Tuolumne, and Merced Rivers (LSJR tributaries), together with San Joaquin River flows into Millerton Lake (Upper SJR) are the major sources flow to the LSJR. The Chowchilla and Fresno Rivers, the Valley Floor, and Tulare Lake Basin also contribute a small portion of flow to the LSJR.

2.1 Basin Characteristics and Descriptive Studies

In the Sierra Nevada, as in other systems dependent on snow pack and snow melt, the typical components of the unimpaired flow regime generally include: fall storm flows, winter storm flows, spring snowmelt, and summer baseflows (McBain and Trush 2000; Kondolf et al. 2001; Stillwater Sciences 2001; Cain et al. 2003). These characteristics are present in the LSJR tributaries and Upper SJR in nearly all years, with wide temporal variations in magnitude throughout the year and from year to year. These characteristics are illustrated in Figure 2.1 and Figure 2.2 for a Wet water year (2005) and a Critically Dry water year (2008), respectively, for the Stanislaus River. Though the overall flow magnitudes may be different, the other characteristics of the flow regimes of the LSJR tributaries and the Upper SJR are all similar.

The mainstem of the SJR is 330 miles long from its headwaters in the Sierra Nevada Mountains to its confluence with the Sacramento River and drains an area of approximately 15,550 square miles. The SJR near Vernalis (Vernalis) is roughly the location where all non-floodplain flows from the SJR basin flow into the Delta. Vernalis is located at river mile (RM) 72, as measured from its confluence with the Sacramento River, and is upstream of tidal effects in the Delta. Table 2.1 summarizes the basin characteristics of the LSJR tributaries and Upper SJR.

The Stanislaus River flows into the mainstem SJR approximately three miles upstream of Vernalis. The Stanislaus River is 161 miles long and drains approximately 1,195 square miles of mountainous and valley terrain. Approximately 66 miles of the Stanislaus River are downstream of the New Melones Dam, 59 miles of which are downstream of Goodwin Dam, the most downstream impediment to fish passage. There are 28 Division of Safety of Dams (DSOD) dams on the Stanislaus River (and 12 additional non-DSOD dams) with a total capacity of 2.85 million acre-feet (MAF).

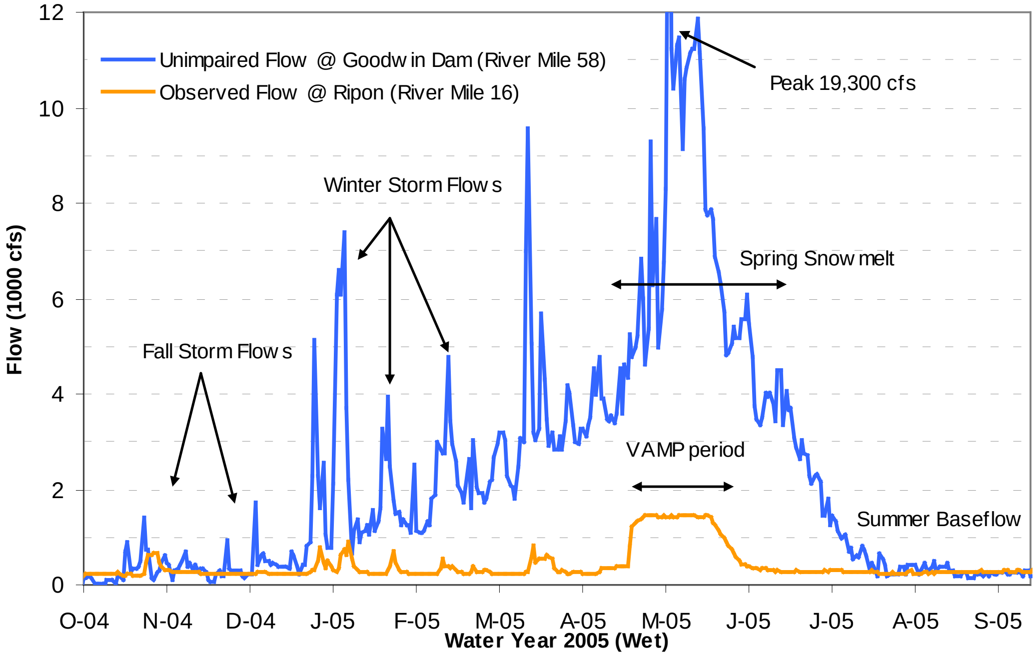

Figure 2.1. Typical Stanislaus River Annual Hydrograph of Daily Average Unimpaired and Observed Flows during a Wet Water Year (2005) Illustrating Important Hydrograph Components

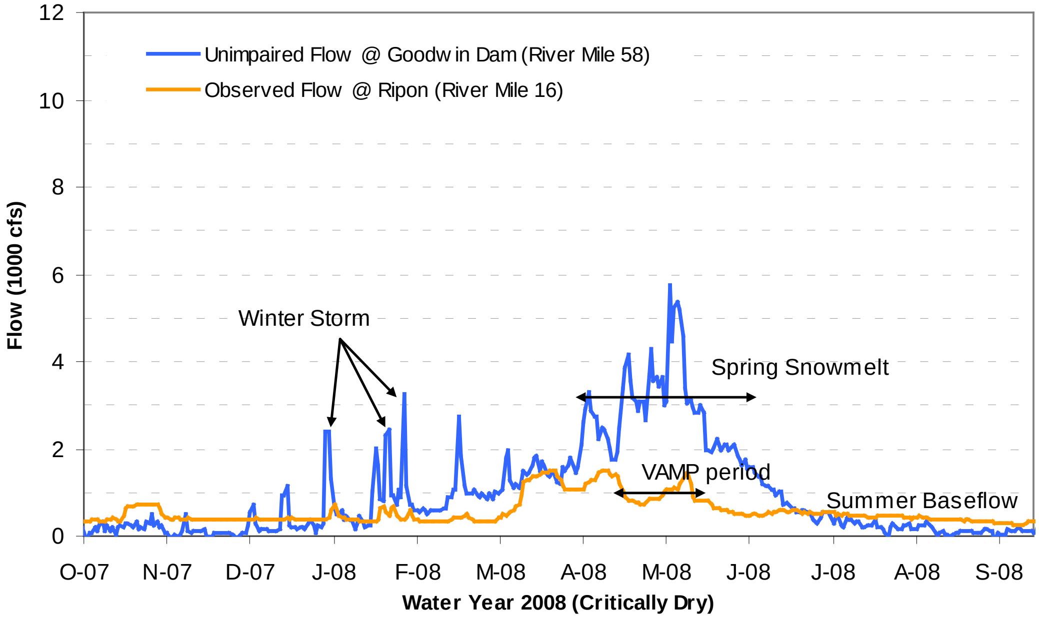

Figure 2.2. Typical Stanislaus River Annual Hydrograph of Daily Average Unimpaired and Observed Flows during a Critically Dry Water Year (2008) Illustrating Important Hydrograph Components

Table 2.1. Summary of Watershed and Dam Characteristics for each of the LSJR tributaries and Upper SJR.

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

Source: Adjusted from Cain et al. 2003; [1]NRCS Watershed Boundary Dataset (2009); [2]Kondolf et. al. 1996 (adapted from Kondolf et al. 1991) as cited by Cain et al. 2003; [3]Division of Safety of Dams (DSOD) dams are those > 50 ft in height and > 50 ac-ft, [4]Cain et al. 2003; [5] No water through Gravelly Ford (RM 229) except during high runoff periods (Meade 2010).

The Tuolumne River flows into the SJR at RM 83, approximately eight miles upstream of the Stanislaus River confluence. The Tuolumne River is 155 miles long and drains an area of 1,870 square miles. Approximately 55 miles of the Tuolumne River are downstream of New Don Pedro Dam, 52 miles of which are downstream of La Grange Dam, the furthest downstream impediment to fish passage. There are 27 DSOD dams on the Tuolumne River with a total capacity of 2.94 MAF.

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

Additional flow enters the SJR upstream of the Merced River confluence and downstream of Friant Dam from the Chowchilla and the Fresno Rivers and the Tulare Lake Basin. These two rivers have smaller watersheds that do not extend to the crest of the Sierra Nevada Mountains and consequently, deliver a much smaller portion of flow to the SJR. In most years, no flow enters the SJR from the Tulare Lake Basin, with the exception being years with high rainfall, when the Tulare Lake Basin connects to the SJR and contributes flow to the system. Flow from these sources is discussed further in Section 2.4 of this report.

The headwaters of the SJR are on the western slope of the Sierra Nevada Mountains at elevations in excess of 10,000 feet. At the foot of the mountains, the Upper SJR is impounded by Friant Dam, forming Millerton Lake. The SJR upstream of the Merced River confluence, including the Upper SJR, and the Fresno and Chowchilla Rivers, drains a watershed area of approximately 5,800 square miles, with approximately 1,660 square miles occurring upstream of Friant Dam. There are 19 DSOD dams with a total storage capacity of 1.15 MAF in the SJR watershed upstream of the Merced River confluence.

Previous to this technical report, studies of SJR hydrology and effects on fisheries (McBain and Trush 2000; Kondolf et al. 2001; Stillwater Sciences 2001; USACE 2002; Cain et al. 2003, Brown and Bauer 2009) focused on floods and flow frequencies within the tributaries and provide less detail regarding annual, seasonal, and inter-annual trends. These studies relied primarily on historical, daily time-step gage data rather than on daily unimpaired flow for each tributary because unimpaired flow data was not readily available for all tributaries. These studies did not evaluate the possible effects of human alteration within the tributaries to flows at Vernalis.

These studies relied upon flow gage data from periods prior to major changes in the watershed as a proxy for unimpaired flows. This is often called pre-regulated flow or pre-dam flow, and generally represents flows that occurred prior to construction of a specific project or multiple projects within the water system. For example, pre-regulated flows could be the flows that existed prior to the construction of a hydroelectric or water supply reservoir. In most cases, pre-regulated flows do not fully represent unimpaired flow unless there was no development of water in the watershed for the period of time chosen by the researcher. Three potential differences or issues with using pre-regulated flow in place of unimpaired flow are: 1) each researcher may choose different periods of time to describe the alteration or pre-regulated period, 2) it is nearly impossible to obtain observed flows for time periods prior to all modifications, and 3) depending on the time period used, that time period may bias the results due to differences in climate, and/or decadal trends when comparing pre-regulated and present-day periods. In contrast, use of unimpaired flow allows for a more direct comparison with, and assessment of, the magnitude of alteration of flows relative to past conditions.

The appendices to *San Joaquin Basin Ecological Flow Analysis* by Cain et al. (2003) contain comprehensive hydrologic analyses of the hydrology of the SJR basin focusing on the LSJR tributaries and Upper SJR. The investigators used various approaches to analyze the hydrology of the SJR basin including a Hydrograph Component Analysis and an analysis using Indicators of Hydrologic Alteration. The Hydrograph Component Analysis on the LSJR tributaries and the Upper SJR (Appendix B of Cain et al. [2003]) was done by taking the unimpaired flow hydrograph and segregating various components (roughly seasonal) based on similar specific characteristics important to the natural ecosystem (Figure 2.1 and Figure 2.2). When unimpaired flow is not available, previous researchers have often separated the historical data into assorted periods that represent varying degrees of watershed modifications, such as the construction of dams and diversions. In some instances, the earlier gaged flows may represent natural flow; however, given that early settlement and diversions within the Central Valley began in the mid-19th century, historical flows may not fully represent unimpaired flow. The Hydrograph Component Analysis in Appendix B of Cain et al. (2003) was based on available unimpaired flow estimates for the Tuolumne and the Upper SJR, and observed flow from early periods representing less modified and/or pre-dam conditions for the Merced and Stanislaus Rivers.

The Nature Conservancy (TNC) developed the Indicators of Hydrologic Alteration software to calculate a set of metrics that evaluate magnitude, timing, and frequency of various events. Such metrics include annual peak daily flow, 30-day peak flow, annual minimum flow, and 30-day minimum flow among several others (Richter et al. 1996, 1997; Cain et al. 2003, TNC 2005). At the time of the Cain et al. 2003 study, daily unimpaired data was only available for the Tuolumne River, thus the Indicators of Hydrologic Alteration analysis used gage data from earlier periods to best represent pre-dam conditions in lieu of unimpaired data, and compared these to post-dam conditions. Brown and Bauer (2009) also completed an Indicators of Hydrologic Alteration analysis for the SJR basin.

2.2 Hydrologic Analysis Methods

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

2.2.1 Selection of Flow Data and Gages

This report uses the USGS gages located at the most downstream location for each of the LSJR tributaries, the Upper SJR, and at Vernalis to characterize historical observed flows. The most downstream gage was selected in order to account for as many diversions and return flows as possible in each of the tributaries (primarily within the Tuolumne and Merced Rivers). In general, the flows measured by the selected gages represent flows originating within the river basin; however, there are some inter-basin transfers. For example, the Highline Canal transfers drainage and urban runoff from the Tuolumne River watershed to the Merced River through the

High Line Spill. This report does not attempt to adjust for differences among river basins resulting from inter-basin transfers or return flows and other accretions from the valley floor entering downstream between the gage and the confluence with the SJR. A summary of gages used in this analysis is provided in Table 2.2.

Table 2.2. Streamflow and Gage Data used in Hydrologic Analysis and Sources of Data

Flow Data	Location/Gage No.	Source/ Reporting Agency	Dates Available and Source
Vernalis Monthly Unimpaired Flow	Flow at Vernalis	DWR	1922 to 2003[2]; 2004 to Present[1]
Vernalis Daily and Monthly Observed Flow	USGS #11303500	USGS	1923 to Present[3, 4]
Garwood Daily Observed Flow.	USGS # 11304810	USGS	1995 to Present[3]
Stanislaus Monthly Unimpaired Flow	Inflow to New Melones	DWR	1922 to 2003[2]; 2004 to Present[1]
Stanislaus Daily and Monthly Observed Flow	USGS #11303000	USGS	1940 to 2009[3]; 2009 to Present[1]
Tuolumne Monthly Unimpaired Flow	Inflow to Don Pedro	DWR	1922 to 2003[2]; 2004 to Present[1]
Tuolumne Daily and Monthly Observed Flow	USGS #11290000	USGS	1940 to Present[3]
Merced Monthly Unimpaired Flow	Inflow to Exchequer	DWR	1922 to 2003[2]: 2004 to Present[1]
Merced Daily and Monthly Observed Flow	USGS #11272500	USGS	1940 to 1995, 2001 to 2008[3]; 1995 to 1999, 2008 to Present[1]
Upper SJR Monthly Unimpaired Flow	Inflow to Millerton Lake	DWR	1922 to 2003[2]: 2004 to Present[1]
Upper SJR Daily and Monthly Observed Flow	USGS#11251000	USGS	1907 to Present[3]

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

2.2.2 Unimpaired Flow Sources and Calculation Procedures

This report uses unimpaired flow estimates for comparisons to the historical data from the LSJR tributary and Upper SJR gages. Unimpaired flow is the flow that would have occurred had the natural flow regime remained unaltered in rivers instead of being stored in reservoirs, imported, exported, or diverted. Unimpaired flow is a modeled flow generally based on historical gage data with factors applied to primarily remove the effects of dams and diversion within the watersheds. Unimpaired flow differs from full natural flow in that the modeled unimpaired flow does not remove changes that have occurred such as channelization and levees, loss of floodplain and wetlands, deforestation, and urbanization. Where no diversion, storage, or consumptive use exists in the watershed, the historical gage data is often assumed to represent unimpaired flow. Observed flow is simply the measured flow in the river.

DWR periodically updates and publishes unimpaired flow estimates for various rivers in the Central Valley. The latest edition is *California Central Valley Unimpaired Flow Data, Fourth*

Edition, Draft (UF Report; DWR 2007a). The UF Report contains monthly estimates of the volume of unimpaired flow for all sub-basins within the Central Valley divided into 24 sub-basins, identified as sub-basins UF-1 through UF-24. The individual sub-basins of the SJR (sub-basins UF-16 to UF-24) are summed in the UF Report to estimate the "San Joaquin Valley Outflow" which roughly coincides with Vernalis. For the purposes of analysis presented in this chapter, however, the "West Side Minor Streams"[2] (UF-24 in the UF Report), was subtracted from the "San Joaquin Valley Outflow" as this sub-basin enters downstream of Vernalis. The analysis in this chapter uses monthly unimpaired flow from the UF Report for each LSJR tributary, the Upper SJR, other inflows, and the flow at Vernalis as follows:

- UF-16: Stanislaus River at New Melones Reservoir;
- UF-17: San Joaquin Valley Floor;
- UF-18: Tuolumne River at New Don Pedro Reservoir;
- UF-19: Merced River at Lake McClure;
- UF-22: SJR at Millerton Lake (Upper SJR)
- UF-20, UF-21, UF-23: summed to equal unimpaired flow from Fresno River, Chowchilla River and Tulare Lake Basin Outflows
- "San Joaquin Valley Unimpaired Total Outflow" less UF-24: to represent unimpaired flow at Vernalis.

Because the UF Report does not present unimpaired flows beyond 2003, monthly unimpaired flow data was downloaded from the California Data Exchange Center (CDEC; sensor #65 "Full Natural Flow") for the LSJR tributaries and Upper SJR. To estimate monthly unimpaired flow at Vernalis for the period beyond 2003, the LSJR tributaries and Upper SJR were summed using the CDEC data and a linear correlation of tributary-to-Vernalis flow for 1984 to 2003 was developed. This linear correlation was then applied to the 2004 to 2009 LSJR tributary and the Upper SJR flows to result in the corresponding flows at Vernalis. The LSJR tributaries and Upper SJR are the only locations in the SJR basin with monthly data available from CDEC.

Unimpaired flow calculations for sub-basins 16, 18, 19, and 22 are conducted by the DWR Snow Survey Team. The methods of calculation are consistent for each sub-basin. Each begins with a flow gage downstream of the major rim dam. This is adjusted by adding or subtracting changes in storage within the major dams upstream, adding losses due to evaporation from the reservoir surfaces, and adding flow diverted upstream of the gage (Ejeta, M. and Nemeth, S., personal communication, 2010). Within DWR's calculations, the San Joaquin Valley Floor sub-basin is taken into account approximately at Vernalis, rather than within each LSJR tributary and the Upper SJR. It is possible that some portion of the flow attributed to the Valley Floor enters the tributaries themselves rather than the mainstem SJR; however, no attempt was made to do so as the valley floor component makes up only roughly 3% of the average annual unimpaired flow on the LSJR tributaries (DWR 2007a). Therefore, without Valley Floor unimpaired estimates for the LSJR tributaries and Upper SJR, it is assumed the monthly unimpaired flow estimates at the tributary rim dams provide an adequate portrayal of the natural flow regime for comparison against observed flows at the mouths of the tributaries.

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

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

In addition to the monthly estimates available in the UF Report, CDEC publishes real time average daily estimates of unimpaired flow just downstream of the major rim dams for the Stanislaus River at New Melones Dam starting in 1992, the Tuolumne River at New Don Pedro Dam starting in 1989, the Merced River at New Exchequer Dam starting in 1988, and the Upper SJR at Friant Dam starting in 1987. Only monthly unimpaired flow data is currently available for application at Vernalis. To assess alterations to storm flows or short term peak flows at this location, daily unimpaired flow estimates would be needed.

2.3 Hydrology of the San Joaquin River at Vernalis

The current hydrology of the SJR is highly managed through the operations of dams and diversions. As a result, the natural hydrologic variability in the SJR basin has been substantially altered over multiple spatial and temporal scales. Alterations to the unimpaired flow regime include a reduced annual discharge, reduced frequency and less intense late fall and winter storm flows, reduced spring and early summer snowmelt flows, and a general decline in hydrologic variability (McBain and Trush 2002; Cain et al. 2003; Brown and Bauer 2009; NMFS 2009a). The historical annual and inter-annual hydrologic trends at Vernalis are presented in Section 2.3.1 below, and the currently altered hydrology at Vernalis on annual, monthly, and daily temporal scales is presented in Sections 2.3.2 through Section 2.3.4, respectively, below.

2.3.1 Historical Flow Delivery, Reservoir Storage, and Inter-Annual Trends

Figure 2.3 displays the annual difference between unimpaired flow and observed flow in the SJR at Vernalis from 1930 to 2009, the overlapping range of historical gage data, and unimpaired flow data. Before 1955 the cumulative storage of reservoirs in the SJR basin was less than 2.1 MAF. However, by 1978 the cumulative storage in the SJR basin had increased to just below 8 MAF. Lake McClure (formed by New Exchequer Dam) on the Merced River and New Don Pedro Reservoir (formed by New Don Pedro Dam) on the Tuolumne River added 0.75 MAF and 1.7 MAF of storage in 1967 and 1970, respectively. New Melones Reservoir (formed by New Melones Dam) on the Stanislaus River added 2.34 MAF of storage in 1978. Prior to 1955, there was little variation in the volume stored, diverted, or consumptively used; observed flows were generally between 1.5 and 3 MAF lower than unimpaired flows. After 1955 and again after 1970, the annual difference in volume became larger and more variable from year to year, attributable mostly to large increases in storage capacity within the basin. Some of this change in variability, however, could also be attributable to changes in climate from year-to-year and decadal trends, which have not been accounted for in this analysis.

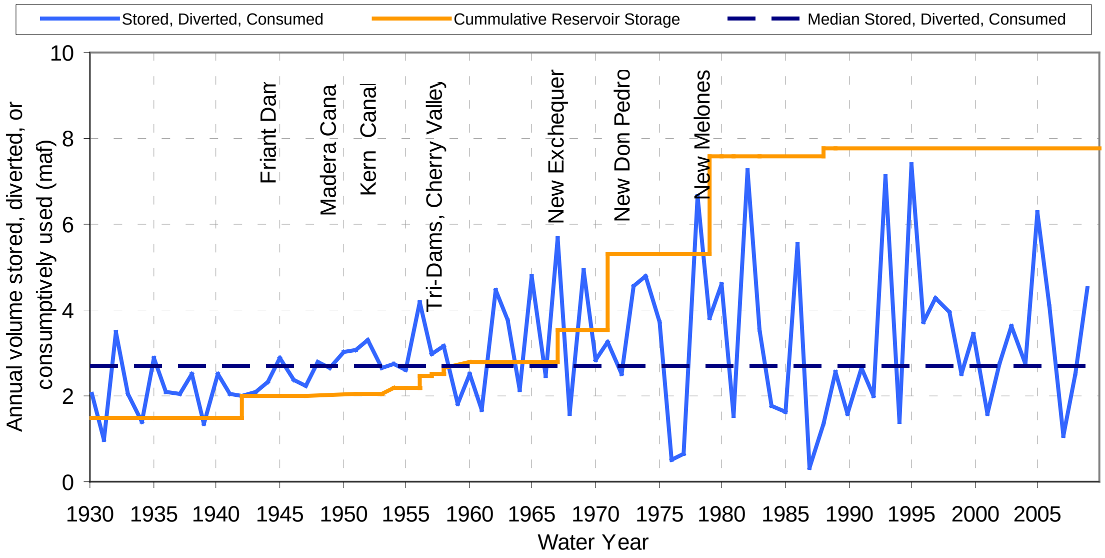


Figure 2.3. Annual Volume Stored, Diverted, or Consumptively Used Upstream of Vernalis, and Cumulative Reservoir Storage Capacity within the SJR River Basin Upstream of Vernalis

The median annual unimpaired flow in the SJR at Vernalis from water year 1930 through 2009 was 5.6 MAF. The median annual volume stored, diverted, or consumed was 2.7 MAF, while the median observed flow as a percentage of unimpaired flow was 44% over the 80 year period. This median annual reduction in flow relative to unimpaired flow is attributable to exports of water outside the basin and consumptive use of water in the basin. As shown in Table 2.3, the volume stored, diverted or used for individual years tends to be greatest in Below Normal to Critically Dry years because relatively more water is stored and consumptively used than released in such years.

The greatest volumetric reduction of annual flow has generally occurred during Wet years, and most significantly in the first year or years following a drought. Water Year 1995 experienced the greatest reduction from unimpaired flow on record when 7.4 MAF was stored or diverted in the LSJR tributaries and Upper SJR, ultimately reducing observed flow to 46% of unimpaired flow. Examples of this effect can be seen in Figure 2.4 in 1993, 1995, and again in 2005 (among others), which show large diversions to storage during wetter years that follow years of drought.

The years leading up to high storage Wet or Above Normal years were a series of Dry years forming drought conditions from 1987 to 1993 and again from 2000 to 2004, during which the quantity of water stored in the major reservoirs within the LSJR tributaries and Upper SJR (New Melones, New Don Pedro, Lake McClure, and Millerton Lake) was greatly reduced. In contrast, during the second and third Normal or wetter year following a drought, 1996 to 1997 and again in 2006, less of the inflows to these reservoirs is stored, resulting in higher percentage of flow released downstream than during the preceding wetter years.

Table 2.3. Observed and Unimpaired Annual Flow Statistics and Percent of Unimpaired Flow (1930 to 2009) in the San Joaquin River at Vernalis

	Number of Occurrences	Unimpaired Flow	Observed Flow	Volume Stored, Diverted, or Consumed	Observed Flow as a Percent of Unimpaired Flow
	# Years/ (year)	(TAF)	(TAF)	(TAF)	(%)
Average of All Years	80	6,290	3,280	3,010	48
Median of All Years[1]	80	5,640	1,850	2,660	44
Average of Wet Years	25	10,600	6,210	4,390	57
Average of AN Years	14	6,840	3,840	2,990	56
Average of BN Years	11	4,610	1,620	2,990	35
Average of Dry Years	14	3,610	1,400	2,220	40
Average of Critical Years	16	2,590	1,010	1,580	41
Wettest of Years	(1983)	18,940	15,410	3,530	81
Driest of Years	(1977)	1,060	420	640	40
Greatest % of Unimpaired Flow Stored, Diverted, Consumed	(2009)	5,390	870	4,520	16
Greatest Volume Stored, Diverted, Consumed	(1995)	13,680	6,300	7,380	46

[1] Median occurred in 2009 for unimpaired flow, 1987 for observed flow, and 1955 for volume stored, diverted, consumed.

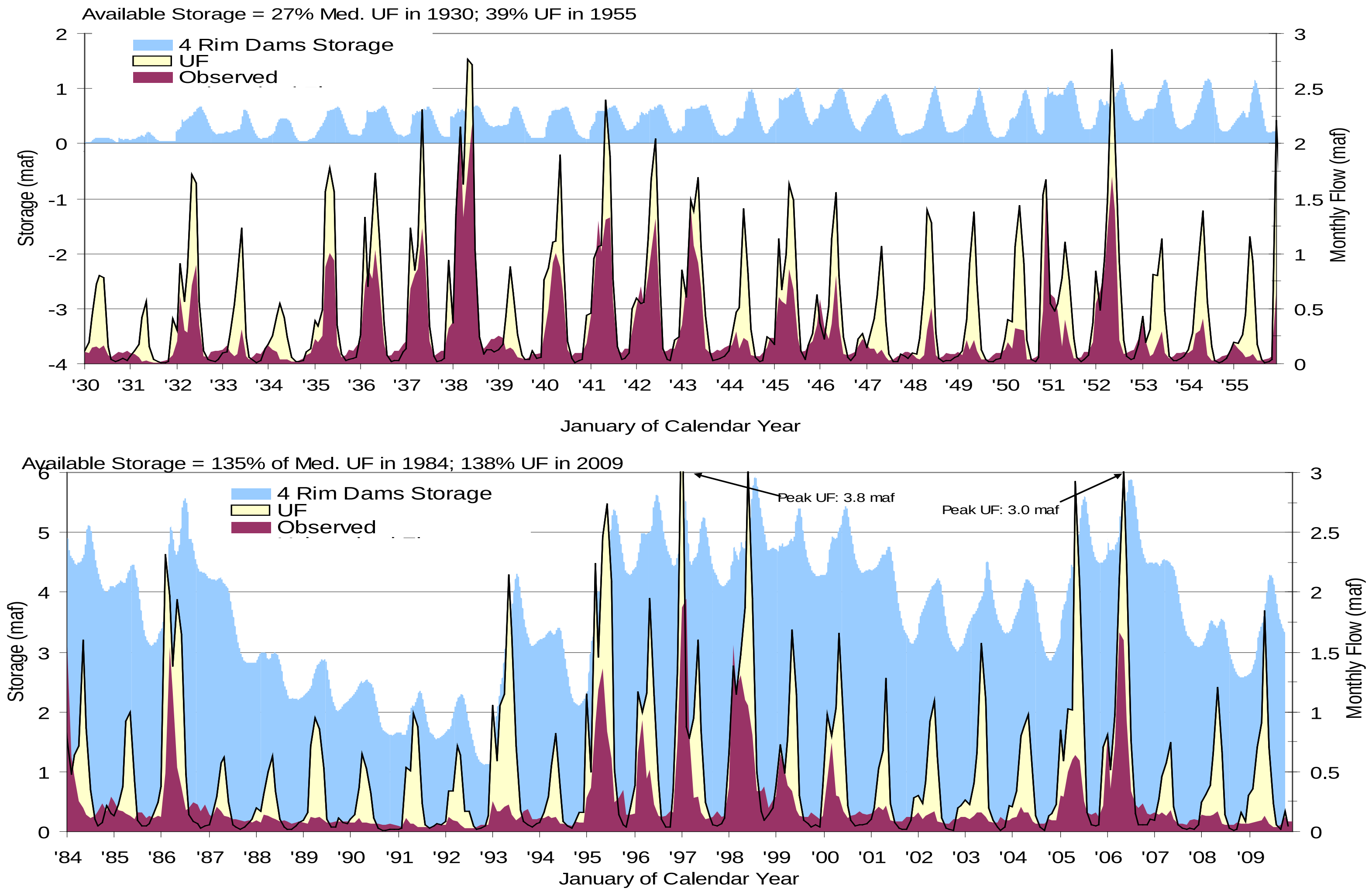


Figure 2.4. Monthly Unimpaired and Observed Flow in the San Joaquin River at Vernalis and Total Storage Behind New Melones, New Don Pedro, New Exchequer, and Friant Dams for Two Periods in Time (1930 to 1955 and 1984 to 2009)

2.3.2 Annual Flows for Pre-Dam and Post-Dam Periods

To help differentiate flow changes that have occurred as a result of changes in water storage facilities and management from changes in hydrology, the hydrologic patterns for two time periods are presented: 1930 to 1955 and 1984 to 2009. The period from 1930 to 1955 shows the time before major water storage projects were completed on the Merced, Tuolumne and Stanislaus Rivers. The period from 1984 through 2009 shows the time after completion and filling of major water storage projects on these tributaries; New Melones Reservoir was initially filled during two Wet years—1982 and 1983. Table 2.4 provides summary statistics for these two time periods which demonstrates that they had similar but not identical hydrologic conditions. Average annual unimpaired flows for these two periods were 5.9 MAF and 6.1 MAF respectively, and median annual unimpaired flows were 5.4 MAF and 4.6 MAF respectively. This shows that the later period was skewed towards lower flows, with twice as many Critically Dry and Dry years and fewer Above Normal and Below Normal years.

Table 2.4. Unimpaired and Observed Flow Statistics by Water Year Type for 1930 to 1955 and 1984 to 2009

	1930-1955			1984 - 2009			
	# Years (year)	Unimpaired Flow (TAF)	Observed Flow (TAF)	# Years (year)	Unimpaired Flow (TAF)	Observed Flow (TAF)	Observed Flow as Percentage of Unimpaired Flow
Average of All Years	26	5,900	3,520	26	6,070	2,900	45
Median of All Years	26	5,400	2,760	26	4,580	1,720	46
Average of Wet Years	6	9,490	7,160	8	10,750	5,450	50
Average of AN Years	7	7,070	4,320	3	6,820	4,240	61
Average of BN Years	6	4,350	1,670	1	4,990	1,360	27
Average of Dry Years	4	3,410	1,350	5	4,140	1,490	38
Average of Critical Years	3	2,450	960	9	2,840	1,150	42
Wettest of Years	(1938)	13,370	10,840	(1995)	13,680	8,490	84[1]
Driest of Years	(1931)	1,680	680	(1987)	2,160	660	16[2]

[1] Highest percentage of unimpaired flow
[2] Lowest percentage of unimpaired flow.

The period from 1930 to 1955 is representative of conditions where total reservoir storage volume in the SJR basin ranged from 1.5 MAF to 2.2 MAF, or 27% to 39% of the long-term median annual unimpaired flow in the basin. The period from 1984 to 2009 is representative of current conditions, with reservoir storage of 7.6 MAF to 7.8 MAF, or 135% to 138% of the long-term median annual unimpaired flow in the basin.

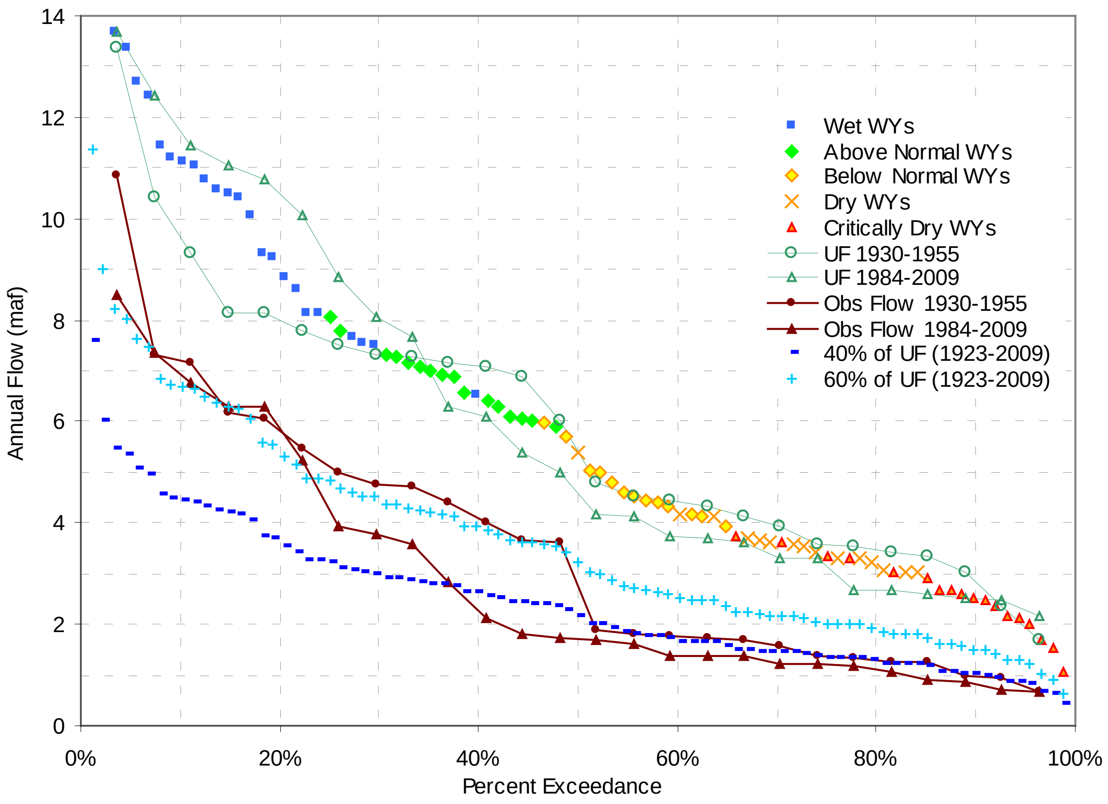


Figure 2.5. Exceedance Curves of Observed and Unimpaired Flow Hydrology in the San Joaquin River at Vernalis

Exceedance curves for unimpaired and observed flow for the two periods are superimposed on the long-term unimpaired flow for the entire unimpaired flow data set spanning 1923 to 2009 in Figure 2.5. A percent chance of exceedance was assigned to each year using the Weibull plotting positions (Viessman and Lewis 2003). This approach assigns an equal difference in percent chance exceedance per record. The period from 1930 to 1955 was slightly wetter than the period from 1984 to 2009. The earlier period had fewer extremes; that is to say there were fewer Critically Dry and Wet years, and more moderate, Below Normal and Above Normal years.

As a result of changes in storage and diversion, flow in the river has been reduced, resulting in low flow conditions more frequently than would have occurred under natural conditions. From Figure 2.5, based on the unimpaired flow data set, annual flow would have been less than approximately 2.5 MAF in only about 10% of years, roughly the 10 driest years on record. Under present-day conditions, annual flows less than approximately 2.5 MAF have been observed in 60% to 65% of years (the 35% to 40% exceedance level). From 1930 to 1955, observed annual flows less than approximately 2.5 MAF occurred in fewer than 50% of years.

Between 39% and 68% of annual unimpaired flow remained in the river for the 1930 to 1955 period, and between 34% and 58% remained in the river during the 1984 to 2009 period. The curves corresponding to 40% and 60% of unimpaired flow are overlaid for reference to the percentage of unimpaired flow ultimately remaining in the river.

In addition to inferences regarding changes over time, the long-term unimpaired flow exceedance curve in Figure 2.5 indicates that water year classification types do not always accurately describe the unimpaired flow volume within that year. For example, many of the Critically Dry water years had higher annual flow volumes than many of the Dry water years. This is in part because the water year classification depends partially on the preceding water year type. An exceedance curve of unimpaired flow is a more direct measurement of estimated flow because it is derived from hydrologic conditions and ranks them from wettest to driest. The exceedance curves for 1930 to 1955 and 1984 to 2009 are not separated by water year type as was done for the long term data, because there are too few years to accurately represent each water year classification.

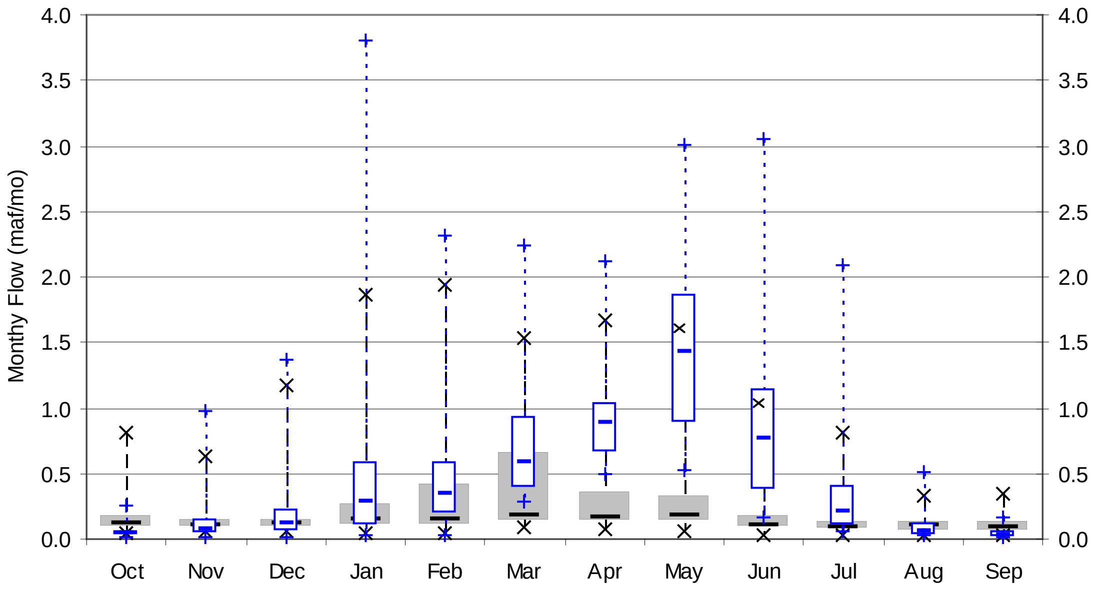
2.3.3 Monthly and Seasonal Trends

Increased storage and operational changes have resulted in flow conditions that are more static with less seasonally variable flows throughout the year (Figure 2.6). There is now a severely dampened springtime magnitude and more flow in the fall, both of which combine to create managed flows that diverge significantly from what would occur under an unimpaired condition. Tables 2.5 through 2.7 contain monthly unimpaired flow, observed monthly flow, and observed monthly flow as a percentage of monthly unimpaired flow, respectively, in the SJR at Vernalis for water years 1984 through 2009.

The percentile monthly unimpaired, observed, and percentages of unimpaired flow at Vernalis are presented in Table 2.8. The median (i.e., middle value of each data set) is given by the 50th percentile value. These statistics are presented instead of the average (or mean) in order to focus more on how often various flows occur, and to avoid a statistic that can be skewed by exceptionally high or low values. Flows presented in this table are not exceeded (i.e., flow is equal to, or less than given value) for the given percentile. For example, the 60th percentile percentage of unimpaired flow for May is 18%. This means 60% of monthly May flows between 1984 and 2009 did not exceed 18% of the corresponding monthly unimpaired flow.

Overall the annual flow volumes at Vernalis have been reduced to a median of 46% of unimpaired flow, while the February through June flow volume has been reduced to a median of 27% of unimpaired flow. In terms of median values, the greatest reduction of the monthly flows occurs during peak spring snowmelt months of April, May, and June. As presented in Table 2.8, observed flows during these months are a median of 25%, 17%, and 18% of unimpaired flow, respectively. This means that in 50% of the water years between 1984 and 2009 the observed flow as a percentage of unimpaired flow is lower than the median, with the lowest percentages of unimpaired flow (as seen from Table 2.7) reaching 4% in June of 1991, 7% in May of 1991 and 2009, and 9% in June of 2008 and 2009. These were all in water years classified as either Critically Dry or Dry. In contrast, the months of August through November have median flows higher than unimpaired: 133%, 269%, 342%, and 133% of unimpaired flow, respectively, as shown in Table 2.8.

The unimpaired flow magnitude of the snowmelt varies dramatically each year as shown in Table 2.8 by an inter-quartile range (i.e., the difference between 75th percentile and 25th percentile) of 376, 981, and 766 TAF for the months of April, May, and June, respectively, compared to observed conditions, where this range has been reduced to roughly 233, 199, and 92 TAF, respectively. By comparison, Table 2.8 shows the inter-quartile range is slightly increased for September and October. This large decrease in spring flow magnitude and variation throughout the year, as well as the augmentation of summer and fall flows is apparent in nearly all recent years. Figure 2.4 emphasizes this, especially during the later period of 1984 to 2009 where observed flows are significantly lower than unimpaired flow during the wet season and are higher than unimpaired flow during the dry season.



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

Figure 2.6. Monthly Unimpaired Flow (Open Bars) and Observed Flow (Filled Bars) in the SJR at Vernalis from 1984 to 2009

Table 2.5. Monthly, Annual, and February through June Unimpaired Flow in the SJR at Vernalis from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	263	981	1,254	773	482	635	714	1,600	864	345	108	44	8,063	5,068
1985	D	78	220	149	134	228	380	926	997	420	95	43	45	3,715	3,085
1986	W	68	148	249	378	2,311	1,965	1,384	1,941	1,643	478	139	81	10,785	9,622
1987	C	63	30	45	52	137	287	569	624	242	60	34	17	2,160	1,911
1988	C	35	76	104	193	169	310	499	627	337	105	42	19	2,516	2,135
1989	C	21	46	75	93	158	719	947	858	523	108	34	36	3,618	3,298
1990	C	109	76	62	108	138	363	645	523	322	112	25	11	2,494	2,099
1991	C	14	17	18	23	24	538	510	987	874	231	53	28	3,317	2,956
1992	C	46	69	58	81	339	341	711	635	170	166	44	21	2,681	2,277
1993	W	31	46	135	1,052	593	1,049	1,144	2,146	1,659	719	177	83	8,834	7,643
1994	C	57	41	65	73	164	291	545	820	371	89	50	28	2,594	2,264
1995	W	75	156	160	1,152	497	2,237	1,458	2,468	2,734	2,088	515	139	13,679	10,546
1996	W	60	41	209	385	1,168	998	1,158	1,947	1,141	420	108	37	7,672	6,797
1997	W	37	352	1,374	3,810	879	782	952	1,600	845	242	122	53	11,048	8,868
1998	W	47	70	114	650	1,387	1,149	1,473	1,876	3,048	1,951	500	169	12,434	9,583
1999	AN	90	143	195	380	726	490	784	1,682	1,151	302	96	63	6,102	5,213
2000	AN	39	58	41	388	974	802	1,037	1,655	938	213	94	51	6,290	5,794
2001	D	57	55	62	103	193	531	681	1,276	234	78	24	18	3,312	3,018
2002	D	22	97	281	304	238	417	921	1,095	630	109	32	17	4,163	3,605
2003	BN	10	198	220	264	224	406	663	1,571	1,102	202	93	40	4,993	4,230
2004	D	11	40	212	208	340	802	877	976	474	127	34	12	4,113	3,676
2005	W	131	147	225	844	590	1,026	1,015	2,926	2,056	906	161	54	10,082	8,459
2006	W	51	54	702	809	515	981	2,116	3,014	2,226	760	147	61	11,436	9,661
2007	C	58	54	102	97	275	460	577	739	206	56	31	20	2,674	2,354
2008	C	25	19	53	247	312	383	654	1,207	667	145	28	13	3,753	3,470
2009	D	16	158	80	303	360	703	908	1,844	701	232	58	23	5,387	4,820

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.6. Monthly, Annual, and February through June Observed Flow in the SJR at Vernalis from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	819	635	1,176	1,576	623	461	255	199	137	117	134	174	6,306	1,675
1985	D	235	168	293	250	180	168	147	131	104	157	160	115	2,108	730
1986	W	127	115	136	127	486	1,539	1,166	539	371	178	196	249	5,227	4,100
1987	C	230	167	228	142	119	210	171	134	118	100	100	95	1,814	752
1988	C	84	92	79	91	80	138	128	110	102	83	96	86	1,168	557
1989	C	69	76	84	77	69	124	114	120	94	79	72	81	1,059	521
1990	C	86	84	85	76	76	108	78	79	66	62	64	52	916	407
1991	C	61	66	56	50	42	109	70	65	34	37	33	34	657	319
1992	C	48	65	55	59	120	90	84	55	29	27	30	38	700	379
1993	W	52	57	60	253	169	166	204	222	139	93	123	165	1,703	900
1994	C	187	105	100	109	110	136	111	121	66	70	53	52	1,220	544
1995	W	84	77	80	283	364	898	1,186	1,364	834	608	241	282	6,301	4,647
1996	W	350	144	138	149	660	927	446	518	222	136	125	129	3,945	2,773
1997	W	165	162	750	1,868	1,947	801	281	294	158	108	115	123	6,772	3,482
1998	W	166	118	130	370	1,562	1,190	1,305	1,104	1,057	811	335	343	8,491	6,217
1999	AN	378	196	266	291	650	512	383	341	179	129	121	121	3,568	2,066
2000	AN	156	128	104	131	435	744	298	296	165	117	133	139	2,846	1,938
2001	D	174	150	138	150	172	211	179	217	92	86	82	82	1,732	871
2002	D	123	125	127	164	105	131	155	168	84	75	69	70	1,396	643
2003	BN	105	102	122	118	104	135	159	161	121	81	79	78	1,365	680
2004	D	123	98	92	110	127	207	164	163	84	71	69	67	1,373	743
2005	W	108	97	97	302	295	496	599	640	594	255	161	144	3,787	2,623
2006	W	161	121	216	810	359	720	1,662	1,602	934	341	227	197	7,351	5,276
2007	C	237	151	145	159	141	157	132	178	104	70	62	60	1,596	712
2008	C	97	102	92	143	136	130	143	169	61	53	53	54	1,234	641
2009	D	76	68	69	68	79	87	90	131	65	37	37	56	866	453

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.7. Monthly, Annual, and February through June Observed Flow as a Percentage of Unimpaired Flow in the SJR at Vernalis from 1984 to 2009

Water Year	Water Year Type[1]	Oct (%)	Nov (%)	Dec (%)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Annual (%)	Feb-Jun (%)
1984	AN	311	65	94	204	129	73	36	12	16	34	124	394	78	33
1985	D	301	76	197	187	79	44	16	13	25	165	372	255	57	24
1986	W	187	78	54	34	21	78	84	28	23	37	141	307	48	43
1987	C	365	557	506	273	87	73	30	21	49	167	294	559	84	39
1988	C	241	121	76	47	47	44	26	17	30	79	228	455	46	26
1989	C	330	165	112	83	43	17	12	14	18	73	211	224	29	16
1990	C	79	110	137	71	55	30	12	15	21	55	254	474	37	19
1991	C	436	390	314	218	175	20	14	7	4	16	62	122	20	11
1992	C	105	93	95	73	35	27	12	9	17	17	67	180	26	17
1993	W	168	124	45	24	28	16	18	10	8	13	69	199	19	12
1994	C	328	255	154	149	67	47	20	15	18	78	107	185	47	24
1995	W	112	49	50	25	73	40	81	55	30	29	47	203	46	44
1996	W	583	352	66	39	57	93	39	27	19	32	116	348	51	41
1997	W	447	46	55	49	221	102	30	18	19	45	94	232	61	39
1998	W	354	168	114	57	113	104	89	59	35	42	67	203	68	65
1999	AN	420	137	137	77	89	105	49	20	16	43	126	192	58	40
2000	AN	399	221	253	34	45	93	29	18	18	55	142	272	45	33
2001	D	305	273	222	146	89	40	26	17	39	110	341	455	52	29
2002	D	560	129	45	54	44	31	17	15	13	69	214	411	34	18
2003	BN	1,048	52	56	45	47	33	24	10	11	40	85	195	27	16
2004	D	1,071	248	43	53	37	26	19	17	18	56	206	540	33	20
2005	W	82	66	43	36	50	48	59	22	29	28	100	267	38	31
2006	W	318	226	31	100	70	73	79	53	42	45	154	325	64	55
2007	C	407	280	141	164	51	34	23	24	50	126	203	309	60	30
2008	C	390	532	173	58	44	34	22	14	9	37	193	404	33	18
2009	D	462	43	86	22	22	12	10	7	9	16	65	247	16	9

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.8. Statistics of Unimpaired Flow, Observed Flow, and Observed Flows as a Percent of Unimpaired Flow in the SJR at Vernalis from 1984 to 2009

Unimpaired flow (TAF)													
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
10%tile	15	35	49	77	148	326	557	631	238	84	29	15	2,555	2,200
20%tile	22	41	62	97	169	380	645	820	337	105	34	18	2,681	2,354
25%tile	26	46	63	104	201	389	656	887	383	108	34	19	3,313	2,972
30%tile	33	50	70	121	226	412	672	981	447	111	38	20	3,468	3,052
40%tile	39	55	102	208	275	490	714	1,095	630	145	44	28	3,753	3,470
50%tile	49	70	125	284	339	587	892	1,424	773	208	55	37	4,578	3,953
60%tile	57	76	160	378	482	719	926	1,600	874	232	94	44	6,102	5,068
70%tile	62	145	211	387	553	802	984	1,763	1,122	324	108	52	7,868	6,296
75%tile	67	148	218	585	592	936	1,032	1,868	1,149	401	119	54	8,641	7,432
80%tile	75	156	225	773	726	998	1,144	1,941	1,643	478	139	61	10,082	8,459
90%tile	100	209	491	948	1,071	1,099	1,421	2,307	2,141	833	169	82	11,242	9,603
Observed flow (TAF)														
10%tile	65	67	65	72	78	109	87	94	63	45	45	52	891	430
20%tile	84	77	80	91	104	130	114	121	66	70	62	56	1,168	544
25%tile	85	86	84	109	107	132	129	131	84	70	65	62	1,223	578
30%tile	91	95	89	114	114	135	138	133	88	73	69	68	1,300	642
40%tile	108	102	97	131	127	157	155	163	102	81	79	81	1,396	712
50%tile	125	110	113	146	155	187	167	174	111	89	98	91	1,718	747
60%tile	161	121	130	159	180	211	204	217	137	108	121	121	2,108	900
70%tile	170	136	138	252	361	504	290	295	161	123	129	134	3,678	2,002
75%tile	184	149	143	275	417	668	362	330	176	134	134	142	3,906	2,484
80%tile	230	151	216	291	486	744	446	518	222	157	160	165	5,227	2,773
90%tile	293	168	280	590	655	913	1,176	872	714	298	212	223	6,539	4,374
Observed flow as a percent of unimpaired flow (%)														
10%tile	109	50	44	29	32	19	12	9	9	16	66	189	23	14
20%tile	187	66	50	36	43	27	16	12	13	29	69	199	29	17
25%tile	256	77	54	40	44	30	17	13	16	33	87	203	33	18
30%tile	303	86	55	46	44	32	18	14	16	35	97	213	33	19
40%tile	318	121	76	53	47	34	22	15	18	40	116	247	38	24
50%tile	342	133	94	57	53	42	25	17	18	44	133	269	46	27
60%tile	390	168	114	73	67	47	29	18	21	55	154	309	48	31
70%tile	414	237	139	92	76	73	33	21	27	62	204	371	55	36
75%tile	432	253	151	134	85	73	38	22	30	72	210	401	58	39
80%tile	447	273	173	149	89	78	49	24	30	78	214	411	60	40
90%tile	572	371	238	195	121	98	80	40	41	118	274	464	66	43

Based on a review of the unimpaired flow estimates, the wettest month (i.e. the month in the water year with the greatest volume of flow) generally occurred between April and June. In 7 out of 80 years (9% of years) from 1930 to 2009, the wettest month of the year would have been April; in 57 years it would have been May and in 12 years it would have been June, one year each it would have been in January and February, and twice it was December. Six of the seven years that April was the wettest month of the year were either Dry or Critically Dry water years. To put this into perspective and show the present conditions, Table 2.9 summarizes the wettest months for the two periods discussed above.

The wettest month of the year is now less predictable as is distributed more evenly from year to year. From 1984 to 2009 the wettest month was most often March, followed by May, February, and October (Table 2.9). The early period was already severely altered with the wettest month occurring many times in either May or June and frequently in March and January. Table 2.9 summarizes the alterations to the timing of the wettest month for the two periods previously discussed using percentage of years each month was the wettest.

Table 2.9. The Wettest Months of Each Year in the SJR at Vernalis as a Percentage of Years during the Two Periods (1930 to 1955 and 1984 to 2009) for Unimpaired Flow and Observed Flow

		Percent of years by month											
Period	No. of yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unimpaired (1930 to 1955)	26	0	0	0	8	77	12	0	0	0	0	0	4
Observed (1930 to 1955)	26	15	0	8	8	31	27	0	0	0	0	0	8
Unimpaired (1984 to 2009)	26	4	4	0	12	73	8	0	0	0	0	0	0
Observed (1984 to 2009)	26	8	15	31	4	27	0	0	0	0	12	0	4

2.3.4 Short Term Peak Flows and Flood Frequency

As shown in Figure 2.1 and Figure 2.2, short term peak or storm flows that occur several times within a given year, generally between November and March, are dramatically reduced under the present management conditions. No attempt was made to calculate the short term peak flows and flood frequencies of unimpaired flow at Vernalis in this report because daily unimpaired flow data are not readily available at Vernalis. Comparisons were made between two periods, 1930 to 1955 and 1984 to 2009 using daily gage data in place of unimpaired flow data to attempt to demonstrate and quantify how peak flows have changed between these two periods. The *Sacramento-San Joaquin Comprehensive Study* (USACE 2002) provides a flood frequency analysis at Vernalis.

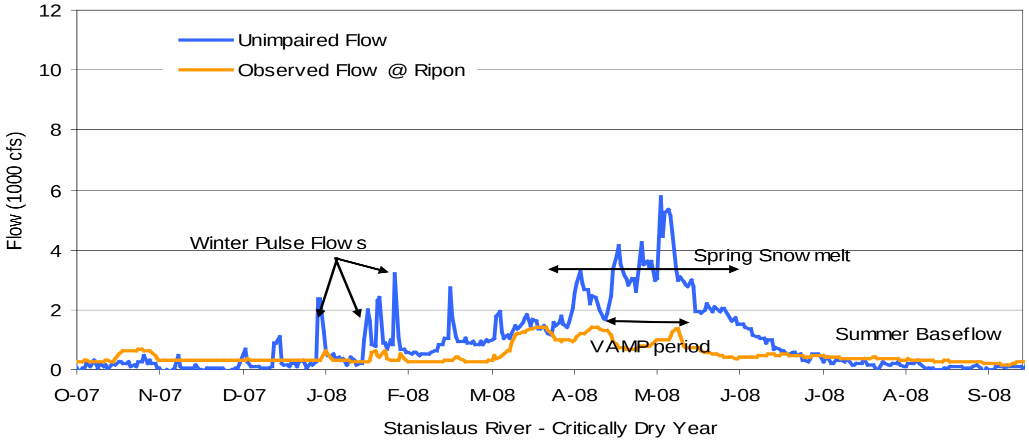
Under natural conditions the, October to March storm flows are generally less intense than the peak flows that occur during the spring snowmelt. By separating the fall and winter storm peaks from the rest of the year, it is possible to see alterations to the various components of the natural flow regime as depicted in Figure 2.1 and Figure 2.2. In the 1984 to 2009 period, peak flows generally occurred between October and March, while in the 1930 to 1955 period, they occurred during the spring. Table 2.10 summarizes the exceedances of the fall and winter component. The spring component is deduced from the annual peak. If the annual peak was greater than observed between October to March, the peak flows occurred at another time during the year, specifically April to June. In order to better characterize the altered regime at Vernalis, it would be necessary to calculate these statistics using daily unimpaired flow estimates in place of the 1930 to 1955 observed flows.

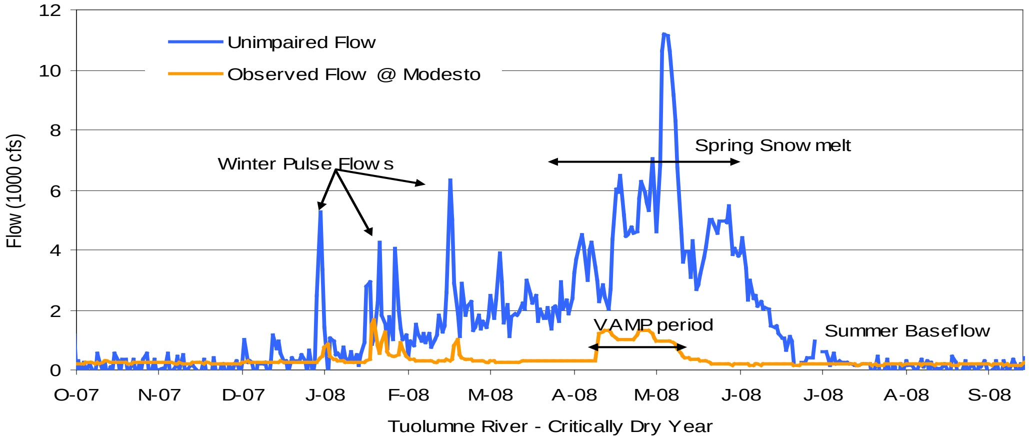
Table 2.10. Percent Chance of Exceedance of October through March and Annual Maximum Daily Average Flow in the SJR at Vernalis

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

To illustrate the loss of storm flows, including those that would have occurred several times in a given year, Figure 2.7 displays daily unimpaired flow and observed flow for WY 2008, a Critically Dry water year, for each of the LSJR tributaries. Even though this was a Critically Dry water year, there were significant storm flows in response to rainfall and rain falling on snow during the later fall and early winter seasons. It is expected that a similar response would be observed at Vernalis; however, daily unimpaired flow estimates are not yet available at Vernalis.

To quantify the changes to peak flows that have occurred, exceedance curves were developed for annual peak flows using the two distinct periods previously identified, and compared to estimates by USACE (2002) shown in Table 2.11. While other studies have focused separately on the LSJR tributaries and the Upper SJR (McBain and Trush 2000; Kondolf et al. 2001; Stillwater Sciences 2001; Cain et al. 2003), the USACE 2002 analysis is the only study to have addressed the peak flow regime at Vernalis. Even though many alterations had occurred within the watershed prior to 1930, reductions in peak flows were evident between the two periods (1930 to 1955 versus 1984 to 2009). For example, reductions in the peak flows of 49%, 61%, and 23% were observed, respectively, for 1.5-year, 2-year, and 5-year return frequencies. In addition, flows of approximately 15,000 cfs, which would have occurred at least once every year or two, now occur upwards of only once every five years (Table 2.11). The difference in larger peak flows, for those that occur every 10 years on average, is, however, less pronounced, with only a 6% reduction from the early period. The USACE (2002) estimates of peak flows are somewhat higher than those estimated here because USACE used unimpaired flow data, which estimates return frequencies prior to any alterations.





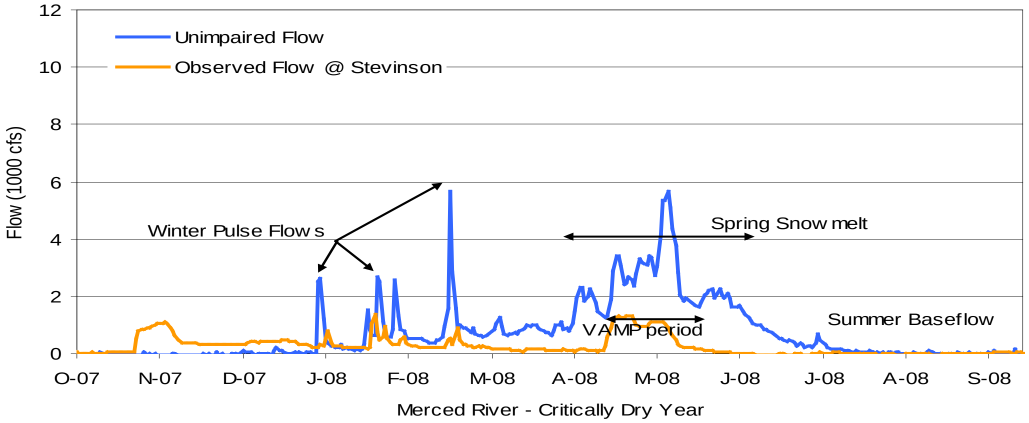


Figure 2.7. Daily Unimpaired Flow and Observed Flow for a Critically Dry Water Year (WY 2008) in the Stanislaus At Ripon (Top), Tuolumne at Modesto (Middle), and Merced at Stevinson (Bottom)

Table 2.11. Frequency Analyses of Annual Peak Flows in the SJR at Vernalis as Compared to USACE (2002)

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

[1] As interpolated from 1-Day Flood Frequency Curves in attachment B.2 page 45 in USACE (2002). Values were based on a simulated unimpaired flow.

[2] Source of data USGS Gage. # 11303500.

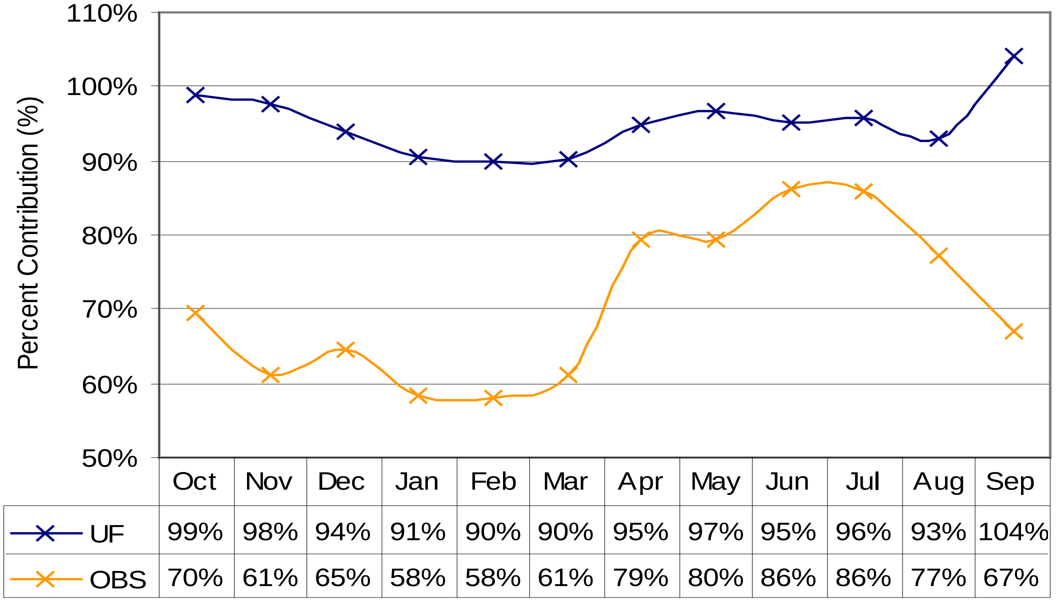
2.4 Hydrology of Tributaries to the Lower San Joaquin River

This section describes the relative contribution to SJR flow at Vernalis and the unimpaired and observed hydrology of the Stanislaus, Tuolumne, and Merced Rivers (LSJR tributaries), the Upper SJR, and the combined Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin.

2.4.1 Relative Contribution from Tributaries to SJR Flow at Vernalis

SJR flow at Vernalis is largely comprised of flows from the LSJR tributaries and the Upper SJR. The combined Chowchilla and Fresno Rivers and Valley Floor also contribute flow, and in some years water from the Tulare Lake Basin also flows to the SJR via Fresno Slough. This section summarizes the contribution to flows at Vernalis from these different sources. Under unimpaired conditions, flows from the LSJR tributaries and Upper SJR account for approximately 90% to 100% of the flow at Vernalis. In contrast, these tributaries accounted for only 58% to 86% of observed flow for the 1984 to 2009 period (Figure 2.8). The remainder of flow comes from the Valley Floor, Tulare Lake Basin, Fresno River, and Chowchilla River.

Figure 2.9 displays the monthly median flow contribution by each of the LSJR tributaries and the Upper SJR as a percentage of flow at Vernalis. The LSJR tributaries and Upper SJR have been altered and now generally contribute a different percentage of the monthly flow at Vernalis as compared to unimpaired flow. Under unimpaired conditions the Stanislaus, Tuolumne, Merced, and Upper SJR would have contributed a median of 20%, 31%, 14%, and 30%, respectively, on an annual basis to the flow at Vernalis. The remaining portion, including the Fresno River, Chowchilla River, Valley Floor, and the Tulare Lake Basin, contributes 2%. The percentages presented in Figures 2.8 and 2.9 do not necessarily add up to 100% because they are median values.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	99%	98%	94%	91%	90%	90%	95%	97%	95%	96%	93%	104%
OBS	70%	61%	65%	58%	58%	61%	79%	80%	86%	86%	77%	67%

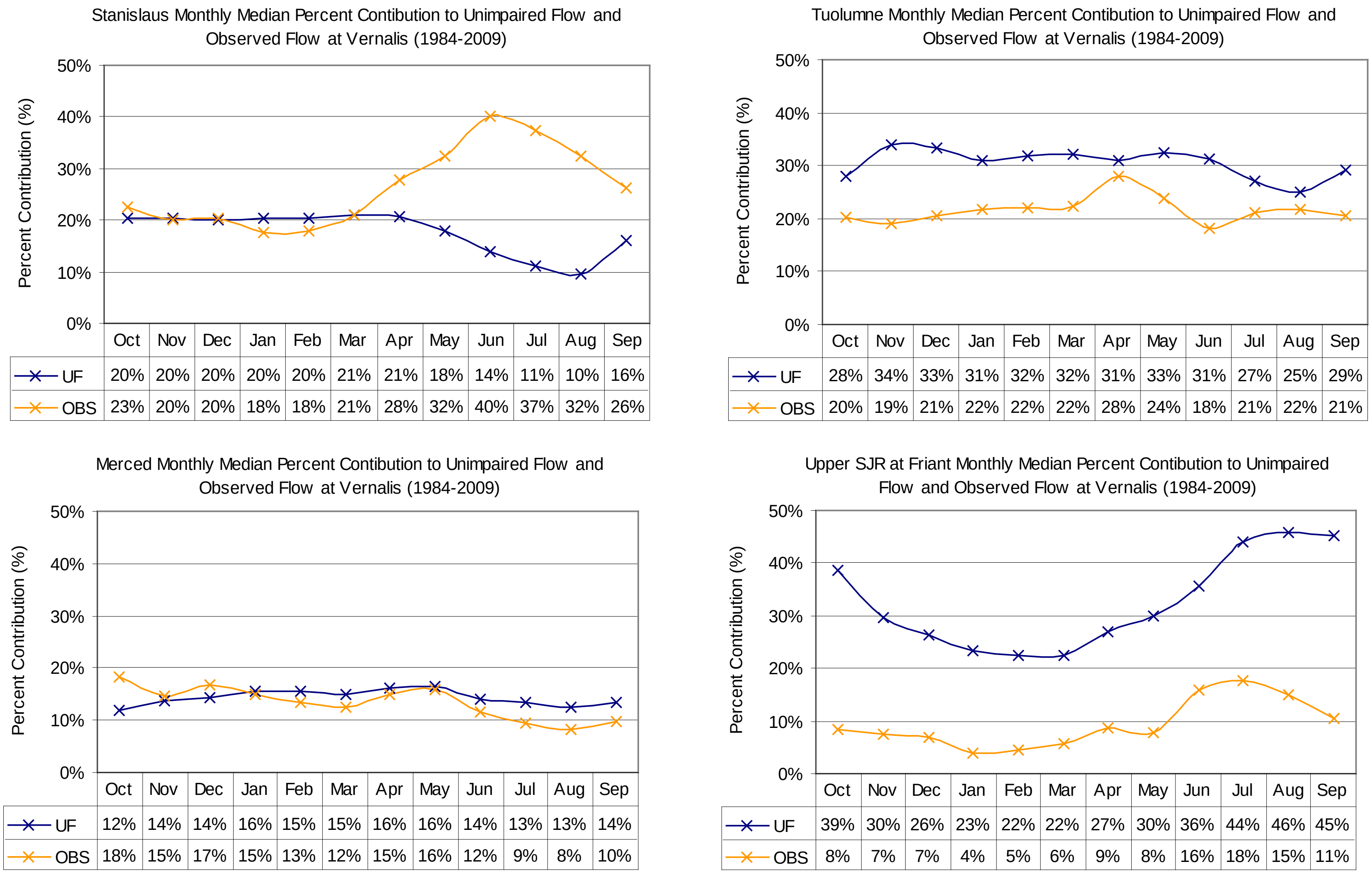
Figure 2.8. Median Observed and Unimpaired Flow Contributed by the LSJR Tributaries and Upper SJR Combined (1984 to 2009)

As shown in Table 2.12, under current conditions, the Stanislaus, Tuolumne, and Merced contribute an annual median of 24%, 21%, and 14% unimpaired flow, respectively, while the Upper SJR now contributes an annual median of 8% of flow. The difference between unimpaired and observed flow for the remainder is due primarily to the operation of the Delta Mendota Canal that adds additional flow from the Delta. Again, the percentages in this table do not necessarily add up to 100% because they are median values.

Table 2.12. Median Annual Percent Contribution of Unimpaired Flow and Observed Flow by SJR Tributary and Upper SJR to Flow at Vernalis (1984 to 2009)

	Stanislaus	Tuolumne	Merced	Upper SJR at Friant	Fresno/ Chowchilla/ Tulare/ Valley Floor
Unimpaired Flow(1984 to 2009)	20%	31%	14%	30%	2%
Observed Flow (1984 to 2009)	24%	21%	14%	8%	26%

The percent of flow contributed at Vernalis by the Stanislaus River during June and July has increased dramatically, accounting for roughly 40% of flow during these months, while the contributions from the Tuolumne have been reduced to roughly 20% during these same months (Figure 2.9). The Upper SJR contributes a much lower percentage of flow compared to unimpaired conditions.



Stanislaus Monthly Median Percent Contibution to Unimpaired Flow and Observed Flow at Vernalis (1984-2009)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	20%	20%	20%	20%	20%	21%	21%	18%	14%	11%	10%	16%
OBS	23%	20%	20%	18%	18%	21%	28%	32%	40%	37%	32%	26%

Tuolumne Monthly Median Percent Contibution to Unimpaired Flow and Observed Flow at Vernalis (1984-2009)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	28%	34%	33%	31%	32%	32%	31%	33%	31%	27%	25%	29%
OBS	20%	19%	21%	22%	22%	22%	28%	24%	18%	21%	22%	21%

Merced Monthly Median Percent Contibution to Unimpaired Flow and Observed Flow at Vernalis (1984-2009)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	12%	14%	14%	16%	15%	15%	16%	16%	14%	13%	13%	14%
OBS	18%	15%	17%	15%	13%	12%	15%	16%	12%	9%	8%	10%

Upper SJR at Friant Monthly Median Percent Contibution to Unimpaired Flow and Observed Flow at Vernalis (1984-2009)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	39%	30%	26%	23%	22%	22%	27%	30%	36%	44%	46%	45%
OBS	8%	7%	7%	4%	5%	6%	9%	8%	16%	18%	15%	11%

Figure 2.9. Median Monthly Unimpaired and Observed Tributary Flow Contribution to Flow at Vernalis (1984 to 2009)

2.4.2 Monthly and Seasonal Trends

Similar to the SJR at Vernalis (as described in section 2.3.2), spring flows in each of the LSJR tributaries and Upper SJR have been significantly reduced while flows during late summer and fall (generally August to November) have increased, resulting in less variability in flow during the year. Additionally, the year to year variability in winter and spring flows has been greatly reduced. Alterations to flow characteristics at Vernalis are driven mainly by the alterations that have occurred on the main LSJR tributaries and the Upper SJR.

Boxplots of the median, 25th percentile, 75th percentile, and the wettest and driest months of water years 1984 to 2009 are presented in Figure 2.10 for the Stanislaus River, Figure 2.11 for the Tuolumne River, Figure 2.12 for the Merced River, Figure 2.13 for the Upper SJR, and Figure 2.14 for the combined Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin flow contributions to the SJR. These graphical comparisons of the unimpaired flow and observed flows illustrate the magnitude of alteration in the timing, variability, and volume of flows.

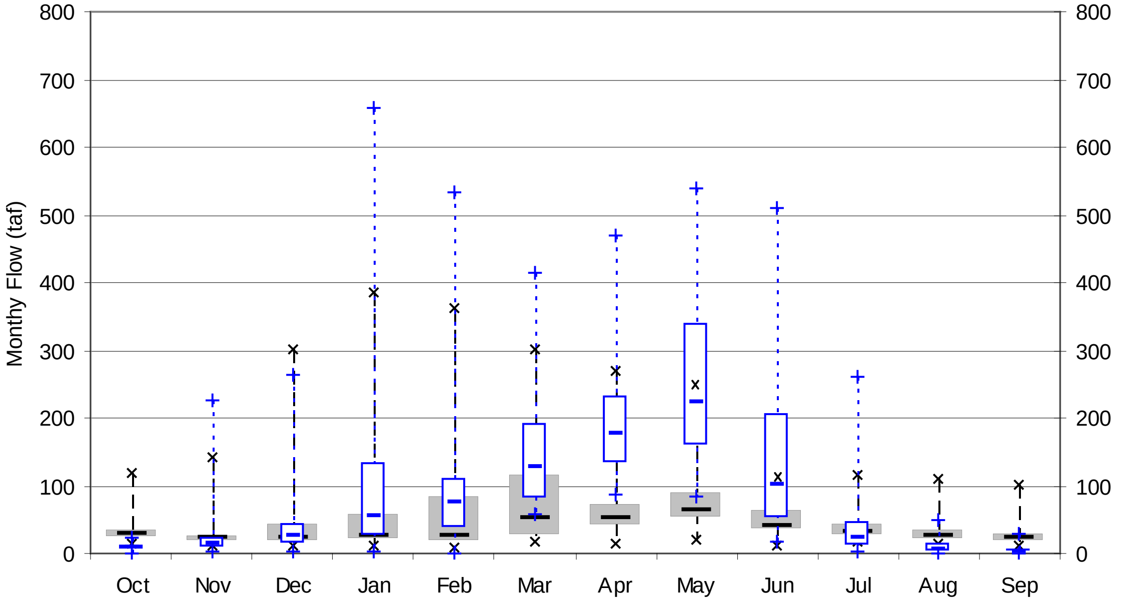
Monthly unimpaired flow, observed monthly flow, and observed monthly flow as a percentage of monthly unimpaired flow for water years 1984 through 2009 are presented in Tables 2.13 through 2.15, respectively, for the Stanislaus River. The same information is presented in Tables 2.17 through 2.19 for the Tuolumne River, Tables 2.21 through 2.23 for the Merced River, Tables 2.25 through 2.27 for the Upper SJR, and Tables 2.29 through 2.31 for the combined Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin flow contributions to the SJR.

The percentile monthly unimpaired, observed, and percentages of unimpaired flow for water years 1984 through 2009 are presented in Table 2.16 for the Stanislaus River, Table 2.20 for the Tuolumne River, Table 2.24 for the Merced River, Table 2.28 for the Upper SJR, and Table 2.32 for the combined Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin flow contributions to the SJR. As with the SJR at Vernalis, observed flows from these tributaries are much lower, primarily during the wet season, and with much less variation from year to year and within the year than the unimpaired flows. The inter-quartile ranges of each month are also much less than the corresponding unimpaired range. Although late summer and fall flows have been augmented, it is of lower magnitude than the spring reduction such that annual flows are greatly reduced.

Although the median February through June observed flows are 40%, 21%, 26% of unimpaired flows in the Stanislaus, Tuolumne, and Merced Rivers respectively, the April, May and June values are generally far lower, especially May and June flows on the Tuolumne and Merced Rivers (see Tables 2.16, 2.20, and 2.24). For April, May and June, the medians are 32, 26 and 40% of unimpaired flow for the Stanislaus River, 22%, 12% and 9% of unimpaired flow for the Tuolumne River, and 25%, 18% and 15% of unimpaired flow on the Merced River. Flows were as low as 2% and 1% of unimpaired flow on the Tuolumne and Merced Rivers, respectively, in June, 1991. Annual observed flows in each of the tributaries have also been reduced, and now only 58%, 40%, 46%, and 13% of annual unimpaired flow remain in the Stanislaus, Tuolumne, Merced, and Upper SJR, respectively.

The observed flow as a percentage of unimpaired flow for the Valley Floor, Fresno River, Chowchilla River, and Tulare Lake Basin outflows combined, developed by subtracting the Upper SJR, Stanislaus, Tuolumne, and Merced Rivers from the SJR at Vernalis, has a median of 150% of unimpaired flow (Table 2.16). This increase is likely due to addition of water via the DMC.

Based on the unimpaired data, the wettest month during the spring snowmelt period is generally either April or May for each of the LSJR tributaries and Upper SJR. For example in the Stanislaus River, May was the peak month for 17 of the 26 years between 1984 and 2009; April was the peak in seven years, all of which were classified Dry or Critically Dry water years. This corresponds to findings in Cain et al. (2003) using daily observed flows from 1896 to 1932, which found that the date of the median pre-dam peak was roughly May 17 for most water year types, ranging from April 21 to June 13.



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

Figure 2.10. Monthly Unimpaired Flow (Open Bars) and Observed Flow (Filled Bars) in the Stanislaus River from 1984 to 2009

Table 2.13. Monthly, Annual, and February through June Unimpaired Flow in the Stanislaus River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	24	225	153	144	98	137	157	297	148	41	10	1	1,435	837
1985	D	11	48	31	26	48	79	206	171	53	3	1	2	679	557
1986	W	1	40	43	99	532	353	253	300	215	57	19	25	1,937	1,653
1987	C	13	3	9	13	29	59	104	94	27	11	6	4	372	313
1988	C	3	10	14	27	35	59	86	83	40	12	6	3	378	303
1989	C	9	6	14	18	30	181	234	162	94	24	7	1	780	701
1990	C	22	17	13	25	24	83	134	87	51	12	1	1	470	379
1991	C	3	2	3	3	1	81	97	183	106	21	4	6	510	468
1992	C	12	14	13	18	72	78	136	95	17	19	6	6	486	398
1993	W	6	8	27	182	108	234	249	407	241	76	17	3	1,558	1,239
1994	C	10	10	13	15	29	61	106	159	41	4	1	6	455	396
1995	W	5	24	26	230	100	415	276	484	460	261	50	18	2,349	1,735
1996	W	11	10	42	86	276	215	255	377	175	38	4	1	1,490	1,298
1997	W	7	50	265	659	90	129	180	231	110	22	11	4	1,758	740
1998	W	12	17	20	152	250	231	245	341	511	245	40	28	2,092	1,578
1999	AN	15	31	39	101	197	124	173	370	215	49	16	17	1,347	1,079
2000	AN	9	18	12	91	189	160	222	292	128	24	7	10	1,162	991
2001	D	13	13	12	23	36	96	134	200	28	5	2	4	566	494
2002	D	6	20	57	62	55	102	213	216	97	15	5	1	849	683
2003	BN	3	31	48	58	55	96	155	325	181	22	13	7	994	812
2004	D	2	8	47	42	76	164	175	153	61	17	5	1	752	629
2005	W	17	23	41	146	111	194	211	533	292	101	15	6	1,692	1,342
2006	W	13	11	210	199	138	229	470	538	277	77	23	16	2,201	1,652
2007	C	16	13	29	27	78	112	124	124	32	5	2	1	565	471
2008	C	9	3	14	47	52	73	130	192	85	13	4	3	625	532
2009	D	5	24	15	53	73	170	190	334	100	32	13	6	1,014	867

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.14. Monthly, Annual and February through June Observed Flow in the Stanislaus River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	109	143	303	282	101	84	52	52	29	28	32	45	1,260	318
1985	D	49	22	49	64	41	35	46	40	35	82	77	27	568	196
1986	W	26	25	27	29	91	300	116	77	73	52	73	77	967	657
1987	C	43	32	55	35	45	71	66	47	49	35	29	25	532	277
1988	C	15	19	14	13	13	67	52	54	53	47	46	42	435	239
1989	C	29	27	29	15	12	67	57	67	53	41	25	25	448	256
1990	C	20	15	13	11	10	53	33	34	36	37	33	19	314	166
1991	C	21	25	12	11	10	16	15	23	13	19	13	12	192	77
1992	C	18	22	11	10	18	16	40	21	15	16	17	18	223	110
1993	W	20	13	14	38	17	20	29	85	35	24	20	22	338	187
1994	C	34	18	19	19	17	52	32	32	28	29	25	18	324	162
1995	W	24	19	20	42	20	43	54	87	40	26	25	21	422	245
1996	W	31	19	21	25	85	214	102	92	63	45	34	28	758	555
1997	W	35	44	196	386	361	171	75	99	70	31	27	27	1,521	776
1998	W	51	24	25	71	234	150	118	127	111	115	110	101	1,237	740
1999	AN	120	57	59	107	199	126	85	94	81	45	39	33	1,046	585
2000	AN	31	25	24	26	83	135	74	97	62	25	24	24	629	451
2001	D	34	25	25	24	21	24	54	76	35	31	23	19	390	209
2002	D	29	22	26	25	27	32	59	59	33	30	20	17	379	210
2003	BN	23	19	20	20	30	31	47	51	72	32	22	19	386	232
2004	D	36	19	19	19	25	21	36	51	42	34	22	17	342	175
2005	W	21	18	19	28	18	24	22	91	35	20	19	19	333	189
2006	W	32	23	71	257	94	192	270	254	109	78	74	69	1,522	919
2007	C	96	41	56	69	48	59	49	88	47	28	22	16	619	291
2008	C	27	19	19	23	18	48	66	53	27	26	21	14	360	212
2009	D	24	17	17	13	15	18	44	54	37	22	19	28	306	167

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

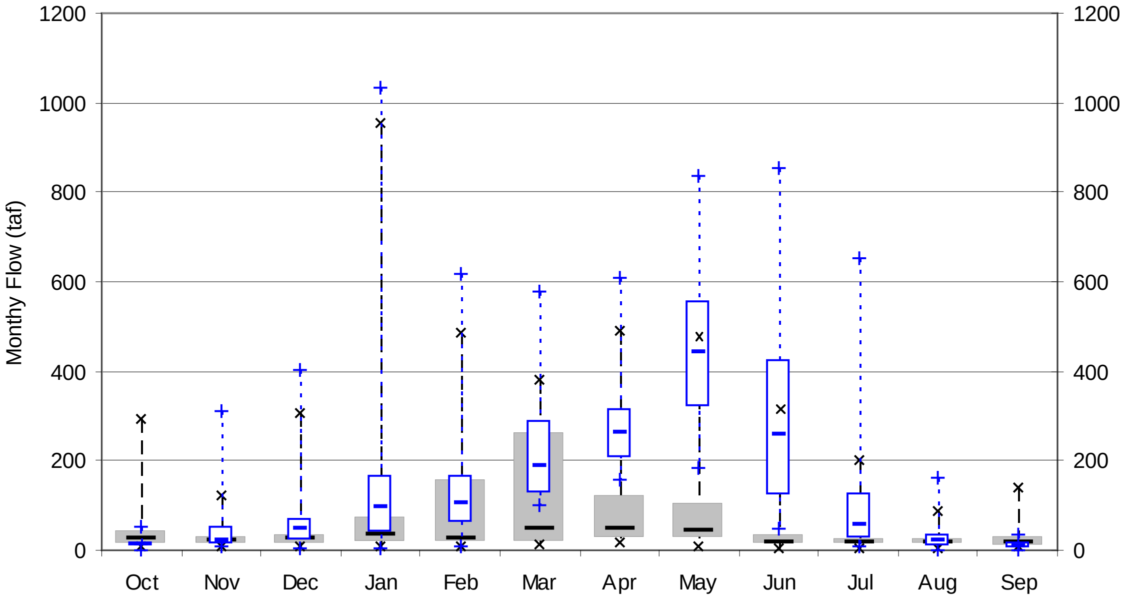
Table 2.15. Monthly, Annual, and February through June Observed Flow as a Percentage of Unimpaired Flow in the Stanislaus River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (%)	Nov (%)	Dec (%)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Annual (%)	Feb-Jun (%)
1984	AN	455	63	198	196	103	61	33	17	19	69	325	4,502	88	38
1985	D	446	46	158	248	85	44	22	23	66	2,738	7,736	1,368	84	35
1986	W	2,648	61	64	29	17	85	46	26	34	91	387	309	50	40
1987	C	332	1,062	610	273	155	120	63	50	181	318	489	615	143	89
1988	C	515	188	103	47	38	113	61	65	133	388	766	1,404	115	79
1989	C	327	451	206	84	39	37	25	41	57	171	357	2,500	57	37
1990	C	90	87	102	44	43	64	24	39	70	311	3,277	1,912	67	44
1991	C	698	1,231	413	379	1,014	20	15	13	12	92	330	206	38	17
1992	C	151	158	85	57	25	21	29	23	87	85	278	305	46	28
1993	W	334	162	53	21	16	9	12	21	15	31	119	732	22	15
1994	C	338	184	144	126	60	86	30	20	68	724	2,497	305	71	41
1995	W	481	78	76	18	20	10	20	18	9	10	50	119	18	14
1996	W	278	192	50	29	31	99	40	24	36	118	853	2,828	51	43
1997	W	500	88	74	59	401	132	42	43	63	140	241	670	87	105
1998	W	427	143	123	47	93	65	48	37	22	47	275	362	59	47
1999	AN	800	185	152	106	101	102	49	25	38	93	244	193	78	54
2000	AN	340	137	199	28	44	85	33	33	49	106	348	237	54	45
2001	D	264	193	207	102	57	25	40	38	124	615	1,139	482	69	42
2002	D	490	112	46	40	49	31	28	27	34	199	391	1,745	45	31
2003	BN	771	61	42	35	55	32	31	16	40	143	168	268	39	29
2004	D	1,594	242	40	45	33	13	21	34	69	199	426	1,655	45	28
2005	W	122	79	46	19	16	12	10	17	12	20	123	302	20	14
2006	W	254	205	34	129	68	84	57	47	39	101	325	438	69	56
2007	C	590	314	190	254	61	53	40	70	147	602	993	1,135	110	62
2008	C	312	622	131	49	34	66	51	27	32	202	505	502	58	40
2009	D	526	69	112	25	21	11	23	16	37	68	147	483	30	19

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.16. Statistics of Unimpaired Flow, Observed Flow, and Observed Flow as Percent of Unimpaired Flow in the Stanislaus River from 1984 to 2009

Unimpaired flow (TAF)													
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
10%tile	3	5	12	17	29	67	105	95	30	5	2	1	463	388
20%tile	5	8	13	23	35	79	130	153	41	12	4	1	510	468
25%tile	5	10	13	25	39	82	134	160	52	12	4	2	565	476
30%tile	6	10	14	27	50	90	135	167	57	14	5	2	595	513
40%tile	9	13	15	42	55	102	157	192	94	19	6	3	752	629
50%tile	10	16	27	55	75	127	178	224	103	22	7	4	922	721
60%tile	11	18	31	86	90	160	206	297	128	24	10	6	1,162	837
70%tile	12	24	42	100	104	176	218	329	178	40	13	6	1,463	1,035
75%tile	13	24	43	133	110	191	231	339	207	47	15	7	1,541	1,199
80%tile	13	31	47	146	138	215	245	370	215	57	16	10	1,692	1,298
90%tile	17	44	105	191	224	233	254	446	285	89	21	18	2,015	1,615
Observed flow (TAF)														
10%tile	20	17	14	12	13	19	30	33	28	21	19	16	310	164
20%tile	21	19	17	15	17	24	36	47	33	25	20	18	333	175
25%tile	23	19	19	19	17	26	41	51	35	26	21	18	339	187
30%tile	24	19	19	20	18	31	45	51	35	27	22	19	351	193
40%tile	27	19	20	24	20	43	49	54	36	29	23	19	386	210
50%tile	30	22	22	25	26	53	53	63	41	31	25	23	429	235
60%tile	32	24	25	29	41	67	57	77	49	34	27	25	532	256
70%tile	35	25	28	40	65	77	66	87	58	39	33	28	624	304
75%tile	36	25	44	59	84	116	72	90	63	44	34	28	725	417
80%tile	43	27	55	69	91	135	75	92	70	45	39	33	967	555
90%tile	74	43	65	182	150	181	109	98	77	65	74	57	1,249	698
Observed flow as a percent of unimpaired flow (%)														
10%tile	202	62	44	23	19	11	18	17	13	39	135	221	26	16
20%tile	278	78	50	29	25	20	22	18	22	69	241	302	39	28
25%tile	315	81	56	31	31	22	23	20	33	86	252	305	45	28
30%tile	330	88	69	37	33	28	24	22	34	92	277	307	46	30
40%tile	338	137	85	45	39	37	29	24	37	101	325	438	51	37
50%tile	437	160	107	48	46	57	32	26	40	129	353	493	58	40
60%tile	481	185	131	59	57	65	40	33	57	171	391	670	67	42
70%tile	508	192	155	104	65	84	41	38	67	201	497	1,251	70	45
75%tile	523	202	182	121	81	85	45	39	69	284	701	1,395	76	47
80%tile	590	242	198	129	93	86	48	41	70	318	853	1,655	84	54
90%tile	786	536	207	251	129	107	54	49	128	608	1,818	2,206	99	70



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

Figure 2.11. Monthly Unimpaired Flow (Open Bars) and Observed Flow (Filled Bars) in the Tuolumne River from 1984 to 2009

Table 2.17. Monthly, Annual, and February through June Unimpaired Flow in the Tuolumne River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	44	310	402	175	151	200	203	536	330	93	21	7	2,472	1,420
1985	D	26	85	48	41	69	126	302	341	135	23	15	18	1,229	973
1986	W	31	49	94	129	616	493	320	540	507	144	30	18	2,971	2,476
1987	C	18	8	13	6	37	99	194	203	65	10	8	3	664	598
1988	C	11	26	50	70	57	105	159	213	98	24	6	1	820	632
1989	C	4	21	27	37	61	285	309	321	207	28	2	10	1,312	1,183
1990	C	49	25	22	38	53	130	220	182	100	20	4	1	844	685
1991	C	1	8	5	5	8	168	180	336	295	67	19	7	1,099	987
1992	C	16	25	18	25	93	115	230	189	46	59	14	4	834	673
1993	W	10	14	46	278	161	319	335	631	524	226	54	25	2,623	1,970
1994	C	19	7	18	22	53	108	195	275	119	33	25	10	884	750
1995	W	10	64	58	348	160	579	385	659	811	652	162	35	3,923	2,594
1996	W	12	7	72	129	348	290	323	576	389	133	26	11	2,316	1,926
1997	W	8	112	387	1,033	170	232	277	542	336	57	49	21	3,224	1,557
1998	W	10	18	35	202	358	354	351	477	855	559	84	35	3,338	2,395
1999	AN	21	48	68	136	252	171	262	569	436	109	35	20	2,127	1,690
2000	AN	11	17	10	132	277	253	334	539	322	70	35	18	2,018	1,725
2001	D	17	17	22	32	60	179	227	408	55	12	2	2	1,033	929
2002	D	4	40	93	109	79	141	301	372	223	24	8	6	1,400	1,116
2003	BN	1	69	69	89	65	124	218	520	372	55	30	15	1,627	1,299
2004	D	5	13	82	70	110	257	264	318	148	33	13	7	1,321	1,097
2005	W	54	55	71	260	192	325	305	837	589	258	40	21	3,006	2,248
2006	W	15	16	248	248	154	296	610	816	649	208	37	15	3,313	2,526
2007	C	11	19	29	28	94	147	175	251	61	15	10	8	849	729
2008	C	7	7	18	78	101	124	189	360	204	32	5	4	1,129	977
2009	D	4	62	27	105	118	228	260	563	225	57	9	7	1,665	1,395

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.18. Monthly, Annual, and February through June Observed Flow in the Tuolumne River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	293	124	263	367	268	188	56	39	19	18	19	23	1,677	569
1985	D	62	69	131	96	76	46	23	21	19	17	16	15	593	186
1986	W	29	33	38	37	140	380	305	170	103	22	21	56	1,334	1,098
1987	C	78	72	127	56	26	46	45	27	12	11	12	11	522	156
1988	C	17	18	19	18	13	15	22	9	7	6	6	7	156	65
1989	C	8	10	11	11	9	16	21	10	8	8	9	10	134	65
1990	C	15	18	16	15	15	16	16	14	7	7	8	9	157	68
1991	C	12	12	11	9	9	23	23	26	6	6	7	7	152	88
1992	C	10	12	11	12	27	16	19	22	7	6	6	7	153	90
1993	W	10	12	13	46	25	18	49	45	29	20	30	59	357	166
1994	C	46	23	27	38	23	20	31	27	9	7	8	7	266	110
1995	W	11	14	15	98	236	348	426	483	326	202	88	141	2,389	1,820
1996	W	110	26	26	41	316	328	180	252	47	21	27	31	1,406	1,123
1997	W	38	30	307	953	488	182	96	70	27	30	28	28	2,275	862
1998	W	45	29	28	167	417	348	343	224	266	184	74	97	2,223	1,599
1999	AN	71	31	80	83	288	230	129	113	28	29	27	29	1,138	788
2000	AN	36	28	26	28	149	294	109	87	35	37	60	54	942	674
2001	D	44	29	28	33	76	61	43	56	15	16	17	17	435	251
2002	D	21	16	25	28	15	19	43	38	14	15	16	14	264	129
2003	BN	21	17	20	18	15	18	48	38	20	21	23	23	284	140
2004	D	25	19	20	21	27	79	76	36	15	15	15	14	362	233
2005	W	23	15	15	53	126	275	294	299	235	133	62	32	1,560	1,229
2006	W	35	27	78	295	160	291	492	490	281	73	49	38	2,309	1,714
2007	C	39	28	29	28	29	33	38	34	15	15	15	13	316	149
2008	C	15	14	15	31	24	18	36	52	12	12	12	11	251	142
2009	D	15	13	14	14	15	18	26	49	15	14	11	12	213	122

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

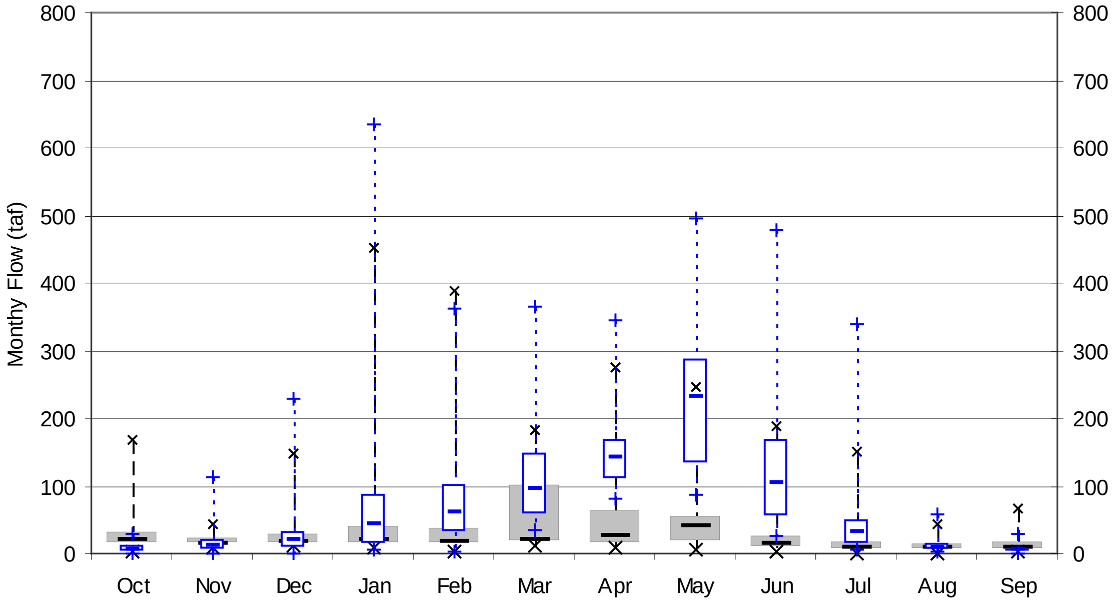
Table 2.19. Monthly, Annual, and February through June Observed Flow as a Percentage of Unimpaired Flow in the Tuolumne River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (%)	Nov (%)	Dec (%)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Annual (%)	Feb-Jun (%)
1984	AN	665	40	65	210	177	94	28	7	6	20	90	330	68	40
1985	D	240	82	273	235	111	37	8	6	14	73	105	85	48	19
1986	W	92	68	40	29	23	77	95	32	20	15	71	310	45	44
1987	C	431	901	979	940	71	46	23	13	19	107	151	361	79	26
1988	C	150	70	37	26	23	14	14	4	7	25	107	660	19	10
1989	C	208	46	42	31	15	6	7	3	4	30	443	102	10	6
1990	C	31	71	74	39	28	12	7	8	7	36	209	881	19	10
1991	C	1,211	147	216	189	115	14	13	8	2	10	38	101	14	9
1992	C	60	48	62	48	29	14	8	12	14	10	43	176	18	13
1993	W	99	89	27	17	16	6	15	7	5	9	56	238	14	8
1994	C	240	335	150	174	44	18	16	10	7	21	31	74	30	15
1995	W	106	22	27	28	148	60	111	73	40	31	55	402	61	70
1996	W	919	373	35	32	91	113	56	44	12	16	105	281	61	58
1997	W	470	27	79	92	287	78	34	13	8	52	57	132	71	55
1998	W	445	162	81	83	117	98	98	47	31	33	89	278	67	67
1999	AN	338	64	118	61	114	135	49	20	6	27	77	147	54	47
2000	AN	326	162	259	22	54	116	33	16	11	52	172	298	47	39
2001	D	260	172	126	104	127	34	19	14	27	130	849	851	42	27
2002	D	513	41	27	26	18	13	14	10	6	61	203	235	19	12
2003	BN	2,084	25	29	21	23	15	22	7	6	38	76	156	17	11
2004	D	474	140	24	30	24	31	29	11	10	46	111	188	27	21
2005	W	42	27	21	20	66	85	96	36	40	51	155	153	52	55
2006	W	241	166	31	119	104	98	81	60	43	35	133	246	70	68
2007	C	356	150	97	101	31	23	21	14	25	103	143	166	37	21
2008	C	217	195	83	40	24	14	19	14	6	36	233	245	22	15
2009	D	351	21	49	13	12	8	10	9	7	24	133	178	13	9

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.20. Statistics of Unimpaired Flow, Observed Flow, and Observed Flow as Percent of Unimpaired Flow in the Tuolumne River from 1984 to 2009

Unimpaired flow (TAF)													
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
10%tile	4	8	16	24	53	112	184	208	63	17	4	3	839	679
20%tile	5	13	18	32	60	124	195	275	100	24	8	4	884	750
25%tile	7	15	22	37	62	127	207	319	123	25	8	6	1,050	940
30%tile	9	17	25	40	67	136	219	329	141	30	9	7	1,114	975
40%tile	10	18	29	70	93	168	230	360	207	33	14	7	1,312	1,097
50%tile	11	23	47	97	105	190	263	443	260	57	20	10	1,514	1,241
60%tile	15	26	58	129	151	232	301	536	330	67	26	15	2,018	1,420
70%tile	18	49	70	134	161	271	307	541	381	101	33	18	2,394	1,708
75%tile	19	53	72	165	168	289	317	558	424	127	35	18	2,585	1,876
80%tile	21	62	82	202	192	296	323	569	507	144	37	20	2,971	1,970
90%tile	38	77	171	269	313	340	343	645	619	242	52	23	3,268	2,436
Observed flow (TAF)														
10%tile	10	12	12	13	14	16	22	17	7	7	7	7	155	78
20%tile	15	14	15	18	15	18	23	26	9	8	9	10	213	110
25%tile	15	14	15	19	17	18	27	27	12	11	11	11	254	124
30%tile	16	16	16	25	24	19	34	31	13	13	12	11	265	135
40%tile	21	18	20	28	26	23	43	38	15	15	15	14	316	149
50%tile	27	21	25	35	28	46	46	42	17	16	17	16	398	176
60%tile	36	27	27	41	76	79	56	52	20	20	21	23	593	251
70%tile	42	29	28	54	144	209	102	79	28	21	27	30	1,236	731
75%tile	44	29	35	76	158	264	124	106	33	27	28	32	1,388	844
80%tile	46	30	78	96	236	291	180	170	47	30	30	38	1,560	1,098
90%tile	74	51	129	231	302	338	324	275	251	103	61	58	2,249	1,414
Observed flow as a percent of unimpaired flow (%)														
10%tile	76	26	27	20	17	10	8	7	5	13	49	102	14	9
20%tile	106	40	29	26	23	14	13	7	6	20	57	147	18	10
25%tile	165	42	32	27	24	14	14	8	6	22	72	153	19	11
30%tile	212	47	36	28	24	14	14	8	7	24	77	161	19	12
40%tile	240	68	42	31	29	18	19	10	7	30	90	178	27	15
50%tile	293	76	64	40	49	33	22	12	9	34	106	236	40	21
60%tile	351	140	79	61	71	46	28	14	12	36	133	246	47	27
70%tile	438	156	90	97	107	78	34	15	16	49	147	289	53	42
75%tile	464	162	113	104	113	83	45	19	20	52	154	307	59	46
80%tile	474	166	126	119	115	94	56	32	25	52	172	330	61	55
90%tile	792	265	238	199	137	106	96	45	36	88	221	531	69	63



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

Figure 2.12. Monthly Unimpaired Flow (Open Bars) and Observed Flow (Filled Bars) in the Merced River from 1984 to 2009

Table 2.21. Monthly, Annual, and February through June Unimpaired Flow in the Merced River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	28	114	204	93	81	97	129	265	114	47	8	1	1,181	686
1985	D	8	28	21	19	33	59	147	171	57	12	5	6	566	467
1986	W	12	16	34	45	362	287	191	316	228	51	12	5	1,559	1,384
1987	C	7	3	5	6	18	36	95	95	25	6	3	1	300	269
1988	C	4	15	13	28	24	48	93	107	55	19	6	3	415	327
1989	C	1	5	10	12	23	96	160	132	73	13	5	5	535	484
1990	C	15	11	9	15	21	56	114	87	48	23	6	2	407	326
1991	C	2	1	1	5	3	96	81	184	145	36	4	2	560	509
1992	C	5	11	8	13	54	51	131	105	31	33	6	2	450	372
1993	W	2	7	22	190	100	157	181	384	280	95	21	8	1,447	1,102
1994	C	7	5	8	9	28	40	87	117	43	9	9	1	363	315
1995	W	16	22	25	200	70	364	206	388	471	340	59	13	2,174	1,499
1996	W	11	7	30	66	191	161	197	317	157	51	14	6	1,208	1,023
1997	W	2	57	230	634	102	116	169	278	114	29	13	6	1,750	779
1998	W	1	7	17	103	253	168	201	251	478	286	51	29	1,845	1,351
1999	AN	15	19	28	49	111	67	128	282	154	35	11	7	906	742
2000	AN	4	10	2	57	171	116	166	276	130	26	11	7	976	859
2001	D	4	6	10	13	31	86	108	215	33	10	3	1	520	473
2002	D	2	13	47	44	35	59	151	178	85	14	4	2	634	508
2003	BN	1	31	34	41	34	62	112	270	170	32	15	6	808	648
2004	D	2	9	26	35	60	120	139	135	54	17	7	4	608	509
2005	W	20	22	41	200	105	191	152	467	325	126	25	12	1,684	1,240
2006	W	8	7	74	129	68	171	344	496	332	85	17	9	1,741	1,411
2007	C	13	10	15	16	37	69	94	103	29	13	8	6	413	331
2008	C	5	6	7	48	64	56	104	196	93	25	7	4	617	514
2009	D	3	21	12	50	61	105	147	287	95	32	11	6	831	695

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.22. Monthly, Annual, and February through June Observed Flow in the Merced River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	168	44	149	198	71	38	27	25	22	18	17	18	795	183
1985	D	27	32	72	42	18	19	18	18	15	13	12	13	299	87
1986	W	16	14	19	13	25	182	159	104	40	17	16	19	623	510
1987	C	28	15	14	14	13	18	11	12	10	8	8	9	159	64
1988	C	6	12	13	15	12	12	11	11	8	4	4	2	110	53
1989	C	2	8	12	12	11	19	12	10	7	2	1	3	100	58
1990	C	5	10	12	12	14	10	8	8	6	2	1	1	89	46
1991	C	2	8	10	8	4	20	8	6	1	0	1	4	74	40
1992	C	4	12	14	14	18	17	9	6	4	2	2	2	105	54
1993	W	11	15	13	36	21	21	60	56	35	22	37	36	363	194
1994	C	52	15	14	15	18	15	22	26	10	19	6	5	216	91
1995	W	21	14	13	36	17	144	194	231	190	151	34	44	1,089	776
1996	W	114	36	35	30	91	178	66	82	24	11	10	13	690	441
1997	W	32	20	124	452	388	113	41	44	11	9	9	11	1,255	598
1998	W	16	15	14	47	256	167	178	170	145	126	44	67	1,245	916
1999	AN	75	21	26	48	90	49	65	53	18	12	7	12	477	276
2000	AN	20	17	15	17	90	150	52	46	15	11	10	11	454	353
2001	D	34	35	25	21	18	24	34	43	16	8	9	8	274	135
2002	D	25	31	29	23	14	15	21	39	11	6	5	6	224	99
2003	BN	20	15	16	14	12	14	29	41	11	8	6	6	193	108
2004	D	17	16	15	16	19	17	25	41	8	6	6	7	193	111
2005	W	19	15	17	52	27	68	159	149	109	58	44	46	764	513
2006	W	25	15	41	156	43	169	275	253	153	43	42	41	1,255	892
2007	C	59	24	20	20	16	16	20	41	29	8	8	7	268	122
2008	C	19	38	30	30	25	17	27	51	7	6	5	7	261	126
2009	D	17	19	17	16	15	15	11	17	9	3	3	5	148	67

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

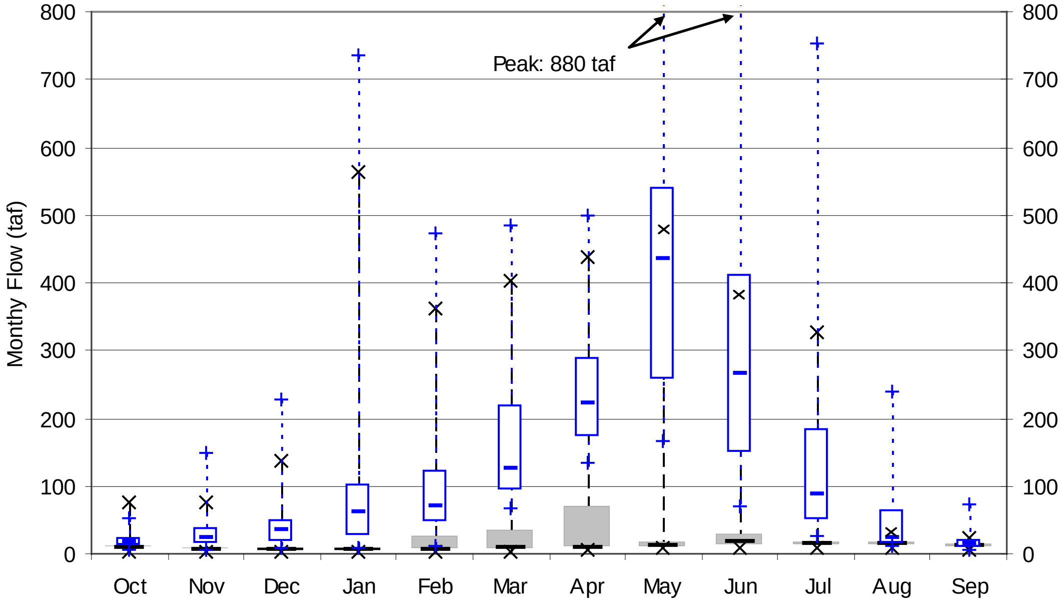
Table 2.23. Monthly, Annual, and February through June Observed Flow as a Percentage of Unimpaired Flow in the Merced River from 1984 to 2009

Water Year	Water Year Type[1]	Oct (%)	Nov (%)	Dec (%)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Annual (%)	Feb-Jun (%)
1984	AN	601	39	73	213	88	39	21	9	20	39	213	1,798	67	27
1985	D	344	116	343	220	54	33	12	10	26	109	232	223	53	19
1986	W	132	88	55	29	7	63	83	33	17	33	130	375	40	37
1987	C	397	490	281	236	73	50	11	13	40	127	256	903	53	24
1988	C	160	79	103	55	52	24	12	10	14	20	71	71	27	16
1989	C	233	162	120	103	49	20	7	7	9	16	30	61	19	12
1990	C	34	94	130	80	65	18	7	9	12	7	19	73	22	14
1991	C	97	779	1,050	159	128	21	10	3	1	1	28	219	13	8
1992	C	85	111	171	107	34	33	7	5	11	6	39	123	23	14
1993	W	532	213	58	19	21	14	33	15	13	23	175	445	25	18
1994	C	742	295	174	164	64	38	25	22	24	212	63	472	59	29
1995	W	134	64	54	18	24	40	94	60	40	44	57	337	50	52
1996	W	1,040	520	117	45	48	111	34	26	15	21	71	211	57	43
1997	W	1,592	35	54	71	381	97	24	16	10	32	73	180	72	77
1998	W	1,595	209	83	46	101	99	89	68	30	44	87	231	67	68
1999	AN	497	112	92	99	81	74	51	19	12	35	66	171	53	37
2000	AN	499	167	769	29	52	129	31	17	11	43	91	163	47	41
2001	D	857	580	245	163	59	28	32	20	49	84	284	753	53	28
2002	D	1,270	236	62	53	39	25	14	22	13	43	133	280	35	19
2003	BN	2,028	50	46	34	36	23	26	15	7	24	41	95	24	17
2004	D	768	185	56	46	32	14	18	30	15	34	93	186	32	22
2005	W	97	70	43	26	25	36	105	32	34	46	176	398	45	41
2006	W	304	212	55	120	64	99	80	51	46	50	238	468	72	63
2007	C	462	232	132	122	44	24	22	39	99	61	94	129	65	37
2008	C	396	622	424	64	39	30	26	26	7	25	65	157	42	25
2009	D	517	87	140	32	24	15	7	6	10	9	28	90	18	10

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.24. Statistics of Unimpaired Flow, Observed Flow, and Observed Flow as a Percentage of Unimpaired Flow in the Merced River from 1984 to 2009

Unimpaired flow (TAF)													
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
10%tile	2	5	6	11	22	50	93	104	32	11	4	1	410	327
20%tile	2	6	8	13	28	56	104	117	48	13	5	2	450	372
25%tile	2	7	9	15	32	59	109	133	54	15	6	2	524	469
30%tile	3	7	10	18	34	61	113	153	56	18	6	3	548	479
40%tile	4	9	13	35	37	69	129	184	85	25	7	4	608	509
50%tile	5	11	19	45	60	96	143	233	104	31	9	5	721	581
60%tile	7	13	25	49	68	105	151	270	130	33	11	6	906	695
70%tile	10	18	29	62	91	118	163	280	156	42	13	6	1,195	819
75%tile	12	21	33	86	102	148	168	286	167	50	14	7	1387	982
80%tile	13	22	34	103	105	161	181	316	228	51	15	7	1,559	1,102
90%tile	16	30	61	195	181	181	199	386	328	110	23	10	1,746	1,368
Observed flow (TAF)														
10%tile	5	11	12	13	12	15	10	9	6	2	2	3	102	54
20%tile	11	14	13	14	14	15	11	12	8	4	4	5	148	64
25%tile	16	14	14	14	14	16	13	17	9	6	5	5	168	72
30%tile	17	15	14	15	15	17	19	21	10	6	6	6	193	89
40%tile	19	15	15	16	18	18	22	39	11	8	6	7	224	108
50%tile	20	15	16	20	18	20	27	41	13	9	8	8	271	124
60%tile	25	17	19	30	21	24	34	44	16	11	9	11	363	183
70%tile	28	21	25	36	26	59	56	52	23	15	11	13	550	314
75%tile	31	23	28	40	39	102	64	55	27	18	15	17	673	419
80%tile	34	31	30	47	71	144	66	82	35	19	17	19	764	510
90%tile	67	36	57	104	90	168	169	160	127	50	39	43	1,167	687
Observed flow as a percent of unimpaired flow (%)														
10%tile	97	57	54	28	24	16	7	7	8	8	29	82	20	13
20%tile	134	79	55	32	32	21	11	9	10	20	41	123	24	16
25%tile	179	87	56	37	35	23	12	10	11	22	59	136	25	17
30%tile	268	91	60	45	37	24	13	11	12	24	64	160	29	18
40%tile	396	112	83	53	44	28	21	15	13	32	71	180	40	22
50%tile	480	164	110	68	51	33	25	18	15	34	80	215	46	26
60%tile	517	209	130	99	54	38	26	22	17	43	93	231	53	29
70%tile	672	222	155	114	64	45	32	26	25	44	132	356	53	37
75%tile	762	235	173	121	65	60	34	29	29	45	165	392	56	40
80%tile	857	295	245	159	73	74	51	32	34	50	176	445	59	41
90%tile	1,431	550	383	189	95	99	86	45	43	96	235	613	67	57



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

Figure 2.13. Monthly Unimpaired Flow (Open Bars) and Observed Flow (Filled Bars) in the SJR at Friant from 1984 to 2009

Table 2.25. Monthly, Annual, and February through June Unimpaired Flow in the SJR at Friant from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	53	149	227	126	107	162	203	489	266	162	67	36	2,047	1,227
1985	D	31	50	41	40	56	84	254	308	169	55	22	19	1,129	871
1986	W	24	38	68	93	472	426	361	624	593	222	76	32	3,029	2,476
1987	C	24	14	15	21	39	66	172	229	121	33	15	10	759	627
1988	C	16	24	25	59	48	91	153	220	142	49	23	12	862	654
1989	C	7	14	20	22	37	133	237	240	149	41	19	19	938	796
1990	C	23	22	17	25	34	85	173	165	122	54	14	8	742	579
1991	C	8	6	9	10	11	118	135	277	321	102	24	13	1,034	862
1992	C	12	19	18	21	68	77	209	238	76	46	17	9	810	668
1993	W	13	17	32	189	124	243	330	701	599	316	82	26	2,672	1,997
1994	C	19	17	21	23	42	75	150	258	159	36	14	12	826	684
1995	W	43	45	48	213	122	485	350	634	881	752	239	66	3,878	2,472
1996	W	24	15	50	70	229	222	333	589	412	184	55	18	2,201	1,785
1997	W	18	99	213	735	181	219	302	539	280	130	44	21	2,781	1,521
1998	W	18	24	36	102	210	232	288	446	886	686	159	72	3,159	2,062
1999	AN	36	39	50	69	111	102	182	446	337	105	32	17	1,526	1,178
2000	AN	12	12	16	80	155	164	280	530	351	91	37	15	1,743	1,480
2001	D	20	17	16	26	42	126	188	445	115	47	13	10	1,065	916
2002	D	10	22	58	64	57	94	247	323	223	53	13	8	1,172	944
2003	BN	7	62	45	62	60	109	158	436	375	89	34	12	1,449	1,138
2004	D	8	14	44	48	69	192	223	284	173	55	13	7	1,131	941
2005	W	36	41	58	165	133	226	257	818	662	343	73	17	2,830	2,096
2006	W	18	22	110	163	113	198	498	884	763	326	64	23	3,181	2,456
2007	C	20	14	26	24	47	96	137	197	71	25	14	11	684	549
2008	C	10	9	17	58	72	102	176	351	230	68	16	8	1,117	930
2009	D	10	43	26	75	82	139	231	492	223	96	28	10	1,455	1,167

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.26. Monthly, Annual, and February through June Observed Flow in the SJR at Friant from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	77	76	138	240	26	6	14	8	9	8	8	6	615	63
1985	D	5	3	2	2	2	3	6	7	8	9	8	7	64	27
1986	W	6	5	4	4	204	403	277	16	32	11	8	7	974	931
1987	C	4	4	2	2	3	2	8	8	8	10	9	8	67	28
1988	C	7	4	4	3	4	7	6	8	9	11	10	8	80	33
1989	C	8	6	4	2	4	6	7	8	9	11	12	8	84	34
1990	C	7	6	6	3	5	7	9	10	10	13	13	10	99	41
1991	C	9	7	7	6	7	6	7	10	11	13	12	10	105	40
1992	C	9	7	6	5	5	7	8	11	16	17	17	14	123	47
1993	W	12	7	6	7	5	28	69	53	63	42	16	14	322	218
1994	C	10	7	6	6	6	9	9	10	12	15	16	14	120	46
1995	W	10	7	6	6	25	258	361	470	158	327	29	11	1,668	1,272
1996	W	10	8	5	4	37	101	71	100	21	14	14	11	396	330
1997	W	10	6	71	562	362	79	12	16	17	17	19	16	1,187	486
1998	W	14	11	9	7	185	145	277	252	389	268	23	23	1,603	1,248
1999	AN	22	22	33	15	27	5	6	9	20	34	17	12	223	67
2000	AN	8	5	5	6	7	57	8	8	28	14	15	15	177	109
2001	D	12	10	11	9	6	6	7	9	16	13	15	19	132	43
2002	D	12	7	7	6	5	8	10	11	11	14	12	11	114	46
2003	BN	10	8	7	7	6	7	8	10	19	15	12	12	121	50
2004	D	11	7	6	6	6	9	11	12	13	12	12	11	117	50
2005	W	10	8	7	7	8	18	91	311	187	38	15	14	714	614
2006	W	11	9	6	26	5	34	438	409	346	48	20	18	1,370	1,233
2007	C	18	10	8	8	4	8	12	16	17	18	17	16	151	57
2008	C	10	9	6	6	6	13	16	17	17	17	14	10	142	69
2009	D	9	7	6	6	4	8	9	11	11	13	12	10	106	43

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

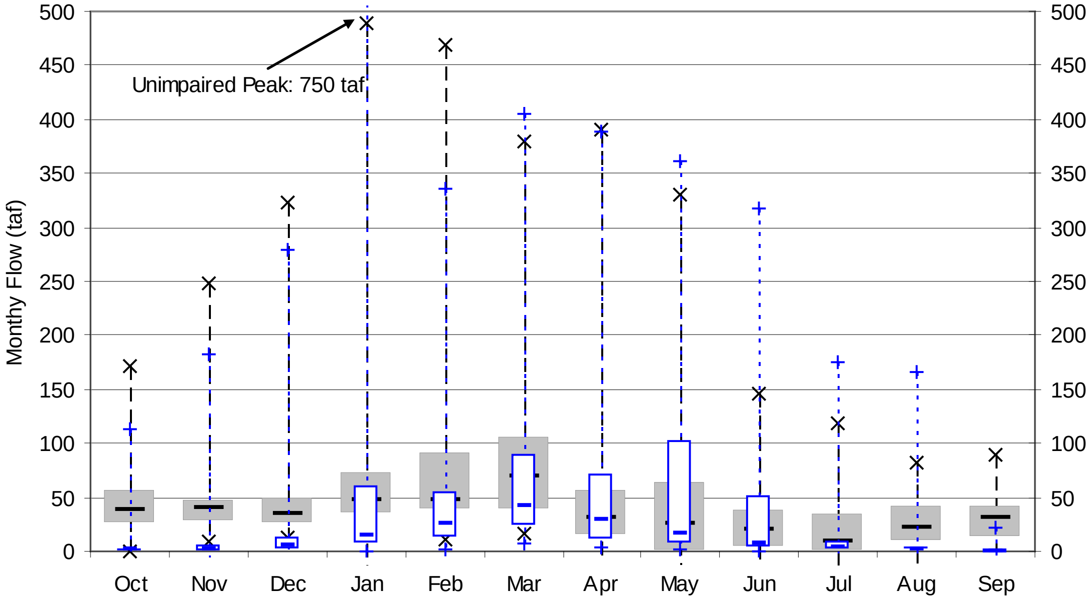
Table 2.27. Monthly, Annual, and February through June Observed Flow as a Percentage of Unimpaired Flow in the SJR at Friant from 1984 to 2009

Water Year	Water Year Type[1]	Oct (%)	Nov (%)	Dec (%)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Annual (%)	Feb-Jun (%)
1984	AN	145	51	61	190	25	4	7	2	3	5	11	17	30	5
1985	D	16	7	5	5	4	3	2	2	5	17	37	38	6	3
1986	W	26	13	5	4	43	95	77	3	5	5	10	21	32	38
1987	C	16	29	15	9	7	3	4	3	7	30	59	77	9	5
1988	C	44	17	15	5	7	8	4	3	6	22	44	68	9	5
1989	C	110	42	18	9	12	4	3	3	6	28	62	44	9	4
1990	C	32	28	35	11	14	8	5	6	8	24	93	131	13	7
1991	C	117	125	72	60	65	5	5	4	3	13	51	74	10	5
1992	C	78	37	35	24	8	9	4	5	21	36	101	157	15	7
1993	W	93	41	18	4	4	12	21	8	11	13	20	54	12	11
1994	C	51	42	27	28	14	12	6	4	8	43	111	116	15	7
1995	W	23	16	13	3	20	53	103	74	18	44	12	16	43	51
1996	W	40	52	10	6	16	46	21	17	5	8	25	61	18	18
1997	W	54	6	33	76	200	36	4	3	6	13	44	77	43	32
1998	W	78	44	26	7	88	63	96	57	44	39	15	32	51	61
1999	AN	61	58	66	22	24	5	3	2	6	33	53	72	15	6
2000	AN	68	43	32	7	5	35	3	2	8	15	41	98	10	7
2001	D	61	60	66	34	13	4	4	2	14	28	115	189	12	5
2002	D	116	32	12	9	9	9	4	4	5	26	90	138	10	5
2003	BN	142	13	16	11	9	6	5	2	5	17	37	104	8	4
2004	D	132	53	15	12	8	5	5	4	7	22	97	158	10	5
2005	W	28	19	12	4	6	8	36	38	28	11	20	82	25	29
2006	W	60	40	6	16	5	17	88	46	45	15	31	80	43	50
2007	C	90	71	29	31	9	9	9	8	23	69	119	151	22	10
2008	C	101	99	38	10	9	13	9	5	7	25	88	127	13	7
2009	D	86	16	23	8	5	5	4	2	5	13	44	102	7	4

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.28. Statistics of Unimpaired Flow, Observed Flow, and Observed Flow as a Percentage of Unimpaired Flow in the SJR at Friant from 1984 to 2009

Unimpaired flow (TAF)													
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
10%tile	8	13	16	22	38	81	152	225	118	39	14	8	785	641
20%tile	10	14	17	24	42	91	172	240	142	47	14	10	862	684
25%tile	12	14	18	25	47	94	173	258	149	49	15	10	938	813
30%tile	12	16	21	33	52	99	179	281	164	54	17	10	1,050	867
40%tile	16	17	26	58	60	109	203	323	223	55	22	12	1,129	930
50%tile	18	22	34	63	71	130	227	441	248	90	26	14	1,311	1,041
60%tile	20	24	44	70	107	162	247	446	321	102	34	17	1,526	1,178
70%tile	24	39	49	87	118	195	269	511	363	146	50	19	2,124	1,501
75%tile	24	39	50	102	124	219	288	539	412	184	64	21	2,672	1,719
80%tile	24	43	58	126	133	222	302	589	593	222	67	23	2,781	1,997
90%tile	36	56	89	177	196	238	342	668	713	334	79	34	3,094	2,276
Observed flow (TAF)														
10%tile	7	4	4	2	4	5	6	8	9	10	9	7	82	33
20%tile	8	6	5	4	4	6	7	8	10	11	12	8	105	41
25%tile	8	6	5	4	5	6	8	9	11	12	12	10	114	43
30%tile	9	7	6	5	5	7	8	9	11	13	12	10	115	45
40%tile	10	7	6	6	5	7	9	10	13	13	12	11	121	47
50%tile	10	7	6	6	6	8	10	11	16	14	14	11	137	54
60%tile	10	7	6	6	6	9	12	12	17	15	15	12	177	67
70%tile	11	8	7	7	7	23	15	16	20	17	16	14	359	164
75%tile	12	9	7	7	25	34	69	17	28	18	17	14	615	302
80%tile	12	9	8	8	26	57	71	53	32	34	17	15	714	486
90%tile	16	11	22	20	111	123	277	281	172	45	20	17	1,279	1,082
Observed flow as a percent of unimpaired flow (%)														
10%tile	24	13	8	4	5	4	3	2	5	9	13	26	9	4
20%tile	32	16	12	5	6	5	4	2	5	13	20	44	9	5
25%tile	41	18	14	7	7	5	4	2	5	13	26	56	10	5
30%tile	47	24	15	7	8	5	4	3	6	14	34	64	10	5
40%tile	60	32	16	9	9	8	4	3	6	17	41	74	12	5
50%tile	65	40	20	10	9	8	5	4	7	22	44	79	13	7
60%tile	78	42	27	11	13	9	6	4	8	25	53	98	15	7
70%tile	91	48	33	19	15	12	9	5	10	28	75	110	20	11
75%tile	99	52	35	24	19	16	18	7	13	29	90	124	24	17
80%tile	110	53	35	28	24	35	21	8	18	33	93	131	30	29
90%tile	125	66	63	47	54	49	82	42	26	41	106	154	43	44



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

Figure 2.14. Monthly Unimpaired Flow (Open Bars) and Observed Flow (Filled Bars) Attributed to the Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin Outflows Combined from 1984 to 2009

Table 2.29. Monthly, Annual, and February through June Unimpaired Flow Attributed to the Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin outflows combined from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	114	183	268	235	45	39	22	13	6	2	2	-1	928	125
1985	D	2	9	8	8	22	32	17	6	6	2	0	0	112	83
1986	W	0	5	10	12	329	406	259	161	100	4	2	1	1,289	1,255
1987	C	1	2	3	6	14	27	4	3	4	0	2	-1	65	52
1988	C	1	1	2	9	5	7	8	4	2	1	1	0	41	26
1989	C	0	0	4	4	7	24	7	3	0	2	1	1	53	41
1990	C	0	1	1	5	6	9	4	2	1	3	0	-1	31	22
1991	C	0	0	0	0	1	75	17	7	7	5	2	0	114	107
1992	C	1	0	1	4	52	20	5	8	0	9	1	0	101	85
1993	W	0	0	8	213	100	96	49	23	15	6	3	21	534	283
1994	C	2	2	5	4	12	7	7	11	9	7	1	-1	66	46
1995	W	1	1	3	161	45	394	241	303	111	83	5	7	1,355	1,094
1996	W	2	2	15	34	124	110	50	88	8	14	9	1	457	380
1997	W	2	34	279	749	336	86	24	10	5	4	5	1	1,535	461
1998	W	6	4	6	91	316	164	388	361	318	175	166	5	2,000	1,547
1999	AN	3	6	10	25	55	26	39	15	9	4	2	2	196	144
2000	AN	3	1	1	28	182	109	35	18	7	2	4	1	391	351
2001	D	3	2	2	9	24	44	24	8	3	4	4	1	128	103
2002	D	0	2	26	25	12	21	9	6	2	3	2	0	108	50
2003	BN	-2	5	24	14	10	15	20	20	4	4	1	0	115	69
2004	D	-7	-4	13	12	25	69	76	85	38	4	-4	-6	300	293
2005	W	5	6	14	73	49	90	89	272	189	79	8	-3	870	688
2006	W	-3	-3	59	70	41	86	194	280	205	65	6	-2	999	806
2007	C	-2	-3	2	2	19	36	47	63	12	-2	-5	-6	163	177
2008	C	-5	-6	-3	16	22	29	55	108	56	6	-5	-6	266	269
2009	D	-6	7	0	21	27	59	79	168	59	14	-2	-5	422	393

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.30. Monthly, Annual, and February through June Observed Flow Attributed to the Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin outflows combined from 1984 to 2009

Water Year	Water Year Type[1]	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)	Annual (TAF)	Feb-Jun (TAF)
1984	AN	172	248	324	489	156	145	105	77	59	44	58	81	1,958	542
1985	D	91	41	39	45	43	65	54	45	27	36	47	51	584	234
1986	W	50	38	48	44	26	274	309	172	124	77	78	90	1,329	904
1987	C	78	44	29	34	32	73	41	40	39	37	42	43	533	226
1988	C	39	39	28	42	37	38	37	28	25	16	29	27	387	166
1989	C	22	25	29	36	32	17	17	25	17	16	25	34	294	107
1990	C	39	34	38	36	32	22	12	13	7	3	8	12	256	87
1991	C	17	15	16	15	12	45	17	-1	2	-3	-1	1	135	74
1992	C	7	11	13	18	52	35	8	-5	-12	-13	-12	-4	97	78
1993	W	0	10	15	126	101	78	-4	-17	-23	-15	19	34	323	134
1994	C	46	41	35	31	46	39	17	27	7	-1	-1	7	294	136
1995	W	18	22	25	102	66	106	150	93	120	-99	66	65	733	534
1996	W	85	55	52	49	130	106	28	-8	68	45	40	46	696	324
1997	W	51	61	51	-485	348	257	57	65	33	21	32	42	534	760
1998	W	41	39	54	78	469	380	390	331	146	119	82	54	2,183	1,715
1999	AN	91	64	68	37	46	101	99	73	32	7	31	35	683	350
2000	AN	61	54	33	54	106	107	55	58	25	30	24	35	644	352
2001	D	49	51	50	63	51	96	41	32	11	18	19	19	501	232
2002	D	36	48	40	82	45	57	21	21	14	11	16	22	415	160
2003	BN	31	43	59	59	41	65	26	20	-2	6	15	17	380	150
2004	D	33	37	32	48	50	81	15	23	5	3	14	19	360	174
2005	W	36	41	39	163	116	111	33	-209	27	7	21	32	417	78
2006	W	58	48	20	77	56	33	188	196	45	100	43	31	895	518
2007	C	25	48	32	34	43	40	13	0	-4	1	0	8	241	93
2008	C	26	23	23	52	63	34	-1	-3	-2	-8	2	12	220	91
2009	D	11	13	16	19	31	29	1	0	-6	-14	-8	1	93	54

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.31. Monthly, Annual, and February through June Observed Flow as a Percentage of Unimpaired Flow Attributed to the Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin outflows combined from 1984 to 2009

Water Year	Water Year Type[1]	Oct (%)	Nov (%)	Dec (%)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Annual (%)	Feb-Jun (%)
1984	AN	151	136	121	208	348	372	477	592	979	2,191	2,900	-8,124	211	434
1985	D	4,533	451	487	565	195	204	318	758	447	1,803	0	0	522	282
1986	W	0	760	479	363	8	67	119	107	124	1,920	3,884	9,032	103	72
1987	C	7,775	2,215	981	562	226	272	1,035	1,343	985	0	2,103	-4,287	821	435
1988	C	3,882	3,929	1,425	464	748	544	459	702	1,272	1,646	2,910	0	944	638
1989	C	0	0	716	910	451	70	242	834	0	797	2,479	3,386	554	261
1990	C	0	3,448	3,761	713	541	246	303	628	727	97	0	-1,225	827	393
1991	C	0	0	0	0	1,178	59	97	-13	31	-53	-30	0	118	69
1992	C	712	0	1,287	443	100	175	156	-64	0	-148	-1,240	0	96	92
1993	W	0	0	189	59	101	81	-8	-76	-155	-247	640	162	61	48
1994	C	2,296	2,044	696	768	382	560	246	244	75	-12	-58	-744	446	295
1995	W	1,829	2,222	826	63	146	27	62	31	108	-120	1,319	929	54	49
1996	W	4,253	2,746	345	145	105	96	56	-10	854	321	446	4,598	152	85
1997	W	2,567	180	18	-65	104	298	236	647	668	537	638	4,159	35	165
1998	W	679	981	896	86	149	231	100	92	46	68	50	1,082	109	111
1999	AN	3,032	1,064	677	148	84	388	253	483	356	187	1,534	1,735	348	243
2000	AN	2,036	5,423	3,346	195	59	98	158	322	359	1,489	594	3,518	165	100
2001	D	1,629	2,556	2,503	701	213	219	173	405	358	455	463	1,919	391	225
2002	D	0	2,419	154	327	376	273	239	356	713	375	789	0	384	319
2003	BN	-1,531	850	245	420	408	434	131	101	-51	155	1,546	0	331	218
2004	D	-506	-952	257	395	203	118	20	27	12	74	-306	-290	120	59
2005	W	734	645	283	223	239	123	37	-77	14	9	280	-1,257	48	11
2006	W	-2,041	-1,896	34	111	134	39	97	70	22	154	677	-1,665	90	64
2007	C	-1,161	-1,902	1,541	2,113	235	109	28	0	-30	-49	4	-142	148	52
2008	C	-486	-394	-885	330	284	118	-3	-2	-3	-134	-40	-181	83	34
2009	D	-176	174	106,793	90	114	49	1	0	-11	-96	377	-20	22	14

Notes: [1] W, AN, BN, D, C stand for Wet, Above Normal, Below Normal, Dry, and Critically Dry classified water years, respectively.

Table 2.32. Statistics of Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow Statistics Attributed to the Chowchilla and Fresno Rivers, San Joaquin Valley Floor, and Tulare Lake Basin Outflows Combined from 1984 to 2009

Unimpaired flow (TAF)													
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
10%tile	-4	-3	1	4	7	12	6	4	2	2	-3	-6	59	44
20%tile	-2	0	1	5	12	21	8	6	3	2	0	-2	101	52
25%tile	0	0	2	7	13	25	11	7	4	2	1	-1	109	73
30%tile	0	1	2	9	16	27	17	8	5	3	1	-1	113	84
40%tile	0	1	3	12	22	32	22	11	6	4	1	0	128	107
50%tile	1	2	6	15	26	42	30	17	8	4	2	0	231	161
60%tile	1	2	8	25	45	69	47	23	9	5	2	0	391	283
70%tile	2	5	11	31	50	86	52	87	26	7	4	1	496	366
75%tile	2	5	13	61	54	89	71	103	51	9	4	1	786	389
80%tile	3	6	15	73	100	96	79	161	59	14	5	1	928	461
90%tile	4	8	43	187	249	137	218	276	150	72	7	4	1,322	950
Observed flow (TAF)														
10%tile	14	14	16	18	31	31	4	-7	-5	-14	-1	4	178	78
20%tile	22	23	23	34	32	35	13	-1	-2	-3	2	12	256	91
25%tile	25	28	26	35	38	38	15	0	3	0	10	14	294	96
30%tile	28	36	29	36	42	39	17	6	6	2	15	18	309	121
40%tile	36	39	32	42	45	57	21	21	11	6	19	22	380	150
50%tile	39	41	34	47	48	69	30	26	21	9	23	31	416	170
60%tile	46	43	39	52	52	81	41	32	27	16	29	34	533	232
70%tile	51	48	44	61	64	103	55	52	33	26	36	38	614	337
75%tile	56	48	50	74	92	106	56	63	38	34	42	43	673	352
80%tile	61	51	51	78	106	107	99	73	45	37	43	46	696	518
90%tile	88	58	56	114	143	201	169	132	94	61	62	60	1,112	651
Observed flow as a percent of unimpaired flow (%)														
10%tile	-1198	-897	69	72	92	54	11	-38	-24	-128	-53	-1,927	51	41
20%tile	-490	143	182	107	104	70	37	-2	6	-62	-10	-1,232	83	52
25%tile	-254	175	245	145	107	85	57	0	14	-49	38	-864	91	61
30%tile	53	262	262	157	124	97	79	13	21	-8	257	-426	100	67
40%tile	699	691	425	217	149	118	100	70	52	71	449	-158	118	85
50%tile	1,181	916	677	330	208	149	144	104	116	154	616	71	150	106
60%tile	1,912	1,652	760	405	235	219	173	322	358	241	670	990	211	218
70%tile	2,377	2,220	964	460	316	259	240	444	469	439	1,341	1,790	366	252

Unimpaired flow (TAF)														
Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Feb-Jun
75%tile	2,683	2,370	1,287	562	369	273	245	565	679	537	1,537	2,285	389	277
80%tile	3,202	2,529	1,448	592	382	298	253	628	719	935	1,769	3,412	446	295
90%tile	4,281	3,378	3,009	746	496	411	389	730	941	1,740	2,774	4,203	687	414

[1] To calculate observed flow as percent unimpaired flow, months with unimpaired flow = zero were omitted. 6 Octobers, 4 Novembers, 1 December, 2 Junes, 1 July, 2 Augusts, and 6 Septembers.

2.5 Hydrodynamics Downstream of Vernalis

As previously stated, Vernalis is the location where all non-floodplain flows from the SJR basin flow into the Delta. Downstream from Vernalis, flows in the SJR and the southern and central Delta channels are affected by numerous factors including tides, in-Delta diversions, and barrier operations. This section provides a general overview of three important flow conditions associated with Central Valley Project (CVP) and State Water Project (SWP) pumping operations in the southern Delta: 1) water levels and circulation in the southern Delta; 2) the flow split at the head of Old River (HOR); and 3) reverse flows in Old and Middle Rivers.

Flow conditions downstream of Vernalis are largely affected by export operations of the two major water diverters in the Delta, the USBR and the DWR. The USBR exports water from the Delta for the CVP at the Jones Pumping Plant and the DWR exports water from the Delta for the SWP at the Banks Pumping Plant. In addition to these pumping plants, there are many smaller local agricultural diversions in the southern Delta that can affect flow conditions (State Water Board 1999.)

2.5.1 Water Levels and Circulation in the Southern Delta

The State Water Board D-1641 states that the CVP Tracy (Jones) pumping plant and SWP (Banks) pumping plant operations were having a negative effect on water levels and circulation patterns, occasionally resulting in areas of low or no circulation (i.e. null zones) (State Water Board 1999; DOI and SDWA 1980). Low water levels interfere with the ability of local agricultural diverters to access water with their pumps and siphons, and null zones can contribute to localized concentration of salts associated with agricultural return flows and municipal discharges.

As part of the South Delta Temporary Barriers Project initiated in 1991 by the DWR, three tidal flow control structures (agricultural barriers) are installed each season (from roughly April 15 to November 25) to increase water levels and circulation patterns in the southern Delta area for local agricultural diversions. These barriers are constructed of rock with culverts and flap gates designed to capture tidal flood flows and maintain higher water levels and increase circulation upstream of the barriers. The barriers are installed at Old River near Tracy, Middle River, and Grant Line Canal as shown in Figure 1.2. As will be discussed in the next section, a fourth barrier is installed in fall months at the HOR.

Based on July 1985 conditions, DWR performed modeling to quantify the effect of CVP and SWP pumping on water levels (tidal ranges) and the mitigating effects of the three agricultural barriers in the southern Delta. The output from this analysis is summarized in Table 2.33 for “no pumping/no barriers”, “full pumping/no barriers”, and “full pumping/temporary barriers” scenarios. Pumping operations were estimated to lower the otherwise natural lower-low tide levels by about 0.5 to 0.7 feet, and higher-high tides by about 0.9 to 2.0 feet, and installation of the agricultural barriers were demonstrated to provide significant mitigation for these effects (DWR and USDOI 2005).

A report by the DOI and SDWA (1980) stated that the effects of tidal mixing, and available downstream flow is insufficient to offset the effect of salt accumulation in these areas. Reduced flows and lower water levels have further exacerbated the occurrence of limited circulation in Middle River and portions of Old River. The channel bottom is raised in Old River just west of Tom Paine Slough and has a reduced cross sectional area and may have an effect on tidal fluctuation in Old River (DOI and SDWA 1980).

Table 2.33. Range of Tidal Fluctuation Under Various Conditions Modeled in DWR and USDOI 2005

	No Pumping/No Gates		Full Pumping[1]/ No Gates		Full Pumping[1]/ Temporary Barriers	
Barrier	Lower Low	Higher High	Lower Low	Higher High	Lower Low	Higher High
	(ft msl)	(ft msl)	(ft msl)	(ft msl)	(ft msl)	(ft msl)
Head of Old River	0.4	4.1	0.0	3.1	0.9	3.5
Grant Line Canal Barrier	-0.8	4.1	-1.4	2.1	Not Presented in Reference	
Old River Barrier	-0.8	4	-1.5	2	0.8	2.7
Middle River Barrier	-0.9	4.1	-1.3	3	0.1	3.7

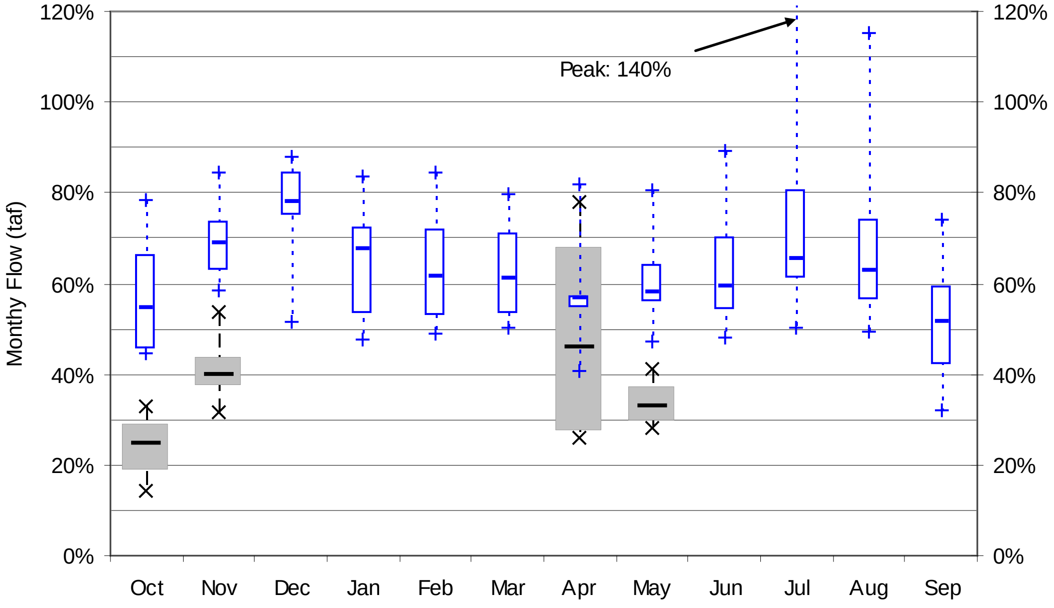
[1]Full pumping corresponds to 8,500 cfs at Clifton Court Forebay and 4,600 cfs at CVP Tracy (Jones).Source: DWR and USDOI 2005.

2.5.2 Flow Split to Old River

Downstream of Vernalis, flow from the SJR splits at the HOR and either continues downstream in the SJR toward Stockton or enters Old River, toward the CVP and SWP pumps. When Vernalis flow is greater than 16,000 cfs, a portion of the flow entering the south Delta enters through Paradise Cut, just upstream of the HOR. The amount of flow split in each direction at HOR (including flow through Paradise Cut) is affected by the agricultural and HOR barriers, and the combined pumping rates of CVP and SWP relative to SJR inflows at Vernalis. When the combined CVP and SWP pumping rates are less than the flow rate at Vernalis, the flow split to the SJR and Old River is roughly 50/50. When combined CVP and SWP pumping rates reach about five times the SJR flow at Vernalis, and without the installation of the HOR barrier, about 80% of the SJR at the HOR flows into Old River towards the pumps (Jones and Stokes 2001). Dr. Hutton (2008) also states that as south Delta diversions increase, the fraction of flow entering Old River increases.

The HOR barrier (HORB) has been installed in most years during the fall (roughly between September 30 and November 15) since 1968, and in some years during the spring (roughly between April 15 and May 30) since 1992. In general, the HORB was not installed during the spring in years with higher flows. In addition, the HORB has not been installed in the spring since 2007 due to a court order. A non-physical fish barrier was installed in its place in 2009 and 2010 (see discussion in Section 3). When the physical barrier at HOR is installed, the flow into Old River is reduced to between 20% and 50% (Jones and Stokes 2001). Data from Jones and Stokes (2001) further suggests that the agricultural barriers alone (when physical barrier at HOR was not installed), reduces flow into Old River for all pumping ranges, and reduced the effects of increased pumping on water levels and circulation. Dr. Hutton (2008) states that the increase in water levels that occur as a result of the Grant Line Canal barrier alone, decreases the flow entering Old River.

The observed amount of flow diverted to Old River using recent gage data from 1996 through 2009 is estimated by subtracting the gaged flow on the SJR at Garwood Bridge (USGS gage #11304810) from the gaged flow on the SJR at Vernalis (USGS gage #11303500) and is presented in Figure 2.15 and Table 2.34. As stated by Jones and Stokes (2001) the agricultural barriers may also affect the flow split with and without the HORB. For the months when the HORB was not installed, the percentage of flow that entered Old River was generally between 50% and 80%. For the months when all barriers were generally installed (October and November in most years, and April and May in most years prior to 2007), the percentage of flow entering Old River was roughly less than 50%. During May, both the Old and Middle River barriers were generally installed, however during April, the barriers were only in place during the second half of the month, thus May shows a reduced percentage of flow entering Old River than in April. The Grant Line Canal barrier was rarely installed during May, thus the percentage of flow entering Old River in May is greater than in October. Since 2001, all three agricultural barriers have been installed for the entire month of October, and generally the first half of November. The lowest percentage of flow entering Old River occurs in October when all barriers are installed, as shown in Figure 2.15. During July and August, the percentage of flow entering the HOR may exceed 100%; this occurs when large volumes of water are diverted from Old River in excess of SJR flows at Vernalis and water flows upstream to the HOR from the Central Delta.



Key to boxplots: median, horizontal line; box, 25th and 75th percentiles; whiskers, range barrier out (“+”sign) and barrier in (“x” sign).

Figure 2.15. Monthly Average Percentage of Flow Entering Old River from 1996 to 2009 with Barriers (Filled Bars) and without Barriers (Open Bars)

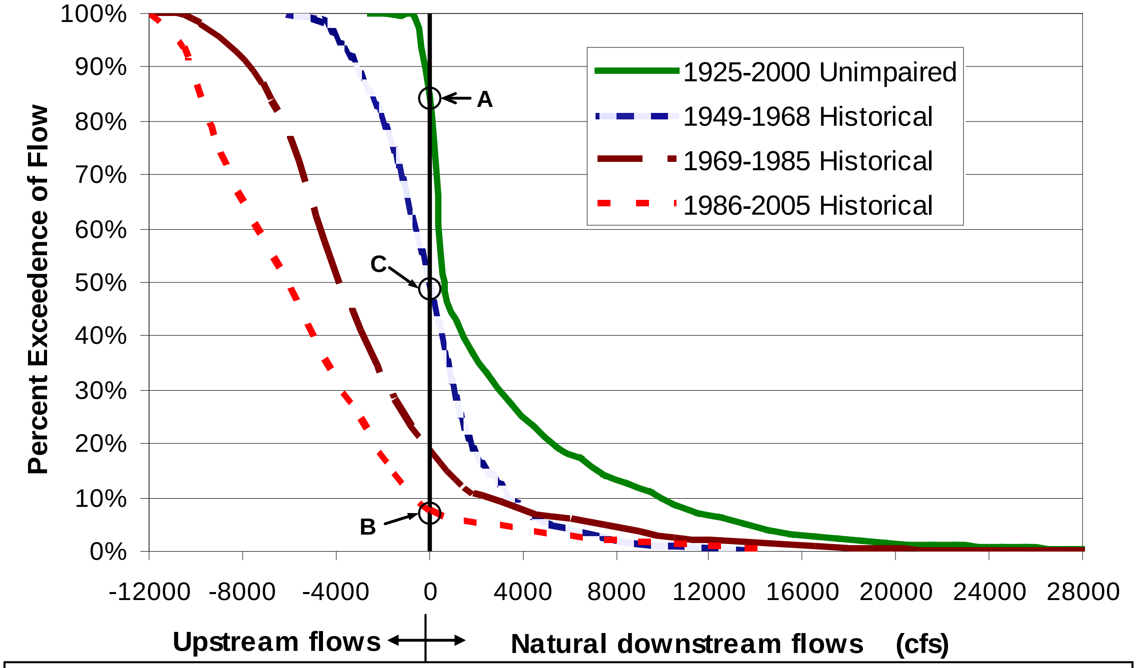
Table 2.34. Monthly Average Percentage of Flow Entering Old River from 1996 to 2009

Percent of flow entering Old River with barrier removed.												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
25%tile	45%	63%	75%	53%	53%	53%	55%	56%	54%	61%	56%	42%
Median	54%	69%	78%	68%	62%	61%	57%	58%	60%	65%	63%	52%
75%tile	66%	74%	84%	72%	72%	71%	57%	64%	70%	81%	74%	59%
Percent of flow entering Old River with barrier installed.												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
25%tile	18%	37%					27%	30%				
Median	25%	40%					46%	33%				
75%tile	29%	44%					68%	37%				

2.5.3 Reverse Old and Middle River Flows

SWP and CVP pumping operations also increase the occurrence of net Old and Middle River reverse flows (OMR) reverse flows. OMR reverse flows are now a regular occurrence in the Delta. Net OMR reverse flows occur because the major freshwater source, the Sacramento River, enters on the northern side of the Delta while the two major pumping facilities, the SWP and CVP, are located in the south. This results in a net water movement across the Delta in a north to south direction along a network of channels including Old and Middle Rivers. Net OMR is calculated as half the flow of the SJR at Vernalis minus the combined SWP and CVP pumping rate (CCWD 2010). A negative value, or a reverse flow, indicates a net water movement across the Delta along Old and Middle river channels towards the CVP and SWP pumping facilities.

Water balance models by the USGS and DWR’s DSM2, are used to model OMR flows based upon CVP and SWP pumping rates and temporary barrier operations. Dr. Hutton compared the USGS and DWR models and developed a water balance regression that estimates OMR flow based on combined pumping rates and net delta channel depletions. In general the models show that increased pumping rates and lower flow entering at the HOR lead to higher OMR reverse flows (Hutton 2008). 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 as shown in Figure 2.16. The 1925-2000 unimpaired line in this figure 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% of the time before most modern water development, including construction of the major pumping facilities in the South Delta (Point A in Figure 2.16). The magnitude of net OMR reverse flows under unimpaired conditions was seldom more negative than 2,000 cfs. In contrast, between 1986 and 2005 net OMR reverse flows occurred more than 90% of the time (Point B in Figure 2.16). The magnitude of net OMR reverse flows may now be as much as -12,000 cfs.



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

Figure 2.16. Old and Middle River Cumulative Probability Flows from Fleenor et al. 2010

2.6 Conclusions

In conclusion alterations to the unimpaired flow regime include reduced annual discharge, reduction in frequency and intensity of late fall and winter storm flows, reduced spring and early summer snowmelt flows, and a general decline in hydrologic variability. The following is a list of the findings:

A) Annual flow volumes at Vernalis have been reduced to a median of 46% of unimpaired flow, while the February through June flow volume has been reduced to a median of 27% of unimpaired flow. In terms of median values, the greatest reduction of the monthly flows occurs during peak spring snowmelt months of April, May, and June. Observed flows during these months are a median of 25%, 17%, and 18% of unimpaired flow, respectively.

B) Observed flows from February through June as percentages of unimpaired flows have fallen well below medians of 41%, 21%, and 26% in the Stanislaus, Tuolumne, and Merced Rivers respectively, with the April, May and June values generally far lower, especially May and June flows on the Tuolumne and Merced Rivers. For April, May and June, the medians are 32%, 26%, and 40% of unimpaired flow for the Stanislaus River, 22%, 12%, and 9% of unimpaired flow for the Tuolumne River, and 25%, 18% and 15% of unimpaired flow on the Merced River. This included values as low as 1% and 2% of unimpaired flow in the Merced and Tuolumne Rivers respectively in June 1991.

C) Flow conditions are more static with less seasonally variable flows throughout the year. The springtime magnitude is now severely dampened and there is more flow in the fall than would occur under an unimpaired condition. The wettest month of the year is now less predictable and is distributed over more months from year to year.

D) Short term peak or storm flows that occur several times within a given year, generally between November and March, are dramatically reduced under the present management conditions.

E) Tributary contributions are altered leading to a greater percentage of flow being delivered by the Stanislaus River, and much lower percentage of flow being delivered by the upper San Joaquin River.

3 Scientific Basis for Developing Alternate San Joaquin River Flow Objectives

3.1 Introduction

This section describes the scientific basis for developing alternative SJR flow objectives for the protection of fish and wildlife beneficial uses and the program of implementation for those objectives to be included in the Bay-Delta Plan (referred to as the LSJR flow alternatives in the SED). Draft changes to the SJR flow objectives and program of implementation are described in the conclusions section of this chapter and provided in Appendix A. Specifically, this section focuses on the Delta inflow needs from the SJR basin for SJR basin fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*Oncorhynchus mykiss*), as these anadromous species are among the most sensitive to inflows from the SJR basin to the Bay-Delta. The State Water Board has determined that higher and more variable inflows during the February through June time frame are needed to support existing salmon and steelhead populations in the major SJR tributaries to the southern Delta at Vernalis. This will provide greater connectivity to the Delta and will more closely mimic the flow regime to which native migratory fish are adapted. Water needed to support sustainable salmonid populations at Vernalis should be provided on a generally proportional basis from the major SJR tributaries (Stanislaus, Tuolumne, and Merced Rivers). Flow in the mainstem SJR, below Friant Dam, for anadromous fish will be increased under a different regulatory and cooperative water management program (SJRRP 2010). The draft program of implementation for the SJR flow objectives includes requirements that additional analyses be conducted to determine flow needs for other times of year and includes a commitment to evaluate potential changes to the Bay-Delta Plan to address other times of year and whether additional flows are needed from the upstream SJR below Friant Dam.

While aquatic resources in the SJR basin have been adversely impacted by numerous factors, flow remains a key factor and is the focus of the State Water Board’s current review. A number of other factors (e.g., non-native species, exposure to contaminants, nutrient loading, climate change) need to be evaluated as potential contributors to the degradation of fish and wildlife beneficial uses in the SJR basin and Delta. These environmental factors or “stressors” will be addressed in the SED, and are not the focus of this review. Flow regimes needed to maintain desired conditions will change through time, as our understanding of how flow interacts with these other stressors improves and in response to changes in the geometry of waterways, global climate change, and other factors. The adaptive management approach proposed in the draft program of implementation for the SJR fish and wildlife flow objectives would provide a venue through which the flow regime could be modified in response to improved understanding of flow needs and other stressors.

3.1.1 Terminology

The following provides definitions, as used in this chapter, for observed flow, unimpaired flow, flow regime, and natural flow regime. For additional discussion regarding the methods used in the hydrologic analysis, refer to Section 2.2 of this report.

- Observed flow is the measured streamflow recorded at USGS gages located at the most downstream location for each of the major SJR tributaries and at Vernalis.

- Unimpaired flow is a modeled flow generally based on historical gage data with factors applied to primarily remove the effects of dams and diversions within the watersheds. The modeled unimpaired flow does not attempt to remove changes that have occurred such as channelization and levees, loss of floodplain and wetlands, deforestation, and urbanization.
- Flow regime describes the characteristic pattern of a river's flow, quantity, timing, and variability (Poff et al. 1997). The 'natural flow regime' represents the range of intra-and interannual variation of the hydrological regime, and associated characteristics of magnitude, frequency, duration, timing and rate of change that occurred when human perturbations to the hydrological regime were negligible (Richter et al. 1996, Richter et al. 1997, Poff et al. 1997, Bunn and Arthington 2002, Lytle and Poff 2004, Poff et al. 2010).
- For the purposes of this report, a more natural flow regime is defined as a flow regime that more closely mimics the shape of the unimpaired hydrograph.

3.1.2 Problem Statement

Scientific evidence indicates that reductions in flows and alterations to the flow regime in the SJR basin, resulting from water development over the past several decades, have the potential to negatively impact fish and wildlife beneficial uses. As outlined in the hydrology section of this report, water development in the SJR basin has resulted in: reduced annual flows; fewer peak flows; reduced and shifted spring and early summer flows; reduced frequency of peak flows from winter rainfall events; shifted fall and winter flows; and a general decline in hydrologic variability over multiple spatial and temporal scales (McBain and Trush 2002, Cain et al. 2003, Richter and Thomas 2007, Brown and Bauer 2009, NMFS 2009a). Currently, there is relatively little unregulated runoff from the SJR basin with dams regulating at least 90% of the inflow (Cain et al. 2010). Dams and diversions in the SJR basin have caused a substantial overall reduction of flows, compared to unimpaired hydrographic conditions, with a median reduction in annual flows at Vernalis of 54% and median reduction of critical spring flows of 74%, 83%, and 81% during April, May, and June, respectively.

The SJR basin once supported large spring-run and fall-run Chinook salmon populations; however, the basin now only supports a declining fall-run population. Scientific evidence indicates that in order to protect fish and wildlife beneficial uses in the SJR basin, including increasing the populations of fall-run Chinook salmon and Central Valley steelhead to sustainable levels, changes to the altered hydrology of the SJR basin are needed. Over the past several decades, various flow requirements have been established to protect fisheries resources in the SJR and its major tributaries (described below). Despite these efforts though, SJR basin fall-run Chinook salmon populations have continued to decline. In the SJR basin, it is recognized that the most critical life stage for salmonid populations is the spring juvenile rearing and migration period (DFG 2005a, Mesick and Marston 2007, Mesick et al. 2007, and Mesick 2009). Scientific evidence indicates that in order to protect fish and wildlife beneficial uses in the SJR basin, including increasing the populations of SJR basin fall-run Chinook salmon and Central Valley steelhead to sustainable levels, changes to the current flow regime of the SJR basin are needed. Specifically, a more natural flow regime from the salmon bearing tributaries (Stanislaus, Tuolumne, and Merced Rivers) is needed during the February through June time frame.

3.1.3 Existing Flow Requirements

In order to maintain and enhance fish and wildlife beneficial uses in the SJR basin several entities, through various and disparate processes, have established flow prescriptions on the mainstem SJR and its major tributaries. The existing and historical instream flow requirements for the major SJR tributaries consist of requirements set forth in water quality control plans, water right decisions, Federal Energy Regulatory Commission (FERC) proceedings, agreements and settlements, and biological opinions (BO) issued pursuant to the Federal Endangered Species Act.

Central Valley

Central Valley Project Improvement Act (CVPIA)

The Central Valley Project Improvement Act (CVPIA), which was signed into law on October 30, 1992, modified priorities for managing water resources of the CVP, a major link in California's water supply network. The intent was to make fish and wildlife protection, restoration, and enhancement as project purposes that have equal priority with agriculture, municipal and industrial, and power uses. Several environmental requirements were designed to lessen the impacts of the water projects; these include increasing instream flows, and curtailing export pumps at key times to protect fisheries. Section 3406 of the CVPIA includes actions:

> *3406(b)(1) – Special efforts to restore anadromous fish populations by 2002, including habitat restoration actions the Anadromous Fish Restoration Program (AFRP) Core Group believes necessary to at least double the production of anadromous fish in the Central Valley (see USFWS 1995)(proposed instream flow actions are described in Section 3.7 of this report).*
>
> *3406(b)(2) – Dedicate and manage annually 800,000 acre-feet of CVP yield for the primary purpose of implementing the fish, wildlife, and habitat restoration purposes and measures authorized by this title; to assist the State of California in its efforts to protect the waters of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary; and to help to meet such obligations as may be legally imposed upon the CVP under State or Federal law following the date of enactment of this title, including but not limited to additional obligations under the Federal Endangered Species Act (see Table 3.1).*
>
> *3406(b)(3) – Require acquisition of water for protecting, restoring, and enhancing fish and wildlife populations (Sections 3406(b)(3) and 3406(d)). To meet water acquisition needs under CVPIA, the U.S. Department of the Interior (USDOI) has developed a Water Acquisition Program (WAP), a joint effort by the U.S. Bureau of Reclamation (Bureau) and the U.S. Fish and Wildlife Service (USFWS). The target for acquisitions is approximately 200,000 acre-feet per year, for use on the San Joaquin and Sacramento rivers and their tributaries. The USBR has yet to acquire the full 200,000 acre-feet of target flows for Section 3406(b)(3) (Table 3.2), due to a lack of willing sellers as well as the high cost of water on the open market. The actual volume of water acquired each year fluctuates based on the basin hydrology, reservoir storage and the water supplies available to WAP pursuant to the San Joaquin River Agreement (SJRA, described below).*

Table 3.1. Central Valley Project Improvement Act Environmental 3406(b)(2) Water Supplies

Allocation and Use of (b)(2) Water by Year (Approximate)					
Allocation of (b)(2) Water			Use of (b)(2) Water		
Year	Sac Valley Index Water Year Type	(b)(2) Allocated (acre-feet)	Flow (acre-feet)	Unused (acre-feet)*	Banked (acre-feet)**
2001	Dry	800,000	798,000		
2002	Dry	800,000	793,000		
2003	Above Normal	800,000	796,000		
2004	Below Normal	800,000	800,000		
2005	Above Normal	800,000	672,000		128,000
2006	Wet	800,000	422,000	183,000	195,000
2007	Dry	800,000	798,000		
2008	Critical	600,000	600,000		
2009	Dry	600,000	600,000		
2010	Below Normal	800,000	800,000		

Source: USDOI In Prep

*Section 3406 (b)(2)(D): If the quantity of water dedicated under this paragraph, or any portion thereof, is not needed for the purposes of this section, based on a finding by the Secretary, the Secretary is authorized to make such water available for other project purposes.
**In wetter precipitation years such as 2005 and 2006, a portion of the dedicated water was banked pursuant to CVPIA Section 3408(d). Banked water is ~~reallocated back~~added into the CVP yield in the subsequent year.

Table 3.2. Annual (b)(3) Instream Water Acquisitions

Year	Water Year Type	Annual Water Acquisitions (acre-feet)
2001	Dry	109,785
2002	Dry	68,105
2003	Above Normal	91,526
2004	Below Normal	98,211
2005	Above Normal	148,500
2006	Wet	148,500
2007	Dry	92,145
2008	Critical	106,490
2009	Dry	38,500

San Joaquin River

Bay-Delta Accord

In December 1994, State and Federal agencies, along with stakeholders, developed a proposal for water quality standards, which led to the signing of a document titled “Principles for Agreement on Bay-Delta Standards between the State of California and the Federal Government”. This agreement is known as the Bay-Delta Accord. The Bay-Delta Accord initiated a long-term planning process to improve the Delta and increase the reliability of its water supply. Among the Delta specific requirements, the Bay-Delta Accord also specified in-stream flows (Table 3.3) on the mainstem SJR below Friant (compliance point at Vernalis) for the benefit of Chinook salmon.

Table 3.3. Bay-Delta Accord Instream Flow Requirements at Vernalis

Water Year	February - June Flows (cfs)	April - May Pulse Flows (cfs)
Critical	710 - 1,140	3,110 - 3,540
Dry	1,420 - 2,280	4,020 - 4,880
Below Normal	1,420 - 2,280	4,620 - 5,480
Above Normal	2,130 - 3,420	5,730 - 7,020
Wet	2,130 - 3,420	7,330 - 8,620

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Bay-Delta Plan and D-1641

In the 1995 Water Quality Control Plan for the Bay-Delta Plan (1995 Bay-Delta Plan), the State Water Board included objectives for the SJR flows specified in the Bay-Delta Accord and added an additional October pulse flow objective. For all water year types, the October flow objective requires flows at Vernalis of 1,000 cfs in October plus up to an additional 28,000 AF to in order to provide a monthly average flow of 2,000 cfs (with the additional flow not required in a critical year that follows a critical year). These flow objectives were primarily intended to protect fall-run Chinook salmon and provide incidental benefits to Central Valley steelhead.

During proceedings regarding implementation of the 1995 Bay-Delta Plan, as an alternate approach to deciding the responsibilities of the water right holders, the State Water Board provided the water right holders an opportunity to reach settlement agreements with other water right holders and interested parties proposing allocations of responsibly to meet the flow-dependent objectives in the 1995 Bay-Delta Plan. The result was the SJRA, which proposed an alternate method to meeting the SJR portions of the objectives included in the 1995 Bay-Delta Plan. The signatory parties, including the California Resources Agency, USDOI, San Joaquin River Group, CVP/SWP Export Interests, and two environmental groups, agreed that the San Joaquin River Group Authority (SJRGA) members would meet the experimental flows specified in the Vernalis Adaptive Management Plan (VAMP) in lieu of meeting the spring pulse flow objectives adopted in the 1995 Bay-Delta Plan. In Water Right Decision 1641 (D-1641), the State Water Board approved the conduct of the VAMP for a period of 12 years in lieu of meeting the SJR pulse flow objectives and assigned responsibility to USBR for meeting the SJR flow objectives. The State Water Board also conditioned the water rights of various SJRGA members to provide water for the VAMP and the October pulse flow objective.

The VAMP, initiated in 2000, is a large scale, 12-year experimental management program designed to protect juvenile Chinook salmon migration from the SJR through the Delta. It is also a scientific experiment to determine how juvenile fall-run Chinook salmon survival rates change in response to alterations in SJR flows and SWP and CVP exports with the installation of the HORB. The VAMP experiment (implemented for a 31-day period during April and May) is designed to assess a combination of flows, varying between 3,200 cfs and 7,000 cfs, and exports varying between 1,500 cfs and 3,000 cfs.

In addition to the SJR flow objectives, the 1995 Bay-Delta Plan (and subsequently the 2006 Bay-Delta Plan) includes a narrative objective for salmon protection that is consistent with the anadromous fish doubling goals of the CVPIA. Under the AFRP, State, Federal and local entities are continuing to implement programs within and outside the Delta geared towards achieving the CVPIA anadromous fish doubling goals. Specifically, implementation of the Bay-Delta Plan flow objectives is intended to contribute toward achieving the narrative objective.

The 1995 and 2006 Bay-Delta Plan also include salinity objectives for the protection of agriculture in the southern Delta at four compliance locations including: the SJR at Vernalis; the SJR at Brandt Bridge; Old River near Middle River; and Old River at Tracy Road Bridge. The

State Water Board set an objective of 0.7 mmhos/cm EC during the summer irrigation season (April 1 through August 31) based on the salt sensitivity and growing season of beans and an objective of 1.0 mmhos/cm EC during the winter irrigation season (September 1 through March 31) based on the growing season and salt sensitivity of alfalfa during the seedling stage. These salinity objectives were not established for the protection of fish and wildlife, but their implementation may result in releases of water from New Melones on the Stanislaus River and as a result may affect flow conditions downstream at Vernalis.

National Marine Fisheries Service Biological Opinion

In June 2009, the National Marine Fisheries Service (NMFS) issued a final biological opinion and conference opinion, based on its review of the proposed long-term operations of the CVP and SWP in the Central Valley, California, and its effects on listed anadromous fishes and marine mammal species, and designated and proposed critical habitats in accordance with section 7 of the Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531 *et seq*.). NMFS' final biological opinion concluded that the CVP/SWP operations are likely to jeopardize the continued existence of Federally listed endangered Sacramento River winter-run Chinook salmon (*Oncorhynchus tsawytscha*), threatened Central Valley spring-run Chinook salmon (*Oncorhynchus tsawytscha*), threatened Central Valley steelhead (*Oncorhynchus mykiss*), threatened Southern Distinct Population Segment of North American green sturgeon (*Acipenser medirostris*), and southern resident killer whales (*Orcinus orca*). As a consequence of the above jeopardy finding, NMFS (as required by the ESA) proposed several Reasonable and Prudent Alternatives (RPAs) that would enable the project to go forward in compliance with the ESA. The RPA for the SJR (RPA IV 2.1) is described below in Tables 3.4, 3.5, and 3.6 and includes interim (Phase I which applied in April and May of 2010 and 2011) and long-term flow requirements for the SJR at Vernalis and restrictions on SWP and CVP export operations in the southern Delta based on SJR inflows.

The biological opinion and associated RPAs have been the subject of ongoing litigation (Consolidated Salmonid Cases, Case No. 1:09-cf-01053-OWWV-DL). Regarding RPA IV 2.1, Judge Wanger, the court justice presiding over the case, concluded that NMFS failed to adequately justify, by generally recognized scientific principles, the precise flow prescriptions imposed by RPA action IV.2.1. Furthermore, RPA action IV.2.1 was found to be arbitrary, capricious, and scientifically unreasonable. In September 2011, the Court remanded the 2009 biological opinion back to NMFS to address flaws identified by the Court. In response to the remand, NMFS submitted a proposed schedule to the Court for re-issuance of a final biological opinion with new RPAs by September 2015. In December 2011, the Court issued an order granting the parties to the litigation the opportunity to reach agreement on the manner in which the RPA will be modified and applied during Water Year 2012. On January 12, 2012, a proposed agreement for 2012 was reached.

Table 3.4. Phase I (which applied in April and May of 2010 and 2011) of the NMFS Biological Opinion RPA action IV 2.1

1. Flows at Vernalis (7-day running average shall not be less than 7% of the target requirement) shall be based on the New Melones Index. In addition to the Goodwin flow schedule for the Stanislaus River prescribed in Action III.1.3 (described in the Stanislaus River discussion below), Reclamation shall increase its releases at Goodwin Reservoir, if necessary, in order to meet the flows required at Vernalis, as provided in the following table:

New Melones Index (TAF)	Minimum flow required at Vernalis (cfs)
0-999	No new requirements
1,000-1,399	D1641 requirements or 1,500, whichever is greater
1,400-1,999	D1641 requirements or 3,000, whichever is greater
2,000-2,499	4,500
2,500 or greater	6,000

2. Combined CVP and SWP exports shall be restricted through the following:

Flows at Vernalis (cfs)	Combined CVP and SWP Export
0-6,000	1,500 cfs
6,000-21,750	4:1 (Vernalis flow:export ratio)
21,750 or greater	Unrestricted until flood recedes below 21,750

In addition Reclamation/DWR shall seek supplemental agreement with the SJRGA, as soon as possible, to achieve minimum long term flows at Vernalis (Table 3.5) through all existing authorities.

Table 3.5. Minimum Long-Term Vernalis Flows

San Joaquin River Index (60-20-20)	Minimum long-term flow at Vernalis (cfs)
C	1,500
D	3,000
BN	4,500
AN	6,000
W	6,000

Phase II of RPA action IV.2.1 operations will begin in 2012 from April 1 to May 31 (Table 3.6).

Table 3.6. Phase II of the NMFS Biological Opinion RPA action IV 2.1

1. Reclamation shall continue to implement the Goodwin flow schedule for the Stanislaus River prescribed in Action III.1.3 (described in the Stanislaus River discussion below).
2. Reclamation and DWR shall implement the Vernalis flow-to-combined export ratios in the following table, based on a 14-day running average.

San Joaquin Valley Classification	Vernalis flow (cfs):CVP/SWP combined export ratio
C	1:1
D	2:1
BN	3:1
AN	4:1
W	4:1
Vernalis flow equal to or greater than 21,750	Unrestricted exports until flood recedes bellow 21,750

Other NMFS BO flow actions are subsequently described in the Stanislaus River discussion.

Stanislaus River

1987 Agreement

Reclamation and the DFG executed an agreement titled “Interim Instream Flows and Fishery Studies in the Stanislaus River Below New Melones Reservoir” on June 5, 1987 (1987 Agreement). The 1987 Agreement proposed that the signatories provide an appropriate amount of instream flows in the Stanislaus River as needed to maintain or enhance the fishery resource during an interim period in which habitat requirements are better defined. The agreement specified an Interim Plan of Operations (IPO) that would be beneficial to fishery resources and habitat downstream of New Melones dam. In 1997, t~~T~~he subsequent IPO increased the fisheries release by changing 98,300 AF from the maximum to the minimum required, and allowed for releases as high as 302,100 AF in wetter years. The exact quantity to be released each year is determined based on a formulation involving storage, projected inflows, projected water supply and water quality demands, projected CVP contractor demands, and target carryover storage (Tables 3.7 and 3.8).

Table 3.7. Inflow Characterization for the New Melones IPO

Annual water supply catetory	March-September forecasted inflow plus end of February storage (TAF)
Low	0 - 1,400
Medium-low	1,400 - 2,000
Medium	2,000 - 2,500
Medium-high	2,500 - 3,000
High	3,000 - 6,000

Table 3.8. New Melones IPO Flow Objectives (TAF)

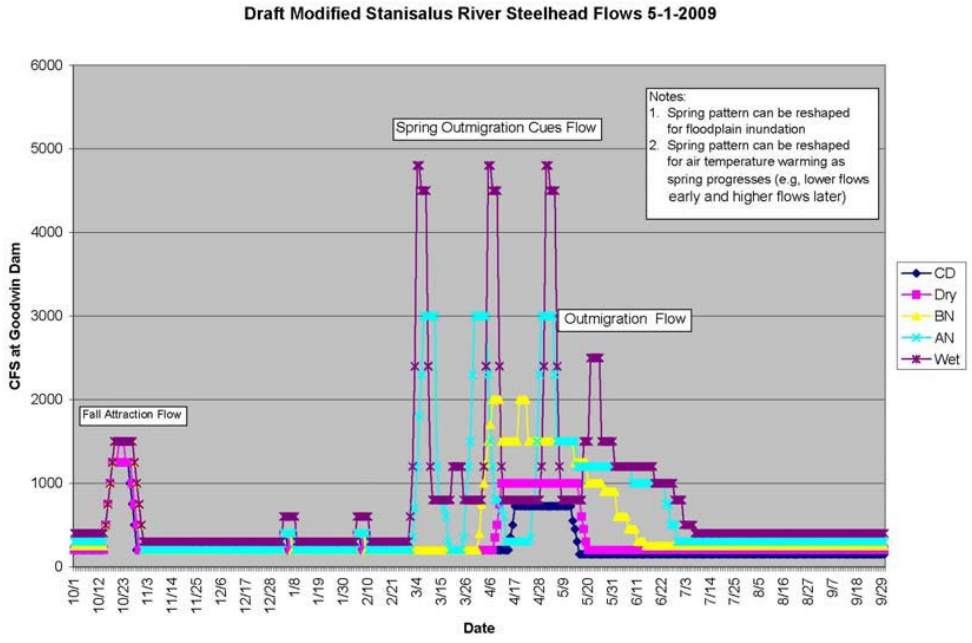
Storage plus inflow		Fishery		Vernalis Water Quality		Vernalis Flow		CVP contractors	
From	To	From	To	From	To	From	To	From	To
1,400	2,000	98	125	70	80	0	0	0	0
2,000	2,500	125	245	80	175	0	0	0	59
2,500	3,000	345	467	175	250	75	75	90	90
3,000	6,000	467	467	250	250	75	75	90	90

State Water Board Water Right Decision 1422 (D-1422)

This decision requires flow releases from New Melones Reservoir up to 70,000 AF in any one year for water quality control purposes in order to maintain a mean monthly total dissolved solids (TDS) concentration in the SJR below the mouth of the Stanislaus River at 500 ppm maximum and to maintain a dissolved oxygen level of at least five ppm in the Stanislaus River.

National Marine Fisheries Service Biological Opinion

RPA action III.1.3 (Figure 3.1) calls for maintaining minimum Stanislaus River instream flows according to a flow schedule as measured at Goodwin Dam to ensure viability of the Central Valley steelhead population on the Stanislaus River. In the Consolidated Salmonid Cases mentioned above, Judge Wanger also found that the record and best available science do not support Action III.3.1’s 5,000 cfs spring pulse flow requirement.



Source: NMFS 2009a

Figure 3.1. NMFS 2009 Biological Opinion Flow Schedule for the Stanislaus River Measured at Goodwin Dam

Tuolumne River

Federal Energy Regulatory Commission (FERC) Project Number 2299

Turlock and Modesto Irrigation Districts (TID and MID) jointly hold the initial FERC license (Project Number 2299) for the New Don Pedro Project, which was issued by the Federal Power Commission, FERC's predecessor, on March 10, 1964. The license became effective on May 1, 1966, for a term ending April 30, 2016. The FERC license for project number 2299 is conditioned to require specified releases of water from New Don Pedro for the protection of fall-run Chinook salmon which spawn in the Tuolumne River below La Grange dam (Table 3.9).

Table 3.9. FERC Project Number 2299 Instream Flow Requirements for the Tuolumne River

Period	Normal Year (cfs)	Dry Year (cfs)
October 1 - 15	200	50
October 16 – October 31	250	200
November	385	200
December 1 - 15	385	200
December 16 - 31	280	135
January	280	135
February	280	135
March	350	200
April	100	85
May - September	3	3

Table 3.10. Settlement Agreement Instream Flow Requirements for the Tuolumne River

Schedule	Days	Critical & below	Median Critical	Intermediate C-D	Median Dry	Intermediate D-BN
October 1 - October 15	15	100 cfs 2,975 ac-ft	100 cfs 2,975 ac-ft	150 cfs 4,463 ac-ft	150 cfs 4,463 ac-ft	180 cfs 5,355 ac-ft
Attraction Pulse Flow		none	none	none	none	1,676 ac-ft
October 16 - May 31	228	150 cfs 67,835 ac-ft	150 cfs 67,835 ac-ft	150 cfs 67,835 ac-ft	150 cfs 67,835 ac-ft	180 cfs 81,402 ac-ft
Outmigration Pulse Flow		11,091 ac-ft	20,091 ac-ft	32,619 ac-ft	37,060 ac-ft	35,920 ac-ft
June 1 - September 30	122	50 cfs 12,099 ac-ft	50 cfs 12,099 ac-ft	50 cfs 12,099 ac-ft	75 cfs 18,149 ac-ft	76 cfs 18,149 ac-ft
Volume	365	94,000 ac-ft	103,000 ac-ft	117,016 ac-ft	127,507 ac-ft	142,502 ac-ft
		Median Below Normal	**Intermediate BN-AN**	**Median Above Normal**	**Intermediate AN-W**	**Median Wet/Maximum**
October 1 - October 15	15	200 cfs 5,950 ac-ft	300 cfs 8,926 ac-ft	300 cfs 8,926 ac-ft	300 cfs 8,926 ac-ft	300 cfs 8,926 ac-ft
Attraction Pulse Flow		1,739 ac-ft	5,950 ac-ft	5,950 ac-ft	5,950 ac-ft	5,950 ac-ft
October 16 - May 31	228	175 cfs 79,140 ac-ft	300 cfs 135,669 ac-ft	300 cfs 135,669 ac-ft	300 cfs 135,669 ac-ft	300 cfs 135,669 ac-ft
Outmigration Pulse Flow		60,027 ac-ft	89,882 ac-ft	89,882 ac-ft	89,882 ac-ft	89,882 ac-ft
June 1 - September 30	122	75 cfs 18,149 ac-ft	250 cfs 60,496 ac-ft	250 cfs 60,496 ac-ft	250 cfs 60,496 ac-ft	250 cfs 60,496 ac-ft
Volume	365	165,002 ac-ft	300,923 ac-ft	300,923 ac-ft	300,923 ac-ft	300,923 ac-ft

1995 (Settlement Agreement)
The settlement agreement (between the Bureau and DFG) established in 1995 proposed that Article 37 of the FERC license (Project Number 2299) for the New Don Pedro Project on the Tuolumne River be amended to increase flows (Table 3.10) released from the New Don Pedro dam.

Merced River

1967 Davis-Grunsky Contract
In 1967, Merced Irrigation District (Merced ID) executed the Davis-Grunsky Contract (Number D-GGR17) with DWR. The contract provides minimum flow standards whereby flows of no less than 180-220 cfs will be maintained from November through March from Crocker-Huffman Dam to Shaffer Bridge.

Cowell Agreement
The Cowell Agreement is the result of a water rights adjudication and requires Merced ID to make specified quantities of water available below Crocker-Huffman diversion dam. This water can then be diverted from the river at a number of private ditches between Crocker-Huffman Dam and Shaffer Bridge. The minimum flow requirements are provided in Table 3.11.

Table 3.11. Cowell Agreement Instream Flow Requirements for the Merced River

Month	Flow (cfs)
October 1 - 15	50
October 16 - 31	50
November	50
December	50
January	50
February	50
March	100
April	175
May	225
June	250
July	225
August	175
September	150

Federal Energy Regulatory Commission (FERC) Project Number 2179
Merced ID owns and operates the Merced River Hydroelectric Project. Merced ID holds the initial FERC license (Project Number 2179) for the Project, which was issued on April 18, 1964. The license became effective on March 1, 1964, for a term ending February 28, 2014. The Merced River Hydroelectric Project expanded the existing Exchequer Project, a water supply/power project that was constructed in 1926–1927. FERC Project Number 2179 required the licensee to provide minimum instream flows (Table 3.12) in the Merced River downstream from the project reservoirs.

Table 3.12. FERC Project Number 2179 Instream Flow Requirements for the Merced River

Period	Normal Year (cfs)	Dry Year (cfs)
June 1 – October 15	25	15
October 16 – October 31	75	60
November 1 – December 31	100	75
January 1 – MaY 31	75	60

The FERC license for Project Number 2179 also requires, insofar as possible, that between November 1 and December 31 flows be maintained downstream from the Exchequer afterbay development (McSwain Development) between 100 and 200 cfs except during dry years when the streamflow is required to be maintained between 75 and 150 cfs. Streamflow is required to be measured at Shaffer Bridge.

3.1.4 Approach

In order to develop potential change to the SJR flow objectives and their program of implementation, existing scientific literature relating to SJR flows and protection of fish and wildlife beneficial uses was evaluated. This chapter describes: life-history information and population trends of SJR basin fall-run Chinook salmon and Central Valley steelhead; flow prescriptions in the SJR basin; fall-run Chinook salmon Delta inflow needs (measured at Vernalis), including the functions supported by inflows and the relationship between flows and SJR basin fall-run Chinook salmon survival and abundance; and the importance of unaltered hydrographic conditions in supporting ecosystem processes for Chinook salmon, Central Valley steelhead, and other native species.

There is very little specific information available concerning the relationships between flow and the survival and abundance of SJR basin Central Valley steelhead. Central Valley steelhead differ distinctly from SJR basin fall-run Chinook salmon with regard to their year-round dependence on suitable habitat conditions for rearing. However, Central Valley steelhead co-occurs with fall-run Chinook salmon in the SJR basin and both species have somewhat similar environmental needs for river flows, cool water, and migratory corridors. As a result, conditions that favor fall-run Chinook salmon are assumed to provide benefits to co-occurring steelhead populations, and other native fishes (NMFS 2009a).

Information concerning flow needs of fish and wildlife beneficial uses in the SJR basin was used to develop a range of potential SJR flow alternatives to protect fish and wildlife beneficial uses. These alternatives do not necessarily represent the alternatives that will be evaluated in the SED, which is being prepared in support of potential amendments to the SJR flow objectives in the Bay-Delta Plan. Instead, these alternatives represent the range of alternatives that will be analyzed. This range may be further refined to develop alternatives for analysis in the environmental review process. The potential environmental, economic, water supply, and related impacts of the various alternatives will then be analyzed and disclosed in the SED prior to any determination concerning changes to the existing SJR flow objectives. Based on information included in the SED (including this appendix) and other information submitted to the State Water Board, the State Water Board will determine what changes to make to the SJR flow objectives in the Bay-Delta Plan to reasonably protect fish and wildlife beneficial uses and balance beneficial uses. The State Water Board may choose to adopt one of the identified alternatives or an alternative that falls within the range of the various alternatives analyzed.

3.2 Fall-Run Chinook Salmon

Within the Central Valley, three Evolutionarily Significant Units (ESUs) of Central Valley Chinook salmon have been identified. The three ESUs of Chinook salmon are winter-, spring-, and fall-/late fall–run (DFG 2010c). These separate ESU classifications are based on the timing of spawning migration, stage of sexual maturity when entering freshwater, timing of juvenile or smolt outmigration, and by the populations' reproductive isolation and contribution to the genetic diversity of the species as a whole. This section addresses fall-run Chinook salmon within the proposed project area, the SJR and its major tributaries (Stanislaus, Tuolumne, and Merced Rivers).

The SJR and its tributaries historically (prior to 1940) supported spring, fall, and possibly late fall–run Chinook salmon. However, winter-run Chinook salmon are not known to have occurred in the SJR or its tributaries. Spring-run Chinook salmon were extirpated from the SJR following the construction of impassible dams on the mainstem SJR and the major SJR tributaries. This was due, in part, to the need of spring-run Chinook to migrate to higher elevations in the watershed, where cooler water temperatures provided suitable over summering habitat. In addition, operating procedures of the dams created conditions that lead to the extirpation of any remaining populations of late fall–run Chinook salmon from the system. Fall-run Chinook salmon are the only remaining population present in the SJR basin. Winter-, spring-, fall-, and late fall–run populations still remain in the Sacramento River basin.

3.2.1 Life History

Chinook salmon are an anadromous species that are native to the North Pacific Ocean and spend most of their adult life in open ocean waters, only returning to freshwater streams to spawn a single time before they die. Chinook salmon commonly occur as one of two life-history types which are characterized by age at seaward migration. "Stream-type" Chinook reside in fresh water for a year or more before migrating seaward as age 1 or older smolts (Gilbert 1913). By contrast "ocean-type" Chinook may begin their seaward migration as recently-emerged fry and rear in freshwater for up to 5 months before entering the ocean as subyearling smolts. Environmental and genetic factors (e.g., latitude, growth-opportunity, migration distance, selection for size at migration) differing among populations may both promote variability in age at seaward migration (Taylor 1990). As a result, the seasonal patterns of adult salmon (e.g., fall and spring) do not necessarily correspond to the juvenile life history traits (ocean-type and stream-type). Fall-run Chinook salmon predominantly exhibit the ocean-type life history; meaning that they have adapted to spend most of their lives in the ocean, spawn soon after entering freshwater in summer and fall, and as juveniles, migrate to the ocean within a relatively short time (3 to 12 months; Moyle 2002). Fall-run Chinook salmon typically remain in the ocean for 2 to 4 years before returning to their natal streams to spawn (McBain and Trush 2002). However, most Central Valley salmon return to their natal streams after 2 years of ocean maturation and a small fraction (10–20%) return after 1 year of ocean maturation. These smaller 2-year old fish are called "jacks" if male and "jills" if female (PFMC 2007, Williams 2006, Moyle 2002). The SJR and its tributaries are the most southerly rivers in the Central Valley that support fall-run Chinook salmon. Table 3.13 lists the approximate monthly timing of Central Valley fall-run Chinook salmon life history stages.

Table 3.13. Generalized Life History Timing of Central Valley Fall-Run Chinook Salmon

	Upstream Migration Period	Spawning Period	Incubation	Juvenile Rearing and Outmigration	Ocean Entry
Central Valley Basin	June to December	September to December	October to March	December to June	April to June
SJR Basin	October to December	November to January	November to March	February to June	April to June
Peak SJR Basin	November	November	November to December	February to March and April to May	June

3.2.2 Adult Migration

The literature on migration timing of fall-run Chinook salmon reports a broad range of months in which upstream migration can occur, beginning as early as June and continuing through early January (DFG 2010a, BDCP 2009, DFG 1993). SJR fall-run Chinook salmon are observed to migrate into the natal streams from late October to early December, with peak migration typically occurring in November. Carcass surveys, adult fish counting weirs on the Stanislaus and Tuolumne, and daily returns to the Merced Hatchery confirm this much shorter return period for the SJR basin fall-run Chinook salmon.

The majority of Chinook begin upstream migration during the rising limb of the hydrograph, as pulse flows cue the start of the migration period (USDOI 2010). Once flow conditions and other environmental factors are suitable the mating pairs begin the construction and defense of the redd. Figure 3.2 presents an example from the Tuolumne River that highlights this chronology, with the majority of redds appearing after a pulse flow in October ends and flows stabilize.

Fall-run Chinook salmon enter freshwater at an advanced stage of maturity and move rapidly to suitable spawning areas on lower reaches of the major SJR tributaries. Migrating adults exhibit a crepuscular movement pattern, with the majority of migration activities occurring at dawn and dusk hours (NMFS 2009a). Additionally, migrating adults often forgo feeding and rely on stored energy reserves for the duration of their freshwater migration. Once adults have found a suitable spawning area, within a few days or weeks of freshwater entry, they build a redd and spawn (Healey 1991).

Adult fall-run Chinook salmon use environmental cues during upstream migration, most notably olfactory cues, as the primary method to locate and return to natal streams (Dittman and Quinn 1996, NMFS 2009a, DFG 2010a). The importance of olfactory cues and stream “odor” was established by Arthur Hasler and colleagues in the 1950s and 1960s, and the home-stream odor hypothesis is restated in Williams 2006:

> *Because of local differences in soil and vegetation of the drainage basin, each stream has a unique chemical composition and, thus, a distinctive odor; 2) before juvenile salmon go to sea they become imprinted to the distinctive odor of their home stream; and 3) adult salmon use this information as a cue for homing when they migrate through the home-stream network to the home tributary.*

If natal streams have low flows during periods of upstream migration, and salmon cannot perceive the scent of their natal stream, straying rates (i.e., proportion of returning adults that spawn in non-natal streams) are likely to increase. In addition, straying rates, on average, of hatchery Chinook salmon are also generally higher than that of naturally produced Chinook salmon (Williams 2006). Straying rates of naturally produced fish are typically low. In British Columbia straying rates averaged roughly 1.2% for naturally produced fish, 5.3% for naturally produced fish that are trucked into the estuary, and between 1% and 18% for hatchery fish (Candy and Beacham as cited in Williams 2000). In the SJR roughly 60–100% of SJR flows are diverted into the pumping facilities in the southern Delta thereby never reaching the ocean (Hallock et al. 1970). At the same time, average straying rates of SJR hatchery produced Chinook salmon is estimated to be over 70% (Grant 1997a; Williams 2006).

The upstream migration rate for Chinook salmon from the ocean, through the Bay-Delta, and to the SJR tributaries has not been measured. However, Keefer et al. (2004) found migration rates of Chinook salmon in the Columbia River ranging from 10 to 35 km per day (6–20 miles/day). These migration rates were primarily correlated with date, and secondarily with discharge and reach in the Columbia River basin (Keefer et al. 2004). Matter and Sanford (2003) documented similar migration rates of about 30 km per day (20 miles/day) for adult Chinook salmon in the Snake River. However, adult Chinook salmon in the Delta and lower Sacramento River and SJR have been observed exhibiting substantial upstream and downstream movement, for several days at a time, while migrating upstream (Hallock et al. 1970; Williams 2006).

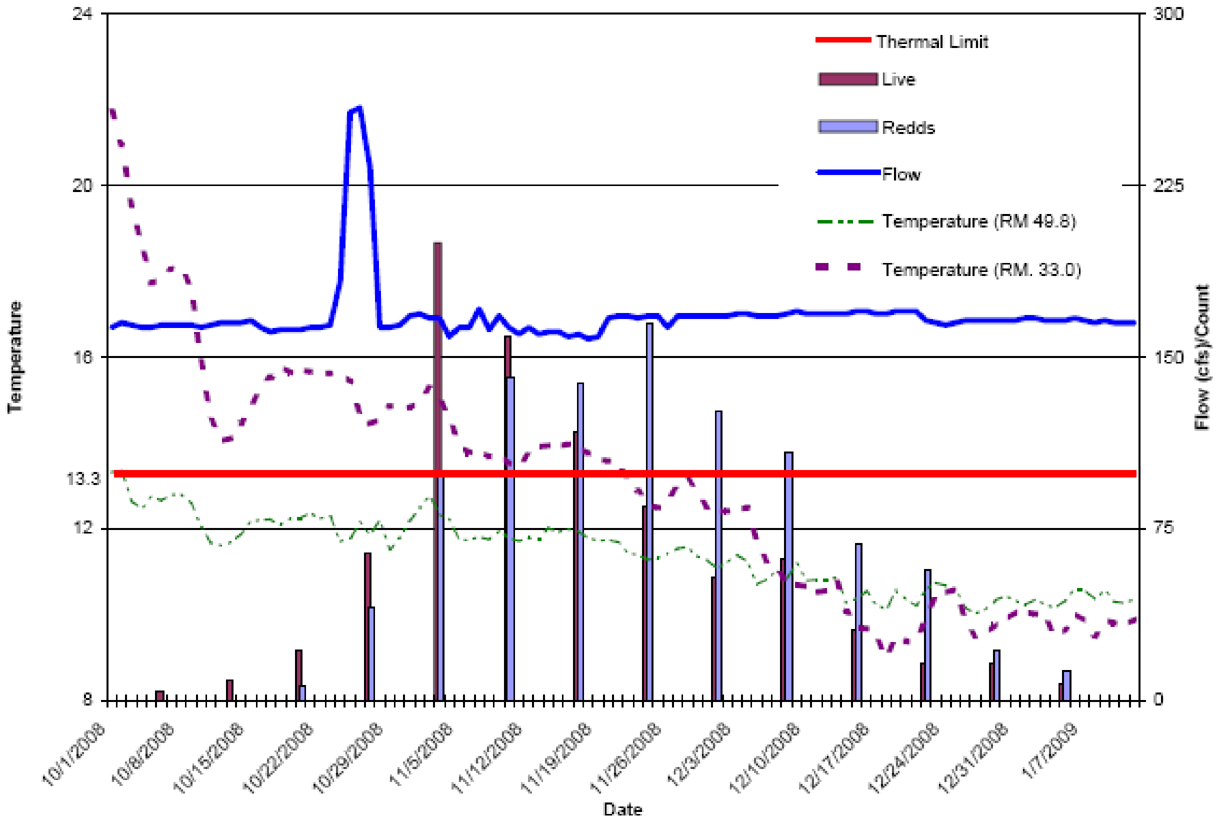
3.2.3 Spawning and Holding

Historically, adult fall-run Chinook salmon spawned in the valley floor and on lower foothill reaches of the major SJR tributaries (DFG 1993). Today, spawning takes place below the first impediment that blocks upstream migration (Crocker-Huffman, La Grange, and Goodwin dams), further limiting potential salmon spawning area. In addition, streamflow alteration, dictated by the dams on the major SJR tributaries, affect the distribution and quantity of spawning habitat.

Once fall-run Chinook salmon enter freshwater and begin migration to spawning habitat they generally do not hold in pools for long periods of time (generally 1 week or less). However, they may briefly use large resting pools during upstream migration as refuge from predators, insulation from solar heat, and to help conserve energy (Mesick 2001b; DFG 2010a).

Spawning may occur at any time between September and December; however, SJR basin Chinook salmon typically begin spawning between November and January, with peaks in November (BDCP 2010; McBain and Trush 2002; DFG 1993). This truncated spawning period is verified by the DFG’s aerial redd counts, the majority of which are observed in the months of November and December (Figure 3.2).

Redds are constructed, by female Chinook salmon, in gravel beds that are typically located at the tails of riffles or holding pools, with clean, loose gravel in swift flows that provide adequate oxygenation of incubating eggs and suitable water temperatures (NMFS 2009a). The upper preferred water temperature for spawning and egg incubation is 56ºF (Bjorn and Reiser 1991), and salmon may hold until water temperature is acceptable for spawning. The range of water depths and velocities in spawning beds that Chinook salmon find acceptable is very broad, but generally, if a salmon can successfully swim in the spawning bed they can spawn (NMFS 2009a).



Source: DFG 2008

Figure 3.2. Live Fish and Redds Observed in the Tuolumne River in October 2008-January 2009, Overlaid with Flow and Temperature

Fall-run Chinook salmon carry an average 5,000 to 6,000 eggs per spawning female (Moyle 2002). However, the actual number of eggs carried depends on the age and size of the fish (Williams 2006). Successful spawning requires closely coordinated release of eggs and sperm by the spawning fish, which follows courtship behavior that may last for several hours (Williams 2006). Competition for the chance to fertilize redds frequently occurs. Being much smaller than a full sized adult male salmon, jack salmon often “sneak” past the fighting adults and fertilize the redd without being noticed (Moyle 2002). A redd may be fertilized by more than one male, and a male can fertilize more than one redd. This combination of large and small males ensures a high degree of egg fertilization (roughly 90%, Moyle 2002). After a male has fertilized the female’s redd, the pair may defend the redd from other spawning salmon before their death.

Spawning habitat is limited due to flow regimes, sedimentation, temperature constraints, impassible barriers, and other factors. Competition for space between spawning pairs in the tributaries also reduces the value of spawning habitat for the entire fall-run Chinook salmon population. For example, it is common, if available spawning habitat is limited, for two redds to overlap (i.e., superposition). This proves to be a significant disadvantage for the bottom redd, as the top redd has greater access to a steady flow of oxygen-containing waters (Moyle 2002).

3.2.4 Egg Development and Emergence

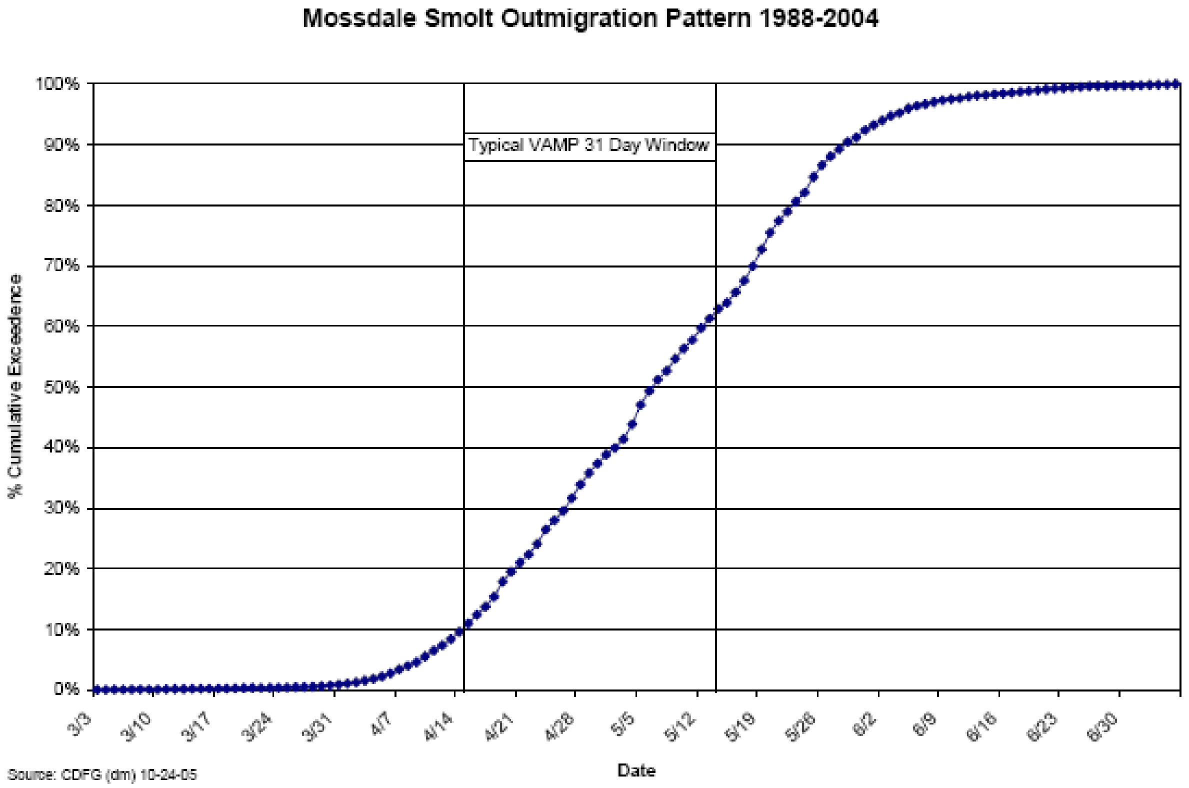
Timing of egg incubation for SJR fall-run Chinook salmon begins with spawning in late October and can extend into March, depending on water temperatures and timing of spawning (BDCP 2010). Egg incubation generally lasts between 40 to 60 days, depending on water temperatures, with optimal water temperatures for egg incubation ranging from 41ºF to 56ºF (Moyle 2002). In order to successfully hatch, incubating eggs require specific conditions such as protection from floods, siltation, desiccation, predation, poor gravel percolation, and poor water quality (NMFS 2009a).

Newly hatched salmon are called alevins, and remain in the gravel for about 4 to 6 weeks until the yolk-sac has been absorbed (NMFS 2009a). Once the yolk sack has been completely absorbed, alevins are called fry, which are roughly one inch (25 mm) long. Most fall-run Chinook salmon fry emerge from the gravel between February and March (Table 3.1; BDCP 2010; McBain and Trush 2002). Once fry grow to be roughly two inches (50 mm) in length and become camouflaged in color, exhibiting vertical stripes (i.e., parr-marks) on their body, they are called parr (Williams 2006).

3.2.5 Rearing, Smoltification, and Outmigration

Both the quantity and quality of habitat determine the productivity of a watershed, in regards to rearing and outmigration of juvenile Chinook salmon (PFMC 2000). Rearing and outmigration of fall-run Chinook salmon occurs simultaneously, and can occur in a variety of complex habitats within streams, rivers, floodplains, and estuaries (PFMC 2000). Outmigration of fry and parr occurs in response to many factors, including inherited behavior, habitat availability, flows, competition for space and food, water temperature, increasing turbidity from runoff, and changes in day length. For example, some fall-run Chinook salmon fry or parr may move immediately downstream into the lower tributary, the mainstem SJR, or the Delta for rearing. Other fry and parr may remain in the tributary to rear, eventually being flushed into downstream habitats by high tributary flows (See Table 3.7a-c Chinook Salmon Trajectory).

On average, SJR juvenile fall-run Chinook salmon rear in riverine and estuarine habitats for three to seven months before they enter the Pacific Ocean in June (DFG 2010a). Rearing and outmigration typically occurs between February and June; however, peaks in fry outmigration occur in February and March and smolt (75 mm) outmigration occurs in April and May (Rotary Screw Trap data, DFG Mossdale Trawl, Figure 3.3).



Source: DFG 2005b

Figure 3.3. Mossdale Smolt Outmigration Pattern 1988–2004, Based Upon an Updated Mossdale Smolt Outmigration Estimate by Ken Johnson (2005)

Successful rearing is associated with the magnitude, timing, and duration of flows, and connectivity with associated riparian and floodplain habitat (Mesick et al. 2007). Historically, Chinook salmon adapted to pulses in instream flows that corresponded to precipitation and snow melt events (Williams 2006, USDOI 2010). This in turn provided intermittent connectivity with riparian habitats that provided salmon with a variety of resources, including (but not limited to): increased amounts of shade, submerged and overhanging large and small woody debris, root wads, log jams, beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks (BDCP 2010).

Shallow water habitats (floodplain and riparian) provide seasonal rearing habitat for fry and parr and have been found to be more productive than main river channels (Sparks et al. 1998; Sommer et al. 2001; Opperman 2006; Williams 2006). This is due in part to favorable environmental temperatures, higher prey consumption rates, and higher densities of zooplankton, small insects, and other microcrustaceans (DFG 2010a; NMFS 2009a; Sommer et al. 2001; DFG 1993). Juveniles that use shallow water habitats typically grow faster and may survive better than fish in main river channels based on evidence of reduced exposure to predators, earlier migration to the ocean, and larger size upon ocean entry. However, increased survival has not yet been demonstrated conclusively in the field (Sommer 2005).

Smoltification usually begins when juveniles reach between three to four inches (75-100 mm). As the juvenile salmon's body chemistry changes from freshwater tolerant to saltwater tolerant in preparation for the oceanic environment, preferred rearing is often where ambient salinity is up to 1.5 to 2.5 ppt (NMFS 2009a). Smoltification is characterized by increased levels of hormones, osmoregulatory changes to tolerate a more saline environment, and replacement of parr marks for a silvery body and blackened fins that are important for camouflage in an ocean environment. Although it is common to refer to juvenile Chinook that rear in river for two to three months and migrate toward the Delta between April and May as smolt migrants, most are only part way along in the smolting process, at least when they begin migrating (Williams 2006).

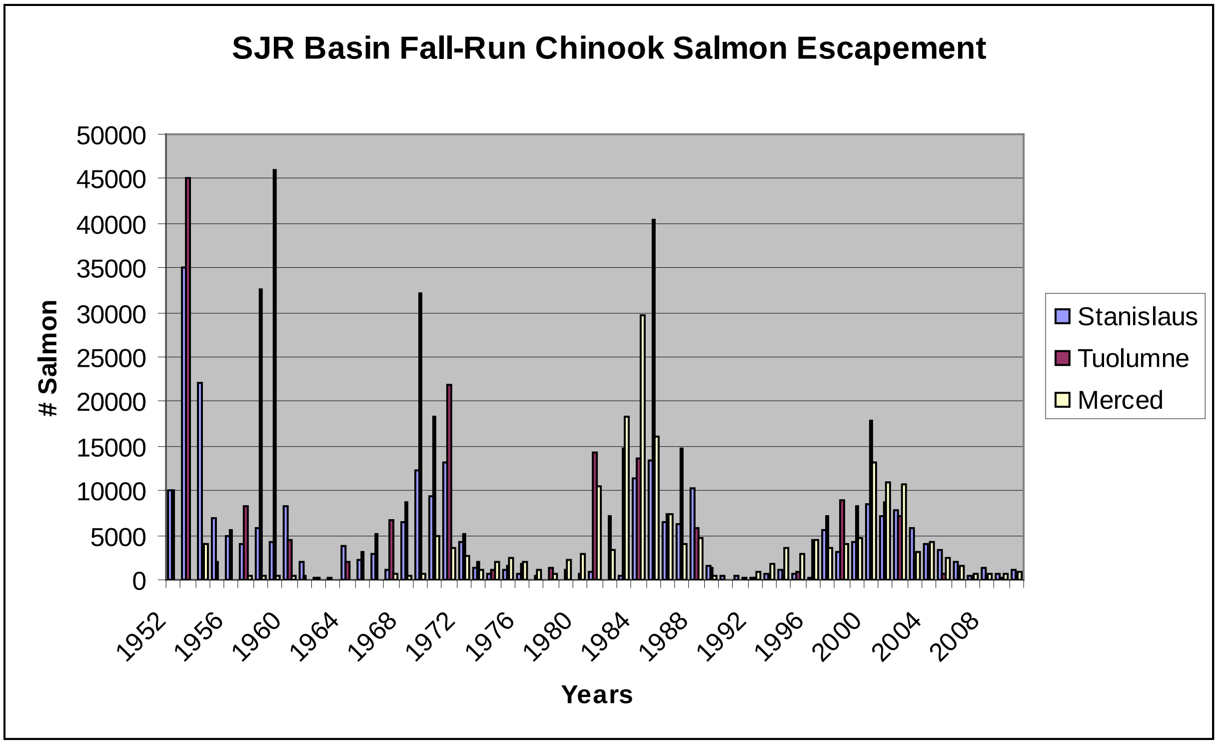
Juvenile salmon can rear in the Delta for an additional one to three months during the smoltification process before moving into the San Francisco Bay and Pacific Ocean (Williams 2006). Juvenile Chinook salmon smolts spend, on average, one month (~40 days) migrating from Chipps Island to the Gulf of the Farallones (MacFarlane and Norton 2002).

Understanding the relationship between freshwater flows and juvenile survival during migration is complicated by the fact that flow often operates indirectly through its effects on other environmental factors that directly influence survival (DFG 2011a). In the Bay-Delta, these include (but are not limited to): water temperatures, dissolved oxygen (DO), salinity, pollutant concentrations, and predation (DFG 2011a). These environmental factors or stressors and others will be discussed in greater detail in the SED.

3.2.6 Population Trends

Spring-run Chinook salmon were probably the most abundant ESU pre-disturbance, based on the habitat and hydrology of the SJR basin (Williams 2006); however, fall-run represent the only Chinook salmon ESU that currently exist in the SJR basin. Annual returns of fall-run Chinook salmon has been estimated since 1940, but poorly documented prior to 1952. Data from 1952 to present suggest that fall-run boom and near-bust cycles have existed in the major SJR tributaries for at least the last 60 plus years.

Methods for estimating the number of returning adults (escapement) have improved over the last five decades, and have shown wide fluctuations in number of returning adult salmon (DFG 2010c). Escapement numbers for the three tributaries are generally similar in many years, suggesting that the total returning salmon may split into the three tributaries uniformly, or that the success of salmon from each tributary is similar. However, in general, the Tuolumne population has been the highest and the Merced population has been the lowest. Figure 3.4 and Appendix B show fall-run Chinook salmon escapement over the period of record for each of the major SJR tributaries.



Source: DFG 2011b

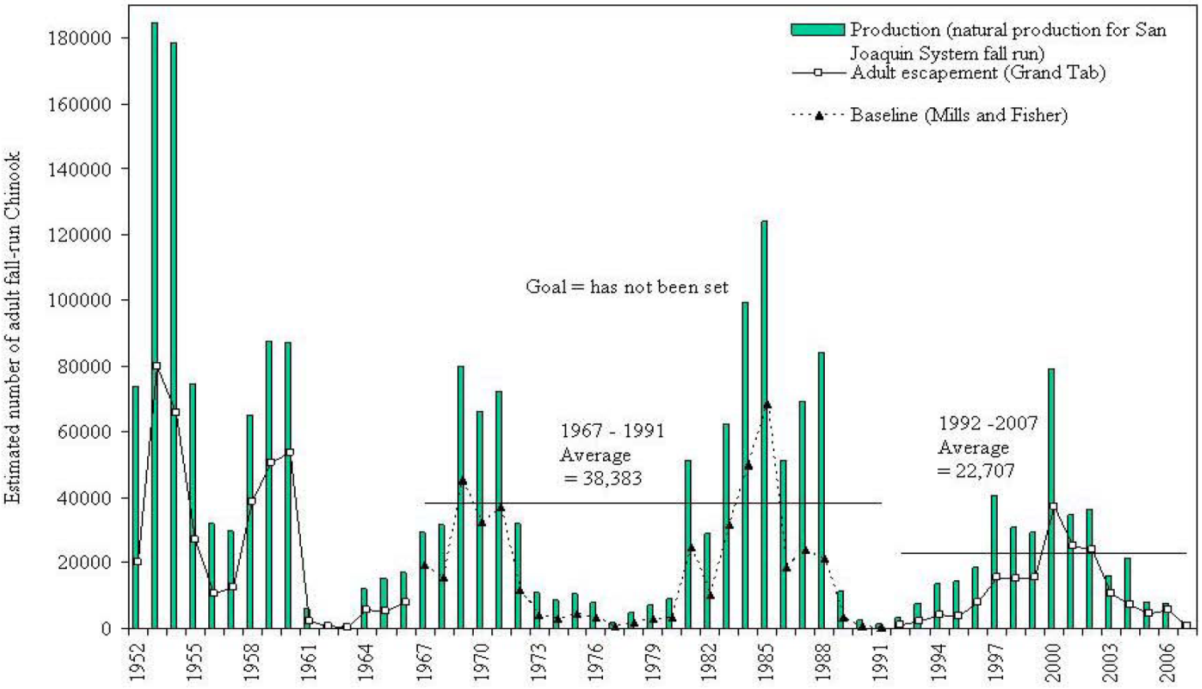
Figure 3.4. Estimated Escapement of Adult Fall-run Chinook Salmon for the Major SJR Tributaries 1952 to 2010

The annual (fall) escapement of adult fall-run Chinook salmon is really three cohort sequences, based on the typical three year return frequency (e.g., cohort “A” returning to spawn in 1952, 1955, 1958; cohort “B” returning to spawn in 1953, 1956, 1959). The success of each cohort depends on a number of factors including spawning conditions three years prior, the rearing success two years prior (dependent on river flow), and ocean conditions during the previous two years. The cohort replacement ratio for Chinook salmon provides a rough measure of the cohort return ratio and is calculated by dividing the escapement number for a given year by the escapement number from three years prior (i.e., 2010 replacement ratio = 2010 escapement/2007 escapement).

Escapement is the total number of returning Chinook salmon and does not take into account the number of salmon that could have returned to the SJR basin had they not been commercially or recreationally harvested. In order to get a more accurate estimate of total adult production, ocean harvest and recreational fishing numbers must be added to escapement. Furthermore, subtracting the number of returning adults that are of hatchery origin will give a more accurate estimate for natural production of Chinook salmon in the SJR basin.

Estimates of the fall-run Chinook salmon population have indicated a decline in both total production for the San Joaquin system and adult escapement (Figure 3.5). With regard to adult escapement, fall-run Chinook salmon escapement to the SJR basin has ranged from about 1,000 to approximately 80,000 adults, with an average escapement of about 20,000 adults. Figure 3.5 indicates that there have been periods with relatively high escapement (>25,000 adults) for several years, and periods with relatively low escapement (<10,000). Recent escapement of adult fall-run Chinook salmon to the SJR basin was estimated at approximately 2,800 fish in 2008 (DFG 2011b) and a slight increase to approximately 3,600 fish in 2009 (DFG

2010c). Declines of Central Valley Chinook salmon populations in 2008 and 2009 have been largely attributed to poor ocean conditions and have resulted in significant curtailment of westcoast commercial and recreational salmon fishing. Although ocean conditions have played a large role in the recent declines of SJR basin fall-run Chinook salmon, it is superimposed on a population that has been declining over a longer time period (Moyle et al. 2008). Looking at a longer time scale, and in the context of the CVPIA's doubling goal and State Water Board's narrative objective for salmon protection, combined escapement in the three San Joaquin tributaries since 2000 has not doubled from the average during the 1967-1991 period, but has significantly declined since the year 2000 (SJRTC 2008).



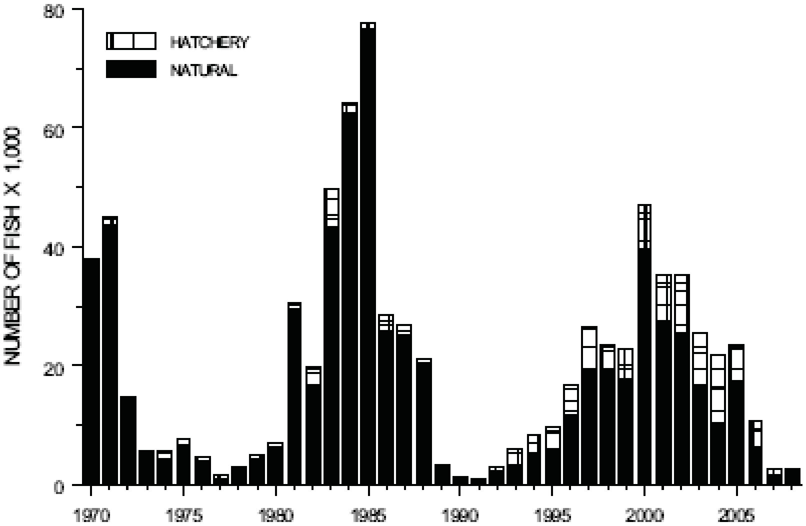
Source: SJRTC 2008

Figure 3.5. Estimated Yearly Natural Production and In-river Escapements of San Joaquin System Adult Fall-run Chinook Salmon from 1952 to 2007

The period of low escapement in the early 1990s was followed by an increase in hatchery escapements, as compared to prior years (Greene 2009, Figure 3.6). In Greene's (2009) analysis, hatchery escapement was defined as all salmon returning to the hatchery facility to spawn, and natural escapement was defined as all salmon spawning in the river. There was no separation between hatchery and natural salmon that returned to the hatchery; the same is true for hatchery and natural salmon that spawned in river. Therefore, Figure 3.6 may overestimate the escapement of natural salmon (in river spawners) and underestimate the escapement of hatchery salmon (hatchery spawners).

In the future, better information will be available concerning hatchery influences on the SJR Chinook salmon population as a result of increased marking activities. The Constant Fractional Marking Program for Central Valley fall run Chinook salmon was initiated in 2007. Through this program, a target rate of 25% of the hatchery fall-run Chinook salmon are implanted with coded-wire tags and the adipose fin is removed. In addition, at the Merced River Hatchery 100% of fish have been marked through the VAMP study and are planned to be marked in the future (Alice Low 2011 pers. comm.). Prior to these programs, relatively few of the juvenile fall-run hatchery fish produced by Central Valley hatcheries were marked and the marking rates were inconsistent.

Currently, Chinook salmon are raised at five major Central Valley hatcheries which release more than 32 million smolts each year (DFG 2010b), up from roughly 24 million in 2006 (Williams 2006). The Merced River Fish Facility is the only hatchery located in the SJR basin project area. Currently, available data indicate that hatchery-produced fish constitute a majority of the natural fall-run spawners in the Central Valley (PFMC 2007). In addition, in recent years the percentage of hatchery reared fall-run Chinook salmon returning to the SJR and its tributaries has been high proportional to wild fish (Figure 3.6, Greene 2009). These conditions may lead to increased hatchery introgression with the naturally produced fall-run Chinook salmon, which not only undermines the genetic integrity of the salmon genome, but it also leads to reduced genetic diversity between natural and hatchery salmon (Williamson and May 2005; Lindley et al. 2009; NMFS 2009a, 2009b; DFG 2011).



Source: Greene 2009

Figure 3.6. Annual Natural and Hatchery Fall-Run Chinook Escapement to the SJR Basin 1970 to 2008

Mesick (2009) evaluated the potential risk to the viability of the fall-run Chinook salmon population, and determined that the SJR basin population is at a high risk (20% risk for natural spawners within 200 years) for extinction according to some criteria and at moderate risk according to others. In making this determination Mesick (2009) used specific population viability criteria developed by Lindley el al. (2007) which identified four key factors (and associated values) that define the status of a population including: prolonged low spawner abundances (<250) over a generation; precipitous (>10%/year) declining trend in abundance;

catastrophic decline of >10% in one generation during the past 10 years; and high hatchery influence. Based on the recent population declines, reduced peak abundance of adult recruitment, and reduced population resiliency and genetic diversity through hatchery introgression, the DFG also considers the fall-run Chinook salmon run in the SJR basin to be in poor condition (DFG 2011).

SJR Basin Monitoring Programs

Comprehensive monitoring and assessment programs are critical for evaluating whether fish and wildlife beneficial uses are being protected. There are numerous agencies that participate in monitoring and assessment activities to evaluate the various life history stages of SJR basin Chinook salmon and other fish species. Sources of salmon monitoring data are identified below and are available upon request:

- Adult Chinook Salmon Escapement - DFG
- CWT Releases/Recapture - Cramer and Associates
- CVP and SWP Salvage - USFWS and DFG
- Mossdale Trawls - DFG
- Chipps Island Trawls - USFWS
- Beach Seines - USFWS
- Rotary Screw Traps on each of the major SJR tributaries - DFG, AFRP, Cramer and Associates, and TID
- Fyke Nets - DFG
- Ocean and Recreational Harvest - Pacific Fisheries Management Council

3.3 Central Valley Steelhead

Within the Central Valley, one Distinct Population Segment (DPS) of Central Valley steelhead has been identified. The steelhead DPS is defined as the portion of the population that is “markedly separated” from the resident life form, rainbow trout, due to physical, ecological, and behavioral factors. This section addresses steelhead within the proposed project area, the SJR and its major tributaries (Stanislaus, Tuolumne, and Merced Rivers).

Oncorhynchus mykiss may exhibit either anadromous (steelhead) or freshwater (resident trout) residency life history types (NMFS 2009c). Within the anadromous life history type, steelhead can be divided into two basic reproductive ecotypes, based on the state of sexual maturity at the time of river entry and duration of spawning migration. The stream-maturing type (commonly known as fall steelhead in Alaska, and summer steelhead in the Pacific Northwest and northern California) enters fresh water in a sexually immature condition and requires several months to mature and spawn. The ocean-maturing type (spring steelhead in Alaska and winter steelhead elsewhere) enters fresh water with well-developed gonads and spawns shortly thereafter (Busby et al. 1996). Summer steelhead are not found in the SJR tributaries. Remnant populations of winter steelhead are currently found in the major SJR tributaries (McEwan 2001; Good et al. 2005; Zimmerman et al. 2008). Unless noted otherwise, subsequent discussions of the anadromous form of Central Valley steelhead refers to the ocean-maturing (winter) life history type.

3.3.1 Life History

The primary differences between fall-run Chinook salmon and steelhead are that: 1) steelhead remain in the river for at least one year and as many as three years before smoltification and outmigration; 2) steelhead are capable of spawning more than once before dying; 3) steelhead can produce anadromous or non-anadromous life forms (Moyle et al. 2010); and 4) steelhead spawn in late winter and early -spring months (Table 3.14). In addition, steelhead produce smaller eggs that incubate over a shorter period during increasing winter-spring water temperatures, whereas salmon produce larger eggs that incubate over a longer period during decreasing fall-winter water temperatures (Moyle 2002; Williams 2006). Microchemistry analysis of steelhead otoliths (inner ear bone) provided evidence that there is no reproductive barrier between resident and anadromous forms, and anadromous steelhead can bear nonanadromous juveniles and vice versa (McEwan 2001; Williams 2006, Zimmerman and Reeves 1999; Zimmerman et al. 2008). Therefore, environmental conditions that become unfavorable to steelhead and favorable to resident trout may inadvertently reduce the incidence of anadromy and increase the incidence of residency in these populations. This is commonly the case on the Sacramento River below Shasta Dam (Williams 2006). This phenomenon can also be true in the opposite scenario where the anadromous life form is favored in a system over the resident life form. However, this does not appear to be the case in the SJR basin where steelhead populations are very small (i.e., remnant levels) and environmental conditions are more favorable to the resident life form. See Table 3.14 for approximate timing of steelhead life history phases.

Table 3.14. Generalized Life History Timing of Central Valley Steelhead

	Upstream Migration Period	Spawning Period	Incubation	Juvenile Rearing and Outmigration	Ocean Entry
Central Valley Basin	August to March	December to March	December to May	Year Round	Year Round
SJR Basin	July to April	December to ~~June~~April	December to June	Year Round	Year Round
Peak SJR Basin	October to February	January to March		March and April	April to June

3.3.2 Adult Migration

The majority of Central Valley steelhead return to their natal streams and spawn as four or five year olds (NMFS 2009c; USFWS 2001). Central Valley steelhead can begin upstream migration beginning as early as July and continue through April, with peaks in upstream migration within the SJR basin typically occurring between October and February (Table 3.2; USDOI 2008; Moyle 2002; McBain and Trush 2002). High flow events help steelhead perceive the scent of their natal stream as they begin upstream migration. Negative environmental factors (e.g., high water temperatures, low dissolved oxygen) often block or delay the migration of adult fall-run Chinook salmon into the SJR (Hallock et al. 1970; Bjornn and Reiser 1991; Mesick 2001a; Williams 2006), causing them to hold below the migration barrier for suitable environmental conditions or stray into a more suitable spawning area (DFG 2011a). Optimal immigration and holding temperatures for steelhead have been reported to range from 46°F to 52°F (NMFS 2009c).

3.3.3 Spawning and Holding

Steelhead enter fresh water with well-developed gonads and spawn downstream of impassable dams on the major SJR tributaries and the mainstem SJR, similar to fall-run Chinook salmon (NMFS 2009c). Spawning typically occurs from December through ~~June~~ April ~~(USDOI 2008, McBain and Trush 2002)~~, with peaks occurring between January and March (Table 3.3; NMFS 2009a; McBain and Trush 2002). Steelhead spawn where cool (30°F to 52°F), well oxygenated water is available year-round (McEwan and Jackson 1996).

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

Unlike Chinook salmon, which are semelparous and spawn only once before dying, steelhead are iteroparous and are capable of spawning more than once before dying (Busby et al. 1996). However, it is rare for steelhead to spawn more than twice before dying, and those that do are typically females (Busby et al. 1996). Iteroparity is more common among southern steelhead populations than northern populations (Busby et al. 1996), and although one-time spawners are still the great majority, Shapovalov and Taft (1954) reported that repeat spawners are relatively numerous (17.2%) in California streams.

Another dissimilarity between steelhead and Chinook salmon is the duration of courtship and spawning behaviors. Briggs (1953) observed steelhead spawning from one to two days and up to as long as a week (Williams 2006). Average residence time around the redd was observed to last only a few days after fertilization. Typically, once a redd is fertilized the female steelhead attempts the journey back to the Pacific Ocean to continue maturation in preparation for another spawning year.

3.3.4 Egg Development and Emergence

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

Incubation for steelhead eggs typically occurs between the months of December through June (Table 3.2; USDOI 2008, McBain and Trush 2002) with factors such as redd depth, gravel size, siltation, and temperature affecting emergence timing (Shapovalov and Taft 1954). Newly emerged fry usually migrate into shallow (<36 cm), protected areas associated with the stream margin (McEwan and Jackson 1996), or low gradient riffles, and begin actively feeding (USFWS 2001). With increasing size, fry move into higher-velocity, deeper, mid-channel areas, generally in the late summer and fall.

3.3.5 Rearing, Smoltification, and Outmigration

Juvenile steelhead rear in cool, clear, fast flowing permanent freshwater streams and rivers where riffles predominate over pools, for one to three years (1% spend three years; DFG 2010a). Compared to fall-run Chinook salmon, this extended amount of time needed for rearing means that juveniles are dependent on the availability of such conditions for at least a full year prior to outmigration, especially during the summer when these conditions are most restricted. Some Central Valley steelhead juveniles may use warm shallow water habitats where feeding and growth are possible throughout the winter (NMFS 2009a). These areas, such as floodplain and tidal marsh areas, allow steelhead juveniles to grow faster, which in turn requires a shorter period in freshwater before smoltification occurs (NMFS 2009a, NMFS 2009c). Diversity and richness of habitat and food sources in shallow water habitats allows juveniles to attain a larger size before ocean entry, thereby increasing their chances for survival in the marine environment (BDCP 2010).

Some Central Valley steelhead may not migrate to the Pacific Ocean (anadromous) at all and remain in rivers (fluvial) or lakes (adfluvial) as resident fish, avoiding migration through the Bay-Delta completely (Moyle 2002). Populations that have both anadromous and resident forms are likely to have an evolutionary advantage. Resident fish persist when ocean conditions cause poor survival of anadromous forms, and anadromous forms can re-colonize streams in which resident populations have been wiped out by drought or other disasters. Less is known about the migration of juvenile steelhead in the Central Valley than about juvenile fall-run Chinook salmon, but better information is becoming available from screw traps that are located in high velocity water that can catch yearlings in significant numbers (Williams 2006). However, interpretation of the data is complicated by the large proportion of the population that has adopted a resident life history pattern; making it unclear if steelhead juveniles captured in the traps are migrating to the ocean (Williams 2006).

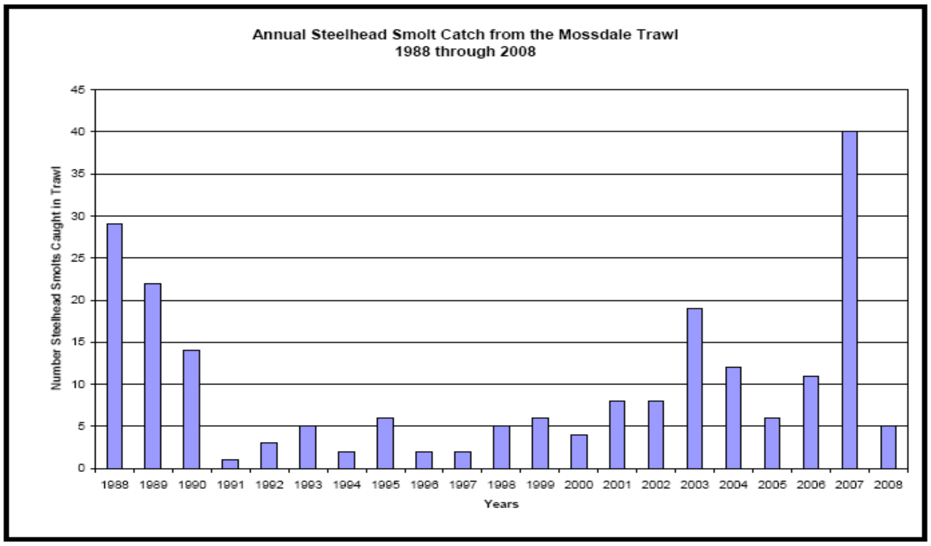
Central Valley steelhead juveniles generally begin outmigration anywhere between late December through July, with peaks occurring between March and April (Table 3.2; USDOI 2008, McBain and Trush 2002). Juvenile steelhead are considerably larger and have a greater swimming ability than Chinook salmon juveniles during outmigration. This is primarily due to a longer rearing period (1–3 years) for juvenile steelhead. During outmigration, juveniles undergo smoltification, a physiologic transformation enabling them to tolerate the ocean environment and its increased salinity. Steelhead smoltification has been reported to occur successfully at 44°F to 52°F (Myrick and Cech 2001; USDOI 2008).

3.3.6 Population Trends

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

Until recently, steelhead were thought to be extirpated from the SJR and major SJR tributaries. DFG records contain reference to a small population characterized as emigrating smolts that are captured at the DFG Kodiak trawl survey station at Mossdale on the lower SJR each year (EA Engineering, Science, and Technology 1999). DFG staff prepared catch summaries for juvenile migrant steelhead on the SJR near Mossdale, which represents migrants from the SJR basin including the major SJR tributaries (NMFS 2009a). Based on trawl recoveries at Mossdale between 1988 and 2002, as well as rotary screw trap efforts on the major SJR tributaries, DFG found that resident rainbow trout do occur in all tributaries as migrants, and that the vast majority of them occur on the Stanislaus River (NMFS 2009a).

Currently, steelhead remain in low numbers on the major SJR tributaries below the major rim dams, as shown by DFG catches on the mainstem SJR near Mossdale (Figure 3.7) and by otolith microchemistry analyses documented by Zimmerman et al. (2008). However, due to the very limited amount of monitoring in the Central Valley, data are lacking regarding a definitive steelhead population size within each tributary. The limited data that do exist indicate that the steelhead populations in the SJR basin continue to decline (Good et al. 2005) and that none of the populations are viable at this time (Lindley et al. 2007). Recent declines are likely due to a combination of declining habitat quality, increased water exports, and land use practices that have reduced the relative capacity of existing steelhead rearing areas (NMFS 2009c; McEwan 2001).



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

Figure 3.7. Annual Number of Central Valley Steelhead Smolts Caught in the Mossdale Trawl 1998–2008

3.4 Fall-Run Chinook Salmon Flow Needs

Flows in the SJR basin affect various life stages of fall-run Chinook salmon including: adult migration (escapement), adult spawning, egg incubation, juvenile rearing, and outmigration to the Pacific Ocean. Analyses indicate that the primary limiting factor for salmon survival and subsequent abundance is reduced flows during the late winter and spring when juveniles are completing the freshwater rearing phase of their life cycle and migrating from the SJR basin to the Delta (February through June; DFG 2005a; Mesick and Marston 2007; Mesick et al. 2007; Mesick 2009). As such, while SJR flows at other times are also important, the focus of the State Water Board's current review is on flows within the salmon-bearing tributaries and the SJR at

Vernalis (inflows to the Delta) during the critical salmon rearing and outmigration period of February through June.

3.5 Functions Supported by Spring Flows

Chinook salmon migration patterns are adapted to variations in-flow conditions (Lytle and Poff 2004). Monitoring shows that both juvenile and adult salmon begin migrating during the rising limb of the hydrograph (USDOI 2010). For juveniles, pulse flows appear to be more important than for adults (USDOI 2010). Delays in precipitation producing flows may result in delayed emigration, which may result in increased susceptibility to in-river mortality from predation and poor habitat conditions (DFG 2010d).

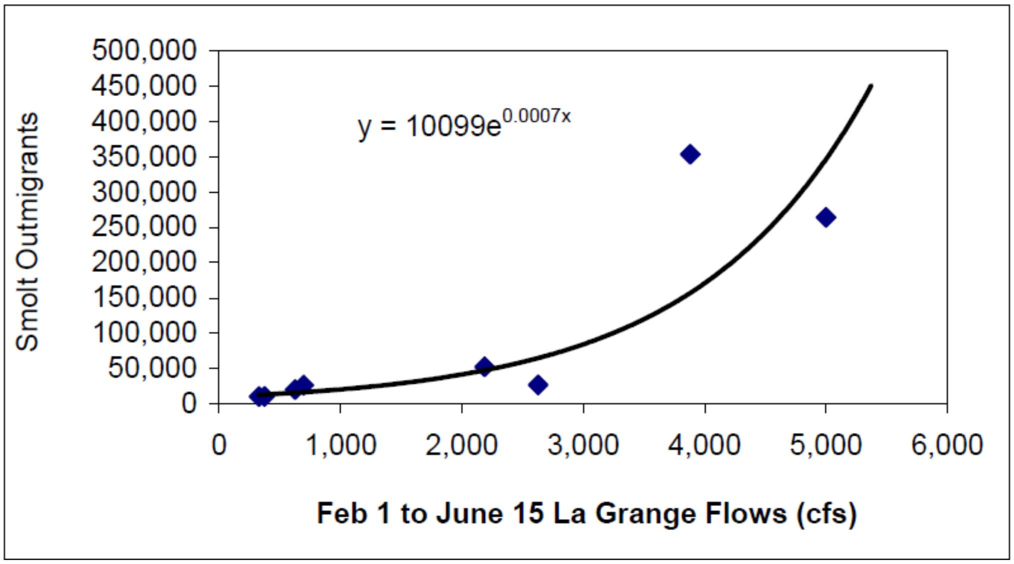
Juvenile Chinook salmon exhibit different migration and life history strategies adapted to variations in flows (Lytle and Poff 2004). Under unaltered hydrographic conditions in the SJR basin, flows on the major SJR tributaries and the mainstem SJR generally increase in response to snow-melt and precipitation during the spring period, with peak flows occurring in May. Increased flow conditions, throughout the late winter to spring period on the major SJR tributaries are important to maintain diversity in Chinook salmon populations. Increases in tributary flow, as a response to snow-melt, allow for a variety of genetic and life history strategies to develop over a variety of year types. These different life history strategies assure the continuation of the species over time and under different hydrologic and environmental conditions. Depending on several factors, some juvenile salmon can migrate as fry during early flow events and others can migrate as parr or smolts when flows increase later in the season. Fry generally begin migrating in early February and March, with peak smolt outmigration occurring during the months of April and May, as verified by monitoring data from the ~~USFWS~~CDFW (formerly CDFG) Mossdale Trawl (see Figure ~~3.2~~3.3).

In late winter and spring, increased flows provide improved transport downstream and improved rearing habitat for salmon migration. These flows may also provide for increased and improved edge habitat (generally inundated areas with vegetation) in addition to increased food production for the remainder of salmon that are rearing in-river. Later in the season, higher inflows function as an environmental cue to trigger migration of smolts, facilitate transport of fish downstream, and improve migration corridor conditions (USDOI 2010). Specifically, higher inflows of various magnitudes in spring support a variety of functions including: maintenance of channel habitat and transport of sediment, biota, and nutrients (Junk et al. 1989). Increased turbidity and more rapid flows may also reduce predation of juvenile Chinook salmon (Gregory 1993; Gregory and Levings 1996, 1998). Higher inflows also provide better water quality conditions by reducing instream water temperatures, increasing dissolved oxygen levels, and reducing contaminant concentrations. NMFS has determined that each of these environmental factors are significantly impaired by current flow conditions in the SJR basin (NMFS 2009a). In addition, the USEPA recently added the portion of the SJR, extending from its confluence with the Merced River to the Delta Boundary, and each of the major SJR tributaries to the Clean Water Act Section 303(d) list for temperature impairments (USEPA 2011). In support of this decision, the USEPA evaluated whether the “Cold Freshwater Habitat (COLD),” “Migration of Aquatic Organisms (MIGR)” and “Spawning, Reproduction, and/or Early Development (SPWN)” uses are supported for Chinook salmon and steelhead trout in the respective reaches of the San Joaquin, Merced, Tuolumne, and Stanislaus rivers. As an example, based on this evaluation, USEPA believes that the frequency of exceedances of the 20° C seven day average of the daily maxima (7DADM) benchmark in the mainstem segments of the San Joaquin River provides an indication of increased risk of disease, migration blockage and delay, and overall reduction in salmonid migration fitness (USEPA 2011).

3.6 Analyses of Flow Effects on Fish Survival and Abundance

Studies that examine the relationship between fall-run Chinook salmon population abundance and flow in the SJR basin generally indicate that: 1) additional flow is needed to significantly improve production (abundance) of fall-run Chinook salmon; and 2) the primary influence on adult abundance is flow 2.5 years earlier during the juvenile rearing and outmigration life phase (AFRP 2005; DFG 2005a; Mesick 2008; DFG 2010a; USDOI 2010). These studies also report that the primary limiting factor for tributary abundances are reduced spring flow, and that populations on the tributaries are highly correlated with tributary, Vernalis, and Delta flows (Kjelson et al. 1981; Kjelson and Brandes 1989; USFWS 1995; Baker and Mohardt 2001; Brandes and McLain 2001; Mesick 2001b; Mesick and Marston 2007; Mesick 2009; Mesick 2010 a-d).

Analyses have been conducted for several decades that examine the relationship between SJR fall-run Chinook salmon survival (escapement) or abundance (e.g., adult Chinook salmon recruitment) and flow. Specifically, analyses have also been conducted to: 1) evaluate escapement (the number of adult fish returning to the basin to spawn) versus flow 2.5 years earlier when those salmon were rearing and outmigrating from the SJR basin; and 2) to estimate juvenile fall-run Chinook salmon survival at various reaches in the SJR basin and the Delta versus flow. For example, flows from March through June have been correlated to the total number of smolt outmigrants within a tributary (Mesick, et al. 2007, SJRRP 2008). Figure 3.8 suggests that prolonged late winter and spring flows in the Tuolumne River are an important factor in determining smolt survival rate (Mesick 2009). Additionally, adult Chinook salmon are thought to be highly correlated with the production of smolt outmigrants, which are highly correlated to spring flows, for each of the major SJR tributaries (Mesick and Marston 2007; Mesick et al. 2007). For a description of escapement and how it relates to production see the fall-run Chinook salmon population trends discussion (Section 3.2.6).



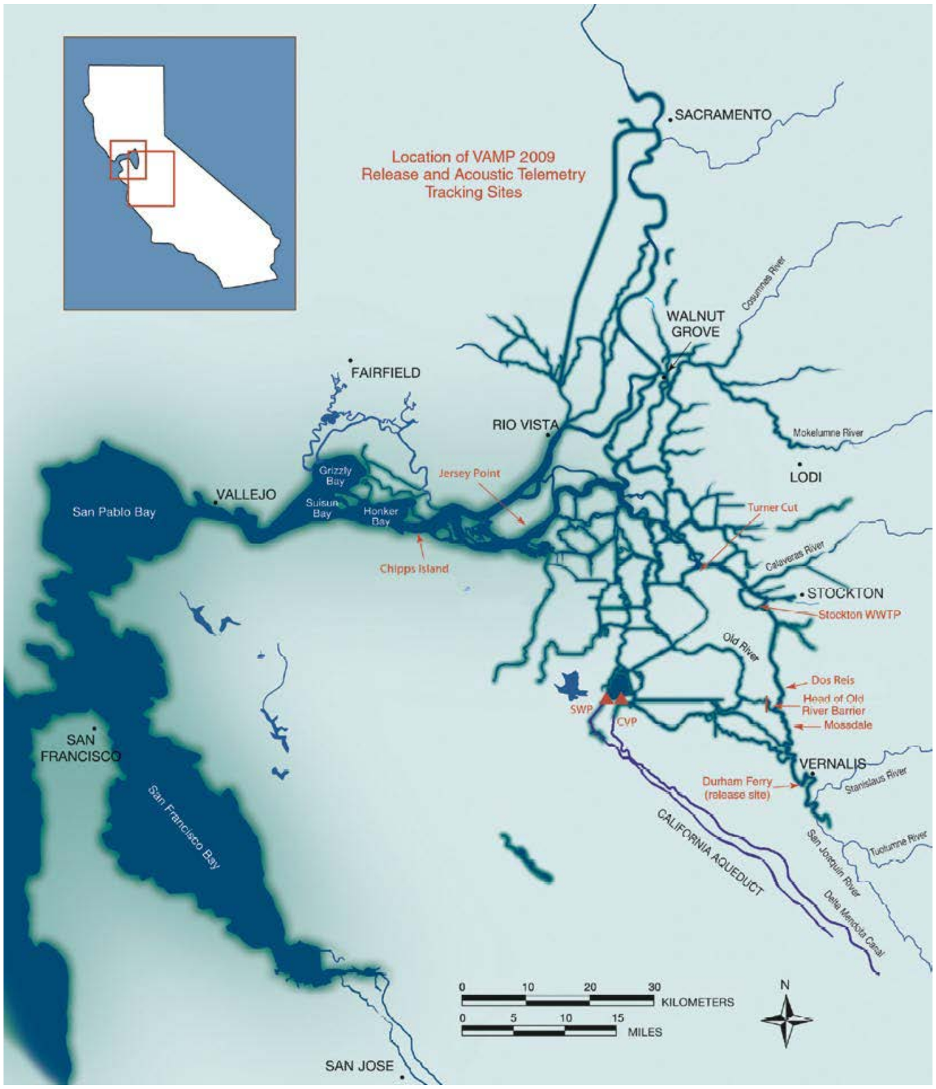
Source: Mesick 2009

Note: the spring 2006 estimates were omitted because the number of Age 3 equivalent spawners in fall of 2005 was only 447 adults, which limited smolt production unlike the other years when flows were the primary determinant.

Figure 3.8. The Number of Smolt-sized Chinook Salmon Outmigrants (>70mm) Passing the Grayson Rotary Screw Trap Site Plotted against Tuolumne River Flow from 1998-2005

3.6.1 SJR CWT Studies

Specific experiments using coded wire tagged (CWT) hatchery smolts released at various locations on the SJR and in the Delta to estimate survival of salmon smolts migrating through the Delta under various circumstances started in the early 1980's. Since 2000, CWT experiments have been conducted pursuant to the VAMP, and since 2007, VAMP survival studies have been conducted using acoustic telemetry devices. The VAMP and pre-VAMP CWT studies were similar and involved releasing hatchery fish at various locations on the SJR including Old River, Jersey Point, Durham Ferry, Mossdale, and Dos Reis (Figure 3.9), and recapturing those fish downstream in the Delta. Under the pre-VAMP studies, fish were released at unspecified flow and export conditions. The 12-year VAMP study was designed to release fish at specified flows during a 31-day period from approximately mid-April through mid-May under specified export conditions in order to evaluate the relative effects of changes in Vernalis flow and SWP and CVP export rates on the survival of SJR salmon smolts passing through the Delta. As part of the original design of VAMP, the physical HORB was also assumed to be in place, although it was recognized that in some years the barrier would not be in place. In recent years, the physical HORB has not been in place and may be precluded in the future due to concerns related to protection of Delta smelt (SJRGA 2008). The following is a summary of the evaluations conducted to date to investigate the relationship between flows and SJR fall-run Chinook salmon survival and abundance during the spring period.



Source: SJRGA 2010

Figure 3.9. Location of VAMP 2009 Release and Acoustic Telemetry Tracking Sites

In 1981, based on studies by the Ecological Study Program for the Delta, Kjelson et al. reported on the effects of freshwater inflows on the survival, abundance, and rearing of salmon in the upstream portions of the Delta. Kjelson et al. (1981) found that peak catches of salmon fry often follow flow increases associated with storm runoff, suggesting that flow surges influence the number of fry that migrate from spawning grounds into the Delta and increase the rate of migration for fry. Kjelson et al. (1981) also found that flows in the SJR and Sacramento River, during spawning and rearing periods, influence the numbers of juvenile Chinook salmon that survive to migrate to the Delta. In addition, observations made in the SJR basin between 1957 and 1973 indicate that numbers of Chinook spawners are influenced by the amount of river flow during the rearing and outmigration period (February to June) 2.5 years earlier. As a result, Kjelson et al. (1981) found that flow appears to affect juvenile survival, which in turn affects adult abundance. In testimony before the State Water Board in 1987, Kjelson again reported that data indicate that the survival of fall-run salmon smolts migrating from the SJR basin through the Delta increases with flow. Kjelson found that increased flows also appear to increase migration rates, with smolt migration rates more than doubling as inflow increased from

2,000 to 7,000 cfs (USFWS 1987). In a 1989 paper, Kjelson and Brandes once again reported a strong long term correlation ($r = 0.82$) between flows at Vernalis during the smolt outmigration period of April through June and resulting SJR basin fall-run Chinook salmon escapement (2.5 year lag) (Kjelson and Brandes 1989).

In 1995, the Anadromous Fish Restoration Program[1] *Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California* (Working Paper) reported that declines in adult fall-run Chinook salmon escapement to SJR basin tributaries were attributed to inadequate streamflow in the mainstem SJR and major SJR tributaries. The Working Paper reported that there is a positive relationship between smolt survival and spring flow in the Tuolumne River, and indicated that substantially higher flows are needed for salmon spawning and rearing on the lower Tuolumne River. The Working Paper also reported that escapement of adult Chinook salmon into the Stanislaus River is associated with spring outflow in both the SJR at Vernalis and the Stanislaus River at Ripon, and that the timing, amount, and quality of flow affects the migration and survival of both juvenile and adult Chinook salmon (USFWS 1995).

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

Baker and Morhardt (2001) found that fall-run Chinook salmon smolt survival through the Delta may be influenced to some extent by the magnitude of flows from the SJR, but that the relationship was not well quantified, especially in the range of flows for which such quantification would be most useful for flow management prescriptions (e.g., 5,000 cfs to 10,000 cfs). In addition, Baker and Morhardt (2001) found that there was a clear relationship when high flows were included in the analysis, but at flows below 10,000 cfs there was very little correlation between flows at Vernalis and escapement, and flows at Vernalis and smolt survival through the Delta. A 2009 NMFS Technical Memorandum regarding the SJR flows analysis for the OCAP Biological Opinion stated that inflows below approximately 5,000 cfs in April and May can produce highly variable adult escapement numbers 2.5 years later. Furthermore, factors other than flow may be responsible for the variable escapement returns. NMFS also states that for flows above approximately 5,000 cfs the relationship with escapement begins to take on a linear form, and adult escapement increases in relation to flow. NMFS explains that anomalies within the flow relationship (i.e., subsequent low adult returns during high spring flows) can be due to poor ocean conditions upon juvenile entry or low adult returns in the fall prior to the high spring flows.

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[1] Representing experts possessing specific technical and biological knowledge of Central Valley drainages and anadromous fish stocks from the DFG, Department of Water Resources, USFWS, Bureau, and NMFS (USFWS 1995).

The general relationship between flow (April and May) and escapement of adult fall-run salmon 2.5 years later is illustrated in Figure 3.10. The average observed and unimpaired April and May flows within each river are shown with the purple and blue symbols, respectively. Fall escapement for the SJR tributaries has been reported since 1952. Such an assessment relies on an assumption that each year's escapement is dominated by three year old salmon. While three year old fish generally return to spawn in the highest numbers, other aged fish may represent a significant portion of annual escapements in some years. The DFG, in consultation with Dr. Carl Mesick, prepared brood year cohort data for the SJR tributaries and compared those data with SJR spring flows at Vernalis (Mesick and Marston 2007). The results of this analysis indicate a strong relationship exists between spring flow magnitude and adult production (both ocean harvest and escapement).

In a 2001 paper, Mesick evaluated the factors that potentially limit fall-run Chinook salmon production in the Stanislaus and Tuolumne Rivers. Mesick found that recruitment to the Stanislaus River population from 1945 to 1995, and to the Tuolumne River population from 1939 to 1995, was strongly correlated with: springtime flows in the mainstem SJR and the tributaries; the ratio of Delta exports at the SWP and CVP to Vernalis flows; and to a lesser degree, the abundance of spawners (stock), ocean harvest, and anchovy landings[2]. Mesick found that correlations with herring landings, November flows during spawning, water temperature at Vernalis, and ocean climate conditions, were not significant. Mesick also found that the influence of flow and Delta exports was greatest in the Delta near Stockton, indicating that the survival of smolts migrating in the Delta downstream from Dos Reis to Jersey Point is strongly correlated with flow and to a lesser degree water temperature and Delta exports (Mesick 2001b).

In 2008, Newman published a comprehensive evaluation of data from several release-recovery experiments conducted in order to estimate the survival of outmigrating juvenile Chinook salmon and to quantify the effect of various factors on survival. This review included a Bayesian hierarchical model analysis of CWT experiments from the VAMP (2000-2006) and pre-VAMP data (1996-1999) with both the HORB in and out, SJR at Mossdale flows ranging from 1,400 cfs (1990) to 29,350 (2006) cfs, and exports ranging from 805 cfs (1998) to 10,295 cfs (1989). In this analysis, Newman found that there was a positive association between flow at Dos Reis (with at least a 97.5% probability of a positive relationship) and subsequent survival from Dos Reis to Jersey Point. If data from 2003 and later were eliminated from analysis, the strength of the association increased and a positive association between flow in Old River and survival in Old River became evident. Newman did not find any relationship for the Durham Ferry to Mossdale reach and the Mossdale to Dos Reis reach. In addition, Newman found that the expected probability of surviving to Jersey Point was consistently larger for fish staying in the SJR (passing Dos Reis) than fish entering Old River, but the magnitude of the difference varied slightly between models. Lastly, Newman found that associations between water export levels and survival probabilities were weak to negligible, however, Newman pointed out that more thorough modeling should be conducted.

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

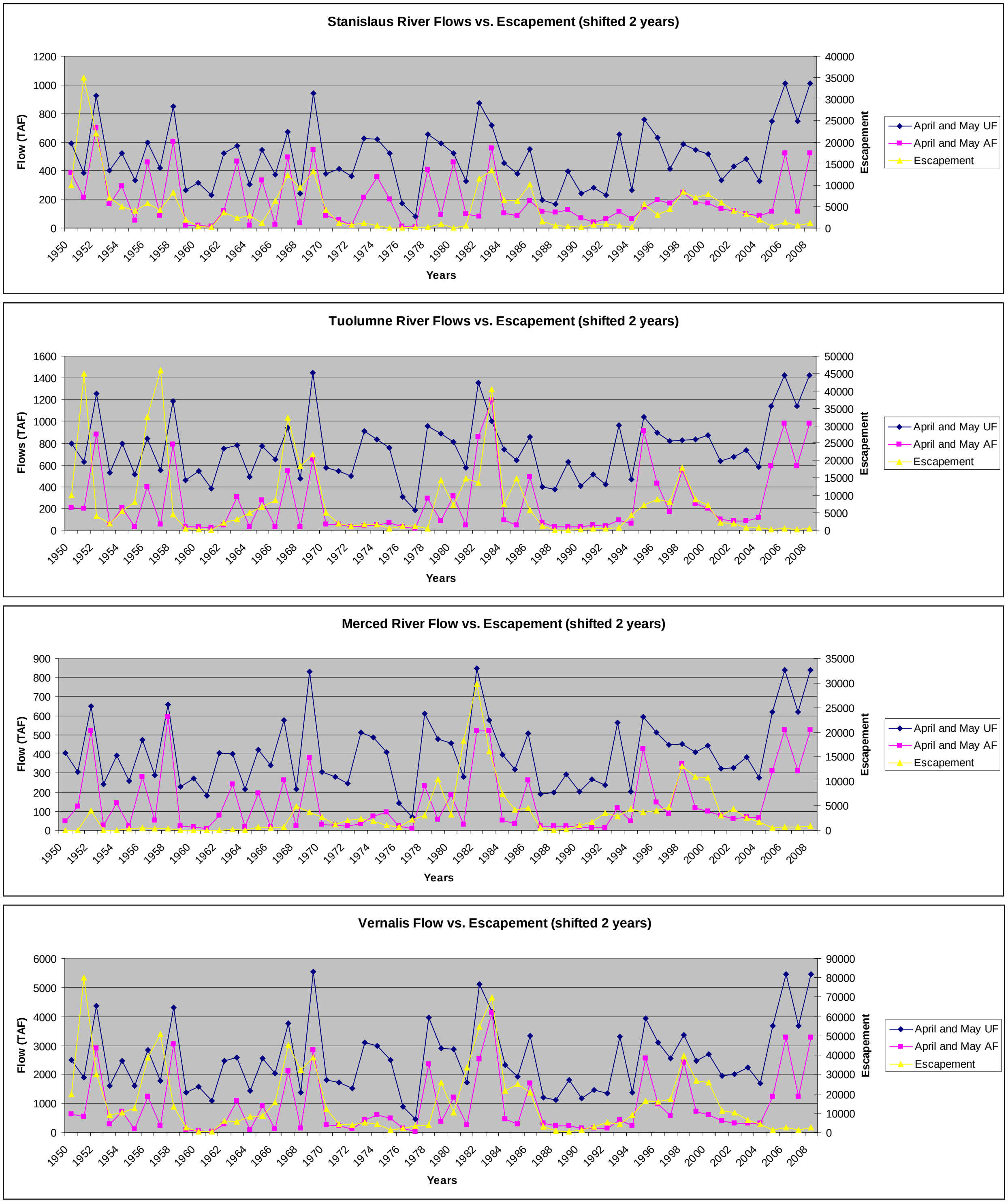


Figure 3.10. Fall-Run Chinook Salmon Escapement Compared to April and May Flows (2.5 Years Earlier) for the Stanislaus, Tuolumne, Merced Rivers, and SJR Basin Measured at Vernalis

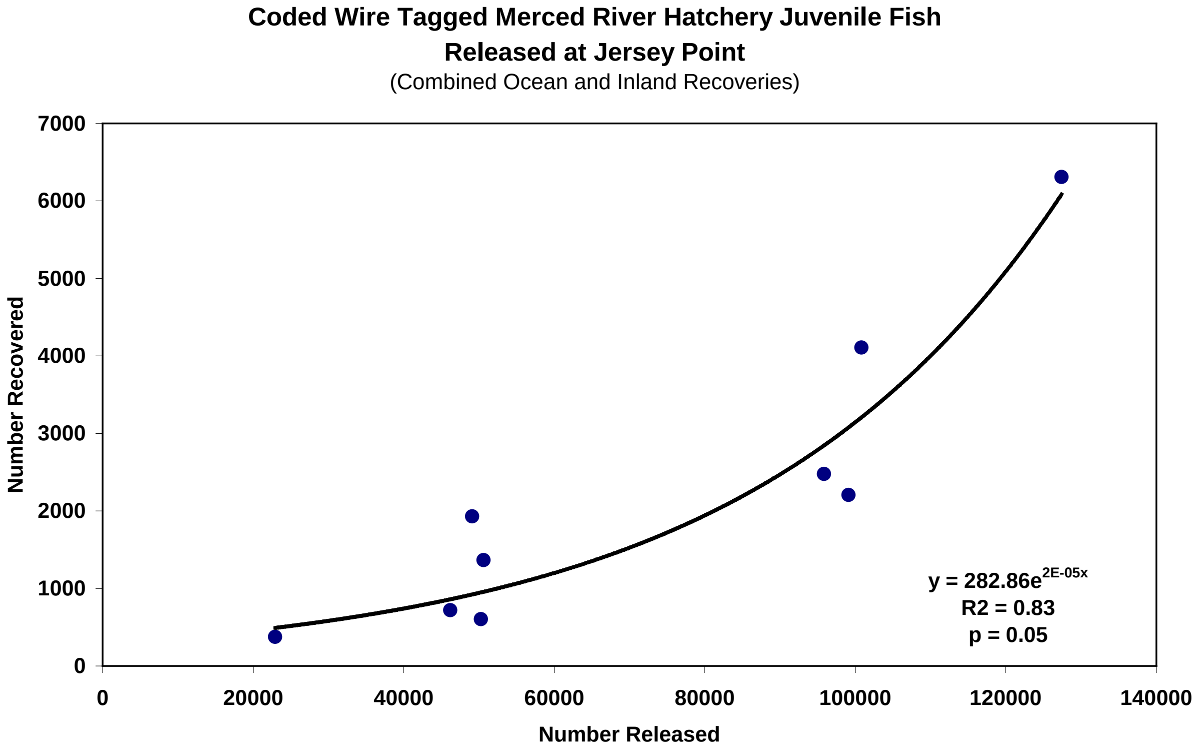
In 2007, Mesick et al. developed a Tuolumne River Management Conceptual Model that included a limiting factor analysis of Tuolumne River Chinook salmon and rainbow trout populations. The limiting factor analyses suggest that adult Chinook salmon recruitment (i.e., the total number of adults in the escapement and harvested in the sport and commercial fisheries in the ocean) is highly correlated with the production of smolt outmigrants in the Tuolumne River, and that late winter and spring flows are highly correlated with the number of smolts produced. Mesick et al. (2007) reports that other evidence from rotary screw trap studies indicate that many more fry are produced in the Tuolumne River than can be supported with the existing minimum flows; therefore, producing more fry by restoring spawning habitat is unlikely to increase adult recruitment. Mesick et al. (2007) indicates that low spawner abundances (less than 500 fish) have occurred as a result of extended periods of drought when juvenile survival is reduced as a result of low winter and spring flows and not as a result of high rates of ocean harvest. Mesick et al. (2007) also found that other factors, such as cyclic changes in ocean productivity, Delta export rates, and *Microcystis* blooms do not explain the trends in the Tuolumne River population. With all environmental factors or stressors being considered, these findings suggest that spring flows are the most important stressor to the viability of fall-run Chinook salmon and that greater magnitude, duration, and frequency of spring flows are needed to improve survival of smolts through the Tuolumne River and Delta (Mesick et al. 2007).

In 2009, Mesick published a paper on the High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases which indicated that fall-run Chinook salmon escapement in the Tuolumne River, has declined from 130,000 salmon during the 1940s to less than 500 salmon during the early 1990s and 2007. Based on this low escapement, the rapid nature of the population declines, and the high mean percentage of hatchery fish in the escapement, Mesick (2009) found that the Tuolumne River's naturally produced fall-run Chinook salmon population has been at a high risk of extinction since 1990. Mesick (2009) identifies two critical flow periods for salmon smolts on the Tuolumne River: 1) winter flows which affect fry survival to the smolt stage, and 2) spring flows which affect the survival of smolts migrating from the river through the Delta. Mesick (2009) concludes that the decline in escapement is primarily due to inadequate minimum instream flow releases from La Grange Dam in late winter and spring during the non-flood years. In addition, Mesick (2009) found that since the 1940s, escapement has been correlated with mean flow at Modesto from February 1 through June 15 (2.5 years earlier), and that flows at Modesto between March 1 and June 15 explain over 90% of the escapement variation. This correlation suggests that escapement has been primarily determined by the rate of juvenile survival, which is primarily determined by the magnitude and duration of late winter and spring flows, since the 1940s. In addition, Mesick reported (as shown by other analyses) that spawner abundance, spawning habitat degradation, and the harvest of adult salmon in the ocean have not caused the decline in escapement.

In 2010, Mesick used an index of smolt survival, made by estimating the total number of CWT salmon that returned to spawn in the inland escapement and were caught in the ocean fisheries divided by the number of juvenile salmon released (Adult Recovery Rate), to compare the relationship between flow, water temperatures, exports and other factors. Mesick's analyses suggest that it is likely that without the physical HORB, flow cannot substantially reduce the impacts of the poor water quality in the Stockton Deepwater Ship Channel (DWSC). In the DWSC, high concentrations of oxygen-demanding organisms (algae from upstream, bacterial uptake of effluent from the City of Stockton Regional Wastewater Control Facility, and other unknown sources), and channel geometry causes rates of biological oxygen demand to exceed rates of gas exchange with the atmosphere and results in a sag (locally depleted concentration) in dissolved oxygen concentration (Lee and Jones-Lee 2002, Kimmerer 2004, Jassby and Van Nieuwenhuyse 2005). With the physical HORB installed, there is a positive association between

Delta flow and smolt survival and an inverse correlation between the Adult Recovery Rate and increasing water temperatures at Mossdale (Mesick 2010c). In addition to directly influencing smolt survival, increased flows reduce the travel time of smolts moving through the SJR and Delta system, thus reducing the duration of their exposure to adverse effects from predators, water diversions, and exposure to contaminants (NMFS 2009b).

In addition to the above conclusions, results of the south Delta juvenile salmon survival studies (described above) support the concept that a positive relationship exists between the number of juvenile fall-run Chinook salmon surviving to Jersey Point and the number of adults being harvested in the ocean and returning to spawn (Figure 3.11). Analyzing recovery data from CWT fish released at Jersey Point (exit point of the south Delta) and later recovered in the ocean and rivers, revealed a positive relationship between the number of juvenile fish released and the number of adults recovered. Figure 3.11 indicates that 83% of the variance in the number of adult fish recovered can be explained by the number of juvenile fish released at Jersey Point.



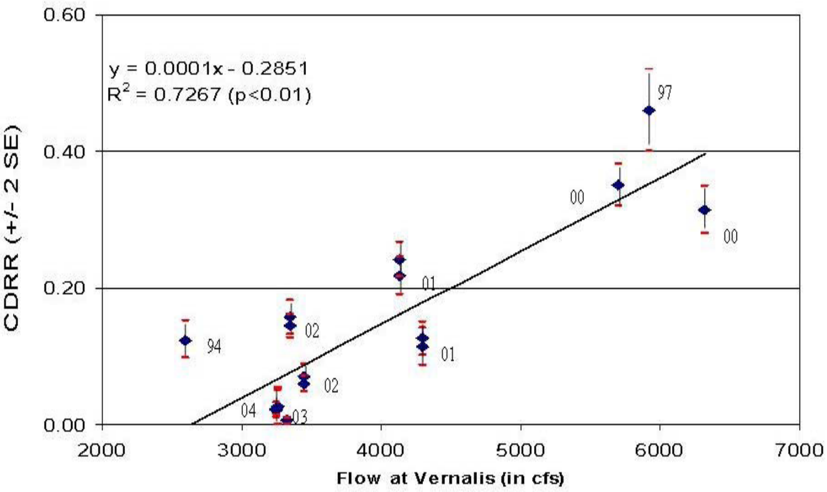
Note: Years 1995 to 2003 were used since Merced River Hatchery fish were released at Jersey Point and both adult and ocean and inland recoveries have been identified

Source: DFG 2010e

Figure 3.11. Coded Wire Tagged Adult Fall-run Chinook Salmon Recoveries as a Function of Number Juveniles Released at Jersey Point

3.6.2 VAMP Review

In 2010, an independent scientific review of the VAMP was conducted to evaluate the CWT results from the VAMP studies (2006 and prior). The independent review panel (IRP) found that two distinct statistical analyses support the conclusion that increased flows generally have a positive effect on SJR fall-run Chinook salmon survival. First, the IRP found data indicating that for flows in excess of about 2,500 to 6,500 cfs, measured at Vernalis for years when the physical HORB was in place (1994, 1997, 2000-2004), the estimated survival of outmigrating salmon between Mossdale or Durham Ferry and Jersey Point on the mainstem SJR exhibits a strong positive relationship with Vernalis flow (Figure 3.12) (see also SJRGA 2007). In addition, there was a positive, though weaker relationship between estimated survival rates from Dos Reis and Jersey Point over a broader range of flows for years with the physical HORB in place or not (see also SJRGA 2008). Second, the IRP pointed to the broader and more sophisticated Bayesian Hierarchical modeling analyses by Newman (2008) that found a positive influence of SJR flow below Old River on survival rates. The IRP also reported on its own summaries of CWT-based estimates of survival rates from Mossdale (when the physical HORB has been in place) or Dos Reis to Jersey Point that are consistent with a general increase of mean survival rates with increasing flows measured at Dos Reis.



Source: SJRGA 2007

CDRR: Point estimates of salmon survival plus or minus 2 standard errors using Chipps Island, Antioch and ocean recoveries in 1994, 1997, 2000–2004.

Figure 3.12. Survival of Outmigrating Salmon Versus Vernalis Flow

The IRP provided further information concerning the relationship between fall-run Chinook salmon survival and flows within the SJR in and near the DWSC. In a preliminary analysis of the relationships between flows, residence time, and reach specific survival in 2008 and 2009 (Holbrook et al. 2009, Vogel 2010), the review panel suggests that the DWSC could be a bottleneck for survival of salmon smolts migrating down the SJR, and that higher flows through the DWSC could benefit migrating salmon (Hankin et al. 2010).

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

In their own analysis of the VAMP data, the IRP found that survival decreased as flows decreased, and that survival has been decreasing over time within each of four flow groupings (very low, low, moderate, high). Survival estimates from Mossdale or Dos Reis to Jersey Point were just greater than 1% in 2003 and 2004 and the estimate was only about 12% in the very high flow year of 2006. This compares to survival estimates that ranged between about 30% and 80% in the years 1995 and 1997 to 2000. The IRP points out that the recent survival estimates are significantly lower than the long-term average survival estimate of about 20%, which the IRP points out is considered low when compared to the Sacramento River and other estuaries like the Columbia River. The review panel concludes that "the very low recent survival rates seem unlikely to be high enough to support a viable salmon population, even with favorable conditions for ocean survival and upstream migration and spawning success for adults" (Hankin et al. 2010).

3.6.3 Acoustic Tracking Studies (2008–2011)

Data from recent VAMP studies using acoustic tagged fish indicate survival remained low during the recent Critically Dry (2007 and 2008) and Dry (2009) water years (survival estimates for the 2010 study are not yet available). In 2007, mean flows during the VAMP period were 3,260 cfs. The lack of two key monitoring stations, receiver malfunctions, and unknown mortality (motionless tags were either in dead fish or had been defecated by a predator) near Stockton of a sizeable number of test fish reduced the ability to develop survival estimates (SJRGA 2008). The 2008 study was conducted during a period with mean flows of 3,160 cfs, and indicated that fish survival through the Delta ranged from 5% to 6% (SJRGA 2009). The most recent VAMP annual technical report for 2009 yielded similar results to 2008 during a period with mean flows of 2,260 cfs. However, VAMP was unable to install the key monitoring stations at Jersey Point and Chipps Island, which prohibited survival calculations through the Delta and data comparability with other years. Total survival for 2009 was calculated by combining survival estimates from the Old River route (survival of 8%) and the SJR route (survival of 5%). Only an estimated 6% of salmon survived through the study area. Survival in the Old River and the SJR River, and total survival through the study area would be even lower if the detection sites where no salmon were detected (Turner Cut, Middle River, and the interior of Clifton Court Forebay) were incorporated into the survival calculation. In addition, survival estimates may be even lower if data for fish survival into the holding tanks or fish salvage facilities of the SWP and CVP export facilities were incorporated into the calculation (SJRGA 2010).

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

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

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

3.7 Importance of the Flow Regime

This section describes the importance of the flow regime in protecting aquatic fish and wildlife beneficial uses. In general, variable flow conditions provide the conditions needed to support the biological and ecosystem processes which are imperative to the protection of fish and wildlife beneficial uses. Although changes to additional ecosystem attributes, in addition to flows, are needed in order to fully restore biological and ecosystem processes on the SJR, flow remains a critical element of that restoration.

Using a river’s unaltered hydrographic conditions as a foundation for determining ecosystem flow requirements is well supported by the current scientific literature (Poff et al. 1997; Tennant 1976; Orth and Maughan 1981; Marchetti and Moyle 2001; Mazvimavi et al. 2007; Moyle et al. 2011). In addition, major regulatory programs in Texas, Florida, Australia and South Africa have developed flow prescriptions based on unimpaired hydrographic conditions in order to enhance or protect aquatic ecosystems (Arthington et al. 1992; Arthington et al. 2004; NRĐC 2005; Florida Administrative Code 2010), and the World Bank now uses a framework for ecosystem flows based on the unaltered quality, quantity, and timing of water flows (Hirji and Davis 2009). Major researchers involved in developing ecologically protective flow prescriptions concur that mimicking the unimpaired hydrographic conditions of a river is essential to protecting populations of native aquatic species and promoting natural ecological functions (Sparks 1995; Walker et al. 1995; Richter et al. 1996; Poff et al. 1997; Tharme and King 1998; Bunn and Arthington 2002; Richter et al. 2003; Tharme 2003; Poff et al. 2006; Poff et al. 2007; Brown and Bauer 2009). Poff et al. (1997) describes the flow regime as the “master variable” that limits the distribution and abundance of riverine species (Resh et al. 1988; Power et al. 1995) and regulates the ecological integrity of rivers. The structure and function of riverine ecosystems, and the adaptations of their constituent freshwater and riparian species, are determined by patterns of intra- and inter-annual variation in river flows (Poff et al. 1997; Naiman et al. 2008). A key foundation of the natural flow paradigm is that the long-term physical characteristics of flow variability have strong ecological consequences at local to regional scales, and at time intervals ranging from days (ecological effects) to millennia (evolutionary effects) (Lytle and Poff 2004). Nearly every other habitat factor that affects community structure; from temperature, to water chemistry to physical habitat complexity, is determined by flow to a certain extent (Moyle et al. 2011).

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

A more natural flow regime is anticipated to improve a number of ecosystem attributes such as (but not limited to): 1) native fish communities; 2) food web; 3) habitat; 4) geomorphic processes; 5) temperature; and 6) water quality. The effects of altered flows on each of these attributes are described below, along with the expected benefits of a more variable flow regime. These ecosystem attributes and others will be further discussed in the SED.

3.7.1 Effects on Fish Communities

Altered flow regimes have been found to negatively impact native fish communities and the aquatic ecosystem (Pringle et al. 2000, Freeman et al. 2001, Bunn and Arthington 2002, Moyle and Mount 2007). An assessment of streams across the conterminous U.S. showed that there is a strong correlation between diminished streamflow magnitudes and impaired biological communities including fish (Carlisle et al. 2011). In addition, when streams are dammed and flow regimes are simplified by dam releases, stream fish communities tend to become simplified and more predictable, usually dominated by selected species favored by fisheries, or by species that thrive in simplified and less variable habitats (Moyle et al. 2011). This has been found to be the case in the SJR basin where native fish and other aquatic organisms have been increasingly replaced by non-native species (Brown 2000; Freyer and Healey 2003; Brown and May 2006; Brown and Michniuk 2007; Brown and Bauer 2009). With respect to high flows in the spring, Moyle et al. (2011) found the proportion of the total fish community comprised of non-natives was inversely correlated to mean spring discharge, and annual 7-day maximum discharge.

Native communities of fish and other aquatic species are adapted to spatial and temporal variations in river flows under which those species evolved, including extreme events such as floods and droughts (Sparks 1995; Lytle and Poff 2004). On the other hand, permanent or more constant flows, created by damming or diverting river flows, favor introduced species (Moyle and Mount 2007; Poff et al. 2007). Long-term success (i.e., integration) of an invading species is much more likely in an aquatic system, like the SJR, that has been permanently altered by human activity than in a less disturbed system. Unlike unaltered systems, systems altered by human activity tend to resemble one another; and favor species that are desirable to humans (Gido and Brown 1999).

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

The genetic and life-cycle diversity provided by maintaining sub-populations and varied life history timing of juvenile Chinook salmon through achieving a more natural flow regime with improved temporal and spatial variability is anticipated to help protect the population against both short-term and long-term environmental disturbances. Fish with differing characteristics between populations (i.e., greater diversity) have different likelihoods of persisting, depending on local environmental conditions. Thus, the more diverse a species is, the greater the probability that some individuals will survive and reproduce when presented with environmental variation (McElhany et al. 2000; TBI/NRDC 2010a). Genetic diversity also provides the raw material for surviving long-term environmental changes. Salmonids regularly face cyclic or directional change in their freshwater, estuarine, and ocean environments due to natural and human causes. Sustaining genetic and life-cycle diversity allows them to persist through these changes (McElhany et al. 2000; Moore et al. 2010; Carlson and Satterthwaite 2011).

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

Protecting and enhancing genetic (and life history) variability also helps to protect salmon populations from a significant loss in genetic diversity from the use of hatcheries. Fall-run Chinook salmon and other salmon hatcheries have unintentionally caused a reduction of genetic variability within the species by altering the genetic makeup of native salmon due to interbreeding with stocked strains of salmon. In addition, the greater quantity of hatchery fish within the river system has caused declines in native salmon, and further reduced the genetic viability of naturally produced strains due to predation and competition for spawning grounds, food, and space (Figure 3.6, Jones and Stokes 2010). A more natural flow regime is anticipated to maintain, and perhaps even enhance, the remaining genetic variability of natural stocks and reduce the negative effects of hatcheries on naturally produced populations.

3.7.2 Effects on Food Web

Establishing a more natural flow regime is anticipated to also benefit the food web to which native species are adapted. The diversity and abundance of beneficial algae and diatoms (the base of the food web) are higher in unregulated reference streams than in more perturbed streams (Power et al. 1996). In contrast, the benthic macroinvertebrate community (a key fish food resource) is typically characterized by species-poor communities in regulated river reaches (Munn and Brusven 1991). Carlisle et al. (2011) found that impaired macroinvertebrate communities were associated with diminished maximum flows characteristic of streams that have undergone human alteration. Additionally, loss of variability in flows, and increasingly stable regulated flows can lead to proliferation of certain nuisance insects such as larval blackflies (De Moor 1986). In regulated rivers of northern California, Wootton et al. (1996) found that seasonal shifting of scouring flows from winter to summer increased the relative abundance of predator-resistant invertebrates that diverted energy away from the natural food web and caused a shift toward predatory fish. In unregulated rivers, high winter flows reduce these predator-resistant insects and favor species that are more palatable to fish (Wooton et al. 1996, Poff et al. 1997). Additionally, reduced flows in the spring, indicative of the altered SJR system, likely negatively impact the food resources that juvenile salmon depend on. The survival of juvenile Chinook salmon to the adult stage partially depends on the ability to grow rapidly and smolt in early spring, when chances for survival and migration though the Bay-Delta and into the ocean are highest. Larger, healthier smolts are more likely to survive outmigration than smaller, poorly fed smolts (SJRRP 2008).

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

Altered flow regimes may also decrease nutrients at the base of the food web if such alterations result in a reduction of salmon that would have normally been a major nutrient source for the local food web. Salmon carcasses that remain in the stream corridor and decompose are recognized as a source of marine-derived nutrients that play an important role in the ecology of Pacific Northwest streams, and are an important nutrient source for the local food web. Salmon carcasses contain nutrients that can affect the productivity of algal and macroinvertebrate communities that are food sources for juvenile salmonids, and have been shown to be vital to the growth of juvenile salmonids (Cederholm et al. 1999; Gresh et al. 2000).

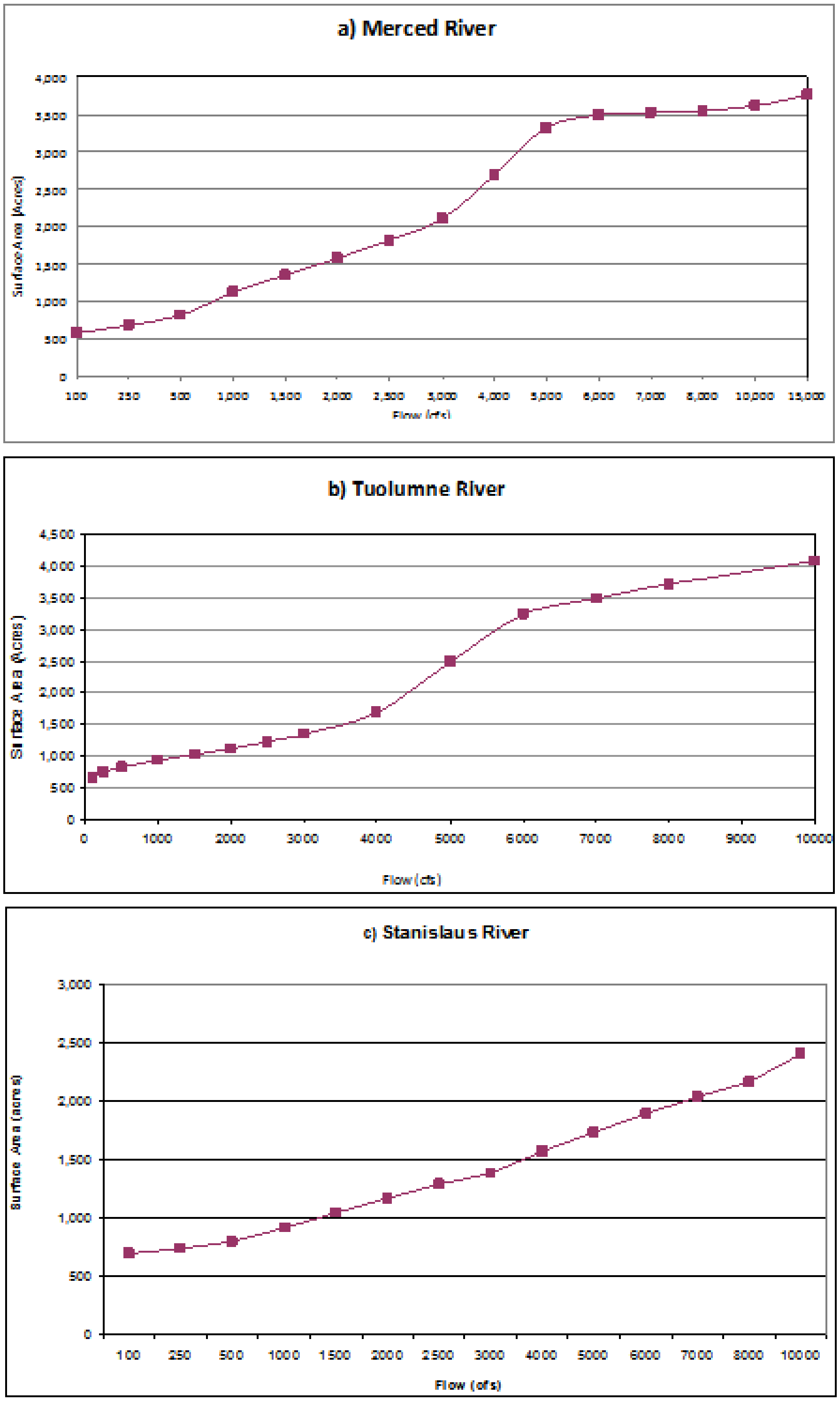
3.7.3 Effects on Aquatic Habitat

Altered flow regimes tend to decrease habitat connectivity in riverine and deltaic systems which results in a loss of lateral and longitudinal connectivity (Bunn and Arthington 2002). This loss of lateral connectivity is manifested as a loss in remnant seasonal wetlands and riparian areas, which, in turn causes a general loss of productivity and a decrease in aquatic habitat quality associated with the communities that depend on these habitats (Cain et al. 2003; McBain and Trush 2002).

Implementation of a more natural flow regime in the SJR basin is anticipated to increase longitudinal connectivity, create more beneficial migration transport, less hostile rearing conditions (protection from predators), greater net downstream flow, and connectivity with the estuary and near-shore ocean during periods that are beneficial for aquatic organisms who have adapted to this system (McBain and Trush 2002; Cain et al. 2003; Kondolf et al. 2006; Poff et al. 2007; Mesick 2009). Specifically, a more natural flow regime in the SJR basin will increase riparian and floodplain activation which in turn would increase habitat quality and quantity, allowing for energy flow between wetland areas and the river, and would provide the river and estuary with nutrients and food. Floodplain inundation provides flood peak attenuation and promotes exchange of nutrients, organic matter, organisms, sediment, and energy between the terrestrial and aquatic systems (Cain et al. 2003; Mesick 2009). It also improves juvenile fish survival by improving food availability in addition to providing refuges from predators during the critical rearing and migration time in the SJR and major SJR tributaries (Jeffres et al. 2008; Mesick 2009). Increased lateral and longitudinal connectivity also positively affects spatial distribution of organisms by facilitating the movement of organisms and creating important spawning, nursery, and foraging areas for many fish species, including salmon (Bunn and Arthington 2002; Cain et al. 2003; Jeffres et al. 2008; TBI/NRDC 2010a).

Currently, salmonids use the SJR tributaries downstream of the water diversion dams for spawning and rearing habitat including: the 24-mile reach of the Merced River between the Crocker-Huffman Dam and the town of Cressy for spawning, with rearing extending downstream to the confluence with the SJR; the 25-mile reach of the Tuolumne River between LaGrange Dam and the town of Waterford for spawning, with rearing in the entire lower river (between LaGrange Dam and the confluence with the SJR); and the 23-mile reach in the Stanislaus River between Goodwin Dam and the town of Riverbank for spawning and the entire lower river (between Goodwin Dam and the confluence with the SJR) for rearing (USFWS 1995).

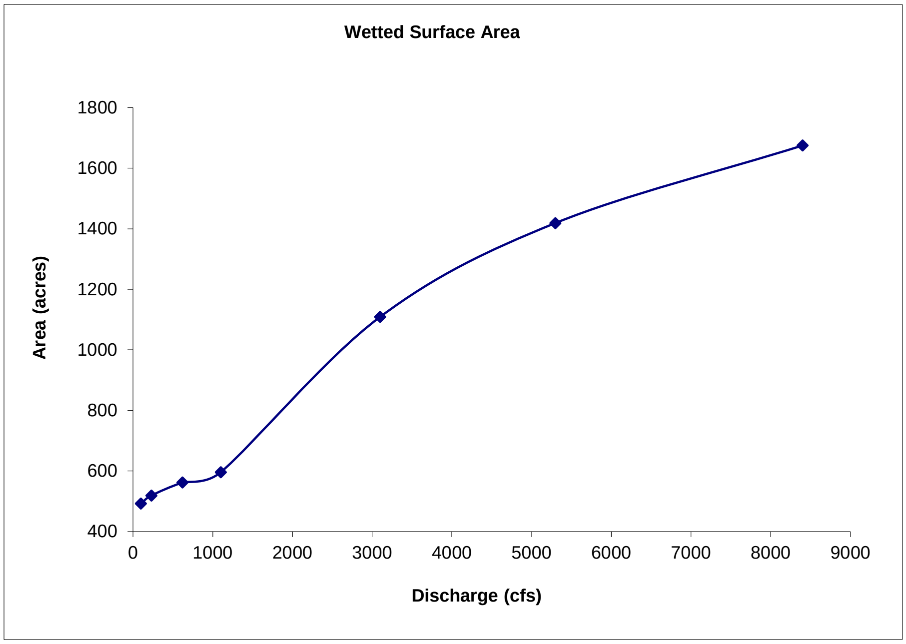
For the three major SJR tributaries (Stanislaus, Tuolumne, and Merced Rivers) DFG analyzed cross-sectional data developed by the United States Army Corps of Engineers and calculated the estimated wetted surface area from the first upstream barrier downstream to each tributary's SJR confluence (Figure 3.13). For the Merced River the wetted surface area increases more quickly from about 3,000-5,000 cfs indicating a corresponding greater increase in width within this flow range. The increase in width with flows greater than 3,000 cfs suggests the occurrence of bank overtopping or a strong likelihood for floodplain inundation. Likewise, running a similar comparison on the Tuolumne River indicates flows ranging from 4,000-6,000 cfs provide a rapid increase in width which suggests that floodplain inundation likely occurs at flows greater than 4,000 cfs. The Stanislaus River channel does not appear to have a well-defined floodplain within the 100 to 10,000 cfs flow range (DFG 2010e). Additional work is needed to confirm if flows in the ranges discussed above generate inundated floodplain conditions within the subject tributaries.



Source: DFG 2010e

Figure 3.13. Estimated Wetted Surface Areas for the three SJR tributaries. a) Merced River, b) Tuolumne River, c) Stanislaus River

In a separate analysis, the USFWS used GIS techniques to map the wetted surface area for a range of flows between 100 cfs and about 8,500 cfs (flood capacity) in order identify potential floodplain habitat on the Tuolumne River (USFWS 2008). The lower Tuolumne River was chosen for this study, as appropriate GIS data were available for the reach between La Grange Dam at RM 52 and just upstream of Santa Fe Bridge at RM 21.5 near the town of Empire. The data used for this analysis were originally developed as part of the FERC relicensing proceedings for the Don Pedro Project (Project No. 2299). The GIS layers were developed from aerial photographs taken at various flows between 1988 and 1995. The wetted area versus discharge curve for the Tuolumne River is shown in Figure 3.14 (USFWS 2008). A primary inflection is seen around 1,000 cfs which suggests that this is the minimum point where flows may begin to inundate “overbank” areas, or extend out of the channel and into the former floodplain. However, as there are no data points between 1,100 and 3,100 cfs, the actual initiation of overbank flow is not clear, but is likely to occur at a point between these two values. The wetted surface area is shown to increase with discharge from around 1,000 cfs up to the maximum studied flow of 8,400 cfs.



Source: USFWS 2008

Figure 3.14. Lower Tuolumne Inundated Area as a Function of Discharge

For comparison, the analysis conducted by DFG (2010e), suggests that floodplain inundation on the Tuolumne occurs at flows greater than 4,000 cfs. An evaluation of floodplain inundation thresholds on the tributaries by Cain et al. (2003) found that flows of 3,000-6,000 cfs (4,500 cfs on average) are necessary to inundate various low-lying floodplains below the terminal reservoirs on the upper Stanislaus, Tuolumne, Merced Rivers and SJR.

Based on the analyses discussed above, there is potential to enhance lateral connectivity on the tributaries, increasing floodplain activation and associated habitat for the benefit of salmonids and other aquatic resources. The increase in surface area and water elevation as a function of flow can be used to identify the river and potential floodplain habitat, and hydraulic models can be used to estimate water velocities in these rivers and overbank areas. Additional work is needed to verify if flows in the ranges discussed above generate inundated floodplain conditions within the subject tributaries, and if so, to better characterize the location, extent, and setting of such conditions. Substantial floodplain benefits can potentially be obtained with less than the maximum flood capacity of these tributaries. The levee flood capacity for the Tuolumne River is shown on the levee capacity map as 15,000 cfs, but the maximum regulated flow goal is 8,500 cfs. The levee capacity for the Merced River is 6,000 cfs, and the regulated flood capacity goal is 6,000 cfs. The levee capacity for the Stanislaus River is 8,000 cfs, and the regulated flood capacity goal is 6,000 cfs (DWR 2011).

3.7.4 Effects on Geomorphic Processes

The rim dams and altered flow regimes have caused a loss of geomorphic processes related to the movement of water and sediment that are important to the ecosystem (Poff et al.1997). Important benefits that these processes provide include increased complexity and diversity of the channel, riparian, and floodplain habitats, and mobilization of the streambed and upstream sediment (Grant 1997b). Floods, and their associated sediment transport, are important drivers of the river-riparian system. Small magnitude, frequent floods maintain channel size, shape, and bed texture, while larger, infrequent floods provide beneficial disturbance to both the channel and its adjacent floodplain and riparian corridor. As a result of alterations to flow regime and other factors, channel morphology within the SJR basin is now characterized by significant incision and loss of channel complexity. Of particular concern is the encroachment of vegetation into historic gravel bar habitat that has probably reduced the recruitment, availability, and quality of spawning gravel habitat for Chinook salmon (Cain et al. 2003; McBain and Trush 2002).

A more natural flow regime is anticipated to generate processes that create a less homogenous channel with structures that are important for fish habitat, such as meanders, pools, riffles, overhanging banks, and gravel substrates of appropriate sizes (Thompson and Larsen 2002, Mount and Moyle 2007). Scour and bed mobilization, associated with geomorphic processes that are driven by more variable flows, rejuvenate riparian forests and clean gravel for salmon, benthic macroinvertebrates, and benthic diatoms (McBain and Trush 2002, Cain et al. 2003, SJRRP 2008). Native fish and other aquatic species have adapted their life cycle to these processes and exploit the diversity of physical habitats these processes create (Poff et al. 1997; Thompson and Larsen 2002; Lytle and Poff 2004).

Increasing turbidity events from more variable flows and the associated geomorphic processes also is anticipated to decrease predation and provide environmental cues needed to stimulate migration (Jager and Rose 2003; Baxter et al. 2008; Mesick et al. 2007; NMFS 2009a). Juvenile salmonids emigrate during periods of increased turbidity that arise from the spring snowmelt phase of the flow regime and are afforded additional protection by the increased turbidity resulting from higher flows (Cain et al 2003). Turbidity reduces predation on young salmon by providing a form of protective cover, enabling them to evade detection or capture (Gregory 1993).

3.7.5 Effects on Temperature

Dams and reservoirs, and their associated operations, alter the temperature regime of rivers, often to the detriment of cold water species such as salmonids and other aquatic plants and animals that have adapted to colder waters and the variability associated with a more natural flow regime (Richter and Thomas 2007; DFG 2010b). Water stored in reservoirs is warmer at the surface and cooler below the thermocline in deeper waters. The temperature of water within these layers is generally different than the temperature of water entering the reservoir at any given time depending on the season, and is also dissimilar to downstream water temperatures that would occur under a natural flow regime (USACE 1987; Bartholow 2001).

Temperature control devices can control the temperature of water released from dams for the protection of downstream fisheries by varying operations of release gates. However, there are no temperature control devices to aid in water temperature management on the major SJR tributaries; therefore, temperature management can only be achieved directly through flow management (NMFS 2009a). Often, water released from reservoirs is colder in the summer and warmer in the winter compared to water temperatures that would have occurred in the absence of a dam and reservoir (Williams 2006). As a result, species experience additional temperature stress due to the river's altered flow and temperature regimes. However, where temperatures are cooler than they would be under a more natural flow regime (because of reservoir discharges of cold water through the summer), populations of *O.mykiss* (both anadromous and resident forms) are often able to persist. These areas are commonly in the reaches immediately below dams.

In addition to the changes in temperature due to reservoir storage and release, reservoirs and diversions also modify the temperature regime of downstream river reaches by diminishing the volume and thermal mass of water. A smaller quantity of water has less thermal mass, and therefore, a decreased ability to absorb temperatures from the surrounding environment (air and solar radiation) without being impacted (USACE 1987). The greatest impact occurs with less flow (less thermal mass) and warmer climate (increased solar radiation), usually in the late spring, summer, and early fall periods (BDCP 2010). The altered flow regime of the rivers in the SJR basin has largely eliminated the cold water refugia upon which salmonid populations depend (USEPA 2001). In addition to the need for cold water spawning habitat, warmer rearing temperatures (8°C to 25°C) are needed for optimal growth if food is readily available. However, temperatures that exceed these optimal levels can lead to decreased food availability, salmonid growth rates, and reduce the amount of suitable habitat for rearing (McCullough 1999, Myrick and Cech, Jr. 2001).

The combined effect of storage and dam operations have contributed to increased water temperatures and altered flow regimes that have negatively impacted salmon and other native fishes, encouraged warm-water and non-native fishes, and altered the base of the food web. In addition, undesirable and nuisance algae (e.g., *Microsystis*), and submerged aquatic vegetation (e.g., *Egeria*) have established and become widespread through the system due, in part, to the altered temperature and flow regime (Brown and May 2006; Brown and Bauer 2009; Moyle et al. 2010). A more natural flow regime; including greater flows in the spring, specifically February through June, and cooler instream water temperatures, is anticipated to benefit multiple levels of the aquatic ecosystem.

3.7.6 Effects on Water Quality

Unless otherwise indicated, the water quality information discussed in this section is taken from McBain and Trush (2002) which is derived from sampling at Newman and Vernalis. Water quality has decreased markedly in recent decades and has generally coincided with SJR flow reductions, population growth, and expanded agricultural production. There are numerous water quality constituents in the SJR basin which can negatively impact fish and wildlife beneficial uses including: dissolved oxygen, salinity and boron, nutrients, trace metals, and pesticides (Central Valley Water Board 2001; Central Valley Water Board 2004; Central Valley Water Board 2005a; Central Valley Water Board 2005b; DFG 2011a). A more natural flow regime would benefit the ecosystem in two ways: first, due to the direct relationships and interaction between flow, temperature (discussed above) and dissolved oxygen, more natural flow would ameliorate negative effects of temperature and dissolved oxygen; and second, an indirect effect of a more natural flow regime in the spring would be dilution of the other water quality constituents listed above.

Low dissolved oxygen levels can cause physiological stress to Chinook salmon and impair development of other aquatic species. In documenting passage delays and seasonal migration blockage of fall-run Chinook salmon in the lower SJR, Hallock et al. (1970) found that few adult fish migrated through water containing less than 5.0 mg/L dissolved oxygen, and the bulk of the salmon did not migrate until the DO concentration exceeded 5.0 mg/L. In addition, many invertebrates are sensitive to change in dissolved oxygen concentrations (McBain and Trush 2002), and low concentrations may alter the abundance and diversity of invertebrate and fish assemblages.

Salinity in the SJR basin is one of the largest water quality concerns, has a large influence on species diversity, and represents a major limiting factor for restoration of aquatic resources with effects on fish, invertebrates, and riparian plant establishment. Water quality data collected by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) indicates that water quality objectives for salinity have been routinely exceeded at locations throughout the SJR including Vernalis and areas upstream (Central Valley Water Board 2002). Agricultural drainage water collection and disposal, including return flows discharged to the SJR through mud slough and salt slough, have been identified as a major source.

Eutrophication from the dissolution of natural minerals from soil or geologic formations (e.g., phosphates and iron), fertilizer application (e.g., ammonia and organic nitrogen), effluent from sewage-treatment plants (e.g., nitrate and organic nitrogen), and atmospheric precipitation of nitrogen oxides may cause chronic stress to fish (McBain and Trush 2002). Algae and plant growth under eutrophic (high nutrient) conditions, along with their subsequent decomposition in the water column, lead to increase oxygen consumption and decreased dissolved oxygen conditions, reduced light penetration and reduced visibility. These conditions may render areas unsuitable for salmonid species, and favor other species (e.g., sucker, blackfish, carp, and shad).

Many trace metals have been identified in the SJR basin that can cause salmonids and other fish and wildlife species serious harm, including mortality, birth defects, and behavioral and carcinogenic consequences. In particular, selenium and mercury can have deleterious interactive effects with the aquatic environment due to the compounds' ability to "bio-magnify" within the food chain. The San Joaquin Valley Drainage Program identified selenium as one of 29 inorganic compounds that are a concern for public health and maintenance of fish and aquatic life (Brown 1996). Agricultural tile drainage has been shown to cause episodic toxicity to juvenile salmonids and striped bass. In addition to the regional selenium contamination, mercury contamination of the lower SJR watershed from past mining activities (primarily gold), from the burning of fuels or garbage, and from municipal and industrial discharges may represent another limiting factor in the protection of fish and wildlife beneficial uses. Methyl mercury bio-magnification in fish can cause death, reduce reproductive success, impair growth and development, and promote behavioral abnormalities (McBain and Trush 2002).

Pesticides from urban and agricultural runoff are a source of toxicity in the SJR and Delta. Pyrethroids are of particular interest because use of these pesticides has increased as use of some of the previous generation of pesticides (e.g., organophasphates) has declined (Amweg et al. 2005; Oros and Werner 2005). Residues of pyrethroid pesticides have been found to occur at concentrations acutely toxic to some benthic macroinvertebrates (e.g., the native amphipod *Hyalella azteca*) in sediments of agricultural water bodies and urban streams (Weston and Lydy 2010). These pyrethroid compounds are introduced to the environment through their use as insecticides in agricultural pest control, and professional and homeowner applications around structures or on landscaping (Weston and Lydy 2010). Recent work has also shown that surface waters may contain pyrethroids at concentrations sufficient to cause acute toxicity (Weston and Lydy 2010). The organophosphate compounds (e.g., diazinon and chlorpyrifos), are highly soluble in water and are relatively short-lived in the environment (Brown 1998). In the early 1990s, toxic concentrations of orpanophosphate pesticides were present in the rivers and Delta channels for several days at a time (Deanovic et al. 1996). In response, the Central Valley Water Board developed and adopted TMDLs to reduce concentrations of diazinon and chlorpyrifos in the Delta and tributaries. Since then, urban uses of the organophosphates have been phased out, the overall agricultural use of diazinon and chlorpyrifos has been significantly reduced, and new label restrictions have been adopted to reduce the amount of these pesticides that enter waterways from agricultural operations.

The generation of pesticides prior to the organophosphates included organochlorine compounds such as DDT and toxaphene, which are non-polar and poorly soluble in water, and may persist in the environment for long periods. Non-polar compounds allow bio-accumulation in animal tissues over time, posing a direct threat to fishery and other aquatic resources, and human health. For salmonids, chemical interference with olfactory functions (and therefore homing), and other chronic toxic effects, are potential problems due to pesticides (and herbicides). Many of these compounds were banned several decades ago, but due to their chemical characteristics are still detected by water quality sampling programs in the SJR basin (Domagalski 1998).

3.8 Previous Flow Recommendations

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

3.8.1 Delta Flow Criteria – Public Informational Proceeding

In March of 2010 the State Water Board conducted a public informational proceeding to develop flow criteria for the Delta ecosystem necessary to protect public trust resources. The following are summaries of recommendations received from various entities regarding SJR inflows.

In 2005, DFG identified several statistical relationships between flow at Vernalis and Chinook salmon abundance (DFG 2005a). DFG analyses indicate that the most important parameters influencing escapement are spring flow magnitude, duration, and frequency, and that non-flow parameters have little or no relationship to escapement. DFG found that the most highly significant relationship between flow at Vernalis and juvenile production occurs at Mossdale. The relationship between flow and Delta survival to Chipps Island is less significant yet remains positive, suggesting that there are other factors also responsible for through Delta survival. Finally, the relationship between smolts at Chipps Island and returning adults to Chipps Island was not significant, suggesting that perhaps ocean conditions or other factors are responsible for mortality during the adult ocean phase. DFG combined these statistical relationships into a model allowing them to develop flow recommendations (Table 3.15) for the SJR during the March 15 through June 15 time period that will achieve doubling of salmon smolts. DFG’s flow recommendations at Vernalis range from 7,000 cfs to 15,000 cfs and are recommended to be apportioned between the tributaries based on the average annual runoff for each tributary (DFG 2010a).

Table 3.15. Recommended Vernalis Flows Needed to Double Smolt Production at Chipps Island

	Water Year Type				
Flow Type	**Critical**	**Dry**	**Below Normal**	**Above Normal**	**Wet**
Base (cfs)	1,500	2,125	2,258	4,339	6,315
Pulse (cfs)	5,500	4,875	6,242	5,661	8,685
Pulse Duration (days)	30	40	50	60	70
Total Flow (cfs)	7,000	7,000	8,500	10,000	15,000
Total (acre-feet)	614,885	778,772	1,035,573	1,474,111	2,370,768

The 2005 *Recommended Streamflow Schedules to Meet the AFRP Doubling Goal in the San Joaquin River Basin* includes similar recommendations for achieving doubling of Chinook salmon. The AFRP recommendations are based on salmon production models for each of the three major SJR tributaries (Stanislaus, Tuolumne, and Merced Rivers) that are based on regression analyses of recruits per spawner, and April through May Vernalis flows. Adjusted R^2 values range from 0.53 to 0.65 for statistically significant positive relationships between production and flow for each tributary. These relationships suggest that increased flows during the spring outmigration period would enhance salmon production. The model combines the above individual recruitment equations to estimate the flows needed at Vernalis during the February through May period to double salmon production in the SJR basin. The flows recommended at Vernalis range from 1,744 cfs in February of Critically Dry years to a maximum of 17,369 cfs in May of Wet years and generally increase from February through May to mimic the shape of the unimpaired hydrograph (peak flow in May) (Table 3.16). Estimates of flows needed on each tributary to double salmon production range from 51% to 97% of unimpaired flow; with a greater percentage of unimpaired flow needed in drier years than wet years (AFRP 2005).

Table 3.16. Recommended Streamflow Schedules to Meet the AFRP Doubling Goal in the San Joaquin River Basin

Water Year Type	February	March	April	May
Stanislaus River				
Critical	500	785	1,385	1,438
Dry	500	927	1,811	1,950
Below Normal	514	1,028	1,998	2,738
Above Normal	787	1,573	2,636	3,676
Wet	1,280	2,560	3,117	4,827
Tuolumne River				
Critical	744	1,487	2,415	2,895
Dry	784	1,568	2,696	4,072
Below Normal	794	1,589	3,225	4,763
Above Normal	1,212	2,424	3,574	6,850
Wet	2,013	4,027	4,811	8,139
Merced River				
Critical	500	559	1,112	1,332
Dry	500	651	1,375	1,766
Below Normal	500	864	1,498	2,410
Above Normal	582	1,165	1,941	3,205
Wet	1,140	2,279	2,559	4,402

Water Year Type	February	March	April	May
Total (Vernalis)				
Critical	1,744	2,832	4,912	5,665
Dry	1,784	3,146	5,883	7,787
Below Normal	1,809	3,481	6,721	9,912
Above Normal	2,581	5,162	8,151	13,732
Wet	4,433	8,866	10,487	17,369

Source: AFRP 2005

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

In their logit analysis, TBI/NRDC found that Vernalis average March through June flows of approximately 4,600 cfs corresponded to an equal probability for positive population growth or negative population growth. TBI/NRDC found that average March through June flows of 5,000 cfs or greater resulted in positive population growth in 84% of years and flows less than 5,000 cfs resulted in population decline in 66% of years. TBI/NRDC found that flows of 6,000 cfs produced a similar response to the 5,000 cfs or greater flows, and flows of 4,000 cfs or lower resulted in significantly reduced population growth in only 37% of years. The TBI/NRDC analysis suggests that 5,000 cfs may represent an important minimum flow threshold for salmon survival on the SJR. Based on abundance to prior flow relationships, TBI/NRDC estimates that average March through June inflows of 10,000 cfs are likely to achieve the salmon doubling goal (TBI/NRDC 2010c). A summary of the SJR inflow recommendations developed by TBI/NRCD is provided in Table 3.17.

Table 3.17. San Joaquin River Inflow Recommendations

	July - Feb	March		April		May		June	
100% of years (all yrs)	2,000	2,000		5,000		5,000		2,000	
80% (D yrs)	2,000	2,000		5,000	10,000	7,000	5,000	2,000	
60% (BN yrs)	2,000	2,000		20,000	10,000	7,000	5,000	2,000	
40% (AN yrs)	2,000	2,000	5,000	20,000		7,000		2,000	
20% (W yrs)	2,000	2,000	5,000	20,000		20,000	7,000	7,000	2,000

Source: TBI/NRDC 2010b

The California Sportfishing Protection Alliance (CSPA) and California Water Impact Network (CWIN) also developed recommendations for flows on the SJR and major SJR tributaries. CSPA and CWIN recommended that the State Water Board apply two general flow regimes to the Delta to protect and recover public trust resources: one regime would be based on the close linkages between riverine inflows to the Delta, the position of X2[3], and Delta outflows and the life histories of estuarine fish species; and a second regime would be based on pulse flows that match and facilitate the early life stages of salmonid larvae, juvenile rearing, and smoltification (CSPA/CWIN 2010). The recommended pulse flow regime (Table 3.16) focuses on late winter through spring flow periods along with a 10-day pulse flow in late October intended to attract adult spawning salmonids to the SJR basin. CSPA and CWIN's San Joaquin Valley outflows (Table 3.18) are derived from recommended flow releases for the Stanislaus, Tuolumne, and Merced Rivers developed by Mesick (2010a) plus flow from the SJR below Millerton Lake reflecting that river's unimpaired flow, as well as accretions and other inflows.

Table 3.18. Recommended Inflows at Vernalis with Tributary Contributions (in cfs)

Water Year	Feb		Mar		Apr		May		Jun		Oct	
C	▨	13,400 (2 days)		4,500	6,700	8,900	1,200			▨	▨	5,400
D	▨	13,400 (2 days)		4,500	6,700	8,900	1,200			▨	▨	5,400
BN	▨	13,400 (16 days), 26800 (2 days)		4,500	6,700	8,900	11,200	1,200		▨	▨	5,400
AN	▨	13,400 (13 days), 26800 (5 days)		4,500	6,700	8,900	11,200	1,200		▨	▨	5,400
W	▨	13,400 (17 days), 26800 (5 days)		13,400				14,900		▨	▨	5,400

Source: CSPA/CWIN 2010

In its 2010 report on *Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem (Delta Flow Criteria Report)*, the State Water Board determined that approximately 60% of unimpaired flow during the February through June period would be protective of fish and wildlife beneficial uses in the SJR. It should be noted that the State Water Board acknowledged that these flow criteria are not exact, but instead represent the general timing and magnitude of flow conditions that were found to be protective of fish and wildlife beneficial uses when considering flow alone. In addition, these flow criteria do not consider other competing uses of water or tributary specific flow needs for cold water and other purposes (State Water Board 2010).

In order to achieve the attributes of a natural hydrograph the criteria developed in the Delta Flow Criteria Report were advanced as a percentage of unimpaired flow (14-day average) to be achieved on a proportional basis from the tributaries to the SJR. The unimpaired flow estimates from which the 60% criterion is calculated are monthly estimates. To determine the percentage of unimpaired flow needed to protect Chinook salmon, the State Water Board reviewed flow exceedance information to determine what percentage of flow would be needed to achieve various flows. The State Water Board analysis indicated that if 60% of unimpaired flow at Vernalis were provided, average February through June flows would meet or exceed 5,000 cfs

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[3] X2 refers to 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.

in over 85% of years and flows of 10,000 cfs in approximately 45% of years. The frequency of exceeding these flows would vary by month (Figures 3.15 to 3.19). Both the AFRP and DFG modeling analyses presented above seem to support the 60% recommendation of the Delta Flow Criteria Report. However, the time periods for the AFRP recommended flows is from February through May and the time period for the DFG recommended flows is from March 15 through June 15. AFRP, DFG, and TBI/NRDC provide different recommendations for how to distribute flows during the spring period in different years, with increasing flows in increasingly wet years. All are generally consistent with an approach that mimics the natural flow regime to which these fish were adapted.

3.8.2 Anadromous Fish Restoration Program (AFRP)

Several restoration actions, with regard to managing flows, were proposed by the AFRP Core Group as part of Section 3406(b)(1) for implementation in the SJR basin. These restoration actions were developed by eight technical teams that were composed of experts who possessed specific technical and biological knowledge of Central Valley drainages and anadromous fish stocks. The restoration flow targets have never been implemented. A restoration action (Table 3.19) was proposed to manage flows (in cfs) to benefit all life stages of fall-run Chinook salmon on the lower SJR (at Stevinson).

Table 3.19. AFRP Instream Flow Proposals for the SJR at Stevinson

Month	Wet	Above Normal	Below Normal	Dry	Critical
April	5,150	2,650	2,050	1,750	1,250
May	7,000	4,450	3,050	2,300	1,600
June	6,800	3,450	2,600	1,700	1,050

A second restoration action designed to increase white and green sturgeon production was proposed to provide mean monthly flows of at least 7,000 cfs (at Newman) between February and May in wet and above normal years. A third restoration action (Table 3.20) was proposed to manage flows (in cfs) to benefit all life stages of Chinook salmon, American Shad, and white and green sturgeon on the lower SJR at Vernalis.

Table 3.20. AFRP Instream Flow Proposals for the SJR at Vernalis

Month	Wet	Above Normal	Below Normal	Dry	Critical
October	1,450	950	900	700	650
November	2,000	1,500	950	900	650
December	2,850	2,250	950	950	700
January	3,950	2,550	1,100	1,000	750
February	14,000	14,000	2,150	1,450	1,050
March	14,000	14,000	2,750	2,100	1,850
April	28,400	21,800	18,900	13,500	7,800
May	28,400	21,800	18,900	13,500	7,800
June	17,300	9,750	7,650	4,600	2,950
July	4,200	1,700	1,250	650	650
August	1,150	800	600	500	450
September	1,050	750	650	500	450

A restoration action (Table 3.21) was proposed to manage flows (in cfs) to benefit all life stages of fall-run Chinook salmon on the Stanislaus River from Goodwin Dam to the confluence with the SJR.

Table 3.21. AFRP Instream Flow Proposals for the Stanislaus River

Month	Wet	Above Normal	Below Normal	Dry	Critical
October	350	350	300	250	250
November	400	350	300	300	250
December	850	650	300	300	250
January	1,150	800	300	300	250
February	1,450	1,150	700	450	300
March	1,550	1,150	850	650	550
April	5,600	4,300	3,800	2,700	1,500
May	5,600	4,300	3,800	2,700	1,500
June	2,650	1,600	1,300	700	450
July	900	400	350	200	250
August	350	300	250	200	200
September	350	300	250	200	200

A restoration action (Table 3.22) was proposed to manage flows (in cfs) to benefit all life stages of fall-run Chinook salmon on the Tuolumne River from LaGrange Dam to the confluence with the SJR.

Table 3.22. AFRP Instream Flow Proposals for the Tuolumne River

Month	Wet	Above Normal	Below Normal	Dry	Critical
October	750	300	300	200	150
November	1250	800	350	300	150
December	1,400	1,050	350	350	200
January	1,700	1,150	500	400	250
February	2,100	1,700	950	700	500
March	2,300	1,700	1,300	1,000	900
April	2,950	2,450	2,350	1,900	1,500
May	5,150	4,200	3,350	2,500	1,800
June	5,000	3,250	2,600	1,550	1,000
July	2,150	900	650	250	200
August	450	200	100	100	50
September	350	150	150	100	50

A restoration action (Table 3.23) was proposed to manage flows (in cfs) to benefit all life stages of fall-run Chinook salmon on the Merced River from Crocker-Huffman Diversion downstream to the confluence with the SJR.

Table 3.23. AFRP Instream Flow Proposals for the Merced River

Month	Wet	Above Normal	Below Normal	Dry	Critical
October	350	300	300	250	250
November	350	350	300	300	250
December	600	550	300	300	250
January	1,100	600	300	300	250
February	1,450	1,050	500	300	250
March	1,500	1,050	600	450	400
April	1,800	1,350	1,150	950	750
May	2,950	2,300	1,750	1,200	850
June	2,850	1,450	1,150	650	450
July	1,150	400	250	200	200
August	350	300	25	200	200
September	350	300	25	200	200

3.9 Conclusions

3.9.1 Description of Draft SJR Flow Objectives and Program of Implementation

Based on the information discussed above, the State Water Board developed draft changes to the SJR flow objectives and program of implementation that were included as an appendix to the October 2011 draft of the Technical Report. Those draft objectives and program of implementation are also included in Appendix A of this report. The draft objectives and program of implementation may be modified to some degree prior to release of the SED, but the draft objectives and program of implementation represent the conceptual framework the State Water Board is considering for any changes to the objectives and program of implementation. The draft changes include the following narrative flow objective:

> *Maintain flow conditions from the SJR Watershed to the Delta at Vernalis, together with other reasonably controllable measures in the SJR Watershed sufficient to support and maintain the natural production of viable native SJR watershed fish populations migrating through the Delta. Specifically, flow conditions shall be maintained, together with other reasonably controllable measures in the SJR watershed, sufficient to support a doubling of natural production of Chinook salmon from the average production of 1967–1991, consistent with the provisions of State and federal law. Flow conditions that reasonably contribute toward maintaining viable native migratory SJR fish populations include, but may not be limited to, flows that more closely mimic the hydrographic conditions to which native fish species are adapted, including the relative magnitude, duration, timing, and spatial extent of flows as they would naturally occur. Indicators of viability include abundance, spatial extent or distribution, genetic and life history diversity, migratory pathways, and productivity.*

Draft changes to the program of implementation for the narrative SJR flow objective call for the flow objective to be implemented by providing a percentage of unimpaired flow ranging from 20% to 60% from February through June from the Stanislaus, Tuolumne, and Merced Rivers, in addition to base flow requirements. To develop precise requirements for implementation, the draft program of implementation calls for establishing a workgroup consisting of parties with expertise in fisheries management, unimpaired flows, and operations on the Stanislaus, Tuolumne, and Merced Rivers to develop recommendations for consideration by the State

Water Board in the implementation proceedings for the flow objective that will follow adoption of any changes to the Bay-Delta Plan.

The draft program of implementation allows for refinement of the percent of unimpaired flow requirement by allowing for adaptive management based on specific information concerning flow needs to protect fish and wildlife beneficial uses. In addition, the draft program of implementation calls for the development of monitoring and special studies programs to develop further information concerning SJR flow needs for the protection of fish and wildlife beneficial uses in order to inform the adaptive management process, implementation actions, and future changes to the Bay-Delta Plan, including potential changes to the October pulse flow requirements and addition of flow requirements for the periods outside of the February through June and October period. The final program of implementation will also include recommendations to other agencies to take additional actions outside of the State Water Board's purview to protect SJR fish and wildlife beneficial uses. Those actions will include non-flow activities that should take place potentially including, but not limited to: habitat restoration (floodplain restoration, gravel enhancement, riparian vegetation management, passage, etc.), hatchery management, predator control, water quality measures, ocean/riverine harvest measures, recommendations for changes to flood control curves, and barrier operations.

3.9.2 Summary of Basis for Alternative SJR Flow Objectives and Program of Implementation Language

The scientific information discussed in this chapter supports the draft narrative SJR flow objective discussed above and the conclusion that a higher and more variable flow regime in salmon-bearing SJR tributaries to the Delta during the spring period (February through June) is needed to protect fish and wildlife beneficial uses (including SJR basin fall-run Chinook salmon) and other important ecosystem processes. For example, numerous studies have reported that the primary limiting factor for tributary abundances of Chinook salmon are reduced spring flow, and that populations on the tributaries are highly correlated with tributary, Vernalis, and Delta flows (Kjelson et al. 1981; Kjelson and Brandes 1989; USFWS 1995; Baker and Mohardt 2001; Brandes and McLain 2001; Mesick 2001b; Mesick and Marston 2007; Mesick 2009; Mesick 2010 a-d).

As a result of construction and operation of the rim dams, flows within the SJR basin have been substantially altered from the flow regime to which SJR basin fish and wildlife are adapted. As outlined in the hydrology section of this report, water development in the SJR basin has resulted in: reduced annual flows; fewer peak flows; reduced and shifted spring and early summer flows; reduced frequency of peak flows from winter rainfall events; shifted fall and winter flows; and a general decline in hydrologic variability over multiple spatial and temporal scales (McBain and Trush 2002; Cain et al. 2003; Richter and Thomas 2007; Brown and Bauer 2009; NMFS 2009a). At the same time, naturally produced fall-run Chinook salmon and other native SJR basin fish and wildlife have also experienced significant population declines, and as a result may be at a high risk of extinction.

While there are many other factors that contribute to impairments of fish and wildlife beneficial uses in the SJR basin, flows remain a critical component in the protection of these beneficial uses. These other factors do not obviate the need for improved SJR inflow conditions to the Delta to protect fish and wildlife beneficial uses. In fact, many of the other habitat factors that affect community structure (e.g., temperature, water chemistry, physical habitat complexity), are to some extent determined by flow (Moyle et al. 2011). There is the need to comprehensively address the various impairments to fish and wildlife beneficial uses in the SJR basin and the Delta. The flow regime has been described as the "master variable" that regulates the ecological integrity of rivers (Resh et al. 1988; Power et al. 1995; Poff et al. 1997; Poff et al. 2010). Improved flow conditions will serve to underpin restoration activities and efforts to address other stressors. As discussed above, the State Water Board will address the need for other measures needed to protect SJR basin fish and wildlife beneficial uses in the program of implementation for the revised Bay-Delta Plan.

Given the extremely flattened hydrograph of SJR flows and the various competing demands for water on the SJR, it merits noting that the State Water Board must ensure the reasonable protection of fish and wildlife beneficial uses, which may entail consideration of competing beneficial uses of water, including municipal and industrial uses, agricultural uses, and other environmental uses. Estimates of flow needs to protect fish and wildlife beneficial uses are imprecise given the various complicating factors affecting survival and abundance of Chinook salmon, steelhead, and other SJR basin fish and wildlife. Given the dynamic and variable environment to which SJR basin fish and wildlife adapted, and imperfect human understanding of these factors, developing precise flow objectives that will provide certainty with regard to protection of fish and wildlife beneficial uses is likely not possible. Nevertheless, the weight of the scientific evidence indicates that increased and more variable flows are needed to protect fish and wildlife beneficial uses. While there is uncertainty regarding specific numeric criteria and how the SJR ecosystem will respond to an alternative flow regime, scientific certainty is not the standard for agency decision making.

To assist the State Water Board in determining the amount of water that should be provided to reasonably protect fish and wildlife beneficial uses in the SJR basin, a range of alternative SJR flows will be analyzed. Based on the information discussed above, retaining the spatial and temporal attributes of the natural flow regime appears to be important in protecting a wide variety of ecosystem processes. The historic practice of developing fixed monthly flow objectives to be met from limited sources has been shown to be less than optimal in protecting fish and wildlife beneficial uses in the SJR basin. Accordingly, to preserve the attributes of the flow regime to which native SJR basin fish and wildlife have adapted, and that are believed to be generally protective of the beneficial uses, each of the alternatives is expressed as a percentage of unimpaired flow, and will consider volumes of water reflective of flow at Vernalis such that flows will come from the major salmon-bearing SJR tributaries (i.e., Stanislaus, Tuolumne, and Merced Rivers). It is important to provide flows from the major SJR tributaries to meet alternative flows at Vernalis because diminishing the water resource disproportionately (e.g., from any one tributary) would be deleterious to fish and wildlife beneficial uses within that tributary. The SJR Management Plan of 1995 recognized the importance of coordinating flows from the tributaries to facilitate migration and increase the survival of Chinook salmon. The highly coordinated fashion in which flows from all three major SJR tributaries are released to meet the VAMP flows (SJRGA 2010) also demonstrates the acknowledged importance of coordinated flows.

In a recent report describing methods for deriving flows needed to protect the Bay-Delta and watershed, Fleenor et al. (2010) suggest that while using unimpaired flows may not indicate precise, or optimum, flow requirements for fish under current conditions, it would, however, provide the general seasonality, magnitude, and duration of flows important for native species (see also Lund et al. 2008). Accordingly, as discussed above, the draft program of implementation for the narrative SJR flow objective provides for development of specific implementation provisions through a multidisciplinary workgroup and allows for adaptive management of the unimpaired flow requirement in order to respond to new information and changing circumstances.

The following water supply impacts analysis, evaluates alternative flows of 20%, 40%, and 60% of unimpaired flows from February through June (Figures 3.15 – 3.20) to demonstrate the ability of the analysis to appropriately evaluate the water supply effects of the range of potential alternative SJR flow objectives that will be analyzed in the SED. Any additional alternatives that may be included in the SED will fall within this range.

In its 2010 report on *Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem*, the State Water Board determined that approximately 60% of unimpaired flow at Vernalis from February through June would be protective of fish and wildlife beneficial uses in the SJR basin when considering flow alone. It should be noted that those criteria did not consider other competing uses of water or tributary specific needs for cold water and other purposes that will need to be considered when making changes to the Bay-Delta Plan (State Water Board 2010). The 60% recommendation is imprecise; it provides an upper end for the range of unimpaired flow alternatives that will be evaluated in the SED. The 20% alternative provides a lower end for this range and the 40% alternative provides an intermediate value for evaluation in the SED. In comparison to the alternatives, February through June flows on the Stanislaus, Tuolumne, Merced and lower SJR at Vernalis from water years 1986 through 2009 have median unimpaired flow values of 40%, 21%, 26%, and 29% respectively.

The SED will include an analysis of the 20%, 40%, and 60% of unimpaired flow alternatives and potentially other alternative flow levels within this range to determine the potential environmental, water supply, economic, and hydroelectric power production impacts of the various alternatives. The State Water Board will then use the information from the various effects analyses included in the SED, along with information included in this report, and other information presented to the State Water Board to make a decision on what changes should be made to the SJR flow objectives and program of implementation to provide for the reasonable protection of fish and wildlife beneficial uses. Flow needed for the protection of fish and wildlife beneficial uses will be balanced against flow needs for other beneficial uses of water including: agriculture and hydropower production.

As indicated above, the State Water Board’s current review of SJR flow requirements is focused on the February through June time frame, as flows (magnitude, duration, frequency) during this period are a dominant factor affecting salmon abundance in the basin. The fall pulse flow objective contained in 2006 Bay-Delta Plan is not the subject of this review. However, the draft program of implementation states that the State Water Board will reevaluate the implementation of the October pulse flow and flows during other times of the year after monitoring and special studies during the water rights and FERC processes have been conducted to determine what, if any, changes should be made to these flow requirements and their implementation to achieve the narrative San Joaquin River flow objective.

Figures 3.15 through 3.19 below present exceedance plots of San Joaquin River at Vernalis monthly unimpaired flows (for 1922 to 2003) and observed flows (for 1986 to 2009), along with 20%, 40%, and 60% of unimpaired monthly flows for the months of February through June, respectively. Figure 3.20 provides the same for all February through June monthly flows together over the same time periods. These flows are presented as average monthly flow rates (in cfs), rather than total monthly volumes (in TAF), for better comparison with various flow recommendations and values in the literature. The 20%, 40%, and 60% of unimpaired flow plots in these figures are simple proportions of unimpaired flow for reference purposes only. They do not necessarily represent, but are similar to, flows that would result from implementation of the 20%, 40%, or 60% unimpaired flow alternatives (as described further in Chapter 5). For instance, releases to meet other flow requirements, flood control releases, and other inflows and accretions would increase the flows that would actually occur under the 20%, 40%, and 60% of unimpaired flow alternatives.

As described in Chapter 2, observed monthly flows are less than the median value 50% of the time, with many instances of very low percentages of unimpaired flow, particularly on the Tuolumne and Merced Rivers. Applying minimum unimpaired flow requirements, however, would eliminate the very low percentage of unimpaired flows seen in the observed flows. In the figures below, this will tend to increase the percentage of time with higher flow levels and provide a similar distribution of flows for a given overall percentage of unimpaired flow.

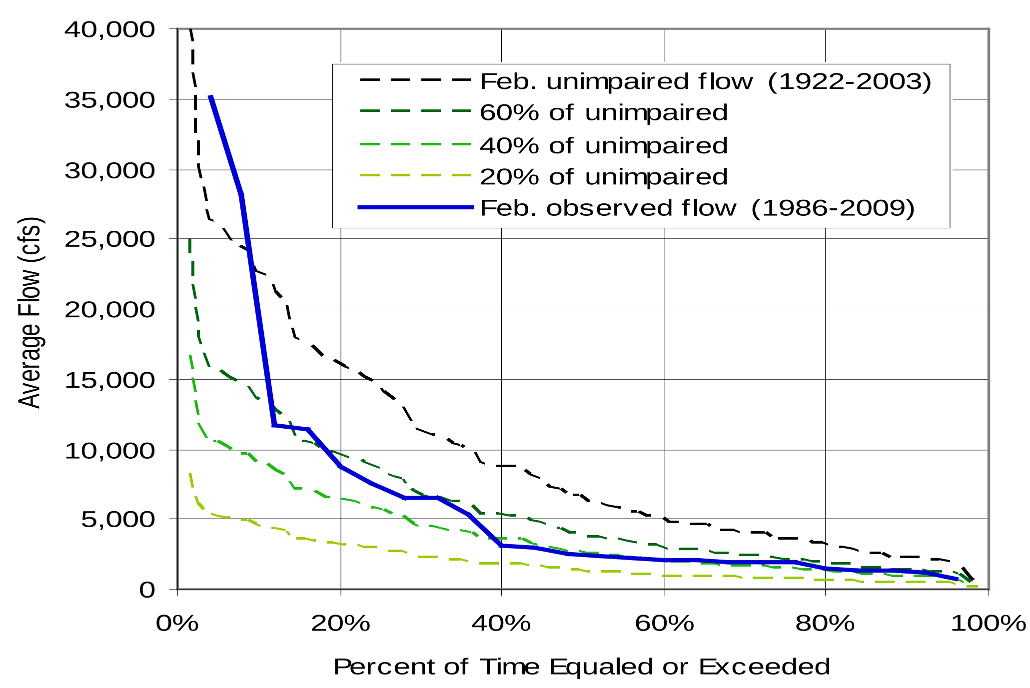

Figure 3.15. Exceedance Plot of February Monthly Average SJR Unimpaired and Observed Flows (cfs) at Vernalis

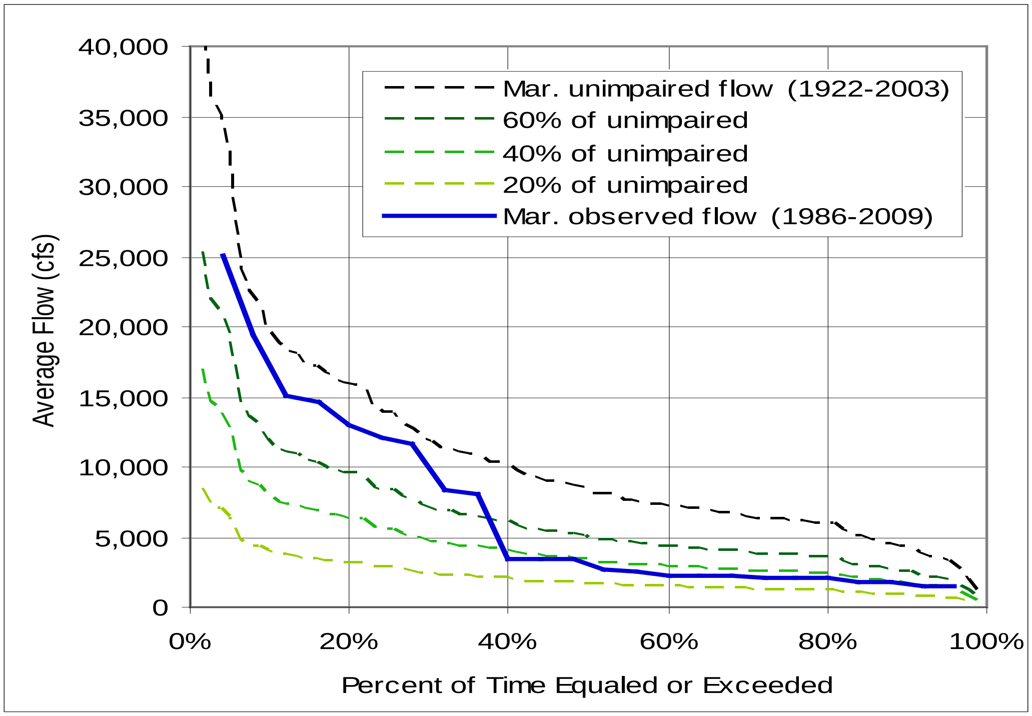

Figure 3.16. Exceedance Plot of March Monthly Average SJR Unimpaired and Observed Flows (cfs) at Vernalis

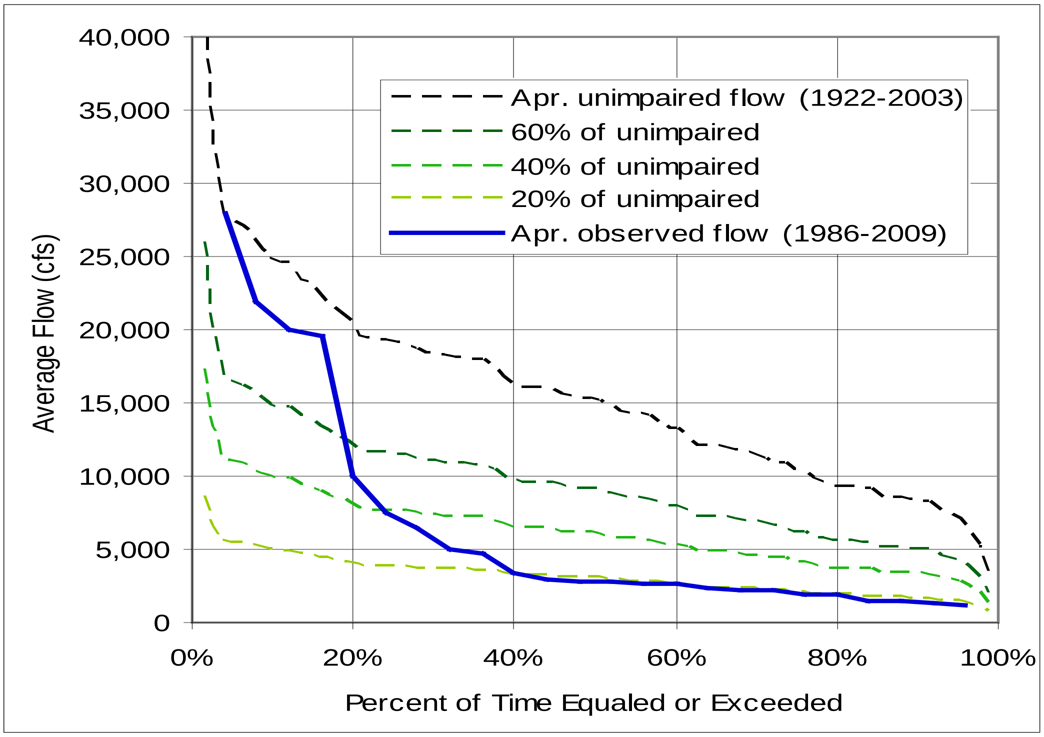

Figure 3.17. Exceedance Plot of April Monthly Average SJR Unimpaired and Observed Flows (cfs) at Vernalis

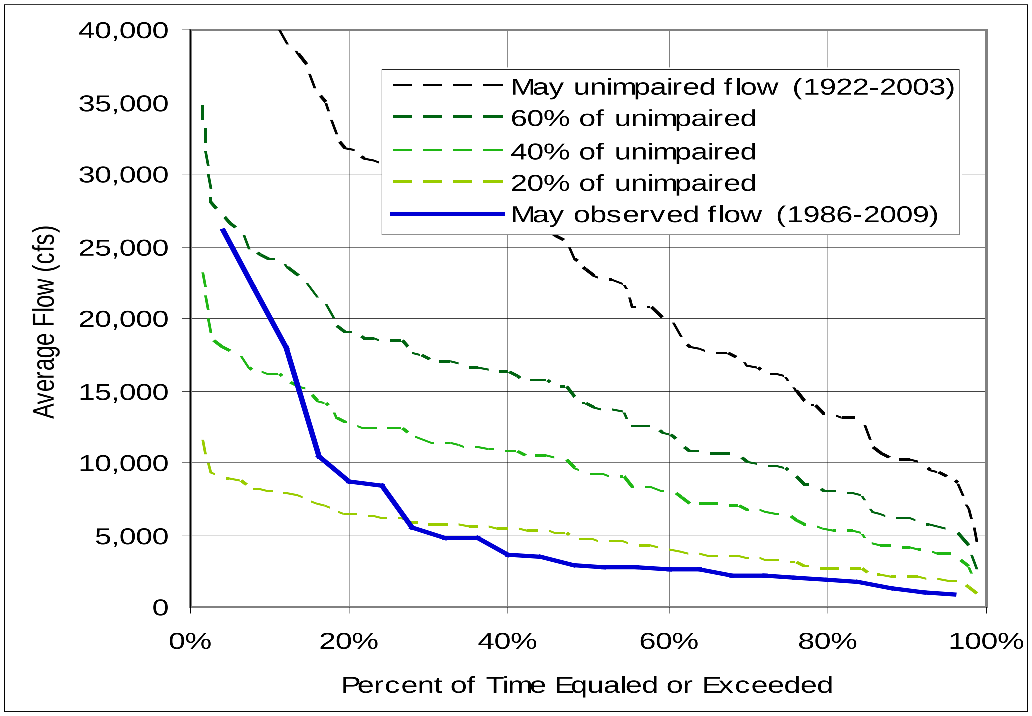

Figure 3.18. Exceedance Plot of May Monthly Average SJR Unimpaired and Observed Flows (cfs) at Vernalis

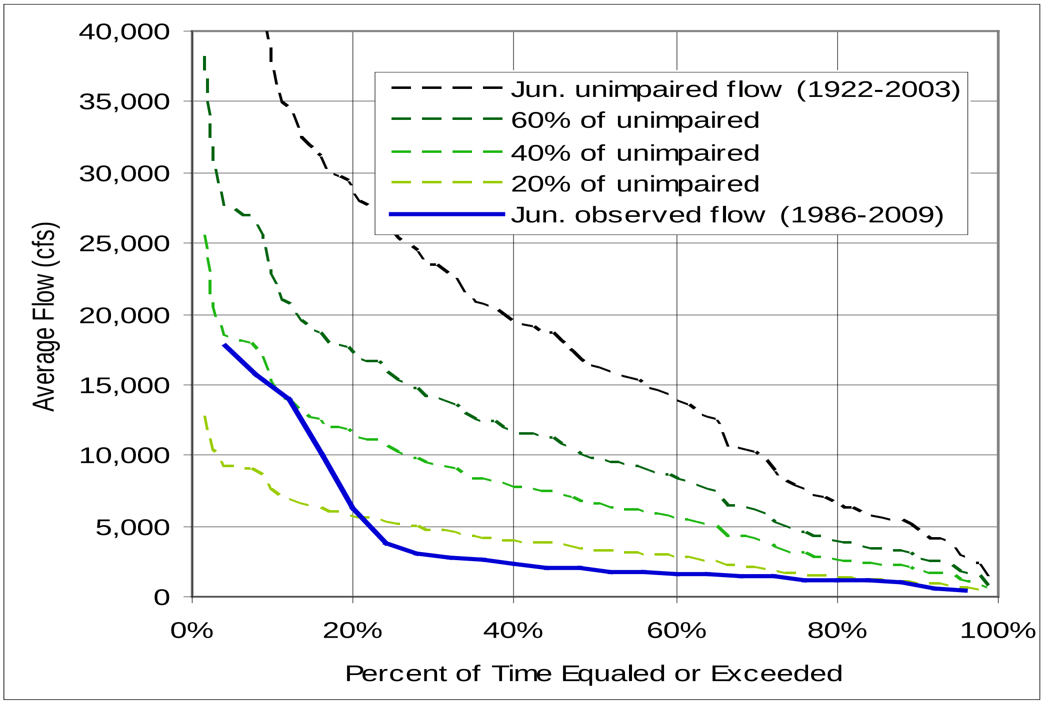

Figure 3.19. Exceedance Plot of June Monthly Average SJR Unimpaired and Observed Flows (cfs) at Vernalis

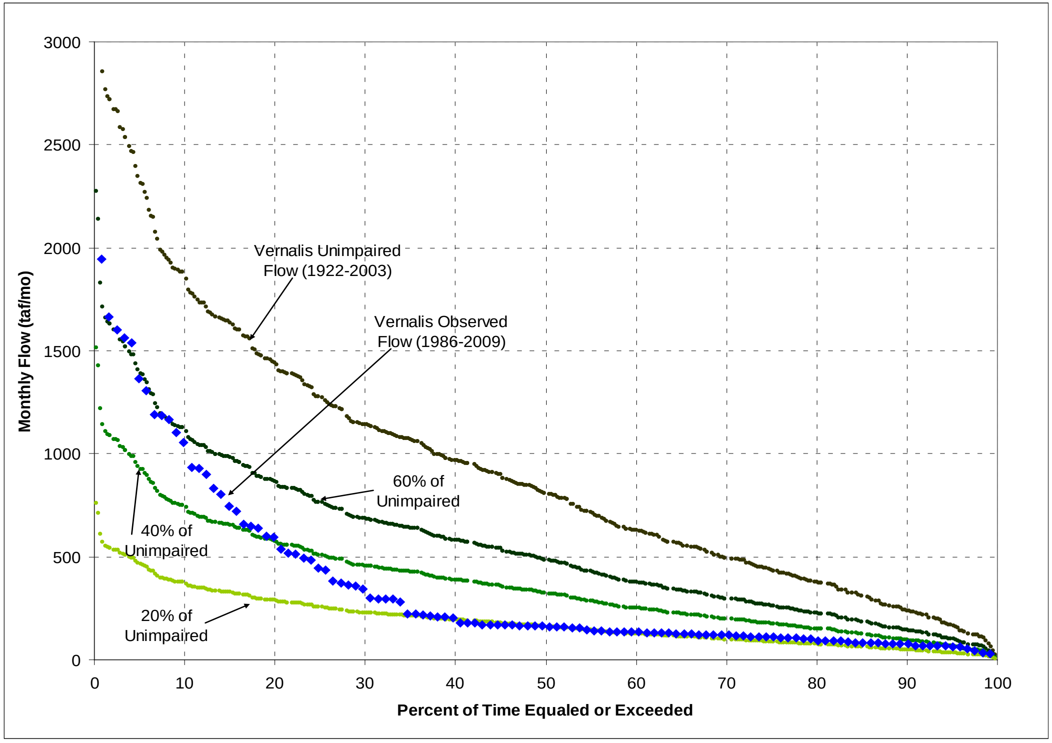

Figure 3.20. Exceedance Plot of Monthly Average SJR Unimpaired and Observed Flows (cfs) at Vernalis, February–June

4 Southern Delta Salinity

Evaluation of the LSJR flow and southern Delta water quality alternatives in the SED will consider their potential effects on various environmental resources and any associated economic impacts. This section describes the technical information and analytical methods that will be used to evaluate the potential salinity-related impacts of these objective alternatives in the SED.

4.1 Background

The State Water Board established salinity compliance stations within the south Delta at the San Joaquin River near Vernalis (station C-10) (Vernalis); the San Joaquin River at Brandt Bridge (station C-6); Old River at Middle River/Union Island (station C-8); and Old River at Tracy Road Bridge (station P-12) as shown in Figure 4.1. The salinity objective at each station is 0.7 millimhos per centimeter (mmhos/cm) electrical conductivity (EC) during the summer irrigation season (April through August) and 1.0 mmhos/cm EC during the winter irrigation season (September through March). Also shown for reference are the boundaries of the legal Delta and the South Delta Water Agency. Salinity objectives at these stations were first established in the *1978 Sacramento–San Joaquin Delta and Suisun Marsh Water Quality Control Plan* (State Water Board 1978).

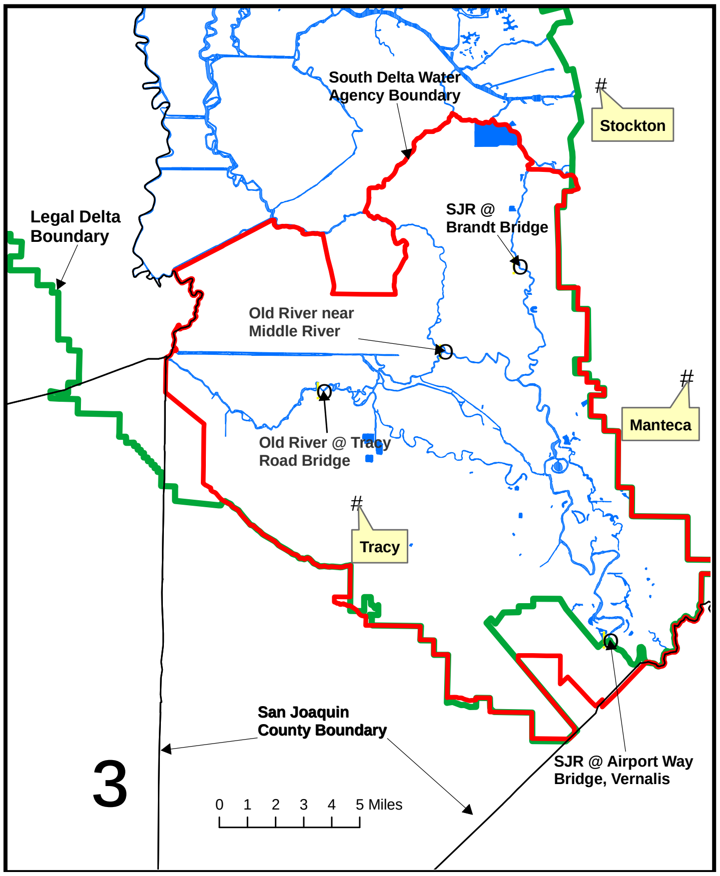

Figure 4.1. Map of Southern Delta Showing State Water Board Salinity Compliance Stations and Boundaries of the Legal Delta and South Delta Water Agency

As stated in the 2010 Hoffman Report, salt stress can damage crops in three different ways. First, and of major concern in the southern Delta, is season-long crop response to salinity. The most common whole-plant response to salt stress is a general stunting of growth. As soil salinity increases beyond a threshold level both the growth rate and ultimate size of crop plants progressively decreases. However, the threshold and the rate of growth reduction vary widely among different crop species. Second, crop sensitivity to soil salinity continually changes during the growing season. Many crops are most sensitive to soil salinity during emergence and early seedling development. Third, when crops are irrigated with sprinkler systems, foliar damage can occur when the leaves are wet with saline water. Sprinkler foliar damage is most likely to occur under hot, dry, and windy weather conditions. For more information on the effects of salinity on crops grown in the southern Delta, refer to the 2010 Hoffman Report which is included as an attachment to this Technical Report.

The approach to developing the objectives involved a determination of the water quality needs of significant crops grown in the area, the predominant soil type, and irrigation practices in the area. The State Water Board based the southern Delta EC objectives on the calculated maximum salinity of applied water which sustains 100% yields of two important salt sensitive crops grown in the southern Delta (beans and alfalfa) in conditions typical of the southern Delta.

In keeping with the literature on crop response to salinity, numerical values for EC are given in units of deciSiemens per meter (dS/m) wherever possible. This is also numerically equal to mmhos/cm, a now-outmoded unit of measure that was used for decades in agriculture to quantify salinity. EC values are sometimes also presented as microSiemens per centimeter (µS/cm) or micromhos per centimeter (µmhos/cm), which are both 1,000 times larger than numerical values in units of dS/m.

4.2 Salinity Model for the San Joaquin River Near Vernalis

An Excel spreadsheet model, created by State Water Board staff, was used to estimate how EC at Vernalis might be affected by changing flows from the Stanislaus, Tuolumne, and Merced Rivers in response to LSJR flow alternatives. The spreadsheet model uses flow and EC input from the CALSIM II model.

The ionic composition of the tributaries with headwaters in the Sierra Nevada Mountains is different from the ionic composition of the SJR as it flows through the valley floor. These different ionic compositions could lead to a combined EC that differs from a simple mass balance, but this difference is generally observed to be small in waters with the ranges of EC observed in the project area. Also, for consistency with CALSIM II, EC from each tributary is calculated as a simple mass balance.

Flow and EC downriver of the confluence of a tributary with the SJR are calculated proportional to the inflow and EC entering the confluence. Following the law of conservation of mass, the model's governing equation is described in Equation 4.1.

$$(EC * Flow)_{Downstream} = (Flow * EC)_{Tributary} + (Flow * EC)_{River} \qquad (Eqn.\ 4.1)$$

The model sums Merced River and upstream SJR flow, and calculates the flow-weighted mixed Merced River and SJR EC. The calculated flow and EC are used as the upstream inputs for the SJR at the confluence of the Tuolumne River. Inflows and salinity loads (i.e., Flow x EC) to the SJR between the Merced and the Tuolumne are held constant. This calculation is repeated through the confluence of the Stanislaus River, yielding a calculated flow and EC at Vernalis that would occur as a result of modifying flows in the major tributaries.

4.2.1 Baseline Salinity Conditions

Average monthly flow and EC estimates are extracted from CALSIM II model output files for water years 1922 through 2003. Table 4.1 shows the CALSIM II channels used in this model.

Table 4.1. CALSIM Channels Used in the Flow-Salinity Model

Location	CALSIM II ID	Description
Vernalis	C639	Flow into Vernalis from the confluence of the Stanislaus River with SJR
Confluence of Stanislaus River with SJR	C528	Flow from the Stanislaus River into the SJR
Confluence of Tuolumne River with SJR	C545	Flow from the Tuolumne River into SJR
Confluence of Merced River with SJR	C566	Flow from the Merced River into SJR

Modeled flows and corresponding salinity from the SJR (above the Merced River confluence) and other sources into the mainstem SJR are lumped together as described below.

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

In Figure 4.2, monthly average observed salinity data from the California Data Exchange Center (CDEC) at Vernalis (DWR 2010a) is plotted together with the CALSIM II estimates of salinity at Vernalis for water years 1994 through September 2003. This represents a period commencing shortly after temporary agricultural flow barriers in the southern Delta were regularly installed through to the end of the overlapping CALSIM II period of simulation.

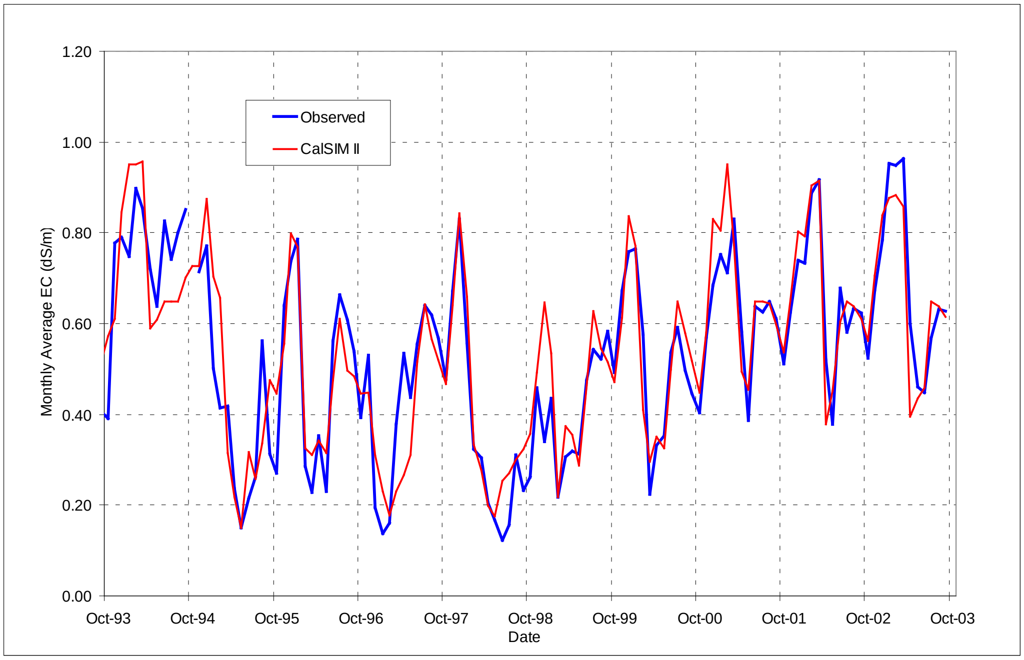

Figure 4.2. Comparison of CALSIM II Salinity (dS/m) Output at Vernalis to Monthly Average Observed Data at the Same Location for Water Years 1994 through 2003

4.2.2 Tributary EC Calculations

Output from the CALSIM II model is used to create an EC to flow relationship for each tributary at the confluence with the SJR. CALSIM II calculated EC at low flow conditions follows an exponential trend while EC at higher flow conditions approaches a constant value. The general form of the exponential equation is Equation 4.2.

$$EC = K_S * F^b \qquad (Eqn.\ 4.2)$$

In Equation 4.2, EC and F represent electrical conductivity and flow respectively. Table 4.2 shows the coefficients used in Equation 4.2 to calculate EC and the coefficient of determination for each exponential equation.

Table 4.2. Coefficients Used to Approximate EC for Each Tributary

Tributary	K_S	b	R^2
Stanislaus	214.2	-0.16	0.18
Tuolumne	461.72	-0.337	0.94
Merced	448.3	-0.368	0.86

At the beginning of the exponential approximation (flows less than 6 TAF), some EC values were not valid, so an upper bound on EC was used. Invalid data were values more than 2 standard deviations from the mean EC. Toward the end of the exponential approximation equation, the EC stops decreasing as flow increases (Figure 4.3, Figure 4.4, and Figure 4.5). For this reason, a reasonable threshold value was selected to approximate EC at high flows. By inspection, these threshold values were selected to yield results similar to CALSIM II calculations. Flows below the threshold used the exponential equation, while flows above the threshold used values summarized in Table 4.3.

Table 4.3. Threshold Values for EC Approximations on Each Tributary

Tributary	Threshold Flow [TAF]	High Flow Constant [μS/cm]	Maximum EC [μS/cm]
Stanislaus	200	95	300
Tuolumne	145	85	None
Merced	100	85	500

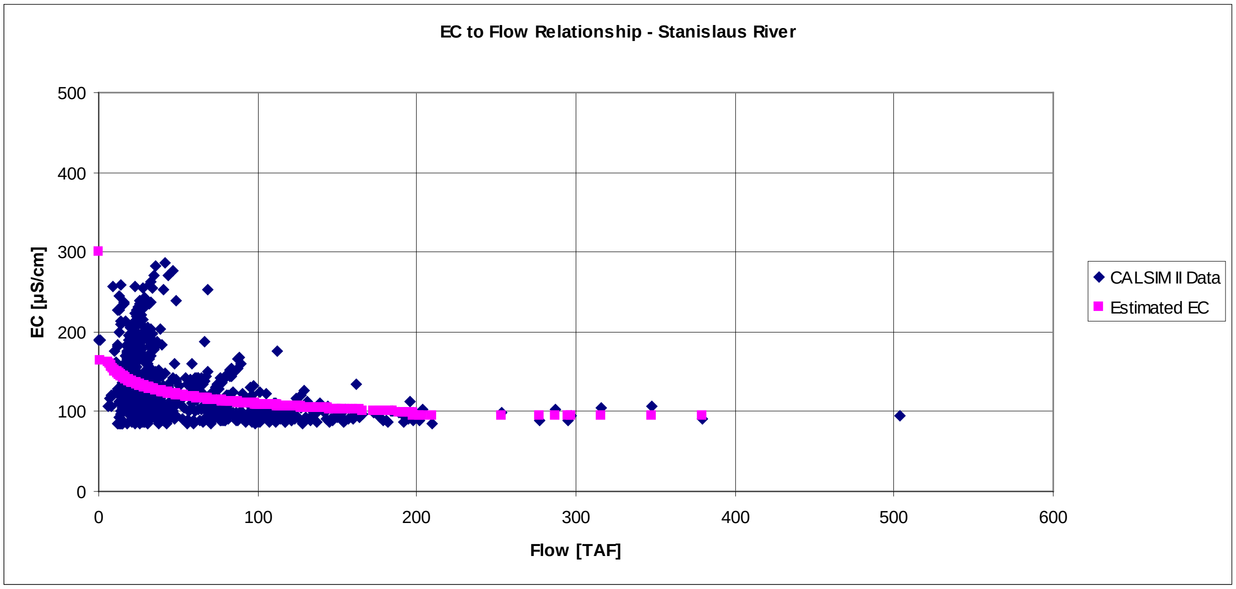

Figure 4.3. Estimated EC from CALSIM II Data on the Stanislaus River

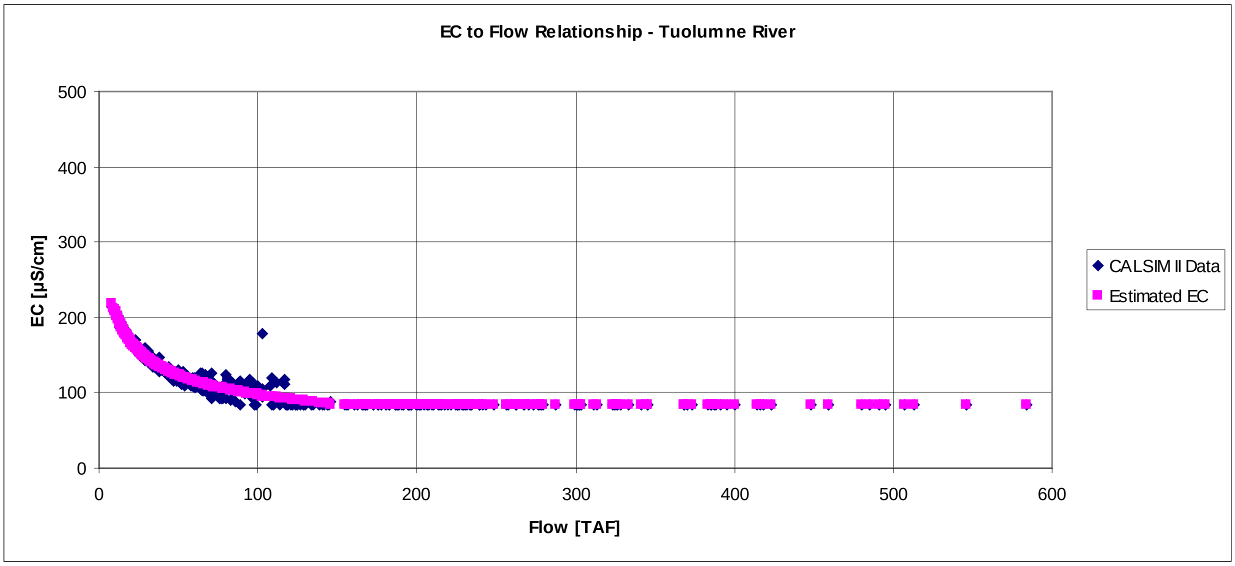

Figure 4.4. Estimated EC from CALSIM II Data on the Tuolumne River

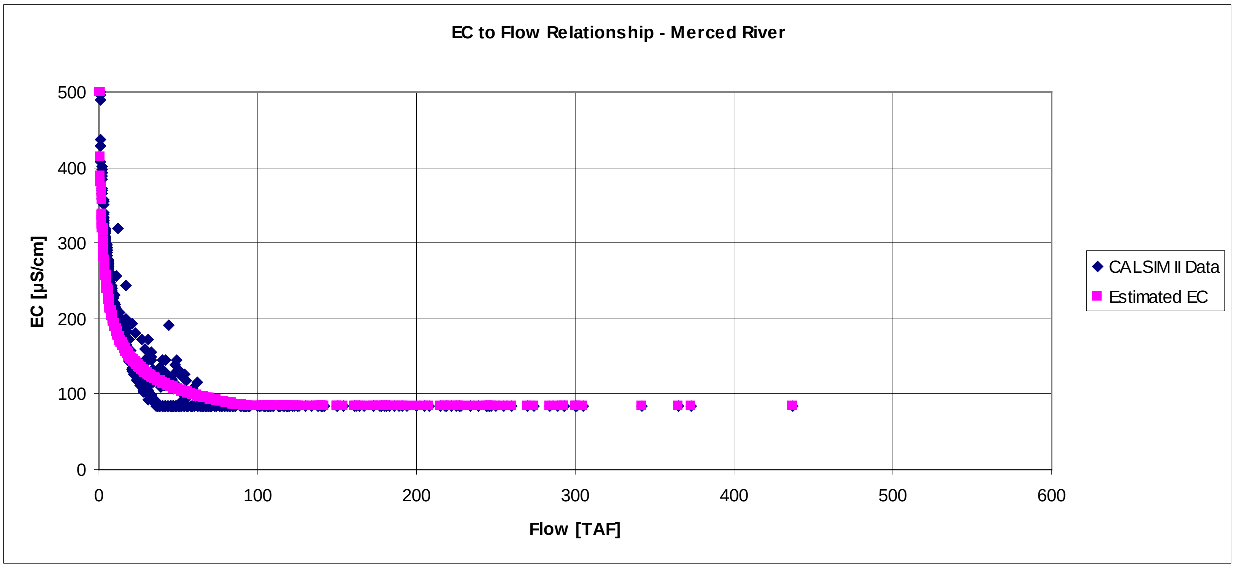

Figure 4.5. Estimated EC from CALSIM II Data on the Merced River

In June 2004 the United States Bureau of Reclamation (USBR) issued a technical memorandum entitled *Development of Water Quality Module,* which calculated EC to flow relationships for the Tuolumne and Merced Rivers (USBR 2004). USBR EC to flow relationships were compared to the EC to flow relationships generated with CALSIM II output and were determined to be approximately equal; thus the CALSIM II EC to flow relationships are used in the model for these two rivers.

4.2.3 Calculating EC at Vernalis

The modeled salt load at Vernalis must equal the sum of the salt loads of the tributaries and all other additional upstream sources. Only the flow on the tributaries varies as a result of evaluating flow alternatives, leaving all other salt load sources as a constant value. The constant value of salt loads from SJR non-tributary sources, L_{SJR}, is found by subtracting the salt loads from the tributaries from the salt load at Vernalis:

$$L_{SJR} = (Flow * EC)_{Vernalis} - (Flow * EC)_{Tributaries} \qquad (Eqn.\ 4.3)$$

Once the EC to flow relationships are established, unimpaired flow data replace the CALSIM II model flows. These new flows for the months of February through June are used with the EC to flow relationships to calculate new EC values associated with the new flows in each tributary. The new EC at Vernalis is the mass balance equation (Equation 4.1) for the salt load at Vernalis divided by the new flow balance at Vernalis, where the new flow and EC values are designated with the prime symbol (‘).

$$EC'_{Vernalis} = \frac{(Flow'{*}EC')_{Tributaries} + L_{SJR}}{Flow_{Vernalis} + (Flow' - Flow)_{Tributaries}} \qquad (Eqn.\ 4.4)$$

Figure 4.6 shows the calculated EC at Vernalis for water years1994–2003 at 40% and 60% of unimpaired flow.

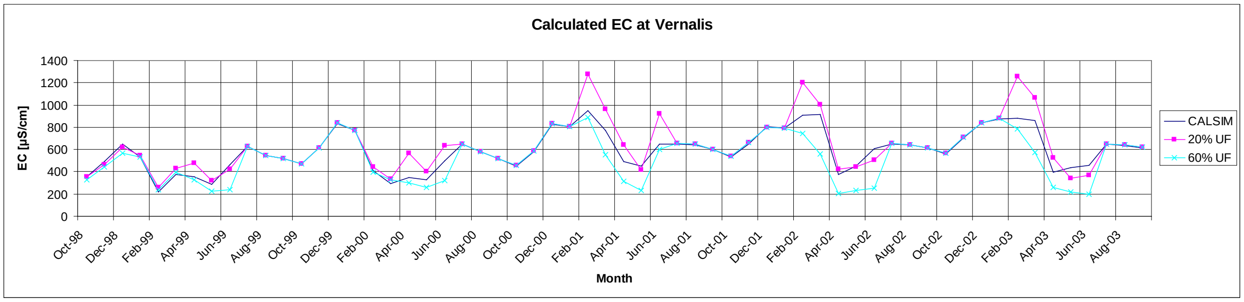

Figure 4.6. Calculated EC at Vernalis for the 40% and 60% Unimpaired Flow Example Compared to CALSIM II Results for Water Years 1994–2003

4.3 Factors Affecting Salinity in the Southern Delta

Salinity levels in the southern Delta are affected primarily by the salinity of water flowing into the southern Delta from the SJR near Vernalis and evapo-concentration of salt in water that is diverted from and discharged back into southern Delta channels for agricultural purposes. Point sources of salt in the southern Delta have a small overall salinity effect. This section discusses the methods used in the SED to evaluate the effect of these sources and processes.

4.3.1 Estimating Southern Delta Salinity Degradation

This section describes the regression analyses used to establish a relationship between salinity at the three interior southern Delta salinity stations and the upstream SJR near Vernalis station. These relationships will be used to estimate the assimilative capacity needed at Vernalis to comply with a particular salinity objective alternative in the southern Delta. This type of planning analysis provides a conservative general estimate of this relationship. This type of analysis does not provide, nor does it require, the dynamic and higher resolution modeling provided by the California DWR Delta simulation model (DSM2) or other hydrodynamic and water quality models of the south Delta. Such simulation models are appropriate for more detailed modeling studies of south Delta barrier operations or changes to CVP and SWP operating conditions. In addition, DWR has found that DSM2 underestimates salinity at Old River near Tracy (an important location for this analysis), and has recommended that regression analysis would be appropriate for this type of analysis (DWR, 2007b).

To estimate salinity degradation between Vernalis and the three southern Delta compliance stations, regression analyses were conducted using salinity data from the DWR CDEC (DWR, 2010a). Figure 4.7, Figure 4.8, and Figure 4.9 present the monthly average salinity data for all months from January 1993 to December 2009 for Old River at Tracy (CDEC station = OLD), Old River at Middle River/Union Island (CDEC station = UNI), and SJR at Brandt Bridge (CDEC station = BDT). Each station is plotted against corresponding salinity data at Vernalis (CDEC station = VER). The least squares linear regression line for each plot is shown on each plot giving the slope, y-intercept and associated correlation coefficient. The 1:1 line, where salinity at the two locations would be equal, is also shown for reference.

In general the increase in salinity downstream of Vernalis is greatest at Old River at Tracy. As such, the regression equation from this location represents a reasonable worst-case estimate of salinity degradation in the south Delta for planning purposes. Two separate regressions were further developed, one for the months of April through August in Figure 4.10 and the other for

September through March in Figure 4.11; the former period corresponding to the main growing season. Each figure shows the best-fit regression line and equation for the estimate of the EC at Old River at Tracy as a function of EC at Vernalis. Also shown is the line representing the equation that will provide an estimate of EC at Old River at Tracy which is at or above the actual EC at Old River at Tracy, 85% of the time (85% prediction line).

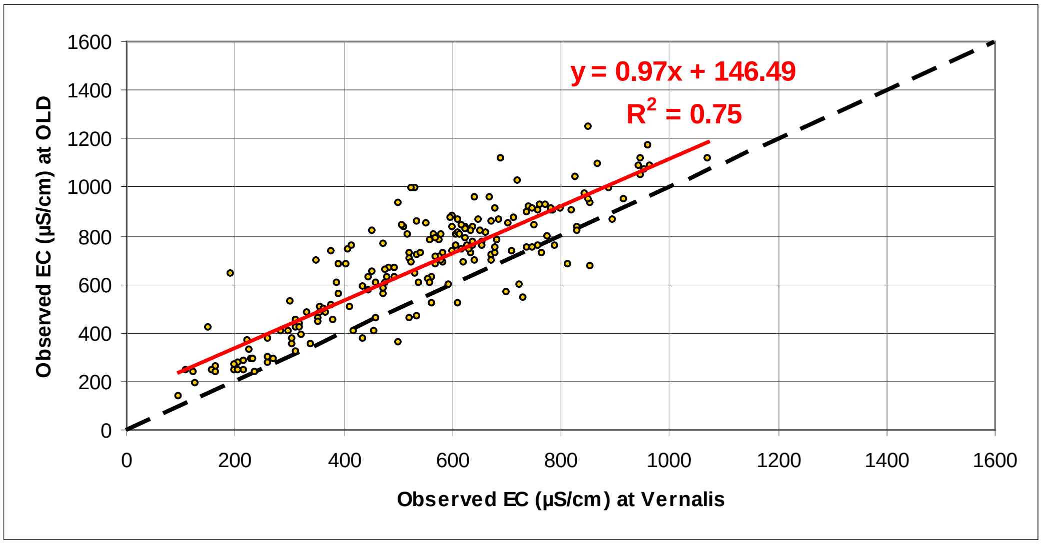

Figure 4.7. Monthly Average Salinity Data from January 1993 to December 2009 for Old River at Tracy (OLD) Plotted Against Corresponding Salinity Data at SJR Near Vernalis

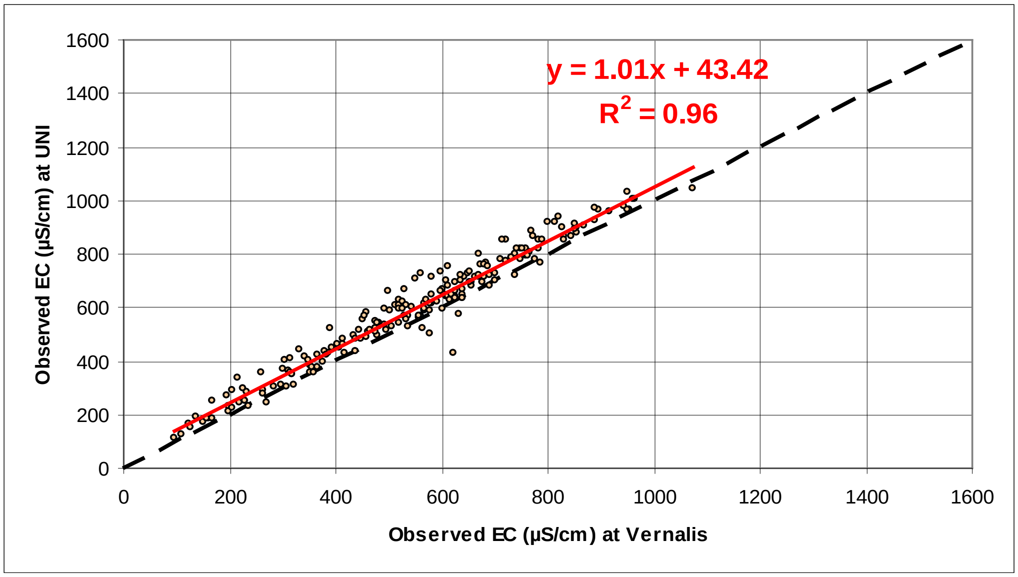

Figure 4.8. Monthly Average Salinity Data from January 1993 to December 2009 for Old River at Middle River/Union Island (UNI) Plotted Against Corresponding Salinity Data at SJR Near Vernalis

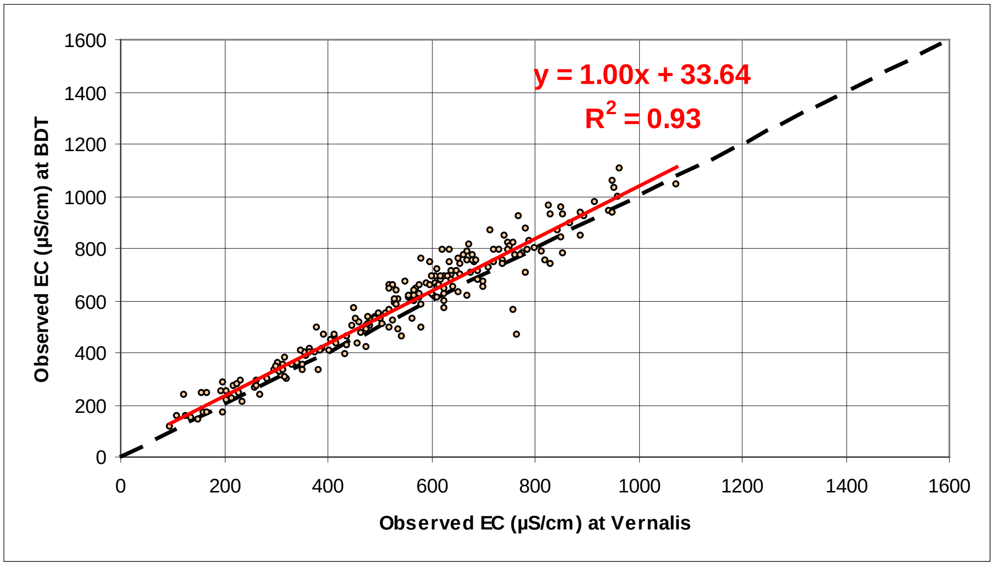

Figure 4.9. Monthly Average Salinity Data from January 1993 to December 2009 for SJR at Brandt Bridge (BDT) Plotted Against Corresponding Salinity Data at SJR Near Vernalis

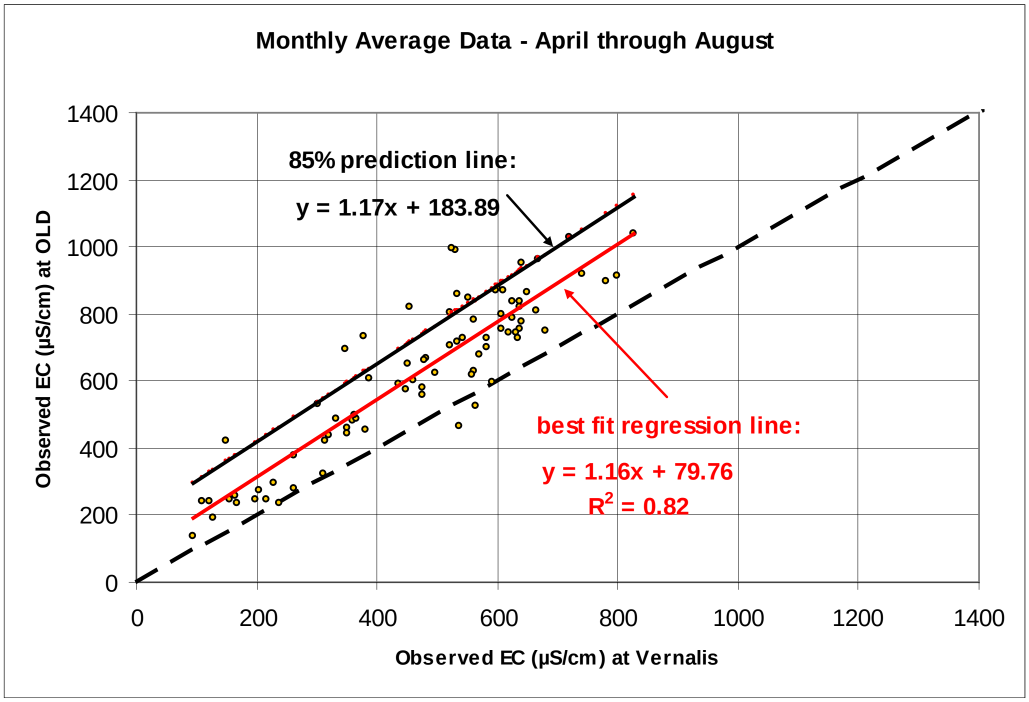

Figure 4.10. Monthly Average Salinity Data for April through August from 1993 through 2009 for Old River at Tracy (OLD) Plotted Against Corresponding Salinity Data at SJR Near Vernalis, with Best Fit Regression and 85% Prediction Lines

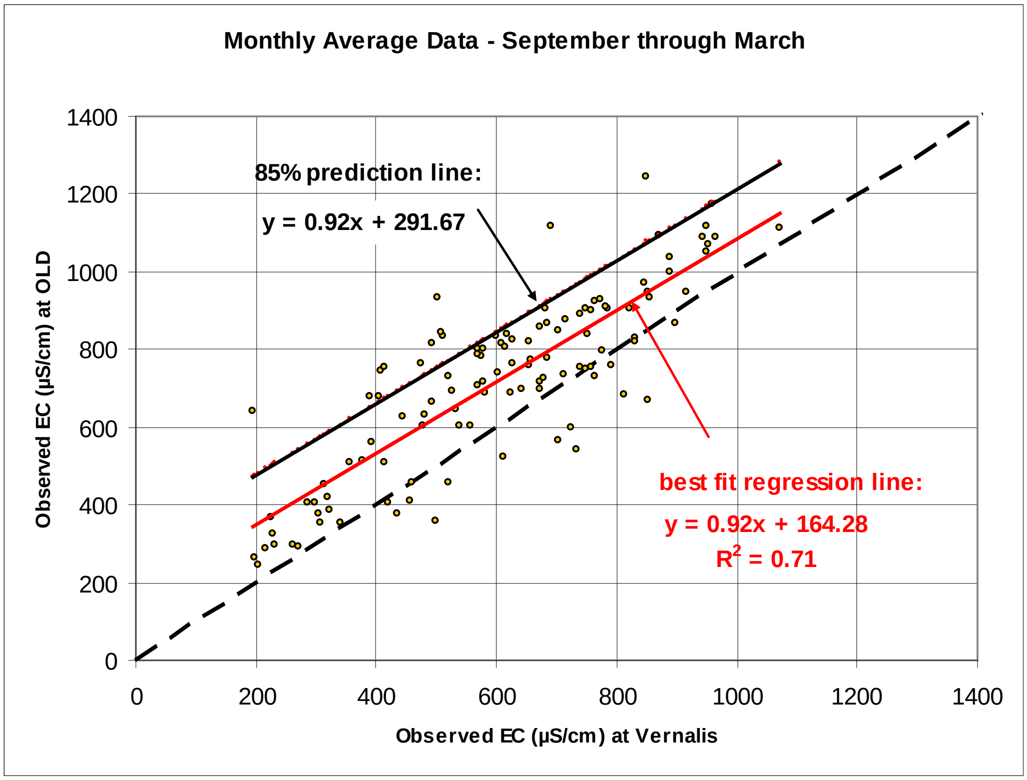

Figure 4.11. Monthly Average Salinity Data for September through March from 1993 through 2009 for Old River at Tracy (OLD) Plotted Against Corresponding Salinity Data at SJR near Vernalis, with Best Fit Regression and 85% Prediction Lines

4.3.2 Salt Loading from NPDES Discharges in Southern Delta

Two methods of analysis were used to understand the relative contribution of salt loading to the southern Delta from local NPDES point sources.

DWR Modeling Study of NPDES Discharges

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

Mass Balance Analysis

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

The analysis compares the permitted maximum salinity loads from the City of Tracy, Deuel Vocational Facility, and Mountain House Community Services District wastewater treatment plants to the salinity load entering at the HOR. Figure 4.12 presents the salt load from HOR in tons/month and the total load from these three point sources as a percentage of the total HOR load for each month from January 1993 to December 2009. The results demonstrate that the salt load from point sources in this part of the southern Delta is a small percentage of the salt load entering from upstream.

Salt loads from point sources were derived using the NPDES permitted discharge rates and water quality limits. Permitted discharges for the City of Tracy, Deuel Vocational Facility, and Mountain House Community Services District wastewater treatment plants are 16.0, 0.62, and 0.54 mgd, respectively. The respective water quality limits for the permitted dischargers are 1,755, 2,604, and 1,054 µS/cm (Central Valley Regional Water Quality Control Board Order Numbers R5-2007-0036, R5-2008-0164, and R5-2007-0039). Salinity inputs at HOR were derived by assuming the same salinity concentrations as those measured at the SJR near Vernalis, and by calculating flow as the difference in the measured flow at the SJR near Vernalis and the measured flow at the HOR (as measured at USGS station #11304810 at the Garwood/Highway 4 bridge immediately upstream of the City of Stockton wastewater treatment plant).

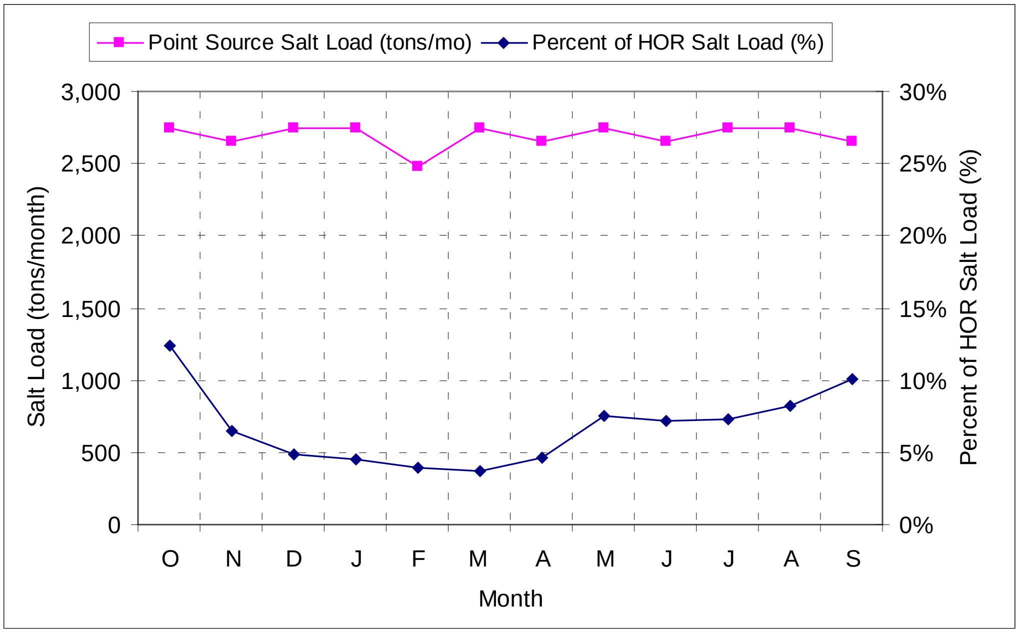

Figure 4.12. Theoretical Salinity Loading from the City of Tracy, Deuel Vocational Facility and Mountain House Wastewater Treatment Plants Stated as Total Load (tons/month) and as a Percent of the Load Entering the Head of Old River

4.4 Effects of Salinity in the Southern Delta

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

4.4.1 Effects on Agricultural Supply Beneficial Use

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

As part of the Bay-Delta Plan the State Water Board committed to re-evaluate the salinity objectives in the southern Delta. With input from stakeholders, a contract was established with Dr. Glenn Hoffman to develop the above report, which reviewed the current scientific literature regarding crop salt tolerance and to assess current conditions in the southern Delta. After presenting background and a description of soils and crops in the southern Delta, this report provides an overview of several factors affecting crop response to salinity, including a discussion of the general state of knowledge and the specific southern Delta situation. The factors considered were:

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

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

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

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

- Salt sensitive crops of significance in the southern Delta include almond, apricot, dry bean, and walnut, with dry bean being the most sensitive.
- Based on the last nine years of data, the current level of salinity in the surface waters of the southern Delta appears suitable for all agricultural crops.
- Neither sodicity nor toxicity should be a concern for irrigated crops; however, based on limited data and known crop tolerances, boron may be a concern.
- Depth to the water table in much of the southern Delta is at an acceptable depth for crop production.
- Relatively high leaching fractions are associated with an overall irrigation efficiency of 75% for furrow and border irrigation methods predominant in the southern Delta.
- Data from drains in the western part of the southern Delta suggest leaching fractions are between 0.21 and 0.27, with minimums ranged from 0.11 to 0.22 (stated as unitless fractions).
- The field study data supporting the salt tolerance of bean is sparse and over 30 years old. There is also no information on the salt sensitivity of bean and many other crops in early growth stages.
- Because the steady-state model doesn’t account for it, salt dissolution from the soil profile may cause the actual salinity in the root zone to be about 5% higher than estimated by the model.
- Steady-state modeling presented in the report, and the results from other transient model studies suggest the water quality standard could be increased up to 0.9 to 1.1 dS/m and be protective of all crops normally grown in the southern Delta under current irrigation practices. During low rainfall years, however, this might lead to yield loss of about 5% under certain conditions.
- Effective rainfall should be included in any modeling of soil water salinity in the southern Delta. Also, the exponential crop water uptake model is recommended as it better matches laboratory data. The model methodology used previously for the development of the existing objectives in the 1978 Bay-Delta Plan was more conservative and did not include consideration of rainfall, which lead to higher estimates of soil water salinity.
- In addition to the conclusions above, a number of recommendations were made for further studies in the southern Delta regarding: i) the crop salt tolerance of bean, ii) transient soil salinity modeling, iii) potential for boron toxicity to crops, and iv) leaching fractions associated with current irrigation practices.

4.4.2 Effects on Municipal and Domestic Supply Beneficial Use

The SED will also evaluate the impact of different salinity objective alternatives on other beneficial uses in the southern Delta, including MUN.

Maximum Contaminant Levels (MCL) are components of drinking water standards adopted by either the United States Environmental Protection Agency (USEPA) under the federal Safe Drinking Water Act or by the California Department of Public Health (DPH) under the California Safe Drinking Water Act. California MCLs may be found in Cal. Code Regs., tit. 22, chapter 15, division 4. Primary MCLs are derived from health-based criteria. The MCL related to salinity is specific conductance, but because specific conductance does not cause health problems, there are no Primary MCLs for specific conductance. However, Secondary MCLs are established on the basis of human welfare considerations (e.g., taste, color, and odor).

Drinking water has a Recommended Secondary MCL for specific conductance of 900 µS/cm, with an Upper MCL of 1,600 µS/cm and a Short Term MCL of 2,200 µS/cm. Specific conductance concentrations lower than the Secondary MCL are more desirable to a higher degree of consumers, however, it can be exceeded and is deemed acceptable to approach the Upper MCL if it is neither reasonable nor feasible to provide more suitable waters. In addition, concentrations ranging up to the Short Term MCL are acceptable only for existing community water systems on a temporary basis. (Note: specific conductance is electrical conductivity normalized to a temperature of 25° C).

5 Water Supply Effects Analysis

5.1 Purpose and Approach

This section describes the water supply effects (WSE) model and the approach used in the SED to quantify the potential effects that the LSJR flow alternatives could have on water supplies in the SED project area. These include the potential effects on the amount and timing of river flows, surface water diversions, and reservoir levels on the Stanislaus, Tuolumne, and Merced rivers. The output from the WSE model is used in the SED to evaluate the potential impacts of these changes on various environmental resources, agricultural revenues, hydropower generation, and the associated local economy.

Much of the input to the WSE model comes from a CALSIM II San Joaquin River Water Quality Module (CALSIM II) run representative of current hydrology and reservoir operations in the San Joaquin watershed. A description of the CALSIM II model is presented in the next section, followed by an explanation of the calculations performed by the WSE model. This model is then applied to a range of illustrative flow objective alternatives and demonstrates the applicability of the methodology across this range of flow objectives. The actual alternatives evaluated in the SED may differ from the general flow objectives described in this chapter.

The WSE model provides a general flow balance for hypothetical surface water diversion reductions and major reservoir re-operation scenarios on the Stanislaus, Tuolumne, and Merced rivers to meet different LSJR flow alternatives. These scenarios do not, however, identify specifically from where within each watershed additional flows will be provided. The model allows re-operation of the reservoirs, constrained by minimum storage and flood control levels, to minimize impacts to surface water diversions.

The methodology in this appendix has been updated and is described in Appendix F.1, *Hydrologic and Water Quality Modeling*, of this SED.

5.2 CALSIM II San Joaquin River Model

CALSIM II is a computer model developed by the USBR to simulate flow, storage, and use of water in the SJR basin. It is a planning model that imposes a specified level of water resources infrastructure development, land use, water supply contracts, and regulatory requirements over the range of historical meteorological and hydrologic conditions experienced from 1922 to 2003. Use of the model as a planning tool for future operations assumes that future meteorological and hydrologic conditions will be similar to historical. The model estimates the amount of water available for diversions, allocates this water based on various priorities, estimates demand and calculates associated return flows. The model calculates annual diversions using an index based on each year’s end-of-February storage plus perfect foresight of March to September reservoir inflow. This allows the model to calculate each year’s diversions dependent on the storage level of the major rim dams and expected inflow. The model uses regression analysis to calculate flow accretions, depletions and salinity at key locations. It also relies upon historical runoff information and standardized reservoir operating rules for determining carryover storage. Demands not met by surface water diversions can be supplemented with groundwater pumping, although CALSIM II does not model changing groundwater levels. The CALSIM II model runs on a monthly time step, with monthly average inputs and outputs (USBR 2005).

CALSIM II model output provides, among other things, monthly average estimates of diversion delivery, reservoir releases and storage, and river flows in the SJR watershed over the 82 years of simulated hydrology. All the CALSIM II model nodes and associated diversions and return flows in this portion of the SJR watershed within the SED project area are listed in Table 5.1. This list of diversions, channel flows, reservoir storage, and return flows was obtained from the flow balance equations for each of the nodes contained in the CALSIM II input files for this portion of the SJR watershed. The diversions and return flows were verified by creating a flow balance for each node, including all diversions, return flows, inflows and changes in reservoir storage.

The basis for the water supply impact analysis described in this section is the CALSIM II "Current (2009) Conditions" model run from the DWR's *State Water Project Delivery Reliability Report 2009*. A detailed description of the hydrology, facilities, regulatory, and operations assumptions are provided in Appendix A of that report (DWR, 2010b). This CALSIM II model run includes representation of both the December 2008 U.S. Fish & Wildlife Service and the June 2009 National Marine Fisheries Service biological opinions on the Central Valley Project and the State Water Project. The WSE model described in the next section can be updated if a more applicable or updated CALSIM II model run becomes available during the SED analysis.

Table 5.1. List of Diversions and Return Flows from all CALSIM II Nodes in the Portion of the SJR Basin including the Stanislaus, Tuolumne, and Merced Rivers

River	CALSIM II Node No.	CALSIM II Diversion No.	CALSIM II Flow No.	Description
Stanislaus	10	None	None	New Melones Reservoir
	76	None	None	Tulloch Reservoir
	520	D520A D520A1 D520B D2520C	None	
	528	D528	R528A R528B R528C	
Tuolumne	81	None	None	New Don Pedro Reservoir
	540	D540A D540B	None	
	545	D545	R545A R545B R545C	
Merced	20	None	None	Lake McCLure
	561	D561	None	
	562	D562	None	
	564	None	R564A R546B	
	566	D566	R566	

A simple comparison of CALSIM II calculated flows and observed monthly average flow data from the USGS gage #11303500 on the SJR at Vernalis (USGS 2010) shows that CALSIM II provides a reasonable estimate of flow for the SJR at Vernalis. Figure 5.1 shows actual flow data from water years 1984 to 2003 and output from the CALSIM II representation of current conditions assuming hydrology for the same time period. This covers a period during which actual operations in the watershed were relatively similar (correlation coefficient of 0.912) to those modeled in the CALSIM II representation of current conditions. After 1984 all major eastside dams were completed and filled and their combined effect on flows at Vernalis should be present in the actual data. CALSIM II model output ends with water year 2003.

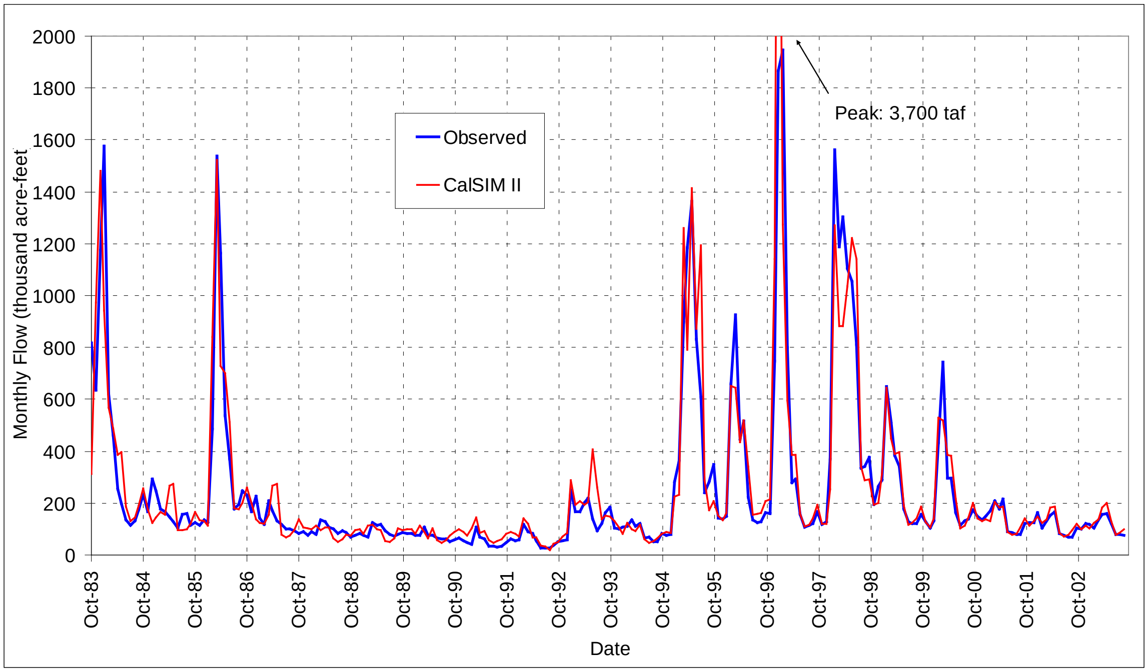

Figure 5.1. Observed Monthly Average Flow from USGS Gage #11303500 (SJR Near Vernalis) Compared to CALSIM II Model Output for SJR Flow at Vernalis

5.3 Water Supply Effects Model

This section describes the WSE model that was developed to estimate additional flows needed for, and the water supply effects of, different LSJR flow alternatives. The methods to calculate the flow targets for the flow objective alternatives and the resulting water supply effects are discussed, followed by a comparison with CALSIM II output data to validate the approach. Flow objective is the user-defined percent of unimpaired flow. Target flow is the variable monthly calculated flow that is needed to achieve the flow objective.

The WSE model is a monthly water balance spreadsheet model that calculates reductions in water supply in each tributary that would occur based upon user-defined inputs, output from CALSIM II, and flood storage rules. User defined inputs to the model include:

- Months for which flow objectives are to be set
- Monthly flow objectives as a percentage of unimpaired flow and caps for maximum or minimum monthly flows,
- Maximum annual diversion (based on CALSIM II maximum diversion)
- Diversion delivery rule curves which set annual diversions based on January storage behind rim dams (New Melones, New Don Pedro, and New Exchequer),

- Minimum annual end-of-September storage (no calculations based on this input; provides only a reference line).

Other inputs not defined by the user include:

- Baseline CALSIM II flows at the confluence with the SJR for calculating effects to river flows due to alternatives,
- Baseline CALSIM II monthly surface water diversions
- CALSIM II inflows to each rim reservoir
- CALSIM II evaporation from each rim reservoir
- CALSIM II accretions downstream from each rim reservoir
- CALSIM II monthly diversion patterns used to distribute the annual diversions
- Flood storage rule curves

Output from the WSE model, including annual and monthly diversions, river flows, and reservoir storage, are compared to CALSIM II baseline conditions to assess the effects of alternative flow objectives.

5.3.1 Calculation of Flow Targets to Meet Desired Flow Objectives

The WSE model first calculates flow targets for each tributary based on the user-defined percent of unimpaired flow. Flow objectives on the Stanislaus, Tuolumne, and Merced rivers, at their confluences with the SJR, are defined as a percentage of monthly unimpaired flow on each tributary for February through June. As described in Section 2.2.2, unimpaired flow is an estimate of the flow that would have existed in the rivers as currently configured if there were no diversions or storage. The monthly unimpaired flow for water years 1922 to 2003 available from DWR (2007a) are estimates of flow that would have entered each of the major upstream reservoirs. There are no estimates of the unimpaired flow for the tributaries at their confluence with the SJR, where the flow objectives are being established. However, the entire valley floor component of unimpaired flow is roughly three percent of the unimpaired flows of the major LSJR tributaries. The component of unimpaired flow that would otherwise be associated with accretions and other inputs downstream of the major reservoirs is therefore not expected to significantly alter the amount or timing of these flows. The unimpaired flows at the rim dams are therefore considered adequate for the purpose of establishing flow objectives.

The model user may also adjust the default minimum and maximum monthly flows. Minimum flows may be selected to limit what could be adverse fishery effects that could occur with otherwise unbounded minimum target flows. Maximum flows may be selected to limit the water supply effects that would occur to meet otherwise unbounded target flows. The default minimum monthly flows specified in the model are: 150 cfs for the Stanislaus River; 200 cfs for the Tuolumne River; and 150 cfs for the Merced River. These minimum flows generally reflect the existing regulatory requirements for minimum flows discussed in Section 3.1.3. The default maximum monthly target flows specified in the model are: 2,500 cfs for the Stanislaus River; 3,500 cfs for the Tuolumne River; and 2,000 cfs for the Merced River. These maximum flows generally reflect the median unimpaired flows in these three rivers during the February through June period (See Tables 2.10, 2.11, and 2.12). The minimum and maximum flows can be adjusted in the WSE model as needed. The model calculates and adds additional flow when required to maintain reservoirs below flood control storage requirements. Because of these adjustments, the overall percentage of unimpaired flow calculated by the WSE model might be slightly different than the user-defined percent of unimpaired flow. For months outside of the February through June period, the target flows for the model are set to the CALSIM II monthly flow.

5.3.2 Calculation of Water Supply Effects

After the WSE model calculates target flows in each of the three rivers, it calculates the surface water diversions and the reservoir releases needed to: 1) meet these target flows; 2) satisfy surface water diversions; and 3) maintain storage levels within minimum pool and flood control limits. The rim reservoir storage level is then calculated using a flow balance equation to determine resulting changes in storage. These calculations are performed monthly using hydrologic conditions for water years 1922 to 2003. The elements of the water balance calculations are described in more detail below.

Flow Target

As described in Section 5.3.1, the flow target at the mouth of each tributary, QF_t, for a particular month is calculated as:

$$QF_t = UF_t \times Fa \begin{Bmatrix} \text{such that} & (UF_t \times Fa) \le Qmx_t \\ \text{and} & (UF_t \times Fa) \ge Qmn_t \end{Bmatrix} \qquad \textit{(Eqn. 5.1)}$$

where:

UF_t is the DWR (2007a) unimpaired flow at time t;
Fa is the target percentage of unimpaired flow defined by the user; and
Qmx_t and Qmn_t are the user defined caps for maximum and minimum monthly flows respectively at time t.

Surface Water Diversions

The surface water diversions, D_t, for a particular month are calculated using:

$$D_t = D_{\max} \times Ka_t \times Kb \qquad \textit{(Eqn. 5.2)}$$

where:

D_{max} is the maximum annual diversion for each tributary defined by the user and based upon CALSIM II data; default values are 750 TAF on the Stanislaus; 1,100 TAF on the Tuolumne; and 625 TAF on the Merced).

Ka_t is the monthly diversion pattern used to distribute the annual diversions for each month at period t (derived from CALSIM II output using the median monthly sum of diversions).

Kb is the percent of maximum diversions for each year, set by a user-defined diversion delivery rule curve of January storage level in the rim reservoir of the associated river. The storage at time t is input to the rule curve and the corresponding percent of maximum diversions (Kb) to be delivered over the following 12 months is interpolated as a straight line between points defined by the user on the rule curve. This curve generally allows for greater percentage of diversions at higher storage levels and requires diversions to be reduced at lower storage levels. For increasing percentage of unimpaired flow objectives a more restrictive diversion delivery rule curve will be needed to meet the objectives.

Reservoir Releases

The reservoir release needed to satisfy the target flow and diversions is determined on each tributary as:

$$R_t = QF_t + D_t + RS_t - QAC_t \qquad \textit{(Eqn. 5.3)}$$

where:

RS_t is the additional reservoir spill release required to stay below flood stage (as defined by the USACE flood storage curves); and

QAC_t is the sum of CALSIM II accretions (including return flows) and depletions downstream of the rim dam in month t. Accretions and return flows are assumed unchanged with respect to CALSIM II.

Reservoir Storage Levels

Storage levels behind the rim dams are initially set to CALSIM II levels at the end of December 1921. The reservoir storage at the end of the following month, and each subsequent month, S_t, is calculated with a water balance equation on each tributary using:

$$S_t = S_{t-1} + QINF_t - R_t - EV_t \qquad \textit{(Eqn. 5.4)}$$

where:

S_{t-1} is the storage of the previous month*;*
$QINF_t$ is the CALSIM II inflow to each reservoir; and
EV_t is the CALSIM II evaporation from the rim reservoir at time t.

River Flows

The flow achieved by the WSE model at the confluence of each tributary with the SJR is determined as follows:

$$Q_t = QF_t + RS_t \qquad \textit{(Eqn. 5.5)}$$

Outside of the February through June period Q_t is generally identical to the CALSIM II flow but may add additional flood spills triggered by a higher storage calculated by the WSE model relative to CALSIM II. For an example of the effects due to a 40% of unimpaired flow objective, Figure 5.2 displays a time series of CALSIM II baseline and WSE model flows and storages for WY 1997 to WY 2000 that would be needed to achieve the target flow.

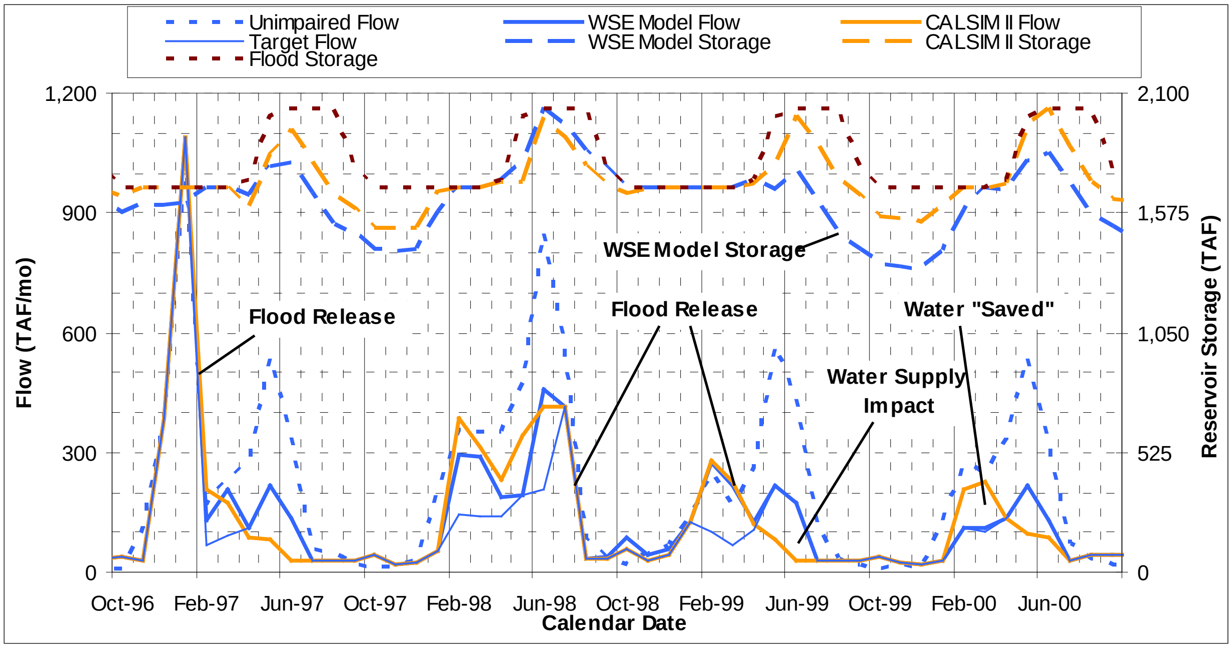

Figure 5.2. Monthly Unimpaired Flow and 40% of Unimpaired Flow Objective Alternative Compared to CALSIM II Flow on the Tuolumne River at CALSIM II Node C545

5.3.3 Comparison of Water Supply Effects Model

This section describes the steps that were taken to compare the WSE model with the CALSIM II baseline results. First, the approximate percentage of unimpaired flow that is most similar to CALSIM II river flows was determined for each of the three rivers. This was done by comparing exceedance plots for WSE and CALSIM II modeled February through June flows. The target percentage of unimpaired flow for the WSE model was adjusted until its exceedance plot matched closely with the CALSIM II plot. As seen in Figures 5.3c, 5.4c, and 5.5c the exceedance plot of CALSIM II February through June flows closely matches the WSE model exceedance plots for the 40% of unimpaired flow target on the Stanislaus River and the 20% of unimpaired flow target on both the Tuolumne and Merced rivers.

In the second step, a diversion delivery rule curve was developed that closely matched the relationship between January storage levels for the major reservoirs on each river against annual diversions as determined from CALSIM II output. The CALSIM II annual diversions were divided by the maximum annual diversion determined for each tributary, resulting in a percent of maximum annual diversion actually delivered each year. This result was then plotted against January storage in Figures 5.3d, 5.4d, and 5.5d. These results show that when storage is lower, a lower percentage of the maximum annual diversion will be delivered that year. In general, sharp cutbacks to diversions begin to occur when reservoir storage is less than roughly one half of the full capacity. Using these plots as guides, diversion delivery rule curves were developed that resulted in annual diversion exceedance curves that matched those of CALSIM II. The annual diversion exceedance curves for CALSIM II and the WSE model are shown in Figures 5.3a, 5.4a, and 5.5a.

The final step in the comparison process was to iteratively refine the diversion delivery rule curves such that end-of-September storages (carryover storage) from the WSE model matched CALSIM II end-of September storages as closely as possible. Figures 5.3b, 5.4b, and 5.5b show exceedance plots of CALSIM II and the WSE model end-of-September storage, and the target minimum end-of-September storage as a reference line. Minimum storage levels were set for each reservoir, and the number of times storages fell below this level were tabulated. The diversion delivery rule curves were further adjusted so the number of times storages dropped below the minimum level were nearly the same between the two models.

The comparison of results in Figures 5.3, 5.4, and 5.5 demonstrates that the WSE model generates similar results to CALSIM II using similar input data and operating assumptions.

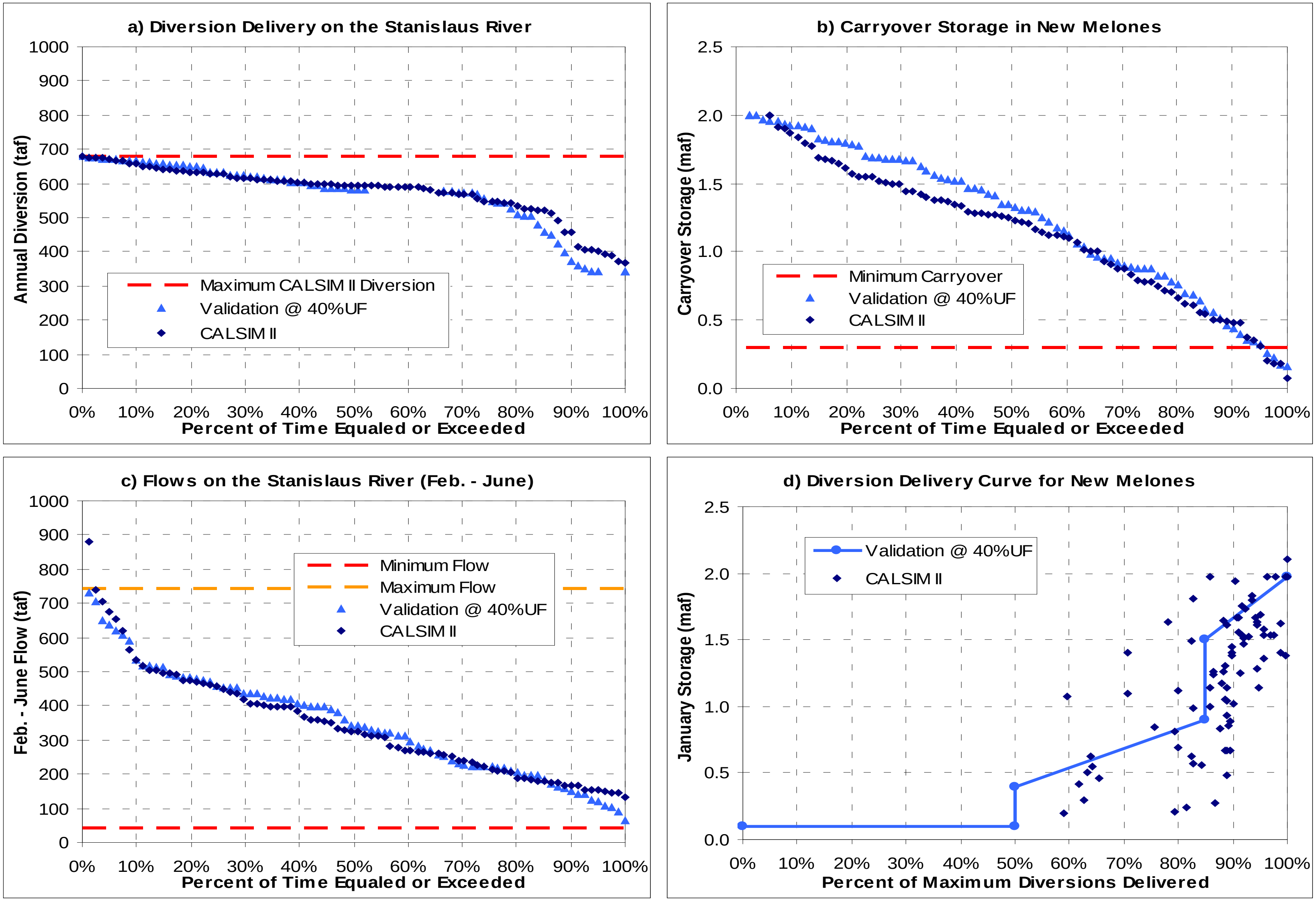

Figure 5.3. Validation of WSE Model Against CALSIM II Output on the Stanislaus River for A) Annual Diversion Delivery, B) End-of-September Storage, C) Flow at CALSIM II Node 528, D) Diversion Delivery Rule Curve Based on January Storage Level

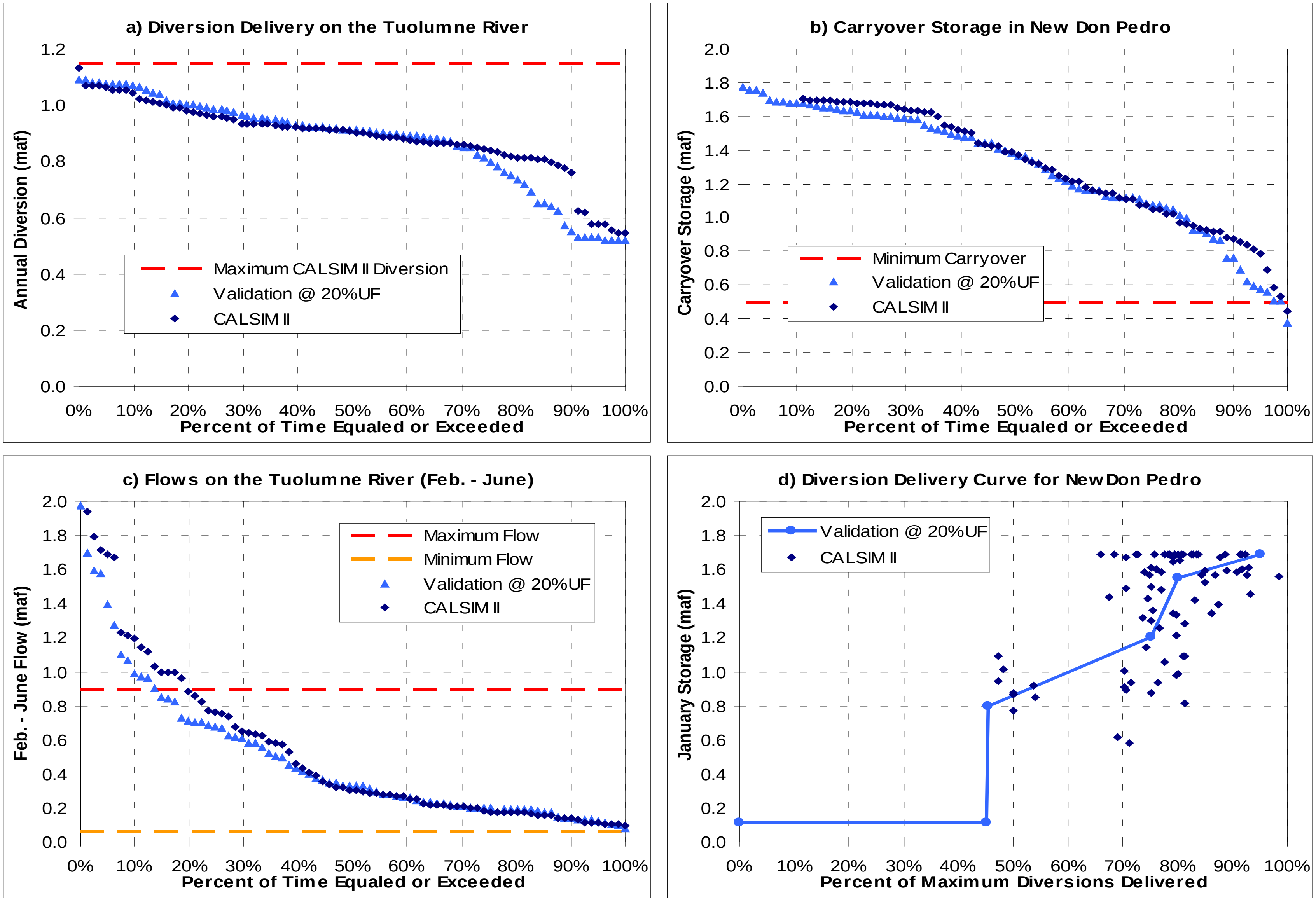

Figure 5.4. Validation Of WSE Model Against CALSIM II Output on the Tuolumne River for A) Annual Diversion Delivery, B) End-of-September Storage, C) Flow at CALSIM II Node 528, D) Diversion Delivery Rule Curve Based on January Storage Level

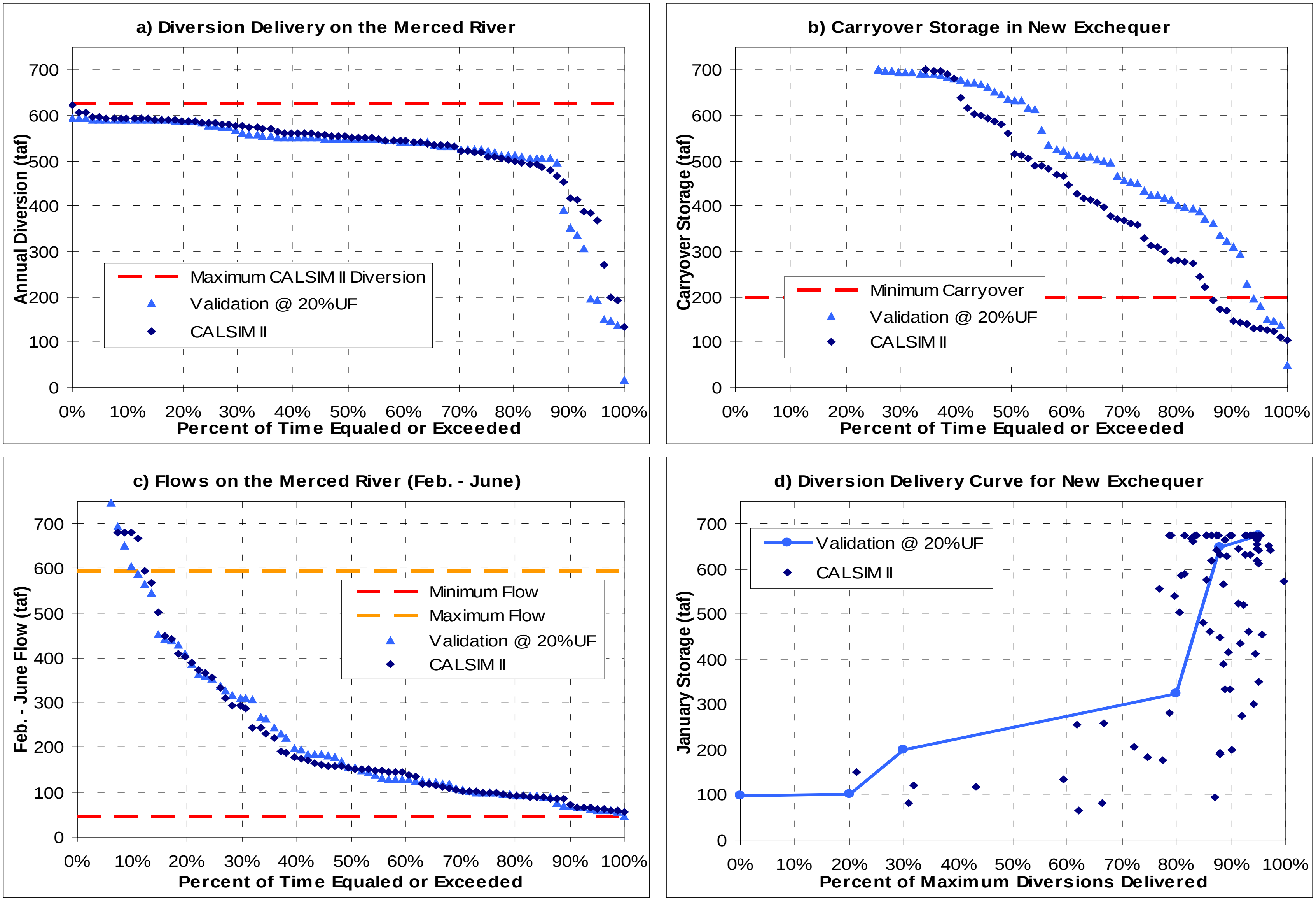

Figure 5.5. Validation of WSE Model Against CALSIM II Output on the Merced River for A) Annual Diversion Delivery, B) End-of-September Storage, C) Flow at CALSIM II Node 528, D) Diversion Delivery Rule Curve Based on January Storage Level

5.4 Summary of Annual Water Supply Effects

Tables 5.2, 5.3, and 5.4 present statistics for estimated water supply effects using the WSE model for the 20%, 40%, and 60% of unimpaired flow targets. The tables show the total annual and February through June unimpaired flow, and total annual CALSIM II diversion volumes for reference. These tables can be used to compare the effect that various flow targets would have on annual diversions and annual flow volumes relative to baseline CALSIM II diversions and flows. These tables also provide the maximum annual diversions for each tributary, as defined by the user (based upon CALSIM II data). For the Stanislaus River, the maximum annual diversion was set at 750 TAF rather than the 680 TAF maximum set in CALSIM II baseline. This additional amount includes the full Stockton East Water District diversion amount, not fully incorporated in the CALSIM II scenario. The maximum Tuolumne diversion was set to 1,100 TAF and the maximum Merced diversion was set at 625 TAF.

The results of the 20%, 40%, and 60% of unimpaired flow targets calculated using the WSE model, along with the CALSIM II representation of baseline for reference, are also presented in exceedance plots for the 82 years of CALSIM II hydrology for Figures 5.6, 5.7, and 5.8 are exceedance plots for: a) total annual diversion deliveries, b) carryover storage, and c) on total annual flow volumes for each river. These figures also show the diversion delivery rule curves (as a function of January reservoir storage) for each of the rivers. The diversion delivery rule curves are roughly linear. As expected, it can be seen that increasing LSJR flow alternatives reduces the volume of annual diversions and increases the total annual volume of flow at the confluence with the SJR in each river.

Table 5.2. Estimated Water Supply Effects (TAF) on the Stanislaus River Associated with Meeting a Range of LSJR Flow Alternatives in Comparison to CALSIM II Annual Diversion Volumes and Unimpaired February to June flow volumes

	Unimpaired Flow (TAF)		Annual Diversions by Percent Unimpaired Flow (TAF)				Feb.–Jun. Flows by Percent Unimpaired Flow (TAF)			
	Annual	Feb.–Jun.	CALSIM II Baseline	20%	40%	60%	CALSIM II Baseline	20%	40%	60%
Average	1118	874	577	672	580	461	355	228	348	465
Minimum	155	136	368	439	333	247	131	45	64	87
90%tile	456	381	455	534	407	308	167	83	152	228
80%tile	591	497	537	567	471	367	193	105	199	298
75%tile	636	550	545	619	484	389	217	113	220	330
70%tile	679	563	568	644	503	401	241	122	225	338
60%tile	891	739	589	691	563	445	270	162	302	435
50%tile	1092	817	593	719	614	486	325	188	340	490
40%tile	1260	997	603	733	636	508	377	212	404	529
30%tile	1362	1078	615	743	672	532	416	238	434	569
25%tile	1472	1130	627	745	683	544	454	254	454	576
20%tile	1560	1182	634	746	693	562	474	298	467	597
10%tile	1916	1461	656	748	716	572	531	411	523	653
Maximum	2950	2005	678	750	742	594	1196	1025	919	1057
Maximum Annual Diversion			750	750	750	750				

Table 5.3. Estimated Water Supply Effects (TAF) on the Tuolumne River Associated with Meeting a Range of LSJR Flow Alternatives in Comparison to CALSIM II Annual Diversion Volumes and unimpaired February to June flow volumes

	Unimpaired Flow (TAF)		Annual Diversions by Percent Unimpaired Flow (TAF)				Feb. – Jun Flows by Percent Unimpaired Flow (TAF)			
	Annual	Feb.–Jun.	CALSIM II Baseline	20%	40%	60%	CALSIM II Baseline	20%	40%	60%
Average	1849	1409	885	853	682	527	540	496	670	814
Minimum	384	330	542	422	317	172	93	81	139	199
90%tile	835	674	762	572	456	281	137	137	270	405
80%tile	1052	894	814	688	519	356	170	193	384	536
75%tile	1106	961	839	767	548	396	178	198	390	582
70%tile	1165	982	858	792	600	432	204	214	411	598
60%tile	1413	1186	877	844	666	496	257	245	486	672
50%tile	1776	1299	906	911	724	565	304	333	625	763
40%tile	2031	1585	920	953	763	606	449	447	678	865
30%tile	2197	1709	935	987	807	666	648	608	771	923
25%tile	2367	1756	959	992	824	680	757	686	830	970
20%tile	2486	1857	978	1001	848	698	878	749	912	1006
10%tile	3099	2194	1042	1026	868	709	1189	1011	1127	1214
Maximum	4632	2904	1132	1045	880	715	2408	1975	2115	2209
Maximum Annual Diversion			1100	1100	1100	1100				

Table 5.4. Estimated Water Supply Effects (TAF/year) on the Merced River Associated with Meeting a Range of LSJR Flow Alternatives in Comparison to CALSIM II Annual Diversion Volumes and Unimpaired February to June Flow Volumes

	Unimpaired Flow (TAF)		Annual Diversions by Percent Unimpaired Flow (TAF)				Feb.–Jun. Flows by Percent Unimpaired Flow (TAF)			
	Annual	Feb.–Jun.	CALSIM II Baseline	20%	40%	60%	CALSIM II Baseline	20%	40%	60%
Avg	956	745	527	517	440	364	270	264	344	419
Minimum	151	128	134	260	203	130	57	45	64	87
90%tile	408	326	421	368	292	209	74	69	130	196
80%tile	489	431	499	446	359	274	93	94	179	258
75%tile	524	458	511	474	374	283	99	99	184	275
70%tile	561	470	525	489	408	325	104	110	191	283
60%tile	668	568	545	539	442	354	141	127	231	335
50%tile	895	646	552	567	477	385	154	155	281	382
40%tile	1080	824	561	573	491	413	176	196	346	442
30%tile	1165	924	578	582	504	439	292	309	385	484
25%tile	1223	978	584	585	517	448	350	343	409	501
20%tile	1399	1033	588	589	523	458	402	373	459	523
10%tile	1712	1223	593	592	529	465	678	593	605	621
Maximum	2786	1837	624	594	531	469	1320	1231	1274	1305
Maximum Annual Diversion			625	625	625	625				

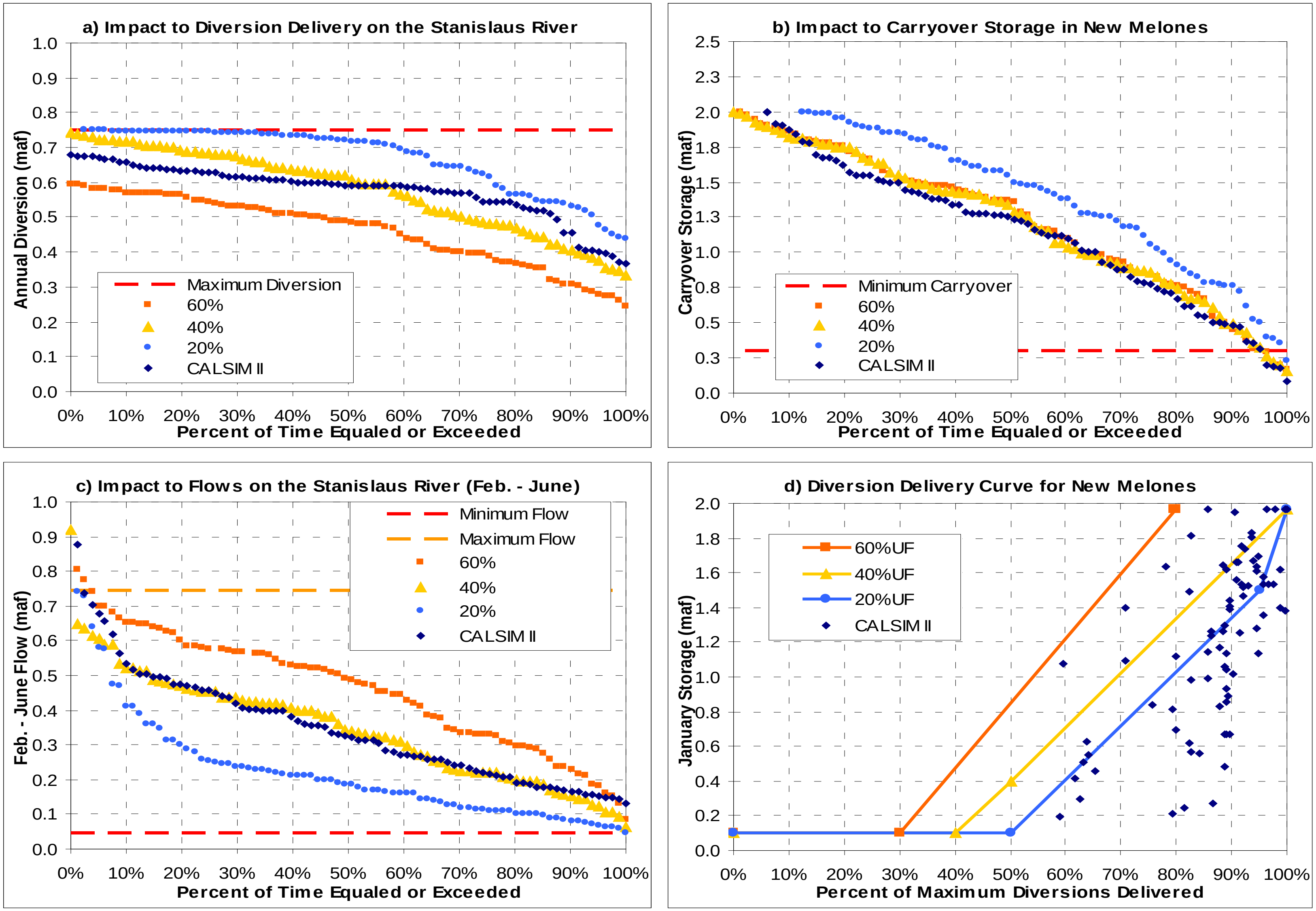

Figure 5.6. Results of Impacts for Illustrative Flow Objective Alternatives of 20%, 40% and 60% of Unimpaired Flow on the Stanislaus River

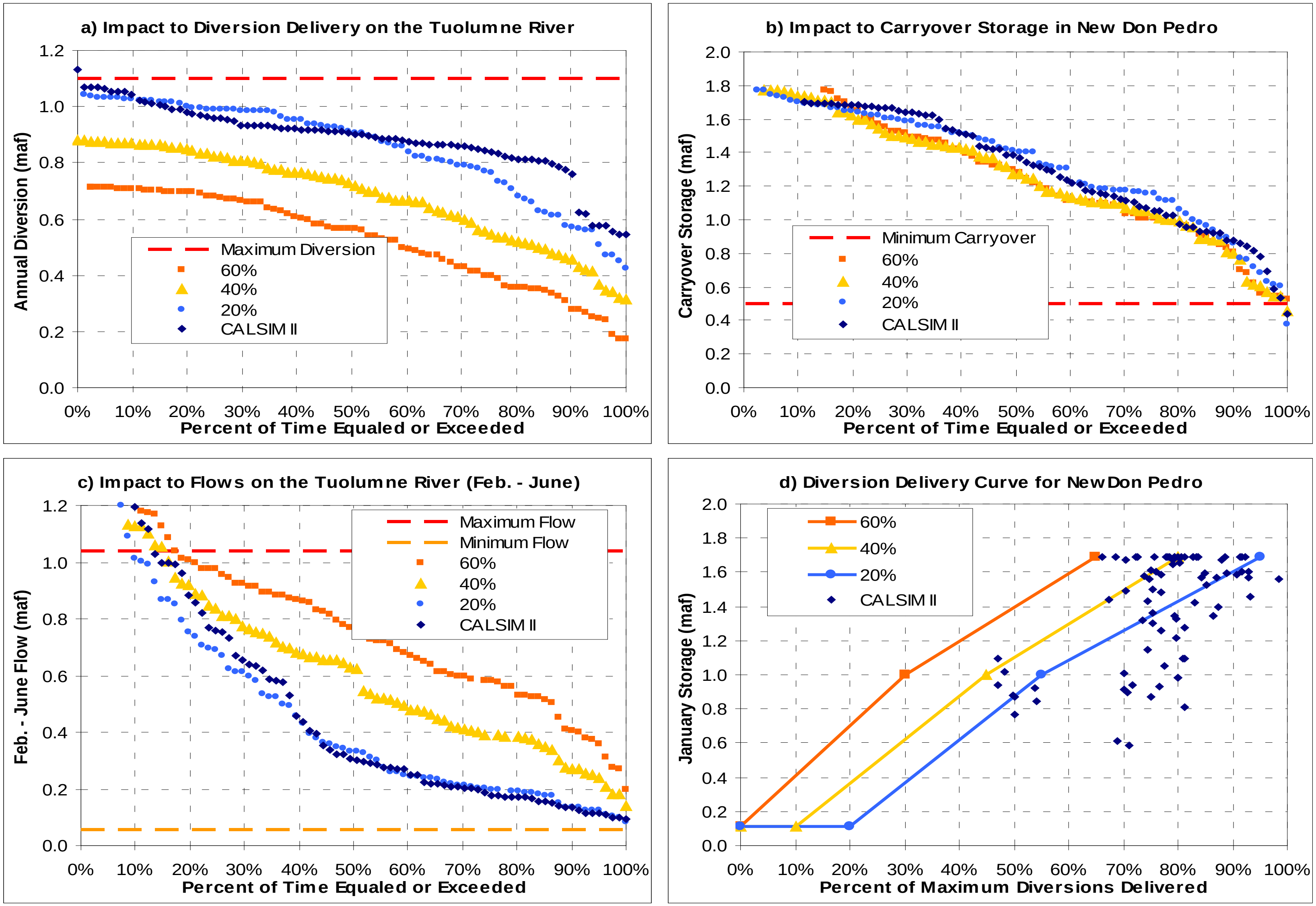

Figure 5.7. Results of Impacts for Illustrative Flow Objective Alternatives of 20%, 40% and 60% of Unimpaired Flow on the Tuolumne River

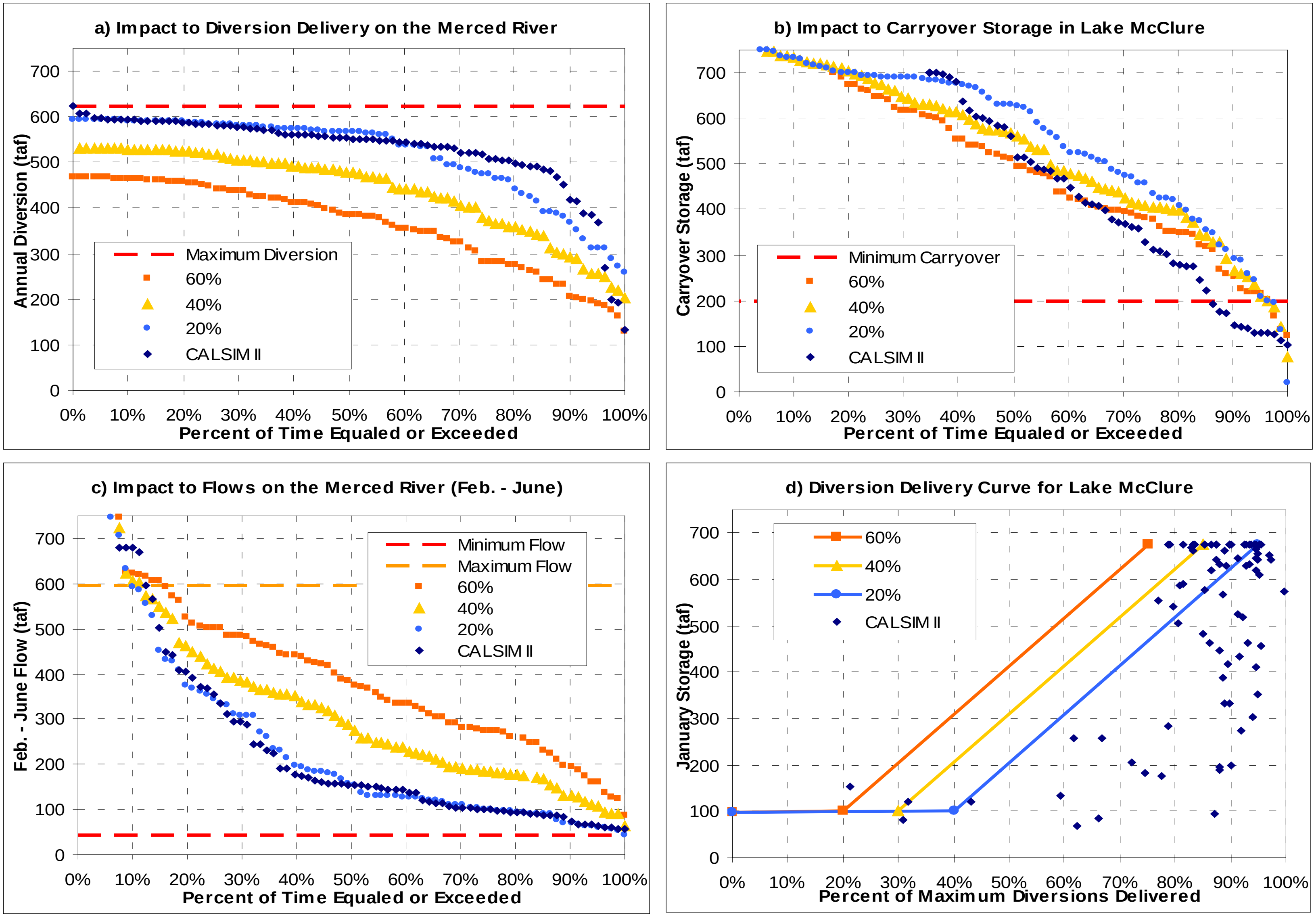

Figure 5.8. Results of Impacts for Illustrative Flow Objective Alternatives of 20%, 40% and 60% of Unimpaired Flow on the Merced River

6 References

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Appendix A. Draft Objectives and Program of Implementation

A.1. Modifications to the San Joaquin River Fish and Wildlife Flow Objectives, and the Program of Implementation

The following is a description of potential draft modifications to SJR flow objectives for the protection of fish and wildlife beneficial uses, the program of implementation for those objectives, and the monitoring and special studies program included in the 2006 Bay-Delta Plan. The exact language of alternative changes may change and will be provided in the draft Substitute Environmental Document prepared for this project.

A. San Joaquin River Fish and Wildlife Flow Objectives

The existing numeric SJR flow objectives at Vernalis during the February through June time frame contained within Table 3 of the 2006 Bay-Delta Plan would be replaced with a narrative SJR flow objective (refer to Table A-1). Draft language for the narrative SJR flow objective is included below:

> *Maintain flow conditions from the SJR Watershed to the Delta at Vernalis, together with other reasonably controllable measures in the SJR Watershed sufficient to support and maintain the natural production of viable native SJR watershed fish populations migrating through the Delta. Specifically, flow conditions shall be maintained, together with other reasonably controllable measures in the SJR watershed, sufficient to support a doubling of natural production of Chinook salmon from the average production of 1967-1991, consistent with the provisions of State and federal law. Flow conditions that reasonably contribute toward maintaining viable native migratory SJR fish populations include, but may not be limited to, flows that more closely mimic the hydrographic conditions to which native fish species are adapted, including the relative magnitude, duration, timing, and spatial extent of flows as they would naturally occur. Indicators of viability include abundance, spatial extent or distribution, genetic and life history diversity, migratory pathways, and productivity.*

A.1.1. Program of Implementation

Delete existing text in Chapter IV. Program of Implementation, A. Implementation Measures within State Water Board Authority, 3. River Flows: SJR at Airport Way Bridge, Vernalis, and add the following new text to Section B. Measures Requiring a Combination of State Water Board Authorities and Actions by Other Agencies:

River Flows: San Joaquin River at Airport Way Bridge, Vernalis

The narrative SJR flow objective is to be implemented through water right actions, water quality actions, and actions by other agencies in an adaptive management framework informed by required monitoring, special studies, and reporting. The purpose of the implementation framework is to achieve the narrative SJR flow objective by providing a flow regime that more closely mimics the shape of the unimpaired hydrograph, including more flow of a more natural spatial and temporal pattern; providing for adaptive management in order to respond to changing information on flow needs and to minimize water supply costs; and allowing for and encouraging coordination and integration of existing and future regulatory processes.

Implementation of Flows February through June

The State Water Board has determined that more flow of a more natural pattern is needed from February through June from the SJR watershed to Vernalis to achieve the narrative SJR flow objective. Specifically, more flow is needed from the existing salmon and steelhead bearing tributaries in the SJR watershed down to Vernalis in order to provide for connectivity with the Delta and more closely mimic the flow regime to which native migratory fish are adapted. Salmon bearing tributaries to the San Joaquin River currently include the Stanislaus, Tuolumne, and Merced Rivers[1].

Thus, the State Water Board has determined that approximately X percent (e.g., 20-60 percent)[2] of unimpaired flow is required from February through June from the Stanislaus, Tuolumne, and Merced Rivers on a X-day average (e.g., 14-day)[2] to a maximum of X cubic-feet per second (cfs) (e.g., 20,000 cfs)[2] at Vernalis, unless otherwise approved by the State Water Board as described below. This flow is in addition to flows in the SJR from sources other than the Stanislaus, Tuolumne, and Merced Rivers. In addition, the State Water Board has determined that base flows of X cfs (e.g., 1,000 cfs)[2] on a X-day average (e.g., 14-day)[2] is required at Vernalis at all times during the February through June period. Water needed to achieve the base flows at Vernalis should be provided on a generally proportional basis from the Stanislaus, Tuolumne, and Merced Rivers. The actions necessary to meet the above requirements are described below.

Assignment of Responsibility for Actions to Achieve the Objective

The State Water Board will require implementation of the narrative objective through water rights actions, FERC hydropower licensing processes, or other processes. In order to assure that the water rights and FERC processes are fully coordinated, implementation of the narrative flow objective may be phased, in order to achieve full compliance with the narrative objective by the completion of the FERC proceedings on the Merced and Tuolumne Rivers, or no later than 2020, whichever occurs first.

To inform the implementation process for the narrative flow objective, the State Water Board will establish a workgroup consisting of State, federal, and local agency staff, stakeholders, and other interested persons with expertise in fisheries management, unimpaired flows, and operations on the Stanislaus, Tuolumne, and Merced Rivers to develop recommendations for establishing water right, FERC, and other related requirements to implement the narrative flow objective in a manner that best achieves the narrative flow objective while minimizing water supply costs. Any recommendation developed by the workgroup shall be submitted to the State Water Board within six months (placeholder date pending additional review) from the date of the State Water Board's approval of this amendment to the Bay-Delta Plan in order to be considered in future State Water Board water right and FERC licensing proceedings.

Although the most downstream compliance location for the SJR flow objective is at Vernalis, the objective is intended to protect migratory fish in a larger area, including areas within the Delta

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[1] Currently, the San Joaquin River does not support salmon runs upstream of the Merced River confluence. However, pursuant to the San Joaquin River Restoration Program (SJRRP), spring-run Chinook salmon are planned to be reintroduced to this reach no later than December 31, 2012. Flows needed to support the reintroduction are being determined and provided through the SJRRP. During the next review of the Bay-Delta Plan, the State Water Board will consider information made available through the SJRRP process, and any other pertinent sources of information, in evaluating the need for any additional flows from the upper San Joaquin River Basin to contribute to the narrative San Joaquin River flow objective.

[2] A placeholder "X" value with examples are shown for several parameters in this draft. The final program of implementation will have a value based on subsequent analyses.

where fish that migrate to or from the SJR watershed depend on adequate flows from the SJR and its tributaries. To assure that flows required to meet the SJR narrative flow objective are not rediverted downstream for other purposes, the State Water Board may take water right and other actions to assure that those flows are used for their intended purpose. In addition, the State Water Board may take actions to assure that provision of flows to meet the narrative SJR flow objective do not result in redirected impacts to groundwater resources, potentially including requiring groundwater management plans, conducting a reasonable use proceeding, or other appropriate actions.

Adaptive Management of Flows during the February through June Period

Implementation of the narrative SJR flow objective will include the adaptive management of flows during the February through June period in order to achieve the narrative flow objective and minimize water supply impacts. Any adaptive management of flows must not result in flows of less than approximately X percent (e.g., 10 percent)[2] of unimpaired flow from each of the Stanislaus, Tuolumne, and Merced Rivers over the entire February through June period, up to a maximum of X cfs (e.g., 20,000 cfs)[2] at Vernalis. This flow is in addition to flows in the SJR from sources other than the Stanislaus, Tuolumne, and Merced Rivers.

The State Water Board or other responsible entity will establish a coordinated operations group (COG), which will be comprised of the DFG; NMFS; USFWS; representatives of water users on the Stanislaus, Tuolumne, and Merced Rivers, and any other representatives deemed appropriate by the State Water Board. The COG must agree to any adaptive management of flows, subject to final approval by the Executive Director of the State Water Board. Other interested persons may provide information to inform the COG process and the Executive Director's approval of any adaptive management. In order to inform implementation actions, State Water Board staff will work with the COG and other interested persons to develop recommendations for an adaptive management process, to be submitted for approval by the Executive Director of the State Water Board within 12 months (placeholder date pending additional review) following the board's approval of this amendment to the Bay-Delta Plan. By January 1 of each year, the COG also must prepare an adaptive management plan for the coming February through June season of that year for approval by the Executive Director.

In addition, based on future monitoring and evaluation to determine flow needs to achieve the narrative SJR flow objective, the State Water Board may approve modifications to the required percentage of unimpaired flows, base flows, and upper end of flows at which a percentage of unimpaired flows are no longer required. Specifically, FERC licensing proceedings on the Merced and Tuolumne Rivers are expected to yield specific information on flow needs for those tributaries. The State Water Board expects this information to inform specific measures needed to implement the narrative SJR flow objective. To obtain similar information for the Stanislaus River, the State Water Board will require the development of any additional information needed to inform specific flow needs on the Stanislaus River. The State Water Board will use the specific in-stream flow information developed for each of the tributaries to determine how to adaptively manage flows on the SJR to meet the narrative SJR flow objective and integrate Bay-Delta Plan flow requirements with FERC licensing requirements.

Any modifications to the required percentage of unimpaired flows, base flows, and upper end of flows at which a percentage of unimpaired flows are no longer required shall not result in a change of more than: X percent (e.g., 10 percent)[2] of unimpaired flow from any one tributary over the entire February through June period; more than plus or minus X cfs (e.g., 200 cfs)[2] at Vernalis for the base flow requirement; and plus or minus X cfs (e.g., 5,000 cfs)[2] for the upper end of the flow requirement at Vernalis without modification to this program of implementation in accordance with applicable water quality control planning processes. Additional specific exceptions for drought considerations or unforeseen disaster circumstances may also be approved by the State Water Board.

Implementation of Flows during October

The State Water Board will reevaluate the assignment of responsibility for meeting the October pulse flow requirement during the water right proceeding or FERC licensing proceeding following adoption of this plan amendment in order to optimize protection for fish and wildlife beneficial uses and minimize impacts to water supplies.

The State Water Board will require persons responsible for meeting the October pulse flow requirement to conduct monitoring and special studies (discussed below) to determine what, if any, changes should be made to the October pulse flow requirement and its implementation to achieve the narrative SJR flow objective. Based on this information, the State Water Board will evaluate the need to modify the October pulse flow requirement during the next review of the Bay-Delta Plan.

Implementation During Other Times of Year (July through September and November through January)

The State Water Board has not established flow requirements for the July through September and November through January time frames that are necessary to implement the narrative SJR flow objective. The State Water Board will require monitoring and special studies (discussed below) during the water rights and FERC processes to be conducted to determine what, if any, flow requirements should be established for this time period to achieve the narrative SJR flow objective. Results from the monitoring and special studies program shall be used to inform the FERC proceedings on the Merced and Tuolumne Rivers and to inform the next review of the SJR flow objectives in the Bay-Delta Plan.

Actions by Other Agencies

To be developed. This may include, but is not limited to, actions such as: habitat restoration (floodplain restoration, gravel enhancement, riparian vegetation management, passage, etc.), hatchery management, predator control, water quality measures, ocean/riverine harvest measures, recommendations for changes to flood control curves, and barrier operations.

A.1.2. New Special Studies, Monitoring, and Reporting Requirements

Add new section with the text below to the end of Chapter IV. Program of Implementation, Section D. Monitoring and Special Studies Program:

San Joaquin River Fish and Wildlife Flow Objectives

In order to inform real time adaptive management and long-term management of flows on the SJR for the protection of fish and wildlife beneficial uses, the State Water Board will require the development of a comprehensive monitoring, special studies, evaluation, and reporting program, referred to as the SJR Monitoring and Evaluation Program (SJRMEP). During the water right and FERC proceedings to implement the narrative SJR flow objective, the State Water Board will establish responsibility for development and implementation of the SJRMEP. The SJRMEP shall be developed with input from the COG and shall be subject to approval by the Executive Director of the State Water Board. The SJRMEP shall at a minimum include monitoring, special studies, and evaluations of flow related factors on the viability of native SJR watershed fish populations, including abundance, spatial extent (or distribution), diversity (both genetic and life history), and productivity. The SJRMEP shall include regular reporting and evaluation of monitoring and special studies data. Evaluations of monitoring and special studies data shall be subject to regular outside scientific review. The Executive Director of the State Water Board may direct or approve changes to the SJRMEP based on monitoring and evaluation needs. The SJRMEP shall be integrated and coordinated with existing monitoring and special studies programs on the SJR, including monitoring and special studies being conducted pursuant to federal biological opinion requirements and as part of the FERC licensing proceedings for the Merced and Tuolumne Rivers.

Specifically, the SJRMEP shall evaluate the effect of flow conditions at various times of year, including spring (February through June), fall (including October), summer, and winter months on the abundance, spatial extent, diversity, and productivity of native SJR Basin fish species in order to inform adaptive management and future changes to the SJR flow objectives and their implementation

A.2. Modifications to the Southern Delta Agricultural Water Quality Objectives, and the Program of Implementation

The following is a description of potential draft modifications to southern Delta water quality objectives for the protection of agricultural beneficial uses, the program of implementation for those objectives, and the monitoring and special studies program included in the 2006 Bay-Delta Plan. The exact language of alternative changes may change and will be provided in the draft Substitute Environmental Document prepared for this project.

A.2.1. Southern Delta Agricultural Water Quality Objectives

The existing water quality objectives for agricultural beneficial uses are contained within Table A-2 of the 2006 Bay-Delta Plan. Draft revisions to the numeric objectives and the addition of a narrative water level and circulation objective are presented in Table A-2.

A.2.2. Program of Implementation

Replace entirely Chapter IV. Program of Implementation, B. Measures Requiring a Combination of State Water Board Authorities and Actions by Other Agencies, 1. Southern Delta Agricultural Salinity Objectives with the following:

Southern Delta Agricultural Water Quality Objectives

Elevated salinity in the southern Delta is caused by various factors, including low flows; salts imported to the San Joaquin Basin in irrigation water; municipal discharges; subsurface accretions from groundwater; tidal actions; diversions of water by the SWP, CVP, and local water users; channel capacity; and discharges from land-derived salts, primarily from agricultural drainage. Salinity in the southern Delta is also affected by evapo-concentration of salts due to local agricultural operations and to a lesser extent by local municipal wastewater treatment plant discharges. Poor flow/circulation patterns in the southern Delta waterways also cause localized increases in salinity concentrations.

The numeric salinity objectives and narrative water level and circulation objectives for the southern Delta listed in Table A-2 of the Bay-Delta Plan address salinity, water levels, and circulation to provide reasonable protection of the agricultural beneficial use in the southern Delta.

State Water Board Regulatory Actions
The southern Delta water quality objectives for protection of agricultural beneficial uses listed in Table A-2 will be implemented as follows:

i. Numeric salinity objectives for the San Joaquin River at Vernalis will continue to be implemented by conditioning the water rights of USBR on compliance with this objective.

ii. Narrative water level and circulation objectives for the southern Delta will be implemented by conditioning the water rights of the USBR and DWR on compliance with this objective through the following measures:

   a. Continued operation of the agricultural barriers at Grant Line Canal, Middle River, and Old River at Tracy, or other reasonable measures, for the purpose of improving surface water levels and circulation in the southern Delta that would otherwise be impacted by operations of the CVP and SWP. This shall include modified design and/or operations as determined by the Comprehensive Operations Plan described below.
   b. Completion of the Monitoring Special Study, Modeling Improvement Plan, and Monitoring and Reporting Protocol described in Section D of the Program of Implementation: *'Monitoring and Special Studies Program'* under a new part 2: *'Southern Delta Water Quality'*.
   c. Development and implementation of a Comprehensive Operations Plan to maximize circulation (i.e. minimize null zones) in order to avoid localized concentration of salts associated with agricultural water use and municipal discharges. The plan shall also address water level issues, and once approved, will supersede the water level and quality response plans required under D-1641. This plan shall include detailed information regarding the configuration and operations of any facilities relied upon in the plan, and shall identify specific water level and circulation performance goals. The plan shall also identify a method to conduct ongoing assessment of the performance and potential improvements to the facilities or their operation. The criteria for assessing compliance with the performance goals should be coordinated with the Monitoring and Reporting Protocol. DWR and USBR shall work together with the South Delta Water Agency (SDWA), State Water Board staff, other state and federal resource agencies, and local stakeholders as appropriate to develop this plan, and hold periodic coordination meetings throughout implementation of the plan.

      The State Water Board will request DWR and USBR to submit the Comprehensive Operations Plan to the Executive Director for approval within six months from the date of State Water Board approval of this amendment to the Bay-Delta Plan. Notwithstanding voluntary compliance with this measure, at a minimum, the State Water Board will require DWR and USBR to submit the plan within six months after the water rights are amended to require compliance with this measure. Once approved, the plan shall be reviewed annually, and updated as needed, with a corresponding report to the Executive Director.

iii. Numeric salinity objectives for the three interior southern Delta waterways will be implemented through:

a. Provision of assimilative capacity by maintaining salinity objectives upstream at Vernalis.
b. Increased inflow of low salinity water into the southern Delta at Vernalis by implementing the SJR flow objectives during February through June.
c. Benefits to local salinity conditions accrued from USBR and DWR implementation of the narrative water level and circulation objectives as described above.

Compliance with the salinity objectives for the interior southern Delta waterways will be measured at stations C-6, C-8, and P-12. The monitoring requirements at these stations will be re-evaluated and possibly modified as part of the Monitoring and Reporting Protocol. Compliance with the salinity objectives for the San Joaquin River at Vernalis will be determined at station C-10. Monitoring requirements to assess compliance with the narrative water level and circulation objective will be established as part of the Monitoring and Reporting Protocol.

The interior southern Delta salinity objectives will be implemented no later than December 2020 in coordination with implementation of San Joaquin River flow objectives. The narrative water level and circulation objectives will be implemented by completion and ongoing execution of the Comprehensive Operations Plan. The salinity objectives at Vernalis will continue to be implemented by conditioning USBR water rights on compliance with this objective. To the extent necessary, the State Water Board may take other water right actions and water quality actions, in concert with actions by other agencies, to implement the objectives.

Central Valley Regional Water Quality Control Board (CVRWQCB) Regulatory Actions
Implementation of the Vernalis and interior southern Delta salinity objectives will also benefit from the following CVRWQCB regulatory actions:

i. Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS): CV-SALTS is a stakeholder-led effort initiated by the State Water Board and the CVRWQCB in 2006 to develop a basin plan amendment and implementation actions to address salinity and nitrate problems in California’s Central Valley.
ii. Discharge Regulation: Using its NPDES and other permitting authorities, the CVRWQCB regulates salt discharges upstream and within the southern Delta in coordination with the ongoing CV-SALTS process. The CVRWQCB, in coordination with various Central Valley stakeholders, is also exploring a region-wide variance policy and interim program to provide variances from water quality standards for salt while CV-SALTS is in progress. This variance policy and interim program is anticipated to be considered by the CVRWQCB before the fall of 2011.
iii. Upstream of Vernalis San Joaquin River Salinity Objectives: CV-SALTS has established a committee to develop a Basin Plan amendment containing numerical salinity objectives and the associated control program for the lower San Joaquin River.
iv. San Joaquin River at Vernalis Salt and Boron TMDL: The CVRWQCB is implementing the salinity and boron TMDL at Vernalis. This effort includes a Management Agency Agreement with the US Bureau of Reclamation addressing salt imported into the San Joaquin River basin via the Delta-Mendota Canal.

Actions by Other Agencies
Implementation of the Vernalis and interior southern Delta salinity objectives will also benefit from the following actions being taken by other agencies:

- i. Grasslands Bypass Project: Implementation of the Grasslands Bypass Project and the associated West Side Regional Drainage Plan will continue to reduce salt loads to the San Joaquin River upstream of Vernalis.
- ii. San Luis Unit Feature Re-evaluation Project: The purpose of this project is to provide agricultural drainage service to the Central Valley Project San Luis Unit with the goal of long-term sustainable salt and water balance for the associated irrigated lands.
- iii. Central Valley Project Improvement Act (CVPIA) Land Retirement Program: The goal of this program is to reduce agricultural drainage by retiring drainage impaired farmland and changing the land use from irrigated agriculture to restored upland habitat.

State Funding of Programs

- i. Implementation of the Vernalis and interior southern Delta salinity objectives will also benefit from State Water Board funding assistance for salinity related projects through the State Revolving Fund Loan Program, the Agricultural Drainage Loan Program, the Agricultural Drainage Management Loan Program, Proposition 13, 40, 50, and grant funding through the Non-point Source Pollution Control Programs and Watershed Protection Programs.

A.2.3. New Special Studies, Monitoring, and Reporting Requirements

Add new section with the text below to the end of Chapter IV. Program of Implementation, Section D. Monitoring and Special Studies Program:

Southern Delta Agricultural Water Quality Objectives

Implementation of the numeric salinity and narrative water level and circulation objectives in the southern Delta will require information collected through the following monitoring and special studies programs:

- i. Monitoring Special Study: As a condition of its water rights, DWR and USBR shall work with State Water Board staff, and solicit other stakeholder input to develop and implement a special study to characterize the spatial and temporal distribution and associated dynamics of water level, circulation, and salinity conditions in the southern Delta waterways. The extent of low/null flow conditions and any associated concentration of local salt discharges should be documented. The State Water Board will solicit participation from local agricultural water users and municipal dischargers to provide more detailed data regarding local diversions and return flows or discharges.

  The State Water Board will request DWR and USBR to submit the plan for this special study to the Executive Director for approval within six months from the date of State Water Board approval of this amendment to the Bay-Delta Plan. Notwithstanding voluntary compliance with this measure, at a minimum, the State Water Board will require DWR and USBR to submit the plan within six months after the water rights are amended to require compliance with this measure. Once approved, the monitoring contained in this plan shall continue to be implemented until the Monitoring and Reporting Protocol (described below) is approved and being implemented.

ii. Modeling Improvement Plan: State Water Board Order WR 2010-0002, paragraph A.3 requires DWR and USBR to provide modeling and other technical assistance to State Water Board staff in association with reviewing and implementing the SJR flow and southern Delta salinity objectives. Plans to assess and improve hydrodynamic and water quality modeling of the southern Delta should be completed. Specific scope and deliverables are being managed as part of this ongoing process.

iii. Monitoring and Reporting Protocol: As a condition of its water rights, DWR and USBR shall work with State Water Board staff and solicit other stakeholder input to develop specific monitoring requirements to measure compliance with the narrative water level and circulation objectives, including monitoring requirements needed to assess compliance with the performance goals of the Comprehensive Operations Plan. DWR and USBR shall also use results of the monitoring special study and improved modeling capabilities described above to evaluate potential improvements to the compliance monitoring for the salinity objectives in the interior southern Delta. The State Water Board will request DWR and USBR to submit the plan to the Executive Director for approval within 18 months from the date of State Water Board approval of this amendment to the Bay-Delta Plan. Notwithstanding voluntary compliance with this measure, at a minimum, the State Water Board will require DWR and USBR to submit the plan within 18 months after the water rights are amended to require compliance with this measure.

Table A-1. Water Quality Objectives for Fish and Wildlife Beneficial Uses

RIVER FLOWS						
COMPLIANCE LOCATION	**STATION**	**PARAMETER**	**DESCRIPTION**	**WATER YEAR**	**TIME**	**VALUE**
SJR at Airport Way Bridge, Vernalis	C-10	Flow Rate	Narrative	All	February through June	*Maintain flow conditions from the SJR Watershed to the Delta at Vernalis, together with other reasonably controllable measures in the SJR Watershed sufficient to support and maintain the natural production of viable native SJR watershed fish populations migrating through the Delta. Specifically, flow conditions shall be maintained, together with other reasonably controllable measures in the SJR watershed, sufficient to support a doubling of natural production of Chinook salmon from the average production of 1967-1991, consistent with the provisions of State and federal law. Flow conditions that reasonably contribute toward maintaining viable native migratory SJR fish populations include, but may not be limited to, flows that more closely mimic the hydrographic conditions to which native fish species are adapted, including the relative magnitude, duration, timing, and spatial extent of flows as they would naturally occur. Indicators of viability include abundance, spatial extent or distribution, genetic and life history diversity, migratory pathways, and productivity.*
Confluence of Tuolumne River with the SJR	TBD					
Confluence of Merced River with the SJR	TBD					
Confluence of Stanislaus River with the SJR	TBD					
SJR at Airport Way Bridge, Vernalis	C-10	Flow Rate	Minimum Average Monthly Flow Rate (cfs)	All	Oct	1,000 [1]

[1] Plus up to an additional 28 thousand acre-feet (TAF) pulse/attraction flow shall be provided during all water year types. The amount of additional water will be limited to that amount necessary to provide a monthly average flow of 2,000 cfs. The additional 28 TAF is not required in a critical year following a critical year. The pulse flow will be scheduled in consultation with USFWS, NOAA Fisheries, and DFG.

Table A-2. Water Quality Objectives for Agricultural Beneficial Uses

COMPLIANCE LOCATIONS	STATION	PARAMETER	DESCRIPTION	WATER YEAR	TIME	VALUE
SOUTHERN DELTA SALINITY						
San Joaquin River at Airport Way Bridge, Vernalis	C-10 (RSAN112)	Electrical Conductivity (EC)	Maximum 30-day running average of mean daily EC (mmhos/cm)	All	Apr-Aug Sep-Mar	0.7 1.0
San Joaquin River from Vernalis to Brandt Bridge - and -	C-6 [1] (RSAN073)	Electrical Conductivity (EC)	Maximum 30-day running average of mean daily EC (mmhos/cm)	All	Apr-Aug (Sep-Mar)*	1.0 (1.0 to 1.4)*
Middle River from Old River to Victoria Canal - and -	C-8 [1] (ROLD69)					
Old River/Grant Line Canal from head of Old River to West Canal	P-12 [1] (ROLD59)					
SOUTHERN DELTA WATER LEVELS AND CIRCULATION						
San Joaquin River from Vernalis to Brandt Bridge - and -	[2]	Water Level & Circulation	Narrative	*Water level and circulation conditions shall be maintained sufficient to provide reasonable protection of agricultural beneficial uses.*		
Middle River from Old River to Victoria Canal - and -	[2]					
Old River/Grant Line Canal from head of Old River to West Canal	[2]					

[1] Compliance monitoring will be re-evaluated and possibly modified as part of the Monitoring and Reporting Protocol described in the implementation plan. Unless modified, compliance with these salinity objectives will be determined at the indicated locations.

[2] Monitoring requirements to assess compliance with this narrative objective will be established as part of the Monitoring and Reporting Protocol described in the implementation plan.

** Note: The salinity objective “value” parameter for September through March above is stated as a range of values that will be evaluated in the SED. Additional breakdown of applicable months for the “Time” parameter may also be evaluated in the SED.*

Appendix B. Tabular Summary of Estimated Escapement of Adult Fall-run Chinook Salmon for the Major SJR Tributaries from 1952 to 2010

Year	Stanislaus	Tuolumne	Merced (In River)	Merced (Hatchery)		
				Total	3+ years old	2 years old
1952	10000	10000				
1953	35000	45000				
1954	22000	4000	4000			
1955	7000	2000				
1956	5000	5500				
1957	4090	8170	380			
1958	5700	32500	500			
1959	4300	45900	400			
1960	8300	4500	350			
1961	1900	500	50			
1962	315	250	60			
1963	200	100	20			
1964	3700	2100	35			
1965	2231	3200	90			
1966	2872	5100	45			
1967	1185	6800	600			
1968	6385	8600	550			
1969	12327	32200	600			
1970	9297	18400	4700	100	100	0
1971	13261	21885	3451	200	200	0
1972	4298	5100	2528	120	120	0
1973	1234	1989	797	375	281	94
1974	750	1150	1000	1000	1,000	0
1975	1200	1600	1700	700	700	0
1976	600	1700	1200	700	700	0
1977	0	450	350	661	661	0
1978	50	1300	525	100	100	0
1979	110	1183	1920	227	114	114
1980	100	559	2849	157	157	0
1981	1000	14253	9491	924	616	308
1982		7126	3074	189	157	32
1983	500	14836	16453	1795	199	1,596
1984	11439	13689	27640	2109	1,888	221
1985	13473	40322	14841	1211	1,124	87
1986	6497	7404	6789	650	488	162
1987	6292	14751	3168	958	491	467
1988	10212	5779	4135	457	418	39
1989	1510	1275	345	82	66	16

Year	Stanislaus	Tuolumne	Merced (In River)	Merced (Hatchery)		
				Total	3+ years old	2 years old
1990	480	96	36	46	29	17
1991	394	77	78	41	32	9
1992	255	132	618	368	123	245
1993	677	471	1269	409	234	175
1994	1031	506	2646	943	497	446
1995	619	827	2320	602	311	291
1996	168	4362	3291	1141	395	746
1997	5588	7146	2714	946	838	108
1998	3087	8910	3292	799	347	452
1999	4349	8232	3129	1637	650	987
2000	8498	17873	11130	1946	1,615	331
2001	7033	8782	9181	1663	1,137	523
2002	7787	7173	8866	1840	1,250	588
2003	5902	2163	2530	549	392	157
2004	4015	1984	3270	1050	456	594
2005	3315	719	1942	421	346	75
2006	1923	625	1429	150	136	15
[2007]	443	224	495	79	70	9
[2008]	1305	455	389	76	39	37
[2009]	595	124	358	246	112	137
[2010]	1086	540	651	146		

Note: Data for those years in brackets (2007 – 2010) are preliminary.
Source: DFG 2011 Grandtab Report and PFMC 2011