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

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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
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 and Figure 1.2 display the project areas corresponding to SJR flow and southern Delta salinity objectives, respectively.

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

In order to receive comments and other technical information related to its October 29, 2010 draft of the Technical Report, the State Water Board issued a notice on October 29, 2010, for a public workshop on January 6 and 7, 2011 and availability of the Draft Technical Report for public comment. 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; 3) scientific basis for developing alternative southern Delta salinity objectives; and 4) water supply impacts of potential alternative SJR flow and southern Delta salinity 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, the State Water Board made several edits to the Draft Technical Report. In addition, many of the comments and questions raised at the workshop are addressed by the draft basin plan amendment. At the time the Draft Technical Report was released for public review, the State Water Board did not release the draft basin plan amendment language. The draft basin plan amendment language has been incorporated into this report as Appendix A. The revised Technical Report will be the subject of an independent peer review. The Final Technical Report and the peer review findings will be included in the SED as an Appendix.

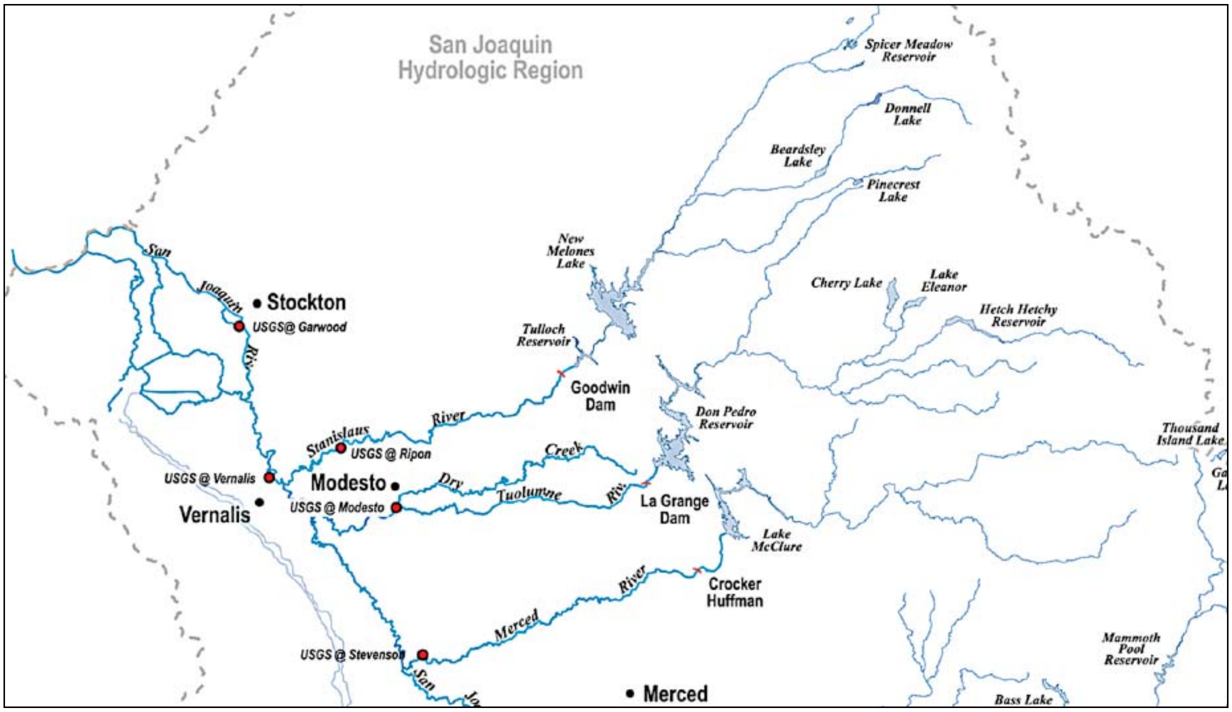


Figure 1.1. Project area: SJR flow objectives

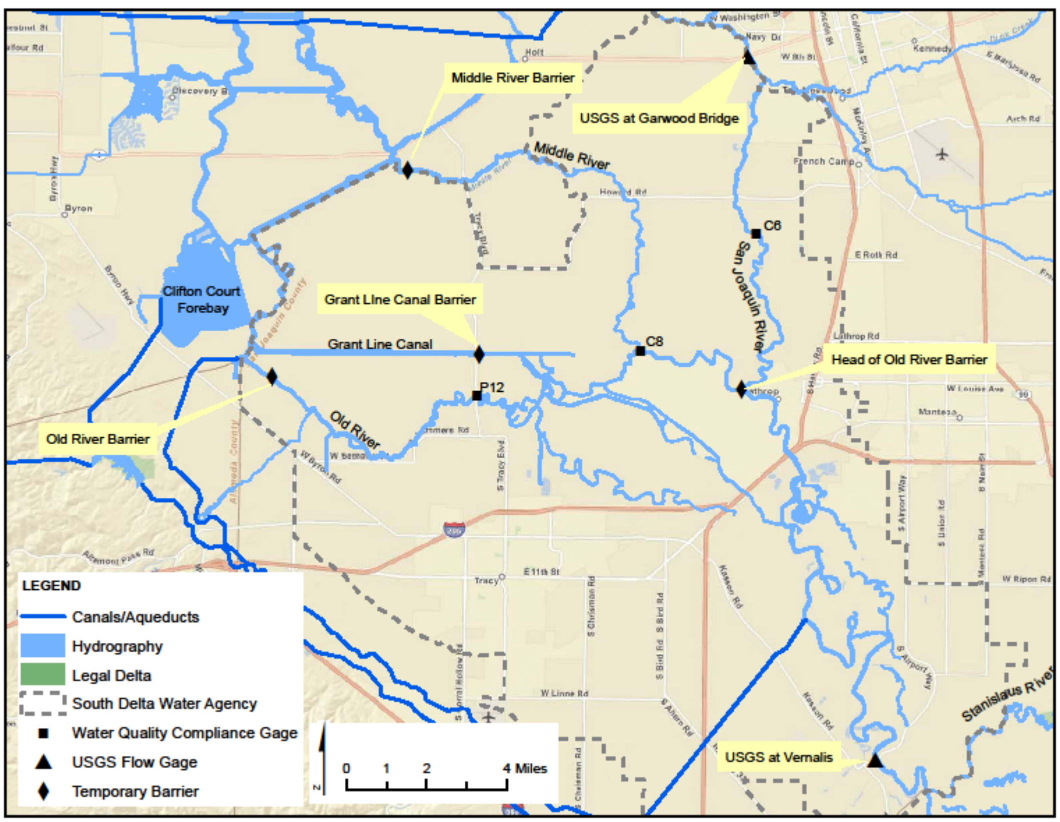


Figure 1.2. Project area: southern Delta salinity objectives, showing agricultural barriers, water quality compliance stations, and major flow gages

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 probable range of alternatives that will be further developed in the SED. The methodology for estimating additional water needed to satisfy these flow alternatives is presented in the water supply impacts analyses in Section five.

Section four provides the scientific basis for developing southern Delta salinity objectives and a program of implementation to achieve those objectives, 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; and model salinity effects on crop salt tolerance. The analysis of salinity effects uses the CALSIM-modeled salinity estimates for the SJR at Vernalis as the baseline conditions and evaluates the salinity changes that would result from alternative SJR flow objectives. In addition, salinity correlations between monitoring stations in the southern Delta and the SJR near Vernalis were developed in order to estimate the assimilative capacity needed at Vernalis to comply with alternative salinity objectives in the southern Delta. Threshold levels for salinity impacts on the Municipal and Domestic Supply (MUN) beneficial uses are also described in this section.

Section five describes the tools and methods that will be used in the SED to analyze the effect of alternative flow and salinity objectives on water supplies in the SJR watershed. The data, methods and tools presented in this section are used to evaluate the water supply effects of the likely range of possible alternative SJR flow objectives. The existing southern Delta salinity objectives are fully protective of agricultural beneficial uses; therefore full implementation of the existing southern Delta salinity objectives for each alternative SJR flow objective will provide a complete evaluation of water supply effects from alternative SJR flow objectives.

For SJR flows, a range of alternatives was selected to demonstrate applicability of the data, methods, and tools to correctly analyze the effects of the SJR and tributary flow across a wide range of alternatives. The range of alternatives discussed in this document includes 20, 40, and

[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.

60 percent of unimpaired flow from the SJR tributaries during the February through June time frame. Specifically, more flow is needed from the existing salmon and steelhead bearing tributaries in the SJR basin above Vernalis in order to provide connectivity with Delta rearing and migration and more closely follow the seasonal flow conditions to which native migratory fish are adapted. Salmon bearing tributaries to the SJR currently include the Stanislaus, Tuolumne, and Merced Rivers. These flow alternatives do not necessarily represent the alternatives that will be evaluated in the SED. Instead, these alternatives represent the likely range of alternatives that will be analyzed. The range of SJR flow and southern Delta salinity objectives will be further refined to develop alternatives for analysis in the SED. The potential environmental, economic, water supply, and related impacts of the various alternatives will then be analyzed and disclosed prior to any determination concerning changes to the existing SJR flow and southern Delta salinity objectives.

2 Hydrologic Analysis of San Joaquin River Basin

Construction of storage infrastructure (dams) and diversions have vastly altered the natural flow regime of the 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. Specifically, this analysis focuses on the San Joaquin River at Vernalis and the Stanislaus, Tuolumne, Merced, and Upper San Joaquin Rivers (major SJR tributaries), and the valley floor, Fresno River, Chowchilla River, and Tulare Lake Basin (non-major SJR tributaries).

2.1 Basin Characteristics and Descriptive Studies

In the Sierra Nevada, as in other systems dependant 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 2002; Cain et al. 2003). These characteristics are present in all major SJR tributaries in nearly all years, with wide temporal variations in magnitude throughout the year and from year to year. 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 major SJR tributaries 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 major SJR tributaries.

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).

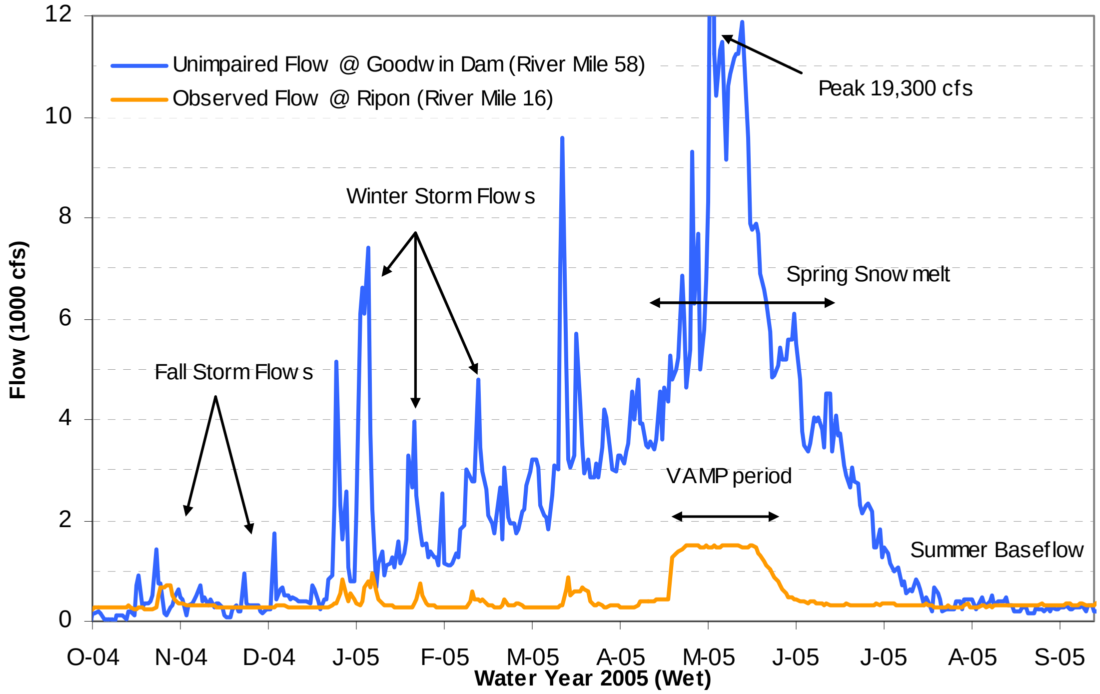


Figure 2.1. Typical Stanislaus River Annual Hydrograph of Daily Average Unimpaired and Observed Flows during a Wet Water Year (2005) Illustrating Important Hydrograph Components

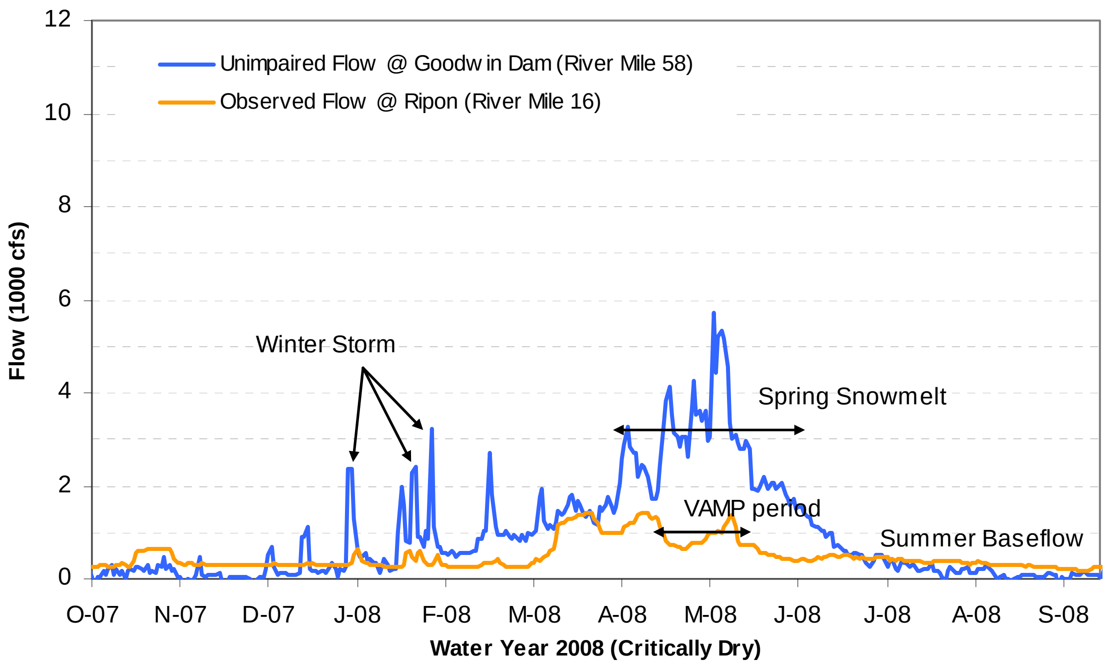


Figure 2.2. Typical Stanislaus River Annual Hydrograph of Daily Average Unimpaired and Observed Flows during a Critically Dry Water Year (2008) Illustrating Important Hydrograph Components

Table 2.1. Summary of Watershed and Dam Characteristics by SJR Tributary

Characteristic	Stanislaus River	Tuolumne River	Merced River	Middle and 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. In this report, the Upper SJR is considered the portion of the SJR upstream of Friant Dam. The Middle SJR, as used in this report, extends from the Merced River confluence to Friant Dam. The SJR upstream of the Merced River confluence, including 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 2002; 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 major SJR tributaries. 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 major SJR tributaries (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 19^{th} 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 major SJR tributaries 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 major SJR tributary 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"[1] (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 SJR tributary 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
- 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 major SJR tributaries. To estimate monthly unimpaired flow at Vernalis for the period beyond 2003, the major SJR tributaries 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 Major SJR tributary flows to result in the corresponding flows at Vernalis. The major SJR tributaries 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 major SJR tributary. It is possible that some portion of the flow attributed to the Valley Floor enters the tributaries themselves rather than the mainstem SJR, however no attempt was made to do so as the valley floor component makes up only roughly three percent of the average annual unimpaired flow on the major tributaries (DWR 2007a). Therefore, without Valley Floor unimpaired estimates for the major SJR tributaries, 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.

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

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

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.

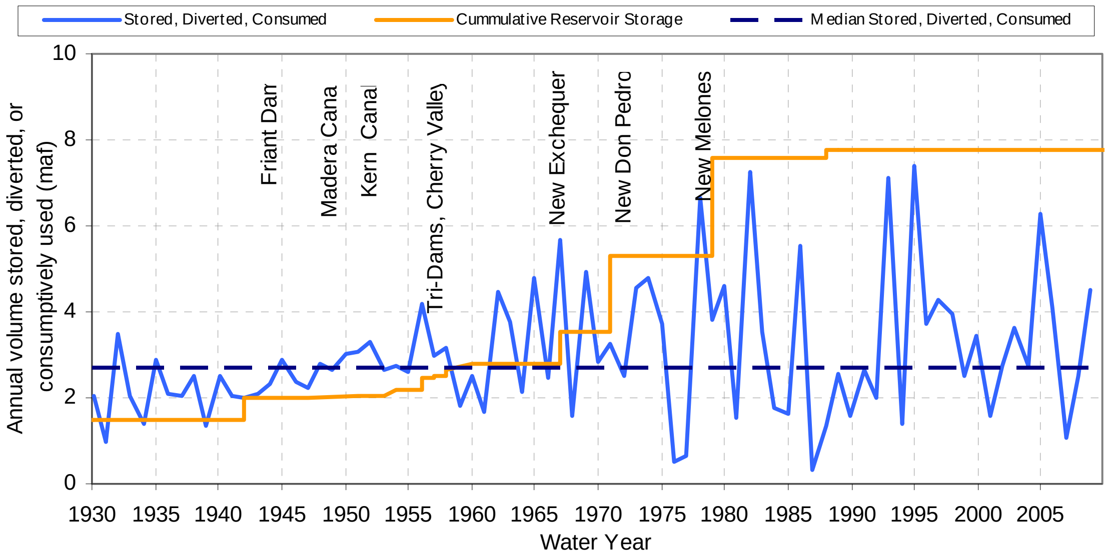


Figure 2.3. Annual Volume Stored, Diverted, or Consumptively Used Upstream of Vernalis, and Cumulative Reservoir Storage Capacity within the SJR River Basin Upstream of Vernalis

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 percent 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 major SJR tributaries, ultimately reducing observed flow to 46 percent 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 major SJR tributaries (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.

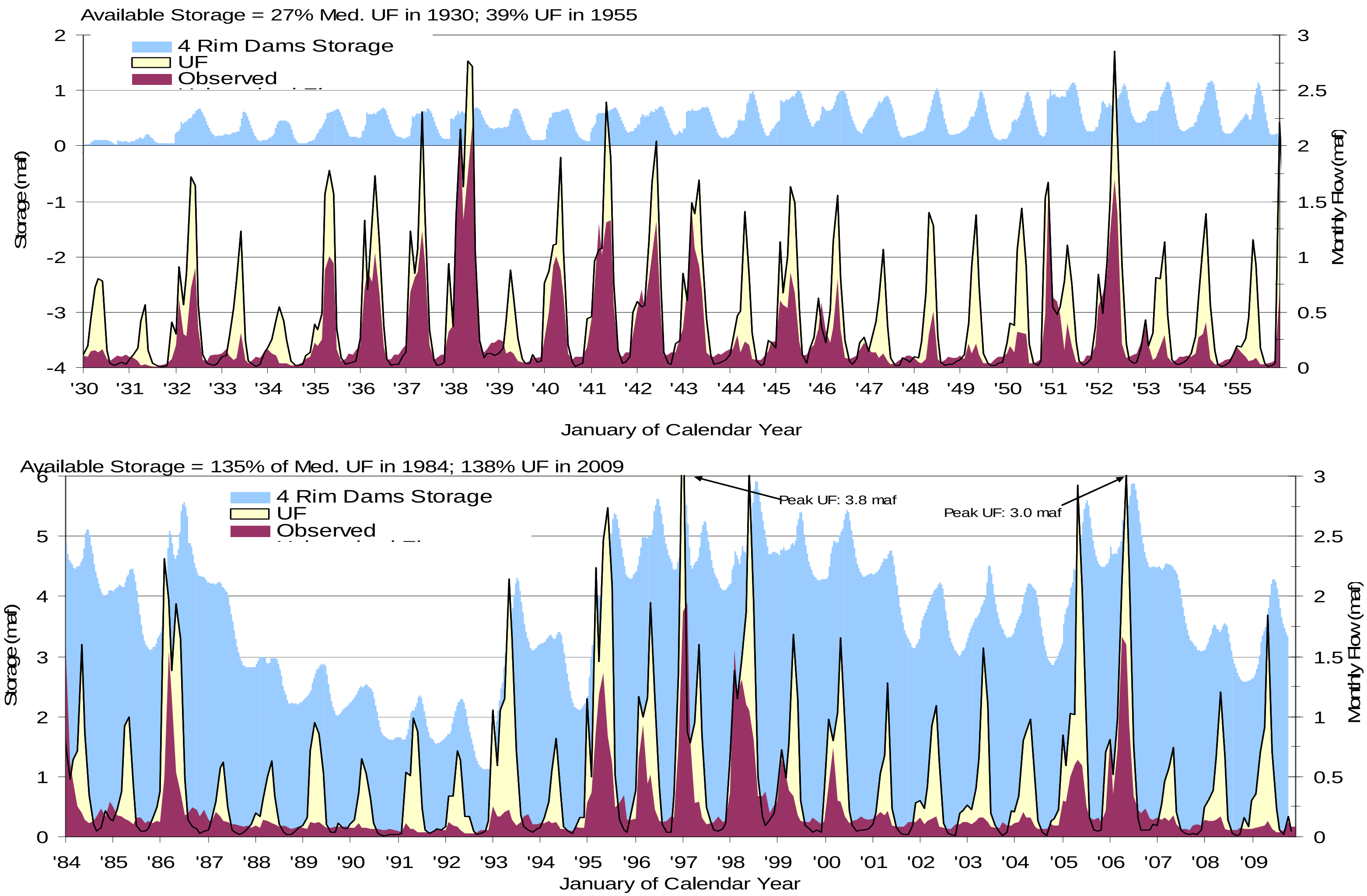


Figure 2.4. Monthly Unimpaired and Observed Flow in the San Joaquin River at Vernalis and Total Storage Behind New Melones, New Don Pedro, New Exchequer, and Friant Dams for Two Periods in Time (1930 to 1955 and 1984 to 2009)

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)
Average of All Years	26	5,900	3,520	26	6,070	2,900
Median of All Years	26	5,400	2,760	26	4,580	1,720
Average of Wet Years	6	9,490	7,160	8	10,750	5,450
Average of AN Years	7	7,070	4,320	3	6,820	4,240
Average of BN Years	6	4,350	1,670	1	4,990	1,360
Average of Dry Years	4	3,410	1,350	5	4,140	1,490
Average of Critical Years	3	2,450	960	9	2,840	1,150
Wettest of Years	(1938)	13,370	10,840	(1995)	13,680	8,490
Driest of Years	(1931)	1,680	680	(1987)	2,160	660

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 percent 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 percent to 138 percent of the long-term median annual unimpaired flow in the basin.

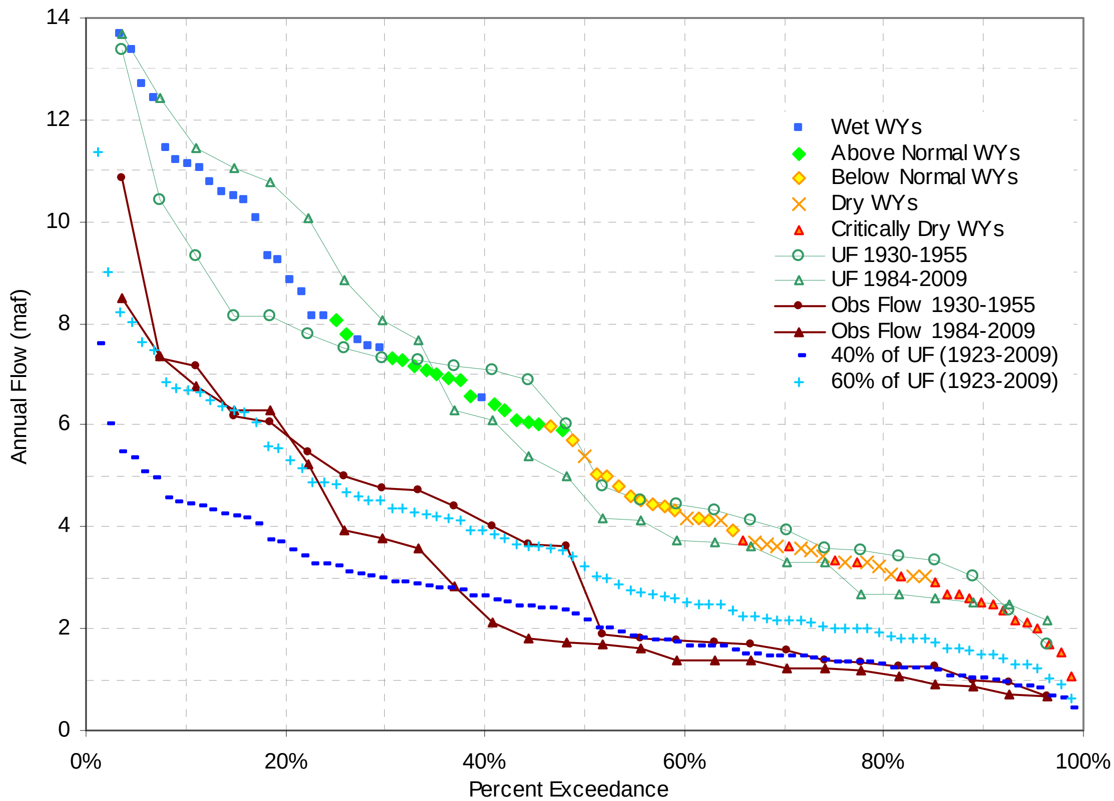


Figure 2.5. Exceedance Curves of Observed and Unimpaired Flow Hydrology in the San Joaquin River at Vernalis

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 less 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 percent 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 percent of years (the 35 percent to 40 percent exceedance level). From 1930 to 1955, observed annual flows less than approximately 2.5 MAF occurred in fewer than 50 percent of years.

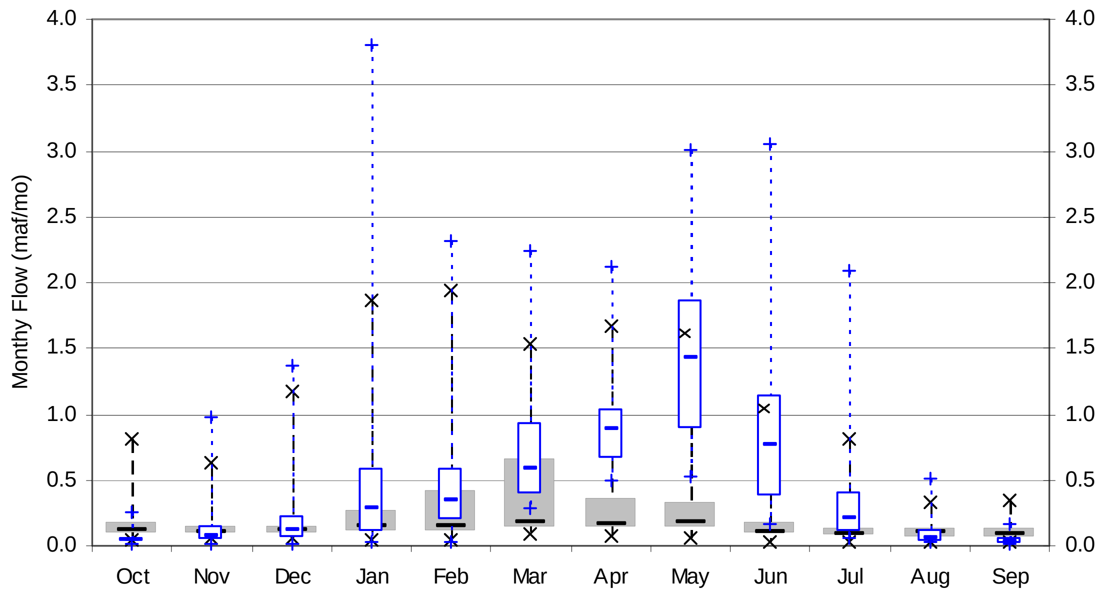
Between 39 and 68 percent of annual unimpaired flow remained in the river for the 1930 to 1955 period, and between 34 and 58 percent remained in the river during the 1984 to 2009 period. The curves corresponding to 40 and 60 percent of unimpaired flow are overlaid for reference to the percentage of unimpaired 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. Table 2.5 contains statistics related to the monthly unimpaired and observed flows at Vernalis. The greatest reduction in the median of monthly flows occurs during peak spring snowmelt months of April, May, and June, during which observed flows represent 25 percent, 17 percent, and 18 percent of unimpaired flow, respectively. In contrast, August, September, October, and November have a higher median flow (133 percent, 269 percent, 342 percent, and 133 percent of unimpaired flow, respectively) than would be expected to occur under natural conditions (Table 2.5).

The unimpaired flow magnitude of the snowmelt varies dramatically each year as is expressed by an inter-quartile range (difference between 75th percentile and 25th percentile) of roughly 0.38, 0.98, and 0.77 MAF for the months of April, May and June. Under present conditions, this range has been reduced to roughly 0.23, 0.20, and 0.09 MAF and is slightly increased for September and October (Table 2.5). This large decrease in spring flow magnitude and variation throughout the year, as well as the augmentation of summer and fall flows is apparent in nearly all recent years. Figure 2.4 emphasizes this, 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 and Annual Statistics of Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow in the SJR at Vernalis from 1984 to 2009

Unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
IQ Range	40	102	155	480	392	547	375	981	765	293	85	34	5,328
10%tile	15	35	49	77	148	326	557	631	238	84	29	15	2,555
20%tile	22	41	62	97	169	380	645	820	337	105	34	18	2,681
25%tile	26	46	63	104	201	389	656	887	383	108	34	19	3,313
30%tile	33	50	70	121	226	412	672	981	447	111	38	20	3,468
40%tile	39	55	102	208	275	490	714	1,095	630	145	44	28	3,753
50%tile	49	70	125	284	339	587	892	1,424	773	208	55	37	4,578
60%tile	57	76	160	378	482	719	926	1,600	874	232	94	44	6,102
70%tile	62	145	211	387	553	802	984	1,763	1,122	324	108	52	7,868
75%tile	67	148	218	585	592	936	1,032	1,868	1,149	401	119	54	8,641
80%tile	75	156	225	773	726	998	1,144	1,941	1,643	478	139	61	10,082
90%tile	100	209	491	948	1,071	1,099	1,421	2,307	2,141	833	169	82	11,242
Observed flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
IQ Range	99	63	59	166	311	536	233	199	92	64	69	80	2,682
10%tile	65	67	65	72	78	109	87	94	63	45	45	52	891
20%tile	84	77	80	91	104	130	114	121	66	70	62	56	1,168
25%tile	85	86	84	109	107	132	129	131	84	70	65	62	1,223
30%tile	91	95	89	114	114	135	138	133	88	73	69	68	1,300
40%tile	108	102	97	131	127	157	155	163	102	81	79	81	1,396
50%tile	125	110	113	146	155	187	167	174	111	89	98	91	1,718
60%tile	161	121	130	159	180	211	204	217	137	108	121	121	2,108
70%tile	170	136	138	252	361	504	290	295	161	123	129	134	3,678
75%tile	184	149	143	275	417	668	362	330	176	134	134	142	3,906
80%tile	230	151	216	291	486	744	446	518	222	157	160	165	5,227
90%tile	293	168	280	590	655	913	1,176	872	714	298	212	223	6,539
Observed flow as a percent of unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	256	77	54	40	44	30	17	13	16	33	87	203	34
Med.	342	133	94	57	53	42	25	17	18	44	133	269	46
75%tile	432	253	151	134	85	73	38	22	30	72	210	401	58
IQ Range	177	177	96	94	41	43	21	8	14	39	123	199	25

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 percent 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 2.6 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 2.6). 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 2.6 summarizes the alterations to the timing of the wettest month for the two periods previously discussed using percentage of years each month was the wettest.

Table 2.6. The Wettest Months of Teach 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

	No. of	Percent of years by month											
Period	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 2.7 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 2.7. 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 major SJR 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 2.8. While other studies have focused separately on the major SJR tributaries (McBain and Trush, 2000; Kondolf et al., 2001; Stillwater Sciences, 2002; Cain et al., 2003), the 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 percent, 61 percent, and 23 percent 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 2.8). The difference in larger peak flows, for those that occur every 10 years on average, is, however, less pronounced, with only a six percent 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.

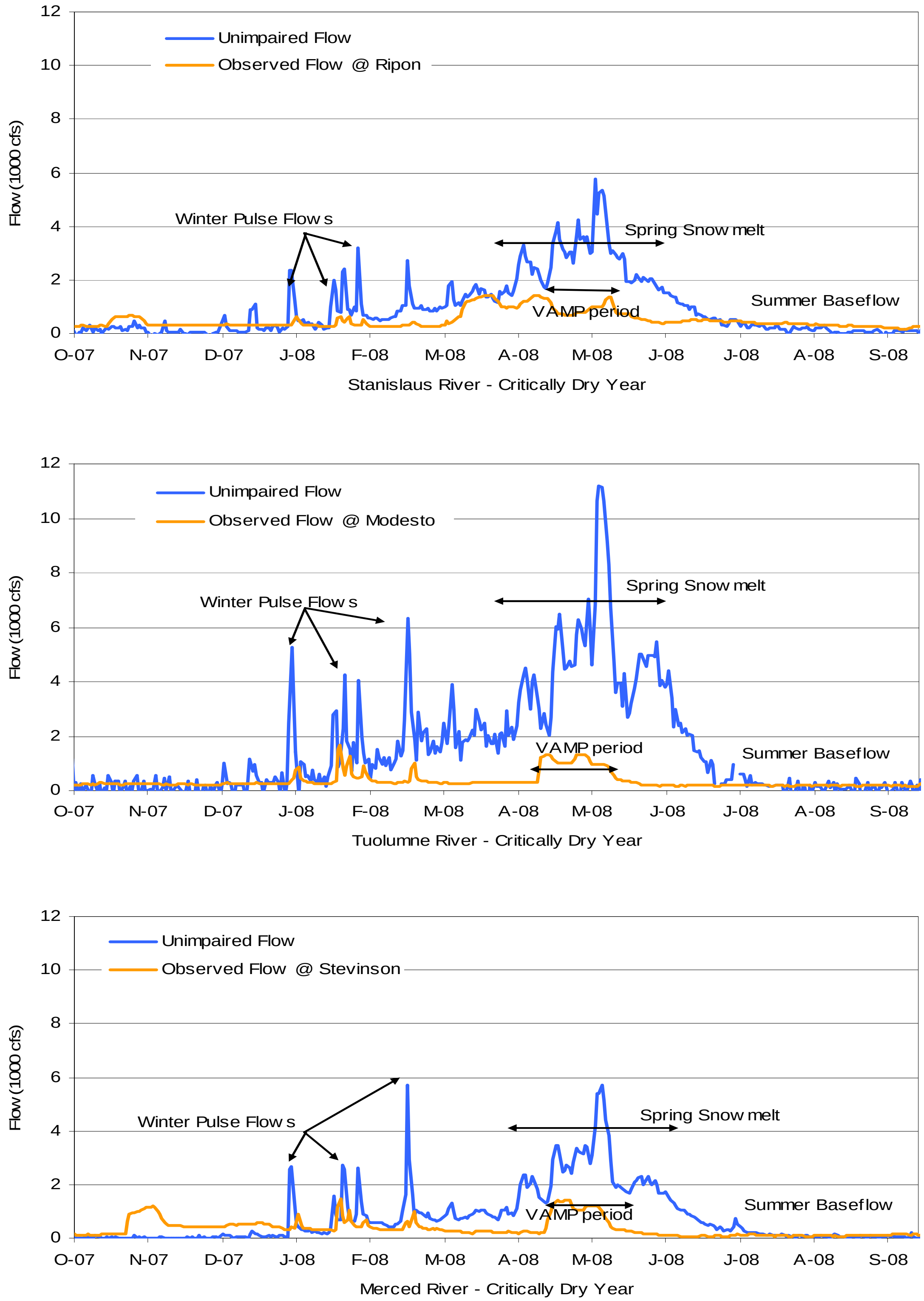


Figure 2.7. Daily Unimpaired Flow and Observed Flow for a Critically Dry Water Year (WY 2008) in the Stanislaus At Ripon (Top), Tuolumne at Modesto (Middle), and Merced at Stevinson (Bottom)

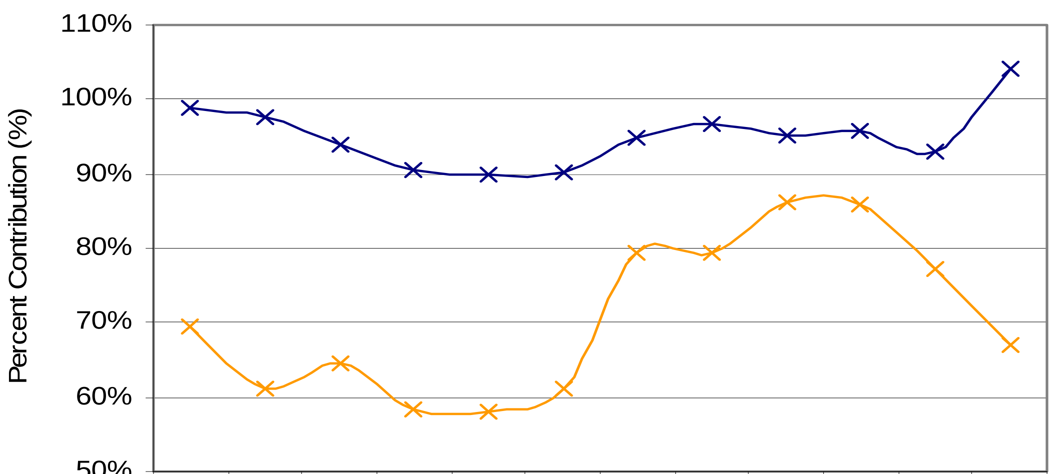
Table 2.8. Frequency Analyses of Annual Peak Flows in the SJR at Vernalis as Compared to USACE (2002)

	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 Major Tributaries to the San Joaquin River

The previous section describes the unimpaired and observed flow conditions in the SJR at Vernalis. Flow in the SJR at Vernalis is largely comprised of flows from the Stanislaus, Tuolumne, Merced Rivers, and the Upper SJR. In some years, water from the Tulare Lake Basin also flows to the SJR via Fresno Slough. Alterations to flow characteristics at Vernalis are driven by the alterations that have occurred on each of these major SJR tributaries. This section summarizes the hydrologic characteristics of, and contribution to flows at Vernalis by, the major SJR tributaries. Under unimpaired conditions, flows from the major SJR tributaries account for approximately 90 to 100 percent of the flow at Vernalis. The remainder of flow comes from the Valley Floor, Tulare Lake Basin, Fresno River, and Chowchilla River. In contrast, these tributaries accounted for only 58 to 86 percent of observed flow for the 1984 to 2009 period (Figure 2.8).



	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 Major SJR Tributaries Combined (1984 to 2009)

Figure 2.9 displays the monthly median flow contribution by the major SJR tributaries as a percentage of flow at Vernalis. The major SJR tributaries 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 percent, 31 percent, 14 percent, and 30 percent respectively on an annual basis to the flow at Vernalis. The remaining portion of the SJR Basin, including the Fresno River, Chowchilla River, Valley Floor, and the Tulare Lake Basin, contributes 2 percent. The percentages presented in Figures 2.8 and 2.9 do not necessarily add up to 100% because they are median values.

Under current conditions, the Stanislaus and Tuolumne contribute an annual median of 24 percent and 21 percent respectively, while the Merced percentage of contribution (14 percent) is roughly unchanged as compared to unimpaired flows (Table 2.9). The Upper SJR now contributes an annual median of 8 percent of flow, and the remaining portion of the SJR basin contributes 26 percent. The difference between unimpaired and observed flow from the non-major SJR tributaries is due primarily to the operation of the Delta Mendota Canal that adds additional flow from the Delta.

Table 2.9. Median Annual Percent Contribution of Unimpaired Flow and Observed Flow by Major SJR Tributary 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%

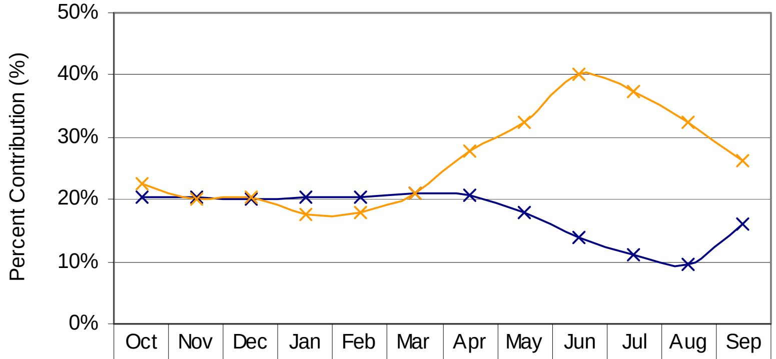
The percent of flow contributed by the Stanislaus River during June and July has increased dramatically, accounting for roughly 40 percent of flow during these months, while the contributions from the Tuolumne have been reduced to roughly 20 percent during these same months (Figure 2.9). The Upper SJR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

Like Vernalis, spring flows in each of the major SJR tributaries have been significantly reduced while flows during late summer and fall (generally August to November) have increased, resulting in less variability in flow during the year. Additionally, the year to year variability in winter and spring flows has been greatly reduced. Boxplots for each of the tributaries (Figure 2.10 through Figure 2.14) depict the median, 25th percentile, 75th percentile, and the wettest and driest months for 1984 to 2009. These graphical comparisons of the unimpaired flow and observed flows demonstrate the magnitude of alteration in the timing, variability, and volume of flows.

Flows are much lower, primarily during the wet season, and with much less variation from year to year and within the year. The inter-quartile range is now much less than the unimpaired range (Table 2.10 through Table 2.14). For emphasis, the third quartile (75th percentile) monthly observed flows are less than the lowest monthly unimpaired flow for all tributaries during April and May (Figure 2.10 to Figure 2.13). 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. Annual observed flows in each of the tributaries have been reduced, and now only 58 percent, 40 percent, 46 percent, and 13 percent of 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 percent of unimpaired flow (Table 2.14). This increase is likely due to addition of water via the DMC. The DMC returns flow from the Delta as if it were a new, non-major tributary inflow, and effectively increases the percent contribution of the non-major SJR tributary flows.

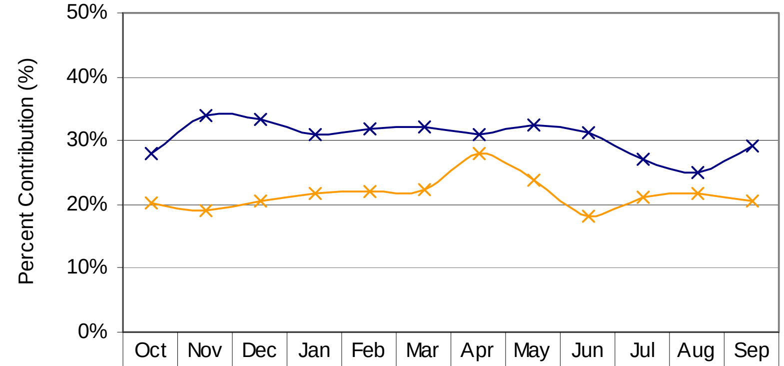
Based on the unimpaired data, the wettest month during the spring snowmelt period is generally either April or May for each of the major SJR tributaries. For example in the Stanislaus River, May was the peak month for 17 of the 26 years between 1984 and 2009; April was the peak in seven years, all of 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.

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



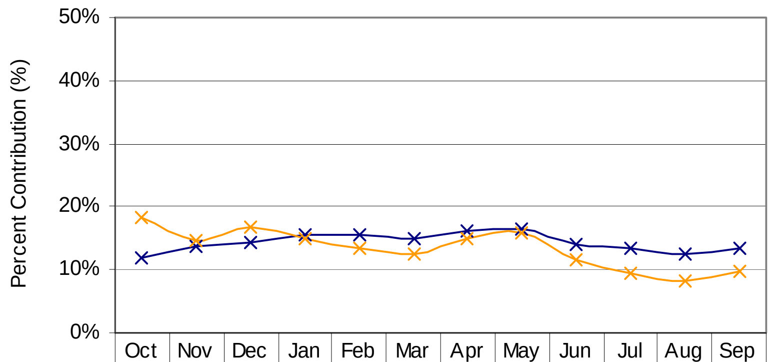
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	20%	20%	20%	20%	20%	21%	21%	18%	14%	11%	10%	16%
OBS	23%	20%	20%	18%	18%	21%	28%	32%	40%	37%	32%	26%

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



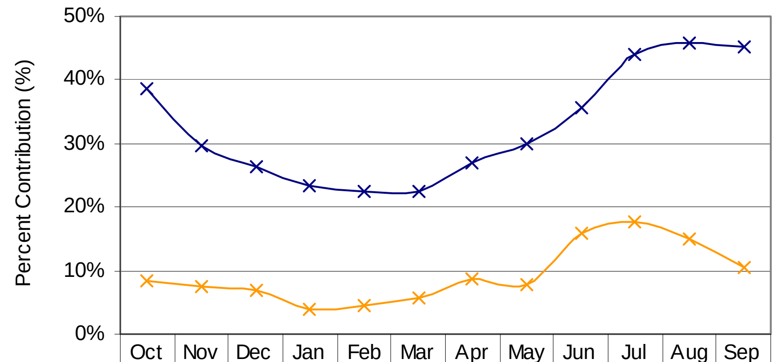
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	28%	34%	33%	31%	32%	32%	31%	33%	31%	27%	25%	29%
OBS	20%	19%	21%	22%	22%	22%	28%	24%	18%	21%	22%	21%

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



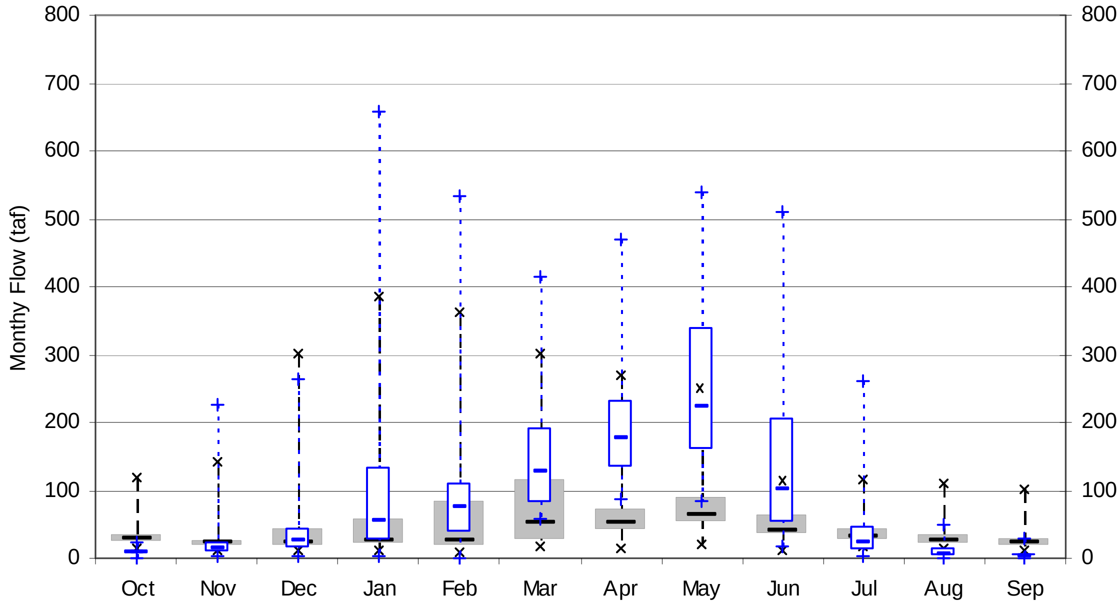
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
UF	12%	14%	14%	16%	15%	15%	16%	16%	14%	13%	13%	14%
OBS	18%	15%	17%	15%	13%	12%	15%	16%	12%	9%	8%	10%

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)

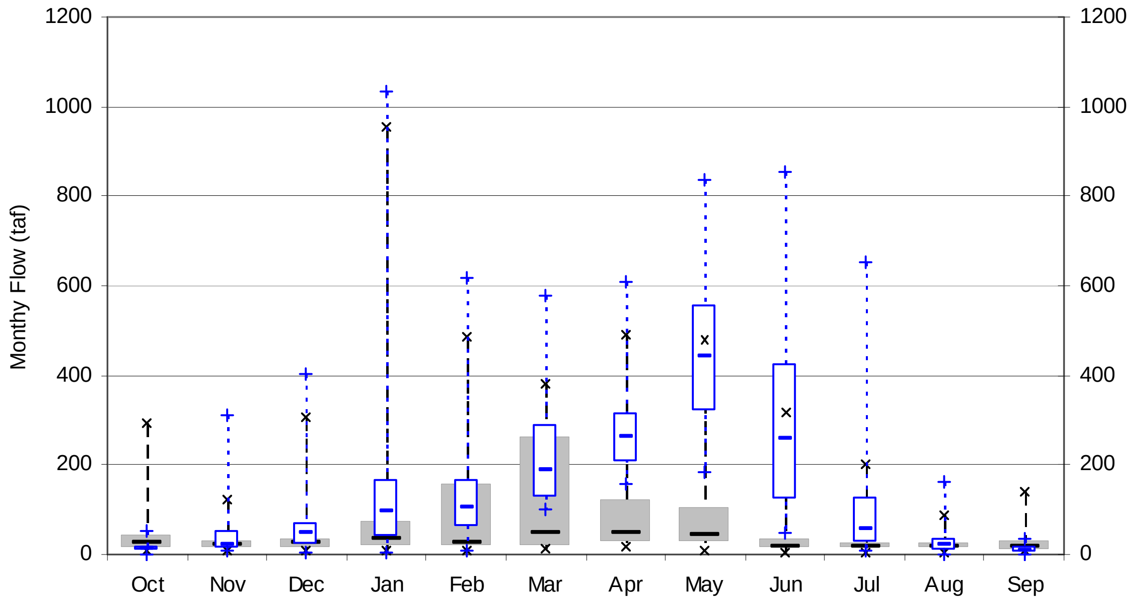


Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow ("+"sign) and observed ("x" sign).

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

Table 2.10. Monthly and Annual Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow Statistics in the Stanislaus River from 1984 to 2009

Unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	3	5	12	17	29	67	105	95	30	5	2	1	463
20%tile	5	8	13	23	35	79	130	153	41	12	4	1	510
25%tile	5	10	13	25	39	82	134	160	52	12	4	2	565
30%tile	6	10	14	27	50	90	135	167	57	14	5	2	595
40%tile	9	13	15	42	55	102	157	192	94	19	6	3	752
50%tile	10	16	27	55	75	127	178	224	103	22	7	4	922
60%tile	11	18	31	86	90	160	206	297	128	24	10	6	1162
70%tile	12	24	42	100	104	176	218	329	178	40	13	6	1463
75%tile	13	24	43	133	110	191	231	339	207	47	15	7	1,541
80%tile	13	31	47	146	138	215	245	370	215	57	16	10	1,692
90%tile	17	44	105	191	224	233	254	446	285	89	21	18	2,015
Observed flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	20	17	14	12	13	19	30	33	28	21	19	16	310
20%tile	21	19	17	15	17	24	36	47	33	25	20	18	333
25%tile	23	19	19	19	17	26	41	51	35	26	21	18	339
30%tile	24	19	19	20	18	31	45	51	35	27	22	19	351
40%tile	27	19	20	24	20	43	49	54	36	29	23	19	386
50%tile	30	22	22	25	26	53	53	63	41	31	25	23	429
60%tile	32	24	25	29	41	67	57	77	49	34	27	25	532
70%tile	35	25	28	40	65	77	66	87	58	39	33	28	624
75%tile	36	25	44	59	84	116	72	90	63	44	34	28	725
80%tile	43	27	55	69	91	135	75	92	70	45	39	33	967
90%tile	74	43	65	182	150	181	109	98	77	65	74	57	1,249
Observed flow as a percent of unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	315	81	56	31	31	22	23	20	33	86	252	305	45
Med.	437	160	107	48	46	57	32	26	40	129	353	493	58
75%tile	523	202	182	121	81	85	45	39	69	284	701	1,395	76

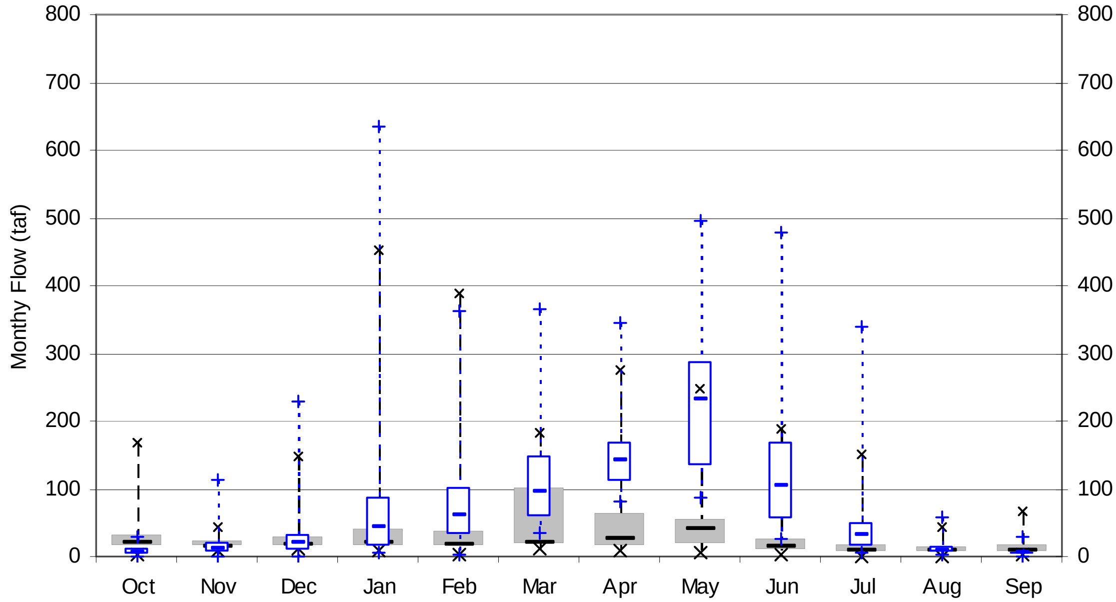


Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow ("+"sign) and observed ("x" sign).

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

Table 2.11. Monthly and Annual Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow Statistics in the Tuolumne River from 1984 to 2009

Unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	4	8	16	24	53	112	184	208	63	17	4	3	839
20%tile	5	13	18	32	60	124	195	275	100	24	8	4	884
25%tile	7	15	22	37	62	127	207	319	123	25	8	6	1,050
30%tile	9	17	25	40	67	136	219	329	141	30	9	7	1,114
40%tile	10	18	29	70	93	168	230	360	207	33	14	7	1,312
50%tile	11	23	47	97	105	190	263	443	260	57	20	10	1,514
60%tile	15	26	58	129	151	232	301	536	330	67	26	15	2,018
70%tile	18	49	70	134	161	271	307	541	381	101	33	18	2394
75%tile	19	53	72	165	168	289	317	558	424	127	35	18	2,585
80%tile	21	62	82	202	192	296	323	569	507	144	37	20	2,971
90%tile	38	77	171	269	313	340	343	645	619	242	52	23	3,268
Observed flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	10	12	12	13	14	16	22	17	7	7	7	7	155
20%tile	15	14	15	18	15	18	23	26	9	8	9	10	213
25%tile	15	14	15	19	17	18	27	27	12	11	11	11	254
30%tile	16	16	16	25	24	19	34	31	13	13	12	11	265
40%tile	21	18	20	28	26	23	43	38	15	15	15	14	316
50%tile	27	21	25	35	28	46	46	42	17	16	17	16	398
60%tile	36	27	27	41	76	79	56	52	20	20	21	23	593
70%tile	42	29	28	54	144	209	102	79	28	21	27	30	1,236
75%tile	44	29	35	76	158	264	124	106	33	27	28	32	1,388
80%tile	46	30	78	96	236	291	180	170	47	30	30	38	1,560
90%tile	74	51	129	231	302	338	324	275	251	103	61	58	2,249
Observed flow as a percent of unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	165	42	32	27	24	14	14	8	6	22	72	153	19
Med.	293	76	64	40	49	33	22	12	9	34	106	236	40
75%tile	464	162	113	104	113	83	45	19	20	52	154	307	59

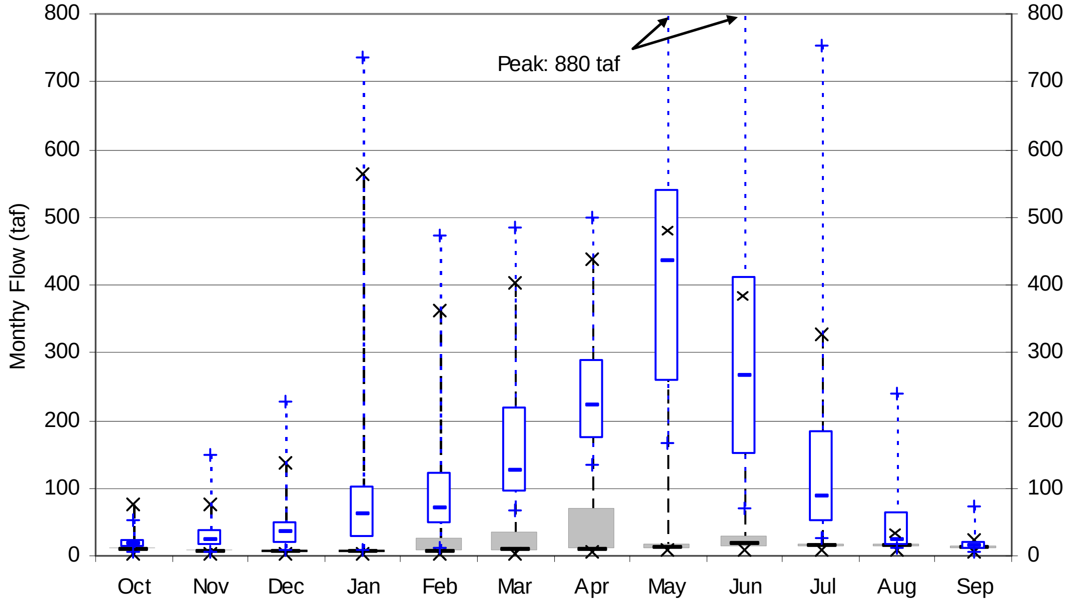


Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow (“+”sign) and observed (“x” sign).

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

Table 2.12. Monthly and Annual Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow Statistics in the Merced River from 1984 to 2009

Unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	2	5	6	11	22	50	93	104	32	11	4	1	410
20%tile	2	6	8	13	28	56	104	117	48	13	5	2	450
25%tile	2	7	9	15	32	59	109	133	54	15	6	2	524
30%tile	3	7	10	18	34	61	113	153	56	18	6	3	548
40%tile	4	9	13	35	37	69	129	184	85	25	7	4	608
50%tile	5	11	19	45	60	96	143	233	104	31	9	5	721
60%tile	7	13	25	49	68	105	151	270	130	33	11	6	906
70%tile	10	18	29	62	91	118	163	280	156	42	13	6	1,195
75%tile	12	21	33	86	102	148	168	286	167	50	14	7	1,387
80%tile	13	22	34	103	105	161	181	316	228	51	15	7	1,559
90%tile	16	30	61	195	181	181	199	386	328	110	23	10	1,746
Observed flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	5	11	12	13	12	15	10	9	6	2	2	3	102
20%tile	11	14	13	14	14	15	11	12	8	4	4	5	148
25%tile	16	14	14	14	14	16	13	17	9	6	5	5	168
30%tile	17	15	14	15	15	17	19	21	10	6	6	6	193
40%tile	19	15	15	16	18	18	22	39	11	8	6	7	224
50%tile	20	15	16	20	18	20	27	41	13	9	8	8	271
60%tile	25	17	19	30	21	24	34	44	16	11	9	11	363
70%tile	28	21	25	36	26	59	56	52	23	15	11	13	550
75%tile	31	23	28	40	39	102	64	55	27	18	15	17	673
80%tile	34	31	30	47	71	144	66	82	35	19	17	19	764
90%tile	67	36	57	104	90	168	169	160	127	50	39	43	1,167
Observed flow as a percent of unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	179	87	56	37	35	23	12	10	11	22	59	136	25
Med.	480	164	110	68	51	33	25	18	15	34	80	215	46
75%tile	762	235	173	121	65	60	34	29	29	45	165	392	56

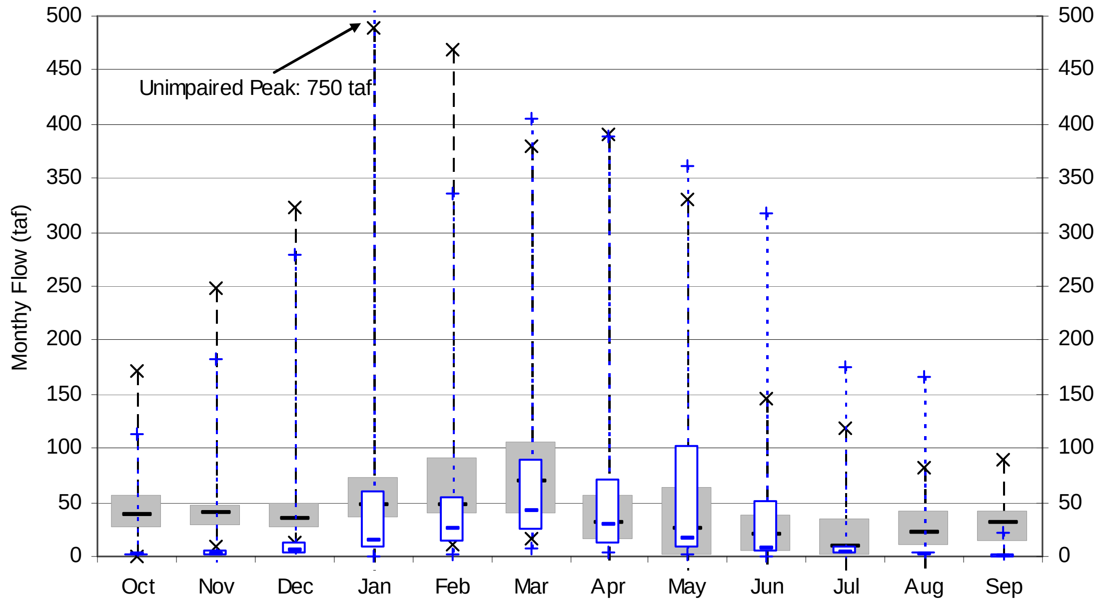


Key to boxplots: Median, horizontal line; box, 25th and 75th percentiles; whiskers, range for unimpaired flow (“+”sign) and observed (“x” sign).

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

Table 2.13. Monthly and Annual Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow Statistics in the SJR at Friant from 1984 to 2009

Unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	8	13	16	22	38	81	152	225	118	39	14	8	785
20%tile	10	14	17	24	42	91	172	240	142	47	14	10	862
25%tile	12	14	18	25	47	94	173	258	149	49	15	10	938
30%tile	12	16	21	33	52	99	179	281	164	54	17	10	1,050
40%tile	16	17	26	58	60	109	203	323	223	55	22	12	1,129
50%tile	18	22	34	63	71	130	227	441	248	90	26	14	1,311
60%tile	20	24	44	70	107	162	247	446	321	102	34	17	1,526
70%tile	24	39	49	87	118	195	269	511	363	146	50	19	2,124
75%tile	24	39	50	102	124	219	288	539	412	184	64	21	2,672
80%tile	24	43	58	126	133	222	302	589	593	222	67	23	2,781
90%tile	36	56	89	177	196	238	342	668	713	334	79	34	3,094
Observed flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	7	4	4	2	4	5	6	8	9	10	9	7	82
20%tile	8	6	5	4	4	6	7	8	10	11	12	8	105
25%tile	8	6	5	4	5	6	8	9	11	12	12	10	114
30%tile	9	7	6	5	5	7	8	9	11	13	12	10	115
40%tile	10	7	6	6	5	7	9	10	13	13	12	11	121
50%tile	10	7	6	6	6	8	10	11	16	14	14	11	137
60%tile	10	7	6	6	6	9	12	12	17	15	15	12	177
70%tile	11	8	7	7	7	23	15	16	20	17	16	14	359
75%tile	12	9	7	7	25	34	69	17	28	18	17	14	615
80%tile	12	9	8	8	26	57	71	53	32	34	17	15	714
90%tile	16	11	22	20	111	123	277	281	172	45	20	17	1,279
Observed flow as a percent of unimpaired flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	40	19	13	6	7	5	4	3	5	13	25	54	10
Med.	61	41	18	10	9	9	5	4	7	22	44	77	13
75%tile	101	52	35	24	20	17	21	8	14	30	90	127	25



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

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

Table 2.14. Monthly and Annual Unimpaired Flow, Observed Flow, and Percent of Unimpaired Flow Statistics Attributed to the Chowchilla and Fresno Rivers, Valley Floor, and Tulare Lake Basin outflows combined from 1984 to 2009

Unimpaired flow												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	-4	-3	1	4	7	12	6	4	2	2	-3	-6	59
20%tile	-2	0	1	5	12	21	8	6	3	2	0	-2	101
25%tile	0	0	2	7	13	25	11	7	4	2	1	-1	109
30%tile	0	1	2	9	16	27	17	8	5	3	1	-1	113
40%tile	0	1	3	12	22	32	22	11	6	4	1	0	128
50%tile	1	2	6	15	26	42	30	17	8	4	2	0	231
60%tile	1	2	8	25	45	69	47	23	9	5	2	0	391
70%tile	2	5	11	31	50	86	52	87	26	7	4	1	496
75%tile	2	5	13	61	54	89	71	103	51	9	4	1	786
80%tile	3	6	15	73	100	96	79	161	59	14	5	1	928
90%tile	4	8	43	187	249	137	218	276	150	72	7	4	1,322
Observed flow													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
10%tile	14	14	16	18	31	31	4	-7	-5	-14	-1	4	178
20%tile	22	23	23	34	32	35	13	-1	-2	-3	2	12	256
25%tile	25	28	26	35	38	38	15	0	3	0	10	14	294
30%tile	28	36	29	36	42	39	17	6	6	2	15	18	309
40%tile	36	39	32	42	45	57	21	21	11	6	19	22	380
50%tile	39	41	34	47	48	69	30	26	21	9	23	31	416
60%tile	46	43	39	52	52	81	41	32	27	16	29	34	533
70%tile	51	48	44	61	64	103	55	52	33	26	36	38	614
75%tile	56	48	50	74	92	106	56	63	38	34	42	43	673
80%tile	61	51	51	78	106	107	99	73	45	37	43	46	696
90%tile	88	58	56	114	143	201	169	132	94	61	62	60	1,112
Observed flow as a percent of unimpaired flow [1]													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
25%tile	-254	175	245	145	107	85	57	0	14	-49	38	-864	91
Med.	1,181	916	677	330	208	149	144	104	116	154	616	71	150
75%tile	2,683	2,370	1,287	562	369	273	245	565	679	537	1,537	2,285	389

[1] To calculate observed flow as percent unimpaired flow, months with unimpaired flow = zero were omitted. 6 years in October, 4 years in November, 1 year in December, 2 years in June, 1, year in July, 2 years in August, and 6 years in September.

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 2.15 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 2.15. 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

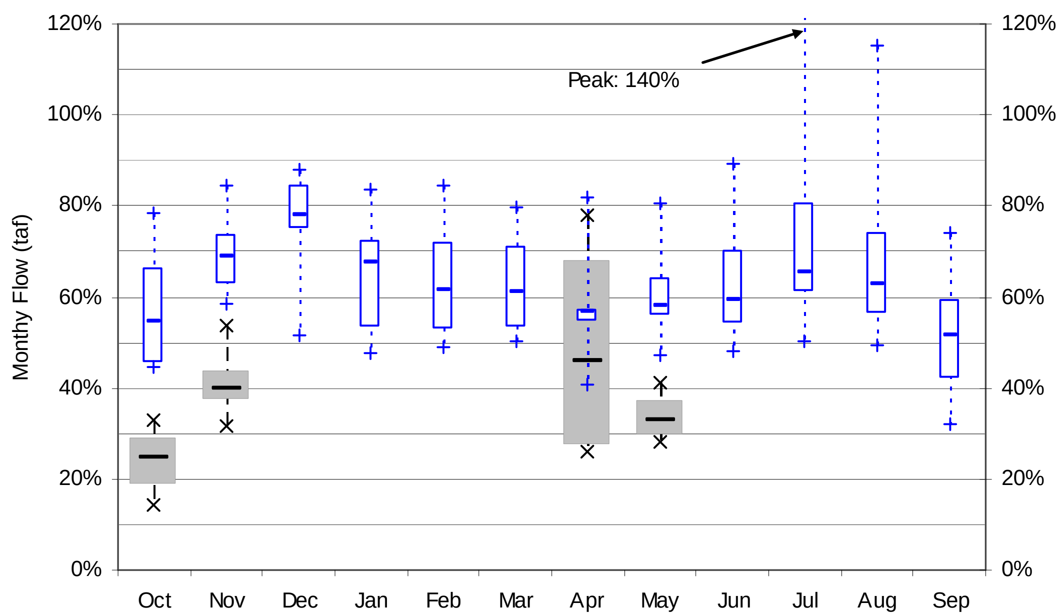
[1]Full pumping corresponds to 8,500 cfs at Clifton Court Forebay and 4,600 cfs at CVP Tracy (Jones).
Source: DWR and USDOI 2005.

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 percent 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 30th and November 15th) since 1968, and in some years during the spring (roughly between April 15th and May 30th) since 1992. In general, the HORB was not installed 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 percent (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 2.16. 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 percent and 80 percent. 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 percent. 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)

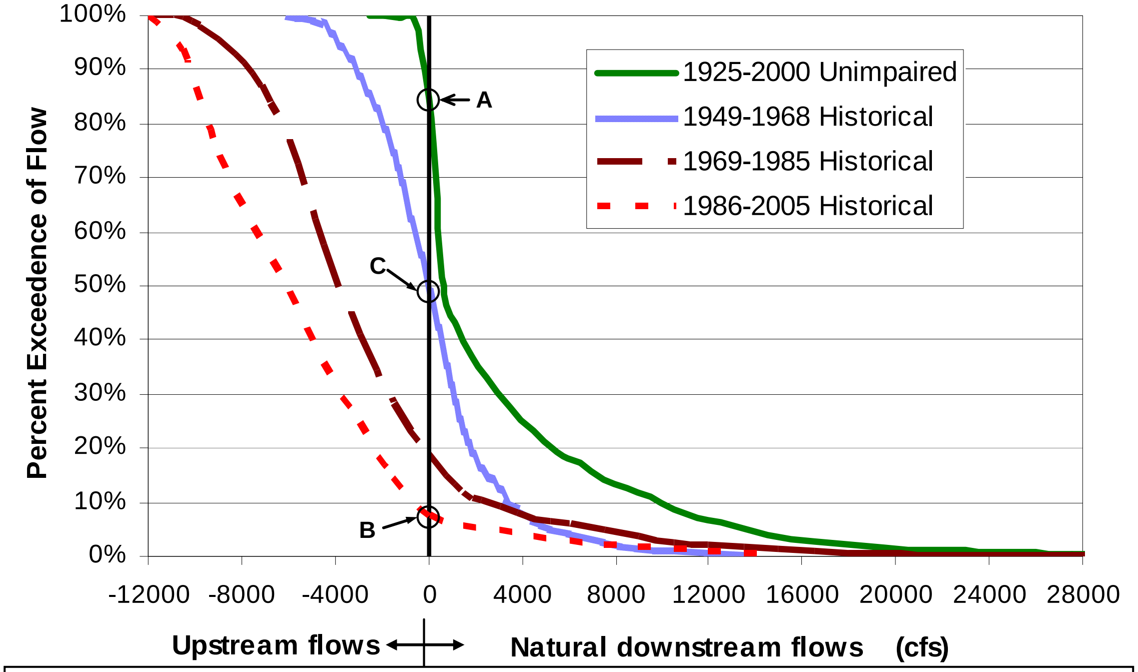
Table 2.16. Monthly Average Percentage of Flow Entering Old River from 1996 to 2009

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 percent 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 percent 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

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. 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 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 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).

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, etc) need to be evaluated as potential contributors to the degradation of fish and wildlife beneficial uses in the SJR basin and Delta. These 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, 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. Refer to Section 2.2 of this report, for additional discussion regarding hydrologic analysis methods.

- 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 percent 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 percent and median reduction of critical spring flows between 74, 83, and 81 percent 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 steadily 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. Specifically, a more natural flow regime, including increases in flow contributions from 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 (Stanislaus, Tuolumne, and Merced Rivers). 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

<u>Central Valley Project Improvement Act (CVPIA)</u>

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 AFRP 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: DOI 2011

*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 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 science-based 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, and it 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 - 1140	3110 - 3540
Dry	1420 - 2280	4020 - 4880
Below Normal	1420 - 2280	4620 - 5480
Above Normal	2130 - 3420	5730 - 7020
Wet	2130 - 3420	7330 - 8620

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Bay-Delta Plan and D-1641

In the 1995 Water Quality Control Plan for the Bay-Delta Plan the State Water Board developed SJR Delta inflow objectives primarily intended to protect fall-run Chinook salmon and provide incidental benefits to Central Valley steelhead. The flow objectives in the 1995 Bay-Delta Plan (and subsequent 2006 Bay-Delta Plan) were consistent with the 1994 Bay-Delta Accord.

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 agreement 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 and subsequent 2006 Bay-Delta Plan. These VAMP experimental flows were implemented in accordance with Water Right Decision 1641 (D-1641).

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 3200 cfs and 7000 cfs, and exports varying between 1500 cfs and 3000 cfs. In addition to VAMP releases, Vernalis flow will be maintained at 1,000 cfs in October. Supplemental water up to 28,000 AF is also released in October during all water year types. The amount of additional water is limited to that amount necessary to provide a monthly average flow of 2,000 cfs. Additional flow is not required in a critical year that follows a critical year.

Additionally, the State Water Board established 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.

The 2006 Bay-Delta Plan includes 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 mmnos/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. The salinity objectives at Vernalis can be attained by releasing dilution water from New Melones and other sources (along with other measures). Therefore, as part of the implementation of these objectives, the State Water Board has conditioned the water rights of some water right holders on the presence of dilution flows.

<u>National Marine Fisheries Service Biological Opinion</u>

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 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 (RPA's) that would enable the project to go forward in compliance with the ESA. The RPA that applies to the SJR (described below) has been the subject of ongoing litigation (Consolidated Salmonid Cases, Case No. 1:09-cf-01053-OWWV-DL), 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.

RPA action IV 2.1 proposes to increase the inflow to export ratio of the SJR, and to provide minimum long-term flows at Vernalis. Phase I (Table 3.4) of this RPA action will provide interim operations in 2010-2011 from April 1 to May 31.

Table 3.4. Phase I of the NMFS Biological Opinion RPA action IV 2.1

1. Flows at Vernalis (7-day running average shall not be less than 7 percent 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
1000-1399	D1641 requirements or 1500, whichever is greater
1400-1999	D1641 requirements or 3000, whichever is greater
2000-2499	4500
2500 or greater	6000

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. The 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 - 1400
Medium-low	1400 - 2000
Medium	2000 - 2500
Medium-high	2500 - 3000
High	3000 - 6000

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
1400	2000	98	125	70	80	0	0	0	0
2000	2500	125	245	80	175	0	0	0	59
2500	3000	345	467	175	250	75	75	90	90
3000	6000	467	467	250	250	75	75	90	90

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

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

National Marine Fisheries Service Biological Opinion

RPA action III.1.3 (Figure 3.1) proposes 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.

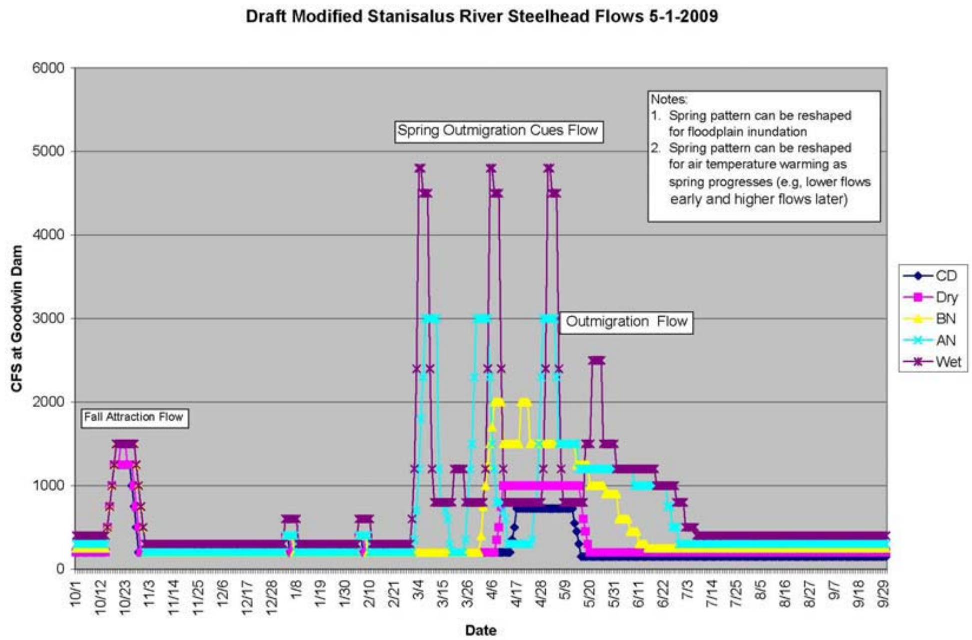


Figure 3.1. RPA Action III 1.3 of the NMFS Biological Opinion

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 for November through March from Crocker-Huffman Dam to Shaffer Bridge.

Cowell Agreement

The Cowell Agreement is a water rights adjudication where Merced ID must make an amount 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 Tuolumne 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

FERC Project Number 2179 also requires, insofar as possible, during the period November 1 through December 31 to regulate the Merced River streamflow downstream from the Exchequer afterbay development (McSwain Development) between 100 and 200 cfs except during dry years when the streamflow shall be maintained between 75 and 150 cfs. Streamflow shall be measured at Shaffer Bridge.

Despite these efforts, 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 when juveniles rear and migrate toward the Pacific Ocean in spring (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.

3.1.4 Approach

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

The SJR flow objective alternatives consider volumes of water reflective of flow at Vernalis. These flows come primarily from the three major salmon bearing SJR tributaries (Stanislaus, Tuolumne, and Merced Rivers), and as such, from an ecosystem perspective, alternatives which consider the major SJR tributaries as the sources of water needed to meet alternative flows at Vernalis are ecologically relevant. 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, and the current management of flows at Vernalis recognizes this as exhibited by the highly coordinated fashion in which flows from all three major SJR tributaries are released to meet the VAMP flows (SJRGA 2010).

3.2 Fall-Run Chinook Salmon

Within the Central Valley, three Evolutionary Significant Units (ESUs) of Central Valley Chinook salmon have been identified. The three ESUs of Chinook salmon are winter-, spring-, and fall-run (DFG 2010b). 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 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.

3.2.1 Life History

Chinook salmon are an anadromous species that spend most of their adult life in open ocean waters, only returning to freshwater streams to spawn a single time before they die. The life history of Chinook salmon is exhibited in two distinct types, an ocean-type and a stream-type. Fall-run Chinook salmon exhibit the ocean-type life history; meaning that they have adapted to spend most of their lives in the ocean, spawn soon after entering freshwater in summer and fall, and as juveniles, migrate to the ocean within a relatively short time (3 to 12 months; Moyle 2002). Fall-run Chinook salmon typically remain in the ocean for two to four years before returning to their natal streams to spawn (McBain and Trush 2002). However, most Central Valley salmon return to their natal streams after two years of ocean maturation and a small fraction (10-20 percent) return after one 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 Chinook salmon supports 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.

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).

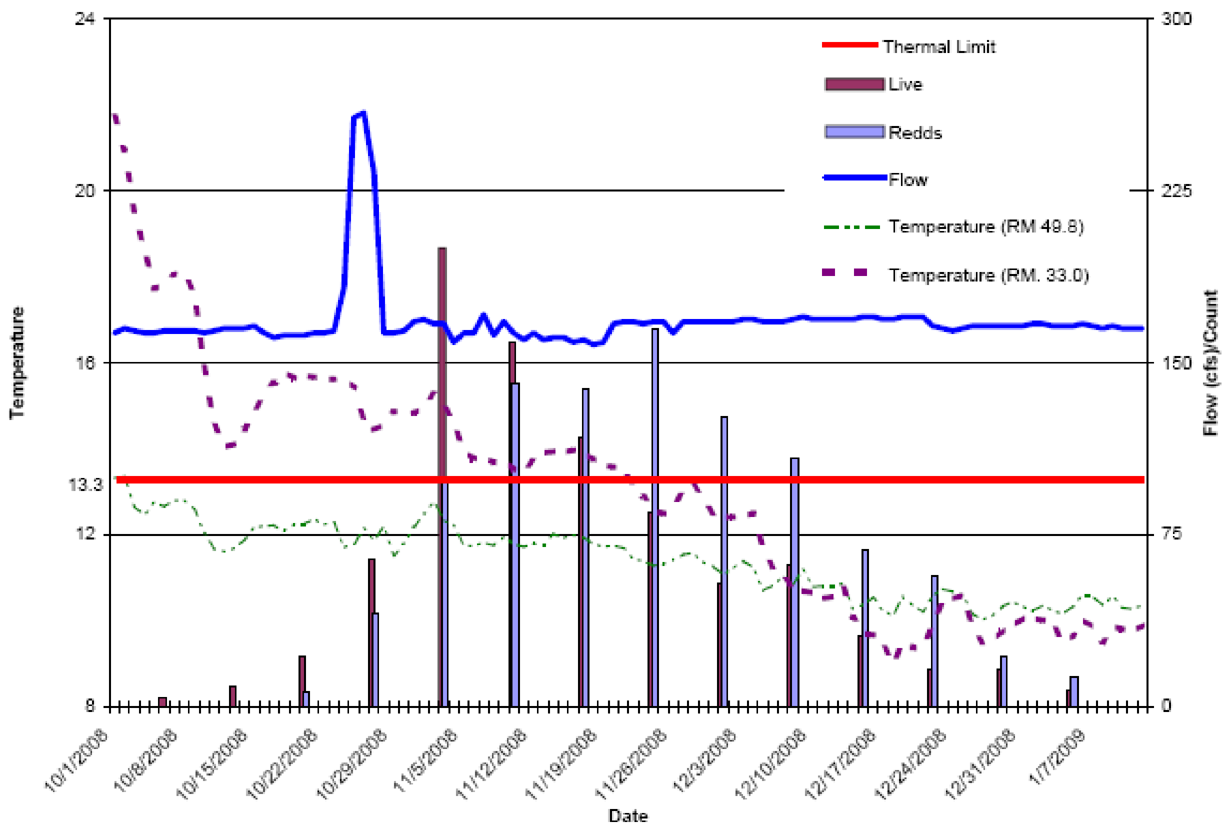
Adult fall-run Chinook salmon use olfactory cues, during upstream migration, to locate their natal streams (NMFS 2009a, DFG 2010a). However, if natal streams have low flows and salmon cannot perceive the scent of their natal stream, straying rates to other streams typically increases. The upstream migration 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.

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 one 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, 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 (Chambers 1956, Smith 1973, Bjorn and Reiser 1991, and Snider 2001 as cited in NMFS 2009a), 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 Tuolumne 2008 Carcass Survey Report

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 percent, 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

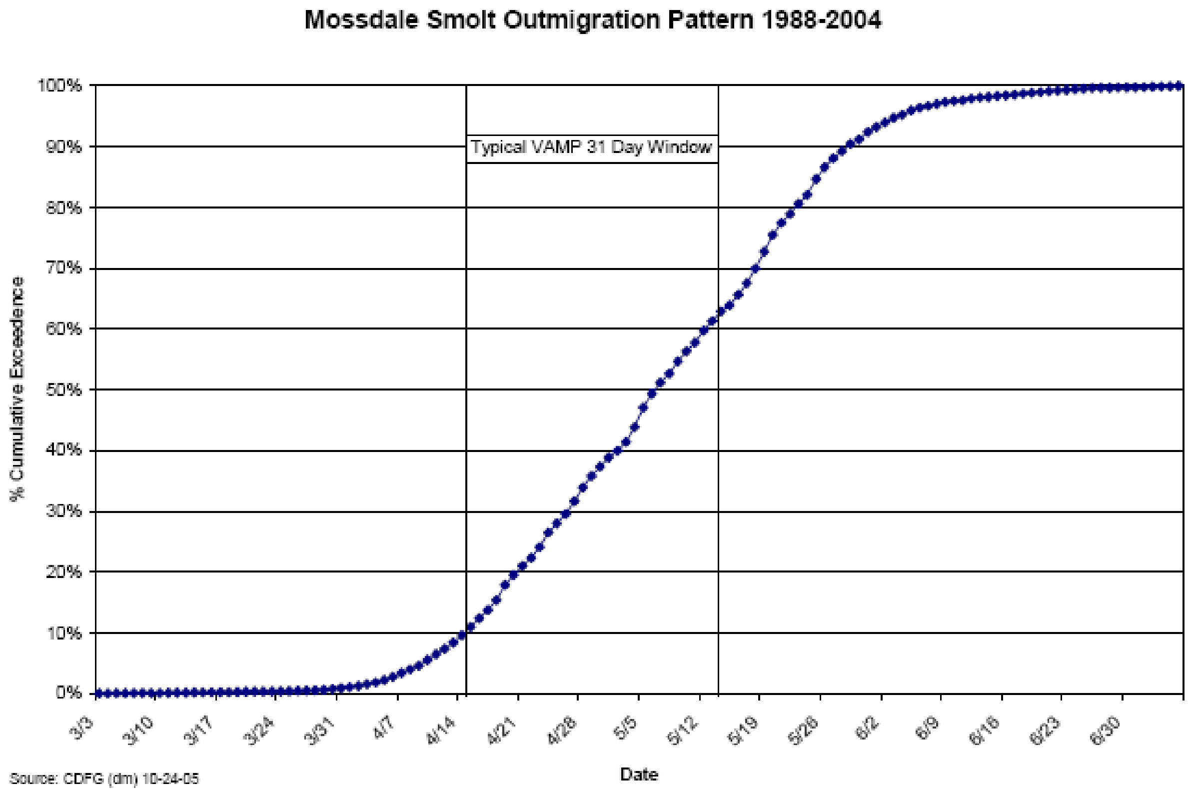
Timing of egg incubation for SJR fall-run Chinook salmon begins with spawning in late October and can extend into March, depending on water temperatures and timing of spawning (BDCP 2010). Egg incubation generally lasts between 40 to 60 days, depending on water temperatures, with optimal water temperatures 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 four to six 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 most often associated with magnitude, timing and duration of flows, connectivity with associated riparian and floodplain habitat (Mesick, et al. 2007). Connectivity with riparian habitats, provides salmon with a variety of resources, including 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).

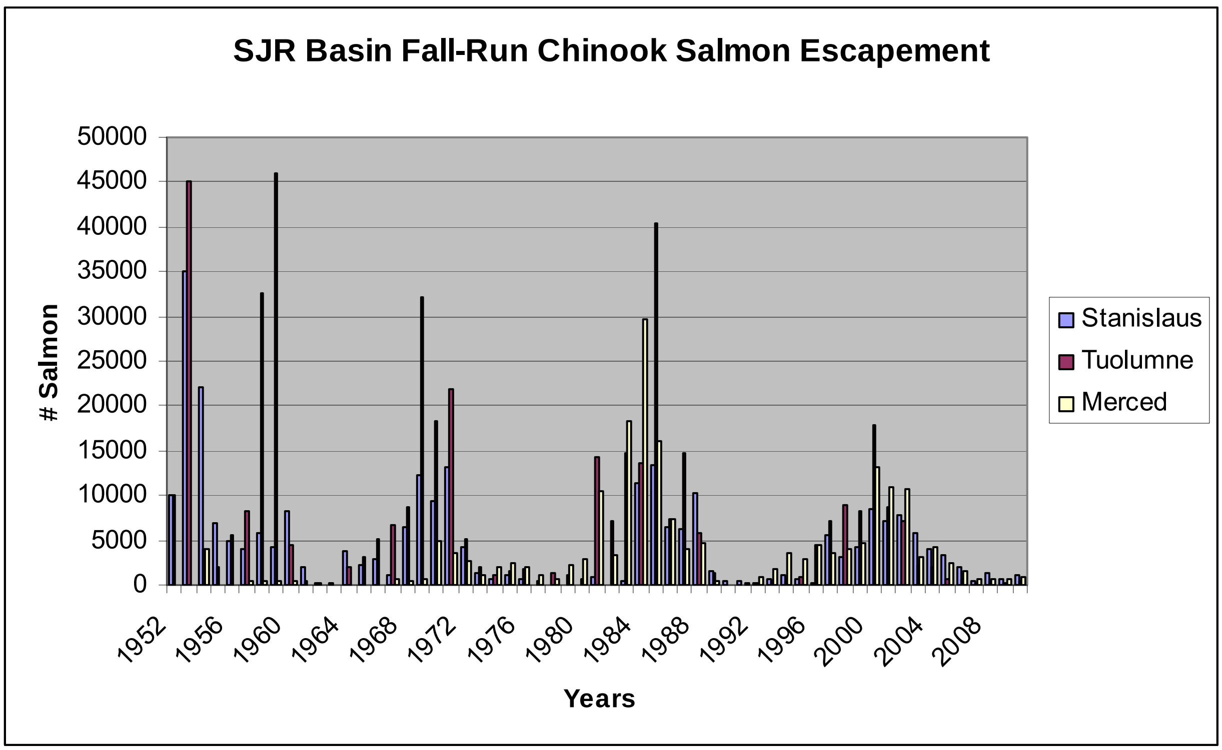
Shallow water habitats (floodplain and riparian) benefit rearing fry and parr, and have been found to be more productive than main river channels (Sommer et al. 2001). This is due in part to high growth rates, favorable environmental temperatures, higher prey consumption rates, and greater selection of zooplankton, small insects, and other microcrustaceans (DFG 2010a; NMFS 2009a, Sommer et al. 2001, DFG 1993). Juveniles that use shallow water habitats typically grow faster, have a greater ability to evade predators, migrate to the ocean earlier, , and a more abundant ocean food supply.

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 migrating from Chipps Island to the Gulf of the Farallones(MacFarlane and Norton 2002).

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, Central Valley 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 2010b). 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 2011 Grandtab Report

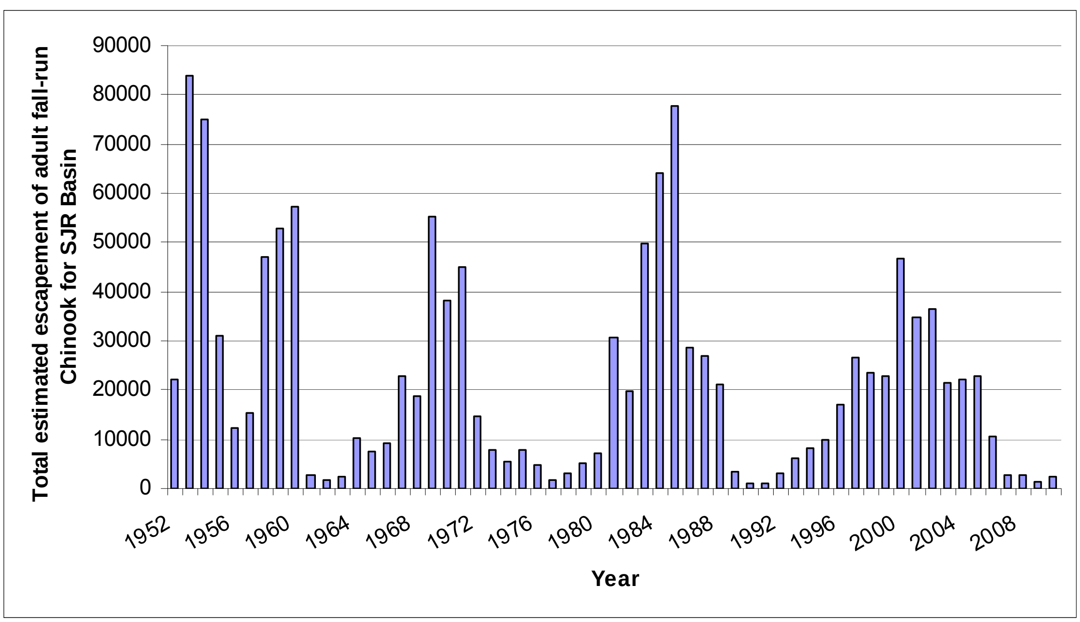
Figure 3.4. Estimated Escapement of Adult Fall-run Chinook Salmon for the Major SJR Tributaries 1952 to 2010

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, etc; cohort “B” returning to spawn in 1953, 1956, 1959, etc.). 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 is the escapement number for a given year divided by the escapement number from three years prior (i.e., 2010 replacement ratio = 2010 escapement/2007 escapement).

Escapement numbers are merely an estimate of the total amount of returning Chinook salmon and do 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 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.

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). However, since 1952, the average escapement of fall-run Chinook salmon has shown a steady decline.

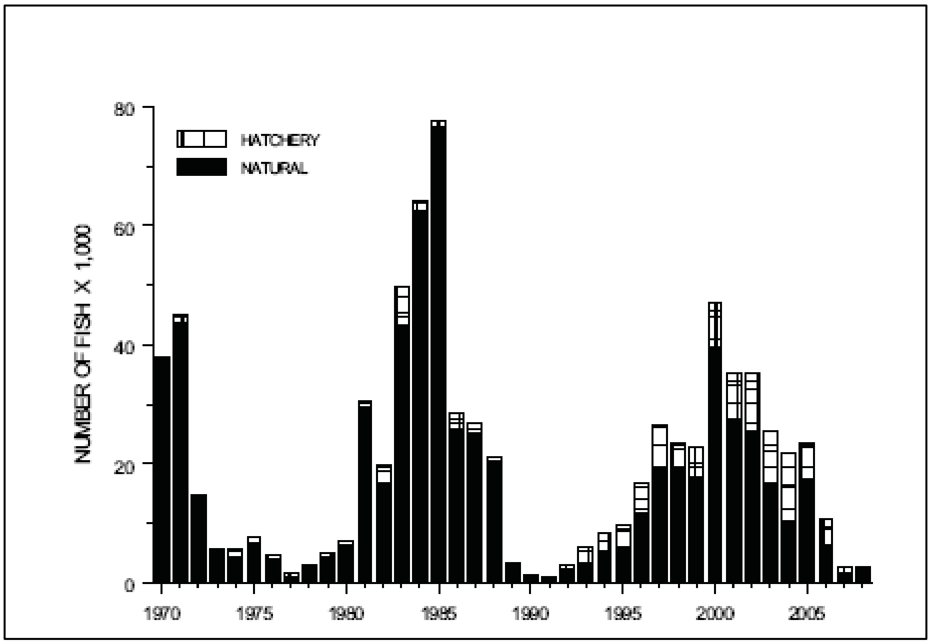
Recent escapement of adult fall-run Chinook salmon to the SJR basin was estimated at approximately 2,800 fish in 2008 (Figure 3.5; DFG 2011 GrandTab Report) and a slight increase to approximately 3,600 fish in 2009 (DFG 2010b). Declines of Central Valley Chinook salmon populations in 2008 and 2009 have been largely attributed to poor ocean conditions and have resulted in significant curtailment of west-coast commercial and recreational salmon fishing. Although ocean conditions have played a large roll 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).



Source: DFG 2011 GrandTab

Figure 3.5. Total Estimated Escapement of Adult Fall-Run Chinook for SJR Basin from 1952 to 2010

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). Available data indicate that hatchery-produced fish constitute a majority of the natural fall-run spawners in the Central Valley (PFMC 2007). This has lead to increased hatchery introgression with the wild fall-run Chinook salmon, which not only undermines the genetic integrity of the wild salmon genome, but it also leads to reduced genetic diversity between wild and hatchery salmon (Williamson and May 2005, Lindley et al. 2009, NMFS 2009a,b, DFG 2011).



Source: Greene 2009

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

Based on the recent population declines, reduced peak abundance of adult recruitment, and reduced population resiliency and genetic diversity, the DFG considers the fall-run Chinook salmon run in the SJR basin to be in poor condition and at risk of extinction from a single catastrophic event.

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:

- 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 are either classified as stream-maturing or ocean-maturing. This classification is based on the state of sexual maturity at the time of freshwater entry and duration of spawning migration. Ocean maturing steelhead are commonly known as winter-run, while stream-maturing steelhead are known as summer-run (NMFS 2009a). Summer-run steelhead are not found in the SJR tributaries. Remnant populations of winter-run steelhead (Central Valley steelhead) are currently found in the major SJR tributaries (Zimmerman 2009, Good et al. 2005, McEwan 2001). Unless noted otherwise, subsequent discussions of the anadromous form of Central Valley steelhead refers to the ocean-maturing (winter-run) 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; and 3) steelhead can produce anadromous or non-anadromous life forms (Moyle et al. 2010). Microchemistry analysis of steelhead otoliths (inner ear bone) provided evidence that there is no reproductive barrier between resident and anadromous forms (Zimmerman et al. 2009). In the SJR basin, steelhead populations are very small (i.e., remnant levels). 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	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 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. If water quality parameters and other environmental conditions are not optimal, steelhead may delay migration to another more suitable year. Optimal immigration and holding temperatures for steelhead have been reported to range from 46°F to 52°F (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 (USDOI 2008, McBain and Trush 2002), with peaks occurring between January and March (Table 3.3; NMFS 2009a). 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, excavate a redd with their 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 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 percent) 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. 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 (one percent 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 (potadromous) or lakes (limnodromous) 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).

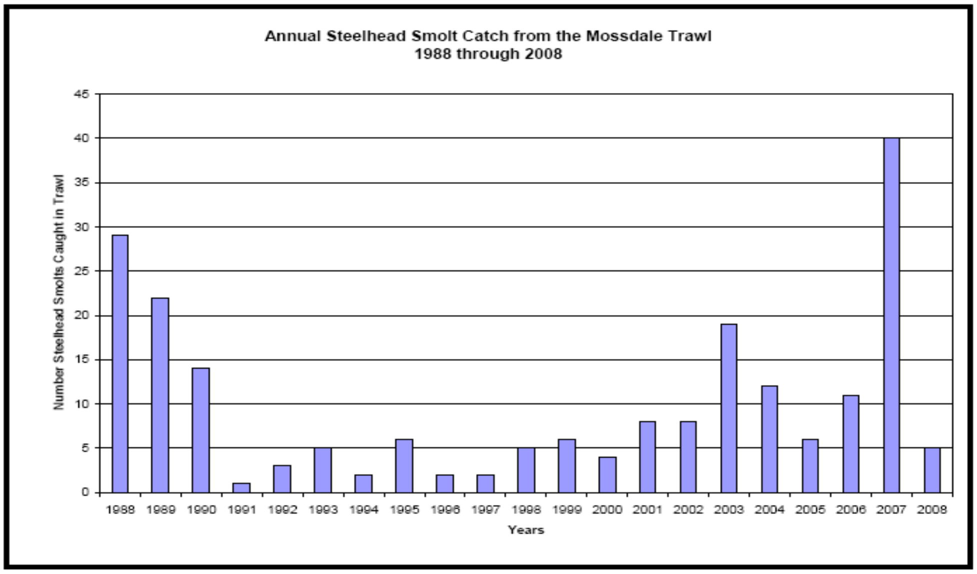
Central Valley steelhead juveniles generally begin outmigration anywhere between late December through July, with peaks occurring between March and April (Table 3.2; USDOI 2008, McBain and Trush 2002). Juvenile steelhead are considerably larger and have a greater swimming ability than Chinook salmon 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 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 Technology1999). 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 (2009). 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, 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).

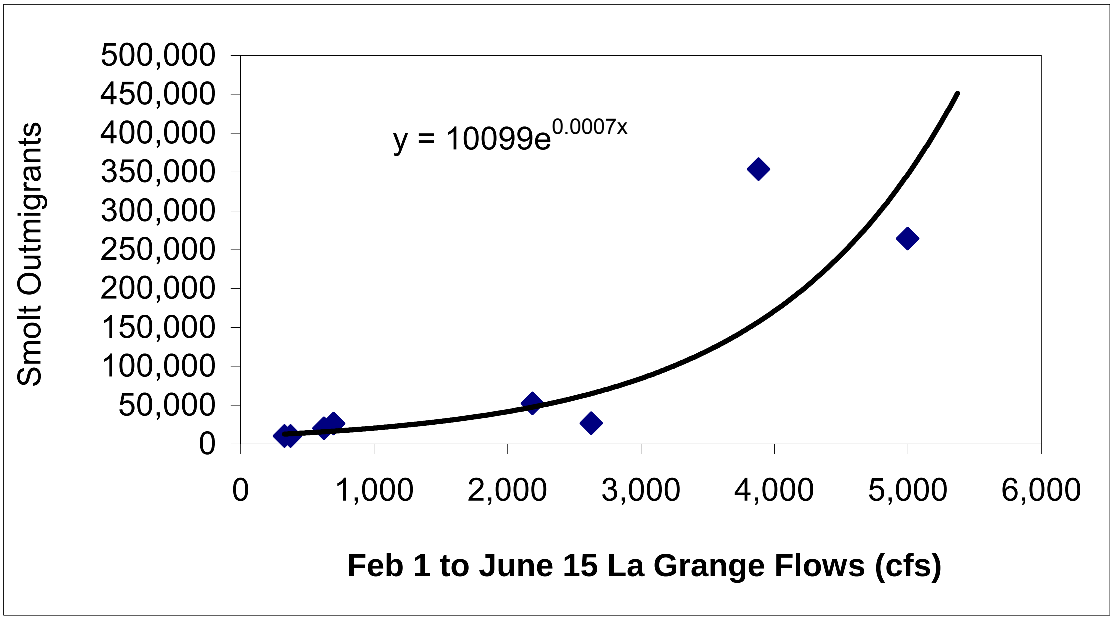
Juvenile Chinook salmon exhibit different migration and life history strategies adapted to variations in flows (Lytle and Poff 2004). Under unaltered hydrographic conditions in the SJR basin, flows on the tributaries and the mainstem SJR generally increase in response to snow-melt and precipitation during the spring period, with peak flows occurring during May. Increased flow conditions, throughout the late winter to spring period on the three salmon bearing tributaries (Stanislaus, Tuolumne, and Merced Rivers) to the mainstem SJR, 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. Different life history strategies assure the continuation of the species over different hydrologic and other 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 Mossdale Trawl (see Figure 3.2).

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 temperatures, increasing dissolved oxygen levels, and reducing contaminant concentrations. NMFS has determined that each of these functions is significantly impaired by current conditions in the SJR basin (NMFS 2009a).

3.6 Analyses of Flow Effects on Fish Survival and Abundance

Studies that examine the relationship between fall-run Chinook salmon population 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, AFRP 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 is 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).



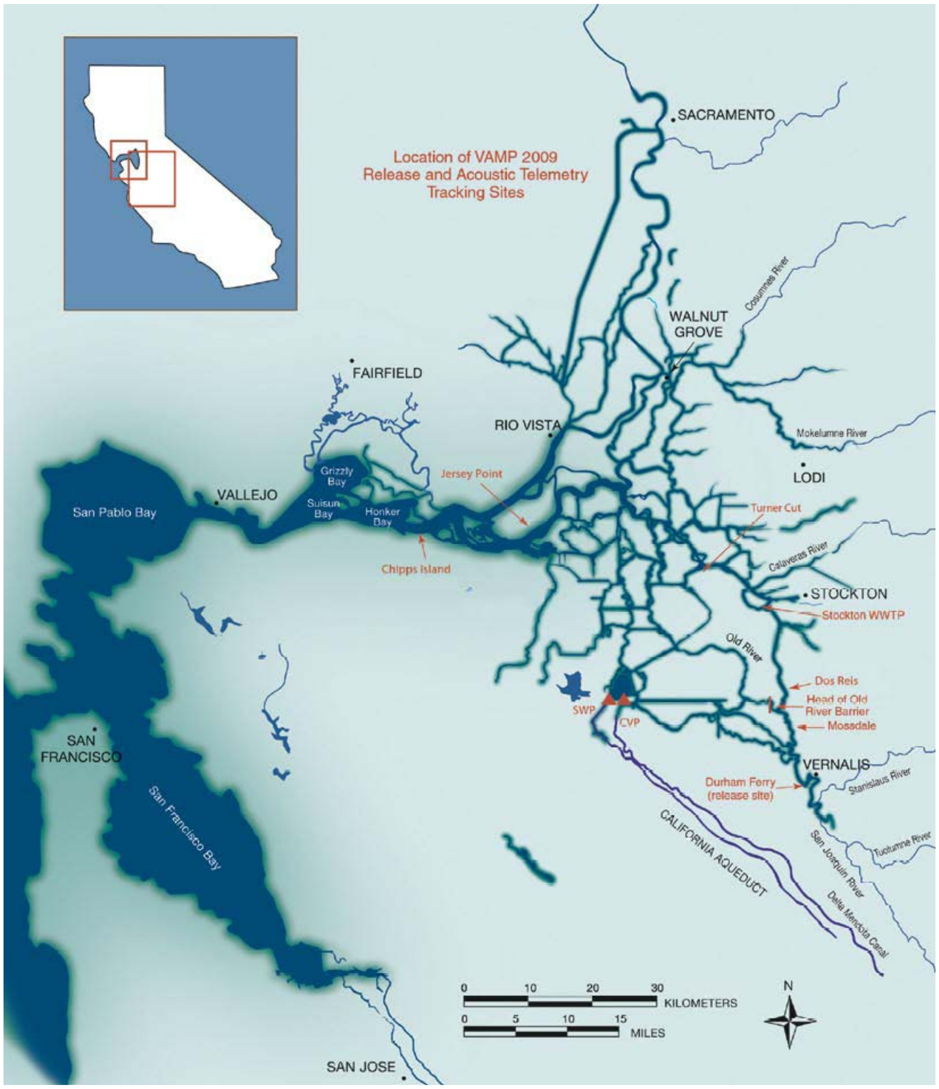
Source: Mesick 2009.

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 (SJRTC 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^2 of 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 1995a).

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-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.

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 1995a).

The general relationship between flow (April and May) and escapement of adult fall-run salmon two and a half 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 percent probability of a positive relationship) and subsequent survival from Dos Reis to Jersey Point. If data from 2003 and later were eliminated from analysis, the strength of the association increased and a positive association between flow in Old River and survival in Old River 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.

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

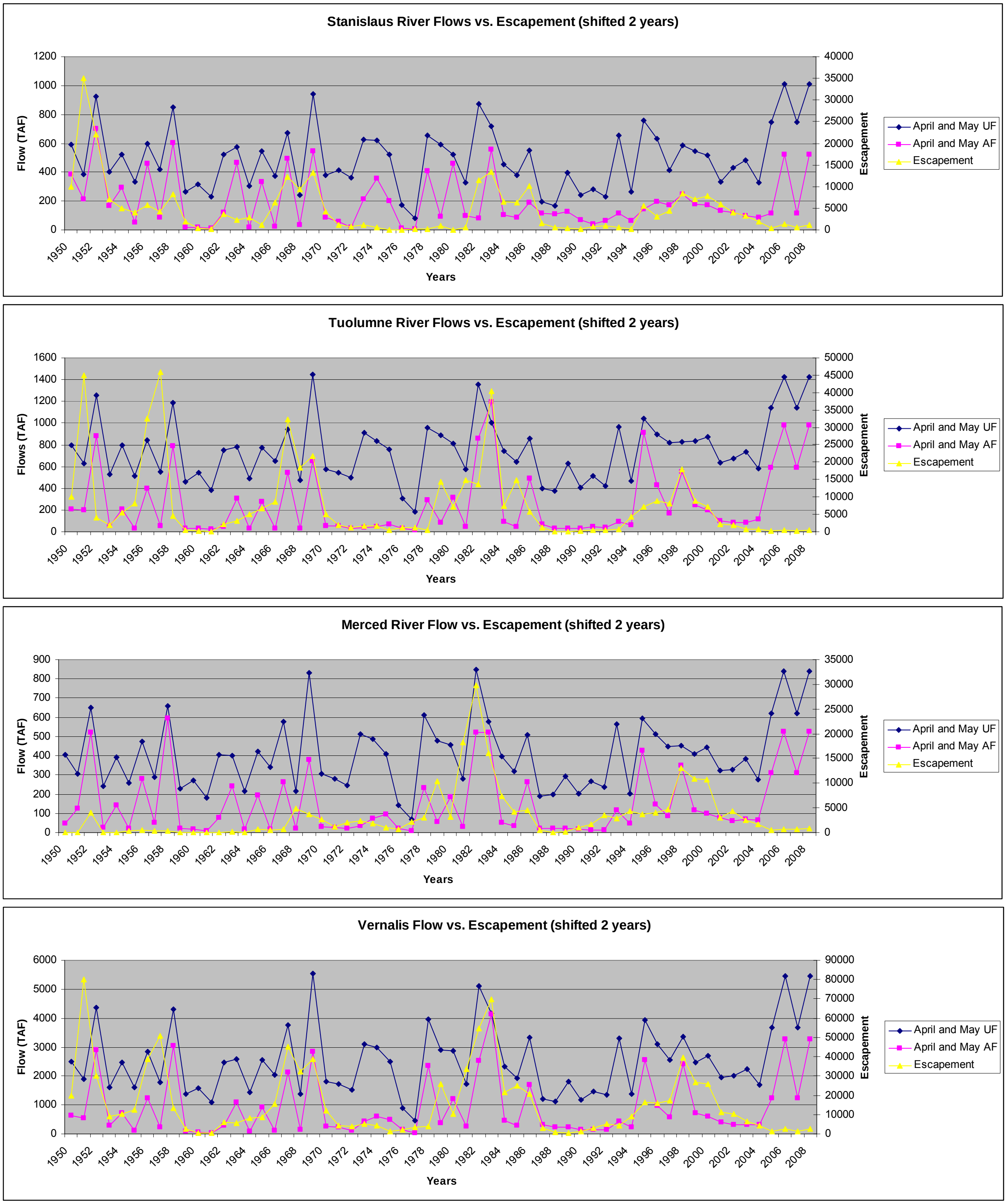


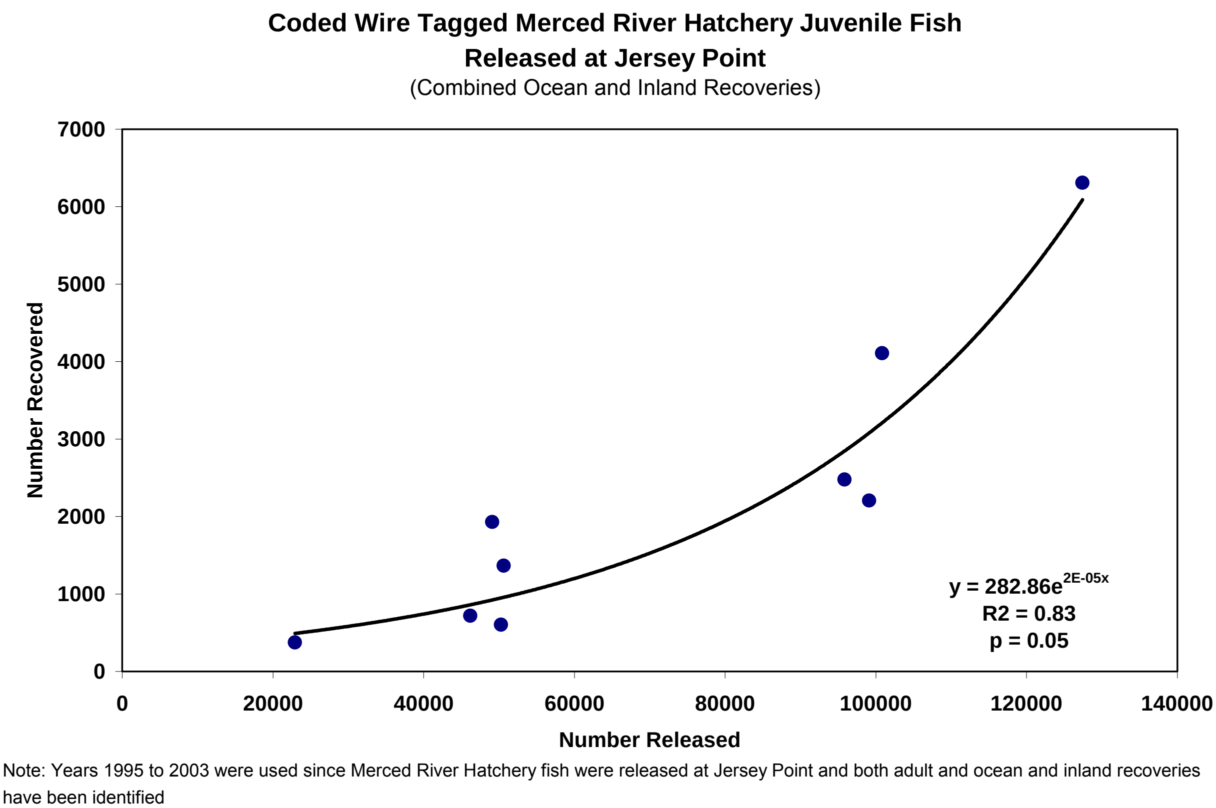
Figure 3.10. Fall-Run Chinook Salmon Escapement Compared to April and May Flows (2.5 Years Earlier) for the Stanislaus, Tuolumne, Merced Rivers, and SJR Basin Measured at Vernalis

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 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 percent of the escapement variation. This correlation suggests that escapement has been primarily determined by the rate of juvenile survival, which is primarily determined by the magnitude and duration of late winter and spring flows, since the 1940s. 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 escapeent.

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 2010). 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 percent of the variance in the number of adult fish recovered can be explained by the number of juvenile fish released at Jersey Point.



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 SJRTC 2008). In addition, there was a positive, though weaker relationship between estimated survival rates from Dos Reis and Jersey Point over a broader range of flows for years with the physical HORB in place or not (see also SJRTC 2008). Second, the IRP pointed to the broader and more sophisticated Bayesian Hierarchical modeling analyses by Newman (2008) that found a positive influence of SJR flow below Old River on survival rates. The IRP also reported on its own summaries of CWT-based estimates of survival rates from Mossdale (when the 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.

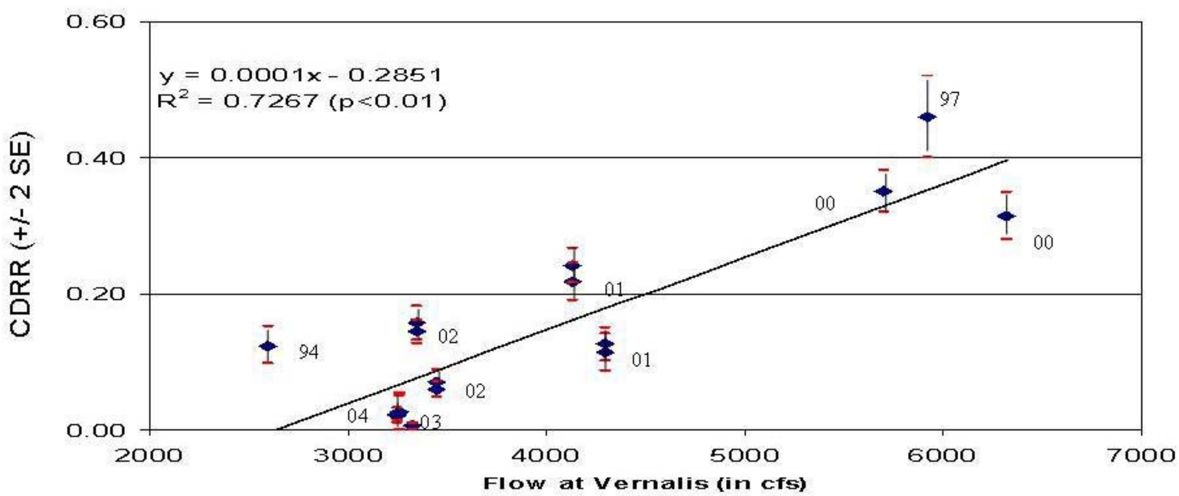


Figure 3.12. Survival of Outmigrating Salmon Versus Vernalis Flow

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 one percent in 2003 and 2004 and the estimate was only about 12 percent in the very high flow year of 2006. This compares to survival estimates that ranged between about 30 and 80 percent in the years 1995 and 1997 to 2000. The IRP points out that the recent survival estimates are significantly lower than the long-term average survival estimate of about 20 percent, which the IRP points out is considered low when compared to the Sacramento River and other estuaries like the Columbia River. The review panel concludes 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 five to six percent (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 eight percent) and the SJR route (survival of five percent). Only an estimated six percent 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 percent down Old River and 25 percent 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 percent) was directly proportional to the amount of flow remaining in the mainstem SJR. With the BAFF on, the protection efficiency increased slightly to 30.8 percent and the deterrence efficiency increased substantially to 81.4 percent. Even though the BAFF was very efficient at deterring salmon that encountered it, the difference between the percentages of salmon remaining in the mainstem SJR was not significant between the BAFF off and BAFF on because predation near the BAFF was high (ranging from 25.2 to 61.6 percent) (Bowen et al. 2009).

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

Bowen 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, and 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, NRDC 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 regulates the ecological integrity of rivers. 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: 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.

3.7.1 Effects on Fish Communities

Altered flow regimes have been found to negatively impact fish communities and the aquatic ecosystem (Pringle et al. 2000, Freeman et al. 2001, Bunn and Arthington 2002, Moyle and Mount 2007). 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, Rosenfield et al. 2010). Genetic diversity also provides the raw material for surviving long-term environmental changes. Salmonids regularly face cyclic or directional change in their freshwater, estuarine, and ocean environments due to natural and human causes. Genetic and life-cycle diversity allows them to persist through these changes (McElhany et al. 2000).

Long term conditions in the region are expected to change as 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 2000s, 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 wild 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 wild stocks and reduce the negative effects of hatcheries on wild 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 out migration 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) and Opperman (2006) found floodplain habitat promotes rapid growth of juvenile salmon. Properly managed floodplains can have widespread benefits at multiple levels ranging from individual organisms to ecosystems (Junk et al. 1989, Moyle et al. 2007).

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).

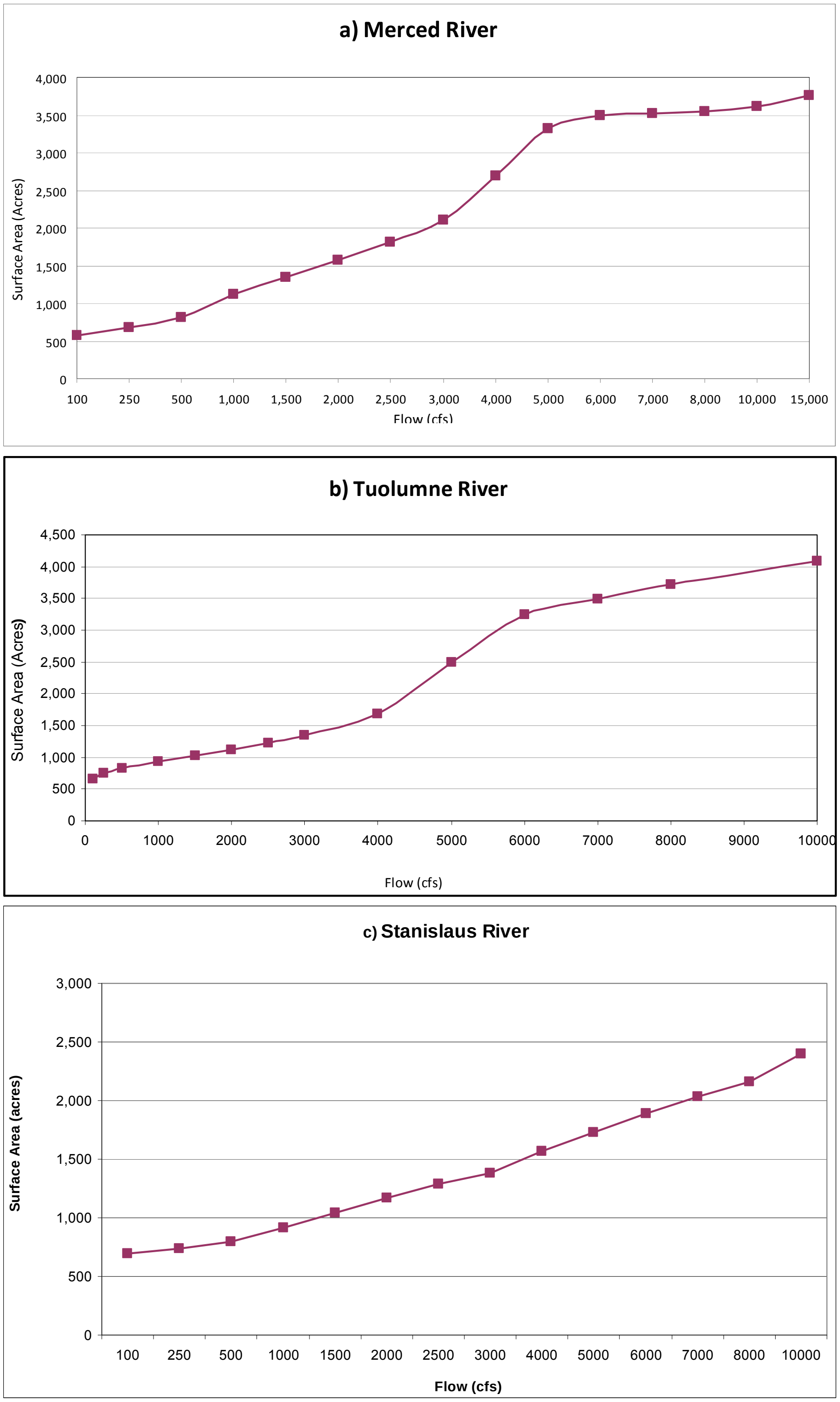
3.7.3 Effects on Aquatic Habitat

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 flow regime on the SJR that increases lateral connectivity by increasing riparian and floodplain activation, would increase habitat quality and space, allowing for energy flow between wetland areas and the river, and providing the river and estuary with nutrients and food. Floodplain inundation provides flood peak attenuation and promotes exchange of nutrients, organic matter, organisms, sediment, and energy between the terrestrial and aquatic systems (Cain et al. 2003, Mesick 2009). It also improves juvenile fish survival by improving food availability, providing refuges from predators, and increasing water temperatures in February and March (Jeffres et al. 2008, Mesick 2009). A more natural flow regime on the SJR 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). Increased lateral and longitudinal connectivity also positively affects spatial distribution of organisms by facilitating the movement of organisms and creating important spawning, nursery, and foraging areas for many fish species, including salmon (Bunn and Arthington 2002, Cain et al. 2003, Jeffres et al. 2008, Rosenfield et al. 2010).

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 (AFRP 1995).

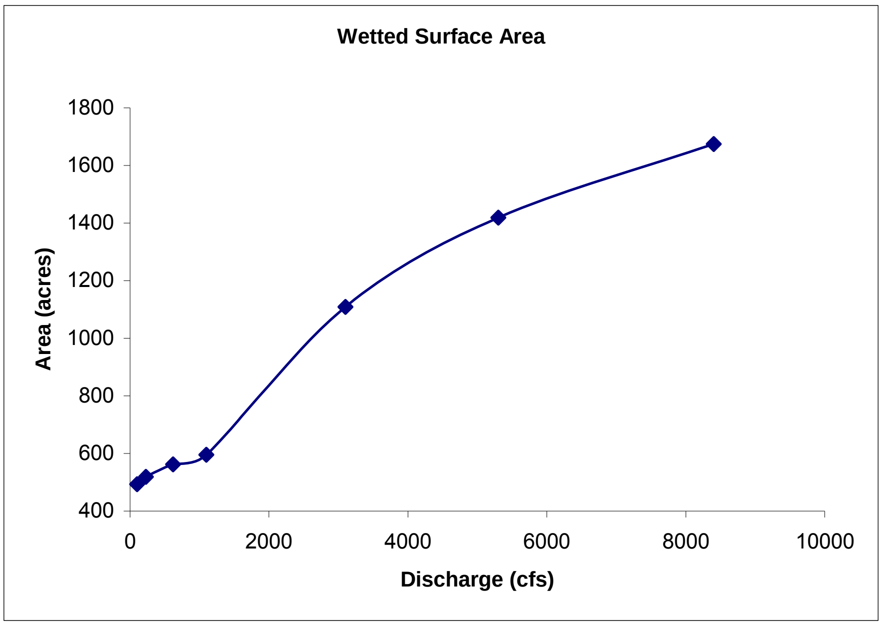
For the three SJR tributaries (Merced, Tuolumne, and Stanislaus Rivers) DFG analyzed cross-sectional data developed by the United States Army Corps of Engineers and calculated the estimated wetted surface area from the first upstream barrier downstream to each tributary's SJR confluence (Figure 3.13). 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 conduced 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 on average) are necessary to inundate various low-lying floodplains below the terminal reservoirs on the upper Stanislaus, Merced, Tuolumne, and San Joaquin rivers.

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 1997). Floods, and their associated sediment transport, are important drivers of the river-riparian system. Small magnitude, frequent floods maintain channel size, shape, and bed texture, while larger, infrequent floods provide beneficial disturbance to both the channel and its adjacent floodplain and riparian corridor. As a result of alterations to 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, San Joaquin River Restoration Program 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 (US EPA 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 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 2010f).

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, reduced reproductive success, impaired growth and development, and 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 percent 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
		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 dependant 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 2010a).

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

<table>
<tr><th></th><th>July - Feb</th><th colspan="2">March</th><th colspan="2">April</th><th colspan="2">May</th><th colspan="2">June</th></tr>
<tr><td>100% of years (all yrs)</td><td>2,000</td><td colspan="2">2,000</td><td colspan="2">5,000</td><td colspan="2">5,000</td><td colspan="2">2,000</td></tr>
<tr><td>80% (D yrs)</td><td>2,000</td><td colspan="2">2,000</td><td>5,000</td><td>10,000</td><td>7,000</td><td>5,000</td><td colspan="2">2,000</td></tr>
<tr><td>60% (BN yrs)</td><td>2,000</td><td colspan="2">2,000</td><td>20,000</td><td>10,000</td><td>7,000</td><td>5,000</td><td colspan="2">2,000</td></tr>
<tr><td>40% (AN yrs)</td><td>2,000</td><td>2,000</td><td>5,000</td><td colspan="2">20,000</td><td colspan="2">7,000</td><td colspan="2">2,000</td></tr>
<tr><td>20% (W yrs)</td><td>2,000</td><td>2,000</td><td>5,000</td><td colspan="2">20,000</td><td>20,000</td><td>7,000</td><td>7,000</td><td>2,000</td></tr>
</table>

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 tributaries (Merced, Tuolumne, and Stanislaus Rivers). 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 (2010e) 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		13400 (2 days)		4500	6700	8900	1200					5400
D		13400 (2 days)		4500	6700	8900	1200					5400
BN		13400 (16 days), 26800 (2 days)		4500	6700	8900	11200	1200				5400
AN		13400 (13 days), 26800 (5 days)		4500	6700	8900	11200	1200				5400
W		13400 (17 days), 26800 (5 days)		13400				14900				5400

Source: CSPA/CWIN 2010

In its 2010 report on *Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem*, the State Water Board determined that approximately 60 percent of unimpaired flow during the February through June period would be protective of fish and wildlife beneficial uses in the SJR. 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). State Water Board analyses indicate that 60 percent of unimpaired SJR flow at Vernalis from March through June would achieve flows of 5,000 cfs in over 85 percent of years and flows of 10,000 cfs in approximately 45 percent of years. The exceedance rates are not significantly different if applied to the February through June period (State Water Board 2010).

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).

[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.

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

The scientific information discussed above supports 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 to support 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, AFRP 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 (Poff et al. 1997, Poff et al. 2010). Improved flow conditions will serve to underpin restoration activities and efforts to address “other stressors”. 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 flow objectives 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).

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. 2010). Accordingly, the State Water Board will use and refine this unimpaired flow approach during its water quality control planning and environmental review processes concerning the reasonable protection of fish and wildlife beneficial uses. In addition, the State Water Board will incorporate appropriate measures for adaptive management in any new SJR flow objective in order to respond to new information and changing circumstances.

For illustrative purposes, 20, 40, and 60 percent of unimpaired flows from February through June (Figures 3.15 – 3.20) will be used in the following water supply impacts analysis to demonstrate the ability of the analysis to appropriately evaluate the water supply effects of these and other potential alternative SJR flow objectives. In addition to an existing conditions scenario, these illustrative alternatives represent the likely range of alternatives the State Water Board will evaluate in the environmental document supporting any revised SJR flow objectives. In its 2010 report on *Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem*, the State Water Board determined that approximately 60 percent of unimpaired flow 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 (State Water Board 2010). While this number is imprecise, it provides an upper range for evaluating the water supply effects of alternative SJR flow objectives. The intermediate ranges of 20 and 40 percent do not represent any specific flow thresholds but will allow for a broad range of comparison with the 60 percent of unimpaired flow alternative.

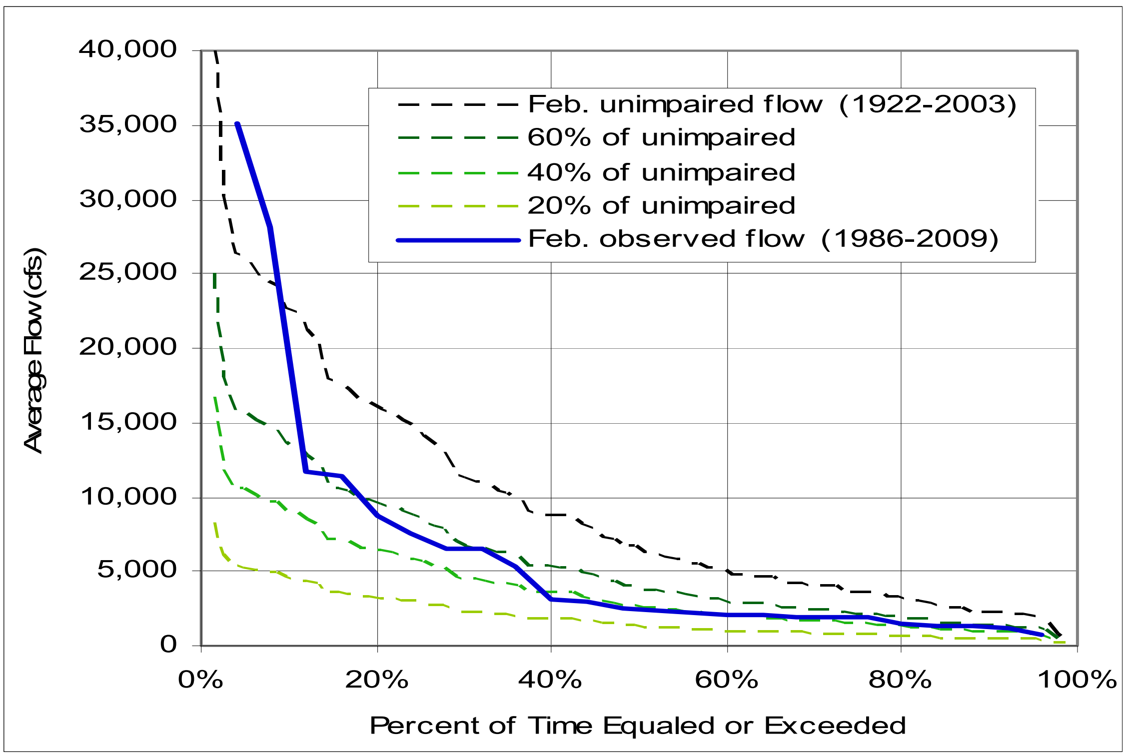


Figure 3.15. Exceedance Plot of February Monthly Average SJR Unimpaired and Observed Flows at Vernalis

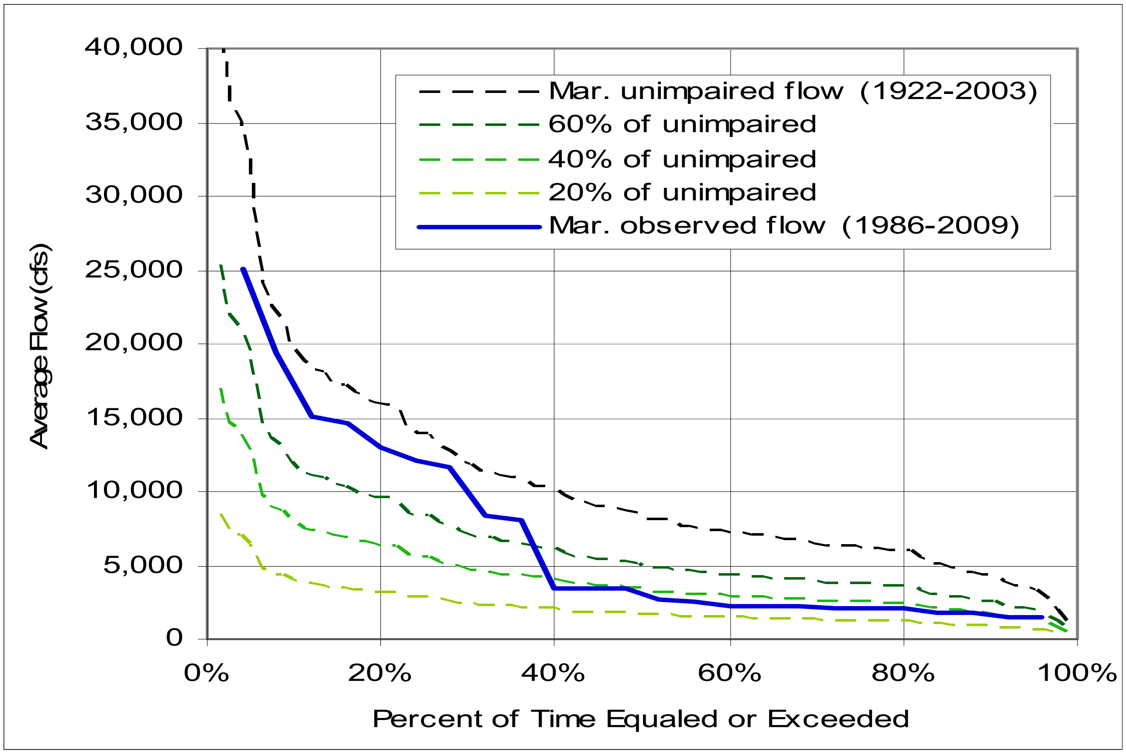


Figure 3.16. Exceedance Plot of March Monthly Average SJR Unimpaired and Observed Flows at Vernalis

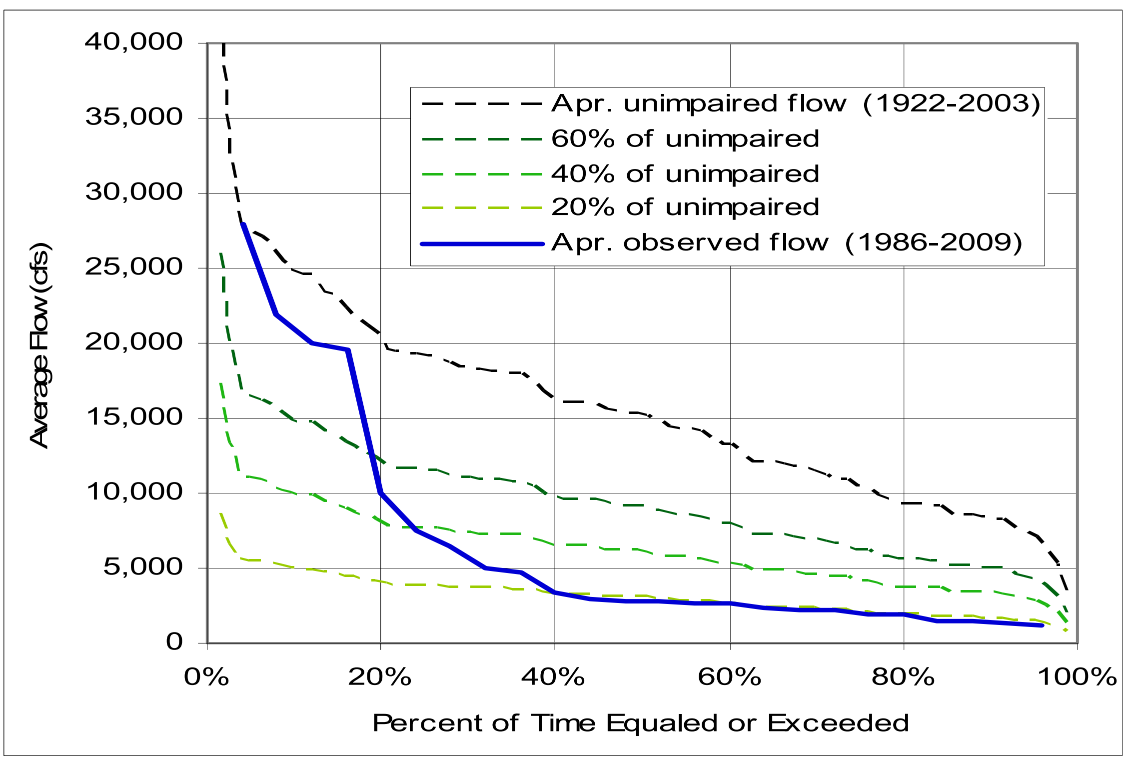


Figure 3.17. Exceedance Plot of April Monthly Average SJR Unimpaired and Observed Flows at Vernalis

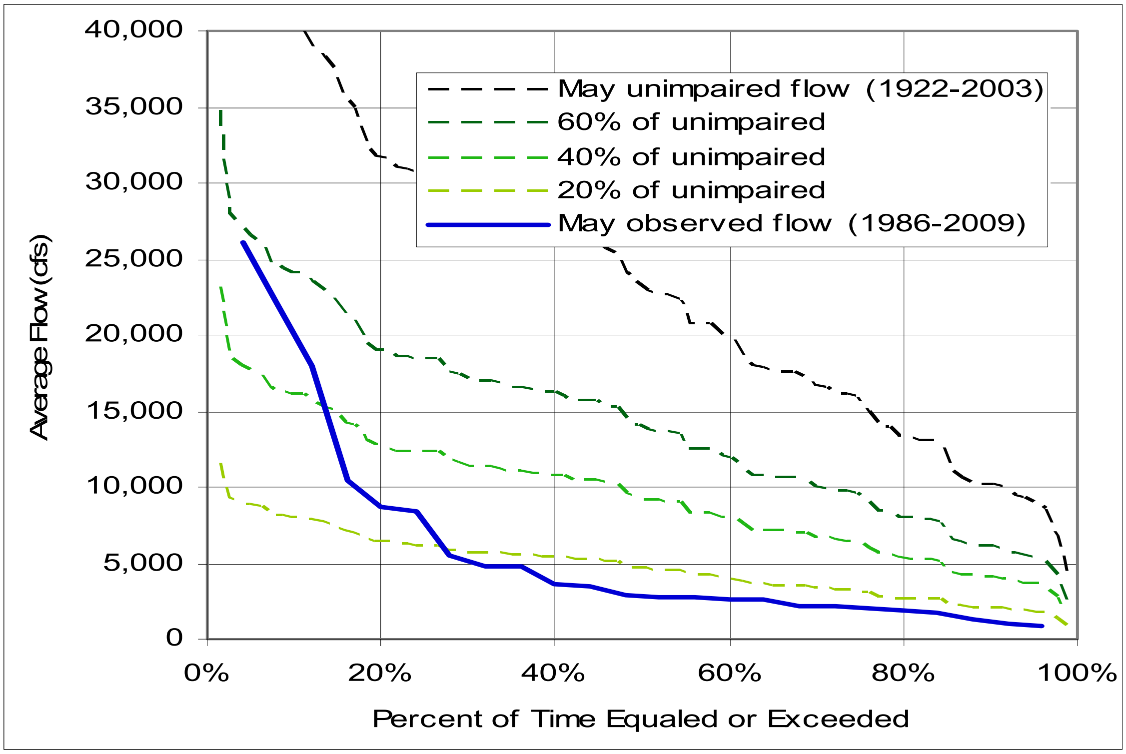


Figure 3.18. Exceedance Plot of May Monthly Average SJR Unimpaired and Observed Flows at Vernalis

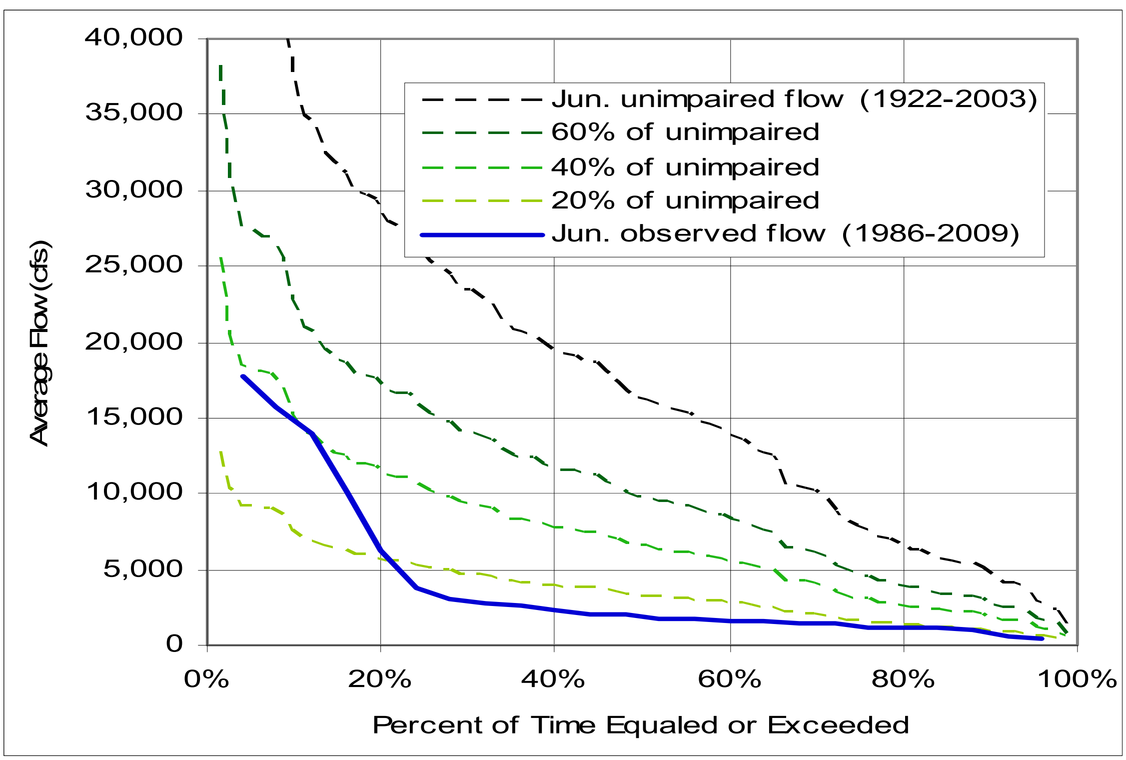


Figure 3.19. Exceedance Plot of June Monthly Average SJR Unimpaired and Observed Flows at Vernalis

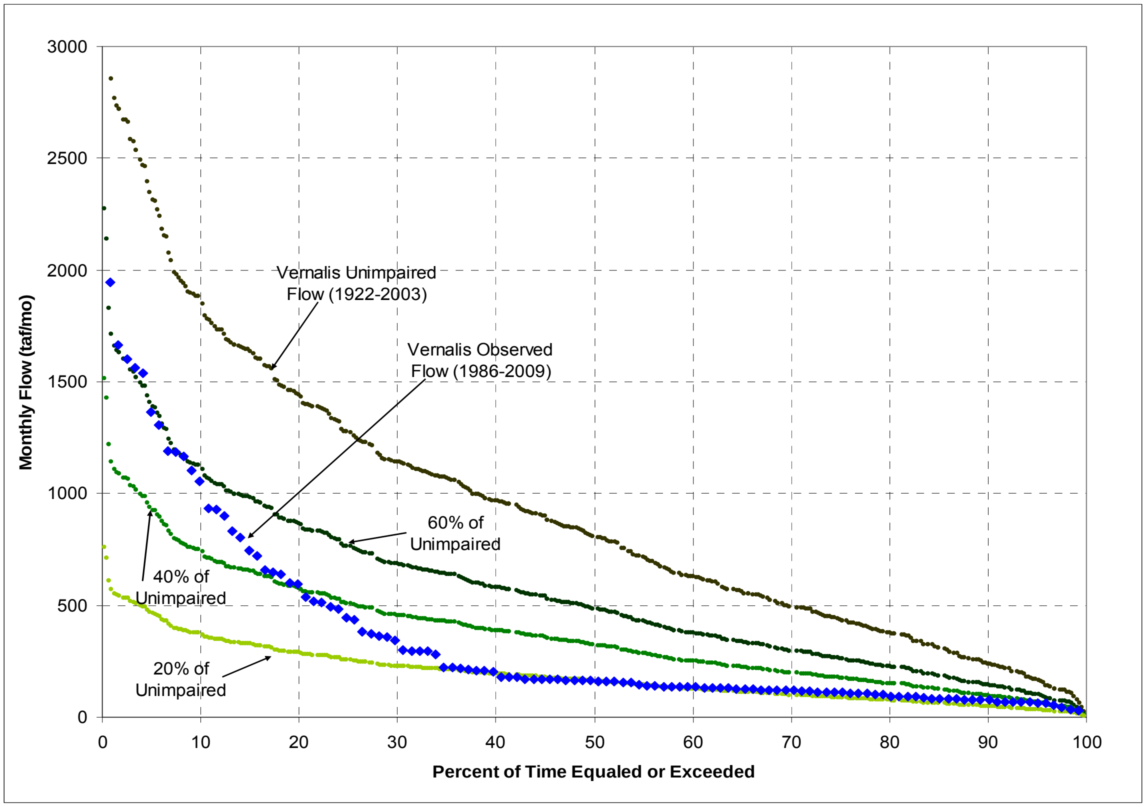


Figure 3.20. Exceedance Plot Of Monthly Average SJR Unimpaired and Observed Flows at Vernalis—February thru June

4 Southern Delta Salinity

Evaluation of the SJR flow and southern Delta salinity objective 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).

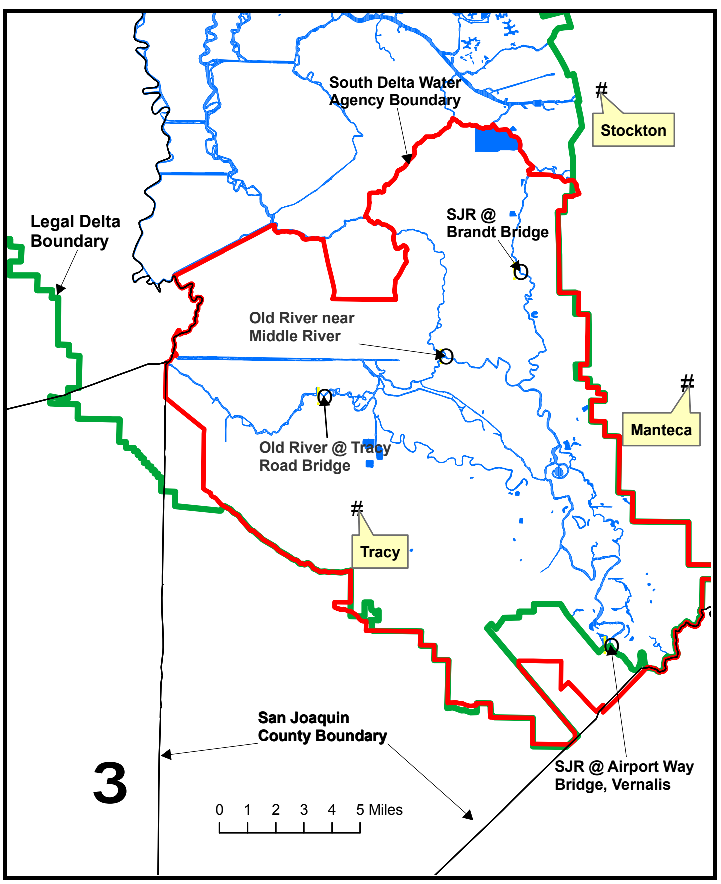


Figure 4.1. Map of southern Delta showing State Water Board salinity compliance stations and boundaries of the legal Delta and South Delta Water Agency

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 percent yields of two important salt sensitive crops grown in the southern Delta (beans and alfalfa) in conditions typical of the southern Delta.

In keeping with the literature on crop response to salinity, numerical values for EC are given in units of deciSiemens per meter (dS/m) wherever possible. This is also numerically equal to 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 (µmho/cm), which are both 1,000 times larger than numerical values in units of dS/m.

4.2 Salinity in the San Joaquin River Near Vernalis

A spreadsheet model was created that estimates how EC at Vernalis might potentially be affected by changing flows from the Stanislaus, Tuolumne, and Merced Rivers in response to SJR flow objective alternatives. The model uses flow and electrical conductivity 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. This calculated flow and EC is used as the upstream input 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 Upper 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.

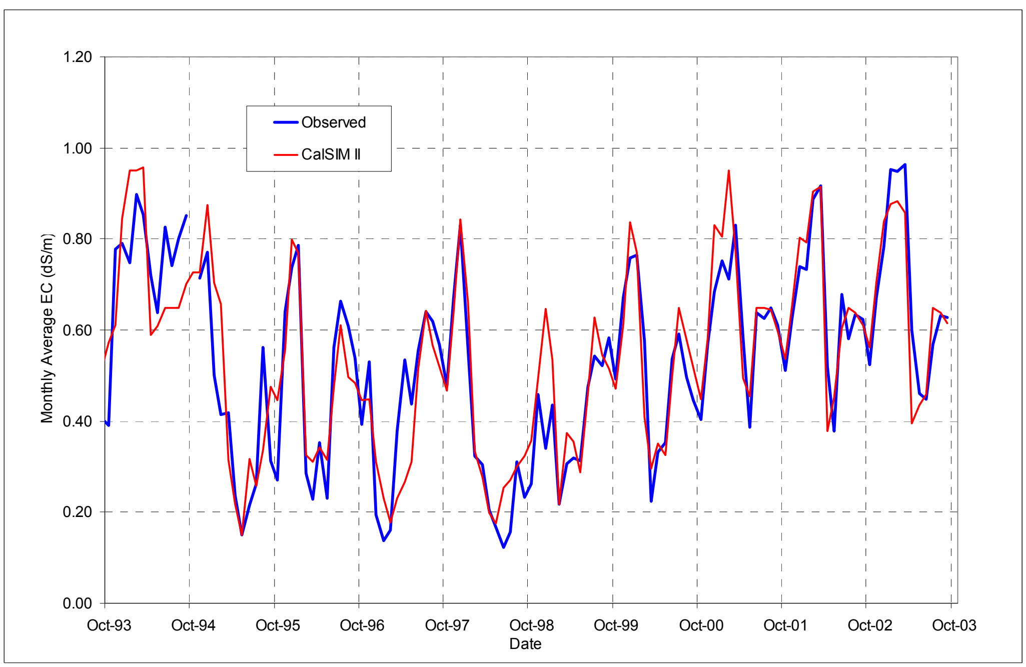


Figure 4.2. Comparison of CALSIM II salinity (dS/m) output at Vernalis to monthly average observed data at the same location for water years 1994 through 2003

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. 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

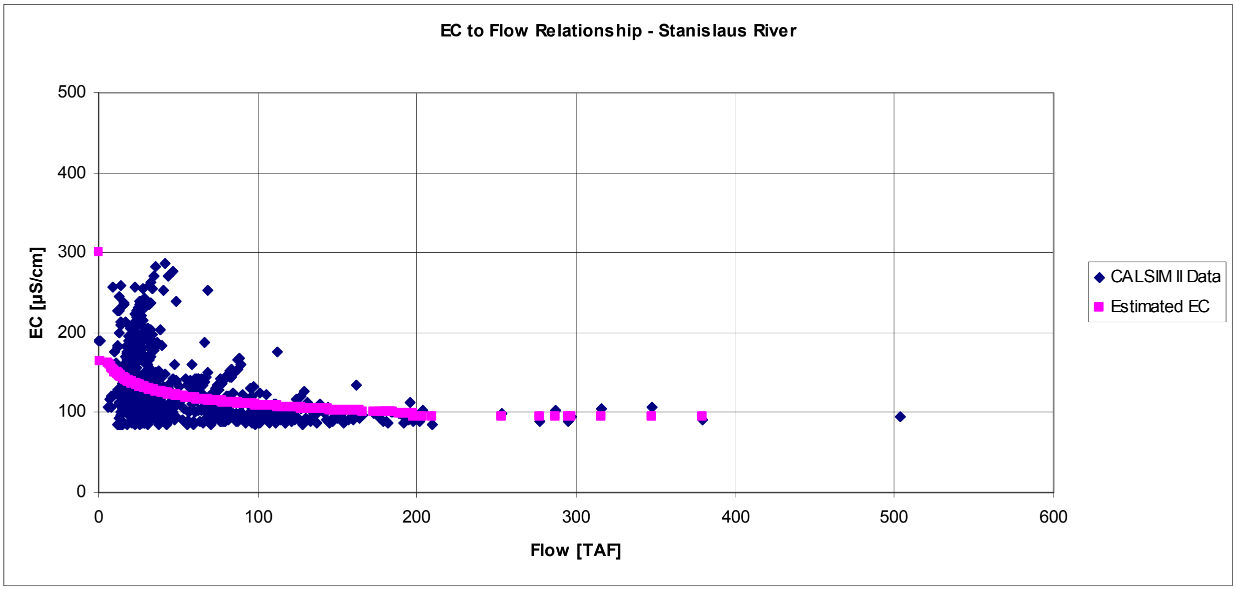


Figure 4.3. Estimated EC from CALSIM II data on the Stanislaus River

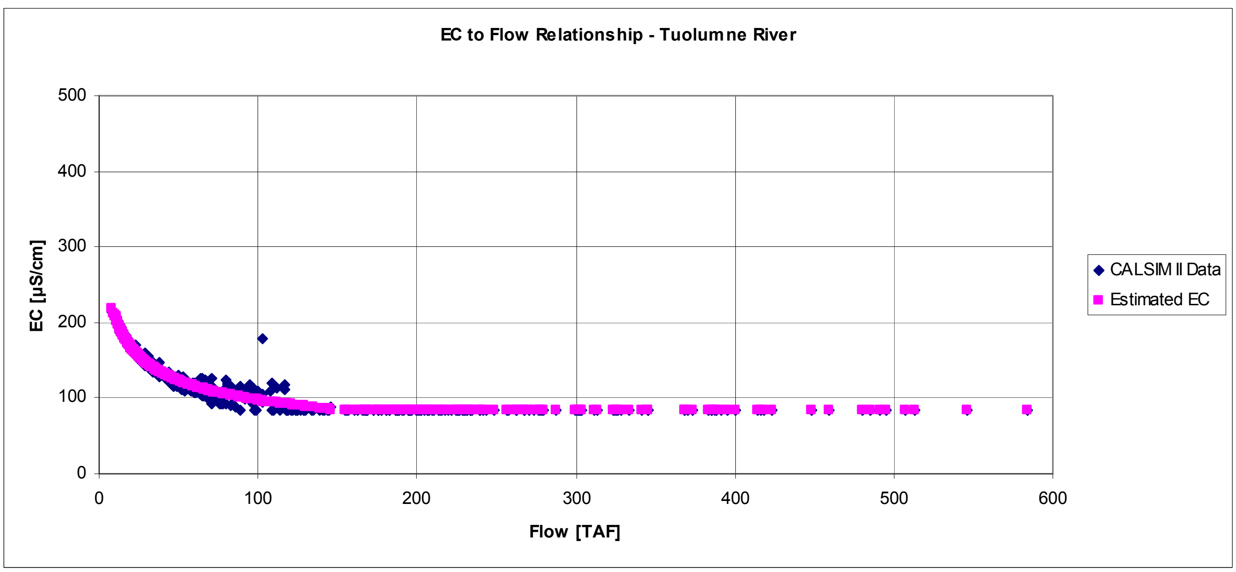


Figure 4.4. Estimated EC from CALSIM II data on the Tuolumne River

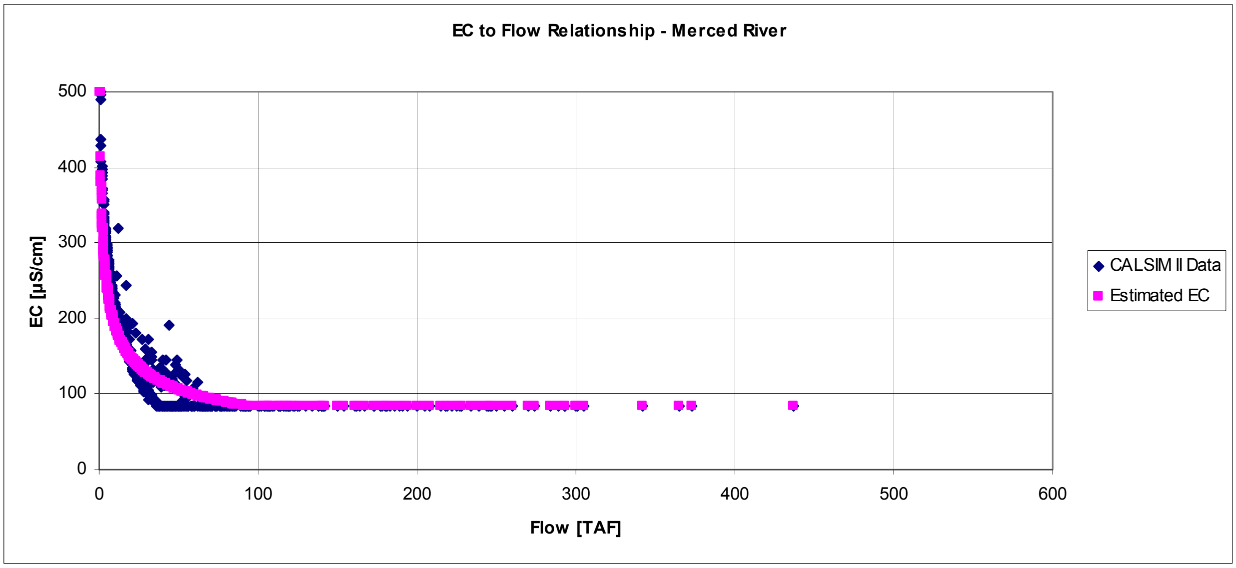


Figure 4.5. Estimated EC from CALSIM II data on the Merced River

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-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 percent and 60 percent of unimpaired flow.

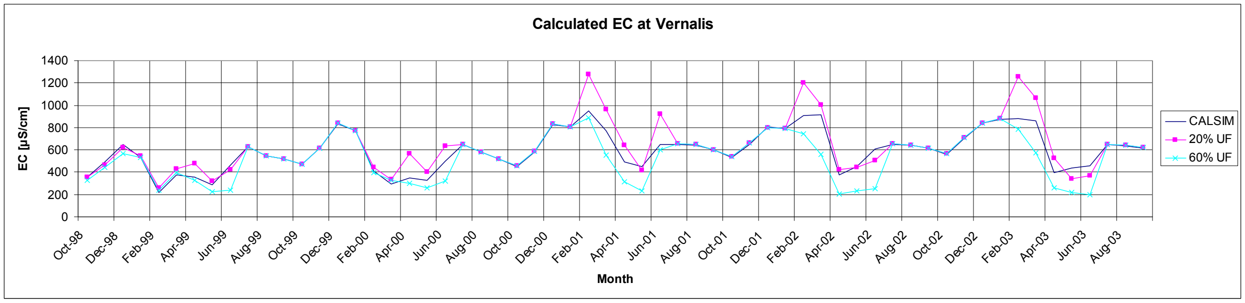


Figure 4.6. Calculated EC at Vernalis for the 40 percent and 60 percent unimpaired flow example compared to CALSIM II results for water years 1994-2003

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 percent of the time (85 percent prediction line).

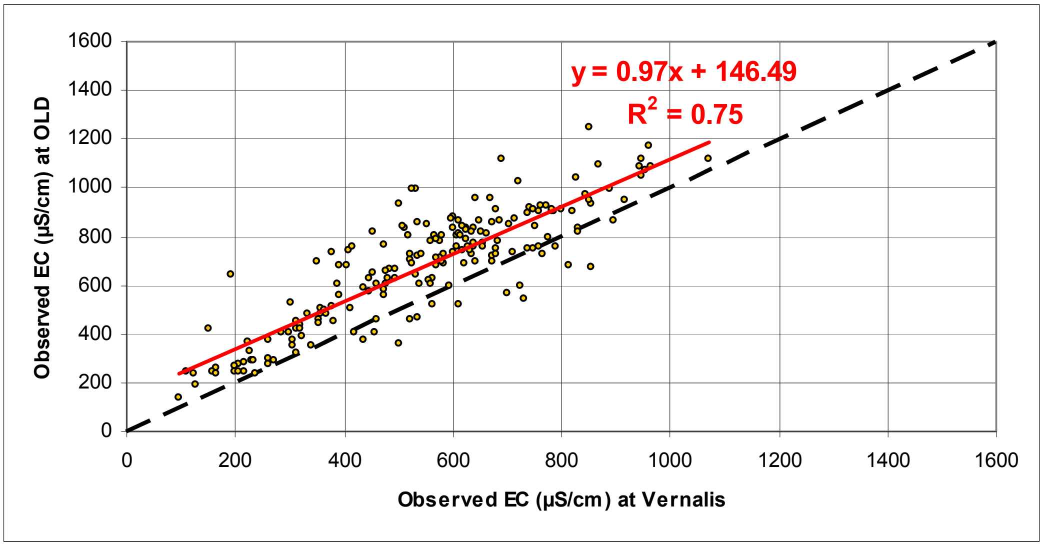


Figure 4.7. Monthly average salinity data from January 1993 to December 2009 for Old River at Tracy (OLD) plotted against corresponding salinity data at SJR near Vernalis

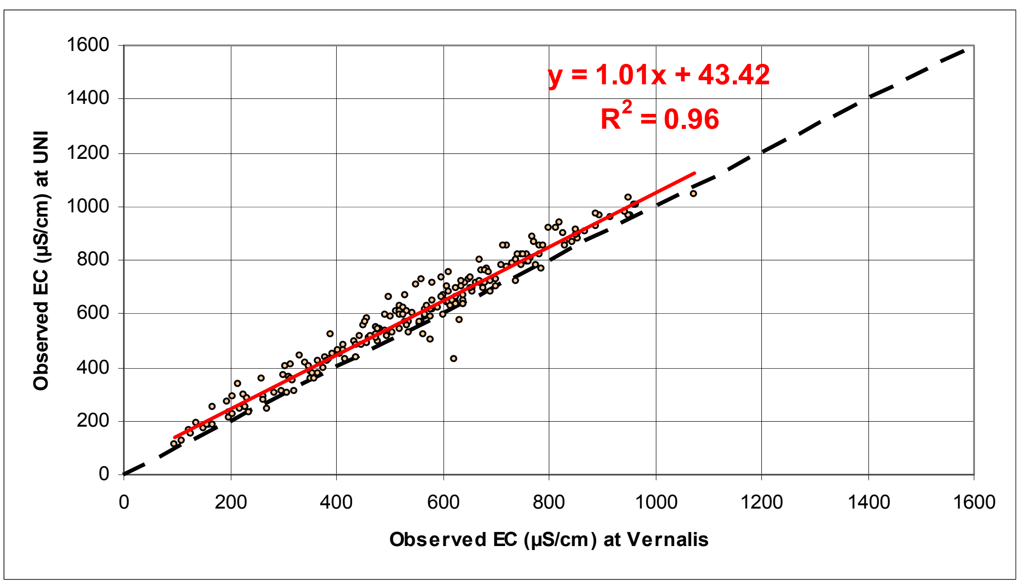


Figure 4.8. Monthly average salinity data from January 1993 to December 2009 for Old River at Middle River/Union Island (UNI) plotted against corresponding salinity data at SJR near Vernalis

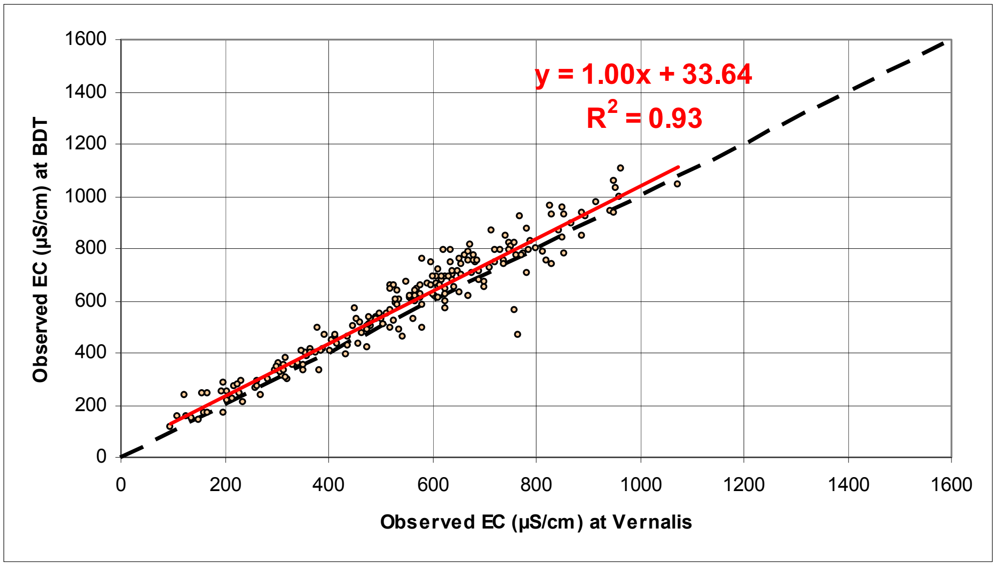


Figure 4.9. Monthly average salinity data from January 1993 to December 2009 for SJR at Brandt Bridge (BDT) plotted against corresponding salinity data at SJR near Vernalis

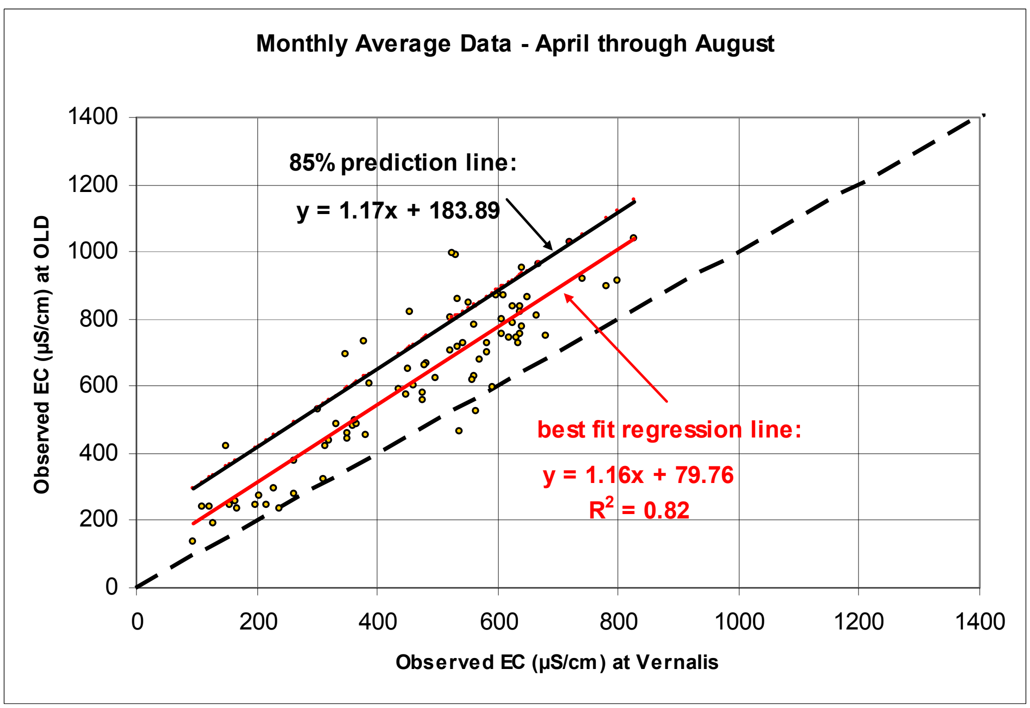


Figure 4.10. Monthly average salinity data for April through August from 1993 through 2009 for Old River at Tracy (OLD) plotted against corresponding salinity data at SJR near Vernalis, with best fit regression and 85 percent prediction lines

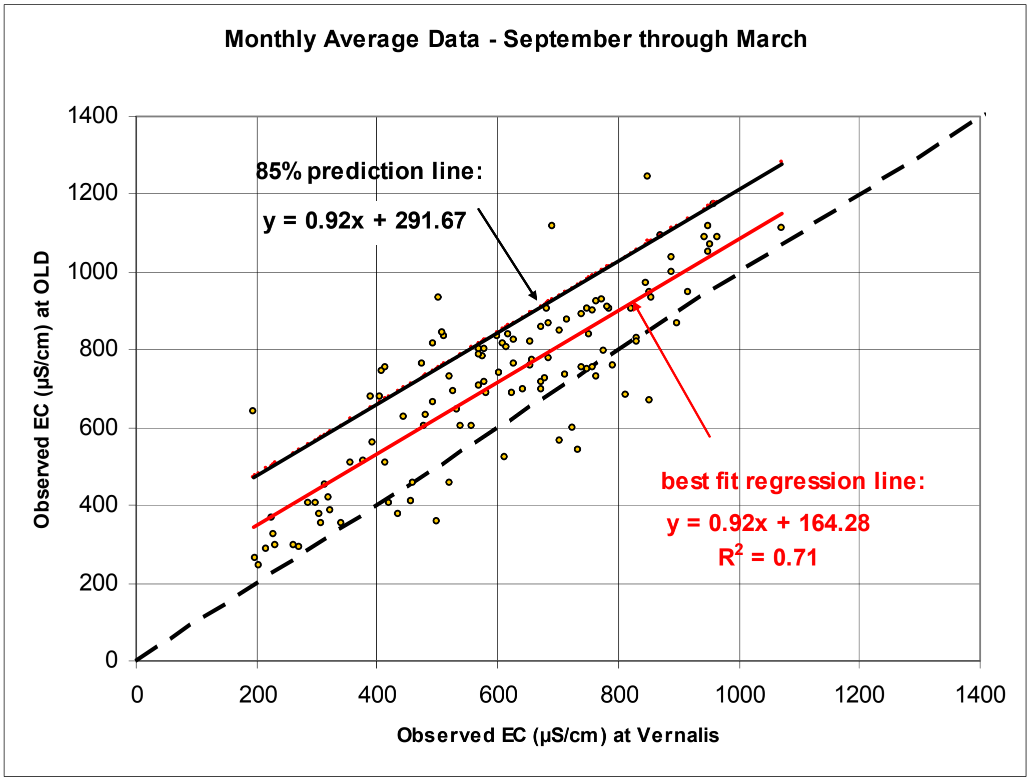


Figure 4.11. Monthly average salinity data for September through March from 1993 through 2009 for Old River at Tracy (OLD) plotted against corresponding salinity data at SJR near Vernalis, with best fit regression and 85 percent prediction lines

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 affect of the Tracy discharge at 16 million gallons per day (mgd) would increase EC by 11 and 3 µS/cm in August, under high and low export pumping scenarios respectively (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).

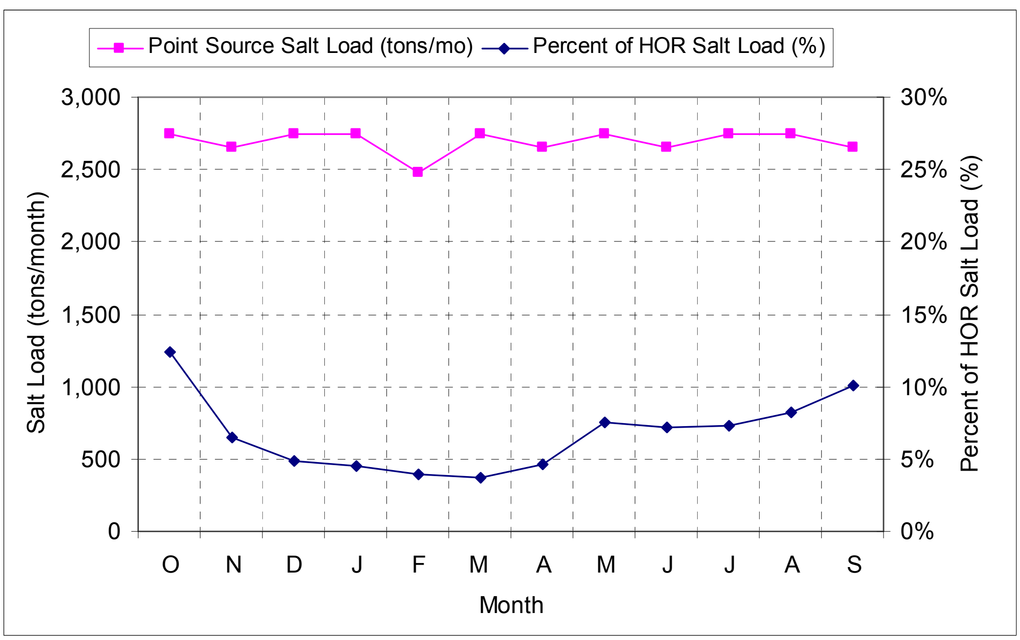


Figure 4.12. Theoretical salinity loading from the City of Tracy, Deuel Vocational Facility and Mountain House wastewater treatment plants stated as total load (tons/month) and as a percent of the load entering the head of Old River

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 staff workshop in August 2009. Written comments and other input were solicited from stakeholders regarding the draft report, and Dr. Hoffman gave a follow-up presentation in November 2009 to summarize and address the comments received. Based on feedback from these presentations, Dr. Hoffman finalized the subject report, including a comment response appendix.

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

a) Salt sensitive crops of significance in the southern Delta include almond, apricot, dry bean, and walnut, with dry bean being the most sensitive.
b) Based on the last nine years of data, the current level of salinity in the surface waters of the southern Delta appears suitable for all agricultural crops.
c) Neither sodicity nor toxicity should be a concern for irrigated crops; however, based on limited data and known crop tolerances, boron may be a concern.
d) Depth to the water table in much of the southern Delta is at an acceptable depth for crop production.
e) Relatively high leaching fractions are associated with an overall irrigation efficiency of 75 percent for furrow and border irrigation methods predominant in the southern Delta.
f) Data from drains in the western part of the southern Delta suggest leaching fractions are between 0.21 and 0.27, with minimums ranged from 0.11 to 0.22 (stated as unitless fractions).
g) The field study data supporting the salt tolerance of bean is sparse and over 30 years old. There is also no information on the salt sensitivity of bean and many other crops in early growth stages.
h) 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 five percent higher than estimated by the model.
i) Steady-state modeling presented in the report, and the results from other transient model studies suggest the water quality standard could be increased up to 0.9 to 1.1 dS/m and be protective of all crops normally grown in the southern Delta under current irrigation practices. During low rainfall years, however, this might lead to yield loss of about five percent under certain conditions.
j) Effective rainfall should be included in any modeling of soil water salinity in the southern Delta. Also, the exponential crop water uptake model is recommended as it better matches laboratory data. The 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 leads to higher estimates of soil water salinity.
k) In addition to the conclusions above, a number of recommendations were made for further studies in the southern Delta regarding: i) the crop salt tolerance of bean, ii) transient soil salinity modeling, iii) potential for boron toxicity to crops, and iv) leaching fractions associated with current irrigation practices.

4.4.2 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^{O} 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 implementation of SJR flow objective 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 SJR flow objective 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.

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 years’ diversions dependant 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 Done Pedtro 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 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.

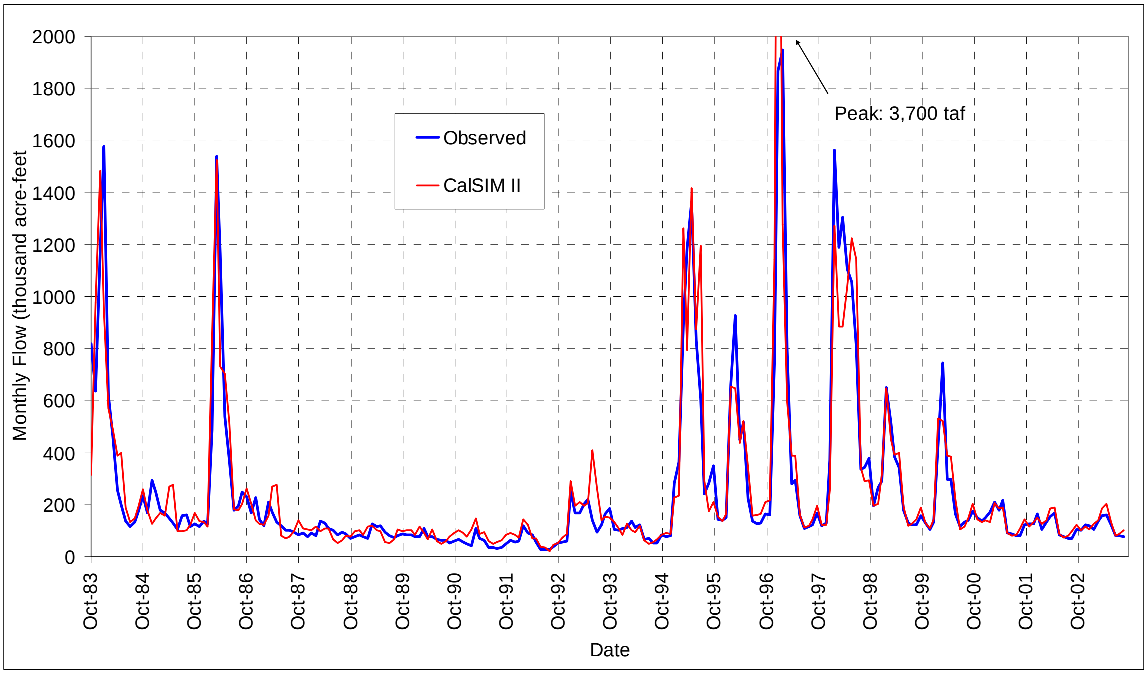


Figure 5.1. Observed Monthly Average Flow from USGS Gage #11303500 (SJR Near Vernalis) Compared to CALSIM II Model Output for SJR Flow at Vernalis

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 SJR flow objective 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 SJR 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.

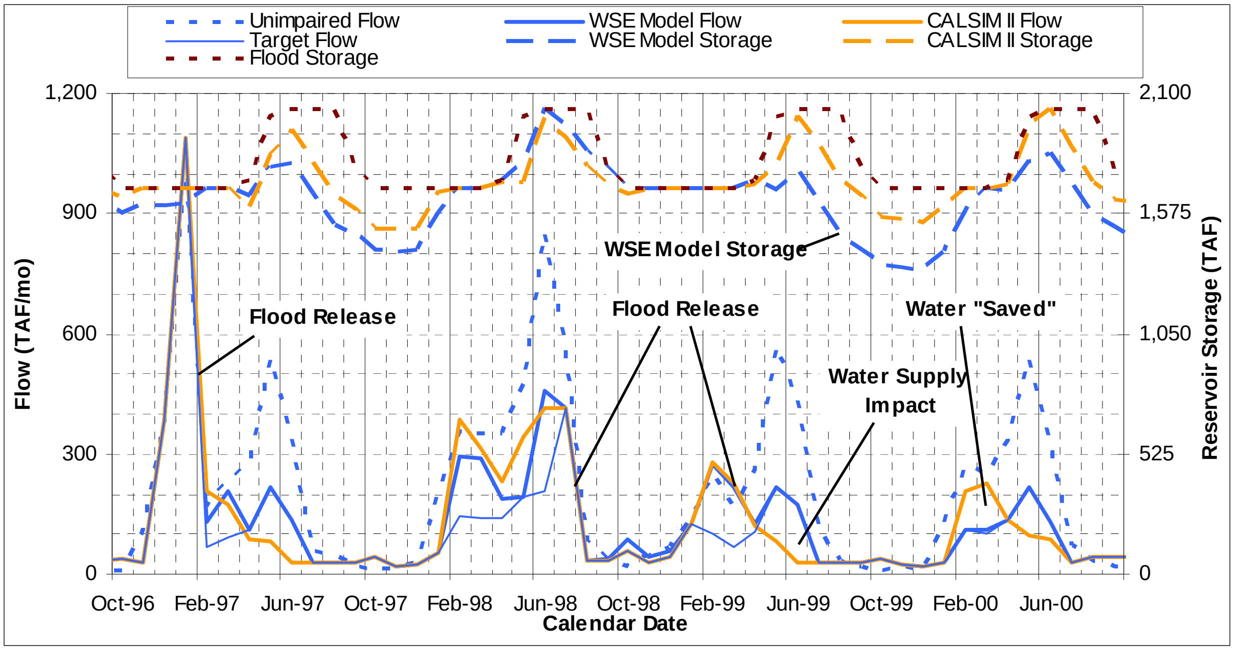


Figure 5.2. Monthly Unimpaired Flow and 40 Percent of Unimpaired Flow Objective Alternative Compared to CALSIM II Flow on the Tuolumne River at CALSIM II Node C545

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 percent of unimpaired flow target on the Stanislaus River and the 20 percent 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 demonstrate that the WSE model generates similar results to CALSIM II using similar input data and operating assumptions.

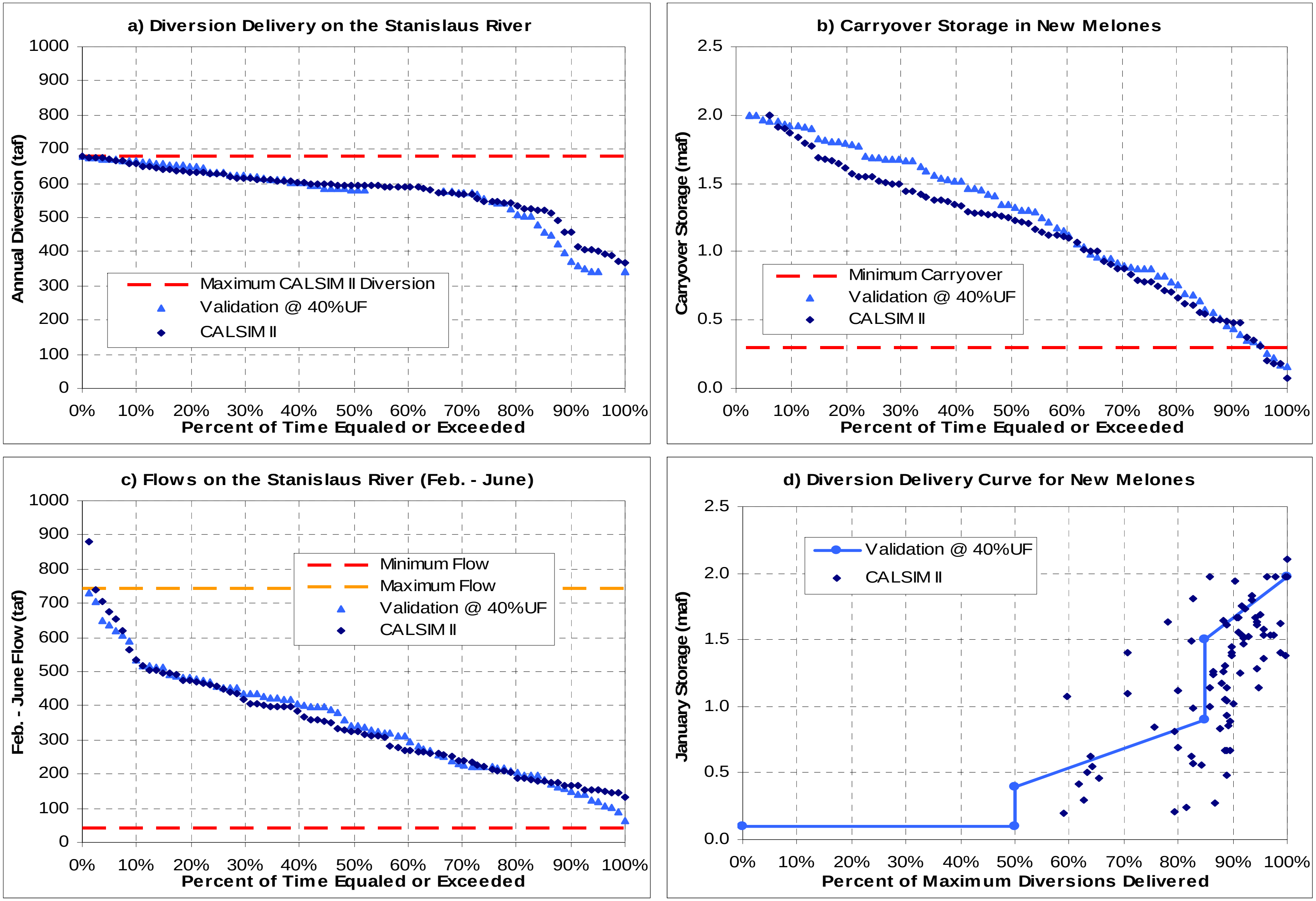


Figure 5.3. Validation of WSE Model Against CALSIM II Output on the Stanislaus River for A) Annual Diversion Delivery, B) End-of-September Storage, C) Flow at CALSIM II Node 528, D) Diversion Delivery Rule Curve Based on January Storage Level

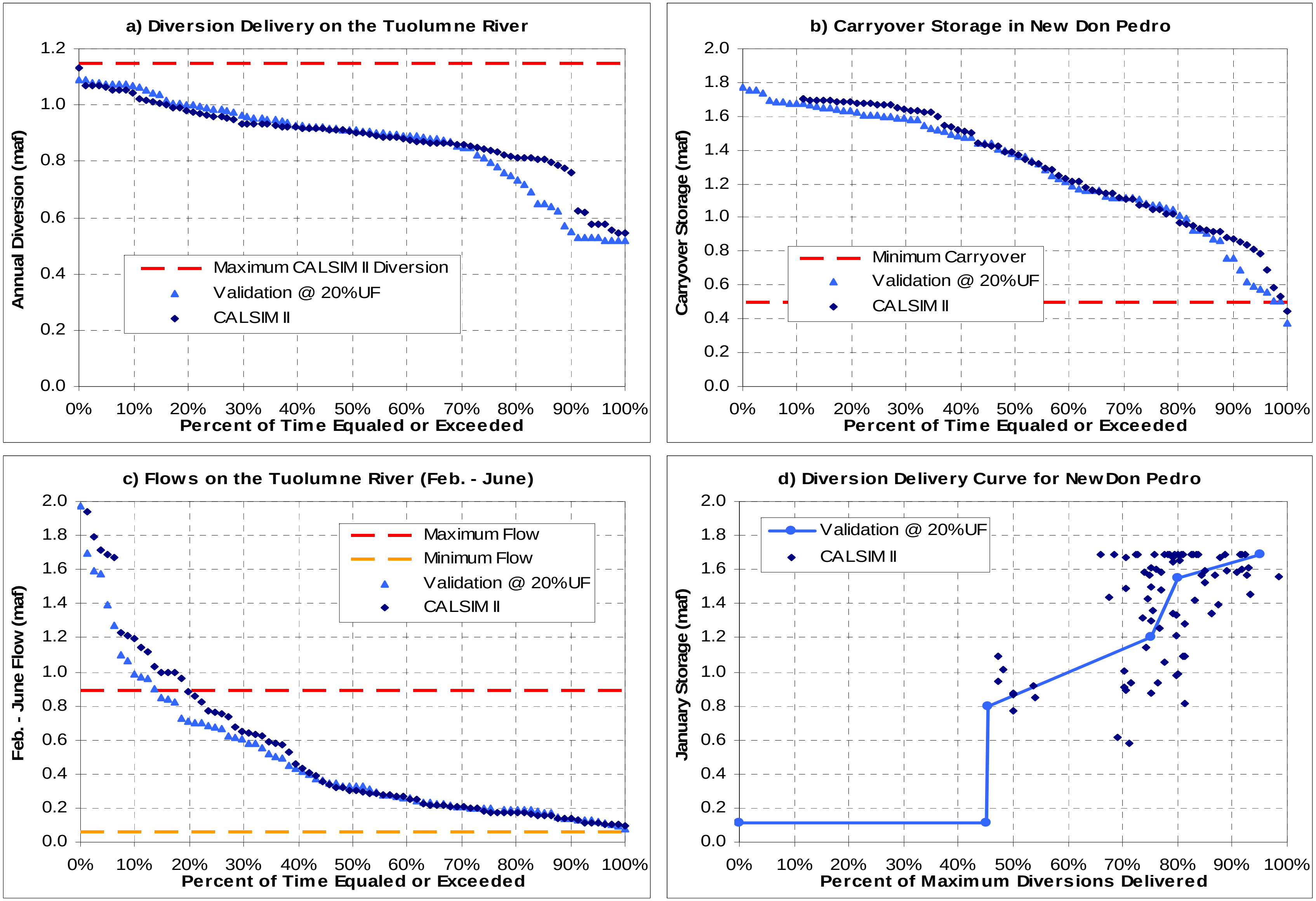


Figure 5.4. Validation Of WSE Model Against CALSIM II Output on the Tuolumne River for A) Annual Diversion Delivery, B) End-of-September Storage, C) Flow at CALSIM II Node 528, D) Diversion Delivery Rule Curve Based on January Storage Level

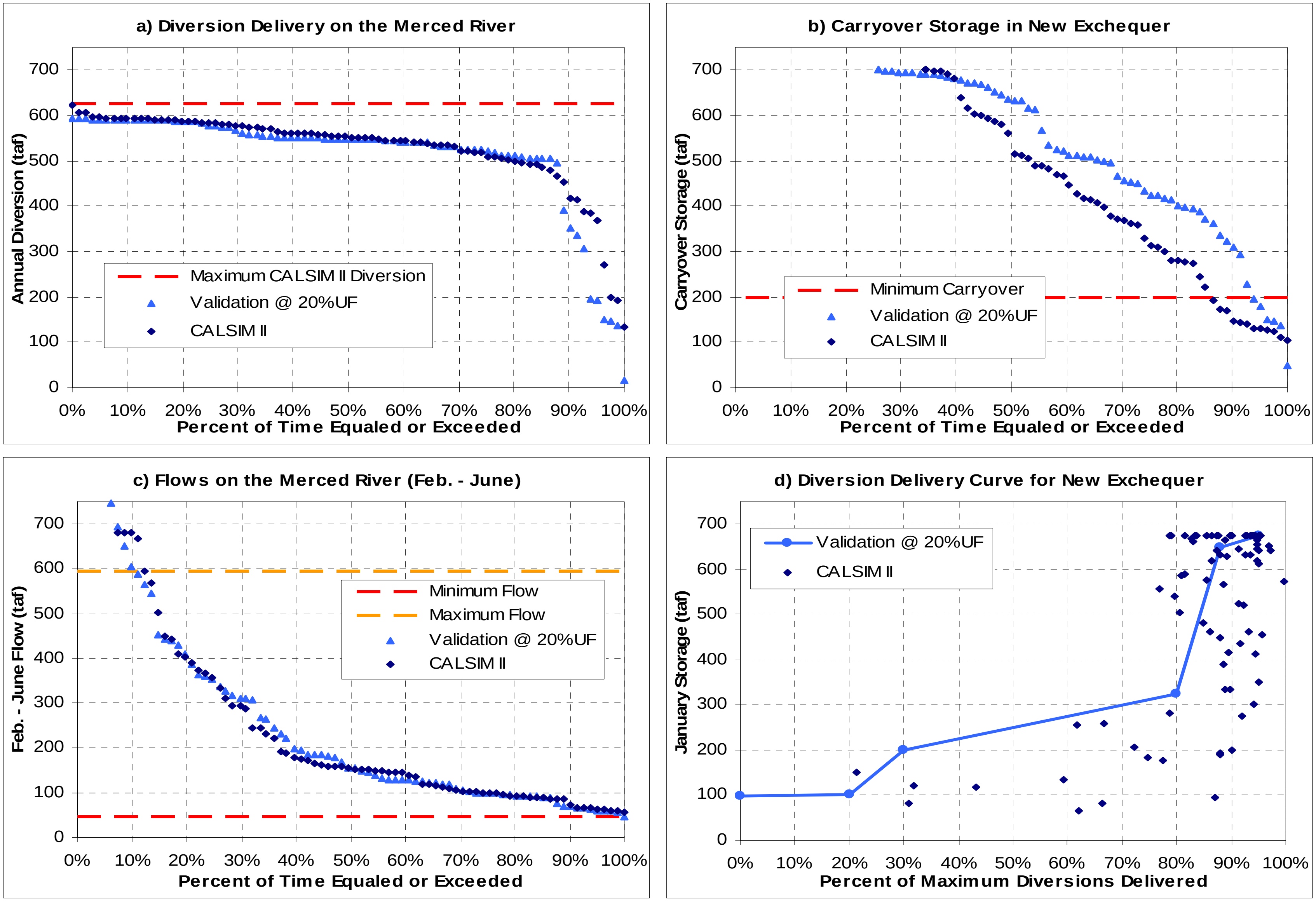


Figure 5.5. Validation of WSE Model Against CALSIM II Output on the Merced River for A) Annual Diversion Delivery, B) End-of-September Storage, C) Flow at CALSIM II Node 528, D) Diversion Delivery Rule Curve Based on January Storage Level

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 percent 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 percent 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 SJR flow objectives 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 SJR Flow Objective 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 SJR Flow Objective 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 SJR Flow Objective 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				

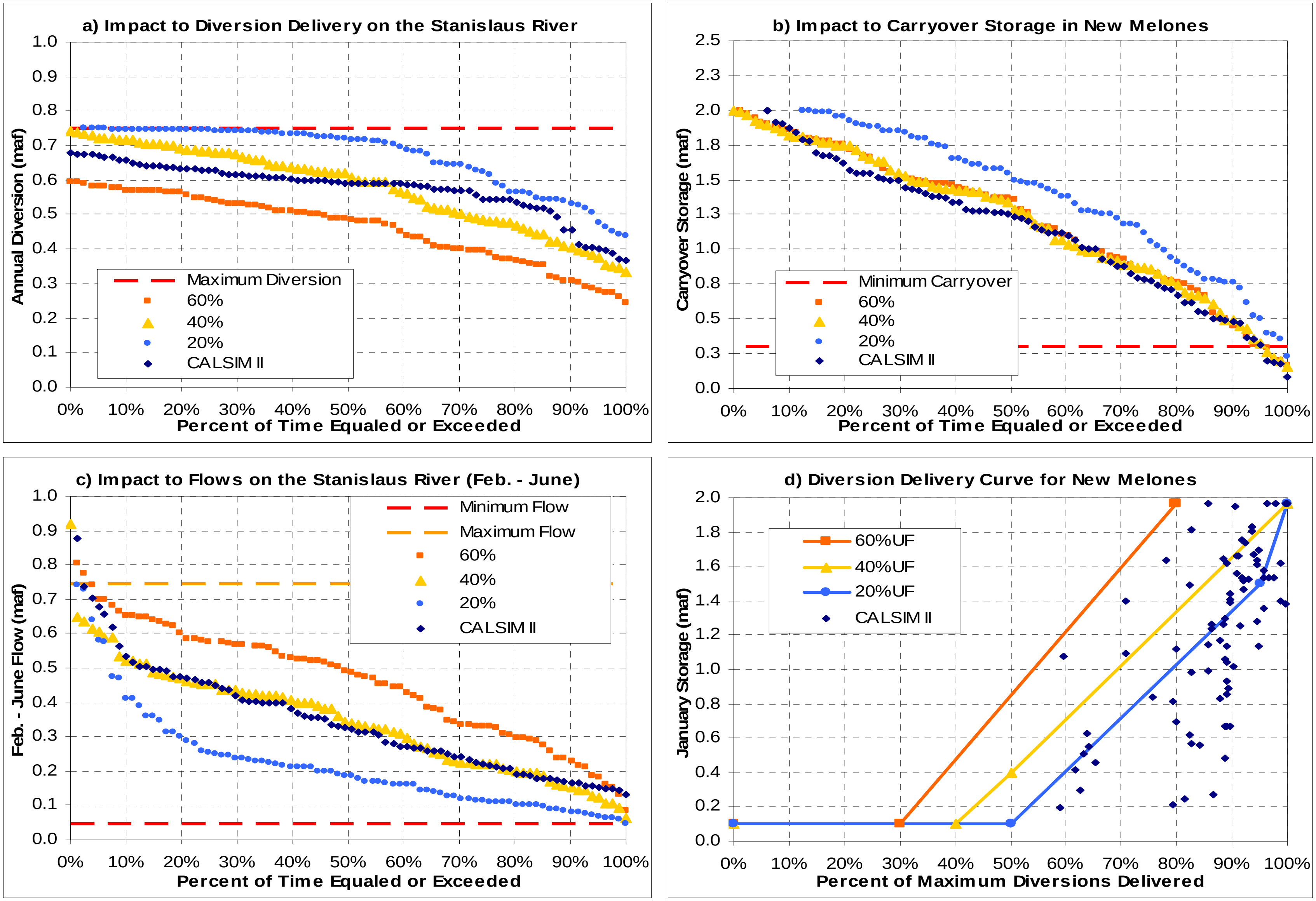


Figure 5.6. Results of Impacts for Illustrative Flow Objective Alternatives of 20, 40 and 60 Percent of Unimpaired Flow on the Stanislaus River.

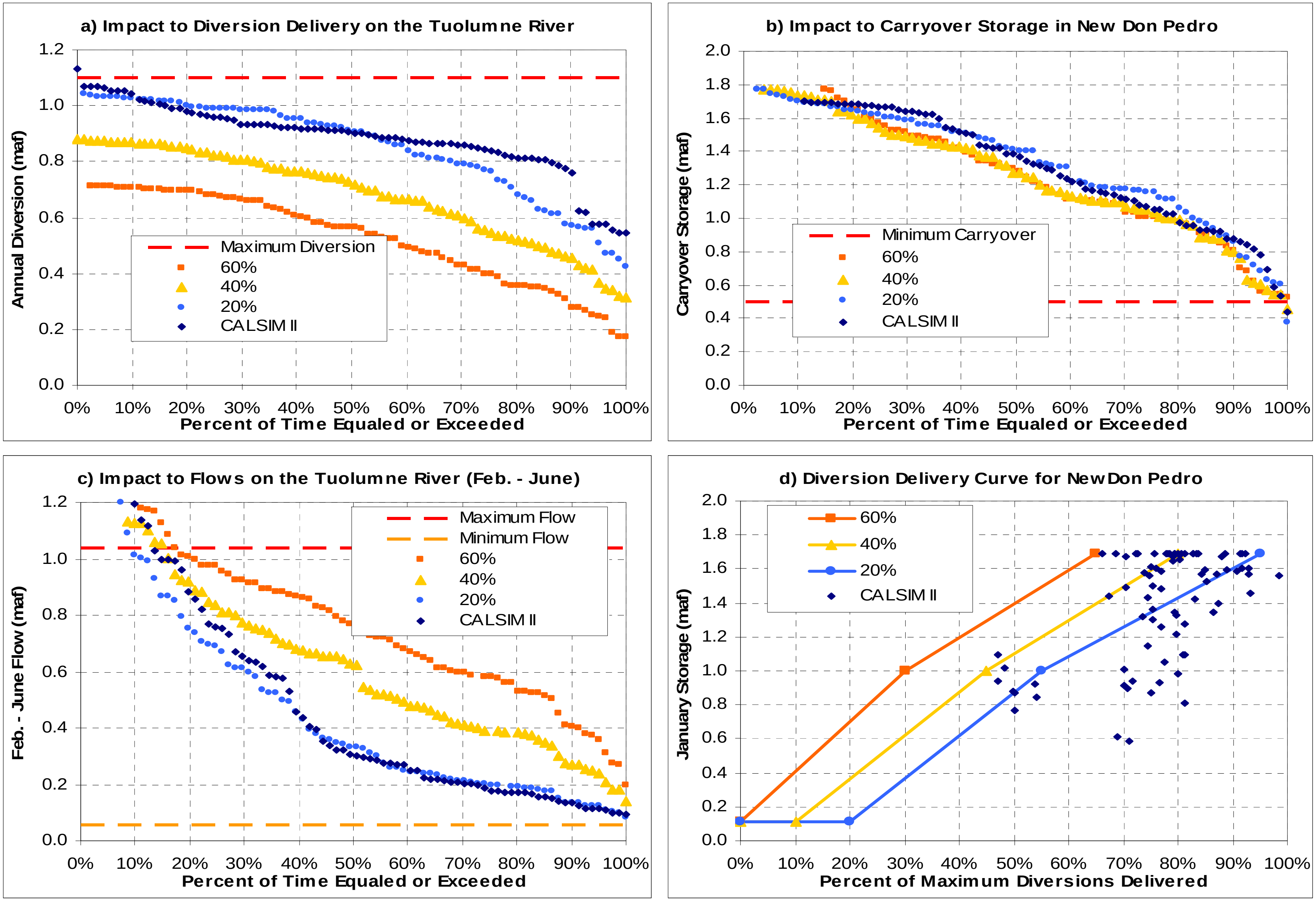


Figure 5.7. Results of Impacts for Illustrative Flow Objective Alternatives of 20, 40 and 60 Percent of Unimpaired Flow on the Tuolumne River.

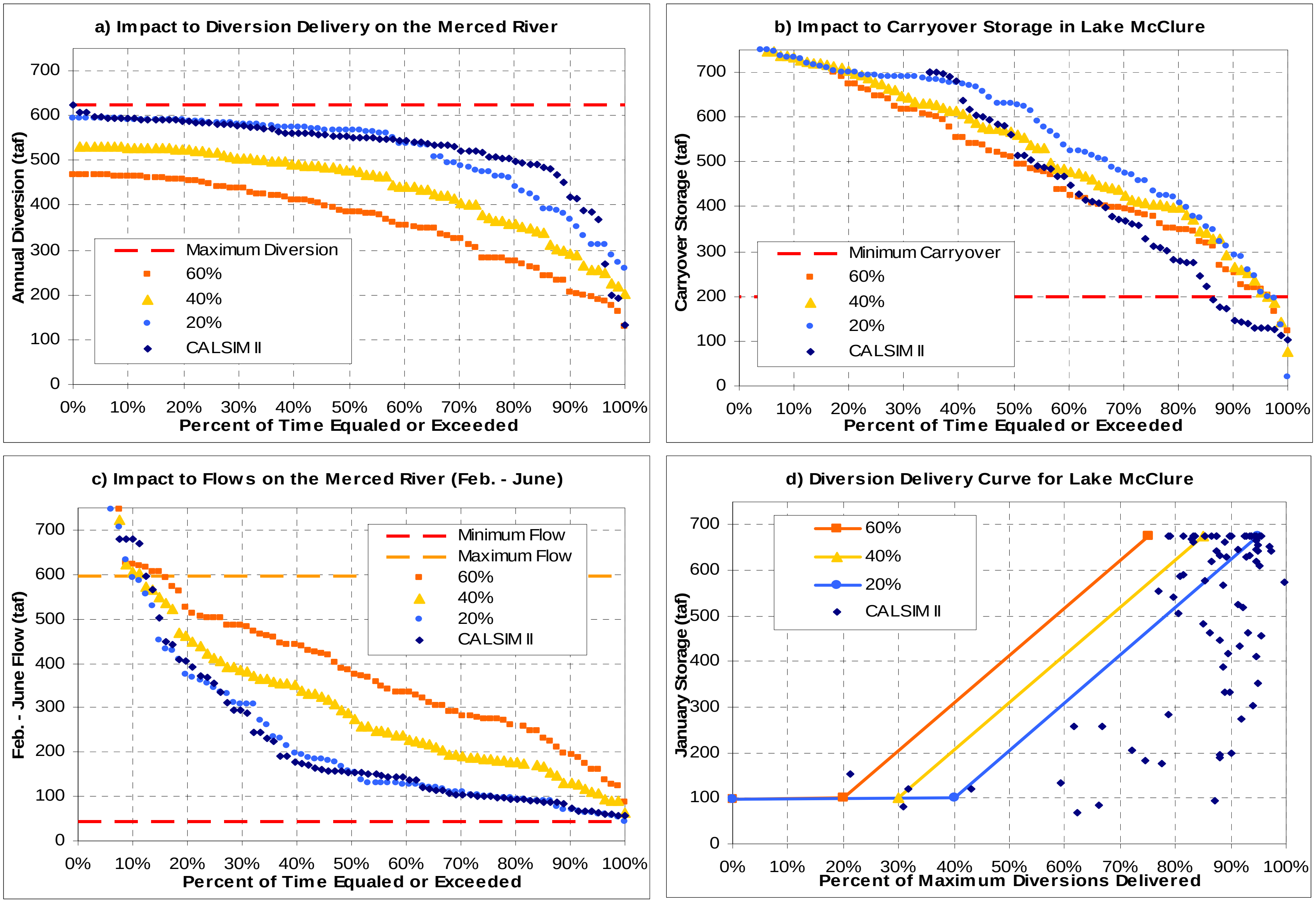


Figure 5.8. Results of Impacts for Illustrative Flow Objective Alternatives of 20, 40 and 60 Percent of Unimpaired Flow on the Merced River

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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.1.1 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 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.1.2 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.

[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.

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 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.1.3 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:

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 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 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 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.

<u>State Water Board Regulatory Actions</u>
The southern Delta water quality objectives for protection of agricultural beneficial uses listed in Table 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.

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

i. <u>Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS)</u>: 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. <u>Discharge Regulation</u>: 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. <u>Upstream of Vernalis San Joaquin River Salinity Objectives</u>: 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. <u>San Joaquin River at Vernalis Salt and Boron TMDL</u>: 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.

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

i. <u>Grasslands Bypass Project</u>: 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 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 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
1990	480	96	36	46	29	17
1991	394	77	78	41	32	9
1992	255	132	618	368	123	245

Year	Stanislaus	Tuolumne	Merced (In River)	Merced (Hatchery)		
				Total	3+ years old	2 years old
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