Appendix I

Supplemental Hydrologic and Water Operations Analyses

Draft
Program Environmental Impact Statement/Report

SAN JOAQUIN RIVER RESTORATION PROGRAM

Draft
April 2011

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List of Abbreviations and Acronyms

Banks	Harvey O. Banks Pumping Plant
cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento-San Joaquin Delta
Jones	C.W. "Bill" Jones Pumping Plant
LOD	level of development
OMR	Old and Middle River
PEIS/R	Program Environmental Impact Statement/Report
Settlement	Stipulation of Settlement in *NRDC, et al., v. Kirk Rodgers, et al.*
SWP	State Water Project
TA	Technical Appendix

1.0 Introduction

The action alternatives include two types of features that present challenges for presentation in impacts. These two types are:

- ***Provisions for Flexible Operations*** **–** The Stipulation of Settlement in *NRDC, et al., v. Kirk Rodgers, et al.* (Settlement) recognizes the need for operational flexibility within the Restoration Flow Schedule to address unforeseen or changing conditions within the project area, and to accommodate the expected - but unpredictable - variation in the restored salmon fishery's requirements. The extent to which these provisions will be evoked cannot be known.

  While the future use of these provisions is unknown, the extent of their utilization is bounded within the Settlement. This feature is addressed by evaluating the outer bound(s) of specific provisions (e.g., full Buffer Flows, maximum timing shifts within the Flexible Flow periods).

- ***Variations in Planning Conditions*** **–** There are potential variations within the defined Existing and Future Conditions that are subject to ongoing change, but that are not constrained by the Settlement (e.g, hydrologic shifts resulting from climate change, changes in flood releases due to the availability of 16(b) water facilities, variations in SJRRP annual allocation procedures, pending Delta regulations).

While the magnitude of these changes are neither bounded by law (e.g., SJRRP annual allocation procedures) nor predictable with certainty (e.g., climate change, Delta regulation), their potential impacts have been bracketed and evaluated.

The following supplemental analysis evaluates the potential for the above features to cause impacts which are outside of the range of those reported in the Program Environmental Impact Statement/Report (PEIS/R) analysis of the alternatives. The supplemental analysis includes the following components:

Exhibit B Flow Schedule – Implements the Restoration Flows as documented in Exhibit B of the Settlement, using the stair-step annual allocation method instead of the proposed continuous method available at the time of PEIS/R publication.

Flexible Flows (earlier and later) – Implements the maximum extent of Flexible Flows by shifting pulses for both Spring and Fall Flexible Flow Periods in two separate evaluations. The first evaluation shifts both periods one month earlier, the second evaluation shifts them one month later. Both evaluations were performed on Alternative A at Existing Level of Development (LOD). All other operations were held constant.

Buffer Flows – Implements the maximum extent of Buffer Flow utilization by uniformly increasing releases for each month by 10 percent. This evaluation was performed on Alternative A at Existing LOD. All other operations were held constant.

No Implementation of 16(b) – Prevents deliveries of surplus water for 16(b). Any available surplus was delivered as Section 215 water before being allowed to spill. This evaluation was performed on Alternative A at Existing LOD. All other operations were held constant.

Restored Friant-Kern Canal Capacity – Restores the Friant-Kern Canal reach capacities to design specifications.

Channel Constrained Releases – Limits Reach 2B to a capacity of 1,300 cubic feet per second (cfs). Restoration Flows in Reach 2B take priority over surplus flow to the Mendota Pool and no Restoration Flows were routed through the Chowchilla Bypass. Since scheduled Restoration Flows in many years can be larger than 1,300 cfs, the release schedule was reduced so that release of Restoration Flows resulted in flows equal to or less than 1,300 cfs in Reach 2B. Losses and diversions upstream from Reach 2B were taken into account in the rescheduling. Friant surplus destined for the Mendota Pool shares Reach 2B capacity with Restoration Flows, but Restoration Flows have the priority. Additionally, Reach 4B is assumed to have zero (0 cfs) capacity and Restoration Flows are routed through the Eastside Bypass. This evaluation was performed on Alternative A at Existing LOD. All other operations were held constant.

Delta Pumping Restrictions – Several pending regulatory decisions are expected to implement new standards in the Sacramento-San Joaquin Delta (Delta) that may restrict Delta pumping. The exact nature of these restrictions is not known at this time. It is anticipated that one of the major restrictions will be limits on Old and Middle River (OMR) reverse flows caused by Delta export pumping at Harvey O. Banks Pumping Plant (Banks)/C.W. “Bill” Jones Pumping Plant (Jones) pumping plants. Restoration Flows that reach the Delta may have a larger impact on allowable pumping with these restrictions in place than without them. This was evaluated by assuming a new OMR limit of -750 cfs. This limit has been used in other studies as a representation of relatively stringent restrictions that could be imposed when the decisions are completed.

Implementation of this evaluation into the CalSim model is more complex than for the other evaluations. The restrictions impose substantial reductions and Central Valley Project (CVP)/State Water Project (SWP) deliveries which impact system operations to the extent that some internal CalSim operational rules need to be modified to produce a representative result. A CalSim simulation at Future LOD was found that did not include the SJRRP but implemented this new standard and included the other modeling adjustments required to obtain a representative simulation. The actions under Alternative A were added to this study to produce a Future LOD CalSim run with both the OMR restrictions and the Alternative A assumptions.

Climate Change and Sea Level Rise – Climate change and its potential impacts could be important factors in future SJRRP operations. These changes are expected to impact precipitation and temperatures, both of which could impact the SJRRP. The analysis of the potential for impacts from climate change is attached to this report.

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2.0 Analysis Procedure

The purpose of this analysis is to assess the potential for impacts outside those covered in the PEIS/R analysis of the alternatives which may result from one of two features: provisions for flexible operations and variations in planning conditions.

Both provisions for flexible operations and variations in planning conditions are expected to impact Millerton operations differently than the Project Alternatives and produce different impacts; but since they are variations on the alternatives they are not necessarily expected to cause impacts outside the range of impacts reported in the PEIS/R.

For the aspects of this analysis concerning provisions for flexible operations, the provisions are always implemented to their greatest extent. It is anticipated that, during Program implementation, these provisions would be implemented on an as needed basis. By picking the outer boundary of implementation, the analysis should overestimate the potential impacts of the provisions and provide an upper bound on the potential for the feature to cause impacts during project implementation.

For aspects of this analysis concerning variations in planning conditions, the variations are either bracketed when outcomes are highly uncertain (e.g. climate change) or evaluated using the most stringent assumptions of potential formulation (e.g. Delta regulations).

The analysis was carried out by modifying the Existing Level Alternative A CalSim simulation as required to impose the feature to the maximum extent possible. The results of these simulations were then screened based on changes to several indicators between the Existing Condition, Alternative A, and the new action simulation. The screening assumes that a change of +/- 10 percent in any of the indicators between the original Alternative and the modified Alternative indicates a need to evaluate the potential for the action to cause impacts outside the range of impacts reported in the PEIS/R.

If there appears to be a substantial potential for these changes, then further analysis, including additional modeling of water operation, stream flow, temperature, and water quality may need to be performed to allow evaluation of the significance of the potential impact using a similar approach and assumptions as used in the PEIS/R.

2.1 Impact Indicators

The following six specific indicators were selected for the evaluation.

- **Millerton Storage –** Assumed to represent potential for changes in Millerton flood releases and release temperatures

- **Millerton Release** – Assumed to represent potential for changes in San Joaquin River flows and temperatures in the Restoration Area
- **Friant-Kern Canal Diversion** – Assumed to represent potential for changes in Friant delivery from Millerton Lake
- **San Joaquin River Delta Inflow** – Assumed to represent potential for changes in water quality operations and quality in the Lower San Joaquin River and the Delta
- **Delta Pumping** – Total of Jones and Banks Pumping, assumed to represent potential for changes in CVP/SWP Delta water operations and water quality
- **Sacramento River Delta Inflow** – Assumed to represent potential for incidental changes in CVP/SPW system operations North of the Delta

2.2 Analysis Outputs

Tables and plots, for all years and by Restoration Year Type, comparing these indicators from the No Project, Existing Level Alternative A and the new simulation were prepared and used to evaluate the potential for impacts from the action outside the impacts from the PEIS/R formulation of Alternative A. Table 2-1 is an example of a summary table used for scanning for potential impacts. The table shows the deviation of an indicator variable from Alternative A for an action. All deviations of more than +/- 10 percent are highlighted for easy identification.

Table 2-1.
Example Summary Table For Initial Scanning

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-1.2%	-1.9%	-2.4%	0.0%	1.1%	0.0%	0.0%
November	-1.4%	-2.5%	-2.1%	0.0%	0.2%	0.0%	0.0%
December	-1.3%	-3.4%	-1.5%	0.0%	0.1%	0.0%	0.0%
January	-0.8%	-3.3%	-0.1%	0.0%	0.1%	0.0%	0.0%
February	-0.9%	-4.8%	-0.2%	0.3%	0.4%	0.0%	3.2%
March	-0.2%	2.0%	0.0%	-0.7%	-4.7%	0.3%	0.0%
April	0.8%	**11.1%**	-4.4%	0.3%	1.1%	0.2%	0.0%
May	2.6%	**17.6%**	-1.6%	0.2%	0.8%	0.2%	0.0%
June	1.8%	5.9%	0.9%	0.1%	0.8%	0.2%	0.0%
July	1.3%	3.7%	0.1%	0.1%	1.1%	0.1%	0.0%
August	1.0%	3.9%	-1.4%	0.0%	1.1%	0.1%	0.0%
September	-0.1%	1.6%	-2.4%	0.0%	1.0%	0.0%	0.0%

Note:
Increase greater than 10%

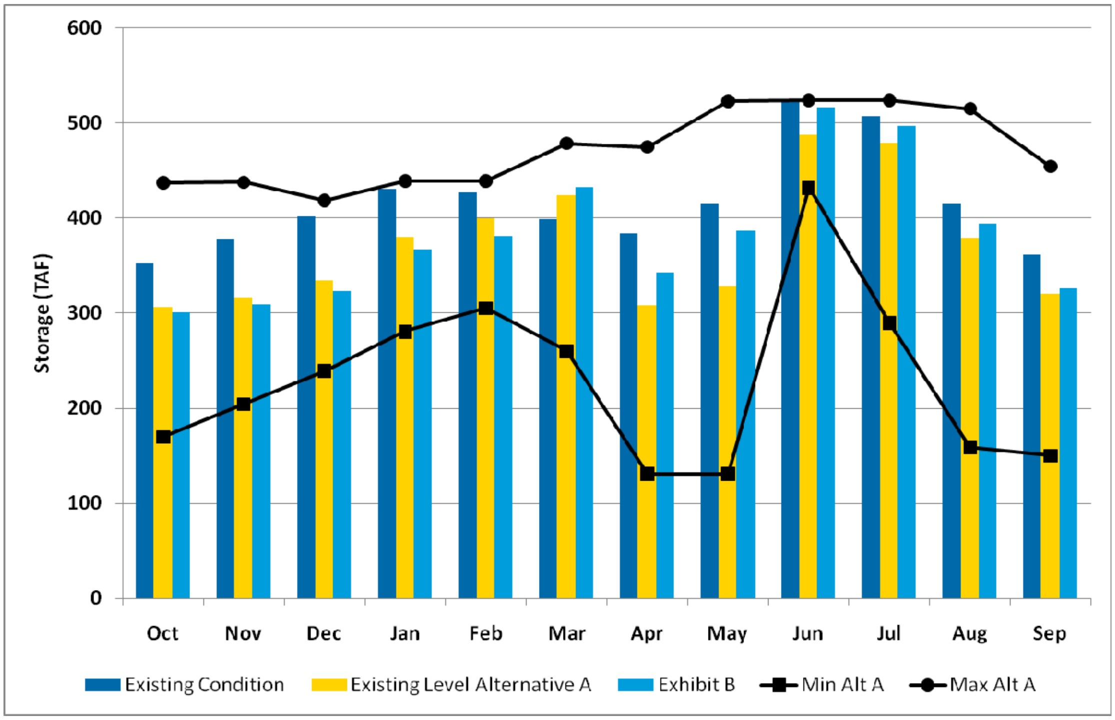
Table 2-2 is an example of a detailed table for a single indicator and Restoration Year Type. The table shows the details of the differences between the Existing Condition, Alternative A, and Action under evaluation. Note that the % Change From Alt A may not match the computed difference between the existing Level Alternative A % Change From Existing Condition and % Change From Existing Condition due to round-off for display purposes.

Table 2-2.
Example Indicator Impact Analysis Table for ______ Year Type

	Existing Condition (TAF)	Existing Level Alternative A (TAF)	Exhibit B (TAF)	Existing Level Alternative A % Change From Existing Condition	Exhibit B	
					% Change From Existing Condition	% Change From Alt A
October	241	217	215	-9.8%	-10.9%	-1.2%
November	280	239	235	-14.9%	-16.0%	-1.4%
December	325	277	274	-14.5%	-15.7%	-1.3%
January	369	323	321	-12.3%	-13.0%	-0.8%
February	387	356	353	-8.1%	-9.0%	-0.9%
March	418	368	367	-12.1%	-12.3%	-0.2%
April	444	333	335	-25.1%	-24.4%	0.8%
May	452	375	385	-17.0%	-14.9%	2.6%
June	446	399	407	-10.5%	-8.8%	1.8%
July	348	317	321	-9.0%	-7.8%	1.3%
August	245	227	229	-7.5%	-6.6%	1.0%
September	230	214	214	-6.9%	-7.0%	-0.1%

Key:
TAF = thousand acre-feet

Figure 2-1 is an example of the plot output for a single indicator and Restoration Year Type. The plot also includes the range of the indicator from Alternative A for comparison purposes.



Key: TAF = thousand acre-feet

Figure 2-1.
Example Indicator Analysis Plot for ______ Year Type

The two lines on the figure represent the minimum and maximum values of the indicator from the Alternative A simulation. These represent the range of values for the specific indicator that were considered in the impact analysis performed on Alternative A. This range was added to the plots to allow evaluation of the potential that the action under investigation would create impacts outside of the range already evaluated under Alternative A.

Table 1 shows a difference of over 10 percent between the Alternative and the action; however, as can easily be seen in Figure 2-1, in April and May the action actually is closer to the baseline condition than the Alternative. This would imply that the expected impacts from the action would be lower than those reported in the PEIS/R for the Alternative and there are already covered.

A full set of tables and plots was prepared for each action and is included as an attachment to this Technical Appendix (TA). Selected tables and plots from this are included in this TA as required for the analysis.

3.0 Analysis

This section presents the results of the analysis and recommendation for further modeling and/or analysis.

3.1 Exhibit B Restoration Flows

The Restoration Flow Schedule from Exhibit B of the Settlement is a stair-step function within each of the Restoration Year Types. This leads to abrupt flow changes from month to month within each year, and small changes in San Joaquin River flow resulting in large changes if the Restoration Flow Schedule for the year. The CalSim Existing LOD Alternative A simulation implements the Restoration Flow Schedule with day-to-day smoothing within each year and between water year types using Method 3.1.

This evaluation replaces the smoothed Restoration Flow Schedule in the Existing LOD simulation of Alternative A with the original, unsmoothed, Exhibit B flow schedules.

All other operations were held constant.

3.1.1 Millerton Storage

Table 3-1 is a summary table of the change in the simulated mean end-of-month Millerton storage between the Alternative A and Exhibit B CalSim simulations.

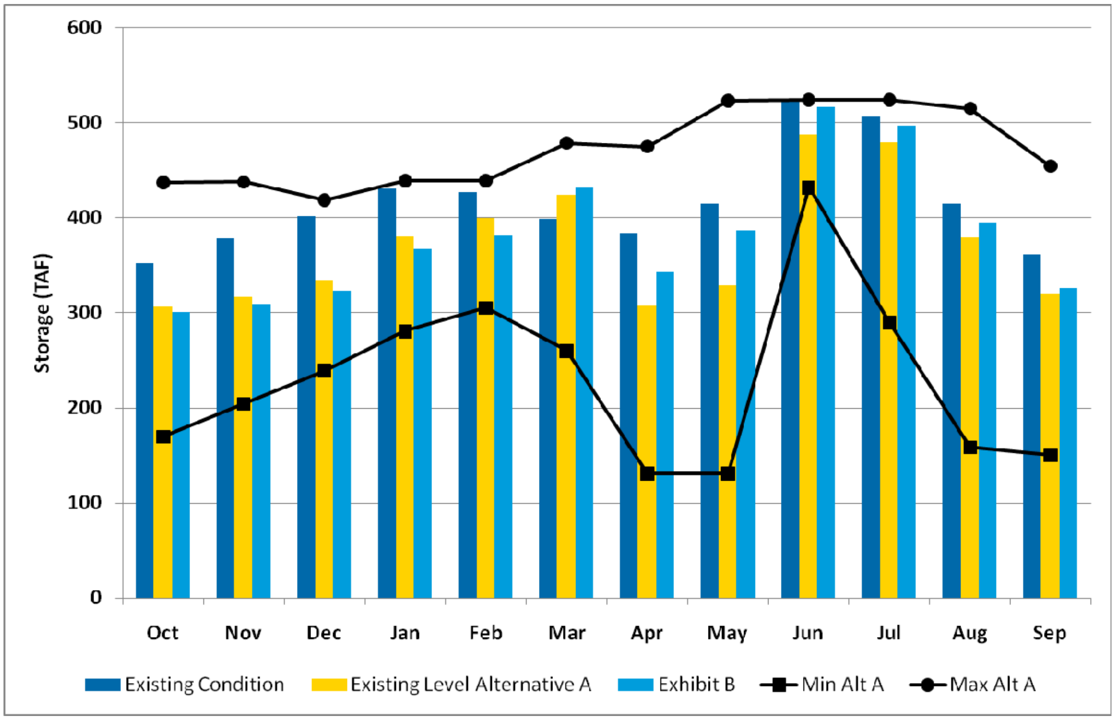
Table 3-1.
Exhibit B – Mean End-of-Month Millerton Storage – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-1.2%	-1.9%	-2.4%	0.0%	1.1%	0.0%	0.0%
November	-1.4%	-2.5%	-2.1%	0.0%	0.2%	0.0%	0.0%
December	-1.3%	-3.4%	-1.5%	0.0%	0.1%	0.0%	0.0%
January	-0.8%	-3.3%	-0.1%	0.0%	0.1%	0.0%	0.0%
February	-0.9%	-4.8%	-0.2%	0.3%	0.4%	0.0%	3.2%
March	-0.2%	2.0%	0.0%	-0.7%	-4.7%	0.3%	0.0%
April	0.8%	**11.1%**	-4.4%	0.3%	1.1%	0.2%	0.0%
May	2.6%	**17.6%**	-1.6%	0.2%	0.8%	0.2%	0.0%
June	1.8%	5.9%	0.9%	0.1%	0.8%	0.2%	0.0%
July	1.3%	3.7%	0.1%	0.1%	1.1%	0.1%	0.0%
August	1.0%	3.9%	-1.4%	0.0%	1.1%	0.1%	0.0%
September	-0.1%	1.6%	-2.4%	0.0%	1.0%	0.0%	0.0%

Note:
[yellow] Increase greater than 10%

Table 3-1 shows changes of over 10 percent in Millerton Storage in April and May of Wet years.

Figure 3-1 shows the simulated mean end-of-month Millerton storage for the Existing Condition, Alternative A, and the Exhibit B CalSim simulations in Wet years.



Key: TAF = thousand acre-feet

Figure 3-1.
Exhibit B – Wet Years – Mean End-of-Month Millerton Storage

The April – May Exhibit B Millerton storages, though higher than the Alternative A storages are closer to the Existing Condition storages, which implies impacts smaller than included in PEIS/R evaluation.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.1.2 Millerton Release

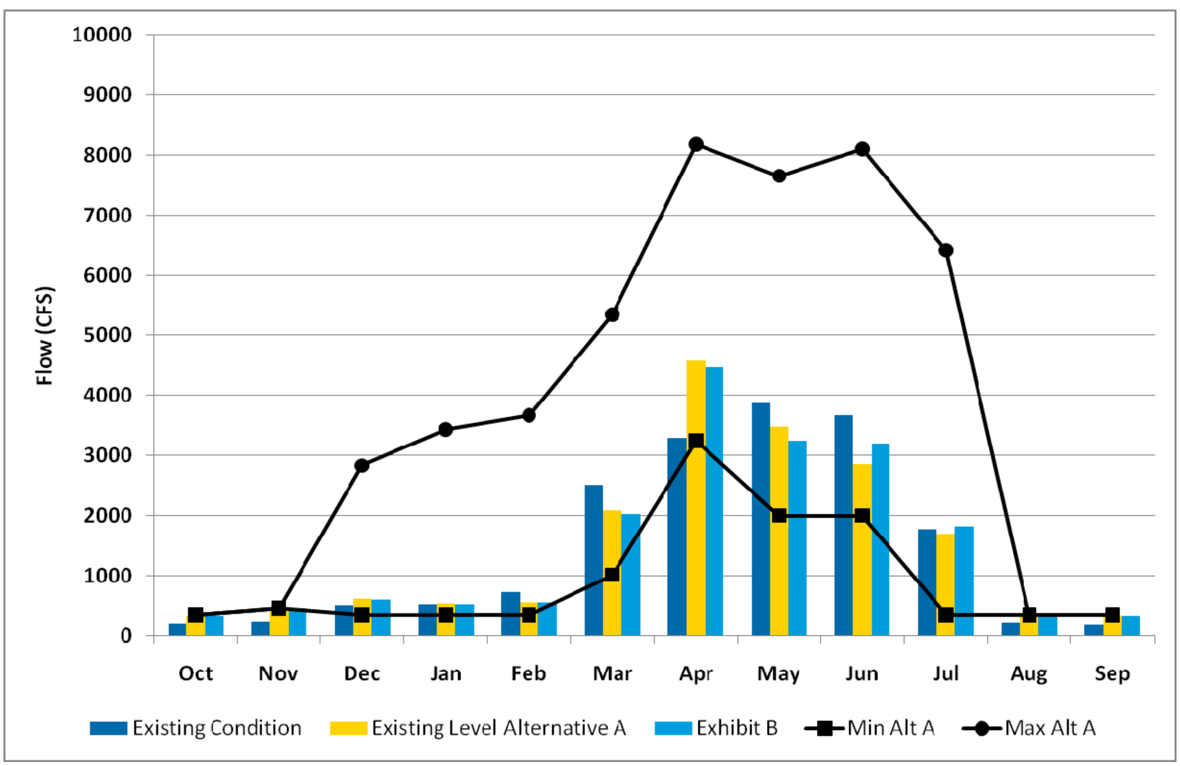
Table 3-2 is a summary table of the change in the simulated mean Millerton release between the Alternative A and Exhibit B CalSim simulations.

Table 3-2.
Exhibit B – Mean Monthly Millerton Release – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
November	0.9%	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%
December	-1.2%	-2.7%	-1.6%	0.0%	0.0%	0.0%	0.0%
January	-1.0%	-1.4%	-1.7%	0.0%	0.0%	0.0%	0.0%
February	-1.3%	-2.1%	1.4%	-2.0%	-2.1%	0.0%	**-14.9%**
March	-1.6%	-2.6%	-2.6%	0.0%	0.0%	0.0%	0.0%
April	1.0%	-2.2%	9.5%	-4.8%	**-33.0%**	0.0%	0.0%
May	-7.6%	-6.9%	**-20.6%**	0.0%	3.2%	0.0%	0.0%
June	5.5%	**12.5%**	**-17.0%**	0.0%	3.2%	0.0%	0.0%
July	4.3%	7.6%	0.0%	0.0%	2.3%	0.0%	0.0%
August	0.3%	0.0%	0.0%	0.0%	2.3%	0.0%	0.0%
September	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

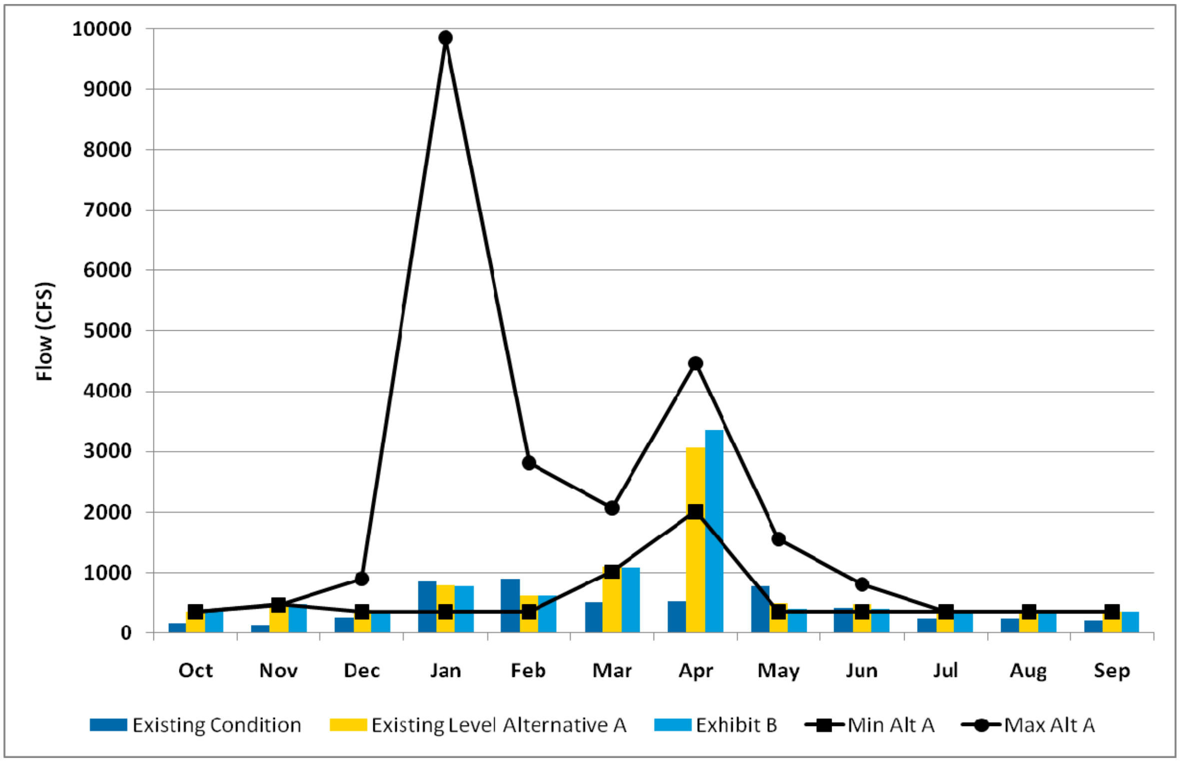
Notes:
Increase greater than 10%
Decrease greater than 10%

Table 3-2 shows changes of over 10 percent in Millerton release for Wet, Normal-Wet and Dry years. Figures 3-2, 3-3, and 3-4 show the simulated mean monthly Millerton release for the Existing Condition, Alternative A, and the Exhibit B CalSim simulations in Wet years, Normal-Wet and Dry years respectively.



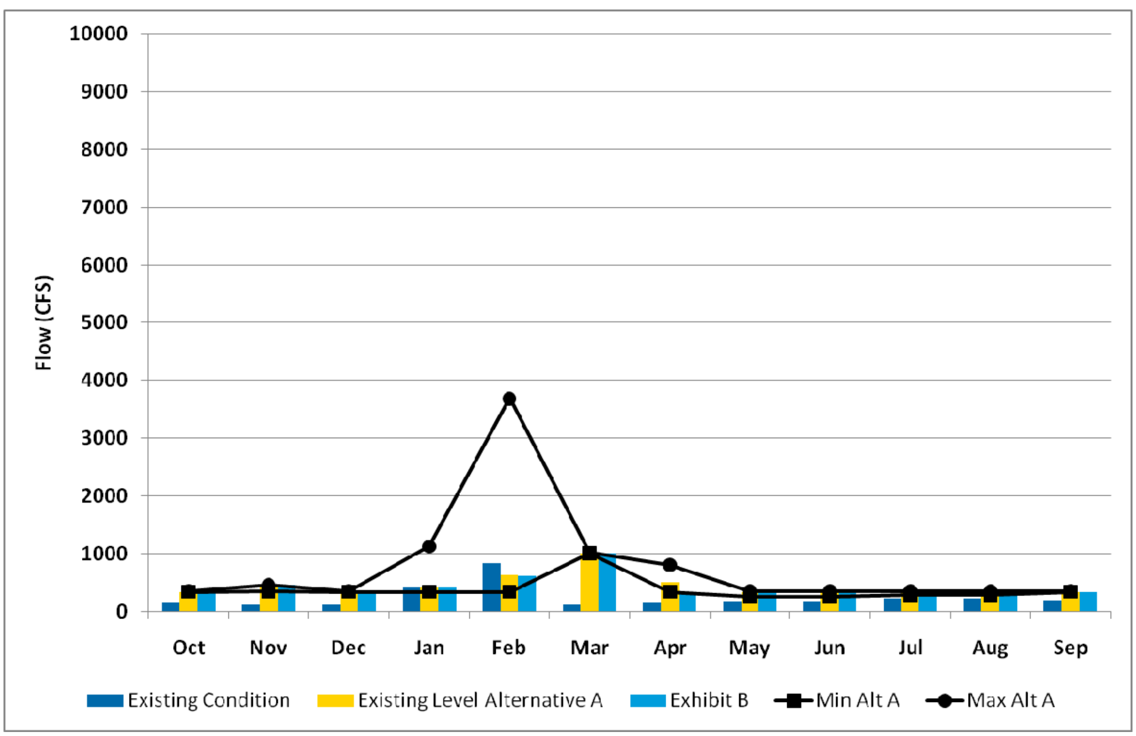
Key: cfs = cubic feet per second

Figure 3-2.
Exhibit B – Wet Years – Mean Monthly Millerton Release



Key: cfs = cubic feet per second

Figure 3-3.
Exhibit B – Normal-Wet Years – Mean Monthly Millerton Release

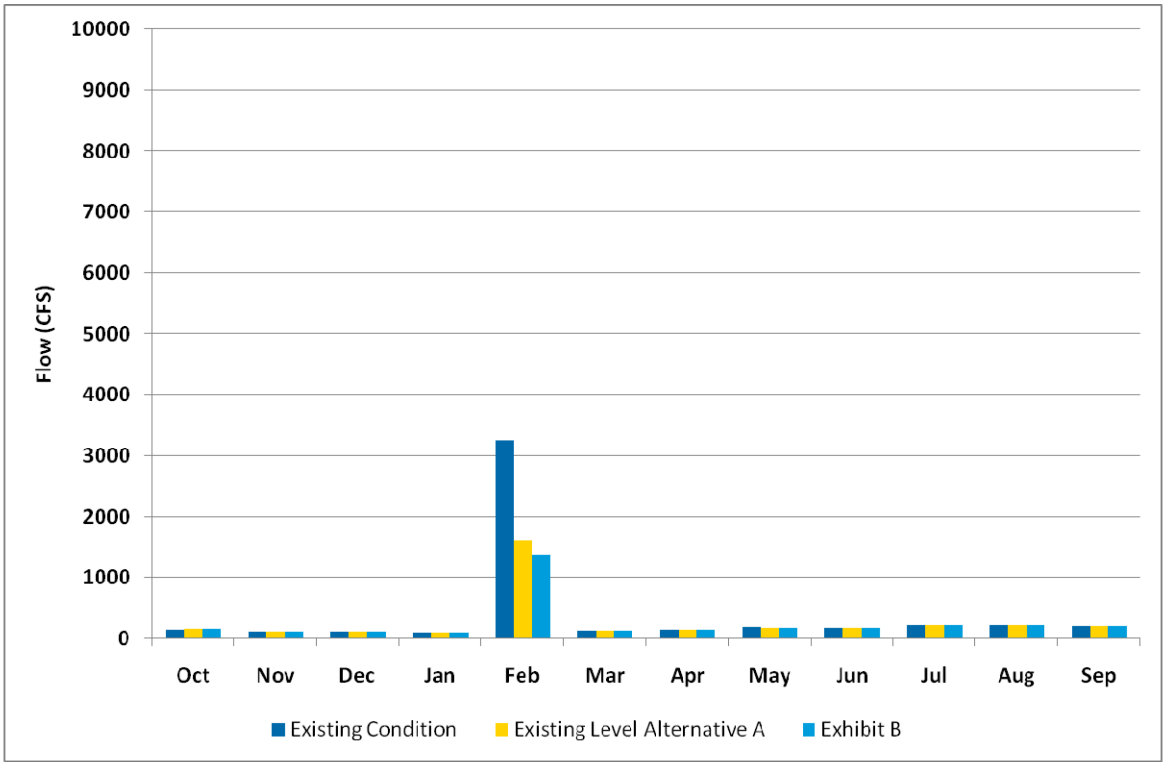


Key: cfs = cubic feet per second

Figure 3-4.
Exhibit B – Dry Years – Mean Monthly Millerton Release

In all three year types, the Exhibit B release is closer to the Existing Condition release than to the Alternative A release, which implies impacts smaller than included in PEIS/R evaluation.

Figure 3-5 shows the simulated mean monthly Millerton release for the Existing Condition, Alternative A, and the Exhibit B CalSim simulations in the Critical-Low year.



Key: cfs = cubic feet per second

Figure 3-5.
Exhibit B – Critical-Low Years – Mean Monthly Millerton Release

There is only one Critical-Low year, 1977, in the 1922 to 2003 time period modeled by CalSim. As can be seen from Figure 3-5, February is the only month with any flood flows at all, the remainder of the year has Millerton releases at a level that will not maintain continuity of flow in the San Joaquin River to the confluence with the Merced. The relatively small change from Alternative A in February will not change this or reduce releases in any other period and is not expected to have a substantial impact.

This year is the driest year of record in the entire 1922 to 2003 time period. If this set of flows did occur in the future it is dry enough where emergency actions would need to be taken to get through the year. The scope and magnitude of this action is unknown and would likely dwarf the extremely low flows that could occur in this year type. Long term planning does not typically try to meet this year type directly as the costs of extreme measures that could be required can easily outweigh the benefits that could occur in all other years.

For this reason, and the fact that the flow requirements are so small that is no continuity of flow in the San Joaquin River to the Merced River and therefore very limited benefit to including this year in the analysis, this year type will be ignored for impact analysis purposes.

There is no substantial potential for impacts outside of PEIS/R evaluation

3.1.3 Friant-Kern Canal Diversion

Table 3-3 is a summary table of the change in the simulated mean Millerton release between the Alternative A and Exhibit B CalSim simulations.

Table 3-3.
Exhibit B – Mean Monthly Millerton Release – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	5.2%	**12.2%**	1.6%	-0.1%	-0.2%	0.2%	0.0%
November	2.9%	5.9%	1.0%	-0.3%	-0.3%	0.1%	0.0%
December	6.5%	**21.1%**	-3.4%	0.2%	0.3%	0.0%	0.0%
January	-5.0%	4.6%	**-16.9%**	-0.7%	0.4%	0.0%	0.0%
February	2.1%	9.0%	-0.8%	-0.8%	-0.6%	0.1%	0.0%
March	-1.7%	-3.7%	0.0%	-0.1%	-4.7%	0.2%	0.0%
April	-5.7%	**-14.5%**	-1.2%	1.1%	**-14.5%**	0.2%	0.0%
May	-2.0%	-5.3%	-1.2%	0.3%	0.0%	0.2%	0.0%
June	-0.2%	3.2%	-2.9%	0.1%	-0.1%	0.2%	0.0%
July	0.8%	1.0%	1.6%	0.0%	-0.2%	0.2%	0.0%
August	0.9%	1.1%	1.6%	0.1%	-0.1%	0.2%	0.0%
September	2.1%	4.9%	1.5%	0.1%	-0.1%	0.2%	0.0%

Notes:
Increase greater than 10%
Decrease greater than 10%

Table 3-3 shows values outside the 10 percent change in Millerton Release in Wet, Normal-Wet, and Dry year types; however it does not show up in the All Years column. Delivery impacts for the SJRRP are typically measured as changes in average annual delivery, which is represented by the All Years column. All of the water management actions and the economic analysis that use delivery values are performed using annual average volumes.

The values in the All Years category show no long-term impact to Friant-Kern diversions, some months are slightly higher and some are slightly lower but overall all are within the limits defined for this analysis. This means that though some individual months in some year types may show changes that there is little or no change in the average annual diversion when comparing Alternative A to Exhibit B. This limited change in average annual volume implies that there would be very limited change in the resulting economic analysis used for impact analysis.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.1.4 San Joaquin River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.1.5 Delta Pumping

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.1.6 Sacramento River Delta Pumping

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.2 Buffer Flows

This was modeled by adding a uniform 10 percent to the Restoration Flows in Alternative A. This is expected to impact operations by increasing Millerton release during non-flood periods resulting in lower storages. The lower storages may impact delivery decisions and flood control operations, resulting in both increases and decreases in Millerton storages releases and diversions. The increased release may also show increases in San Joaquin River Delta inflow.

3.2.1 Millerton End-of-Month Storage

Table 3-4 is a summary table of the change in the simulated mean end-of-month Millerton storage between the Alternative A and Buffer Flow CalSim simulations.

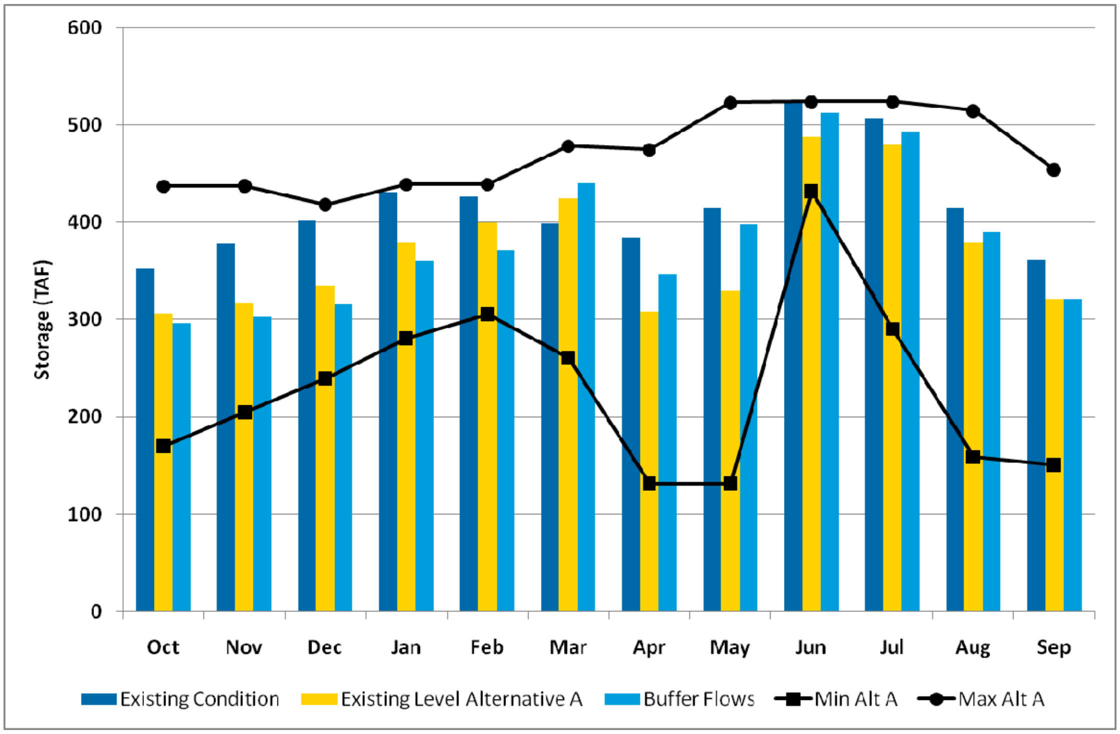
Table 3-4.
Buffer Flows – Mean End-of-Month Millerton Storage – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-2.8%	-3.4%	-4.1%	-1.8%	-0.8%	-0.9%	-0.2%
November	-3.8%	-4.5%	-4.5%	-2.9%	-2.5%	-1.3%	-0.5%
December	-3.9%	-5.7%	-3.9%	-2.9%	-3.1%	-1.4%	-0.7%
January	-3.0%	-5.1%	-2.2%	-3.1%	-2.0%	-1.5%	-0.6%
February	-2.8%	-7.2%	-1.2%	-2.2%	-2.1%	-0.8%	4.7%
March	-2.4%	3.7%	-1.7%	-4.7%	**-10.4%**	-5.1%	-1.9%
April	-2.3%	**12.4%**	-4.7%	-6.2%	-6.5%	-4.3%	-1.8%
May	0.5%	**21.0%**	-2.3%	-4.8%	-5.2%	-4.0%	-2.1%
June	-0.2%	5.2%	0.1%	-3.7%	-4.3%	-3.7%	-1.7%
July	-0.3%	3.0%	-0.5%	-2.8%	-3.5%	-2.5%	-0.8%
August	-0.2%	2.8%	-2.0%	-1.6%	-0.6%	-1.2%	0.0%
September	-1.2%	0.2%	-3.5%	-1.2%	0.3%	-1.0%	0.1%

Notes:
(yellow) Increase greater than 10%
(blue) Decrease greater than 10%

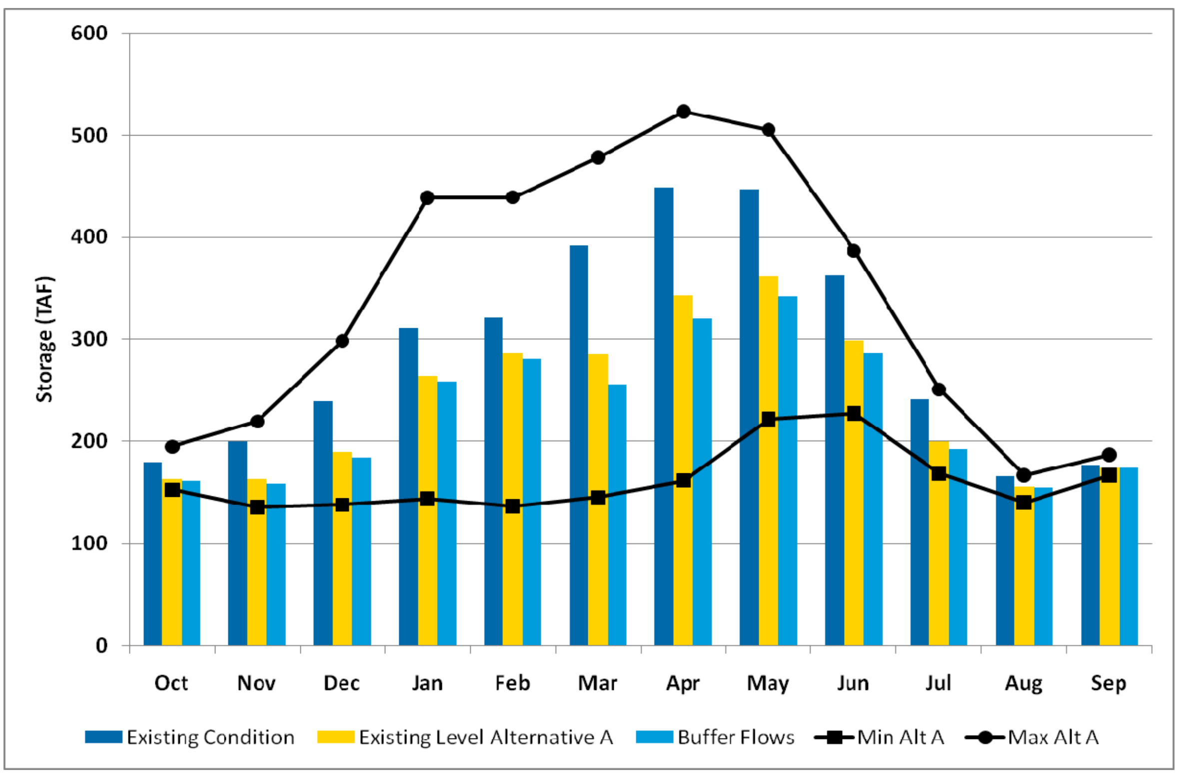
Table 3-4 shows changes of over 10 percent in Millerton storage in April and May of Wet years and March of Dry years.

Figures 3-6 and 3-7 show the simulated end-of-month Millerton storage for the Existing Condition, Alternative A, and the Buffer Flow CalSim simulations in Wet and Dry years.



Key: TAF = thousand acre-feet

Figure 3-6.
Buffer Flows – Wet Years – Mean End-of-Month Millerton Storage



Key: TAF = thousand acre-feet

Figure 3-7.
Buffer Flows – Dry Years – Mean End-of-Month Millerton Storage

Figure 3-8 shows the April and May Millerton storage is closer to the Existing Condition storage than the Alternative A storage, implying less impact to Millerton storage from the Buffer Flows than was evaluated for Alternative A in the PEIS/R.

Figure 3-9 shows the simulated end-of-month Millerton storage for the Existing Condition, Alternative A, and the Buffer Flow CalSim simulations in Dry years. The March Exhibit B Millerton storage is just over the evaluation limit of 10 percent (10.4 percent) lower than the Alternative A values. The value is near the center of the range of storages included in the Alternative A simulation would be unlikely to cause impacts outside the range covered in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.2.2 Millerton Release

Table 3-5 is a summary table of the change in the simulated mean Millerton release between the Alternative A and Buffer Flow CalSim simulations.

Table 3-5.
Buffer Flows – Mean Monthly Millerton Release – Percent Change From Alternative A

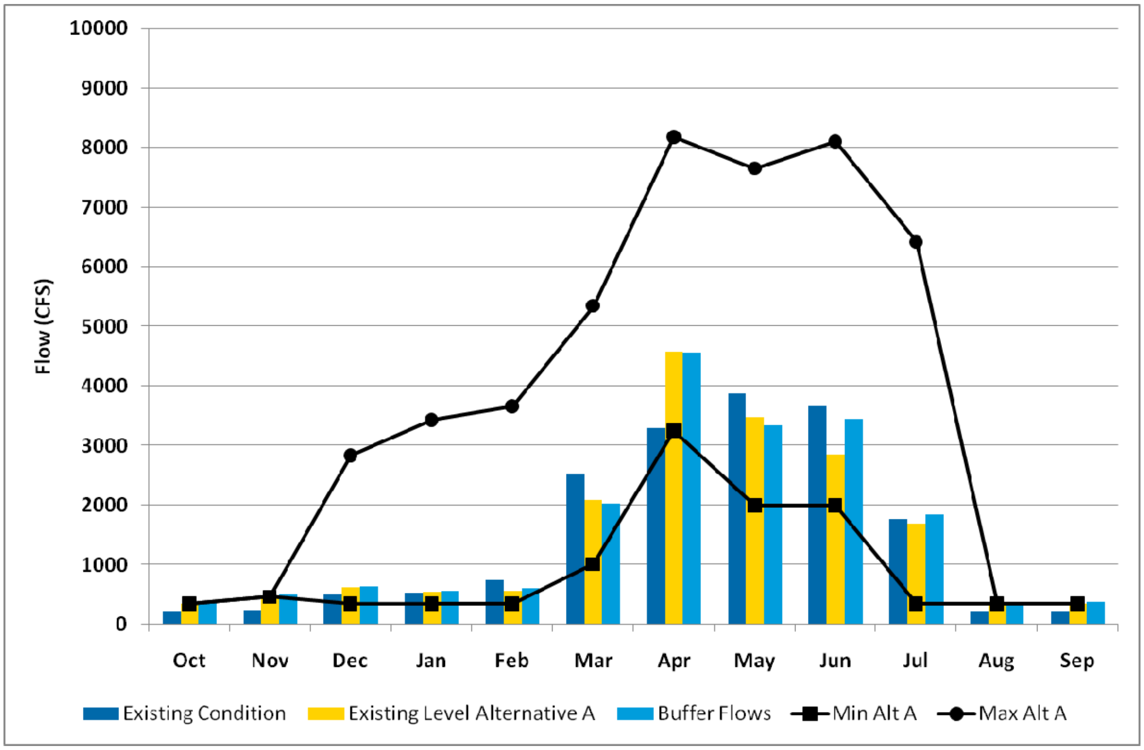
	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
November	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
December	5.8%	2.3%	5.6%	7.7%	10.0%	10.0%	10.0%
January	4.1%	4.7%	1.7%	6.8%	5.3%	10.0%	10.0%
February	3.8%	8.2%	5.1%	1.1%	6.7%	10.0%	**-28.6%**
March	4.5%	-2.8%	5.7%	10.0%	10.0%	7.9%	10.0%
April	5.4%	-0.2%	8.2%	10.0%	10.0%	10.0%	10.0%
May	0.8%	-4.1%	**13.1%**	10.0%	10.0%	10.0%	10.0%
June	**16.8%**	**21.2%**	7.3%	10.0%	10.0%	10.0%	10.0%
July	9.4%	8.9%	10.0%	10.0%	10.0%	10.0%	10.0%
August	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
September	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%

Notes:
(yellow) Increase greater than 10%
(blue) Decrease greater than 10%

Table 3-5 shows a large number of periods with a 10 percent change in Millerton release from Alternative A. These periods represent periods where the Restoration Flows controlled the Millerton release in Alternative A and therefore the 10 percent Buffer Flows show a 10 percent change. These are in low flow periods with Restoration Flows of 350 cfs or lower and Buffer Flows of 385 cfs or lower. These small changes would be unlikely to cause impacts outside those evaluated in the PEIS/R.

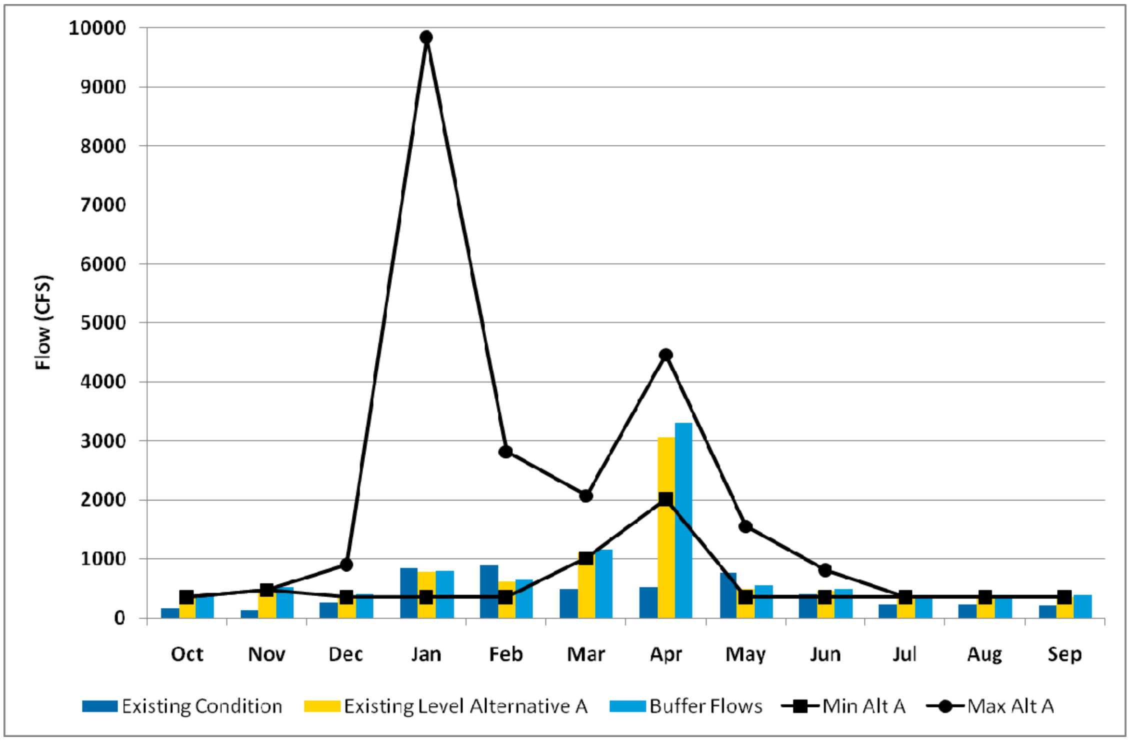
The table does show increases in Millerton releases in June of Wet years and May of Normal-Wet years. Figures 3-8 and 3-9 show the simulated Millerton release for the

Existing Condition, Alternative A, and the Buffer Flow CalSim simulations in Wet and Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-8.
Buffer Flows – Wet Years – Mean Monthly Millerton Release



Key: cfs = cubic feet per second

Figure 3-9.
Buffer Flows – Normal-Wet Years – Mean Monthly Millerton Release

Figures 3-8 and 3-9 both show that the Millerton release in June is in Wet years and in May in Normal-Wet years. This is closer to the Existing Condition release than the Alternative A release implying less impact to Millerton release from the Buffer Flows than was evaluated for Alternative A in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.2.3 Friant-Kern Canal Diversion

Table 3-6 is a summary table of the change in the simulated mean Friant-Kern Canal diversion between the Alternative A and Buffer Flows CalSim simulations.

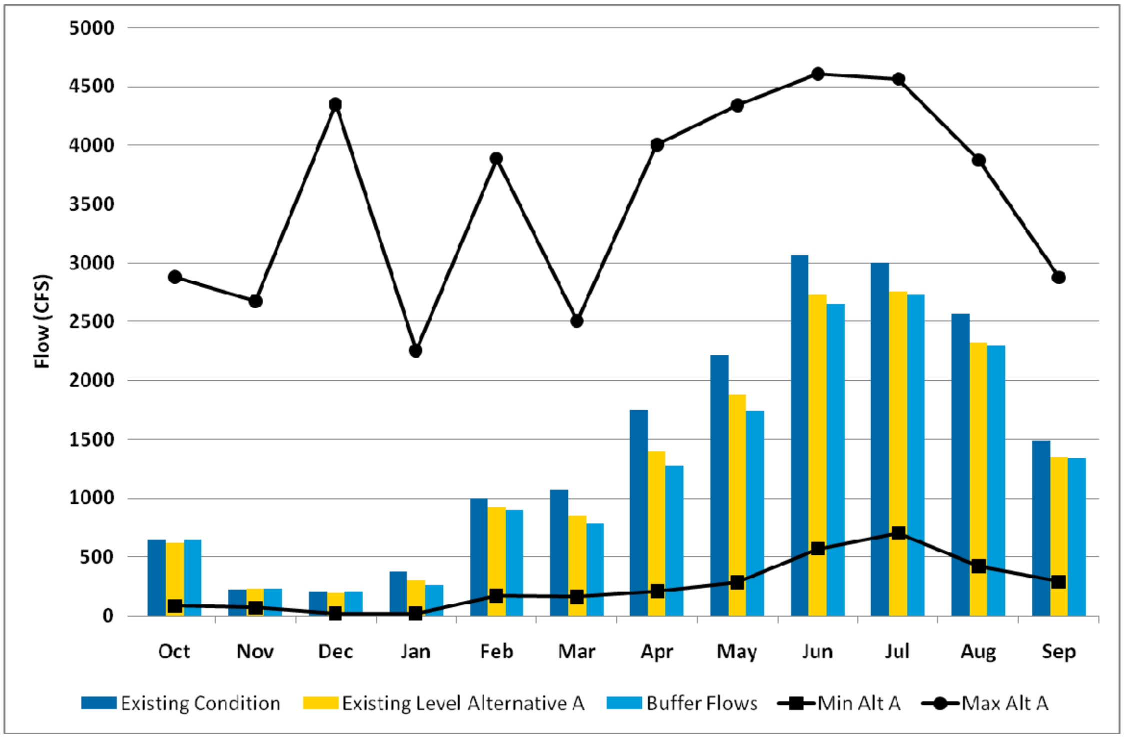
Table 3-6.
Buffer Flows – Mean Monthly Friant-Kern Canal Diversion – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
Oct	3.2%	**10.4%**	0.3%	-3.5%	-1.3%	-5.1%	-4.2%
Nov	0.7%	2.4%	0.2%	-2.1%	0.4%	-3.8%	-2.8%
Dec	3.2%	**19.2%**	-8.3%	-2.8%	**-15.5%**	0.0%	0.0%
Jan	**-12.6%**	-3.9%	**-23.7%**	-3.3%	**-15.8%**	0.0%	0.0%
Feb	-2.1%	8.5%	-7.8%	-5.4%	-4.6%	**-11.7%**	-0.5%
Mar	-7.3%	**-10.4%**	-3.6%	-6.3%	**-11.4%**	**-20.3%**	-4.7%
Apr	-8.8%	**-14.1%**	-4.3%	-4.7%	**-23.3%**	-5.4%	-4.5%
May	-7.5%	**-11.5%**	-5.9%	-4.4%	**-10.0%**	-5.6%	-4.8%
Jun	-2.6%	3.2%	-5.3%	-3.9%	-6.2%	-6.0%	-5.4%
Jul	-1.2%	0.7%	0.3%	-3.9%	-4.6%	-6.1%	-5.5%
Aug	-1.4%	0.8%	0.3%	-3.7%	-8.3%	-5.9%	-9.4%
Sep	-0.2%	4.0%	0.3%	-3.8%	-7.3%	-5.2%	-4.3%

Notes:
- (yellow) Increase greater than 10%
- (blue) Decrease greater than 10%

Table 3-6 shows that while there are changes up and down in different year types, that when summarized for all year types only January has a change in Friant-Kern Canal diversion greater than 10 percent.

Figure 3-11 shows the simulated mean Friant-Kern Canal diversion for the Existing Condition, Alternative A, and the Buffer Flows CalSim simulations in all year types.



Key: cfs = cubic feet per second

Figure 3-10.
Buffer Flows – All Years – Mean Monthly Friant-Kern Canal Diversion

The Friant-Kern diversion is lower in most months in the Buffer Flows simulation. This implies that the average annual Friant delivery may be reduced. The Friant-Kern diversion change only exceeds the 10 percent criteria in January and then only by a small amount. This is also a low delivery month so the actual magnitude of the reduction is very small compared to the annual average diversion. The change in annual average diversion change would be less than the 10 percent criteria.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.2.4 San Joaquin River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.2.5 Delta Pumping

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.2.6 Sacramento River Delta Pumping

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.3 Flexible Flows, Moved Earlier

This was modeled by assuming that the pulse flows during the flexible flow periods in both the spring and fall were moved the maximum allowable of one month earlier in the year, in every year. This is expected to impact operations by changing Millerton storage during the spring flood control operation time period which may impact both flood control and water supply operations. Effects may be quite large as the pulse flows may be five times as large as the Restoration Flows in the previous month. The impact is expected to be somewhat offset by the fact that the pulse flow releases may be masked by additional flood control releases during the spring pulse period.

3.3.1 Millerton End-of-Month Storage

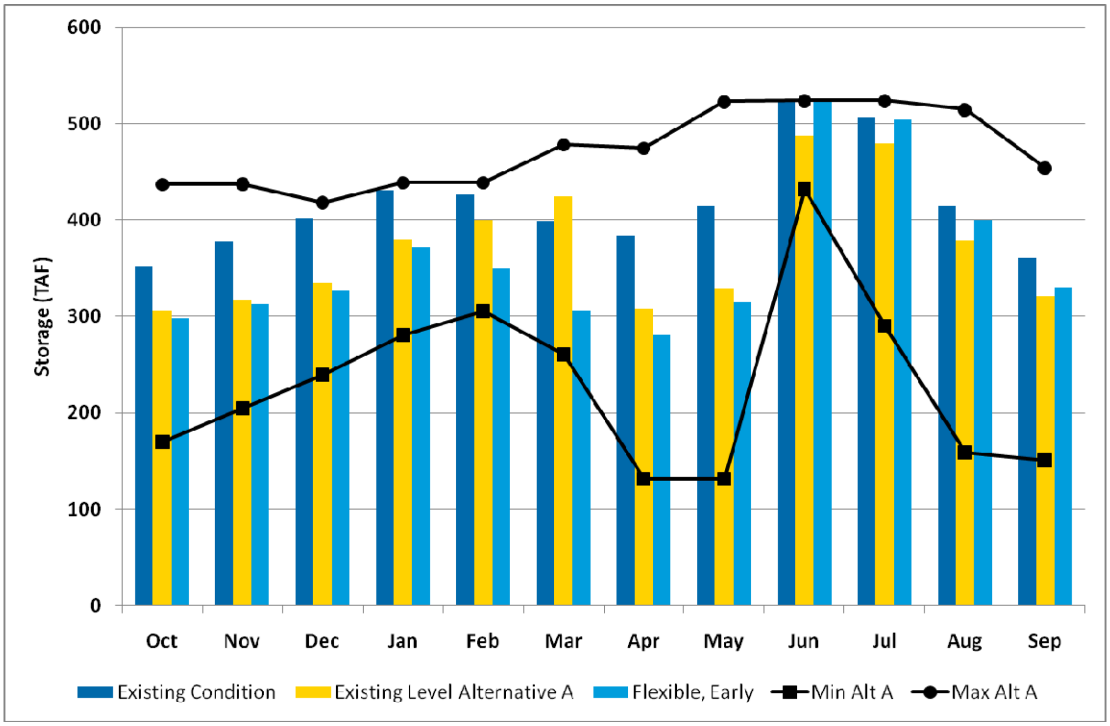
Table 3-7 is a summary table of the change in the simulated mean end-of-month Millerton storage between the Alternative A and Flexible Flow (Early) CalSim simulations.

Table 3-7.
Flexible Flow (Early) – Mean End-of-Month Millerton Storage – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
Oct	-3.8%	-2.7%	-5.8%	-3.8%	-2.3%	-0.7%	2.2%
Nov	-1.0%	-1.3%	-2.4%	0.1%	1.0%	0.8%	1.5%
Dec	-1.0%	-2.2%	-1.8%	0.0%	0.9%	1.0%	1.5%
Jan	-0.5%	-2.3%	-0.4%	0.0%	0.6%	0.8%	0.9%
Feb	-9.0%	**-12.4%**	-6.4%	-8.7%	-9.9%	**-10.3%**	-8.4%
Mar	**-22.1%**	**-27.8%**	**-29.4%**	**-17.4%**	-7.0%	2.9%	-0.5%
Apr	0.3%	-8.8%	4.8%	1.3%	-0.6%	2.0%	-0.9%
May	-0.2%	-4.5%	1.0%	0.7%	-0.4%	2.1%	0.2%
Jun	2.9%	7.4%	2.8%	0.5%	-0.3%	0.9%	-0.8%
Jul	2.3%	5.1%	1.6%	0.8%	0.2%	0.8%	0.3%
Aug	1.6%	5.4%	-0.5%	0.2%	0.5%	-1.7%	0.0%
Sep	0.3%	3.0%	-2.4%	-0.2%	0.9%	1.6%	0.6%

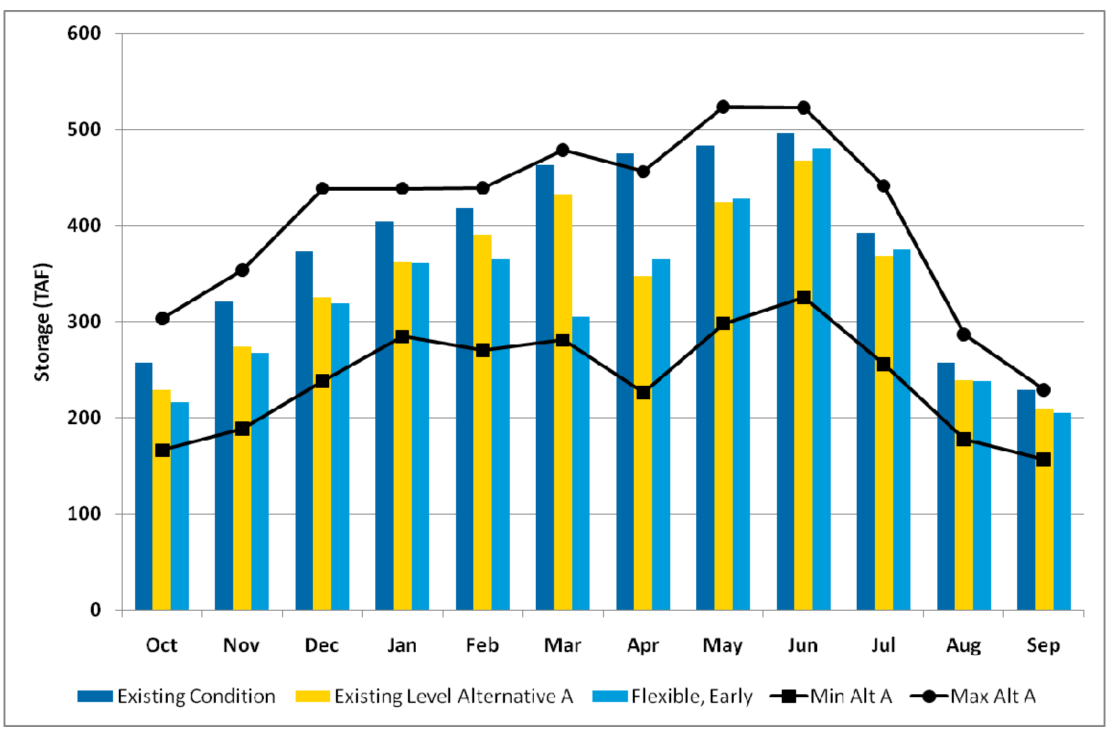
Note:
Decrease greater than 10% (shaded cells)

Table 3-7 shows changes in the Millerton storage of greater than 10 percent in Wet, Normal-Wet, Normal-Dry, and Critical-High years. Figures 3-12, 3-13, and 3-14 show the simulated mean Millerton storage for the Existing Condition, Alternative A, and the Flexible Flow (Early) CalSim simulations in Wet, Normal-Wet, and Normal-Dry years.



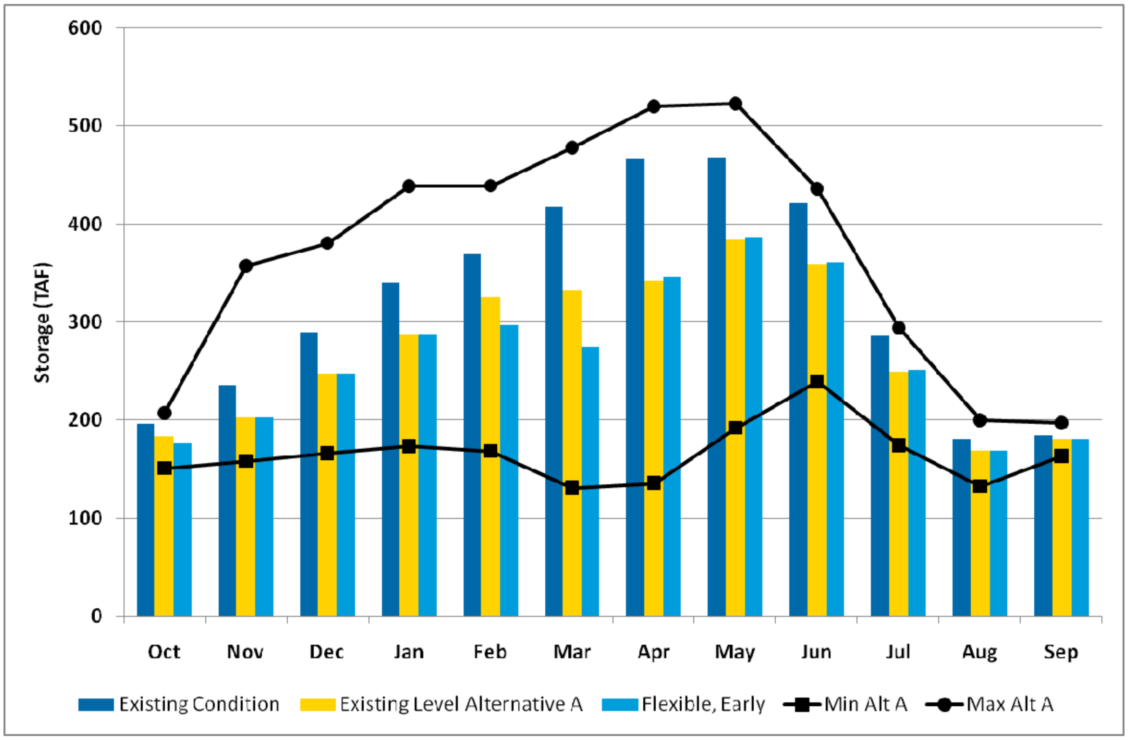
Key: TAF = thousand acre-feet

Figure 3-11.
Flexible Flow (Early) – Wet Years – Mean End-of-Month Millerton Storage



Key: TAF = thousand acre-feet

Figure 3-12.
Flexible Flow (Early) – Normal-Wet Years – Mean End-of-Month Millerton Storage



Key: TAF = thousand acre-feet

Figure 3-13.
Flexible Flow (Early) – Normal-Dry Years – Mean End-of-Month Millerton Storage

The change in storage is caused in these wetter years by the movement of the spring pulse flow release from April to March. The reduced storage at the end of March is refilled to Alternative A levels in April by additional capture of flood flows. This is a short-term, month-to-month variation in caused by flood control operations.

None of the changes are large enough to produce results outside the range evaluated for Alternative A in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.3.2 Millerton Release

Table 3-8 is a summary table of the change in the simulated mean Millerton release between the Alternative A and Flexible Flow Early CalSim simulations.

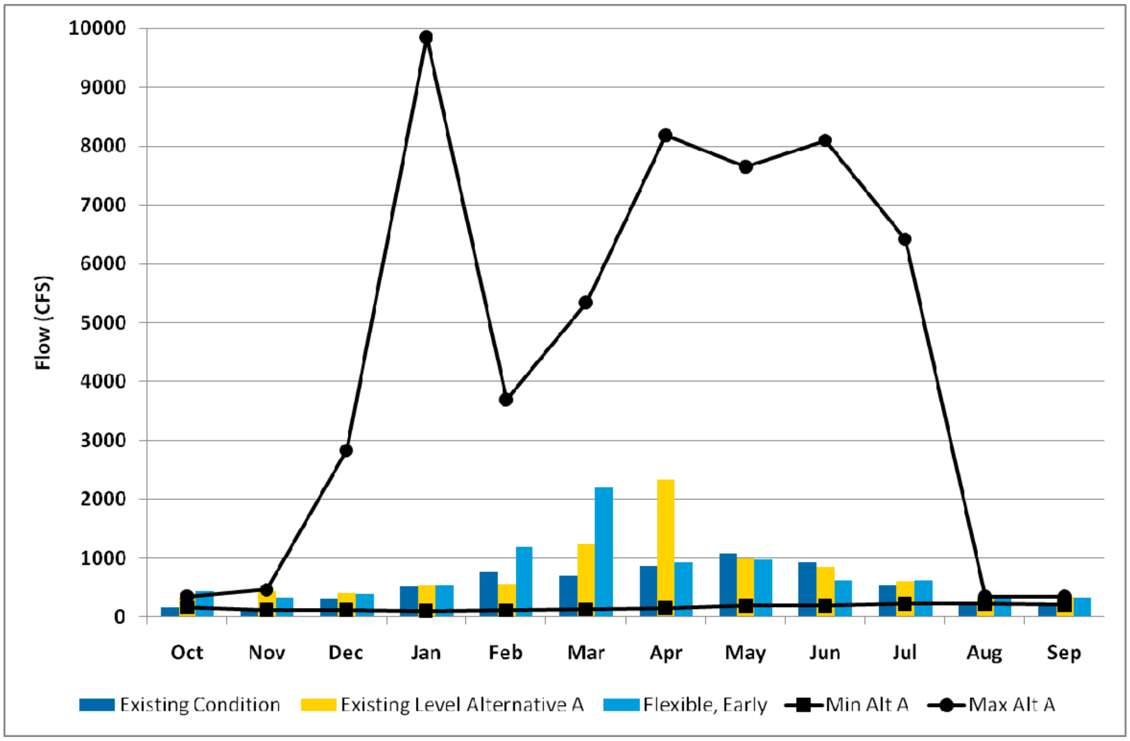
Table 3-8.
Flexible Flow (Early) – Mean Monthly Millerton Release – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	32.0%	33.4%	33.4%	33.4%	25.8%	35.0%	-22.5%
November	-24.3%	-25.1%	-25.1%	-25.1%	-20.5%	-26.1%	14.8%
December	-1.4%	-2.7%	-1.6%	0.0%	0.0%	-8.3%	-16.7%
January	-1.0%	-1.4%	-1.7%	0.0%	-0.2%	0.0%	0.0%
February	112.5%	115.8%	101.7%	121.7%	100.9%	622.3%	43.3%
March	77.4%	94.9%	172.1%	36.0%	-47.5%	-80.3%	0.0%
April	-59.7%	-30.7%	-83.5%	-75.4%	-35.1%	7.5%	13.3%
May	-1.6%	-3.0%	4.2%	0.0%	0.0%	-7.0%	-21.1%
June	-26.9%	-36.4%	-22.9%	0.0%	0.9%	18.6%	21.1%
July	3.9%	7.9%	0.0%	0.0%	-0.9%	-15.7%	-8.7%
August	1.9%	0.0%	0.0%	0.0%	2.3%	39.2%	13.0%
September	-1.8%	0.0%	0.0%	0.0%	-2.2%	-38.5%	-5.7%

Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-7 shows changes in the indicator of greater than 10 percent in every year type. The changes follow a common pattern of higher in October and lower in November, from moving the fall pulse flow, and higher in early spring (February to March) and lower in later spring (April to June) from moving the spring pulse flow.

Figure 3-15 shows the simulated mean Millerton release for the Existing Condition, Alternative A, and the Flexible Flow (Early) CalSim simulations in all years.



Key: cfs = cubic feet per second

Figure 3-14.
Flexible Flow (Early) – All Years – Mean Monthly Millerton Release

The major change due to this action is the increase in Millerton release in February and March and the decrease in April caused by moving the pulse flow release from April to March. The flows in February and March are included in the range of flows evaluated in the PEIS/R and are still in the same portion of the range. The flows in April are closer to the Existing Conditions and therefore have fewer impacts than included in the PEIS/R evaluation.

The increase in flows in October and decrease in November are due to the fall pulse period being moved from November to October. While these represent a relatively high percentage change, the actual magnitude of the release is very small as shown in Figure 3-15 and not likely to cause any impacts outside those covered in the PEIS/R.

The spring and fall pulse flow flexibility was included in the Settlement to allow a level of real time response to real time conditions. In the modeling, these were imposed in all years and all year types. In reality these would only be invoked when there would be beneficial fishery impacts to the change in Millerton releases and the resulting San Joaquin River flows. The potential range of these beneficial impacts was evaluated in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.3.3 Friant-Kern Canal Diversion

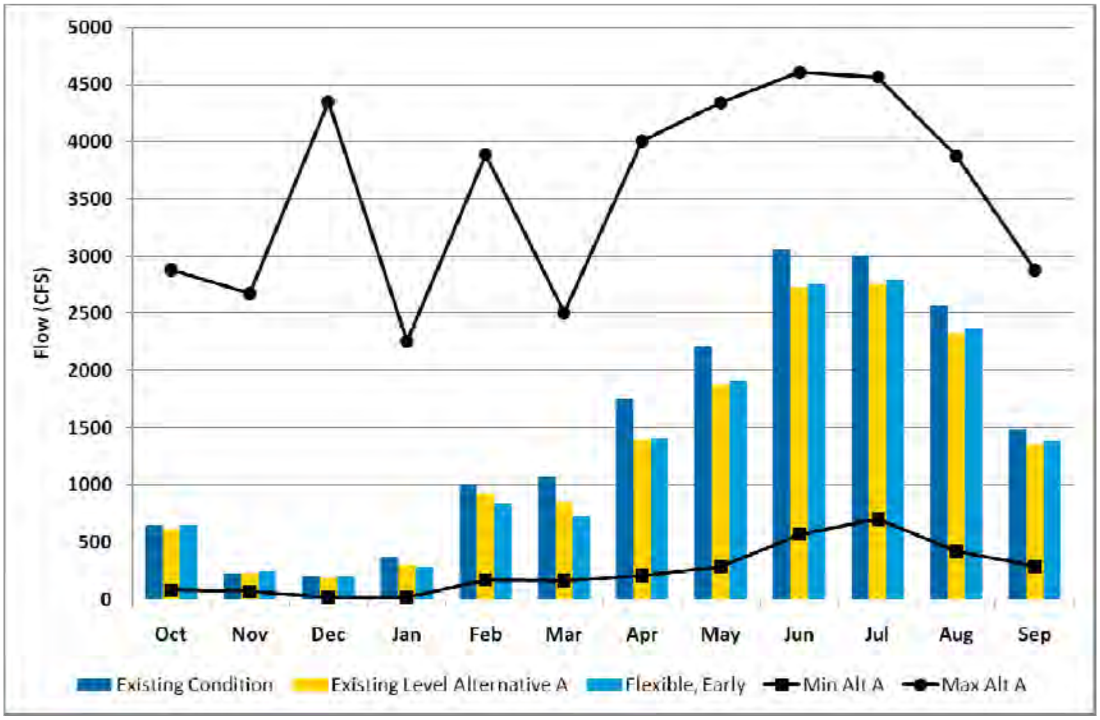
Table 3-9 is a summary table of the change in the simulated mean Friant-Kern Canal diversion between the Alternative A and Flexible Flow (Early) CalSim simulations.

Table 3-9.
Flexible Flow (Early) – Mean Monthly Friant-Kern Canal Diversion – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	5.0%	**11.9%**	2.7%	-1.8%	-0.6%	1.7%	-0.8%
November	3.2%	7.2%	1.7%	-3.5%	-0.4%	1.2%	-0.5%
December	6.9%	**21.3%**	-2.6%	0.7%	-0.6%	0.0%	0.0%
January	-4.8%	4.6%	**-16.8%**	0.5%	-0.2%	0.0%	0.0%
February	-8.9%	5.4%	**-16.3%**	**-12.4%**	**-17.8%**	**-10.6%**	-0.1%
March	**-14.3%**	**-18.5%**	**-18.1%**	-5.5%	-5.3%	1.8%	-0.9%
April	0.3%	-4.8%	6.1%	2.3%	**-15.2%**	1.8%	-0.9%
May	1.4%	-4.3%	5.8%	1.9%	-0.8%	1.8%	-0.9%
June	0.9%	4.7%	-1.5%	0.4%	-0.8%	2.0%	-1.0%
July	1.4%	1.4%	3.1%	-0.2%	-0.7%	2.0%	-1.0%
August	1.7%	1.6%	3.0%	1.1%	-0.8%	-2.5%	-5.2%
September	2.9%	5.3%	2.9%	0.9%	-0.7%	1.7%	-0.8%

Notes:
(yellow) Increase greater than 10%
(blue) Decrease greater than 10%

Table 3-9 shows changes in the Friant-Kern Canal diversion of greater than 10 percent in all year types. In the Wet years there is an increase in Friant Kern diversion due to the increased capture of flood flows made possible by moving the spring pulse flow. In dryer years there is a net reduction in Friant-Kern Canal diversion because of the smaller flood flows available for capture. Also since the magnitude of the flows is lower in dryer years the magnitude of the change is also getting smaller, even at similar percentage change. Figure 3-16 shows the simulated mean Friant-Kern Canal diversion for the Existing Condition, Alternative A, and the Flexible Flows, Early CalSim simulations in all years.



Key: cfs = cubic feet per second

Figure 3-15.
Flexible Flow (Early) – All Years – Mean Monthly Friant-Kern Canal Diversion

The Friant-Kern diversion change only exceeds the 10 percent criterion in March and then only by a small amount. This is also a low delivery month so the actual magnitude of the reduction is very small compared to the annual average diversion. Many of the high delivery months actually increase because of the increased capture of flood flows earlier in the year impacting the delivery decision at Friant. The change in annual average diversion change would be much less than the 10 percent criterion.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.3.4 San Joaquin River Delta Inflow

Table 3-10 is a summary table of the change in the simulated mean San Joaquin River Delta inflow between the Alternative A and Flexible Flow Early CalSim simulations.

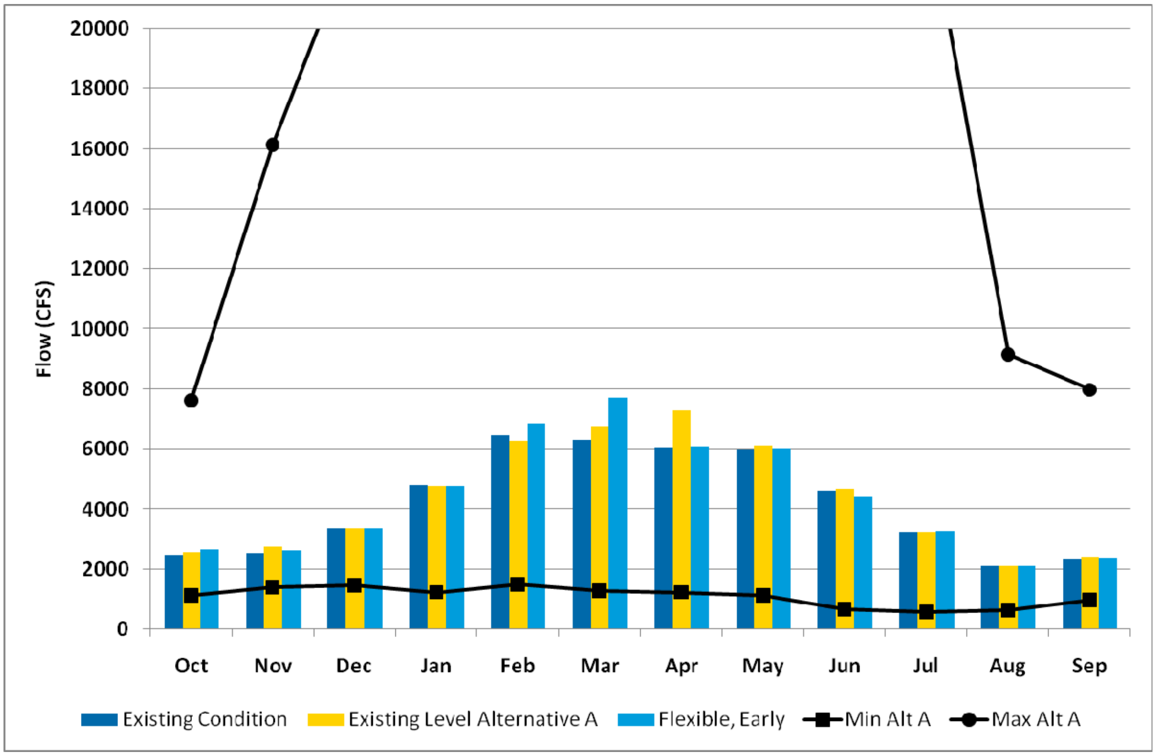
**Table 3-10.
Flexible Flow (Early) – Mean Monthly San Joaquin River Delta Inflow – Percent Change From Alternative A**

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
Oct	3.8%	3.0%	3.6%	5.2%	4.8%	0.0%	0.0%
Nov	-3.9%	-2.7%	-4.5%	-5.0%	-4.4%	0.0%	-0.1%
Dec	-0.6%	0.0%	-0.9%	-1.0%	-0.1%	0.0%	-0.1%
Jan	0.0%	-0.2%	-0.2%	0.7%	-0.1%	0.0%	0.0%
Feb	8.9%	6.6%	7.2%	**12.3%**	**11.2%**	**16.1%**	**10.5%**
Mar	**14.1%**	**11.5%**	**25.8%**	**10.3%**	**-11.8%**	**-18.5%**	0.0%
Apr	**-16.2%**	-9.0%	**-25.0%**	**-19.1%**	-6.0%	0.0%	0.0%
May	-1.4%	-0.8%	-2.4%	-1.8%	-0.5%	0.0%	0.0%
Jun	-6.1%	-9.3%	-2.9%	0.0%	-0.6%	0.0%	0.0%
Jul	0.3%	0.7%	-0.4%	0.0%	0.3%	0.0%	0.0%
Aug	-0.1%	-0.3%	-0.1%	0.0%	0.1%	0.7%	0.0%
Sep	-0.3%	-0.1%	-0.7%	0.0%	-0.2%	0.0%	0.0%

Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-10 shows that the major impact of this action is to increase the Delta inflow in Febraury through March with a decrease in the following month in all year types.

Figure 3-17 shows the simulated mean San Joaquin River Delta Inflow for the Existing Condition, Alternative A, and the Flexible Flows, Early CalSim simulations in all years.



Key: cfs = cubic feet per second

Figure 3-16.
Flexible Flow (Early) – All Years – Mean Monthly Delta Pumping

Figure 3-16 shows that in March there is a larger increase in San Joaquin River Delta inflow for the Flexible Flow (Early) than in Alternative A. Increases in Delta inflow tend to have beneficial impacts, implying that moving the pulse flow earlier may increase benefits to the Delta over the Alternative A during the new pulse period.

In April the Flexible Flow Early is closer to the existing condition which implies a smaller impact than covered in the PEIS/R evaluation.

The impacts in the individual year types follow this same pattern and lead to the same conclusion.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.3.5 Delta Pumping

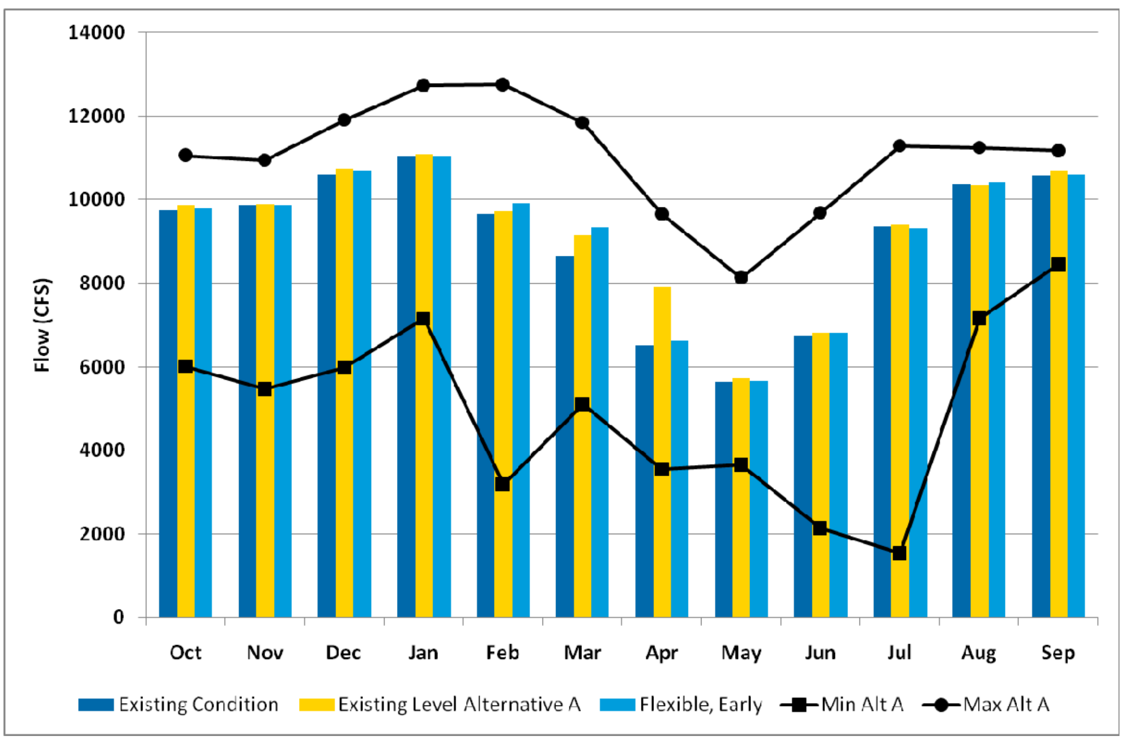
Table 3-11 is a summary table of the change in the simulated mean San Joaquin River Delta inflow between the Alternative A and Flexible Flow Early CalSim simulations.

Table 3-11.
Flexible Flow (Early) – Mean Monthly Delta Pumping – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.4%	0.2%	-0.8%	2.0%	0.5%	0.0%	-0.1%
November	-0.3%	-0.6%	-0.1%	-0.2%	-0.5%	-0.1%	0.1%
December	-0.5%	-1.3%	-0.6%	-0.1%	0.2%	-0.1%	-0.1%
January	0.2%	0.0%	-0.5%	1.1%	0.7%	0.0%	0.0%
February	1.7%	0.9%	2.0%	1.6%	2.9%	1.5%	0.0%
March	0.4%	0.2%	2.1%	-0.8%	-0.8%	-3.4%	-0.7%
April	-8.7%	-2.9%	**-16.2%**	-4.5%	-3.9%	-0.1%	0.0%
May	-0.8%	-0.8%	-1.2%	-0.3%	-0.2%	0.2%	0.0%
June	0.1%	-0.4%	0.0%	0.5%	1.2%	-0.2%	-1.7%
July	-0.3%	-0.7%	-0.7%	0.2%	0.4%	-0.8%	0.0%
August	0.4%	0.3%	0.5%	0.6%	-0.8%	0.0%	1.0%
September	-0.3%	0.8%	-0.8%	-0.9%	0.6%	-0.7%	0.0%

Note:
Decrease greater than 10%

Table 3-11 shows a change in Delta pumping of over 10 percent in April of Normal-Wet years. Figure 3-17 shows the simulated mean monthly Delta Pumping for the Existing Condition, Alternative A, and the Flexible Flows, Early CalSim simulations in Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-17.
Flexible Flow (Early) – Normal-Wet Years – Mean Monthly Delta Pumping

Figure 3-17 shows that the Delta pumping in April in Normal-Wet years is closer to the Existing Condition values than the Alternative A values, implying less impact to Millerton release from the Flexible Flow (Early) Flows than was evaluated for Alternative A in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.3.6 Sacramento River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.4 Flexible Flows, Moved Later

For this evaluation, the assumption was made that the pulse flows would be moved one month later in all years and re-running the CalSim model with the new Restoration Flows. This is expected to impact operations by increasing Millerton release during non-flood periods resulting in lower storages similar to the Flexible Flows, Moved Earlier. The impact may be higher than moving the pulse earlier since moving it later in the year may reduce the periods where flood releases are simultaneous with Restoration Flow releases. This may result in greater total releases which could impact delivery decisions and flood control operations resulting in both increases and decreases in the indicator variables.

3.4.1 Millerton End-of-Month Storage

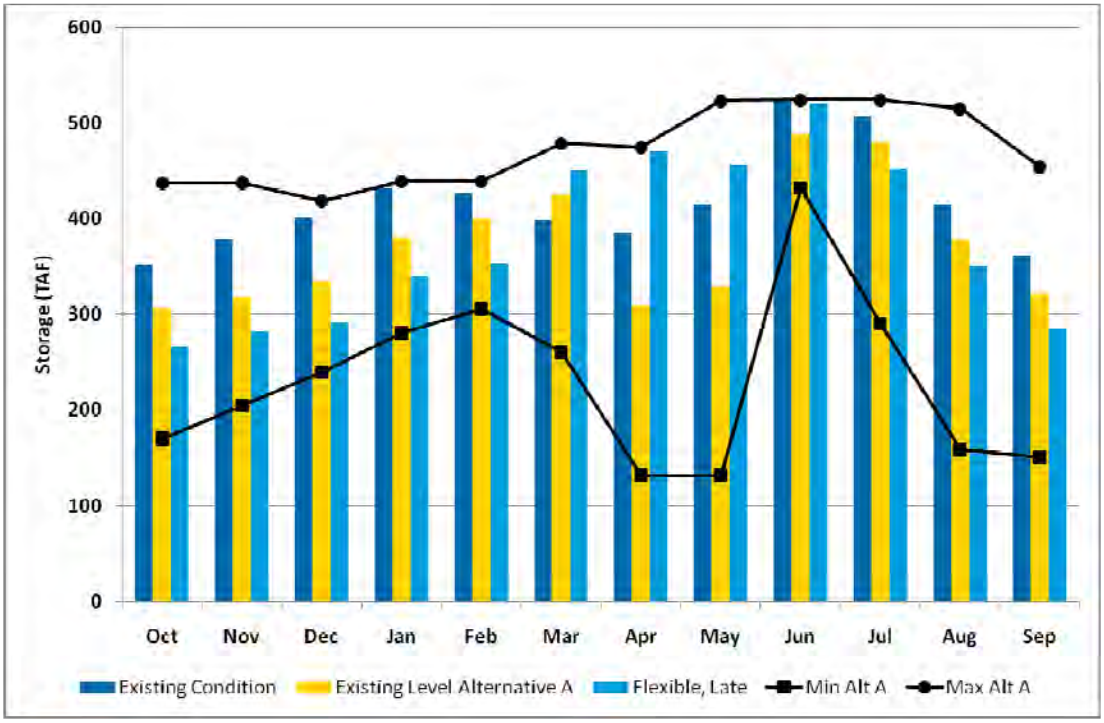
Table 3-12 is a summary table of the change in the simulated mean end-of-month Millerton Storage between the Alternative A and Flexible Flow (Late) CalSim simulations.

Table 3-12.
Flexible Flow (Late) – Mean End-of-Month Millerton Storage – Percent Change from Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-4.8%	-12.9%	-4.2%	-0.2%	0.8%	0.5%	3.4%
November	-1.9%	-10.9%	-1.1%	3.3%	3.9%	2.3%	3.4%
December	-3.9%	-13.0%	-2.7%	-0.2%	0.6%	2.2%	2.8%
January	-2.6%	-10.5%	-0.9%	-0.3%	0.6%	1.9%	1.7%
February	-2.4%	-11.4%	-0.6%	0.2%	1.0%	0.9%	4.5%
March	6.3%	6.3%	5.5%	7.5%	3.9%	17.3%	-4.4%
April	25.9%	52.6%	39.0%	14.4%	-2.4%	0.2%	-3.5%
May	4.8%	38.9%	-0.8%	-3.2%	-4.1%	0.1%	-2.8%
June	1.0%	6.8%	1.2%	-2.5%	-3.4%	-0.9%	-3.4%
July	-3.0%	-5.9%	-1.3%	-2.0%	-3.2%	-1.2%	-2.7%
August	-4.0%	-7.7%	-3.4%	-1.2%	-0.6%	-1.6%	0.0%
September	-4.5%	-11.2%	-4.5%	-0.4%	1.0%	0.8%	1.9%

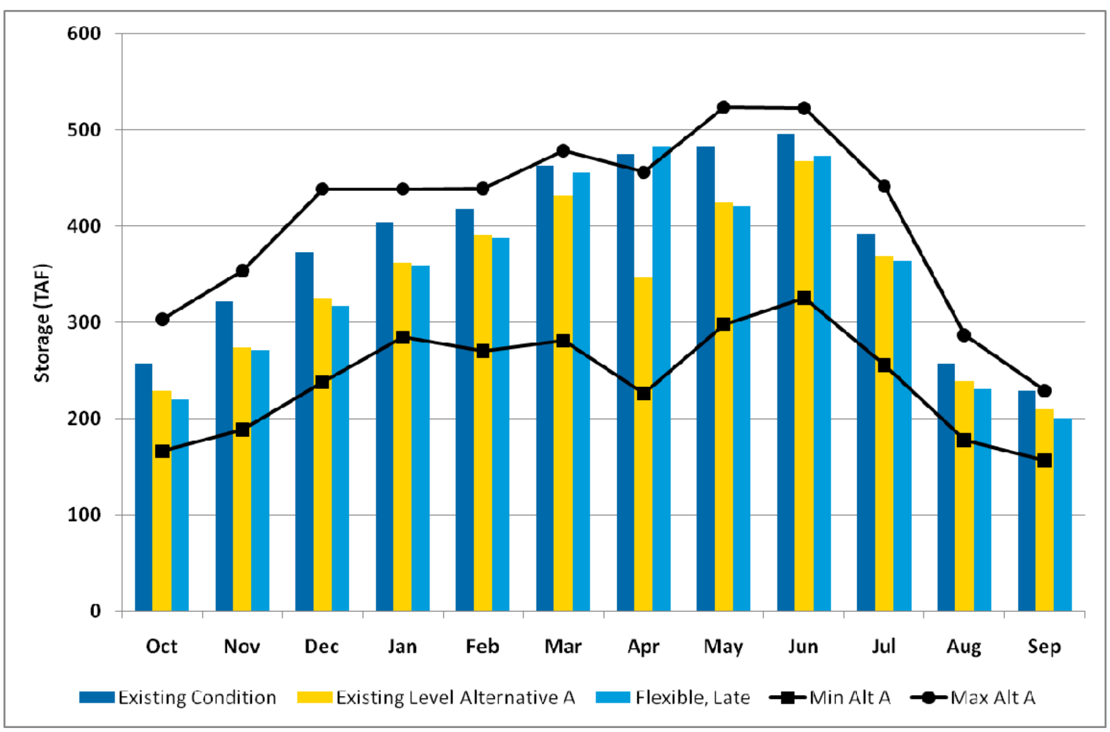
Notes:
Increase greater than 10%
Decrease greater than 10%

Table 3-12 shows reductions in the fall and winter Millerton storage in Wet years and increases in the spring (April-May) period in Normal-Wet, Normal-Dry, and Critical-High years. Figures 3-18 and 3-19 show the simulated mean monthly Millerton storage for the Existing Condition, Alternative A, and the Flexible Flows, Late CalSim simulations in Wet and Normal-Wet years.



Key: TAF = thousand acre-feet

Figure 3-18.
Flexible Flow (Late) – Wet Years – Mean End-of-Month Millerton Storage



Key: TAF = thousand acre-feet

Figure 3-19.
Flexible Flow (Late) – Normal-Wet Years – Mean End-of-Month Millerton Storage

Figures 3-18 and 3-19 show that in both year types the large percent increases are closer to the Existing Conditions values than the Alternative A values, implying less impact to Millerton storage from the Flexible Flow (Late) than was evaluated for Alternative A in the PEIS/R.

Figure 3-18 shows that the reductions in Millerton storage in Wet years is further away from the Existing Conditions values than the Alternative A values but are still within the range of Millerton storages evaluated in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.4.2 Millerton Release

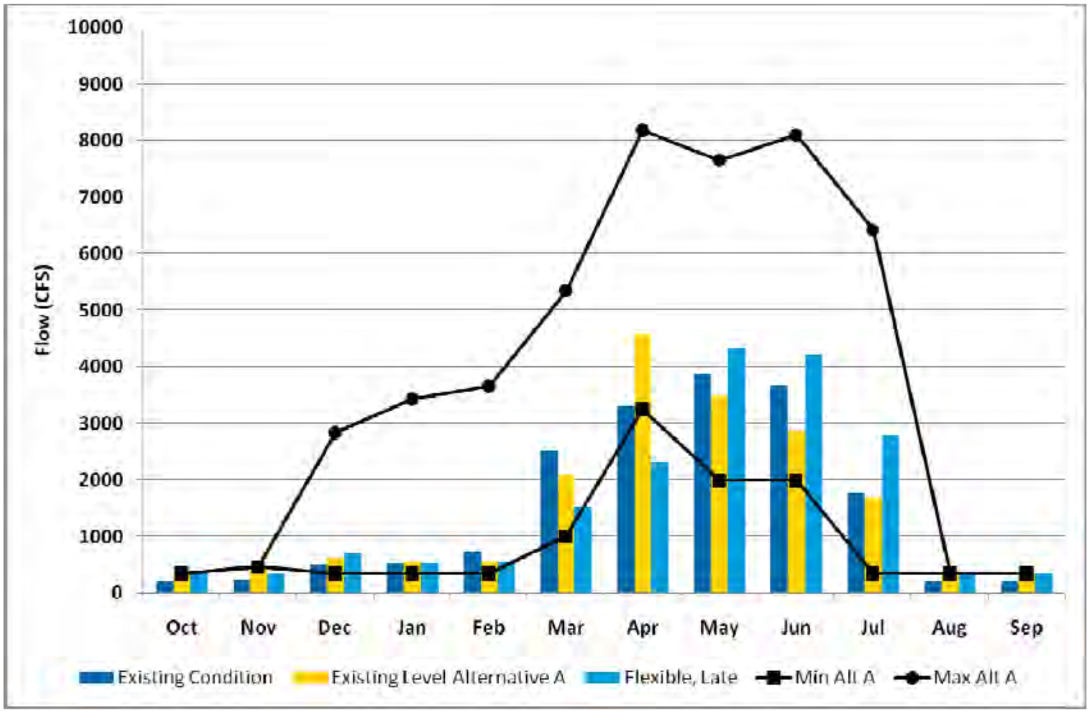
Table 3-13 is a summary table of the change in the simulated mean Millerton Release between the Alternative A and Flexible Flow Late CalSim simulations.

Table 3-13.
Flexible Flow (Late) – Mean Monthly Millerton Release – Percent Change from Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	**-23.8%**
November	**-24.4%**	**-25.1%**	**-25.1%**	**-25.1%**	**-20.5%**	**-31.8%**	-1.6%
December	**23.1%**	**13.9%**	**27.2%**	**29.8%**	**25.8%**	-8.3%	**-16.7%**
January	-0.7%	-1.3%	-0.9%	0.0%	-0.2%	0.0%	0.0%
February	-1.0%	-1.8%	2.3%	-2.2%	-2.2%	0.0%	**-13.8%**
March	**-50.3%**	**-26.7%**	**-57.3%**	**-65.6%**	**-65.6%**	**-65.6%**	**169.2%**
April	**-46.1%**	**-48.9%**	**-66.6%**	**-28.5%**	**92.5%**	**333.0%**	**-13.3%**
May	**129.1%**	**24.1%**	**527.1%**	**306.2%**	**50.8%**	-7.0%	**-21.1%**
June	**30.6%**	**47.9%**	-2.0%	0.0%	0.0%	0.0%	0.0%
July	**39.7%**	**64.4%**	**28.0%**	0.0%	-0.9%	**-15.7%**	**-17.4%**
August	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-8.7%
September	-1.9%	0.0%	0.0%	0.0%	-2.2%	**-38.5%**	**-23.8%**

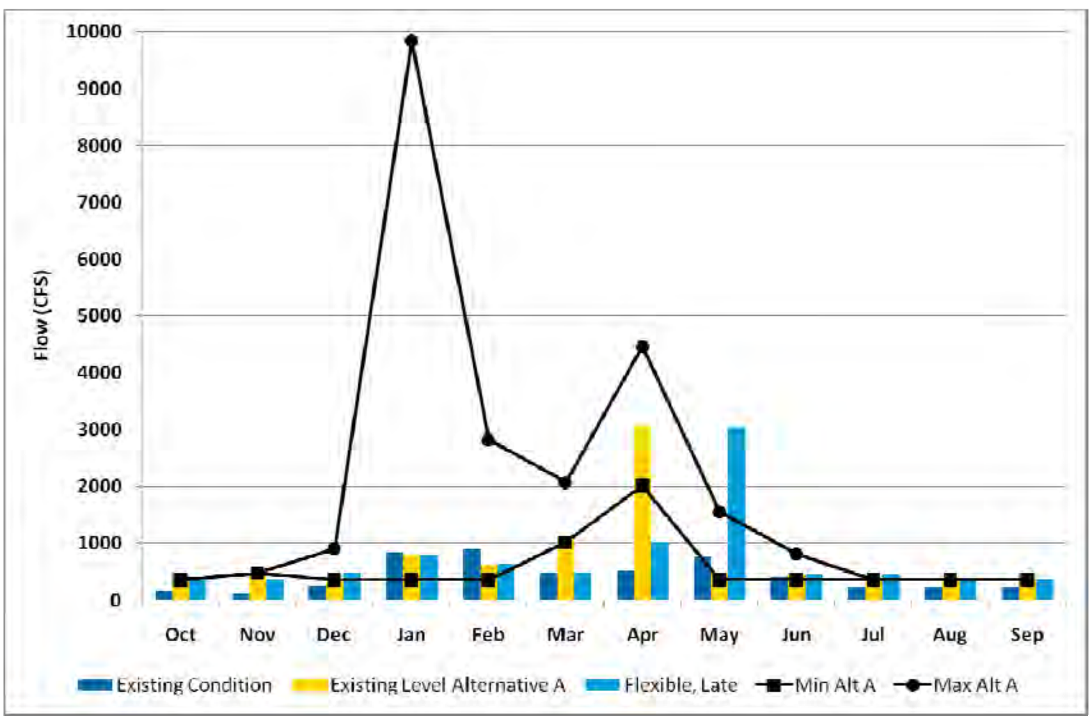
Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-13 clearly shows the movement of the fall pulse flow from November to December and the movement of the spring pulse from the March-April time frame to the May-June time frame in all year types. Figures 3-20 and 3-21 show the change in Millerton release for the Existing Condition, Alternative A, and the Flexible Flow (Late) CalSim simulations in Wet and Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-20.
Flexible Flow (Late) – Wet Years – Mean Monthly Millerton Release



Key: cfs = cubic feet per second

Figure 3-21.
Flexible Flow (Late) – Normal-Wet Years – Mean Monthly Millerton Release

Figure 3-20 shows that in the spring period the increase in Millerton storage, while different from Alternative A is actually about the same change from the Existing conditions, just in the opposite direction. Figure 3-21 shows similar results except that in May the Flexible Flow (Late) Millerton releases are further from the Existing Condition flows than the Alternative A releases, and are outside the range of the Alternative A Millerton Releases evaluated in the PEIS/R. Increased Millerton release during May would be expected to have beneficial impacts in the San Joaquin River. Also, as with the Flexible Flow (Early) , this action will not be taken in all years only in years where it would have a beneficial impact on the San Joaquin River, even better indication that this increase in Millerton release does not have large negative impacts. The results for the other year types follow the same general pattern as for the Normal-Wet years.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.4.3 Friant-Kern Canal Diversion

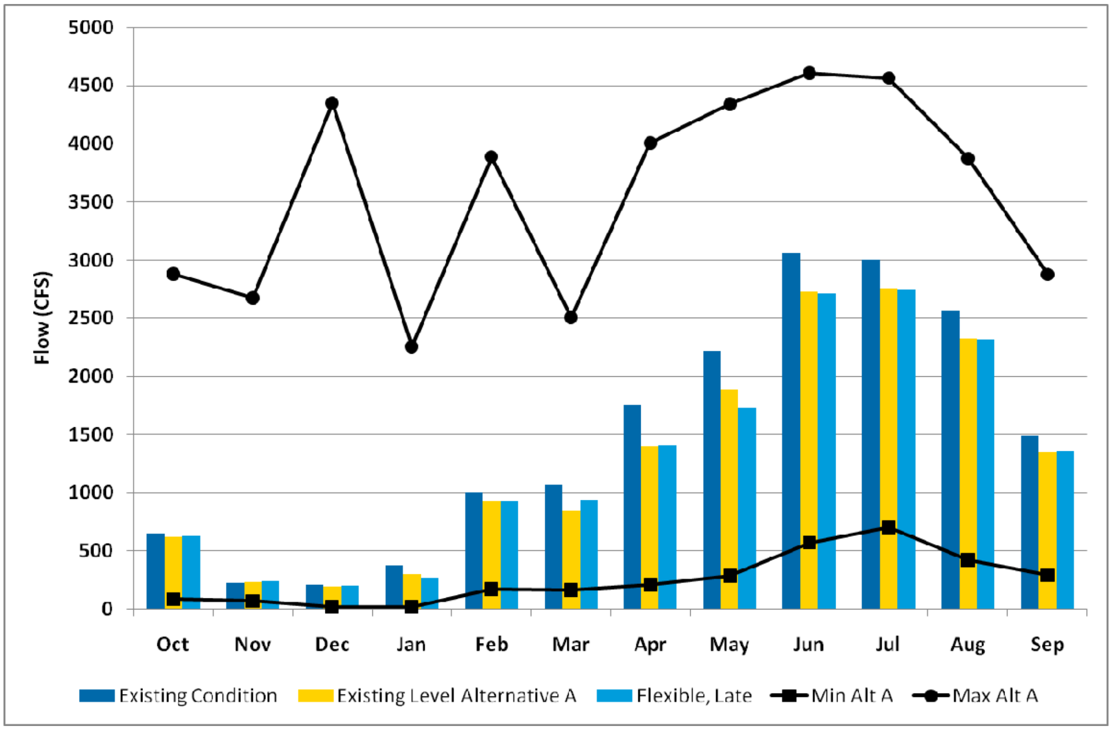
Table 3-14 is a summary table of the change in the simulated mean Friant-Kern Canal diversion between the Alternative A and Flexible Flow Late CalSim simulations.

Table 3-14.
Flexible Flow (Late) – Mean Monthly Friant-Kern Canal Diversion – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	1.8%	4.1%	1.2%	-1.5%	1.2%	2.6%	0.3%
November	2.8%	5.0%	0.8%	-0.8%	3.4%	1.9%	0.2%
December	4.9%	**19.1%**	-4.8%	-0.4%	**-14.6%**	0.0%	0.0%
January	**-11.1%**	-9.7%	**-21.0%**	4.2%	-3.5%	0.0%	0.0%
February	0.8%	8.0%	-3.0%	-2.5%	-1.2%	**13.3%**	0.0%
March	**11.0%**	9.8%	**17.4%**	9.5%	-8.3%	2.8%	0.3%
April	0.6%	-2.6%	7.8%	-0.8%	**-21.1%**	2.7%	0.3%
May	-8.2%	-9.2%	**-10.2%**	-4.3%	-7.4%	2.8%	0.3%
June	-0.5%	5.7%	-4.0%	-1.7%	-3.4%	3.0%	0.4%
July	-0.7%	-2.3%	1.4%	-1.7%	-1.8%	3.1%	0.4%
August	-0.1%	0.6%	1.4%	-1.5%	-5.7%	2.2%	-9.4%
September	0.9%	3.7%	1.3%	-1.8%	-4.8%	2.6%	0.3%

Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-14 shows changes of greater than 10 percent, both larger and smaller, in Wet, Normal-Wet, Dry, and Critical-High year types. The all year summary shows a decrease of greater than 10 percent in January and an increase of 11 percent in March. Figure 3-22 shows the change in Friant-Kern Canal diversion for the Existing Condition, Alternative A, and the Flexible Flow (Late) CalSim simulations for all years.



Key: cfs = cubic feet per second

Figure 3-22.
Flexible Flow (Late) – All Years – Mean Monthly Friant-Kern Canal Diversion

Figure 3-22 shows that the changes, while just over 10 percent in both months, are during a low diversion period and within the range of Friant Kern diversions evaluated in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.4.4 San Joaquin River Delta Inflow

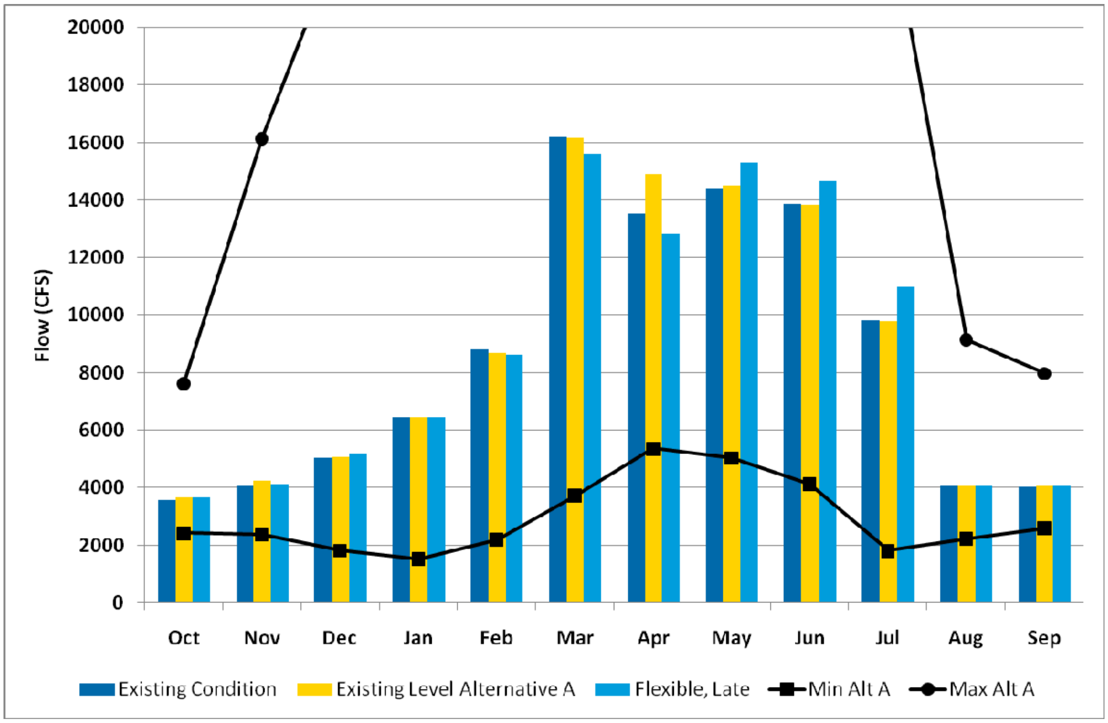
Table 3-15 is a summary table of the change in the simulated mean San Joaquin River Delta inflow between the Alternative A and Flexible Flow Late CalSim simulations.

Table 3-15.
Flexible Flow (Late) – Mean Monthly San Joaquin River Delta Inflow – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.0%	0.0%	0.3%	-0.1%	-0.2%	-0.1%	0.0%
November	-3.7%	-2.7%	-3.6%	-4.6%	-5.6%	-1.7%	-0.1%
December	2.7%	1.9%	2.9%	3.9%	3.1%	-1.5%	0.0%
January	0.2%	0.0%	0.0%	1.1%	-0.1%	-0.1%	0.0%
February	-0.1%	-0.8%	0.6%	0.0%	-0.4%	0.0%	-3.6%
March	-7.7%	-3.4%	-8.1%	**-16.9%**	**-16.4%**	**-14.8%**	8.4%
April	**-13.3%**	**-13.9%**	**-22.1%**	-8.8%	**23.0%**	**39.9%**	0.9%
May	**17.5%**	5.7%	**31.8%**	**24.1%**	**20.5%**	**16.7%**	0.0%
June	3.8%	6.0%	1.7%	0.0%	-1.1%	0.0%	0.0%
July	8.7%	**12.4%**	6.0%	0.0%	0.1%	0.0%	0.0%
August	0.0%	-0.4%	0.5%	0.0%	0.0%	0.0%	0.0%
September	0.2%	-0.2%	0.9%	0.0%	-0.3%	0.0%	0.0%

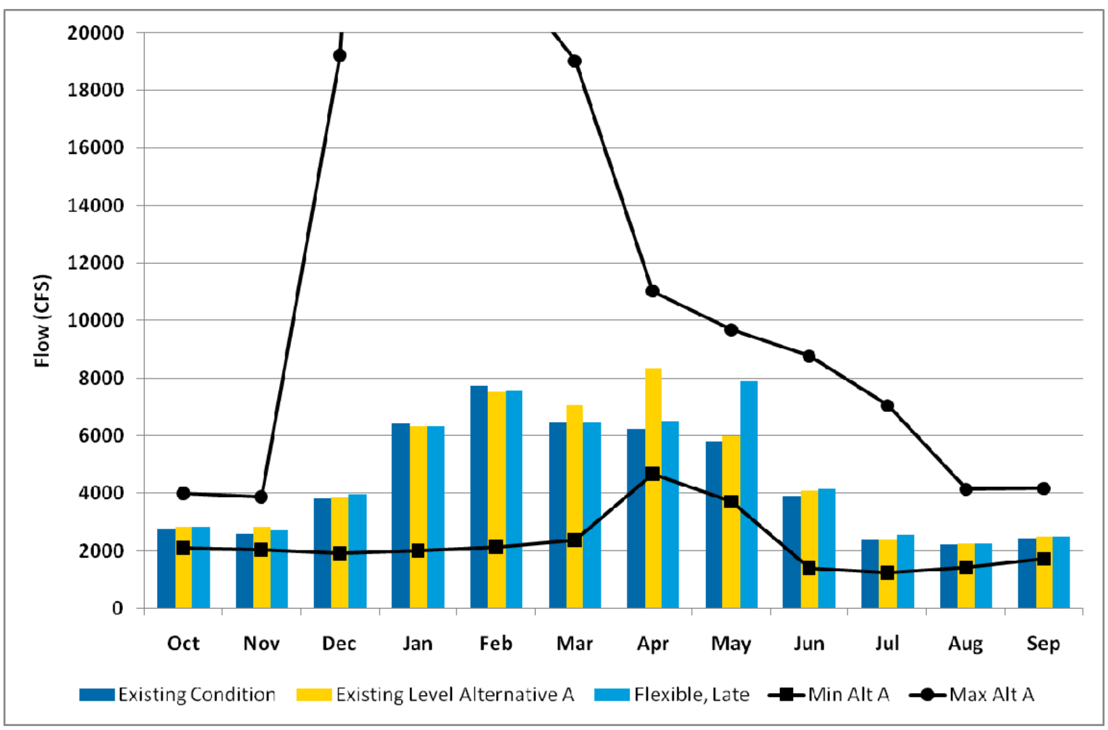
Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-15 shows changes of over 10 percent in the San Joaquin River Delta inflows in all year types, with reductions in the March – April period and increases in the April-May periods. Figures 3-23 and 3-24 show the changes in San Joaquin River Delta inflows for the Existing Condition, Alternative A, and the Flexible Flow (Late) CalSim simulations for Wet and Normal-Wet year types.



Key: cfs = cubic feet per second

Figure 3-23.
Flexible Flow (Late) – Wet Years – Mean Monthly San Joaquin River Delta Inflow



Key: cfs = cubic feet per second

Figure 3-24.
Flexible Flow (Late) – Normal-Wet Years – Mean Monthly Delta Pumping

Figure 3-23 shows that in April of Wet years, the Flexible Flow (Late) San Joaquin River Delta inflow is closer to the Existing Conditions then Alternative A and therefore would have less impact. In May, the Flexible Flow (Late) San Joaquin River Delta inflow is further from the Existing Conditions than the Alternative A but it is still within the range of values evaluated in the PEIS/R. Figure 3-24 shows the movement of the spring pulse flow from April to May, but the as in the Wet years it is closer than Alternative A in April and within the range of values evaluated in the PEIS/R. The results for the Normal-Dry, Dry and Critical-High follow the same pattern.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.4.5 Delta Pumping

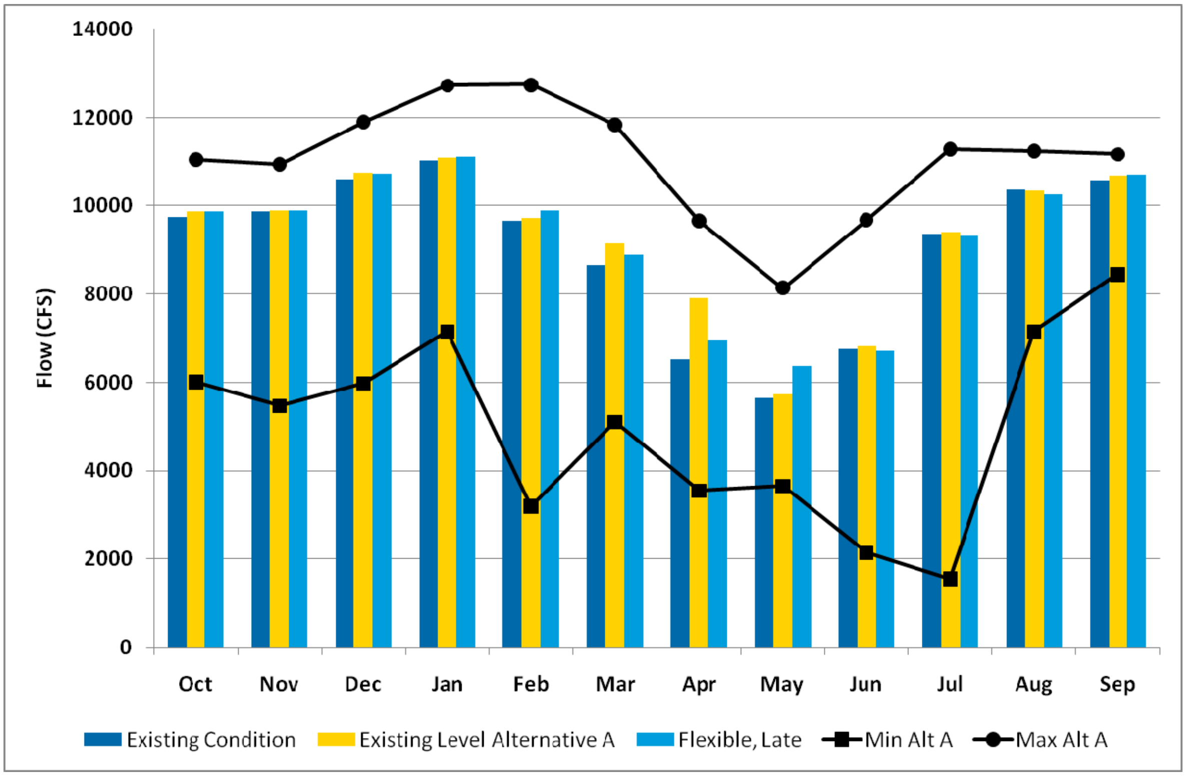
Table 3-16 is a summary table of the change in the simulated mean Delta pumping between the Alternative A and Flexible Flow Late CalSim simulations.

Table 3-16.
Flexible Flow (Late) – Mean Monthly Delta Pumping – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.5%	0.0%	0.0%	1.1%	2.0%	0.0%	0.0%
November	-0.5%	-1.6%	0.2%	-0.6%	-0.1%	-0.9%	0.0%
December	0.0%	-0.8%	-0.2%	0.6%	0.5%	0.2%	0.0%
January	-0.3%	-0.1%	0.1%	-1.2%	0.1%	0.0%	0.0%
February	0.6%	-0.4%	1.7%	0.0%	-0.4%	3.8%	0.1%
March	-1.1%	0.1%	-2.8%	-1.4%	2.9%	-2.7%	1.3%
April	-4.5%	-3.5%	**-12.2%**	3.1%	9.7%	**16.4%**	0.0%
May	7.0%	1.0%	**11.2%**	**10.3%**	5.8%	0.2%	0.0%
June	-0.7%	0.2%	-1.3%	-1.3%	0.5%	-1.4%	-3.7%
July	-0.5%	1.2%	-0.8%	-3.0%	-0.1%	9.5%	0.2%
August	-0.2%	-0.4%	-0.9%	1.8%	-1.6%	-6.1%	1.3%
September	0.6%	0.0%	0.1%	1.5%	2.3%	-2.0%	0.0%

Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-16 shows changes of over 10 percent in Delta pumping in Normal-Wet, Normal Dry and Critical-High year types. Figure 3-25 shows the change in Delta pumping for the Existing Condition, Alternative A, and the Flexible Flow (Late) CalSim simulations for Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-25.
Flexible Flow (Late) – Normal-Wet Years – Mean Monthly Delta Pumping

Figure 3-25 shows that in April of Normal-Wet years the Flexible Flow (Late) Delta pumping is closer to the Existing Conditions than the Alternative A and therefore would have less impact. In May the Flexible Flow (Late) Delta pumping is further from the Existing Conditions than the Alternative A but it is still within the range of values evaluated in the PEIS/R. The Normal-Dry and Critical-High follow a similar pattern.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.4.6 Sacramento River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.5 No Implementation of 16(b)

Surplus water from Millerton Lake is currently made available for delivery as section 215 (215) water to Friant contractors. Paragraph 16(b) of the San Joaquin River Restoration Settlement allows for the development of a Water Recovery Account and a program to implement the program, for the delivery of surplus water (16(b)) to Friant contractors.

This was incorporated in the CalSim modeling by assuming development of a system of groundwater banks serviceable from the Friant-Kern and Madera Canals to allow for greater capture of available surplus as 16(b) water. Any remaining surplus water was then made available as 215 water. Implementation issues required that the priority for delivery of surplus water as follows:

1. Madera Canal 215
2. Friant-Kern Canal 16(b)
3. Friant-Kern Canal 215
4. Madera Canal 16(b)

3.5.1 Millerton End-of-Month Storage

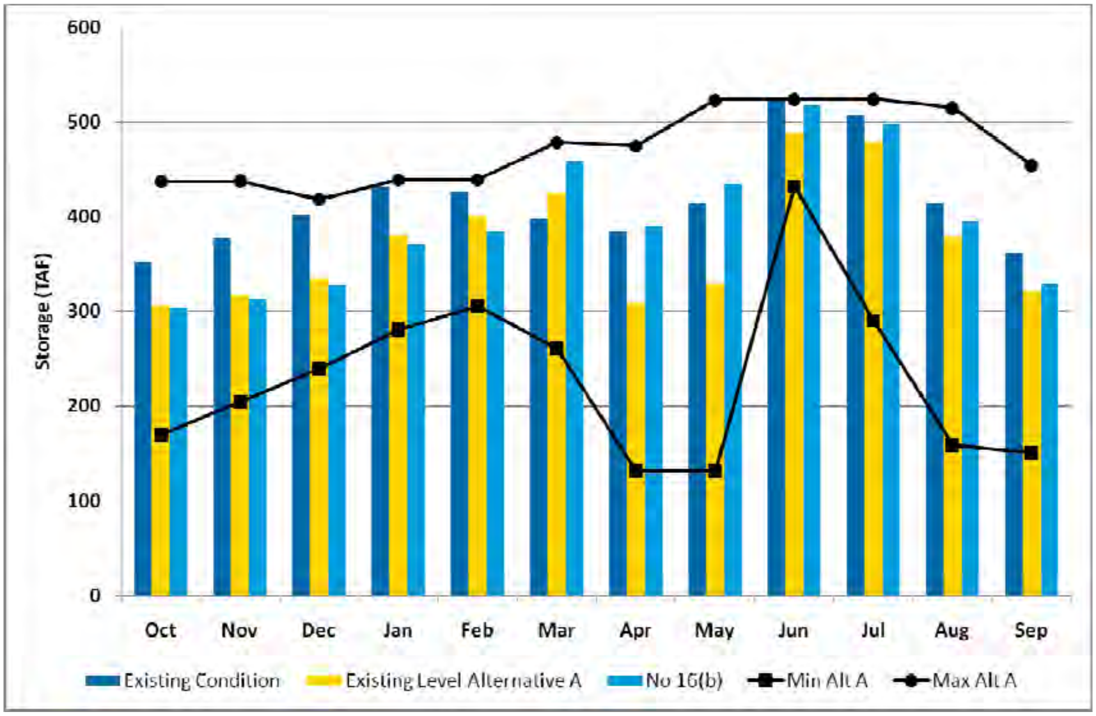
Table 3-17 is a summary table of the change in the simulated mean Millerton End-of-Month Storage between the Alternative A and No 16(b) CalSim simulations.

Table 3-17.
No 16(b) – Mean End-of-Month Millerton Storage – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-0.9%	-0.5%	-2.7%	0.0%	1.0%	0.0%	0.0%
November	-1.0%	-1.3%	-2.3%	0.0%	1.1%	0.0%	0.0%
December	-1.0%	-2.2%	-1.8%	0.0%	0.9%	0.0%	0.0%
January	-0.6%	-2.5%	-0.3%	0.0%	0.7%	0.0%	0.0%
February	-0.1%	-3.7%	0.9%	0.3%	2.6%	0.0%	4.7%
March	1.3%	8.4%	-0.1%	-0.3%	-4.3%	0.2%	0.0%
April	4.7%	**26.5%**	0.6%	-0.2%	-1.5%	0.2%	0.0%
May	5.7%	**31.9%**	1.2%	-0.2%	-1.2%	0.2%	0.0%
June	2.0%	6.2%	1.9%	-0.1%	-0.9%	0.1%	0.0%
July	1.5%	4.0%	0.9%	-0.1%	-0.3%	0.1%	0.0%
August	1.1%	4.3%	-0.9%	-0.1%	0.5%	0.1%	0.0%
September	0.1%	2.6%	-2.6%	0.0%	0.8%	0.0%	0.0%

Note:
Increase greater than 10%

Table 3-17 shows changes of over 10 percent in Millerton storage in Wet year types. Figure 3-26 shows the change in Millerton storage for the Existing Condition, Alternative A, and the No 16(b) CalSim simulations for Normal-Wet years.



Key: TAF = thousand acre-feet

Figure 3-26.
No 16(b) – Wet Years – Mean End-of-Month Millerton Storage

Figure 3-26 shows that in both April and May the Millerton storage for No 16(b) is closer to the Existing Condition than to the Alternative A and therefore would have less impact.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.5.2 Millerton Release

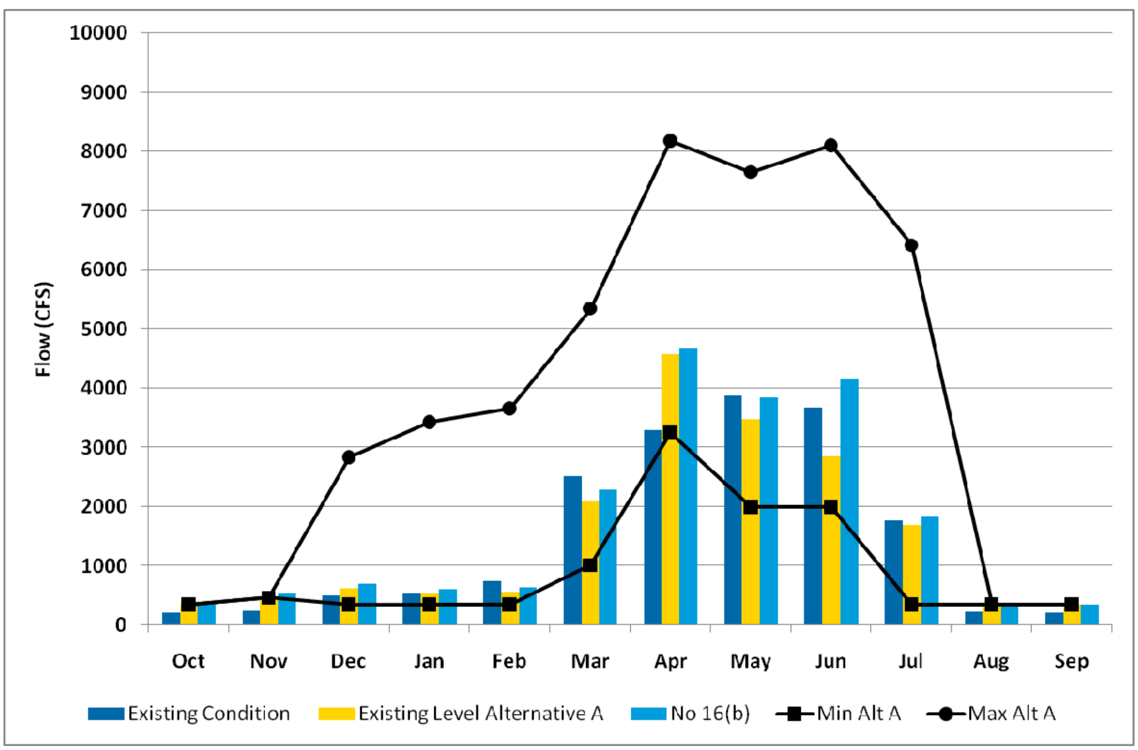
Table 3-18 is a summary table of the change in the simulated mean Millerton Release between the Alternative A and No 16(b) CalSim simulations.

Table 3-18.
No 16(b) – Mean Monthly Millerton Release – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.5%	2.5%	0.0%	0.0%	0.0%	0.0%	0.0%
November	3.9%	**19.0%**	0.0%	0.0%	0.0%	0.0%	0.0%
December	**17.1%**	**12.6%**	8.2%	**39.5%**	0.0%	0.0%	0.0%
January	**12.8%**	**11.6%**	**12.4%**	**11.5%**	**20.7%**	0.0%	0.0%
February	**22.3%**	**13.2%**	**29.3%**	**26.8%**	7.7%	2.3%	**49.3%**
March	5.7%	9.9%	9.0%	0.1%	0.0%	0.0%	0.0%
April	0.8%	2.2%	-0.1%	0.0%	0.0%	0.0%	0.0%
May	7.4%	**10.3%**	2.0%	0.0%	0.0%	0.0%	0.0%
June	**30.0%**	**45.8%**	2.3%	0.0%	0.0%	0.0%	0.0%
July	4.4%	7.9%	0.0%	0.0%	0.0%	0.0%	0.0%
August	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
September	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

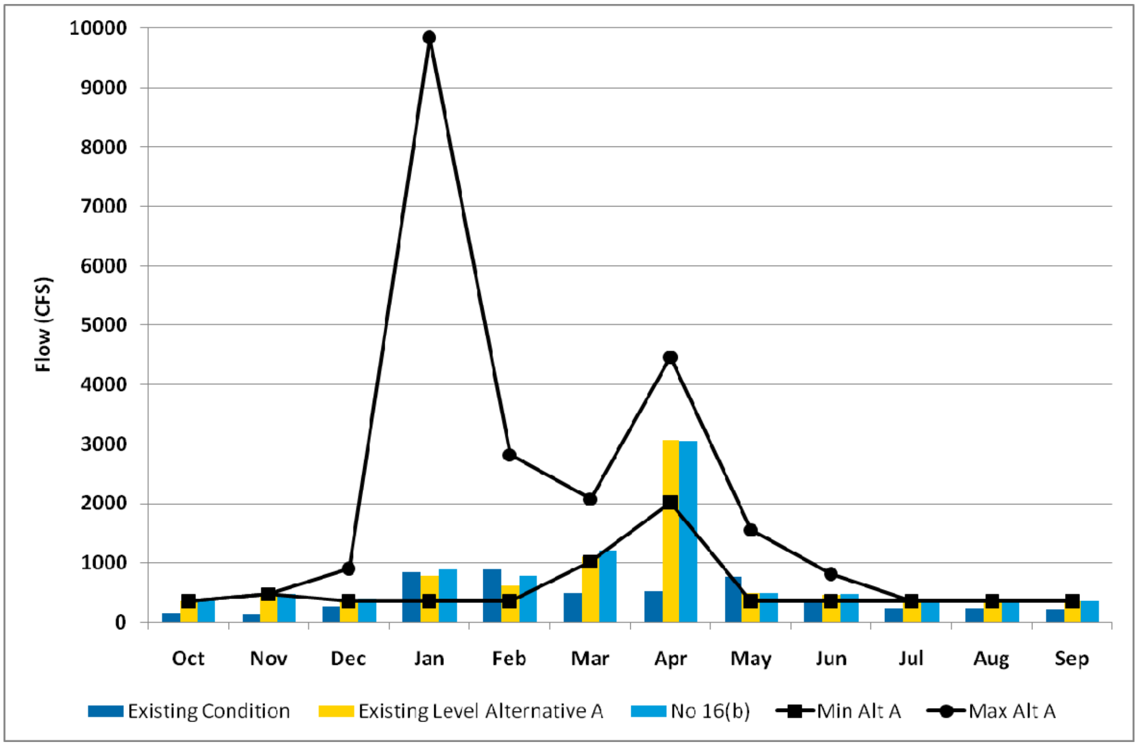
Note:
Increase greater than 10%

Table 3-18 shows changes of over 10 percent in Millerton storage in the winter of all year types except Critical-High. Figures 3-27 and 3-28 show the change in Millerton release for the Existing Condition, Alternative A, and the No 16(b) CalSim simulations for Wet and Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-27.
No 16(b) – Wet Years – Mean Monthly Millerton Release



Key: cfs = cubic feet per second

Figure 3-28.
No 16(b) – Normal-Wet Years – Mean Monthly Millerton Release

Figures 3-27 and 3-28 show that in both Wet and Normal-Wet year types Millerton release in the No 16(b) is usually closer to the existing Conditions than to Alternative A and therefore has lower impacts.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.5.3 Friant-Kern Canal Diversion

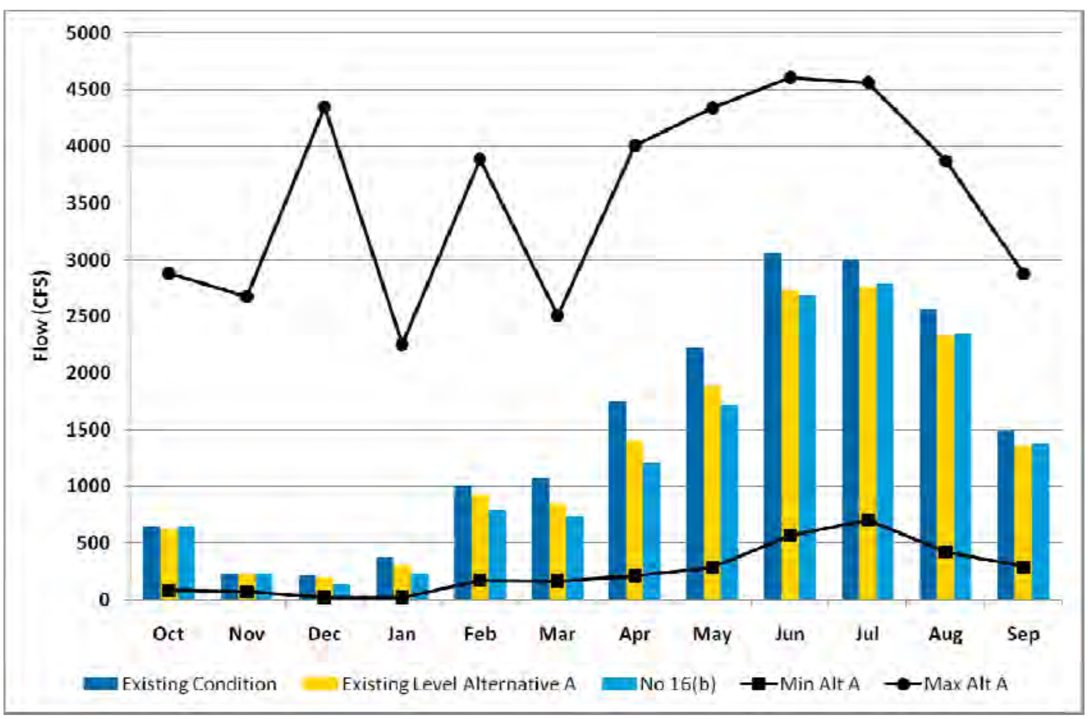
Table 3-19 is a summary table of the change in the simulated mean Friant-Kern Canal diversion between the Alternative A and No 16(b) CalSim simulations.

Table 3-19.
No 16(b) – Mean Monthly Friant-Kern Canal Diversion - Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	4.9%	**11.3%**	2.1%	-0.1%	-1.1%	0.1%	0.0%
November	-2.9%	-6.4%	1.4%	0.0%	-0.8%	0.1%	0.0%
December	**-26.2%**	5.0%	**-20.8%**	**-56.8%**	-0.8%	0.0%	0.0%
January	**-23.9%**	-3.1%	**-37.5%**	**-31.3%**	**-31.5%**	0.0%	0.0%
February	**-13.7%**	3.1%	**-20.3%**	**-18.2%**	**-21.9%**	-1.3%	**-87.9%**
March	**-13.8%**	**-28.6%**	-9.6%	-0.3%	-5.8%	0.1%	0.0%
April	**-13.3%**	**-36.1%**	-2.4%	-0.6%	**-15.7%**	0.1%	0.0%
May	-8.9%	**-26.0%**	-2.6%	-0.1%	-1.4%	0.1%	0.0%
June	-1.3%	-1.6%	-2.0%	0.0%	-1.3%	0.2%	0.0%
July	1.0%	0.9%	2.5%	-0.1%	-1.3%	0.2%	0.0%
August	1.1%	1.1%	2.4%	0.0%	-1.3%	0.1%	0.0%
September	2.2%	4.9%	2.3%	-0.1%	-1.2%	0.1%	0.0%

Notes:
Increase greater than 10%
Decrease greater than 10%

Table 3-19 shows changes of over 10 percent in Friant-Kern Canal diversions in all year types, Millerton storage in year types except Critical-High. Figure 3-29 shows the change in Friant-Kern Canal diversion for the Existing Condition, Alternative A, and the No 16(b) CalSim simulations for all years.



Key: cfs = cubic feet per second

Figure 3-29.
No 16(b) – All Years – Mean Monthly Friant-Kern Canal Diversion

Figure 3-29 shows that the No 16(b) Friant-Kern Canal deliveries in the spring are further from the Existing Conditions than the Alternative A, but are within the range of values evaluated in the PEIS/R.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.5.4 San Joaquin River Delta Inflow

Table 3-20 is a summary table of the change in the simulated mean monthly San Joaquin River Delta inflows between the Alternative A and No 16(b) CalSim simulations.

Table 3-20.
No 16(b) – Mean Monthly San Joaquin River Delta Inflow – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
November	0.5%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%
December	2.1%	2.0%	0.7%	5.5%	0.0%	0.0%	0.0%
January	1.2%	0.8%	1.1%	1.6%	2.0%	0.0%	0.0%
February	1.4%	0.4%	1.9%	2.2%	-0.1%	0.0%	**13.2%**
March	0.8%	1.1%	0.7%	0.0%	0.0%	0.0%	0.0%
April	0.3%	0.7%	-0.1%	0.0%	0.0%	0.0%	0.0%
May	1.2%	2.5%	0.2%	0.0%	0.0%	0.0%	0.0%
June	3.7%	6.4%	0.0%	0.0%	0.0%	0.0%	0.0%
July	0.4%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%
August	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
September	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Note:
Increase greater than 10%

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.5.5 Delta Pumping

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.5.6 Sacramento River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.6 Reach 2B Capacity Limited

The existing capacity of Reach 2B is approximately 1,300 cfs. The Exhibit B Restoration Flows include values of up to 4,500 cfs. For this evaluation, the Restoration Flows release from Millerton Lake were limited to the Reach 2 B channel capacity of 1300 cfs plus the estimated upstream depletions along the San Joaquin River from Millerton Lake to the Chowchilla Diversion structure at the head of Reach 2B. These new, limited flows were then imposed as the Restoration Flows and the system simulated with CalSim.

The new limits will mainly impact the spring pulse period in wetter years. The impact of this may be partially masked by flood flows, but is expected to result in reduced Millerton release with changes in flood control operations and possibly contractor deliveries.

3.6.1 Millerton End-of-Month Storage

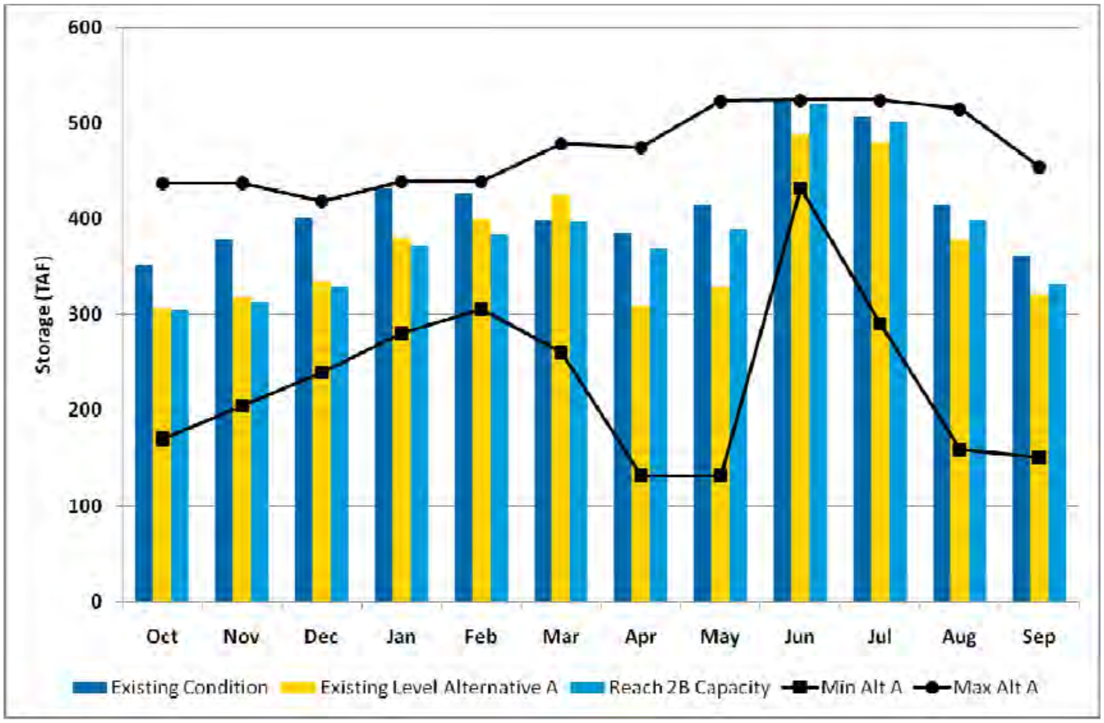
Table 3-21 is a summary table of the change in the simulated mean end-of-month Millerton storage between the Alternative A and Reach 2B Capacity Limited CalSim simulations.

Table 3-21.
Reach 2B Capacity – Mean End-of-Month Millerton Storage – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-1.0%	-0.2%	-3.6%	0.2%	1.0%	-0.1%	0.0%
November	-1.1%	-0.9%	-3.1%	0.4%	1.1%	0.0%	0.0%
December	-1.2%	-1.9%	-2.6%	0.2%	0.9%	0.0%	0.0%
January	-0.8%	-2.2%	-1.1%	0.2%	0.7%	0.0%	0.0%
February	-1.2%	-4.2%	-1.0%	0.0%	0.3%	0.0%	0.8%
March	-2.8%	-6.5%	-1.6%	-0.9%	-4.3%	-1.7%	0.1%
April	**10.1%**	**19.5%**	**17.6%**	4.3%	-1.5%	-1.4%	0.1%
May	6.5%	**18.6%**	7.9%	2.8%	-1.2%	-1.2%	0.1%
June	4.0%	6.8%	5.5%	2.2%	-0.9%	-1.2%	0.1%
July	3.0%	4.7%	3.4%	2.1%	-0.3%	-0.9%	0.0%
August	2.0%	5.2%	0.1%	1.1%	0.5%	-0.3%	0.0%
September	0.1%	3.2%	-3.0%	0.1%	0.8%	-0.2%	0.0%

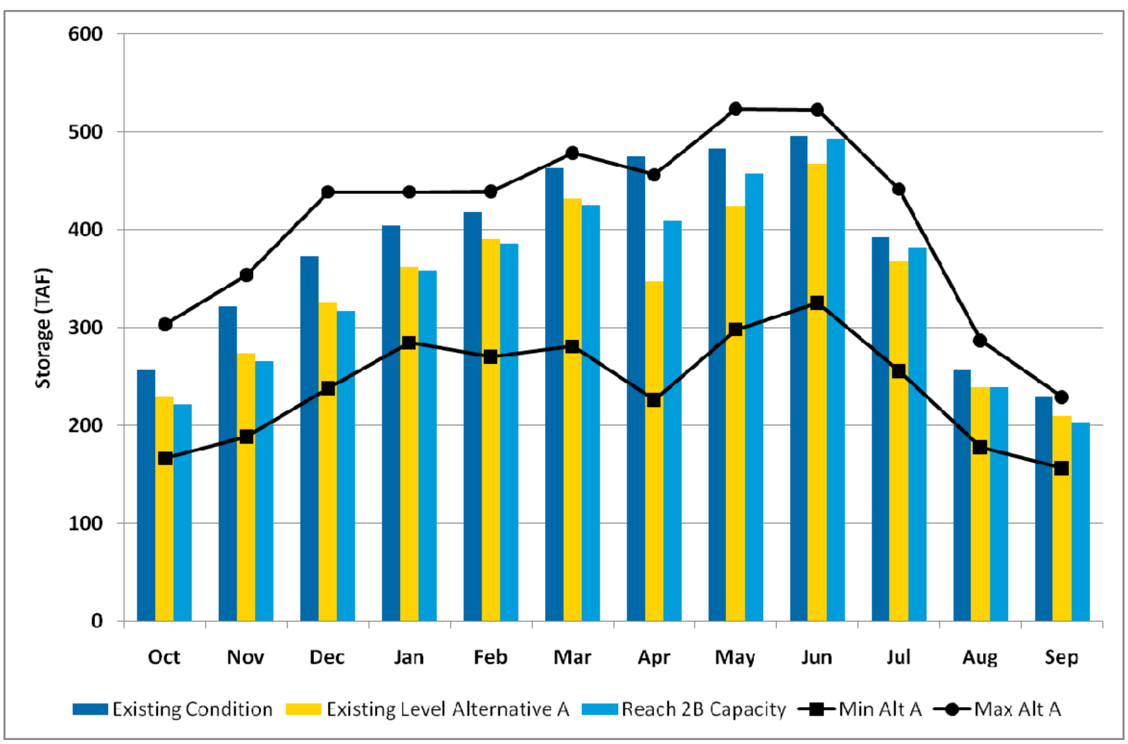
Note:
(yellow) Increase greater than 10%

Table 3-21 shows changes of over 10 percent in Millerton storage in April – May in Wet and Normal-Wet year types. Figures 3-30 and 3-31 show the changes in Millerton storage for the Existing Condition, Alternative A, and the Reach 2B capacity CalSim simulations for Wet and Normal-Wet year types.



Key: TAF = thousand acre-feet

Figure 3-30.
Reach 2B Capacity – Wet Years – Mean End-of-Month Millerton Storage



Key: TAF = thousand acre-feet

Figure 3-31.
Reach 2B Capacity – Normal-Wet Years – Mean End-of-Month Millerton Storage

Figures 3-30 and 3-31 show that in both Wet and Normal-Wet year types Millerton storage in Reach 2B Capacity is closer to the Existing Conditions than to Alternative A and therefore has lower impacts.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.6.2 Millerton Release

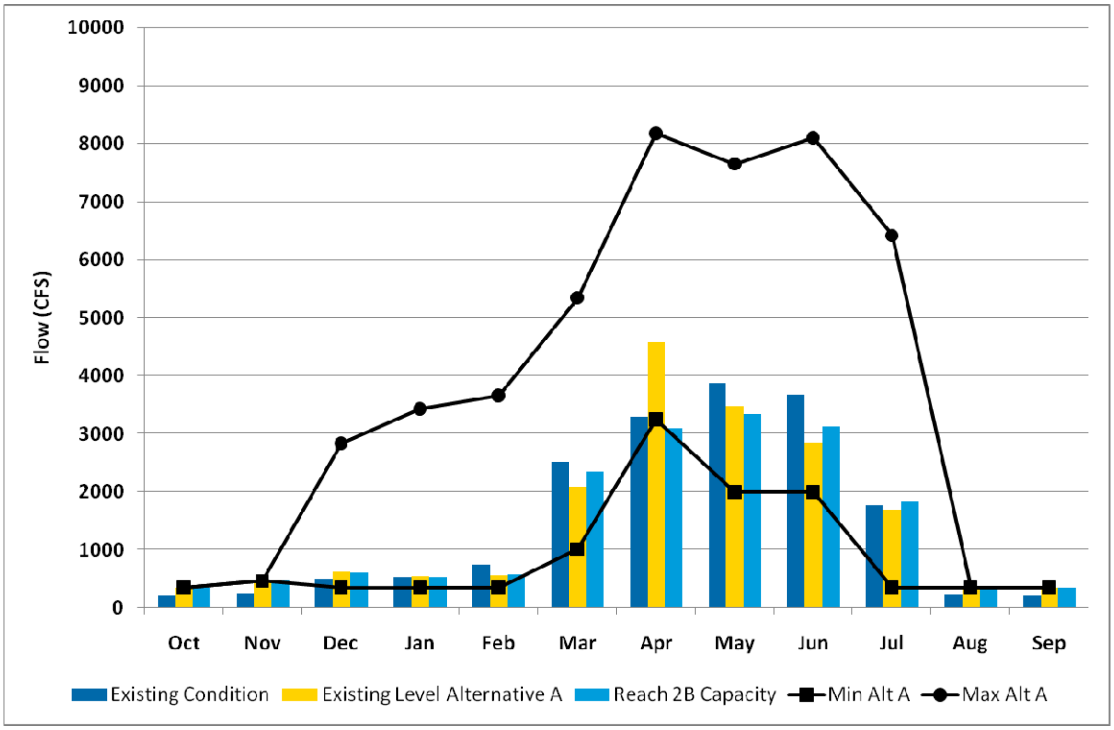
Table 3-22 is a summary table of the change in the simulated mean monthly Millerton release between the Alternative A and Reach 2B Capacity CalSim simulations.

Table 3-22.
Reach 2B Capacity – Mean Monthly Millerton Release – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
November	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
December	-1.2%	-2.7%	-1.6%	0.1%	0.0%	0.0%	0.0%
January	-1.0%	-1.4%	-1.7%	0.0%	-0.1%	0.0%	0.0%
February	1.1%	2.6%	1.6%	-0.5%	1.6%	0.0%	-3.6%
March	4.3%	**13.0%**	0.0%	0.0%	0.0%	0.0%	0.0%
April	**-34.9%**	**-32.4%**	**-45.2%**	**-24.6%**	0.0%	0.0%	0.0%
May	-1.8%	-4.1%	7.2%	0.0%	0.0%	0.0%	0.0%
June	5.7%	9.6%	-2.8%	0.0%	0.0%	0.0%	0.0%
July	4.3%	7.9%	0.0%	0.0%	0.0%	0.0%	0.0%
August	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
September	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

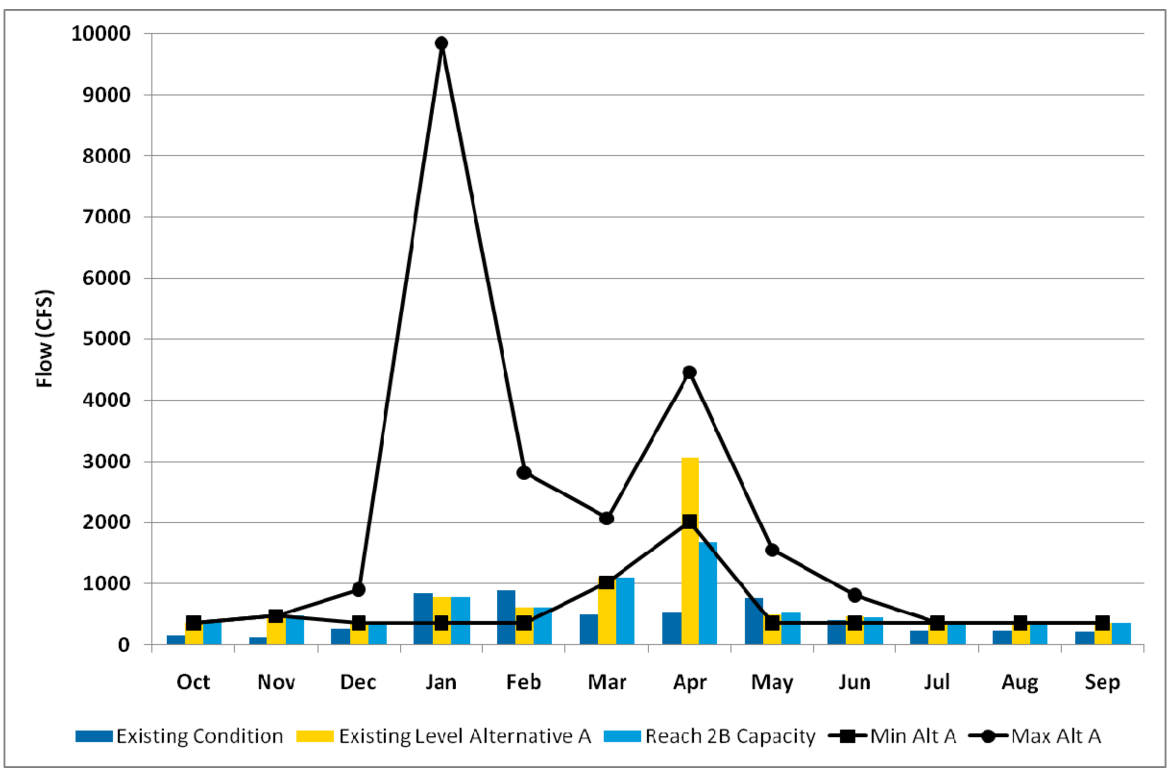
Notes:
(yellow) Increase greater than 10%
(blue) Decrease greater than 10%

Table 3-22 shows changes of over 10 percent in Millerton release in March and April of Wet, and April of Normal-Wet and Normal-Dry year types. Figures 3-21 and 3-33 show the changes in Millerton release for the Existing Condition, Alternative A, and the Reach 2B capacity CalSim simulations in Wet and Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-32.
Reach 2B Capacity – Wet Years – Mean Monthly Millerton Release



Key: cfs = cubic feet per second

Figure 3-33.
Reach 2B Capacity – Normal-Wet Years – Mean Monthly Millerton Release

Figures 3-32 and 3-33 show that in both Wet and Normal-Wet year types Millerton release in Reach 2B Capacity is closer to the Existing Conditions than to Alternative A and therefore has lower impacts. Normal-Dry years follow the same pattern.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.6.3 Friant-Kern Canal Diversion

Table 3-23 is a summary table of the change in the simulated mean monthly Friant-Kern Canal diversion between the Alternative A and Reach 2B Capacity Limited CalSim simulations.

Table 3-23.
Reach 2B Capacity – Mean Monthly Friant-Kern Canal Diversion – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	5.8%	**12.3%**	4.7%	-0.9%	-1.1%	-1.0%	0.1%
November	2.7%	5.9%	3.0%	-3.2%	-0.8%	-0.7%	0.0%
December	8.2%	**21.2%**	2.1%	1.2%	-0.8%	0.0%	0.0%
January	-3.4%	8.0%	**-16.1%**	0.5%	0.0%	0.0%	0.0%
February	2.7%	9.3%	-1.0%	1.3%	0.8%	-0.9%	0.0%
March	5.6%	7.7%	8.7%	1.4%	-5.8%	-1.1%	0.1%
April	4.3%	0.5%	**11.0%**	4.9%	**-15.7%**	-1.1%	0.1%
May	7.2%	2.9%	**14.2%**	3.5%	-1.4%	-1.1%	0.1%
June	2.8%	5.1%	2.9%	1.5%	-1.3%	-1.2%	0.1%
July	2.2%	1.2%	5.3%	0.8%	-1.3%	-1.2%	0.1%
August	2.7%	1.3%	5.2%	2.2%	-1.3%	-1.1%	0.2%
September	3.8%	5.0%	5.2%	2.2%	-1.3%	-1.0%	0.1%

Notes:
Increase greater than 10% (yellow)
Decrease greater than 10% (blue)

Table 3-23 shows changes in Friant-Kern Canal diversion of over 10 percent in various months of Wet, Normal-Wet and Dry year types. When summarized over all years the change in indicator always below +/- 10 percent.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.6.4 San Joaquin River Delta Inflow

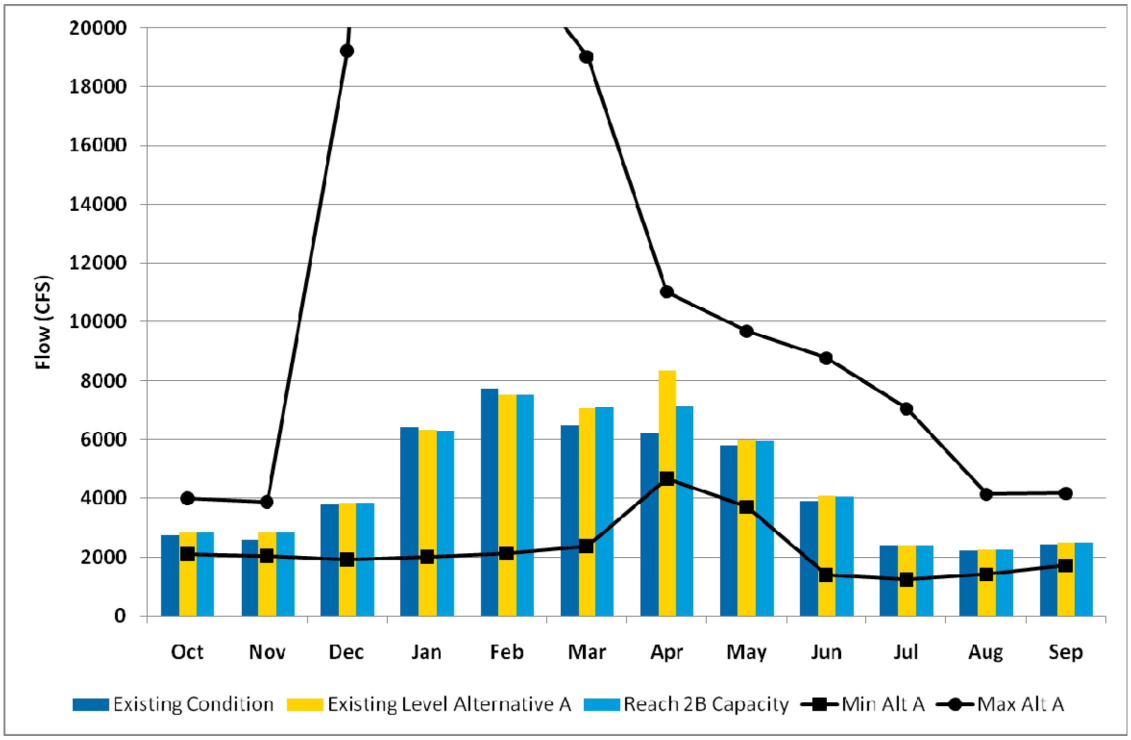
Table 3-24 is a summary table of the change in the simulated mean monthly San Joaquin River Delta inflow between the Alternative A and Reach 2B Capacity Limited CalSim simulations.

Table 3-24.
Reach 2B Capacity – Mean Monthly San Joaquin River Delta Inflow – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
Oct	0.1%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
Nov	-0.2%	-0.1%	-0.2%	-0.3%	-0.1%	0.0%	0.0%
Dec	-0.6%	-0.1%	-0.3%	-1.7%	-0.1%	0.0%	0.0%
Jan	-0.2%	-0.1%	-0.3%	-0.4%	-0.3%	0.0%	0.0%
Feb	-0.1%	-0.2%	0.1%	-0.6%	0.0%	0.0%	-1.1%
Mar	0.7%	1.4%	0.2%	0.0%	0.0%	0.0%	0.0%
Apr	-9.9%	-8.2%	-14.8%	-7.8%	-0.7%	0.0%	0.0%
May	0.4%	-0.6%	-0.6%	4.0%	3.4%	0.0%	0.0%
Jun	0.7%	1.3%	-0.4%	0.0%	0.3%	0.0%	0.0%
Jul	0.5%	0.9%	-0.3%	0.0%	0.3%	0.0%	0.0%
Aug	-0.1%	-0.4%	0.0%	0.0%	0.2%	0.0%	0.0%
Sep	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Note:
Decrease greater than 10%

Table 3-23 shows changes in San Joaquin River Delta inflow of over 10 percent in April of Normal-Wet years. Figure 3-35 shows the changes in San Joaquin River Delta inflow for the Existing Condition, Alternative A, and the Reach 2B capacity CalSim simulations in Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-34.
Reach 2B Capacity – Normal-Wet Years – Mean Monthly San Joaquin River Delta Inflow

Figure 3-25 shows that in Normal-Wet year types San Joaquin River Delta inflow in Reach 2B Capacity is closer to the Existing Conditions than to Alternative A and therefore has lower impacts.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.6.5 Delta Pumping

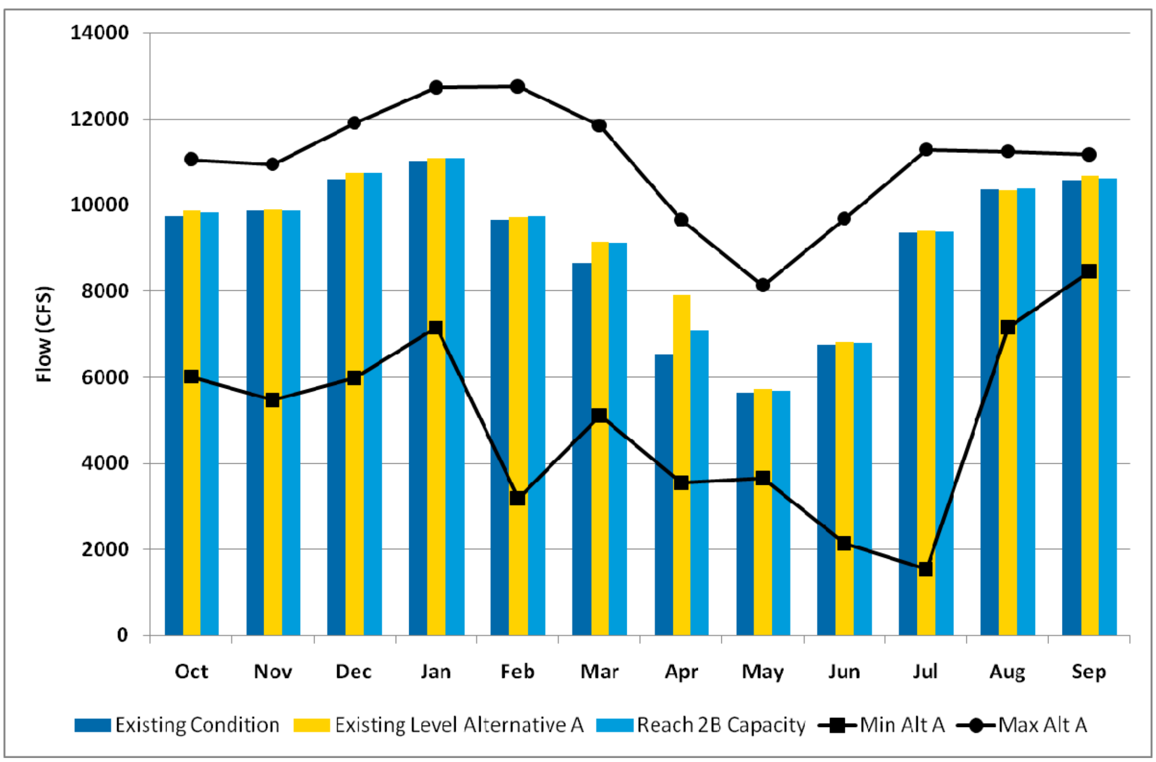
Table 3-25 is a summary table of the change in the simulated mean monthly Delta pumping between the Alternative A and Reach 2B Capacity Limited CalSim simulations.

Table 3-25.
Reach 2B Capacity – Mean Monthly Delta Pumping – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-0.1%	0.0%	-0.4%	0.0%	0.1%	0.0%	0.0%
November	0.0%	-0.2%	-0.2%	0.3%	0.5%	0.0%	0.1%
December	0.0%	-0.2%	-0.1%	0.0%	0.7%	0.0%	0.0%
January	0.0%	0.1%	-0.1%	-0.3%	0.4%	0.0%	0.0%
February	0.2%	0.0%	0.1%	0.5%	-0.2%	1.2%	0.0%
March	0.0%	-0.3%	-0.4%	0.4%	0.8%	0.0%	-0.3%
April	-4.5%	-1.6%	**-10.3%**	0.9%	-0.6%	0.0%	0.0%
May	-0.1%	-1.0%	-0.9%	1.5%	2.1%	-0.2%	0.0%
June	-0.2%	0.3%	-0.1%	-1.1%	0.3%	0.0%	-0.7%
July	-0.5%	-0.2%	0.0%	-1.3%	-0.1%	-0.2%	0.0%
August	0.7%	0.3%	0.3%	1.9%	0.4%	0.2%	0.4%
September	-0.1%	0.6%	-0.7%	0.0%	0.2%	0.2%	0.0%

Note:
Decrease greater than 10%

Table 3-25 shows changes in Delta Pumping of over 10 percent in April of Normal-Wet years. Figure 3-36 shows the changes in Delta pumping for the Existing Condition, Alternative A, and the Reach 2B capacity CalSim simulations in Normal-Wet years.



Key: cfs = cubic feet per second

Figure 3-35.
Reach 2B Capacity – Normal-Wet Years – Mean Monthly Delta Pumping

Figure 3-36 shows that in Normal-Wet year types Delta pumping in Reach 2B Capacity is closer to the Existing Conditions than to Alternative A and therefore has lower impacts.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.6.6 Sacramento River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.7 Restored Friant-Kern Canal Capacity

This evaluation replaces the impaired Friant-Kern Canal capacity in the existing LOD Alternative A with the design capacity. All other operations were held constant.

3.7.1 Millerton End-of-Month Storage

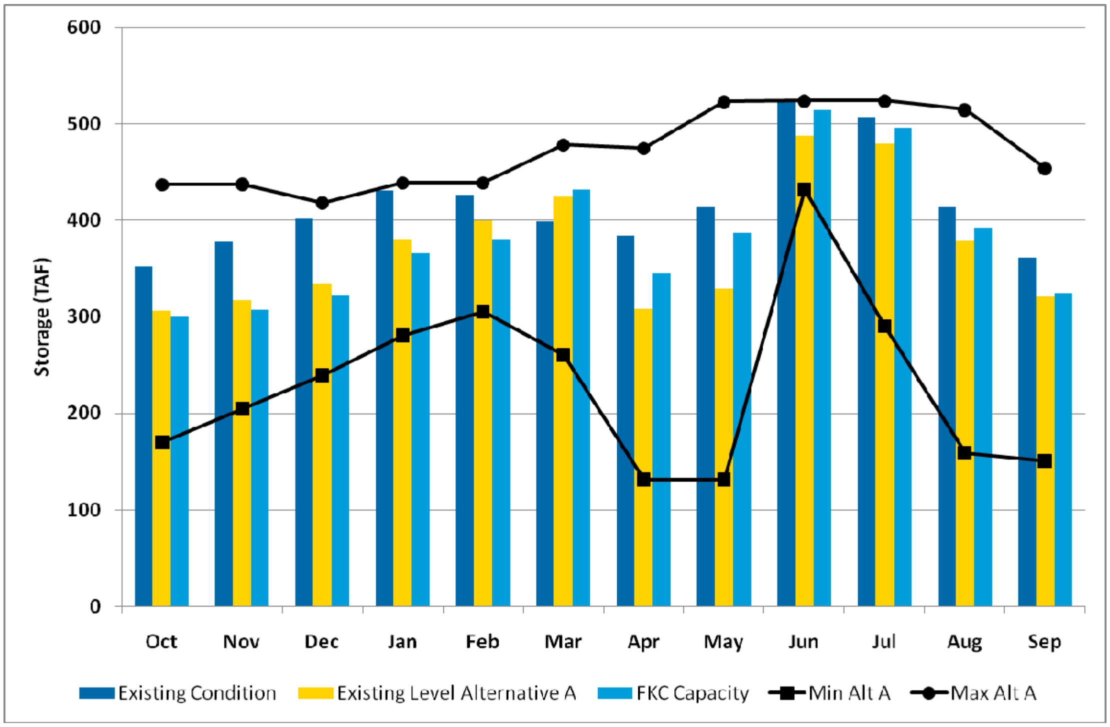
Table 3-26 is a summary table of the change in the simulated mean end-of-month Millerton storage between the Alternative A and Reach 2B Capacity Limited CalSim simulations.

Table 3-26.
FKC Capacity – Mean End-of-Month Millerton Storage – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
October	-1.5%	-2.3%	-2.9%	0.0%	1.0%	0.0%	0.0%
November	-1.5%	-2.9%	-2.5%	0.0%	1.0%	0.0%	0.0%
December	-1.5%	-3.8%	-1.9%	0.0%	0.9%	0.0%	0.0%
January	-0.9%	-3.6%	-0.4%	0.0%	0.7%	0.0%	0.0%
February	-1.0%	-5.1%	-0.4%	0.3%	0.9%	0.0%	3.0%
March	-0.4%	1.9%	-0.1%	-0.8%	-4.9%	0.2%	0.0%
April	1.7%	**12.0%**	-0.1%	-0.7%	-2.0%	0.2%	0.0%
May	2.8%	**17.6%**	0.5%	-0.5%	-1.6%	0.2%	0.0%
June	1.7%	5.5%	1.8%	-0.4%	-1.2%	0.1%	0.0%
July	1.2%	3.5%	0.8%	-0.3%	-0.6%	0.1%	0.0%
August	0.8%	3.6%	-1.1%	-0.2%	0.3%	0.1%	0.0%
September	-0.4%	1.2%	-2.8%	-0.1%	0.7%	0.0%	0.0%

Note:
Increase greater than 10%

Table 3-26 shows changes in Millerton storage of over 10 percent in April and May of Normal-Wet years. Figure 3-37 shows the changes in Millerton storage for the Existing Condition, Alternative A, and the Reach 2B capacity CalSim simulations in Normal-Wet years.



Key: TAF = thousand acre-feet

Figure 3-36.
FKC Capacity – Wet Years – Mean End-of-Month Millerton Storage

Figure 3-36 shows that in Wet year types, Millerton storage in April, and May in FKC Capacity, is closer to the Existing Conditions than to Alternative A and therefore has lower impacts.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.7.2 Millerton Release

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.7.3 Friant-Kern Canal Diversion

Table 3-27 is a summary table of the change in the simulated mean Friant-Kern Canal diversion between the Alternative A and FKC Capacity CalSim simulations.

Table 3-27.
FKC Capacity – Mean Monthly Friant-Kern Canal Diversion – Percent Change From Alternative A

	All Years	Wet	Normal-Wet	Normal-Dry	Dry	Critical-High	Critical-Low
Oct	5.2%	**12.2%**	2.1%	-0.2%	-1.3%	0.1%	0.0%
Nov	2.9%	5.9%	1.4%	-0.1%	-0.9%	0.1%	0.0%
Dec	6.4%	**21.1%**	-3.3%	-0.1%	-1.2%	0.0%	0.0%
Jan	-5.0%	4.6%	**-16.8%**	-0.1%	-0.3%	0.0%	0.0%
Feb	2.3%	9.0%	-0.2%	-1.0%	-0.6%	0.1%	0.0%
Mar	-1.5%	-3.7%	0.7%	-0.3%	-6.1%	0.1%	0.0%
Apr	-5.8%	**-14.5%**	0.0%	-0.8%	**-16.0%**	0.1%	0.0%
May	-2.1%	-4.5%	-1.5%	-0.3%	-1.7%	0.1%	0.0%
Jun	0.9%	6.9%	-2.4%	-0.2%	-1.6%	0.2%	0.0%
Jul	2.3%	5.8%	2.5%	-0.3%	-1.6%	0.2%	0.0%
Aug	1.0%	1.1%	2.4%	-0.2%	-1.7%	0.1%	0.0%
Sep	2.2%	4.9%	2.3%	-0.3%	-1.6%	0.1%	0.0%

Notes:
Increase greater than 10%
Decrease greater than 10%

Table 3-27 shows changes in Millerton storage of over 10 percent in October, December and April of Wet years, January of Normal-Wet, and April of Dry year types.

When summarized for all year types, the change in indicator is always below +/- 10 percent.

There is no substantial potential for impacts outside of PEIS/R evaluation.

3.7.4 San Joaquin River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.7.5 Delta Pumping

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.7.6 Sacramento River Delta Inflow

Change in indicator is always below +/- 10 percent. There is no substantial potential for impacts outside of PEIS/R evaluation.

3.8 Old and Middle River Delta Flow Restrictions

There are a number of on-going processes in the Delta that could impact the ability of the SWP's Banks Pumping Plant, and the CVP's Jones Pumping Plant to export water from the Delta. While the exact result of these processes is unknown at this time, they are all expected to include some sort of restriction on Delta export pumping.

The two pumps have the capacity to cause "reverse flows", or to reverse the net flow through Old and Middle Rivers (OMR) in the southwestern portion of the Delta from towards the ocean to away from the ocean. This reverse flow may confuse fish in the area and cause them to move towards the pumps with the associated risk of increased entrainment. A limit on the reverse flows is expected as a result of the on-going Delta processes.

The purpose of this evaluation is to investigate the potential for future Delta export restrictions to create impacts outside the range of potential impacts described in the PEIS/R.

For this evaluation, a limitation of -750 cfs, or a net flow of 750 cfs towards the pumps in the Old and Middle rivers was assumed to be in place from January to June. This limit has been used in other investigations, and is included in the CalLite model as a preset condition, to represent a relatively strong restriction on Delta export pumping.

A previous analysis of the potential -750 cfs limit that was done to evaluate the potential pumping restriction on the future baseline Common Assumptions version of CalSim. This included two CalSim simulations, one with the OMR restrictions and one without.

In the previous analysis, the OMR limit was discovered to cause large reductions in Delta export pumping during the January to June period. The existing CVP/SWP south of Delta delivery logic was not developed under these extreme export limitations and over-allocated the South of Delta deliveries. These high deliveries resulted in very large south of Delta delivery shortages and San Luis reservoir operating at extremely low levels. Correction of these issues required substantial modification to the CalSim south of Delta delivery logic in order to get a reasonable operation for analysis.

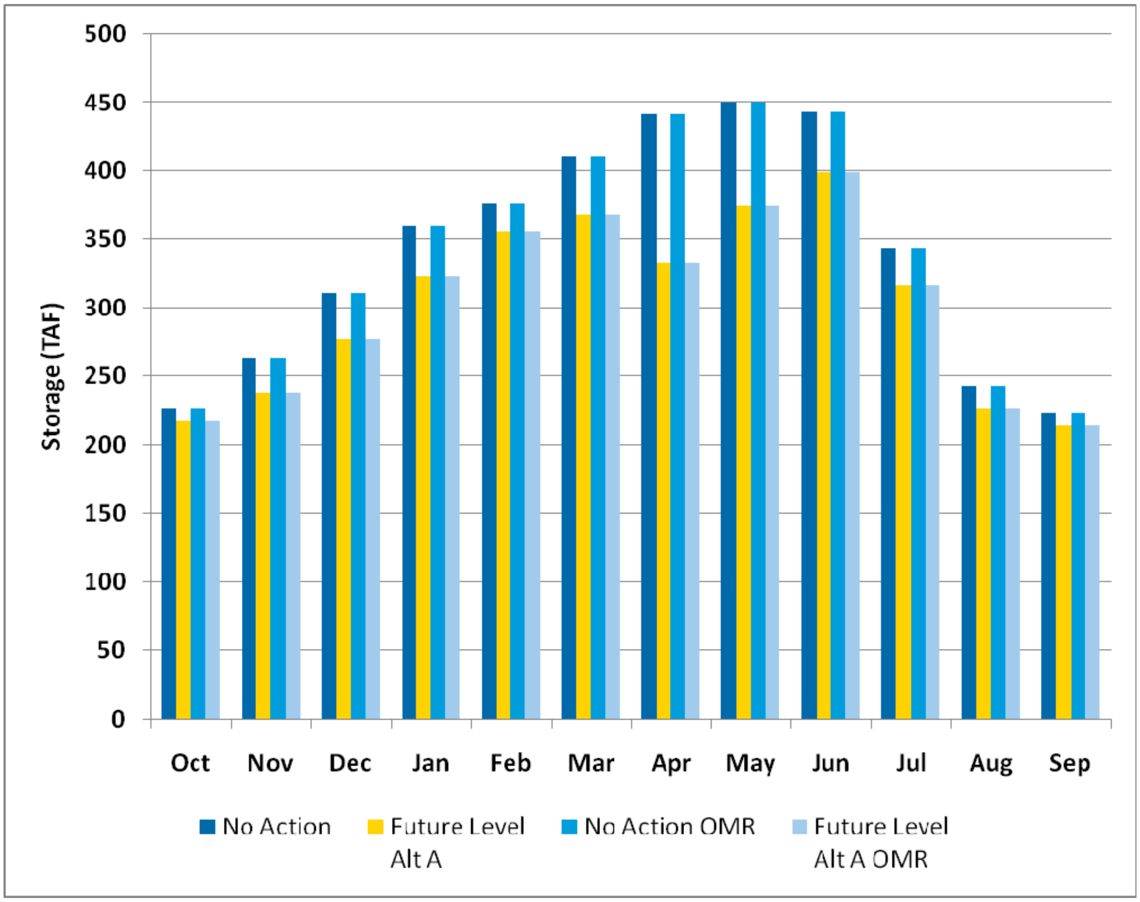
The simulations performed for the PEIS/R all include a number of modifications specific to SJRRP actions in the Restoration Area. These changes were not included in the CalSim simulations performed for the OMR limit analysis, and would require substantial modification to the OMR CalSim simulation to incorporate them.

Since this is a sensitivity analysis, the OMR CalSim simulations were rerun with the Exhibit B release requirement imposed. While this is not a complete representation of the SJRRP, it is very close and was considered acceptable for this analysis.

The same indicators as used for the other analysis in this report were then used to evaluate the potential for additional Delta export restrictions to cause impacts that are not covered in the PEIS/R. The change from the new No Action to the new Alternative A were computed and compared to the change between the OMR restricted No-Action and the OMR restricted Alternative A.

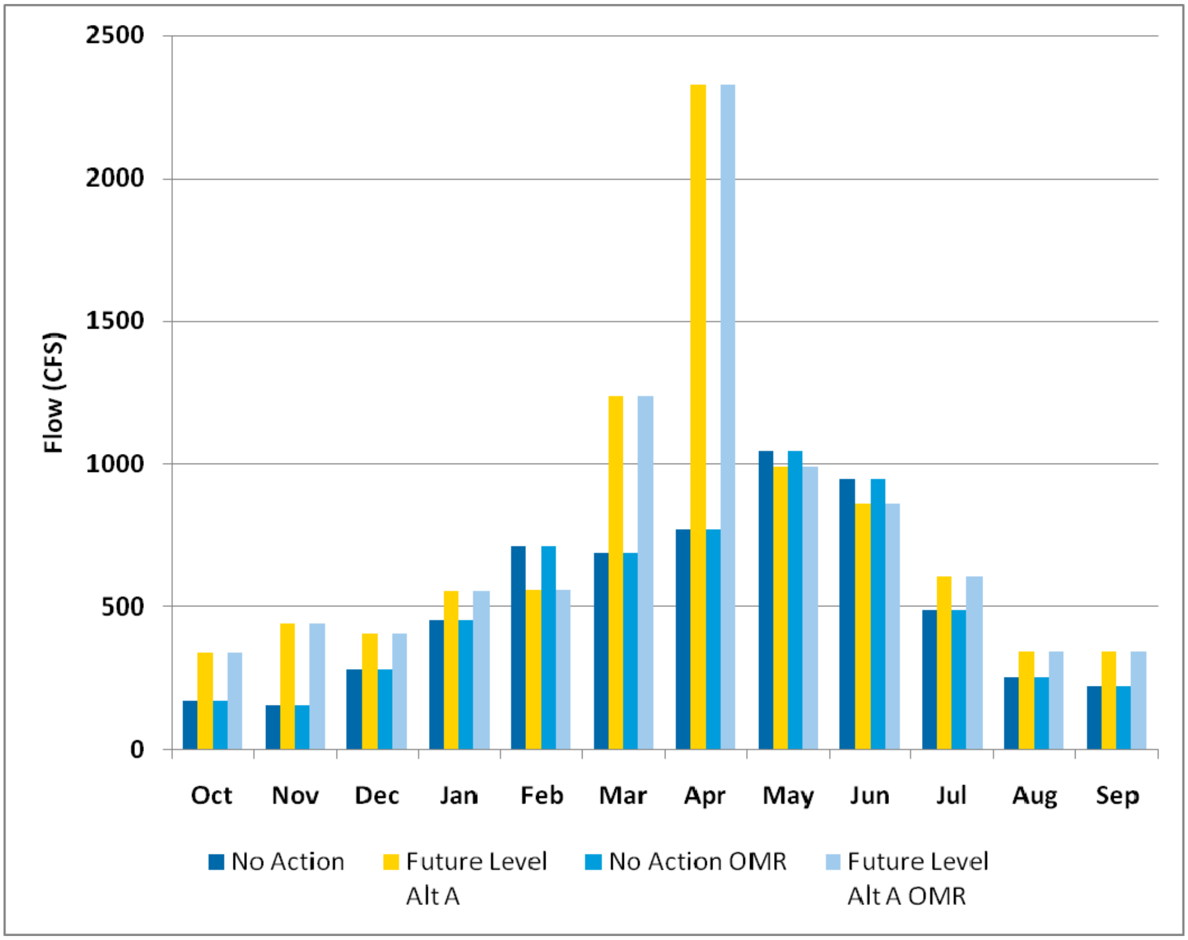
3.8.1 San Joaquin Basin Impacts

Figures 3-37 through 3-39 show the changes to Millerton storage, Millerton release, Friant-Kern Canal diversion, and San Joaquin River Delta inflow.



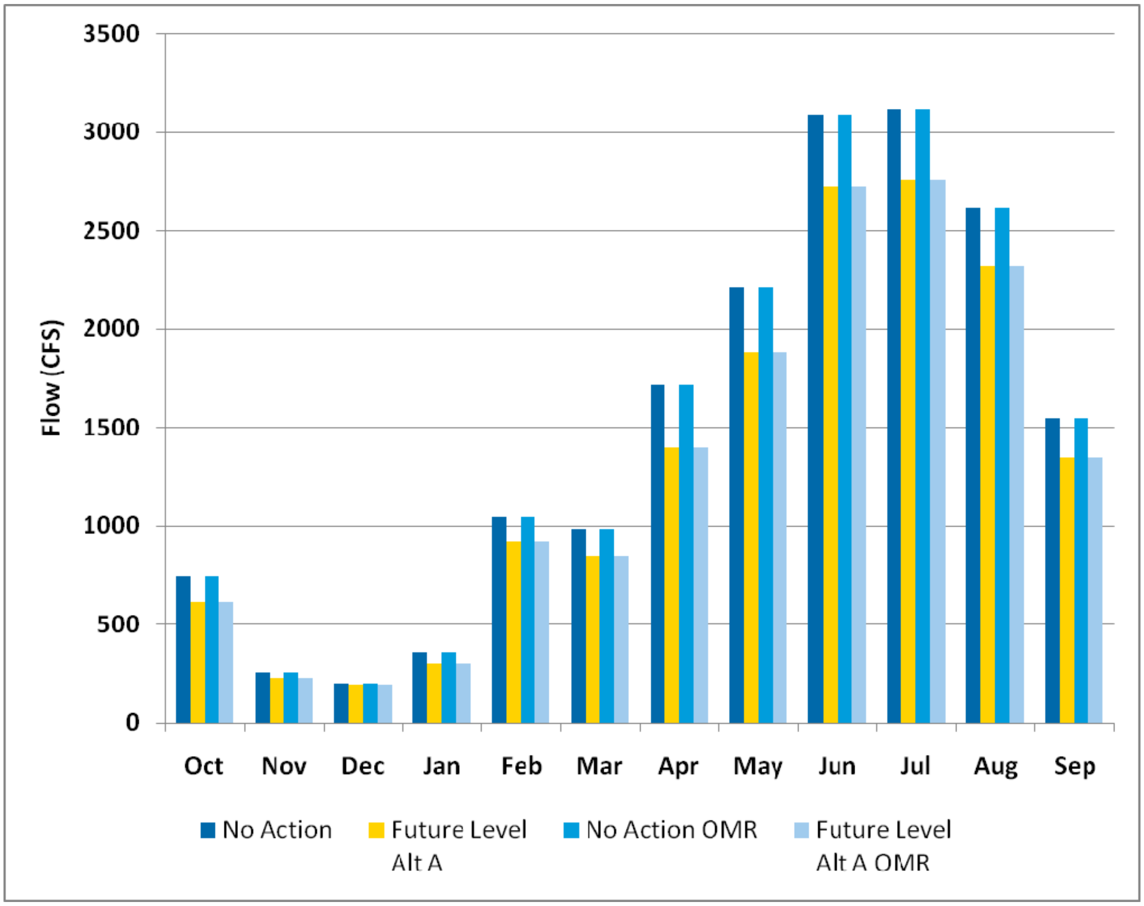
Key: TAF = thousand acre-feet

Figure 3-37.
All Years – Mean End-of-Month Millerton Storage



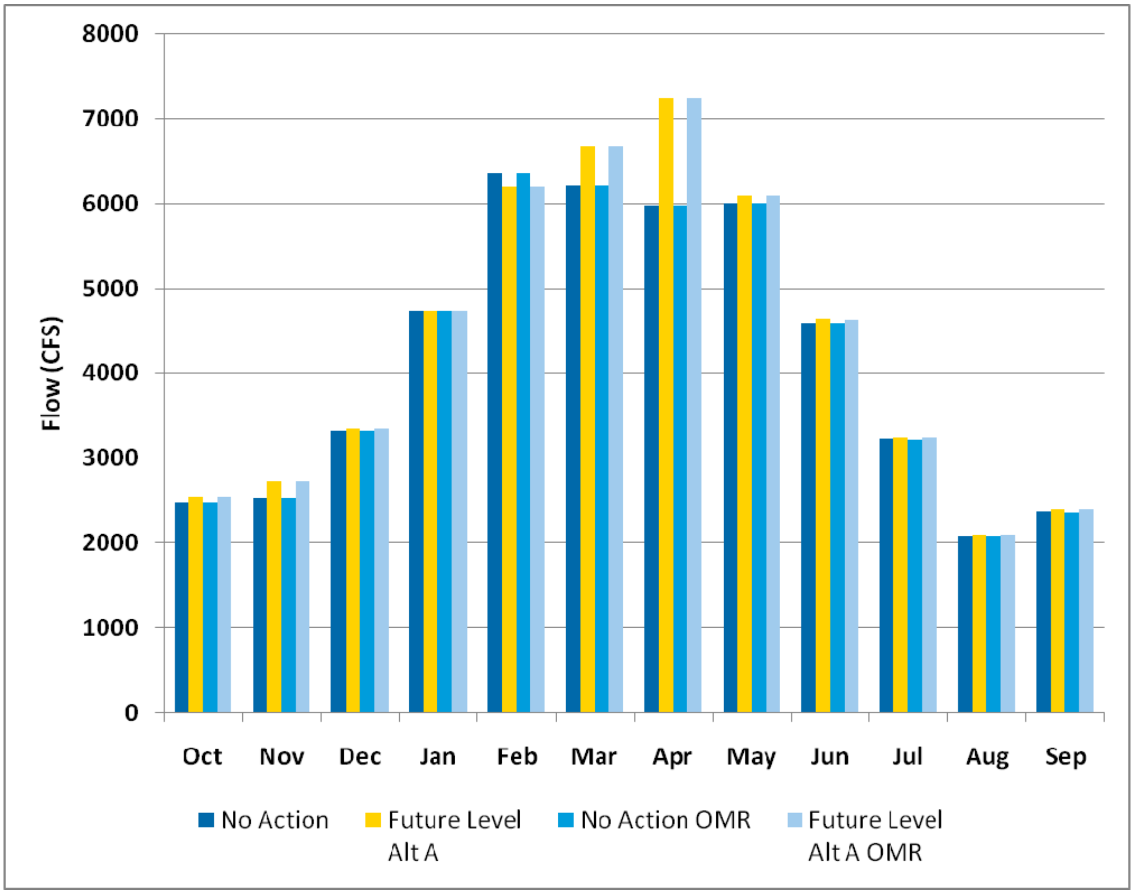
Key: cfs = cubic feet per second

Figure 3-38.
All Years – Mean Monthly Millerton Release



Key: cfs = cubic feet per second

Figure 3-39.
All Years – Friant-Kern Canal Diversion



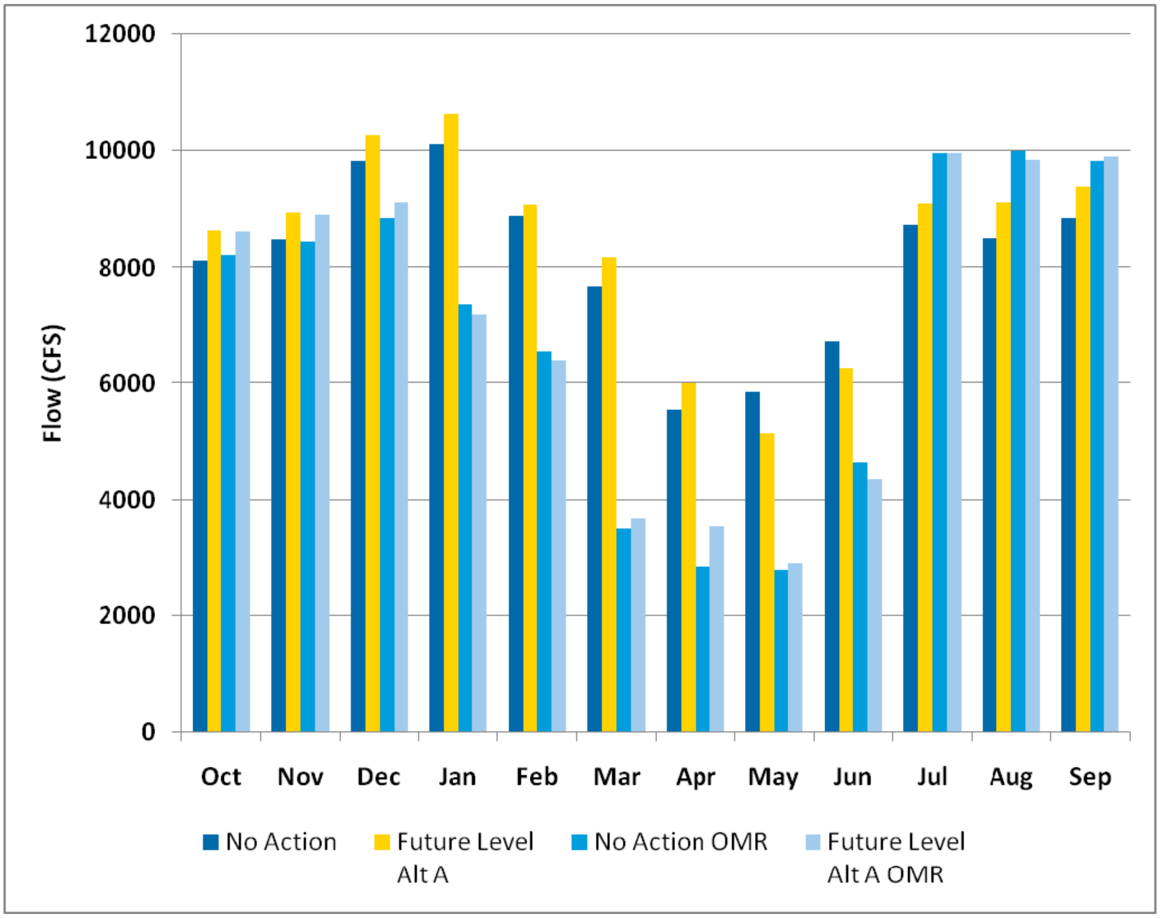
Key: cfs = cubic feet per second

Figure 3-40.
All Years – Mean Monthly San Joaquin River Delta Inflow

As can be seen in the figures, there is no impact to any of these parameters caused by stricter Delta pumping limits. This was expected as there is no connection between Millerton operations and Delta operations in CalSim; they are computed totally independently of each other.

3.8.2 Delta Pumping

Figure 3-41 shows the results for the mean monthly Delta export.



Key: cfs = cubic feet per second

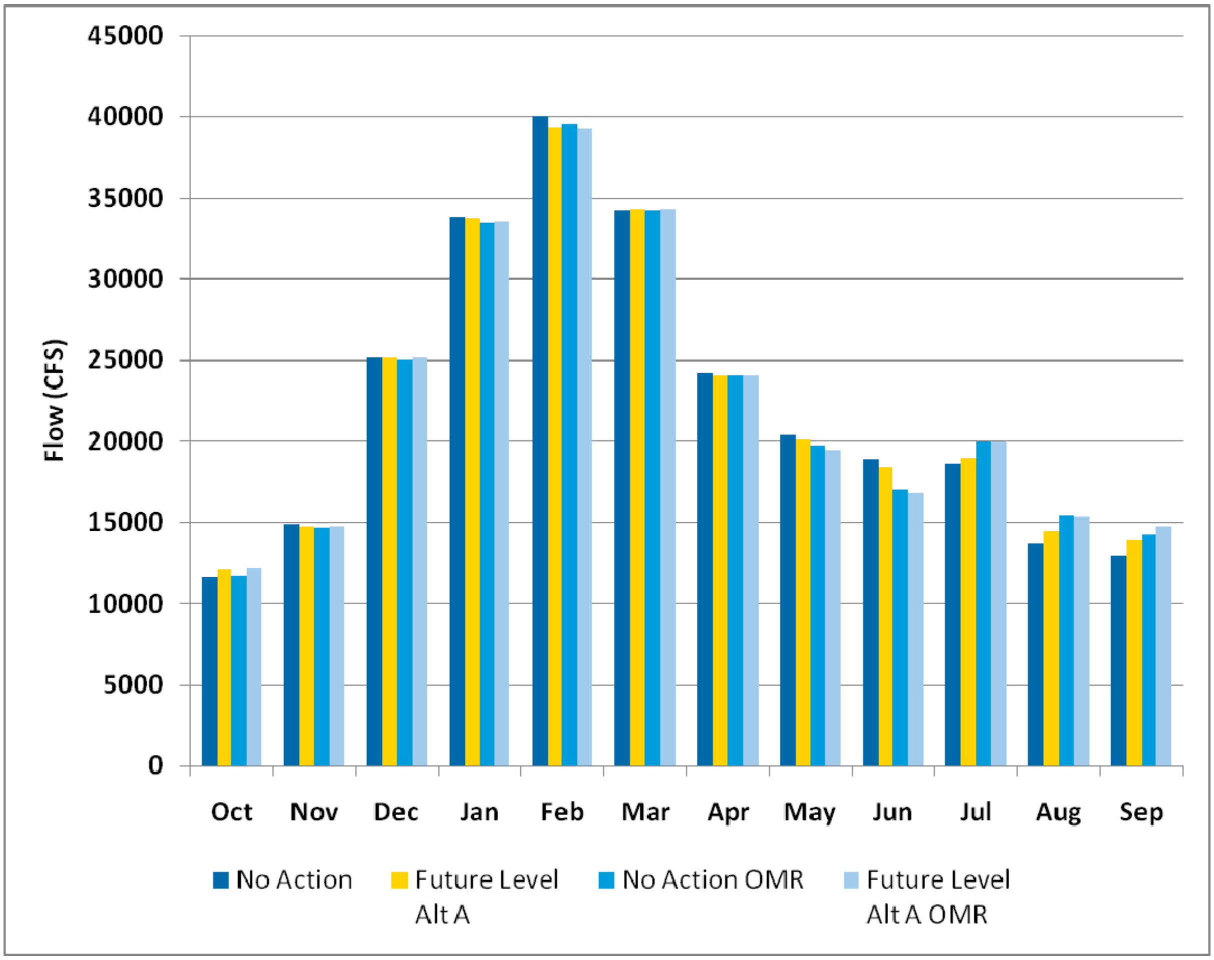
Figure 3-41.
All Years – Mean Monthly Delta Export

As expected this shows a large reduction in Delta export with the OMR restrictions in place during the January through June period. The Delta exports increase during the July to December period as the system tries to “catch up” for the export reductions.

Figure 3-41 also shows that the difference in Delta pumping due to the Restoration Flows is about the same with and without the pumping restrictions. There are some months such as May where the Delta exports increase more with the OMR restrictions in place than without, but overall the impacts are similar.

3.8.3 Sacramento River Delta Inflow

Figure 3-42 shows the results for the mean monthly Sacramento River Delta inflow.



Key: cfs = cubic feet per second

Figure 3-42.
All Years – Mean Monthly Sacramento River Delta Inflow

Figure 3-42 shows some small differences in the Sacramento River Delta inflow. This is due to the reduction in Delta exports for the same San Joaquin River Delta inflow, allowing the Sacramento River basin CVP/SWP system to react differently with and without the OMR restrictions.

3.9 Climate Change and Sea Level Rise

This analysis is documented in a separate report prepared by Reclamation. The report is included as Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise Attachment.

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4.0 Summary

None of the variations evaluated are expected to cause impacts that are outside the range of values analyzed in the PEIS/R.

The variations cause relatively minor changes to water operations. In many cases, the results of the supplemental analyses are closer to the Existing Condition than to the PEIS/R alternatives. This demonstrates that the actions investigated through the supplemental analysis are within the range of impacts described by the PEIS/R alternatives.

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5.0 Additional Modeling Outputs

Representative outputs from the CalSim simulations performed in support of this analysis are included as the Supplemental Water Operations Modeling Output – CalSim Attachment.

The attachment describes several types of outputs including the following:

- CalSim Output Comparison tables
- CalSim Output Data Tables
- Indicator Comparison Tables
- Indicator Comparison Figures
- Indicator Comparison Tables – Delta Restrictions
- Indicator Comparison Figures – Delta Restrictions

5.1 CalSim Output Comparison Tables

These tables show a comparison, by water year type, between each of the actions evaluated in this analysis for selected CalSim output variables. Table 5-1 is an example of these tables.

5.2 CalSim Output Data Tables

These tables are monthly data tables of selected CalSim output variables. The tables include water year type statistics. Table 5-2 is an example of these tables.

Table 5-1.
Example CalSim Output Table

Monthly Averages of Simulated End-of-Month Millerton Lake Storage (TAF) – Restoration All Years								
Month	**Existing Level (2005)**							
	Alternative A	**Exhibit B**	**Buffer**	**Flex Early**	**Flex Late**	**No 16B**	**Cap 2B (1,300 cfs)**	**FKC Cap Restoration**
March	366	367 (0%)	359 (-2%)	286 (-22%)	391 (7%)	372 (2%)	357 (-3%)	366 (0%)
April	339	335 (-1%)	352 (-4%)	334 (-1%)	419 (2%)	348 (3%)	366 (8%)	338 (0%)
May	386	385 (0%)	377 (-2%)	374 (-3%)	393 (2%)	396 (3%)	400 (4%)	386 (0%)
June	406	407 (0%)	398 (-2%)	411 (1%)	403 (-1%)	407 (0%)	415 (2%)	406 (0%)
July	321	321 (0%)	316 (-2%)	324 (1%)	307 (-4%)	321 (0%)	326 (2%)	321 (0%)
August	229	229 (0%)	226 (-1%)	231 (1%)	218 (-5%)	229 (0%)	231 (1%)	229 (0%)
September	214	214 (0%)	212 (-1%)	215 (1%)	205 (-4%)	215 (0%)	215 (0%)	214 (0%)
October	214	215 (0%)	211 (-1%)	209 (-2%)	207 (-3%)	215 (0%)	215 (0%)	214 (0%)
November	235	235 (0%)	230 (-2%)	236 (0%)	234 (0%)	236 (0%)	236 (0%)	235 (0%)
December	274	274 (0%)	267 (-2%)	275 (0%)	267 (-3%)	274 (0%)	274 (0%)	273 (0%)
January	321	321 (0%)	314 (-2%)	322 (0%)	315 (-2%)	322 (0%)	321 (0%)	321 (0%)
February	343	343 (0%)	337 (-2%)	323 (-6%)	338 (-2%)	346 (1%)	342 (0%)	343 (0%)

Source: Calsim II Simulations (Node S18)

Notes:
Simulation Period: October 1921 - September 2003
(%) indicates percent change from Alternative A
Key
TAF = thousand acre-feet

Table 5-2.
Example CalSim Output Data Table

Simulated End-of-Month Millerton Lake Storage (TAF) – Alternative A (2005) – Restoration Year Type													
Year	**Year Type**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**
1921	Normal-Wet								215	233	292	360	439
1922	Normal-Wet	422	168	244	515	481	299	240	248	277	358	424	439
1923	Normal-Wet	441	392	468	430	347	229	211	235	261	275	287	287
1924	Critical High	273	314	316	233	159	134	159	160	177	207	239	313
1925	Normal-Dry	292	293	365	360	283	191	182	207	226	247	262	294
1926	Normal-Dry	295	382	496	433	277	171	176	180	219	267	307	423
1927	Normal-Wet	437	341	428	523	423	265	218	235	311	350	380	380
1928	Normal-Dry	439	450	515	436	277	183	183	165	158	166	174	168
1929	Dry	145	161	244	228	171	142	176	153	135	138	149	163
1930	Dry	147	213	222	239	168	140	175	158	148	153	162	166
1931	Critical High	133	184	205	162	131	131	151	155	153	216	287	287
1932	Normal-Wet	440	324	355	471	423	267	219	230	253	267	290	281
1933	Normal-Dry	277	262	192	257	227	164	181	183	179	213	253	276
1934	Dry	314	402	382	284	188	158	169	160	167	195	253	314
1935	Normal-Wet	281	241	374	508	387	243	209	227	258	275	311	311
1936	Normal-Wet	479	442	523	515	385	240	200	206	228	261	293	439
1937	Normal-Wet	479	323	459	523	403	232	180	196	223	409	439	295
1938	Wet	301	251	348	524	524	430	339	307	311	317	344	314

Table 5-2.
Example CalSim Output Data Table (contd.)

Simulated End-of-Month Millerton Lake Storage (TAF) – Alternative A (2005) – Restoration Year Type

Year	Year Type	March	April	May	June	July	August	September	October	November	December	January	February
1939	Dry	372	485	473	366	241	158	173	189	183	185	301	301
1940	Normal-Wet	456	392	523	523	364	207	170	176	198	283	392	439
1941	Wet	479	430	402	519	524	370	288	291	315	395	439	439
1942	Normal-Wet	462	392	411	514	476	304	238	248	301	342	412	439
1943	Normal-Wet	479	450	523	504	380	239	202	208	234	253	280	280
1944	Normal-Dry	300	251	316	314	248	176	184	199	246	299	338	439
1945	Normal-Wet	457	343	411	469	404	263	223	270	351	439	438	439
1946	Normal-Wet	453	417	524	494	360	225	201	226	296	379	424	439
1947	Normal-Dry	466	456	521	417	266	172	180	177	177	184	193	193
1948	Normal-Dry	131	136	225	292	216	165	189	194	192	210	227	236
1949	Normal-Dry	211	239	336	355	234	160	176	193	202	218	256	320
1950	Normal-Dry	298	338	410	398	278	175	181	202	357	381	438	439
1951	Normal-Wet	455	378	380	347	256	178	184	192	198	261	398	398
1952	Wet	331	194	370	510	499	376	296	282	286	318	405	417
1953	Normal-Dry	420	395	352	301	262	184	188	189	191	203	230	265
1954	Normal-Dry	275	316	440	410	294	191	178	192	206	236	273	299
1955	Normal-Dry	284	240	258	316	226	165	179	181	180	351	351	351

Table 5-2.
Example CalSim Output Data Table (contd.)

Simulated End-of-Month Millerton Lake Storage (TAF) – Alternative A (2005) – Restoration Year Type													
Year	**Year Type**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**
1956	Wet	478	409	434	505	474	347	283	296	318	330	355	378
1957	Normal-Dry	375	302	310	375	285	190	189	207	220	261	298	378
1958	Wet	423	270	406	524	499	362	290	281	286	293	329	376
1959	Normal-Dry	446	500	477	386	246	144	177	179	169	169	176	176
1960	Dry	190	275	309	272	185	155	172	153	151	176	188	198
1961	Critical High	166	230	235	198	136	136	161	167	175	205	234	401
1962	Normal-Wet	367	320	393	466	389	249	214	233	259	269	304	439
1963	Normal-Wet	452	325	341	424	379	252	222	243	314	355	382	382
1964	Dry	369	358	357	315	210	160	175	161	176	299	438	439
1965	Normal-Wet	417	286	298	326	289	240	220	236	339	412	438	439
1966	Normal-Dry	478	520	523	425	261	157	163	151	162	367	438	439
1967	Wet	468	266	257	524	524	450	359	285	272	280	303	303
1968	Dry	327	383	415	340	211	163	185	166	179	223	351	341
1969	Wet	262	132	371	524	524	432	333	293	294	317	438	439
1970	Normal-Dry	478	415	426	414	290	200	197	197	219	288	353	386
1971	Normal-Dry	376	336	339	323	240	172	186	201	218	272	308	308
1972	Normal-Dry	386	354	359	319	199	133	176	175	189	227	294	385

Table 5-2.
Example CalSim Output Data Table (contd.)

Simulated End-of-Month Millerton Lake Storage (TAF) – Alternative A (2005) – Restoration Year Type													
Year	**Year Type**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**
1973	Normal-Wet	377	249	475	523	380	221	177	201	294	384	439	439
1974	Normal-Wet	478	417	497	523	387	242	197	215	247	279	314	347
1975	Normal-Wet	378	220	300	507	398	245	216	260	305	329	345	345
1976	Critical High	372	393	381	270	163	133	176	182	182	194	211	217
1977	Critical Low	219	240	213	181	141	131	152	152	152	230	388	432
1978	Wet	428	303	353	524	524	440	433	378	375	381	439	439
1979	Normal-Wet	479	431	523	523	362	215	181	201	240	269	380	380
1980	Wet	479	471	500	524	524	424	342	303	304	310	331	306
1981	Normal-Dry	337	356	419	363	230	161	178	175	228	284	390	435
1982	Wet	416	488	524	524	524	444	428	437	432	418	412	416
1983	Wet	479	208	131	524	524	507	441	387	437	407	439	439
1984	Normal-Wet	478	385	439	401	296	209	207	231	283	324	360	375
1985	Normal-Dry	380	434	488	396	253	159	179	182	202	262	341	393
1986	Wet	479	395	460	522	436	279	232	258	278	291	314	315
1987	Dry	344	417	456	365	227	170	185	170	174	192	240	240
1988	Dry	254	310	325	273	185	154	175	155	143	156	170	185
1989	Normal-Dry	208	320	362	304	196	155	179	175	173	184	201	213

Table 5-2.
Example CalSim Output Data Table (contd.)

Simulated End-of-Month Millerton Lake Storage (TAF) – Alternative A (2005) – Restoration Year Type													
Year	**Year Type**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**
1990	Dry	207	297	287	230	171	152	166	152	140	142	143	136
1991	Normal-Dry	146	152	193	240	175	143	184	170	168	183	201	201
1992	Dry	239	343	388	287	194	158	173	158	151	175	347	439
1993	Wet	479	383	480	522	507	351	279	281	282	306	328	330
1994	Dry	365	400	416	353	232	157	172	195	220	259	438	426
1995	Wet	454	380	283	524	524	481	367	271	246	261	312	312
1996	Normal-Wet	479	434	523	522	396	246	204	216	315	429	351	422
1997	Wet	478	447	523	432	290	159	150	170	204	239	334	439
1998	Wet	479	508	348	524	524	444	345	284	284	304	353	361
1999	Normal-Wet	389	337	400	432	298	192	188	204	216	230	297	297
2000	Normal-Wet	439	407	517	523	359	220	191	210	237	253	276	297
2001	Normal-Dry	322	332	442	374	237	162	177	167	171	222	276	304
2002	Normal-Dry	289	353	404	375	260	168	173	166	212	250	303	339
2003	Normal-Wet	327	273	331	399	269	182	182					

Table 5-2.
Example CalSim Output Data Table (contd.)

Simulated End-of-Month Millerton Lake Storage (TAF) – Alternative A (2005) – Restoration Year Type													
Year	**Year Type**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**
	Average	366	339	386	406	321	229	214	214	235	274	321	343
	Wet	432	346	387	516	497	393	325	300	308	323	367	376
	Normal-Wet	432	347	426	476	372	236	204	222	267	319	360	378
	Normal-Dry	329	339	382	358	248	168	181	184	203	248	287	319
	Dry	273	337	356	296	199	156	175	164	164	191	265	279
	Critical High	236	280	284	216	147	133	162	166	172	205	243	304
	Critical Low	219	240	213	181	141	131	152	152	152	230	388	432
	Dry and Critical	261	318	331	270	183	149	170	164	165	197	267	294

5.3 Indicator Comparison Tables

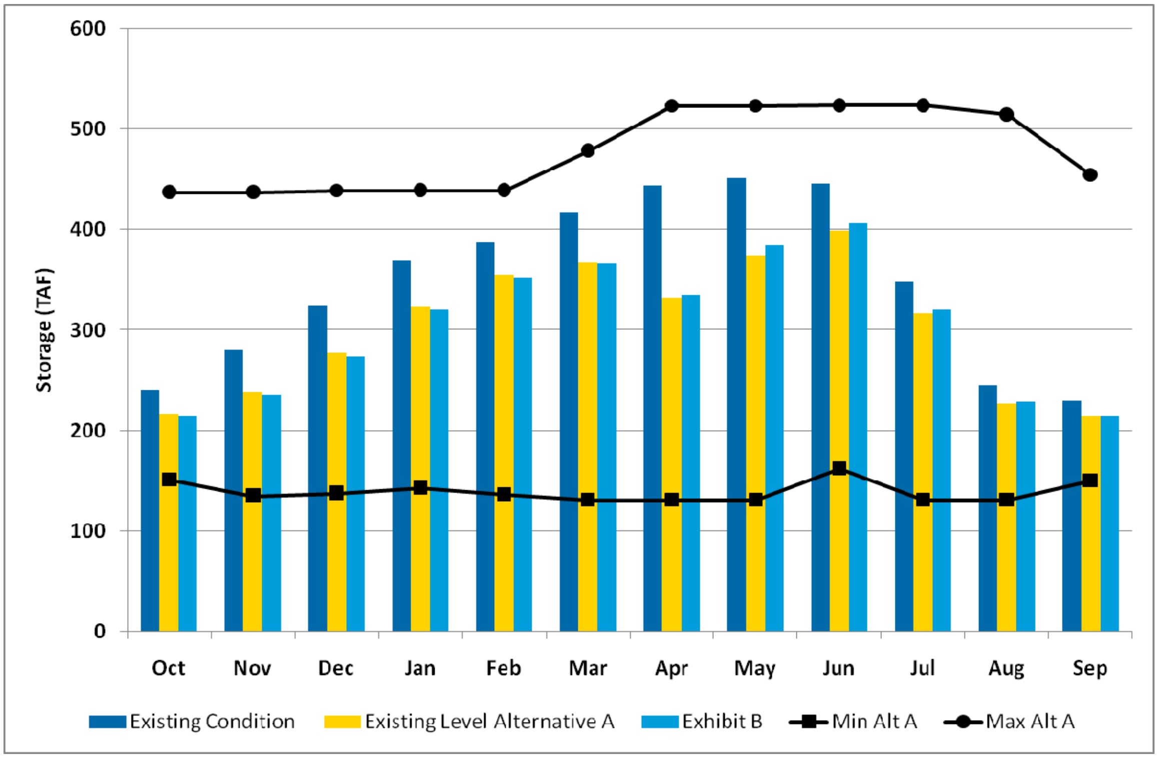
These tables show the change in each impact indicator between the Existing Condition, Alternative A, and the Action simulations.

Table 5-3.
Example Indicator Comparison Table

Exhibit B – All Years – Mean End of Month Millerton Storage					
Existing Condition (TAF)	Existing Level Alternative A (TAF)	Exhibit B (TAF)	Existing Level Alternative A % Change from Existing Condition	Exhibit B	
				% Change from Existing Condition	% Change from Alt A
241	217	215	-9.8%	-10.9%	-1.2%
280	239	235	-14.9%	-16.0%	-1.4%
325	277	274	-14.5%	-15.7%	1.3%
369	323	231	-12.3%	-13.0%	-0.8%
387	356	353	-8.1%	-9.0%	-0.9%
418	368	367	-12.1%	-12.3%	-0.2%
444	333	335	-25.1%	-24.4%	0.8%
452	375	385	-17.0%	-14.9%	2.6%
446	399	407	-10.5%	-8.8%	1.8%
348	317	321	-9.0%	-7.8%	1.3%
245	227	229	-7.5%	-6.6%	1.0%
230	214	214	-6.9%	-0.1%	-0.1%

Key:
TAF = thousand acre-feet

Figure 5-1 is an example of an indicator comparison figure. These show the values of the Existing Condition, Alternative A, and the Action simulations as columns. The two lines are the minimum and maximum values from Alternative A. The lines were added to allow evaluation of the potential for the Action to be outside the range of Alternative A that was evaluated in the PEIS/R. These are a complete set of the figures that were used throughout the analysis.



Key: TAF = thousand acre-feet

Figure 5-1.
Example Indicator Comparison Figure

5.4 Indicator Comparison Tables – Delta Restrictions

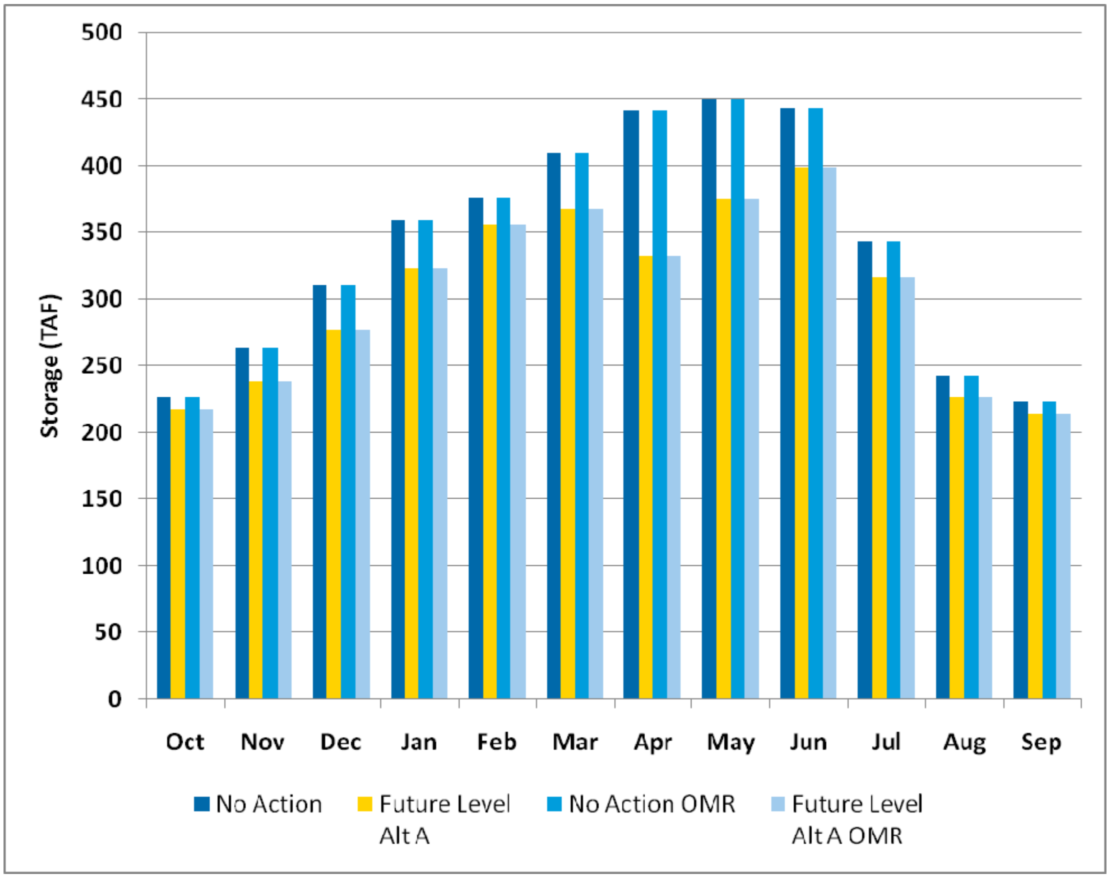
Table 5-4.
Monthly Averages of Simulated End-of-Month Millerton Lake Storage – Restoration All Years

Month	No OMR Restriction		OMR Restriction	
	Future No Action (TAF)	Future Alt A (TAF)	Future No Action (TAF)	Future Alt A (TAF)
March	411	367 (-11%)	411	367 (-11%)
April	442	333 (-25%)	442	333 (-25%)
May	450	375 (-17%)	450	375 (-17%)
June	443	399 (-10%)	443	399 (-10%)
July	344	317 (-8%)	344	317 (-8%)
August	243	227 (-7%)	243	227 (-7%)
September	224	214 (-4%)	224	214 (-4%)
October	227	217 (-4%)	227	217 (-4%)
November	264	238 (-10%)	264	238 (-10%)
December	311	277 (-11%)	311	277 (-11%)
January	360	323 (-10%)	360	323 (-10%)
February	370	346 (-6%)	370	346 (-6%)

Source: CALSIM II Modeling (Node S18)

Notes:
Simulation Period: October 1921 – September 2003
(%) indicates percent change from either No-Action or No-Action with OMR
Key:
Alt = Alternative
TAF = thousand acre-feet

5.5 Indicator Comparison Figures – Delta Restrictions



Key: TAF = thousand acre-feet

Figure 5-2.
Example Indicator Comparison Figure

Attachment

Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise

Draft
Supplemental Hydrologic and Water Operations Analyses Appendix

Draft
April 2011

Executive Summary

Numerous studies have been conducted on the potential implications of climate change for water resources management in California's Central Valley. Such studies have suggested that climate change resulting in future warming would lead to more rain and less snow, less spring-summer runoff, increased crop water needs, and rising sea levels. The uncertainty of coincidental precipitation change confounds these messages, as precipitation increases or decreases would generally offset or reinforce warming-related impacts, respectively.

For the San Joaquin Valley, regional climate change could affect surface water supplies from mountain headwater basins. Further, sea level rise from global climate change could affect San Francisco Bay, Sacramento-San Joaquin Delta (Bay Delta) conditions that constrain Central Valley Project / State Water Project (CVP/SWP) operations in the Sacramento-San Joaquin Delta (Delta), and also lead to changes in upstream operations in the San Joaquin Basin.

This report offers an analysis of how the measured effects of reservoir release changes associated with the San Joaquin River Restoration Program (SJRRP) are sensitive to future assumptions on regional climate affecting Sacramento-San Joaquin Basin hydrology, and sea level affecting Delta conditions. Such effects are measured by comparing storage, delivery and river flow changes associated with the preferred action alternative under the SJRRP versus a future without this action. Effects depend on the underlying climate context, and associated hydrologic and Delta assumptions. This analysis explores how those effects would change if the underlying climate context was also changed.

Because the SJRRP action alternatives would apply through 2026, a look-ahead horizon for climate change implications was adopted as roughly 2030. Similar to the climate change sensitivity analysis featured in the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) *Appendix R of the 2008 Central Valley Project/State Water Project Operations Criteria and Plan –Biological Assessment* (Reclamation 2008a), scoping for this study focused on three areas: definition of regional climate change scenarios, definition of a sea level rise scenario, and selection of methods for conducting "scenario-impacts" analyses.

- Definition of regional climate change scenarios led to the selection of five regional climate possibilities:
    - The first four were chosen for how they bracket a range of possible regional climates, similar to the approach in Reclamation (2008a). Possible regional climates were defined by paired precipitation-temperature conditions. Projection information was surveyed for changes in these conditions, given four selection factors: (1) historical and future climate periods, (2) climate

change metrics, (3) location of climate change, and (4) change-range of interest. SJRRP considerations influenced each factor decision. The resultant projection selections are similar to those selected in Reclamation (2008a) in that they collectively span regional climate changes that vary from: less warming to more warming from historical, and, drier to wetter than historical. They differ from those selected in Reclamation (2008a) in that the selection factors were geographically unique to SJRRP interests rather than the greater Central Valley region featured in Reclamation (2008a).

  - The fifth is chosen for how it represents a centrally projected climate change over the region. Such a selection was not included in the approach in Reclamation (2008a). The projections assessment used to support selection of the four *spanning* regional climate change scenarios above also supported selection of this fifth "centrally expected" scenario. Specifically, the fifth scenario came from the projection that provided a paired precipitation-temperature change that best represented the centrally projected change among the collection of projections considered.

- Definition of the sea level rise scenario followed the rationale in Reclamation (2008a) using a new sea level rise ANN dynamic-link library (DLL) which featured slight changes to the X2 location representation but was virtually identical in its representation of delta salinity. Comparison of model runs with the old and new sea level rise ANN's did not show significant changes to results for delta outflow, exports, or end of year storage. This sea level rise scenario was assumed to occur in combination with each of the five regional climate change scenarios considered.

- Given scenarios for both regional climate change and sea level rise, scenario-impacts assessment followed, using methods described in Reclamation (2008a).

  - Hydrologic response to each of the five regional climate change scenarios was simulated in nine headwater basins tributary to CVP/SWP and San Joaquin systems, following the approach in Reclamation (2008a). Results from each scenario analysis produced information on period-mean monthly changes in natural runoff that were then translated into changes in CVP/SWP reservoir inflows.

  - CVP/SWP and San Joaquin Basin operations were simulated under 12 study conditions, stemming from 2 future operations depictions (i.e., the SJRRP future with preferred-action or no-action) and 6 regional climates (i.e., the future with historical climate, or any of the five regional climate change scenarios mentioned above). For the scenarios involving regional climate change, the associated natural runoff results were used to adjust runoff-related inputs in the operations analysis following methods from in Reclamation (2008a). Also, in each study involving regional climate change, there was the coincidental assumption of sea level rise defined by the scenario above. CVP/SWP water demands were not modified based on the assumption that district-level demand-management flexibility existed for Federal, State and local water users, enough so that district-level water demands wouldn't necessarily change even though crop-specific water needs would be expected to increase with warming.

– To explore how the effects measurement was sensitive to climate assumption, results were evaluated for each pairing of "no action" and "preferred action" studies by climate assumption. Given six climate assumptions, this led to six sets of effects measurements. Results across these sets of effects measurements were then evaluated to assess the sensitivity of effects measurement to the underlying climate assumption.

Results from this climate change study are consistent with previous literature studies, suggesting that a range of possible impacts could occur for water supply, CVP/SWP operations, and dependent conditions.

- **Natural Runoff and Water Supply - Monthly Impacts –** Each of the regional climate change scenarios involved some amount of future warming. Hydrologic analyses show that future warming would cause a greater fraction of annual runoff to occur during winter and early spring. In relation, the fraction of annual runoff during late spring and summer would decrease. This is consistent with earlier studies showing that warming would lead to more rain and less snow, more rainfall-runoff during winter and early spring and less snowmelt volume during late spring and summer. However, magnitude changes depend significantly on precipitation changes. Increased monthly precipitation would reinforce warming-related influences during winter and early spring runoff (presuming storms are still warmer, but involve more precipitation), and perhaps offset warming-related influences in late spring and summer runoff. In contrast, precipitation decreases would interact with warming to produce generally opposite seasonal effects.

- **Natural Runoff and Water Supply - Annual Impacts –** Results suggest that regional climate change over the Central Valley leading to either more or less mean-annual precipitation would be more influential on annual runoff than changes in mean-annual temperature.

- **SJRRP Effects on San Joaquin Basin Operations Above Vernalis –** Sensitivity to Climate and Sea Level Rise Assumptions: SJRRP effects seen under historical climate conditions include the following:

  – 152 thousand acre-feet per year (TAF/year) increase in overall releases from Friant Dam

    - 321 TAF/year increase in main (scheduled) release
    - 169 TAF/year decrease in flood and snowmelt release

  – 150 TAF/year reduction in delivery to Friant Kern and Madera Canals

  – Increased flows at Vernalis of 120 TAF/year

The same effects are maintained for all of the regional climate change scenarios considered. Allocation to Restoration Flow releases depends on the unimpaired inflow at Friant, which varies with the climate projection. Variations in effects are due to the specific Restoration Flow release schedules determined for each climate projection. The ensemble of results is summarized below:

- Increase in overall Friant Dam release was 127 TAF/year under the centrally projected climate scenario, and varied between 108 and 156 TAF/year under the four bracketing climate change scenarios
- Flood and snowmelt release reductions range from 135 to 260 TAF/year
- Reduction to Friant-Kern and Madera canals deliveries was 126 TAF/year under the centrally projected climate change scenario, and varied from 106 to 154 TAF/year under the four bracketing climate change scenarios
- The flow increase at Vernalis was 102 TAF/year under the centrally projected climate change, and varied from 102 to 124 TAF/year under the four bracketing climate change scenarios.

The timing of flood and snowmelt release, coupled with the Restoration Flow release schedule, ultimately determines the effects of flows at Vernalis, which in turn influence overall CVP/SWP operations.

- **SJRRP Effects on CVP/SWP Operations - Sensitivity to Climate and Sea Level Rise Assumptions –** SJRRP effects under historical climate conditions include increased Delta outflow and project export, and modest changes to flows at Freeport and north-of-Delta (NOD) storage:

  - Overall increase in Delta exports of 91 TAF/year
  - Overall increase to Delta outflow of 24 TAF/year
  - Reduced Sacramento River flow at Freeport by 15 TAF/year
  - Increase in carryover storage levels in NOD project reservoirs of 56 TAF

  As with effects in the San Joaquin Basin, SJRRP effects under the range of projected climate scenarios follow similar trends to those seen for historical climate:

  - Delta exports increased under the centrally projected climate scenario by 96 TAF/year, and increases varied from 46 to 110 TAF/year under the four bracketing climate change scenarios
  - Delta outflow increased under the centrally projected climate by 2 TAF/year, and overall average changes varied from -6 to 60 TAF/year under the four bracketing climate change scenarios
  - Sacramento River flow at Freeport decreased by between 6 and 17 TAF/year for the five climate scenarios investigated
  - Carryover storage in NOD project reservoirs increased by between 16 and 43 TAF

These results quantify how the measured effects of reservoir release changes associated with the SJRRP are sensitive to future assumptions on regional climate and sea level affecting Delta conditions. While using the best available scientific information, the results do not fully represent uncertainties associated with a number of key analytical assumptions, including those related to the following:

- Climate forcing (e.g., greenhouse gas (GHG) emissions pathways, translation into perturbed biogeochemical cycles, atmospheric accumulation of GHGs, and altered atmospheric forcing on climate)
- Climate simulation (e.g., physical paradigms that underlie climate models, and computational limitations)
- Climate projection bias-correction (i.e., whether climate model tendencies to be wet/cool or warm/dry should be accounted for and imposed on the analysis, as they were in this study given the projection information used)
- Climate projection downscaling (e.g., how monthly timestep, large-scale climate projections produced by global climate models should translate into "basin-relevant" local scales and with what submonthly time characteristics)
- Watershed response (e.g., how long-term groundwater and/or land cover responses would interact with the hydrologic cycle to affect surface water runoff assessed in this analysis)
- Social response (e.g., how district-level water and energy demands might evolve with climate change and reservoir operating objectives, or, how societal values concerning flood protection, environmental management, recreation, etc., might evolve and lead to changed constraints on reservoir operations)
- Discretionary operational response (i.e., how this analysis, except for adjustments made to CVP/SWP allocation rules related to foresight of reservoir inflows, reflects a "static" operator that is unresponsive to climate change, when realistically some degree of operators' learning and change in discretionary operation might be anticipated)

Consequently, the results from this study should be viewed as conditional on analytical assumptions and with potentially significant uncertainties not quantified or represented.

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Abbreviations and Acronyms

°C	degrees Celsius
°F	degrees Fahrenheit
ANN	Artificial Neural Network
BA	Biological Assessment
BCSD	Bias-Correction Spatial Disaggregation
BSR	Biennial Science Report
CACMP9b	Common Assumptions Common Model Package Version 9b
CALFED	CALFED Bay-Delta Program
CAT	Climate Action Team
CCAT	California Climate Action Team
cfs	cubic feet per second
cm	centimeter
CMIP	Coupled Model Intercomparison Project
CNRFC	California-Nevada River Forecast Center
CO_2	carbon dioxide
CONV	Convolution and polynomial multiplication
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
D-1485	California State Water Resources Control Board Water Right Decision 1485
D-1641	California State Water Resources Control Board Water Right Decision 1641
DCP	downscaled climate projections
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
ET	Evapotranspiration
GCM	General Circulation Model
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace des Sciences de l’Environment Global
ISB	Independent Science Board
MP	Mid-Pacific

NARCCAP	North American Regional Climate Change Assessment Program
NOD	north-of-Delta
OCAP	Operations Criteria and Plan
P	Precipitation
RCM	Regional Climate Model
SJRRP	San Joaquin River Restoration Program
SLR	sea level rise
SOD	south-of-Delta
SRES	IPCC Special Report on Emissions Scenarios
SRES	Special Report on Emissions Scenarios
SWE	snow water equivalent
SWP	State Water Project
T	temperature
TAF	thousand acre-feet
USBR	United States Department of the Interior, Bureau of Reclamation
WCRP	World Climate Research Programme
WSI-DI	water supply index – delivery index

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1.0 Introduction

1.1 Climate Change and its Relation to the SJRRP

The San Joaquin River Restoration Program (SJRRP) was established in late 2006 to implement the Stipulation of Settlement (Settlement) in *NRDC et al. v. Kirk Rodgers et al*. (NRDC 2006).The U.S. Department of the Interior, Bureau of Reclamation (Reclamation), as the Federal lead agency under the National Environmental Policy Act (NEPA), and the California Department of Water Resources (DWR) as the State lead agency under the California Environmental Quality Act (CEQA), are preparing this joint Program Environmental Impact Statement/Report (PEIS/R) to implement the SJRRP.

The PEIS/R evaluates the potential significant impacts on the environment at a program level resulting from implementation of the SJRRP. The PEIS/R also analyzes the effects of the Interim and Restoration flow component of the SJRRP at a project level of detail. The PEIS/R also evaluates project alternatives and includes feasible and available mitigation measures to reduce, minimize, or avoid significant adverse impacts.

The Settlement describes numerous physical and operational actions that would potentially directly or indirectly affect environmental conditions in the San Joaquin River and associated flood bypass system, major tributaries to the San Joaquin River, the Delta, and the water service areas of the Central Valley Project (CVP) and State Water Project (SWP), including the Friant Division. Physical and operational actions are described in Settlement Paragraphs 11 through 16. This report was prepared by Reclamation Technical Service Center to address sensitivity analyses of Future CVP and SWP operations to potential climate change and associated sea level rise.

The Modeling Technical Appendix to the San Joaquin River Restoration Program Environmental Impact Statement/Report (2009) discloses the anticipated effects of reservoir release changes associated with the SJRRP preferred action alternative relative to a future with no action. Measured effects include effect of the preferred action on reservoir storage, water deliveries, and river flow conditions, among other resource areas.

The operational depictions of future with preferred action and future with no action are predicated on assumptions about surface water supplies for the Central Valley Project and State Water Project (CVP/SWP) systems and the San Joaquin Basin tributary systems, water demands for each system, and constraints on system operations (e.g., institutional, regulatory, social, environment). Climate assumptions underlie assumptions about water supplies, demands, and operating constraints including the following examples:

- Regional surface water supply assumptions reflect expected monthly weather patterns that translate into monthly runoff patterns in the Sierra Nevada and Southern Cascades, and ultimately reservoir inflow patterns.

- Flood control rules at these system reservoirs reflect expected storm or runoff possibilities in upstream watersheds and associated reservoir-fill potential. These rules, combined with downstream flood protection capacity, determine reservoir storage space requirements during the calendar year that constrain water supply operations.

- Drought management strategies reflect expected cycles of year-to-year and decade-to-decade climate variability (e.g., cycling between wetter and drier multiyear episodes), which influence Federal, State, and local reservoir operations in the region to satisfy competing objectives of maximizing water deliveries in any given year versus reserving stored water supply for use in subsequent years on the chance that a drought could occur or continue.

These are examples of how operational depictions in the SJRRP contain implicit *regional* climate assumptions. These depictions also contain an implicit *global* climate assumption with respect to how sea level is represented in the depiction of the Sacramento-San Joaquin Delta (Delta). Water conveyance from upstream CVP and SWP reservoirs to Delta-export service areas are constrained by Delta flow and salinity conditions, which are influenced by the Delta's downstream sea level and salinity conditions.

It should be recognized that climate is a relative and encompassing term describing aggregate expected weather aspects and statistics, and defined over some period of time. The World Meteorological Organization traditionally uses a climate definition period of 30 years (IPCC 2007). Climate is also defined within a geographic context. Climate *change* is defined as any statistical change in expected weather conditions, and is typically assessed over a span of multiple decades (IPCC 2007). It is possible that climate change could translate into changes in CVP/SWP and San Joaquin Basin water supplies, water demands, and operational constraints. The significance of such changes depends on the increment of climate change and operational outcome of concern. Evidence from instrumental and paleoclimate records indicates that California's climate has gone through cycles over time, for example, varying between wetter and drier periods (Meko et al. 2001). Such climate oscillations, or natural climate cycles, remain difficult to predict (IPCC 2007). However, recent evidence suggests that humans affecting warming trend is occurring and interacting with such natural climate variations (IPCC 2007). This warming trend is also expected to continue into the twenty-first century (IPCC 2007).

Given the relevance of both global and regional climate conditions in SJRRP operations depictions, and the possibility that future climate change could modulate the measured effects of the SJRRP preferred action relative to the future with no action, it is relevant to consider the implications of projected climate change for the effects disclosure in the Modeling Technical Appendix to the SJRRP PEIS/R (2009). In particular, it is of interest to understand how the measured effects on both CVP/SWP system conditions and San Joaquin Basin conditions (e.g., reservoir storage, water deliveries, river flows) are sensitive to a range of future climate change possibilities occurring during the SJRRP implementation horizon.

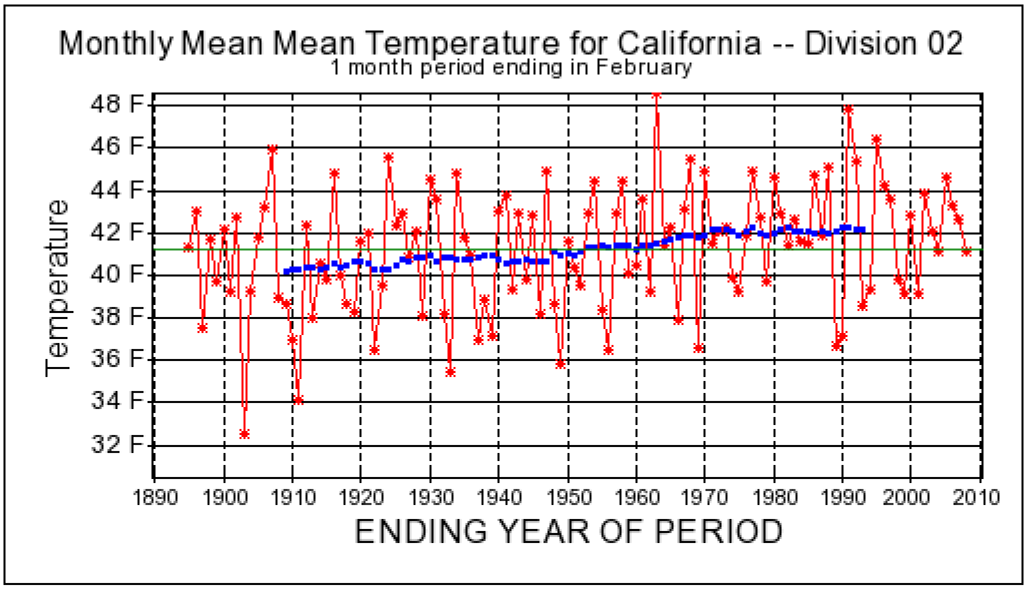
1.2 Current Understanding on Global to Regional Climate Change

Assessments on climate change science and summaries of contemporary climate projections have been periodically updated by the Intergovernmental Panel on Climate Change (IPCC) since 1988. The IPCC was established by the World Meteorological Organization and the United Nations Environment Programme and its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation.

The IPCC recently released its Fourth Assessment Report (AR4) (IPCC 2007). The AR4 offers statements and uncertainty estimates on recent trends, apparent human influence on those trends, and projections for various climate conditions. AR4 offers relatively more certain statements about warming-related events. For example, the AR4's report from Working Group I, *Summary for Policymakers*, Table SPM.2 states that it is "very likely" that global trends of "warmer and fewer cold days" and "warmer and more frequent hot days" occurred during the twentieth century and that it is "virtually certain" that these trends will continue based on twenty-first century climate projections in response to future scenarios for greenhouse gas (GHG) emissions (IPCC 2000). The AR4 synthesis report noted the major projected impacts on water resources to be "effects on water resources relying on snowmelt; effects on some water supplies," and goes on to state that "Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources." Relatively less certain statements are offered about future precipitation-related events (e.g., phenomena like the areal extent of droughts, frequency of heavy precipitation events).

In addition to the findings reported in the IPCC AR4, several U.S. science groups have recently issued statements on climate change. The American Meteorological Society issued a statement in February 2007 that it labels as "consistent with the vast weight of current scientific understanding as expressed in assessments and reports from the Intergovernmental Panel on Climate Change, the U. S. National Academy of Sciences, and the U. S. Climate Change Science Program." The American Geophysical Union adopted a revised climate change policy in December 2007, asserting that the Earth's climate is "now clearly out of balance and is warming. Many components of the climate system—including the temperatures of the atmosphere, land and ocean, the extent of sea ice and mountain glaciers, the sea level, the distribution of precipitation, and the length of seasons—are now changing at rates and in patterns that are not natural and are best explained by the increased atmospheric abundances of greenhouse gases and aerosols generated by human activity during the 20th century." Additionally, the U.S. Climate Change Science Program continues to work on a series of Synthesis and Assessment Product reports addressing various climate research elements, including those related to atmospheric composition, climate variability and change (including climate modeling), global water cycle, land-use and land-cover change, global carbon cycle, ecosystems, decision-support systems, climate monitoring systems, and communication.

Information on historical climate change in the California region, as observed during the period of instrumental record, can be obtained from the Western Regional Climate Center. Figure 1-1 and Figure 1-2 show historical temperature and precipitation time series, respectively, for California's Sacramento Valley. Figure 1-3 and Figure 1-4 show similar information, but for California's San Joaquin Valley. Results in these figures show that Central Valley region temperatures appear to be following a warming trend. Comparatively, annual precipitation has been more variable relative to its long-term mean, which doesn't appear to follow a clear positive or negative trend during the full period of record.



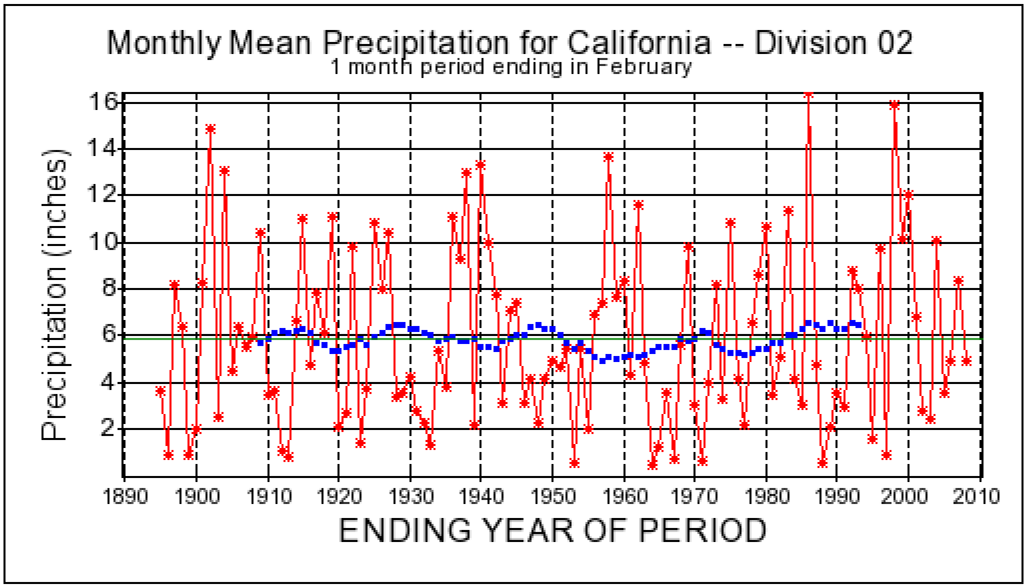
Source: Western Regional Climate Center 2008

Note:

Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean.

Figure 1-1.

Observed Temperature in California Climate Division 02 "Sacramento Drainage"

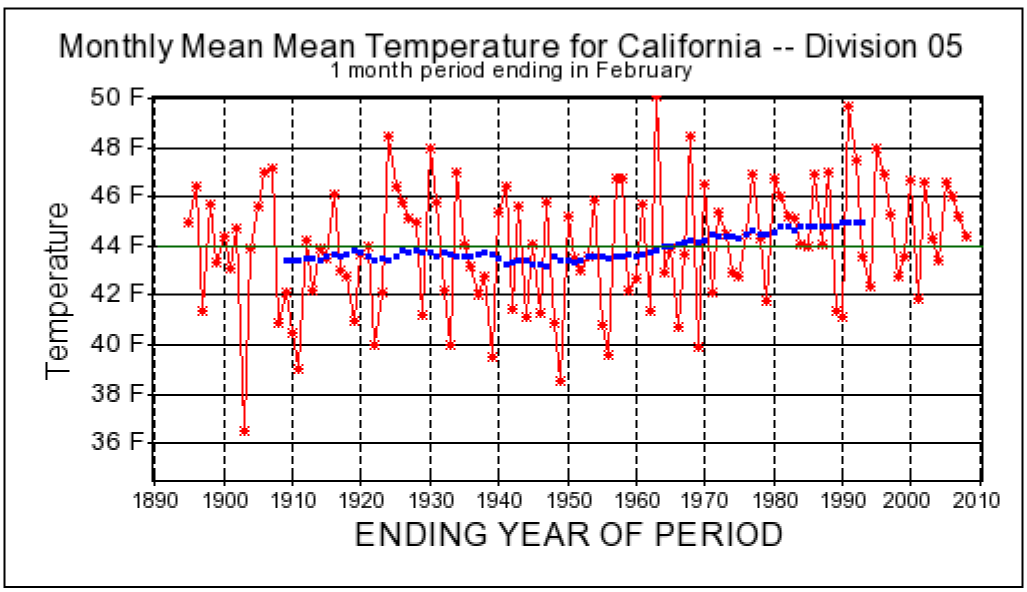


Source: Western Regional Climate Center 2008

Note:

Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full period mean.

Figure 1-2.
Observed Precipitation in California Climate Division 02 “Sacramento Drainage”

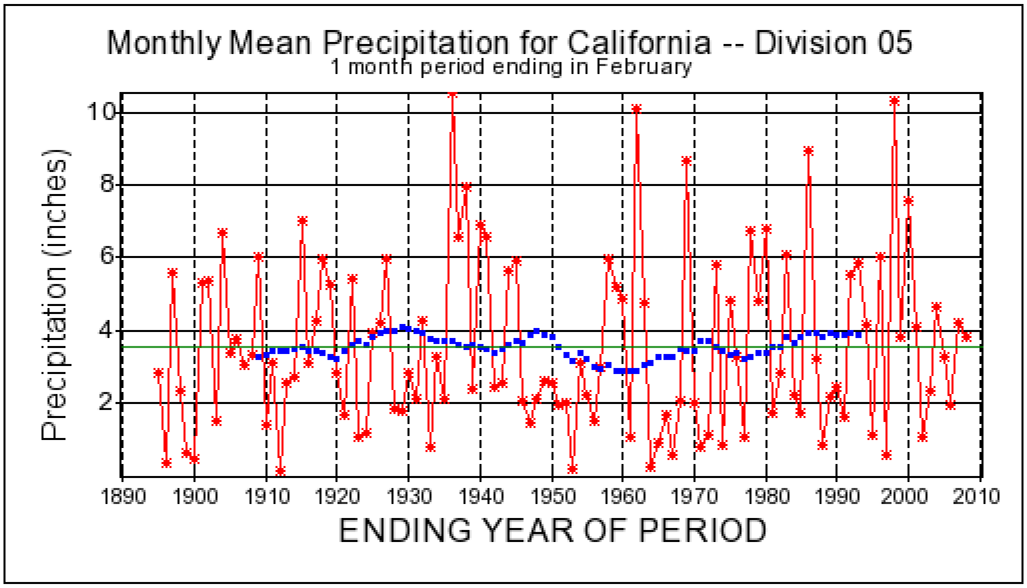


Source: Western Regional Climate Center 2008

Note:

Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean.

Figure 1-3.
Observed Temperature in California Climate Division 05 “San Joaquin Drainage”



Source: Western Regional Climate Center 2008

Note:

Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean.

Figure 1-4.
Observed Precipitation in California Climate Division 05 “San Joaquin Drainage”

1.3 Central Valley Region Studies on Climate Change Impacts for Water Resources

Numerous studies have been conducted on the potential consequences of climate change for water resources in the U.S. Department of the Interior, Bureau of Reclamation’s (Reclamation) Mid-Pacific (MP) Region. This section provides the literature synthesis originally reported by Reclamation (2009). The synthesis reflects findings from recent studies (1994–2008) demonstrating evidence of regional climate change during the twentieth century, and exploring water resources impacts associated with various climate change scenarios. For the MP Region within California, (Vicuna and Dracup 2007) offer an exhaustive literature review of past studies pertaining to climate change impacts on California hydrology and water resources.

1.3.1 Historical Climate and Hydrology

It appears that all areas of the MP Region have become warmer and some areas received more winter precipitation during the twentieth century. Cayan et al. (2001) reports that Western U.S. spring temperatures have increased 1–3 degrees Celsius (°C) since the 1970s. Increasing winter temperature trends observed in central California average about 0.5 °C per decade (Dettinger and Cayan 1995). Regonda et al. (2005) report increased winter precipitation trends from 1950–1999 at many Western U.S. sites, including several in California’s Sierra Nevada, but a consistent region-wide trend is not apparent.

Coincident with these trends, the Western U.S. and MP Region also experienced a general decline in spring snowpack, reduced snowfall-to-winter precipitation ratios, and earlier snowmelt runoff. Reduced snowpack and snowfall ratios are indicated by analyses of 1948–2001 snow water equivalent (SWE) measurements at 173 Western U.S. stations (Knowles et al. 2007). Regonda et al. (2005) report decreasing spring SWE trends in the majority of Western U.S. site records evaluated as well as earlier snowmelt runoff. Peterson et al. (2008) also found earlier runoff trends in an analysis of 18 Sierra Nevada river basins.

These findings are significant for regional water resources management and reservoir operations because snowpack has traditionally played a central role in determining the seasonality of natural runoff. In many MP Region headwater basins, the precipitation stored as snow during winter accounts for a significant portion of spring and summer inflow to lower elevation reservoirs. The mechanism for how this occurs is that (with precipitation being equal) warmer temperatures in these watersheds causes reduced snowpack development during winter, more runoff during the winter season, earlier spring peak flows associated with an earlier snowmelt.

The extent to which observed trends are due to climate change is a subject of ongoing research. Bonfils et al. (2007) report that temperature increase trends observed from 1914–1999 and 1950–1999 at eight California sites are inconsistent with model-based estimates of natural internal climate variability, which implies that external agents were forcing climate during the evaluation period. The authors suggest that the warming of California's winter over the second half of the twentieth century is associated with human-induced changes in large-scale atmospheric circulation. Cayan et al. (2001) reports that warmer-than-normal spring temperatures observed in the Western U.S. were related to larger scale atmospheric conditions across North America and the North Pacific, but whether these anomalies are due to natural variability or are a symptom of global warming is not certain.

1.3.2 Projected Future Climate, Hydrology, and Water Resources

Given observed trends in regional warming and declining snowpack conditions, studies have been conducted to relate potential future climate scenarios to runoff and water resources management impacts. Many of these studies have been summarized already in a literature synthesis focused on California hydrology and water resources impacts under past and projected climate change (Vicuna and Dracup 2007), which summarized studies completed through 2005. Representative findings from these studies are illustrated by Van Rheenan et al. (2004). They identified potential impacts of climate change on Sacramento-San Joaquin river basin hydrology and water resources and evaluated alternatives that could be explored to reduce these impacts. Five climate change scenarios were evaluated under various alternatives. Under the current operations alternative, releases to meet fish targets and historic hydropower levels would decrease during the twenty-first century. Under a conceptual "best case" comprehensive management alternative, average annual future system performance to meet fish targets would improve over current operations slightly, but in separate months and individual systems, large impairments would still occur. Following studies by Anderson et al. (2008) and Brekke et al. (2009) suggest operations impacts generally consistent with those reported by Van

Rheenan et al. (2004), but for more recently developed climate projection scenarios. Brekke et al. (2009) also explored impacts possibilities within a risk assessment framework, considering a greater number of climate projections, and considering how assessed risk is sensitive to choices in analytical design (e.g., whether to weight projection scenarios based on projection consensus, whether to adjust monthly flood control requirements based on simulated runoff changes). Results showed that assessed risk was more sensitive to future flood control assumptions than to consensus-based weighting of projections.

Switching from hydrologic to water demand impacts, Baldocchi and Wong (2006) evaluated how increasing air temperature and atmospheric carbon dioxide (CO_2) concentration may affect aspects of California agriculture, including crop production, water use, and crop phenology. They also offered a literature review, and based their analysis on plant energy balance and physiological responses affected by increased temperatures and CO_2 levels, respectively. Their findings include that increasing air temperatures and CO_2 levels will extend growing seasons, stimulate weed growth, increase pests, and may impact pollination if synchronization of flowers/pollinators is disrupted.

1.3.3 Studies on Historical Sea Level Trends and Projected Sea Level Rise Under Climate Change

Sea level conditions at California's Golden Gate determine water level and salinity conditions in the upstream Delta. Over the twentieth century, sea levels near San Francisco Bay increased by more than 0.21 meters (Anderson et al. 2008). Some tidal gauge and satellite data indicate that rates of sea level rise are accelerating (Church et al. 2006; Beckley et al. 2007). Sea levels are expected to continue to rise because of increasing air temperatures that will cause thermal expansion of the ocean and melting of land-based ice, such as ice on Greenland and in southeastern Alaska (IPCC 2007).

On the matter of sea level rise under climate change, the IPCC AR4 from Working Group I (Chapter 10, "Sea Level Change in the 21st Century" (IPCC 2007)) provides projections of global average sea level rise that primarily represent thermal expansion associated with global air temperature projections from current Global Climate Models (GCMs). These GCMs do not fully represent the potential influence of ice melting on sea level rise (e.g., glaciers, polar ice caps). Given this context, inspection of Figure 10.31 in IPCC 2007 suggests a global average sea level rise of approximately 3 to 10 centimeters (cm) (or 1 to 4 inches) by roughly 2035 relative to 1980–1999 conditions. These projections are based on the "Coupled Model Intercomparison Project - Phase 3" (CMIP3) models' simulation of ocean response to atmospheric warming under a collection of GHG emissions paths. The report goes on to discuss local deviations from global average sea level rise due to effects of ocean density and circulation change. Inspection of Figure 10.32 in IPCC 2007 suggests that sea level rise near California's Golden Gate should be close to the global average rise, based on CMIP3 climate projections associated with the A1b emissions path.

As noted, the current GCMs do not fully account for potential ice melt in their sea level rise calculations, and therefore miss a major source of sea level rise. Bindoff et al. (2007) noted that further accelerations in ice flow of the kind recently observed in some Greenland outlet glaciers and West Antarctic ice streams could substantially increase the contribution from the ice sheets, a possibility not reflected in the CMIP3 projections. Further, the sea level data associated with direct CMIP3 output on sea level rise are potentially unreliable because of elevation datum issues.

A separate approach for estimating global sea level rise (Rahmstorf 2007) uses the observed linear relation between rates of change of global surface air temperature and sea level, along with projected changes in global surface air temperature. Following this approach, the CALFED Bay-Delta Program (CALFED) Independent Science Board (ISB) estimated ranges of sea level rise at Golden Gate of 2.3–3.3 feet (70–100 cm) at mid-century and of 1.6–4.6 feet (50–140 cm) by the end of the century (CALFED ISB 2007). Likewise, the California Department of Water Resources (DWR) applied this approach using the 12 future climate projections selected by the Climate Action Team (CAT) (DWR 2009) to estimate future sea levels. At mid-century, sea level rise estimates based on the 12 future climate projections ranged from 0.8 to 1.0 feet with an uncertainty range spanning 0.5 to 1.3 feet. By the end of the century, sea level rise projections ranged from 1.8 to 3.1 ft, with an uncertainty range spanning from 1.0 to 3.9 feet. These estimates are slightly lower than those from the Rahmstorf (2007) study because the maximum projected air temperature increase in that study was 5.8 °C (10.4 degrees Fahrenheit (°F)), and the maximum projected air temperature increase for the 12 future climate projections selected by the CAT was 4.5 °C (8.1 °F). It should be noted that projections using this air temperature-sea level rise relationship represent the average sea level rise trend and do not reflect water level fluctuations due to factors such as astronomical tides, atmospheric pressure changes, wind stress, floods, or the El Niño/Southern Oscillation.

1.4 Contemporary Climate Projection Information

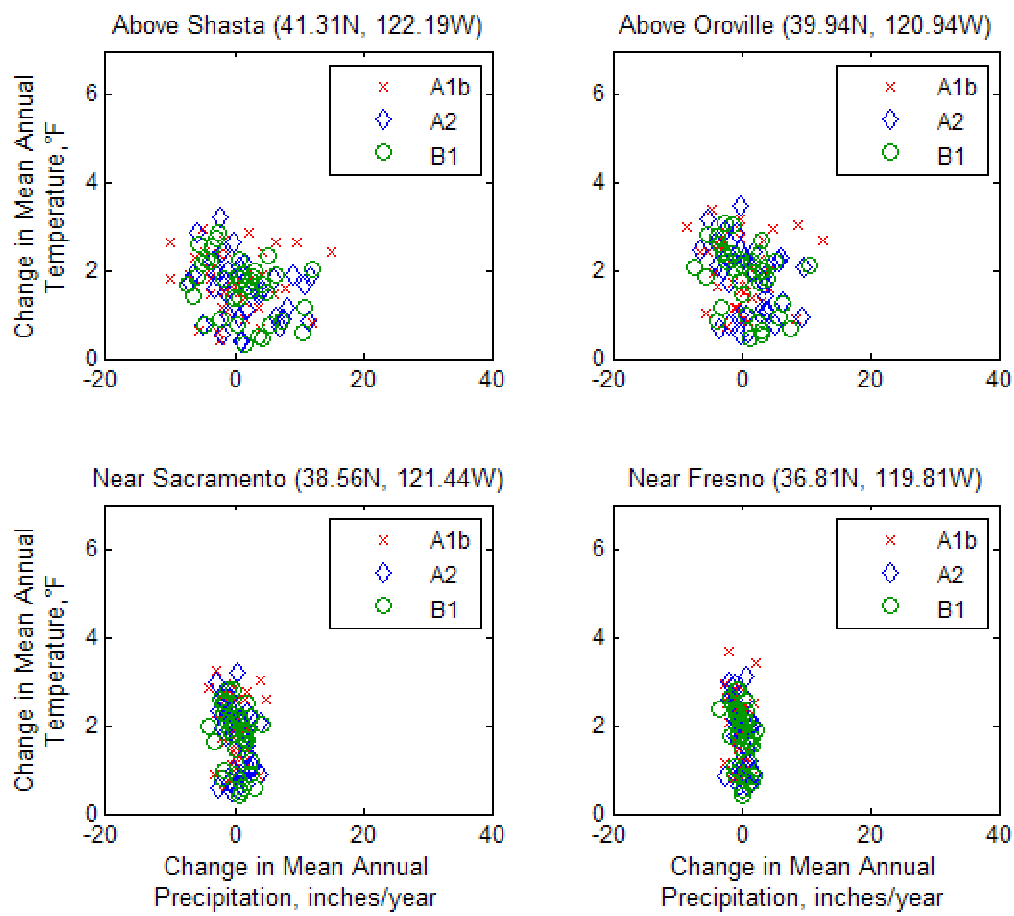
Studies discussed in the previous section relate to Central Valley hydrology and water management implications associated with assumed future climate scenarios. A common theme among those studies is that the underlying climate assumptions were based on climate projection information available at the time of analysis. Those studies did not provide probabilities for the climate scenarios represented. This reflects our current inability to assign a probability to future climate conditions given our limited ability to predict future human influence on climate at relevant temporal and spatial scales and simulate climate response to these influences (Section 5.0).

During the past decade, climate projections have been made available through efforts of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP). This project has advanced in three phases (CMIP1 (Meehl et al. 2000), CMIP2 (Covey et al. 2003), and CMIP3 (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php)). WCRP CMIP3 efforts were fundamental to completion of IPCC AR4. The CMIP3 dataset was produced using climate models that include coupled atmosphere and ocean general circulation models. These were used to simulate global climate response to various future GHG emissions paths (IPCC 2000) from end-of-twentieth century climate conditions. The emission paths vary from lower to higher rates, depending on global technological and economic developments during the twenty-first century.

One limitation with the CMIP3 dataset and climate models projections, in general, is the climate model spatial scale output is too coarse for regional studies on water resources response (Maurer et al. 2007). Spatially downscaled translations of 112 CMIP3 projections have been made available ("Statistically Downscaled WCRP CMIP3 Climate Projections" at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/) to address this limitation, where the projections were collectively produced by 16 different CMIP3 models simulating three different emissions paths (e.g., B1 (low), A1b (middle), A2 (high)) from different end-of-twentieth century climate conditions. Section 3.1 provides discussion on various downscaling approaches that are commonly used, and the considerations that drove selection of the approach supporting development of the downscaled climate projections (DCP) archive mentioned above.

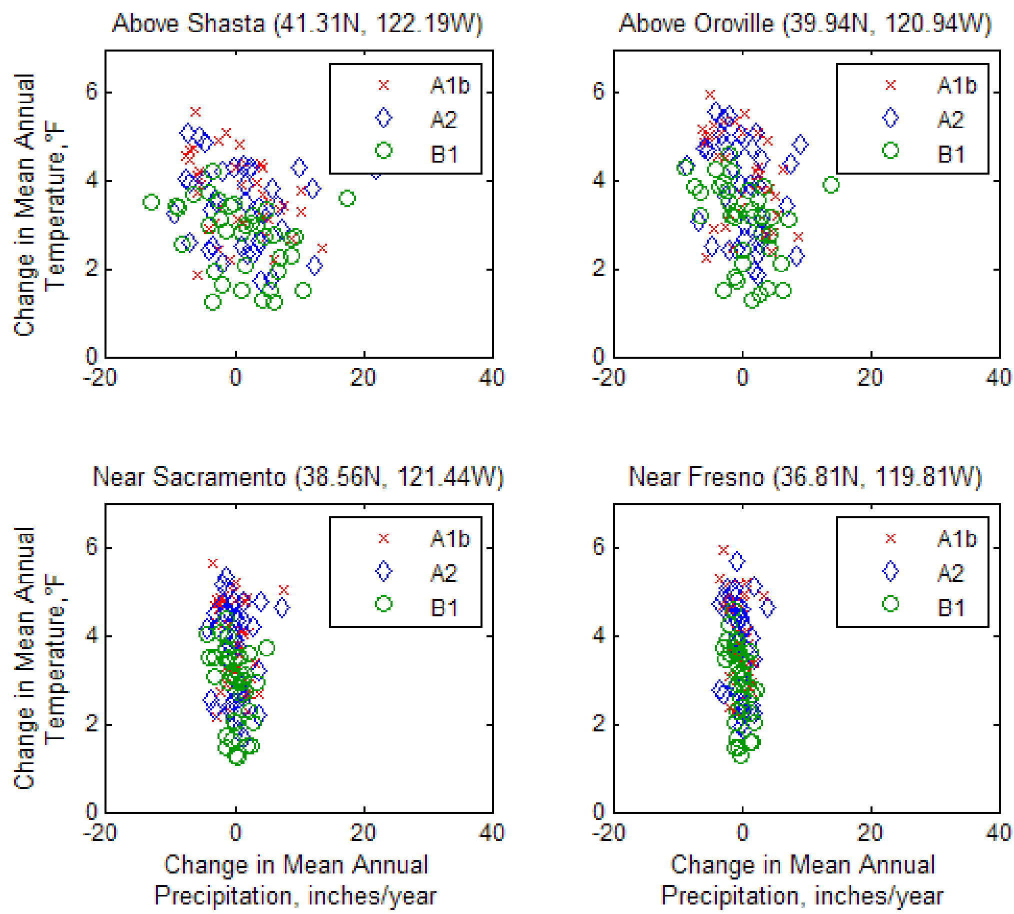
The DCP archive permits survey of projection information at locations within the Sacramento-San Joaquin study region. For example, Figure 1-5 shows distribution of projected changes in mean-annual precipitation and temperature conditions from 1971-2000 to 2011-2040 at four Central Valley locations. Figure 1-6 provides similar information, but with the future period shifted to 2041-2070. Both figures show projection consensus that some increment of warming is expected to occur by the early period, with more warming by the later period. Also, the range of incremental warming among the 112 projections does not vary significantly among the mountain headwater and lower-elevation locations. In contrast, range precipitation change is broader in magnitude for mountain headwater locations than for lower-elevation locations.

The location-specific analyses of period-mean changes from Figure 1-5 and Figure 1-6 were repeated at all downscaling locations in the DPC archive over the California region. These locations are spaced regularly on a 1/8º grid, which means spacing on roughly a 12km by 12km grid. Period-mean change was assessed from 1971-2000 to 2011-2040, and also from 1971-2000 to 2041-2070. Ranked period-mean changes were then sampled at each location and for three ranks: that exceeded by 10%, 50% and 90% of the other values, respectively (i.e. "10%Exc", "50%Exc" and "90%Exc"). Displays of ranked period-mean changes are shown on Figure 1-7 and Figure 1-8. Focusing on expected temperature change (50%Exc), the expected change does not vary much with location for either future period. Focusing on a broad range of projected temperature changes (e.g., comparing changes on 10%Exc and 90%Exc maps, by location), the range of projected change does not depend significantly on location. Focusing on precipitation, the centrally expected change (50%Exc) varies with location, with a tendency toward less precipitation over Southern California and more over Northern California by 2041-2070 (Figure 1-8). However, the range of projected precipitation changes (i.e., comparing 10%Exc and 90%Exc maps) is typically greater at any given location than the centrally expected change (50%Exc value).



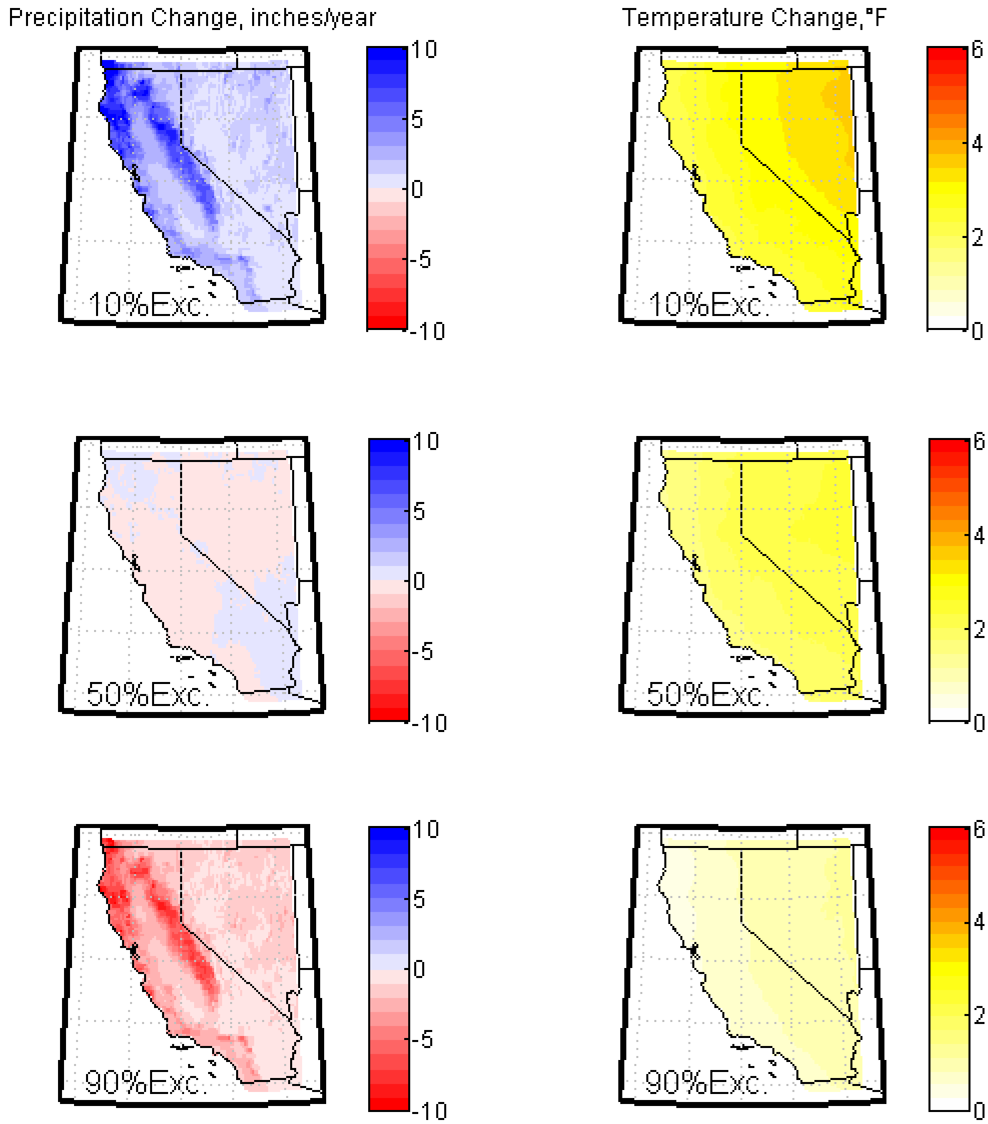
Note:
Each panel represents a location-specific survey of projections listed in Table 2-1. Symbols correspond to projection-specific change, which was assessed as the 2011-2040 Mean Annual condition minus the 1971-2000 Mean Annual condition. Legend indicates projection subsets corresponding to climate simulations forced by one of three greenhouse gas emission pathways (A2 (“higher” path), A1b (“middle” path), or B1 (“lower” path) (IPCC 2000).

Figure 1-5.
Projected climate change at several Central Valley Locations, 1971-2000 to 2011-2040



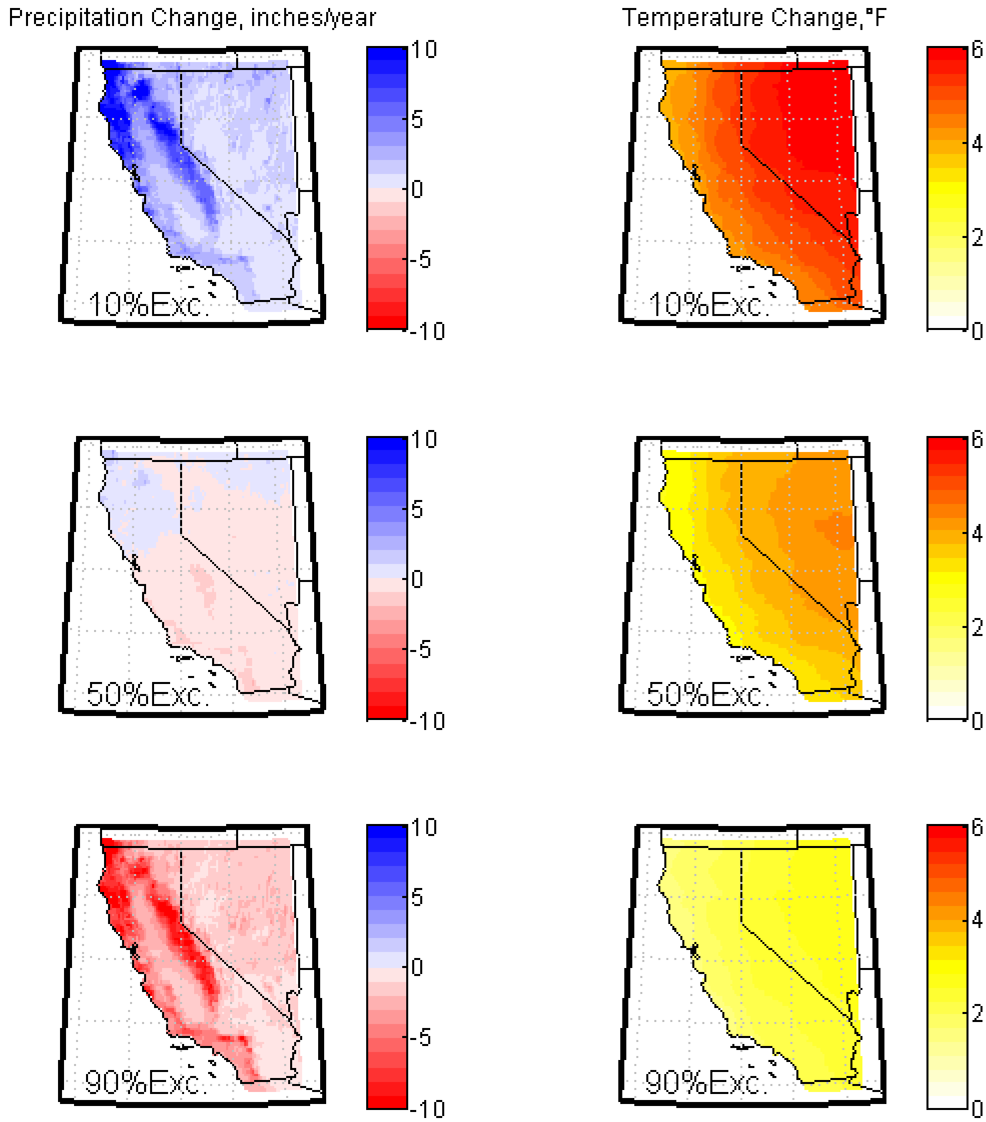
Note:
This figure is the same as Figure 1-5, but with climate change assessed as the 2041-2070 Mean Annual condition minus the 1971-2000 Mean Annual condition.

Figure 1-6.
Projected climate change at several Central Valley Locations, 1971-2000 to 2041-2070



The 112 projected changes from Figure 1-5 were evaluated at each downscaling location (**http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/**) within the CA/NV domain, corresponding to grid of locations at roughly 12km, or 1/8º latitude-longitude, resolution. Ranked-projections are shown for the 10%-, 50%, and 90% exceedence levels within each location's set of 112 projected values. Change was assessed as the 2011-2040 Mean Annual condition minus the 1971-2000 Mean Annual condition.

Figure 1-7.
Rank-Projected climate change over California, 1971-2000 to 2011-2040



Note:
This figure is the same as Figure 1-7, but with climate change assessed as the 2041-2070 Mean Annual condition minus the 1971-2000 Mean Annual condition.

Figure 1-8.
Rank-Projected climate change over California, 1971-2000 to 2041-2070

1.5 SJRRP Climate Change Approach

Several approaches were considered for incorporating climate change information into the SJRRP effects analysis:

- *Qualitative* discussion of implications for future operations and measurement of effects of future with SJRRP preferred action-alternative versus future with no action (i.e., measurement of effects)
- *Quantitative* analysis on measurement of effects under a range of potential climates
- *Quantitative* analysis on measurement of effects on an assumed future climate

The second approach was chosen for this study, hereafter referred to as a "sensitivity analysis," where the sensitivity of measuring SJRRP effects is evaluated relative to a range of regional future-climate scenarios. Each scenario was coupled with a common sea-level rise scenario. Several considerations contributed to this approach decision:

- Computationally, the availability of the DCP archive (Section 1.4) and analytical methodologies (Section 1.3) support implementation of a quantitative approach, which would helps illustrate potential climate change implications for measuring SJRRP effects.

- The SJRRP implementation and effects disclosure horizon extends to 2026, a time scale long enough for detecting climate change according to IPCC AR4 definitions (Section 1.1), thereby supporting the relevancy of a quantitative approach using DCP archive information.

- Defining an expected increment of future climate change (i.e., joint consideration of temperature and precipitation change) is confounded by the considerable range of projected precipitation and temperature changes over the study region (Figure 1-5 to Figure 1-8; thus, the sensitivity analysis approach more easily incorporates this uncertainty by showing how measurement of effects respond to a range of future climate possibilities.

In the sensitivity analysis, two SJRRP depictions are evaluated under multiple climate assumptions. For each climate assumption, the two future operations depictions are analyzed: a future with the preferred SJRRP action-alternative, and a future with no action. This study pairing for the climate assumption, effects are measured by comparing storage, flow and delivery results. Repeating this process for each climate assumption reveals how the measurement of effects is sensitive to the underlying climate assumption.

1.6 Report Organization

The remaining sections of this report are outlined as follows:

- Section 2.0 Development of Climate Change Scenarios for the sensitivity analysis, including SJRRP-specific considerations, rationale for developing regional climate assumptions and its implementation, and rationale for defining a sea level rise scenario.

- Section 3.0 Methodology for translating climate change scenario information into adjusted inputs and adjusted depiction of future CVP/SWP and San Joaquin Basin operations.

- Section 4.0 Scenario-specific results for various natural and operational responses, including changes in natural runoff in headwater basins and changes in the effects of SJRRP preferred action-alternative relative to no-action.

- Section 5.0 Uncertainties associated with relating climate change scenarios to CVP/SWP operational responses, focusing on sources of uncertainty that were not quantified in the analysis.

- Section 6.0 References.

2.0 Climate Change Scenarios for this Analysis

This section describes considerations, assumptions and rationale for defining the mix of regional climate change and sea level rise assumptions framing this sensitivity. After identifying SJRRP-specific considerations, the report discusses available climate projection information and rationale for establishing regional climate change assumptions. Finally, the report describes projected sea level rise, along with rationale for the defined sea level rise scenario.

2.1 SJRRP-Specific Concerns

This sensitivity analysis explores how climate change might affect measuring the SJRRP effects on:

- CVP/SWP and San Joaquin Basin operations of interest (e.g., reservoir storage, water deliveries, river flows, water temperature in reservoirs and downstream river reaches, delta water levels and salinity)
- Conditions described statistically during long-term periods, year-groups classified by hydrologic year-type, or notable drought periods
- Conditions estimated for 2026, consistent with the SJRRP implementation period

2.2 Developing Regional Climate Change Assumptions

2.2.1 Available Climate Projections Data and Culling Considerations

DCP Archive CMIP3 Data

This sensitivity analysis is required to be based on the use of best *available* data. The best available dataset defining future *global* climate possibilities is the WCRP CMIP3 climate projections dataset introduced in Section 1.4. Given the computational requirements and marginal differences described previously, the best available dataset of downscaled climate projections necessary for regional water resources evaluation is the DCP archive introduced in Section 1.4. The DCP archive features data developed using a peer-reviewed downscaling technique that has been applied in support of numerous hydrologic impacts investigations (Maurer 2007). Among efforts that have applied this technique to CMIP3 projections, it offers the most comprehensive subset of available CMIP3 projections (Table 2-1), surveyed as of March 2009 when this sensitivity analysis was completed.

Table 2-1.
Available Downscaled and Bias-Corrected Climate Projections Data

Climate Modeling Group, Country	Climate Model (WCRP CMIP3 I.D.)	SRES runs [1, 2, 3]			Primary Reference
		A2	A1b	B1	
Bjerknes Centre for Climate Research	BCCR-BCM2.0	1	1	1	Furevik et al. 2003
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	Flato and Boer 2001
Meteo-France/Centre National de Recherches Meteorologiques, France	CNRM-CM3	**1**	1	**1**	Salas-Melia et al. 2005
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0	1	1	1	Gordon et al. 2002
US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0	1	1	1	Delworth et al. 2005
US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1	**<u>1</u>**	1	**<u>1</u>**	Delworth et al. 2005
NASA/Goddard Institute for Space Studies, USA	GISS-ER	1	2, 4	1	Russell et al. 2000
Institute for Numerical Mathematics, Russia	INM-CM3.0	1	1	1	Diansky and Volodin 2002
Institut Pierre Simon Laplace, France	IPSL-CM4	1	1	1	IPSL, 2005
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)	**1**, 2, 3	1, 2, 3	**1**, 2, 3	K-1 model developers, 2004
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G	1, 2, 3	1, 2, 3	1, 2, 3	Legutke and Voss 1999
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM	**1**, 2, 3	1, 2, 3	**1**, 2, 3	Jungclaus et al. 2006
Meteorological Research Institute, Japan	MRI-CGCM2.3.2	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	Yukimoto et al. 2001
National Center for Atmospheric Research, USA	CCSM3	1, 2, 3, 4	1, 2, 3, 5, 6, 7	1, 2, 3, 4, **5**, 6, 7	Collins et al. 2006
National Center for Atmospheric Research, USA	PCM	**<u>1</u>**, 2, 3, 4	1, 2, 3, 4	**<u>2</u>**, 3	Washington et al. 2000
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3	1	1	1	Gordon et al. 2000

Notes:

1 These downscaled climate projections are from LLNL-Reclamation-SCU downscaled climate projections dataset, derived from World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, stored and served at the LLNL Green Data Oasis (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/).

2 **Bold**-styling indicates 11 of the 12 projections framing the Second Biennial Science Report to the California Climate Action Team, due in 2008 (http://meteora.ucsd.edu/cap/scen08.html). The 12th projection is produced by CCSM3, run 5 of SRES A2.

3 <u>Underline</u>-styling indicates the 4 projections framing the First Biennial Science Report to the California Climate Action Team, produced in 2006 (http://www.climatechange.ca.gov/biennial_reports/2006report/index.html)

The DCP archive features CMIP3 data that have been processed in two ways. First, they have been "bias-corrected," which means that they have been adjusted to account for climate model tendencies to simulate past conditions that statistically differ from observations (e.g., too warm, cool, wet, or dry). Second, they have been "spatially downscaled," which essentially involves mapping the bias-corrected CMIP3 data to a finer-scale spatial grid while also factoring in historical spatial climate patterns at the finer-scale grid. Techniques for accomplishing both steps are described at the DCP archive website (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections) and were initially introduced by Wood et al. 2002 and Wood et al. 2004.

CA Scenarios 2006 and 2008

Table 2-1 lists the complete menu of CMIP3 climate projections represented in the DCP archive, as well as two notable projection subsets:

- The four CMIP3 projections produced by 2 CMIP3 models and their respective simulations of GHG emissions paths A2 and B1, subsequently used to frame the first biennial science report (BSR) to the California Climate Action Team summarized in CCAT 2006, which included DWR 2006 as an attachment.
- 11 of the 12 CMIP3 projections included in the California Climate Action Team's ongoing update to CCAT 2006 (http://meteora.ucsd.edu/cap/scen08.html), produced by 6 CMIP3 models and respective simulations of GHG emissions paths A2 and B1.

For discussion purposes, the two subsets are referred to as "CA Scenarios 2006" and "CA Scenarios 2008," respectively. These two subsets and the rationale behind assembling them is potentially relevant to climate change assumptions made in this study, given overlapping geographic interests between this effort and the two BSR efforts.

Review of "CA Scenarios 2006" shows that projection selection was influenced by a desire to focus on projections produced by climate models that produce a realistic simulation of California's recent climate, notably distribution of monthly temperatures and the strong seasonal cycle of precipitation that exists in the region (Cayan et al. 2008). Also, selected models were required to contain realistic representations of some regional features, such as the spatial structure of precipitation (e.g., annual cycle of precipitation, interannual-interdecadal variability) and represent differing levels of global temperature "sensitivity" to greenhouse gas forcing (Cayan et al. 2008).

Selection of "CA Scenarios 2008" will again be influenced by these considerations. However, new and significant criteria are being imposed to represent (1) a larger selection of models, and (2) models having readily available *daily* and, to some extent, *hourly* projection data. At the time of assembling "CA Scenarios 2008," not all climate models had readily available data at the daily, and particularly, the hourly time step (see http://meteora.ucsd.edu/cap/scen08.html, link to *"Slideshow used for 21 Nov 2007 WebEx conf call"*). This latter criterion was imposed given that the 2008 BSR update is scoped to explore hydrologic and resource management implications on three time scales (monthly, daily, hourly). Given that this study is primarily concerned with monthly aspects of climate change and associated CVP/SWP and San Joaquin Basin operational responses, the second criterion framing “CA Scenarios 2008” is not applied here. Thus, for defining a starting point for available projections consideration, this study begins with consideration given to all projections in the DCP archive rather than the “CA Scenarios 2008” subset (Table 2-1).

Considerations for Culling Projections

Before moving towards selecting a few available projections to represent future climate possibilities, it might be questioned whether a reduced set of “preferred” projections should first be assembled. Such culling rationale would have to be supported by the notion that there are relatively more likely emissions paths among those represented in projections and/or relatively more credible climate models producing projections.

On determining relative likelihood for emissions paths, there is limited guidance on which path is more probable (IPCC 2007). However, this question may not be significant in the time scale applicable to this study, which is through 2026 (which is a look-ahead year generally encapsulated by a future 2011-2040 climate period considered later in this report). This is because distribution of CMIP3 climate projections presented in AR4 show that expected range of climate possibilities does not become dependent on IPCC Special Report on Emissions Scenarios (SRES) paths (IPCC 2000) until about the middle 21st century (IPCC 2007). Consequently, for defining regional climate change scenarios in this study, a decision was made to consider all of the IPCC AR4 projections in the DCP archive.

On determining relative credibility of climate models, there has been more research activity (e.g., Dettinger 2005, Tebaldi et al. 2005, Brekke et al. 2008, Reichler and Kim 2008, Gleckler et al. 2008). The general approach has been to evaluate climate models’relative skill in simulating historical conditions relative to observed historical conditions. Models found to have a closer match to observations (for the variables and statistical metrics considered) are regarded as having relatively better skill. A philosophical bridge is then made, saying that the relatively more credible models based on past skill assessment offer more reliable climate projection information, although there is currently no evidence to support such a philosophical statement (Reichler and Kim 2008). It has been shown that when such skill assessments are extended to consider multiple aspects of climate, clarity of “better” versus “worse” climate models becomes less obvious and depends on how many simulation aspects are considered (Brekke et al. 2008, Reichler and Kim 2008, Gleckler et al. 2008).

Further, when climate models are rank based on past simulation skill, and when that ranking information is used to affect evaluation of future climate projections (e.g., considering projections produced only by the “better half” of models rather than projections from “all models,” as in Brekke et al. 2008), the assessed range and central tendency of projected climate change doesn’t necessarily adjust significantly. This is because the collective CMIP3-projected climate changes are not found to stratify according to climate model skill, where “better” models (classified based on past simulation skill) produce middle changes and “worse” models produce higher or lower extreme changes (Brekke et al. 2008). Consequently, a decision was made for this study to follow the precedent of the IPCC AR4 and to consider all projections in the DCP archive rather than to attempt to cull projections based assessment of relative climate model skill.

2.2.2 Rationale for Selecting Projections to define Assumed Range of Future Climates

To define a range of future climate possibilities, five climate projections were selected: four to encapsulate a reasonable range of projected temperature and precipitation changes over the study region, and one for providing a pairing of projected temperature and precipitation changes that closely represents the central changes from the collection of DCP projections considered. For labeling purposes, the former four projections are referred to as the "bracketing projections" and the latter is referred to as the "central projection."

The four bracketing projections were selected based on how they collectively represent:

- "Lesser" to "greater" temperature changes, which correspond to "*less warming*" to "*more warming*" over the study region based on Figure 1-5 to Figure 1-8
- "Lesser" to "greater" precipitation changes, which correspond to "*drier*" to "*wetter*" conditions over the study region based on Figure 1-5 to Figure 1-8.

Four factors (Figure 2-1) guided by projection selection, characterized consistently with considerations specific to this study (Section 2.1):

- *Factor 1 – Look-ahead horizon* and future climate period relevant to this study
- *Factor 2 – Climate metric* relevant to the study's operational conditions of interest
- *Factor 3 – Location* representative of the study region
- *Factor 4 – Projected "Change Range" of Interest*, a subjective choice on how much projections spread to represent.

The fifth, or central, projection was selected based on modifying *Factor 4* to be concerned with *"Centrally Projected" change of interest* rather than *Projected "Change Range" of interest*.

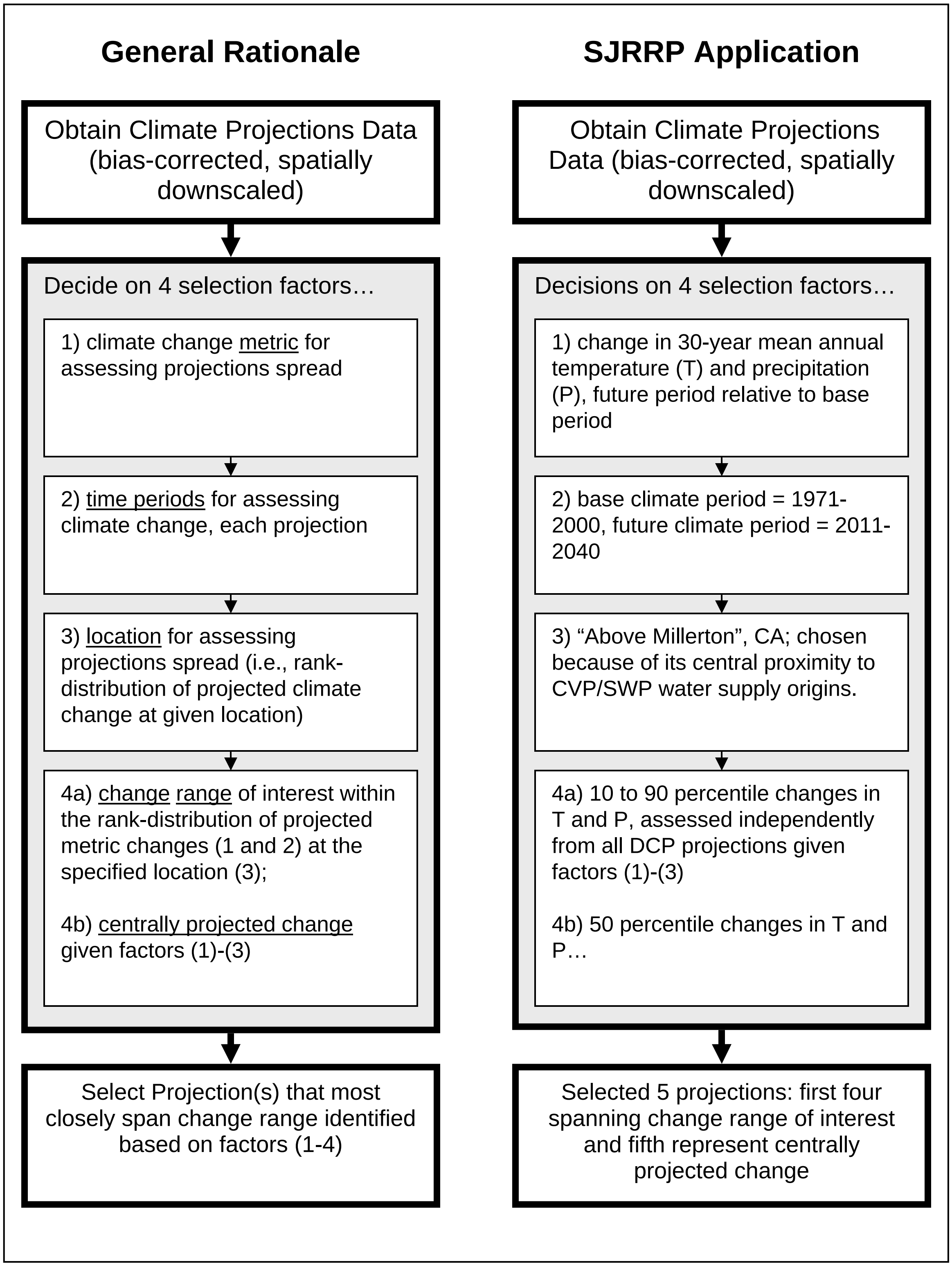


Figure 2-1.
Projection Selections Rationale

2.2.3 Implementing the Projection Selection Rationale

Decisions must be made for each factor to guide the selections that are relevant to a given study. For other studies in the Central Valley, having potentially different study objectives, these decisions could be rationally changed, resulting in a set of different projection selections framing a similar sensitivity analysis. Considerations that led to decisions on selection factors are summarized as follows:

- *Factor 1 – Look-ahead horizo*n: For the SJRRP effects analysis, the implementation period is 2026. A traditional period for climate definition is 30 years (Section 1.1). Decisions were made to define climate change from a base (historical) to future period, where climate is defined for a base period of 1971-2000 and a future period of 2011-2040. Climate change would then be assessed as statistical change in temperature (T) and precipitation (P) from base to future period.

- *Factor 2 – Climate Metric*: For the assessment of projections spread, it is convenient to be able to summarize each projection using a single climate metric, in contrast with the scenario-specific evaluations that would follow where multiple climate projection aspects would be translated into hydrologic and operational responses (Section 3.0). A decision was made to use "period mean-annual" as a measure of either T or P climate in base or future periods. Given the decision for Factor 1, this means that "30-year mean annual" T and P were computed for both 1971-2000 and 2011-2040 periods, for each projection considered. Other single-value climate metrics might have been considered (e.g., season-specific mean T and P, or range and variability of T and P during annual or season periods, etc.). For this study, "period mean-annual" T and P conditions broadly relate to long-term statistics on water supplies managed by CVP/SWP and San Joaquin Basin reservoir operations, and were therefore viewed to be suitable metrics for use in assessing projections spread and selecting projections to represent a desired range of future climate changes (Factor 4).

- *Factor 3 – Location*: Figure 1-5 shows how projected climate change varies by location within the Central Valley region. The assessment of projections spread should be performed at a location that represents the climatic influences targeted in the sensitivity study. As will be discussed in Section 3.0, this sensitivity analysis focuses primarily on measuring effects of the preferred SJRRP action-alternative on San Joaquin Basin operations relative to a future with no action. Further, the primary driver of effects on San Joaquin Basin operations is expected to be upstream hydrology. Given this focus, a location of "Above Millerton" was chosen for its proximity to upstream hydrology driving this study.

- *Factor 4 – Projected "Change Range" of Interest*: As mentioned, it is of interest to represent a range of future T and P possibilities in this sensitivity analysis. This can be done by choosing a set of projections to span the range of possibilities, based on spread among available projections. In this study, both projected T and P conditions are considered. Therefore, it is necessary to consider "change range" of interest for both variables. *Subjectively*, decisions were made to identify projections that come closest to matching the following threshold pairs of projections (given decisions for Selection Factors 1-3):

   - 10^{th} percentile (i.e. 0.1 rank cumulative probability) T change paired with 10^{th} percentile P change.
   - 10^{th} percentile T change paired with 90^{th} percentile P change.
   - 90^{th} percentile T change paired with 10^{th} percentile P change.
   - 90^{th} percentile T change paired with 90^{th} percentile P change.

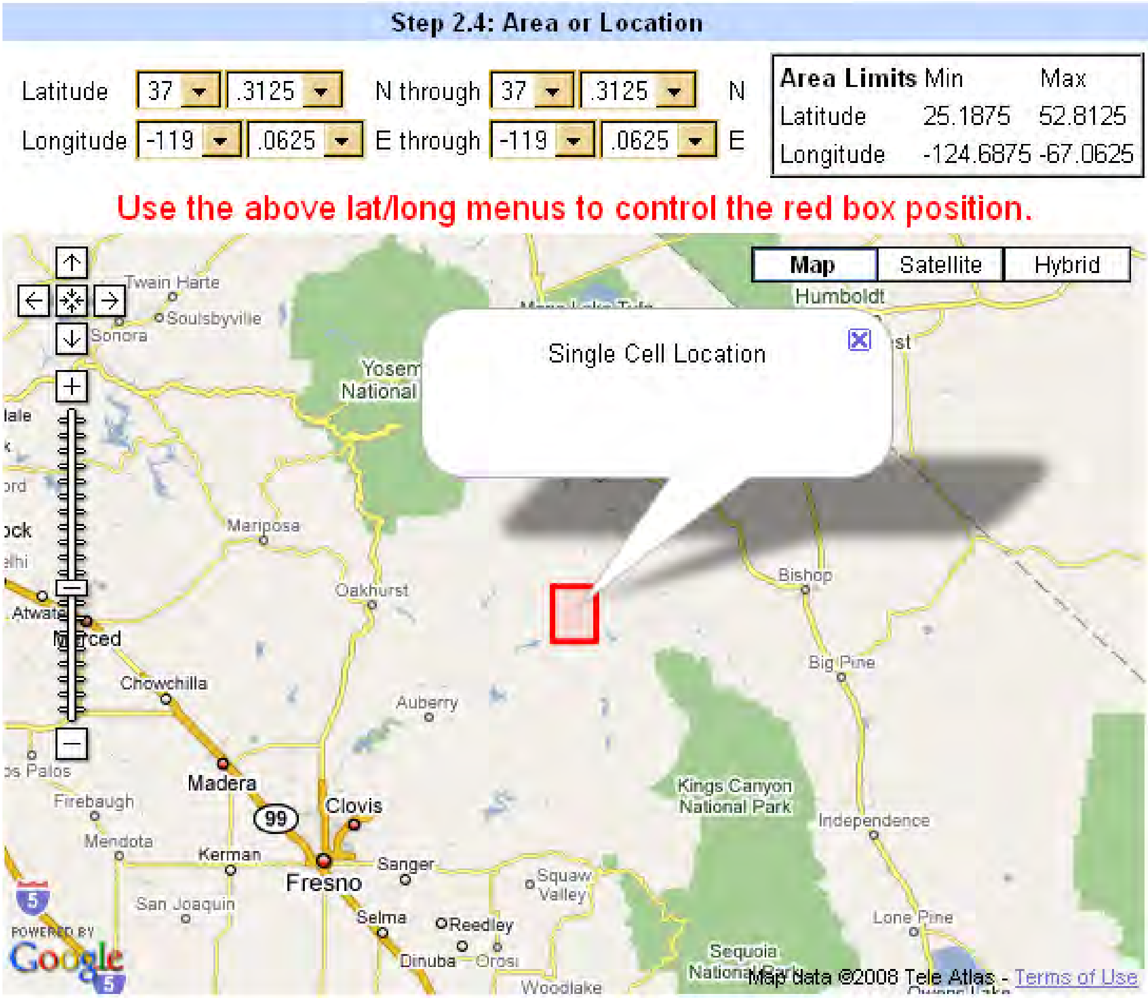
- *Factor 4 (modified) – "Centrally Projected" Change of Interest*: As mentioned, the fifth projection, or central projection, is meant to represent the centrally estimated future T and P possibility. Decisions were made to identify the projection that came closest to matching the following threshold pair of changes:
   - 50^{th} percentile T change paired with 50^{th} percentile P change.

Decisions made for this sensitivity analysis are shown in Figure 2-1, Projection Selection Rational. Following these decisions, the following evaluation steps were conducted to arrive at projection selections.

- *Step 1* – Surveyed all DCP archive data at the location selected (Factor 3) for monthly time series T and P during a period spanning the base and future period decisions (Factor 1), noting that DCP "historical" T and P data reflect simulated historical time series T and P (by climate model) and not observed. Figure 2-2 illustrates "Above Millerton" Location for Assessing Climate Projections Spread

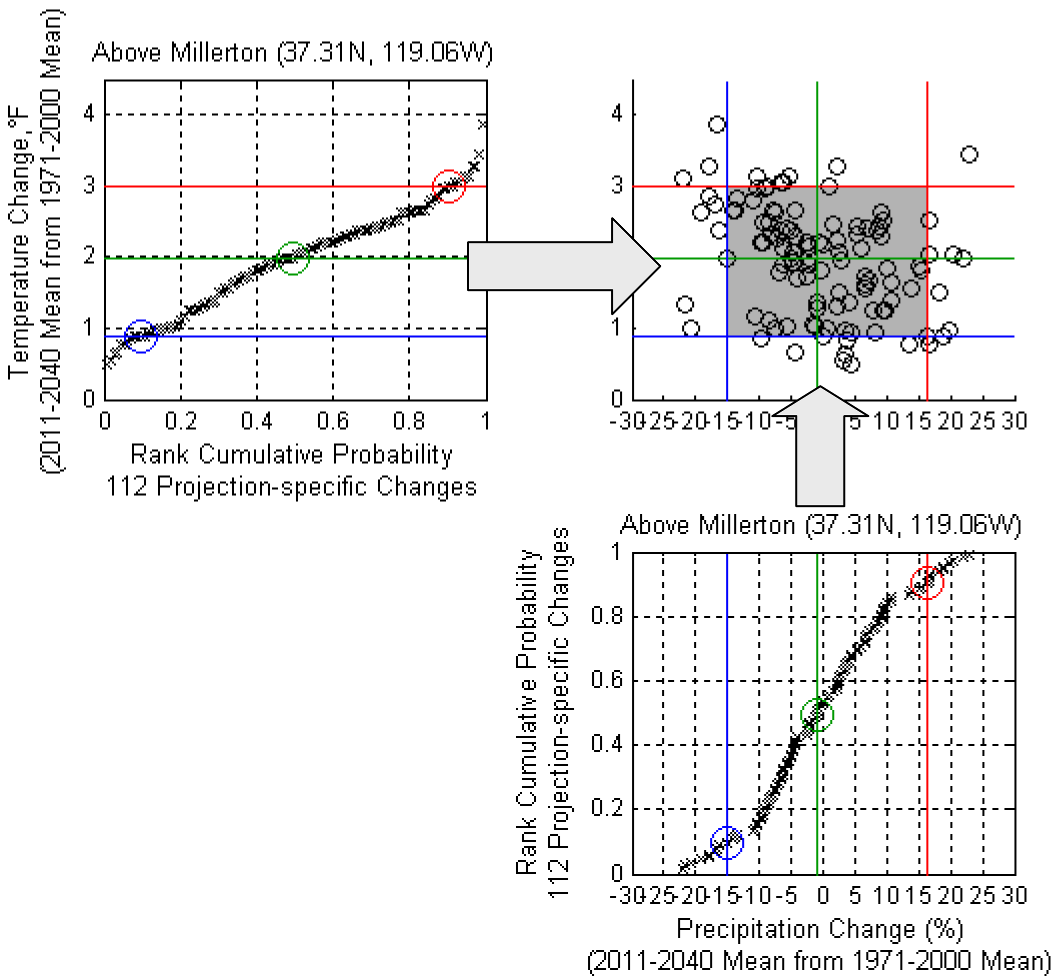
- *Step 2* – Computed 30-year-mean-annual (Factor 2) T and P for both base and future periods for each of the 112 projections surveyed in Step 1, and then the change in mean annual T and P (ΔT and ΔP, respectively) from base to future period, by projection. Assembled rank-distributions for each variable's 112 projected changes (Figure 2-3, upper-left and lower-right panels). Finally, identify the rank-percentile changes for each variable corresponding to thresholds selected in Factor 4 (i.e., 10^{th}, 50^{th} and 90^{th} percentile changes for both ΔT and ΔP).

- *Step 3* – Assessed projections spread by plotting ΔT versus ΔP and overlaying the $\Delta_{10\%\text{-tile}}$, $\Delta_{50\%\text{-tile}}$ and $\Delta_{90\%\text{-tile}}$ values for each variable in Step 2 (Figure 2-3, upper left and lower right panels). Specifically, the intersection of the $\Delta T_{10\%\text{-tile}}$ and $\Delta T_{90\%\text{-tile}}$ with the $\Delta P_{10\%\text{-tile}}$ and $\Delta P_{90\%\text{-tile}}$ formulates a two-variable "change range of interest" (i.e., gray region on Figure 2-3, upper left and lower right panels). The intersection of the $\Delta T_{50\%\text{-tile}}$ with $\Delta P_{50\%\text{-tile}}$ represents the approximate "centrally projected" change of interest.



Note:
Map illustrates decision on Selection Factor No. 3 in this study's application of the Projection Selections Rationale (Figure 2-1).

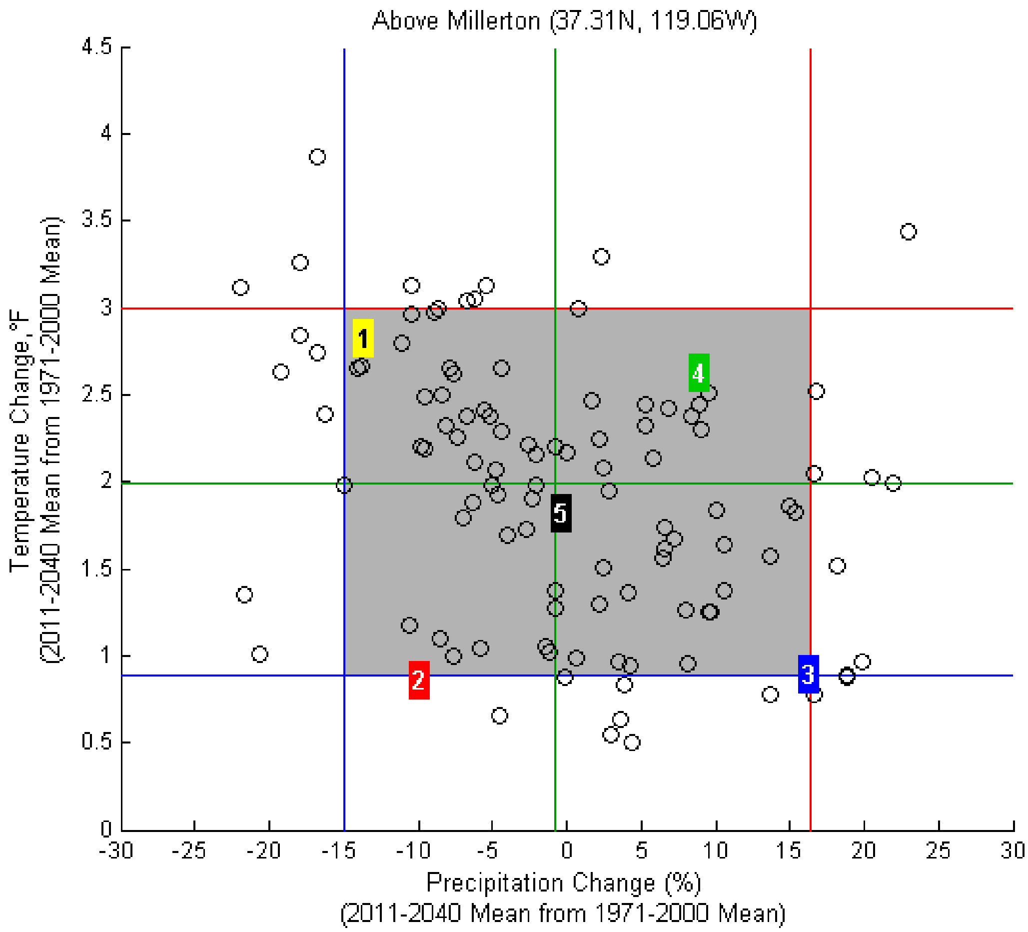
Figure 2-2.
"Above Millerton" Location for Assessing Climate Projections Spread



Note:
Given decisions on Selection Factors No. 1-4 (Figure 2-1), distributions of variable-specific and paired-variable changes are shown. Top left panel shows rank-distribution of change in mean annual T. Lower right panel shows rank-distribution of change in mean annual P. Change range spanned by 10 and 90 percentile values (Selection Factor No. 4) are shown on both plots as separation between blue and red lines; central change is indicated by 50 percentile value shown on both plots as green line. Upper right panel shows scatter of paired changes in mean annual T and P (black circles), with intersected change range of interest (gray region) and intersection of centrally projected changes highlighted.

Figure 2-3.
Climate Projections Spread given Decisions on Projection Selection Factors

- *Step 4* – Selected the four projections having paired projected changes (i.e., {ΔT, ΔP}) that most closely match each of the four vertices of the two-variable "change range of interest," respectively. Selected the fifth projection that has paired projected changes that closely match the "centrally projected" change of interest. Figure 2-4 shows the five projection selections, numbered 1 through 5, plotted at their respective ΔT and ΔP values. Their plotting positions approximately match either the vertices of the yellow rectangle region or the centrally projected change. In each case, the chosen projections happen to not match the targeted changes exactly because no single projection produced a pair of {ΔT, ΔP} that coincide with any combination of the paired rank-percentiles of interest (i.e., $\{\Delta T_{10\%tile}, \Delta P_{10\%tile}\}$, $\{\Delta T_{10\%tile}, \Delta P_{90\%tile}\}$, $\{\Delta T_{90\%tile}, \Delta P_{10\%tile}\}$, $\{\Delta T_{90\%tile}, \Delta P_{90\%tile}\}$, $\{\Delta T_{50\%tile}, \Delta P_{50\%tile}\}$).



Note:
Projections are numbered as follows: 1 = drier with more warming, 2 = drier with less warming, 3 = wetter with less warming, 4 = wetter with more warming, 5 = centrally projected.

Figure 2-4.
Projections Spread with Chosen Projections of this Study Highlighted

If the location decision is changed (Factor 3), the projections selections' changes relative to the spread of changes from all of the projection information will shift. To illustrate, the assessment on the spread of projection information was revisited using a different location in the study region, but keeping the projection selections the same as those shown on Figure 2-4. Specifically, the Factor 3 decision was adjusted to a location above Lake Shasta while Factors 1, 2 and 4 were kept the same. Figure 2-5 show comparison of projections selections results over a location upstream of Lake Shasta. By comparison, the four "bracketing" projection selections No. 1 through No. 4 as shown on Figure 2-4, do less well at spanning the spread of projected changes "Above Lake Shasta" compared to "Above Millerton." As explained in OCAP BA for the sake of assessing projections spread and choosing projections to span a change-range of interest within that spread, no location is ideal for an entire study region. However, this finding does not undermine the basic purpose of the sensitivity analysis, which is to assess operations sensitivity to a range of future climate possibilities. Following the projection selection rationale introduced in this section, it is inevitable that the selected projections will match a change-range of interest in some portions of the study area better than in others.

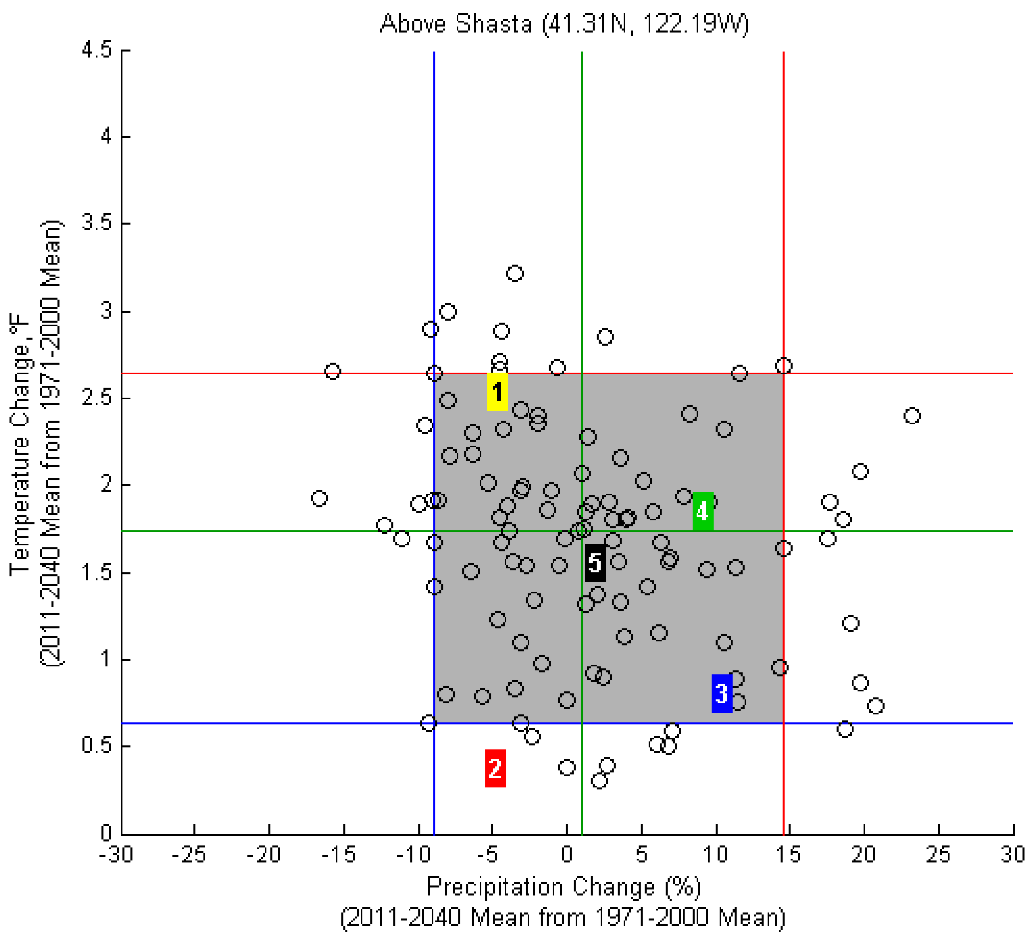


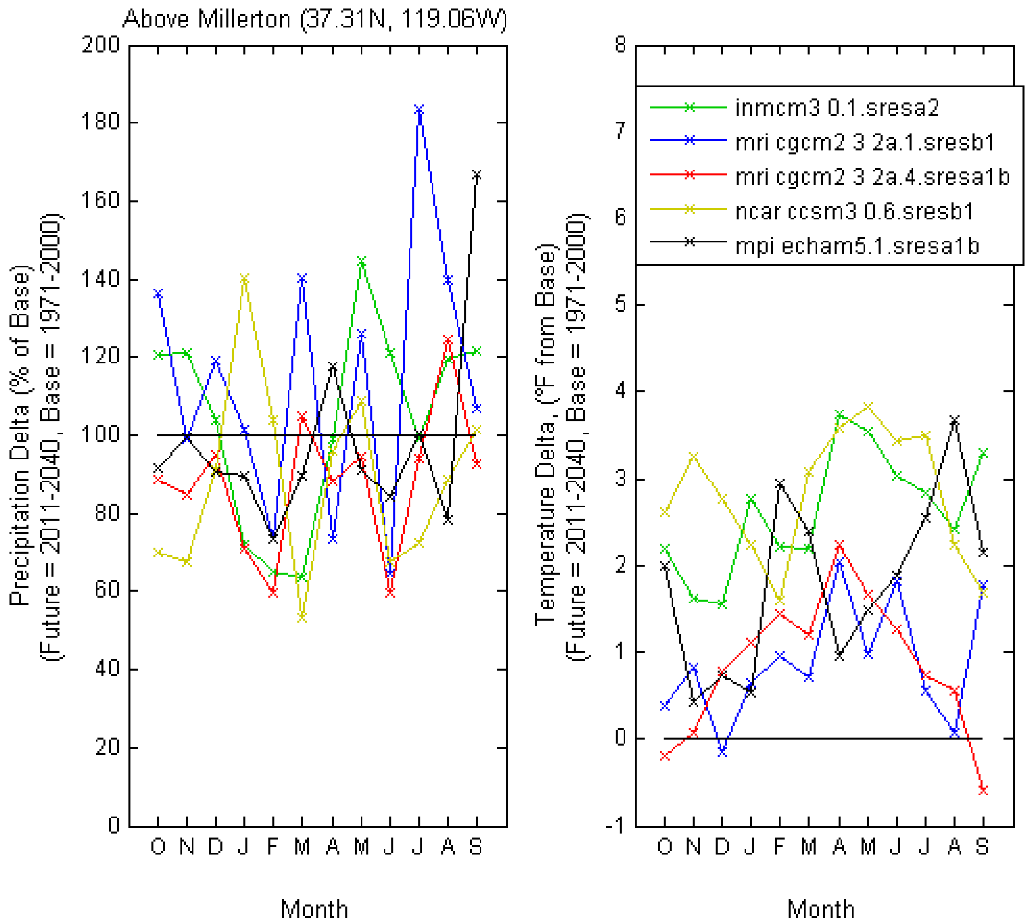
Figure 2-5.
Comparison of Projections Selections Results Over a Location Upstream of Lake Shasta

2.2.4 Summary of Selected Climate Projections for this Analysis

The five selected climate projections from Figure 2-4 are listed below, with *labels* describing general type of climate change from recent historical conditions:

- Bracketing Projections
  - Projection 1: *"Wetter, More Warming"* ($\Delta T_{90\%\text{-tile}}$, $\Delta P_{90\%\text{-tile}}$)
    - Climate Model: inmcm3.0
    - Emissions Pathway: A2
    - Simulation Run Number: 1
  - Projection 2: *"Wetter, Less Warming"* ($\Delta T_{10\%\text{-tile}}$, $\Delta P_{90\%\text{-tile}}$)
    - Climate Model: mri cgcm2.3.2a
    - Emissions Pathway: B1
    - Simulation Run Number: 1
  - Projection 3: *"Drier, Less Warming"* ($\Delta T_{10\%\text{-tile}}$, $\Delta P_{10\%\text{-tile}}$)
    - Climate Model: mri cgcm2.3.2a
    - Emissions Pathway: A1b
    - Simulation Run Number: 4
  - Projection 4: *"Drier, More Warming"* ($\Delta T_{90\%\text{-tile}}$, $\Delta P_{10\%\text{-tile}}$)
    - Climate Model: ncar ccsm3.0
    - Emissions Pathway: B1
    - Simulation Run Number: 6
- Central Projection
  - Projection 5: *"Central Projection"* ($\Delta T_{50\%\text{-tile}}$, $\Delta P_{50\%\text{-tile}}$)
    - Climate Model: mpi echam5
    - Emissions Pathway: A1b
    - Simulation Run Number: 1

Figure 2-6 shows changes in mean-monthly P and T, respectively, for each of the projection selections, assessed over the location "Above Millerton" as previously shown on Figure 2-4.



Note:
Legend labels list {<climate model>.<run number>.<emissions path>} corresponding to projections selected for this study.

Figure 2-6.
Change in Mean Monthly Precipitation and Temperature, from 1971-2000 to 2011-2040, for the Location "Above Millerton"

2.3 Sea Level Rise Assumptions

Sea level conditions at the Golden Gate determine water level and salinity conditions in the San Francisco Bay and upstream Sacramento-San Joaquin Delta. These conditions, in turn, affect upstream operations in the CVP/SWP and San Joaquin Basin reservoir systems. This section defines sea level rise assumptions for this study. These assumptions are meant to describe sea level conditions at the Golden Gate by 2030, consistent with the look-ahead period used to define regional climate change scenarios (Section 2.2.3). Assumptions are meant to represent a reasonable increment of rise that might be anticipated, and translated into upstream Delta water level and salinity conditions. The information on projected sea level conditions in Section 1.3.3 informs these assumptions. The *availability* of model applications for translating projected sea level conditions into Delta flow and salinity conditions *limits* what assumptions can be made (similar to limitations discussed in Reclamation (2008a)).

Currently available model applications for translating projected sea level conditions into Delta flow and salinity conditions have been developed by DWR. The model applications include: (1) an adjusted version of “DSM2,” the DWR’s Delta hydrodynamic simulation model, and (2) a developed version of the computationally efficient DSM2-emulator of Delta outflow and salinity conditions at various Delta regulatory compliance points, necessary for CVP/SWP operations modeling (Section 3.4.2).

The model applications used in this study are nearly identical to those used in Reclamation (2008a). The model application features (a) a scenario increment of potential sea level rise, and (b) a percentage increase in tidal range, similar to assumptions made in supporting analyses for DWR’s development of Delta Risk Management Strategy (URS-Benjamin 2007). The increment of sea level rise represented in the chosen model application is 1 foot, which is the rise increment closest to potential 2030 sea level rise (emphasizing information from Rahmstorf 2007) among the rise increments featured in the currently available DWR model applications. The single difference between the model application used in this study and that of Reclamation (2008a) is the scenario percentage increase in tidal range, which was 9% for the application used in this study compared to 10% for the application used in Reclamation (2008a).

Note that it would be ideal to apply Rahmstorf 2007 individually to the five climate projections associated with selections in 2.2.4 to develop unique sea level rise assumptions associated with each projection. However, lack of available Delta model applications capable of reflecting these assumptions prevented consideration of such an approach for this study. Therefore, a common sea level rise assumption is paired with each of the climate projections listed in Section 2.2.4.

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3.0 Methodology for Scenario-Specific Analysis of Natural Runoff and Reservoir Operations

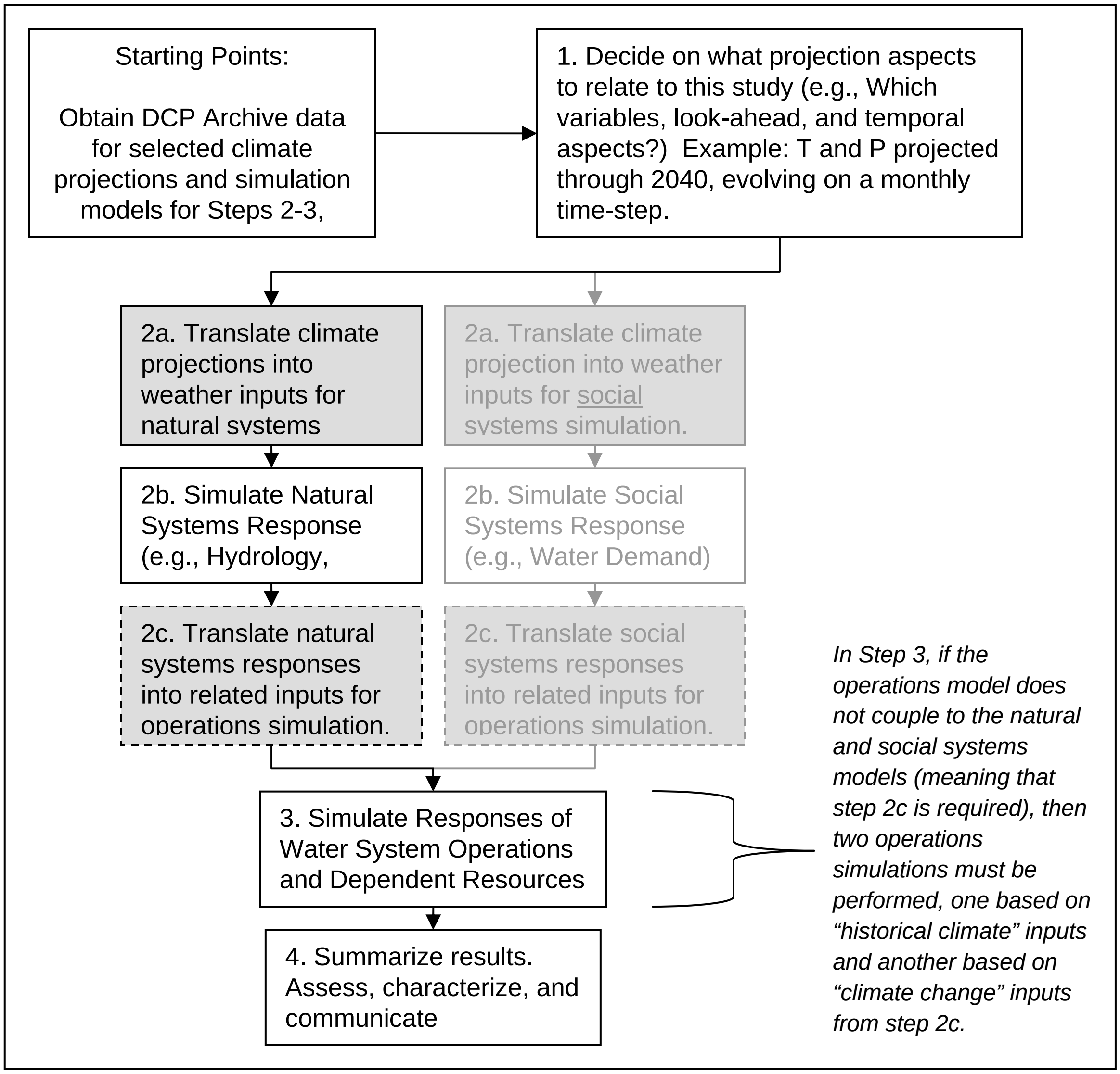
Using the climate projection and sea level rise assumptions defined in Section 2, this study follows a scenario-specific analytical method similar to Maurer 2007 and Anderson et al. 2008. Figure 3-1 offers a generalized analytical sequence for scenario specific impact analysis, which involves four steps:

- (Step 1) Obtain downscaled climate projections data and decide on which aspects of the climate projection to relate to natural systems, social systems, and operational responses.
- (Step 2) Translate climate projection information into responses for the targeted natural systems, social systems, and constraints on operations.
- (Step 3) Simulate operations and operations-dependent responses to adjusted natural systems, social systems, and constraints on operations.
- (Step 4) Summarize results, uncertainties, and limitations of interpretation.

For this study, the generalized method of Figure 3-1 was customized in several ways:

- (Step 1) Obtained downscaled climate projections data and decision to relate monthly evolving climate (T and P conditions) to monthly evolving runoff response.
- (Step 2) Related climate projection information from Step 1 to responses in natural runoff in headwater basins tributary to major CVP/SWP and San Joaquin Basin reservoirs, highlighting climate change impacts on surface water supplies.
- (Step 3) Related natural runoff change information from Step 2 to the runoff-related inputs in *CVP/SWP and San Joaquin Basin operations analyses*.
- (Step 4) Summarized results, uncertainties, and limitations of interpretation.

Table 3-1 provides analytical steps methods and references for projection-specific analysis references for key models and methods used at each analytical step. In summary, the chosen models and methods are a subset of those used in Reclamation (2008a). The following sections provide additional discussion on methods decisions.



Note:
The sequence is tailored for a given study analysis (e.g., this sensitivity analysis). The sequence may include analyses of natural systems, social systems, operations, and operations-dependent responses to climate change. This sensitivity analysis focuses on responses for natural runoff (i.e., surface water supply) and reservoir operations.

Figure 3-1.
Generalized Analytical Sequence for Scenario-Specific Impact Analysis

Table 3-1.
Method Selections for Projection-Specific Analysis

Analytical Step	Reference
Step 1a. Obtain Climate Projections Data, Bias-Corrected and Downscaled	
Method: Bias-Correction Spatial Disaggregation method (BCSD)	Wood et al. 2002; Wood et al. 2004
Step 2. Headwater Runoff Analysis	
Natural Runoff Model Choice(s): NOAA-NWS CA-NV River Forecast Center applications of the Sacramento-Soil Moisture Accounting Model coupled to Snow17 (SacSMA/Snow17) for nine headwater basins listed in Table 3-2.	Burnash et al. 1973; Anderson et al. 1973
Translating Climate Projections into Weather Inputs for Headwater Runoff Simulation: Temporal disaggregation technique (Maurer 2007) that involves randomly selecting and scaling historical weather months to match the projected month's mean T and total P condition. Historical data is model specific (i.e., observed meteorology structured for either the VIC or SacSMA/Snow17).	Maurer 2007
Step 3. CVP/SWP Operations and Dependent Resources Analyses	
CVP/SWP Operations – Model Choice: CalSim II "future" level of development study with one regulatory condition (D1641), defined in the Modeling Technical Appendix to the SJRRP PEIS/R	CalSim II: Draper et al. 2004, Appendix D
Translating Headwater Runoff Response into "Runoff-related" Inputs for Operations Simulation: Streamflow Perturbation Method.	Reclamation (2008a)

Key:
BCSD = Bias-Correction Spatial Disaggregation method
CVP = Central Valley Project
PEIS/R = Programmatic Environmental Impact Statement/Report
SJRRP = San Joaquin River Restoration Program
SWP = State Water Project

3.1 Climate Projections Downscaling Methodology

Table 3-1 references the Bias-Correction Spatial Disaggregation (BCSD) as the downscaling methodology used to produce DCP archive data and regional climate projections selected for this study (Section 2.2.4). By definition, downscaling is the process of taking global climate model output on simulated climate, and translating that to a finer spatial scale that is more meaningful for analyzing local and regional climate conditions. Many downscaling methods have been developed, all of which have strengths and weaknesses. Several reports offer discussion on the various methodologies, notably the IPCC Fourth Assessment (IPCC 2007, Chapter 11, Regional Climate Projections) and Wigley (2004). The various methodologies might be classified into two classes: dynamical, where a fine-scale regional climate model (RCM) with a better representation of local terrain simulates climate processes over the region of interest; and, statistical, where large-scale climate features are statistically related to fine-scale climate for the region.

To date, there has not been a demonstration of using dynamical downscaling to produce a dataset as comprehensive as the DCP archive (in terms of geography, variables, projections and projected years represented). While there are new efforts to downscale multiple climate projections using multiple RCMs, such as the North American Regional Climate Change Assessment Program (NARCCAP, http://www.narccap.ucar.edu/), the computational requirements of RCM implementation for more than a few years of simulation have limited the feasibility of using dynamical downscaling to produce a dataset like the DCP archive.

Among the various statistical methods that might be considered to produce such an archive, certain characteristics are desirable:

- Well tested and documented, especially in applications in the U.S.
- Automated and efficient enough to feasibly permit downscaling of many 21st century climate projections, thereby permitting more comprehensive assessments of downscaled climate projection uncertainty.
- Able to produce output that statistically matches historical observations.
- Capable of producing spatially continuous, fine-scale gridded output of precipitation and temperature suitable for water resources and other watershed-scale impacts analysis.

While there are many statistical techniques available (IPCC 2007, Wigley 2004), only the Bias-Correction and Spatial Disaggregation (BCSD) approach of Wood et al. (2004) met all of these criteria at the time of developing the DCP archive (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/No. Limitations).

Compared to dynamical downscaling approaches, the BCSD method has been shown to provide downscaling capabilities comparable to other statistical and dynamical methods in the context of hydrologic impacts (Wood et al. 2004). However, dynamical downscaling has also been shown to identify some local climate effects and land-surface feedbacks that BCSD cannot readily identify (Salathé et al. 2007). Another potential limitation of BCSD, like any statistical downscaling method, is the assumption of some stationarity in the relationship between large-scale precipitation and temperature and fine-scale precipitation and temperature. For example, the historical processes determining how precipitation and temperature anomalies for any 2 degree grid box are distributed within that grid box are assumed to govern in the future as well. A second assumption included in the bias-correction step of the BCSD method is that any biases exhibited by a GCM for the historical period will also be exhibited in future simulations. Tests of these assumptions, using historic data, show that they appear to be reasonable, inasmuch as the BCSD method compares favorably to other downscaling methods (Wood et al. 2004).

Several of the impacts assessments listed in Section 1.3 involved the use of BCSD to downscale climate projection information prior to runoff analysis (e.g., Van Rheenan et al. 2004, Maurer and Duffy 2005, and Maurer 2007). DWR (2006) and Reclamation

(2008a) also relied on downscaled climate projections information produced using the BCSD methodology. It is noted that the 2008 BSR update involves use of two techniques (http://meteora.ucsd.edu/cap/scen08_data.html): BCSD and "Constructed Analogues" (CA) (Hidalgo et al. 2008). A recent comparison of the methods (Maurer and Hidalgo, 2008) showed that results are not significantly different when the methods are used to develop monthly time series T and P projections. Given that this study is focused on monthly climate projection aspects and monthly runoff and operational responses, it was decided that the BCSD-derived downscaled data is sufficient for this study's purposes.

3.2 Decisions on Which Natural and Social System Responses to Analyze

Quantitative assessment of natural runoff and surface water supply response to each climate projection was supported by the availability of runoff models and well documented methodologies for translating downscaled climate projection into runoff responses (Section 1.3). Other than the Delta model applications developed to represent sea level rise increments (Section 2.3.2), no other quantitative analyses were performed for other natural systems. This was due to data limitations and/or uncertainties about methodology. For example, watershed ecosystem and land cover responses to climate change, and their related effects on hydrologic processes might have been considered given well-established tools and methods.

For social system response, several changes might be anticipated, including shifts in societal values on flood protection (related to CVP/SWP flood control rules), environmental management (related to CVP/SWP operational objectives to support river and Delta environmental conditions), and district-level water and power demands (related to CVP/SWP monthly release patterns as discretion permits). Consideration was given to adjusting water demand assumptions for the operations analysis, given that a warming climate might be expected to increase crop water needs through increased ET potential (e.g., Hidalgo et al. 2005). However, such an analysis performed at district-level depends on understanding future cropping choices and expected trends in demand management. It is recognized that at district-level, flexibility exists that could offset field- and crop-specific increases in water needs associated with warmer temperatures, enough so that district-level demand doesn't necessarily change. Given that the CVP/SWP operations analyses in this study are performed with district-level water demands used as inputs, a decision was made to hold demands constant for this sensitivity analysis.

3.3 Natural Runoff Analysis – Basins, Models, and Weather Generation

3.3.1 Basins and Runoff Model

As indicated in Reclamation (2008a), two runoff model applications were available for use in this study: the NWS California-Nevada River Forecast Center (CNRFC) basin-specific applications of Sacramento Soil Moisture Accounting model (Burnash et al.

1973) coupled to the Snow17 snow accumulation and ablation model (Anderson 1973), also known as SacSMA/Snow17; and, the Variable Infiltration Capacity model (Liang et al. 1994) applied to the Central Valley watershed (Maurer 2007). In Reclamation (2008a), results showed that changes in period-mean monthly and period-mean annual natural runoff under a given climate projection was not significantly sensitive to choice among these two model applications (particularly for changes in period-mean annual natural runoff). Consequently, only one set of results were retained for the operations analyses in Reclamation (2008a). Those findings influenced the decision of this study to simplify the natural runoff impacts assessment, and conduct the study using only one runoff model: SacSMA/Snow17.

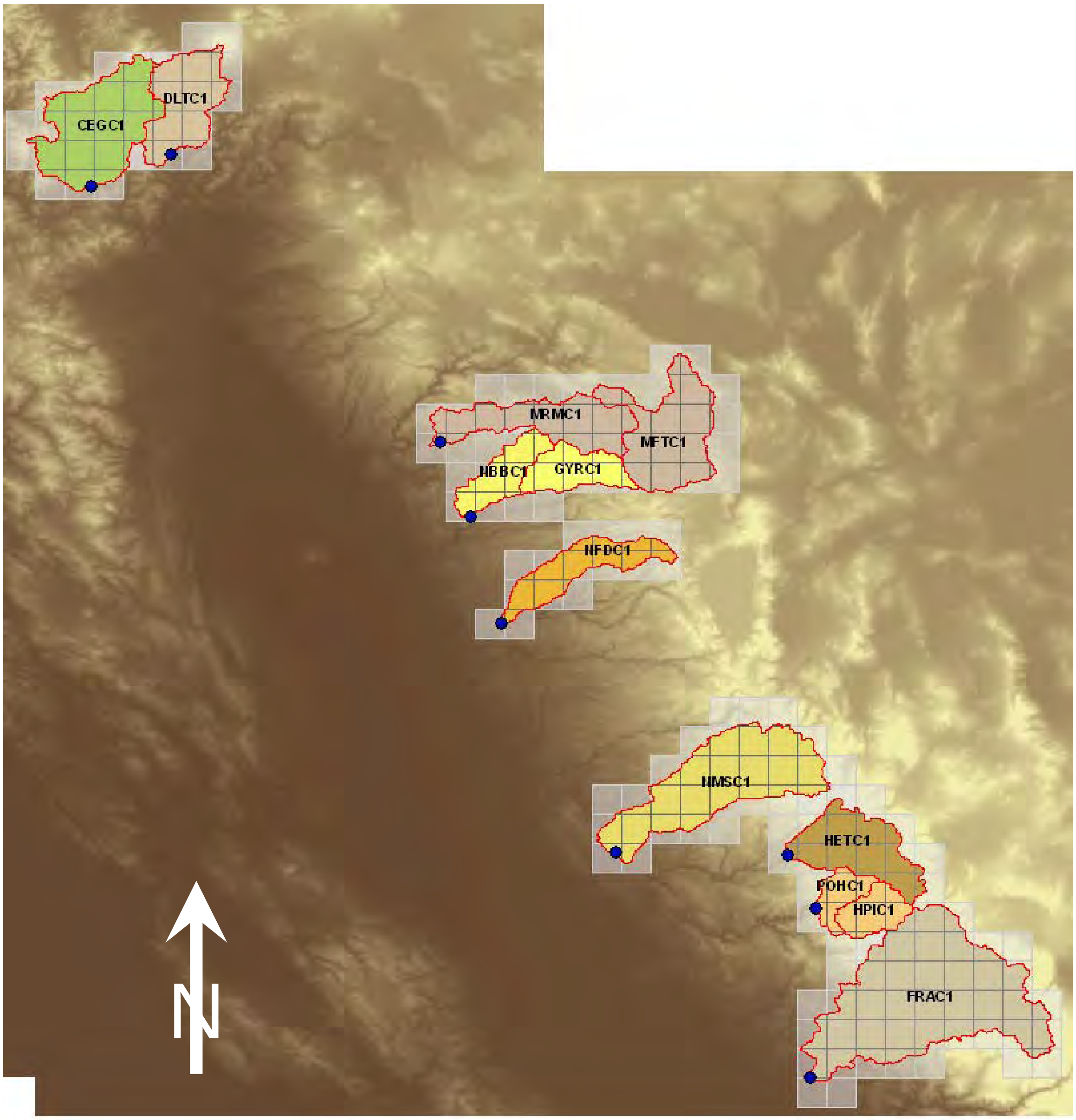
The CNRFC applications of SacSMA/Snow17 were used to translate climate projections into natural runoff projections in the nine Sierra Nevada headwater basins listed in Table 3-2 and shown on Figure 3-2. The nine basins in Table 3-2 were chosen to represent natural runoff responses in basins tributary to CVP/SWP and San Joaquin Basin reservoirs because they contain relatively less impairments than other headwater basins in the Sierra Nevada, and therefore are more desirable for assessing a natural runoff response to projected climate change.

Table 3-2.
Headwater Basins evaluated for Natural Runoff Response

Basin I.D.[1]	Basin Outflow Description[1]	Elevation[2] (m)	Area (km^2)	Outflow Latitude	Outflow Longitude
CEGC1	Trinity at Claire Engle Reservoir	1,510	1,750	40.80	-122.76
DLTC1	Sacramento at Delta	1,248	1,080	40.94	-122.42
FRAC1	San Joaquin at Friant Dam	2,168	4,140	37.00	-119.69
HETC1	Tuolumne at Hetch Hetchy Dam	1,852	1,210	37.95	-119.79
MRMC1[3]	Middle Fork Feather at Merrimac	1,581	2,770	39.71	-121.27
NBBC1[3]	North Yuba at New Bullards Bar Dam	1,485	1,260	39.39	-121.14
NFDC1	North Fork American at North Fork Dam	1,307	890	38.94	-121.01
NMSC1	Stanislaus at New Melones Dam	1,714	2,370	37.96	-120.52
POHC1[3]	Merced at Pohono Bridge	2,581	830	37.72	-119.67

Notes:
[1] I.D. and Description from National Weather Service California-Nevada River Forecast Center.
[2] Elevation represents basin area-average above mean sea level.
[3] Runoff from upstream MFTC1 is routed through MRMC1, runoff from upstream GYRC1 is routed through NBBC1, and runoff from HPIC1 is routed through POHC1.
Key:
m = meters
Km^2 = square kilometers

The SacSMA/Snow17 applications have been applied recently to support studies on climate change implications for Central Valley water resources (i.e., Miller et al. 2003, Brekke et al. 2004, Zhu et al. 2005, Reclamation 2008a, Brekke et al. 2009). Structurally, SacSMA/Snow17 applications depict a water balance evolving through time, where accumulated precipitation eventually leaves the watershed as either runoff or ET; SacSMA/Sno17 applications, like those received from CNRFC, typically do not simulate assumed deep percolation losses in the surface water balance. A SacSMA/Snow17 model is forced by two time series weather inputs: temperature and precipitation. Potential evapotranspiration is also defined as a simulation input. The CNRFC's SacSMA/Snow17 basin-specific applications simulate runoff on a 6-hourly time-step. They were calibrated to reproduce historical runoff given historical streamflow and weather station observations. The latter are aggregated to *topographically-defined mean-area* values (e.g., elevation-dependent lower, middle, and upper areas of a given basin).



Note:
Map shows California's Central Valley region spanning the locations of Trinity Basin above Trinity Reservoir in the northwest (i.e. CEGC1, Table 3-2) to the San Joaquin Basin above Millerton Lake in the southeast (i.e. FRAC1, Table 3-2). Red basin outlines correspond to SacSMA/Snow17 basin-specific model applications (Section 3.3). Gridded overlay indicates the resolution and position of downscaled climate projection information used in this study (Section 3.1).

Figure 3-2.
Basins Analyzed in Natural Runoff Response Analysis

3.3.2 Generating Input Weather Sequences

To generate a natural runoff projection that evolves through time consistent with a given climate projection, it was necessary to generate synthetic weather inputs consistent on a monthly basis with the gridded, monthly downscaled climate projections used in this study (Section 3.1) and consistent with the 6-hourly and topographic-area input structure of the CNRFC SacSMA/Snow17 applications used in this study. Reconciling these differences required spatial and temporal processing.

Spatial processing involved using an area-weighted technique to compute mean-area time series of projected temperature and precipitation in each elevation-defined sub-area within each SacSMA/Snow17 basin-application (i.e., sub-area). In the area-weighted technique, the climate projections' data grid (Figure 3-2, gray grid lines) was intersected with SacSMA/Snow17 basin-boundaries (Figure 3-2, red lines) and interior sub-areas boundaries within the basins (not shown on Figure 3-2). For a given sub-area, its fraction overlap with each projection grid-cell was computed. These fractions then served as weights in the aggregation of multiple grid-cell temperature and precipitation time series intersecting a given sub-area into a single mean sub-area time series.

Temporal processing involves historical data resampling and scaling (shifting) operated on the mean sub-area monthly precipitation (temperature) time series produced from spatial processing. The technique is described in Wood et al. (2002) and Maurer (2007) and involves:

- Step 1. Proceeding through a given sub-area's projection of monthly temperature and precipitation, getting the values for a given projection month.
- Step 2. Randomly selecting an historical observed month to associate with this projection month, and obtaining the observed month's 6-hourly series of precipitation (temperature) for each sub-area in the basin.
- Step 3. Scaling (shifting) each sub-area's 6-hourly precipitation series so that it matches the month-aggregate value from the simulated projection month.

To illustrate, consider making synthetic 6-hourly weather for a single month in a given climate projection. Step 1 involves recognizing the projection month for which we are developing synthetic weather (e.g., January 2031 of the given climate projection). Consider a given sub-area's temperature and precipitation conditions. Step 2 involves randomly sampling a historical month (e.g., January 1979). The observed January 1979 provides a realistic sequence of 6-hour weather variability (e.g., occurrence patterns of precipitation or no precipitation, warmer to cooler spells). Step 3 involves scaling for precipitation or shifting for temperature, such that the adjusted 6-hourly precipitation or temperature series matches the monthly value for the projection month (January 2031). To elaborate, for temperature, the observed historical January 1979 6-hourly series is uniformly shifted by the difference in mean observed January 1979 and mean simulated January 2031. For precipitation, the observed historical January 1979 6-hourly series is uniformly scaled by the ratio of mean simulated January 2031 to mean observed January 1979.

There are some cautions when applying the temporal disaggregation scheme of Wood et al. 2002. The cautions primarily focus on precipitation scaling issues and, generally speaking, not wanting to sample "really dry" observed months for the purpose of generating a precipitation series associated with a "really wet" simulated month. There are also cautions about maintaining space-time coherence of weather patterns propagating across the basin during the month. To address these cautions, several resampling constraints were imposed.

- Sampling was coordinated by month, meaning that for a given simulated calendar month, only the pool of observed historical sequences for that calendar month were eligible for consideration (e.g., observed historical "January" sequences could be sampled for simulated January months, but not others).

- To address the space-time coherence, the sampled observed-historical month had to apply to all basins and their respective sub-areas.

- A non-zero precipitation requirement was applied for eligible observed historical months, avoiding the possibility of infinite scaling ratios. This criterion combined with the previous bullet implies that if a sub-area's observed historical time series has a historical year-month with zero precipitation, then that historical year-month is automatically ineligible for consideration.

Given that the climate projection features a range of possible temperature and precipitation months that mostly overlaps with the range of historically observed conditions (following the bias-correction described in Section 3.1), it can be said that the scaling aspects of this weather generation technique do not (for the most part) generate an envelope of synthetic 6-hourly conditions that differ significantly from the observed envelope. Also, any exceptions to this are somewhat muted given that this study focuses on monthly to annual aggregate runoff from the simulation models. Sub-monthly runoff results would be more sensitive to the 6-hourly weather characterization.

As noted in Reclamation (2008a), while this technique produces a sequence of submonthly weather that temporally aggregates to be consistent with the monthly projections of temperature and precipitation, there are random aspects in the sequencing process. These random aspects cause sub-monthly time-series characteristics of the generated weather to differ if the weather generation process is repeated. Further, as Reclamation (2008a) showed, the interaction of hydrologic processes, basin water storage, and sub-monthly weather characteristics yields different sub-monthly runoff characteristics and some uncertainty in monthly to annual runoff impacts under climate change. As a result, a decision was made to repeat weather generation 30 times for each climate projection and basin combination to support an ensemble of hydrologic simulations for each projection and basin. Ensemble changes in period-mean monthly and period-mean annual natural runoff were then assessed. The ensemble-median changes were then identified and related to subsequent operations analysis.

3.4 Operations Analysis – Water Supply and Delta Adjustments

CVP/SWP operations with and without the preferred SJRRP action-alternative were simulated using a version of CalSim II (Draper et al. 2004) derived from the Common Assumptions Common Model Package Version 9b (CACMP9b) for application to the Upper San Joaquin Storage Investigations. Relative to the version of CalSim II used for Reclamation (2008a), this version includes a more robust representation of the Friant Kern delivery area, which allowed modeling of recovered water delivery and associated groundwater banking options for restoration alternatives. A single step CONV model was used for all study scenarios, collectively representing regulatory environments that include effects of California State Water Control Board Decisions D1485 and D1641, Central Valley Improvement Act (CVPIA) Section 3406(b)(2), Banks Pumping Plant wheeling for CVP, and Stage 1 transfers.

Studies described in the Modeling Technical Appendix to the SJRRP PEIS/R included a no-action (Base) scenario and three action alternatives: A, B, and C. This sensitivity analysis is being been conducted on two scenarios: base and action-alternative A (i.e., the preferred alternative). This analysis allows a comparison of the impacts of restoration release on system operations under the various climate projections.

The PEIS/R studies demonstrated the effects of restoration releases on delta outflow, exports, reservoir storage, and project deliveries. Also, previous studies (Brekke et al. 2004, DWR 2006, Reclamation 2008a) have illustrated the sensitivity of CVP/SWP and San Joaquin Basin operations to potential changes in climate. This report does not focus on general operations impacts associated with potential climate change. Instead, it focuses on how measuring the effects of the preferred SJRRP action-alternative are sensitive to the underlying assumptions about future climate and sea level conditions.

The operational assumptions featured in the CalSim II Base and Alternative A are described in the Modeling Technical Appendix to the SJRRP PEIS/R. Building from those two future operations depictions, this study features 12 CalSim II analyses, each differing by combination of operations depiction and future regional climate. The 10 studies involving regional climate change featured the same sea level rise assumption, as defined in Section 2.3. Studies were labeled as follows:

- Base – Current Climate
- BaseCP1 – Base, Sea Level Rise, Climate Projection No. 1 – Wetter, More Warming
- BaseCP2 – Base, Sea Level Rise, Climate Projection No. 2 – Wetter, Less Warming
- BaseCP3 – Base, Sea Level Rise, Climate Projection No. 3 – Drier, Less Warming

- BaseCP4 – Base, Sea Level Rise, Climate Projection No. 4 – Drier, More Warming
- BaseCP5 – Base, Sea Level Rise, Climate Projection No. 5 – Central
- Alternative A – Current Climate
- Alternative A CP1 – Alternative A, Sea Level Rise, Climate Projection No. 1 – Wetter, More Warming
- Alternative A CP2 – Alternative A, Sea Level Rise, Climate Projection No. 2 – Wetter, Less Warming
- Alternative A CP3 – Alternative A, Sea Level Rise, Climate Projection No. 3 – Drier, Less Warming
- Alternative A CP4 – Alternative A, Sea Level Rise, Climate Projection No. 4 – Drier, More Warming
- Alternative A CP5 – Alternative A, Sea Level Rise, Climate Projection No. 5 – Central

These studies were then paired by operational depiction and climate assumption in order to reveal how measuring the effects of the preferred SJRRP action-alternative is sensitive to the underlying assumptions about future climate and sea level conditions. For each study pairing, a particular effects metric was evaluated by comparing the results of the paired studies. Study pairings are labeled as follows:

- Comparison 1: Alternative A – Base (Current Climate)
- Comparison 2: Alternative A CP1 – BaseCP1 (Climate Projection No. 1)
- Comparison 3: Alternative A CP2 – BaseCP2 (Climate Projection No. 2)
- Comparison 4: Alternative A CP3 – BaseCP3 (Climate Projection No. 3)
- Comparison 5: Alternative A CP4 – BaseCP4 (Climate Projection No. 4)
- Comparison 6: Alternative A CP5 – BaseCP5 (Climate Projection No. 5)

Comparing the differences between any climate-specific pair of studies (Base and Alternative A) reveals the effects of the system to restoration flows. Cross-comparing how these effects differ relative to the underlying climate assumption reveals how robust these effects measurements are to future climate uncertainty.

3.4.1 Adjusting Surface Water Supply Inputs in CalSim II Based on Results from the Natural Runoff Analysis

Adjustments are made to three types of inputs related to CVP/SWP surface water supply in CalSim II: (1) monthly reservoir inflows, (2) hydrologic year-type classifications that constrain operations, and (3) seasonal water supply forecast data that constrain annual delivery allocations in a given simulation year. All three types of inputs have “base” sequences consistent with the 1922-2003 hydroclimate represented in the Base scenario. These sequences were preserved for study comparison purposes, and scaled to reflect mean-monthly effects of regional climate change on natural runoff.

Reservoir inflows were addressed first. They were adjusted so that they are consistent with period-mean changes in natural runoff in associated tributary basins. Subsequently, hydrologic year-types are reclassified for the climate-adjusted inflow sequence, using the context of historical relations between year-types and inflows. Likewise, seasonal water supply forecast data are adjusted consistent with historical relations between forecasts and inflows.

The method for adjusting reservoir inflows is influenced by the fact that *natural* runoff responses to climate change in headwater basins are being used to adjust *impaired* CalSim II inflow variables at lower elevations. The latter inflow variables are situated at a lower elevation reservoir and reflect upstream impairments that are significant at the monthly time scale for some CVP/SWP tributaries. These impairments are introduced by the upstream reservoir operations of water utilities and hydropower generation entities. The system storage capacities of these entities are generally small enough such that these impairments primarily influence monthly runoff patterns and with generally minor influence on annual runoff amount. Preferably, the response of upstream impairments to climate change would be simulated as part of the preparation of CalSim II inflows. However, information on how those impairments would adjust under climate change was not available for this study. Given this limitation, the following approach is taken:

- Establish consistency between period-mean *annual* changes in CalSim II “impaired reservoir inflow” and tributary “natural runoff” based on subjective headwater response assignment to the lower elevation inflow variables (Table 3-3).

- To the extent possible, preserve consistency between the period-mean *monthly* changes in “impaired reservoir inflow” and tributary “natural runoff.”

Table 3-3.
Assignment of Headwater Basin Responses to CalSim II Inflow Variables for Making Climate Change Scenario Inflow Adjustments

Assignment (%)	Basins listed in Table 3-2								
CalSim II Inflow Variable	**CEGC1 (Trin.)**	**DLTC1 (Sac.)**	**FRAC1 (San J.)**	**HETC1 (Tuol.)**	**MRMC1 (M Fea.)**	**NBBC1 (N Yub)**	**NFDC1 (N Am.)**	**NMSC1 (Stan.)**	**POHC1 (Merc.)**
I1 (Trinity)	100%								
I10 (New Melones)								100%	
I18 (Millerton)			100%						
I20 (Exchequer)									100%
I200 (Kelly Ridge)					50%	50%			
I230 (Yuba)						100%			
I285 (Bear)						40%	60%		
I3 (Clear Creek)	100%								
I300 (Folsom)							100%		
I4 (Shasta)		100%							
I501 (Cosumnes)							70%	30%	
I52 (Fresno)			80%						20%
I53 (Chowchilla)			75%						25%
I6 (Oroville)					100%				
I8 (Folsom Local)							100%		
I81 (Tuolumne)				100%					
I90 (Mokelumne)							40%	60%	
I92 (Calaveras)							25%	75%	

The approach is consistent with that featured in Reclamation (2008a) and DWR 2009, and features two steps:

- The first step introduces monthly inflow adjustments. For a given reservoir inflow variable, the sequence of monthly impaired inflows is considered one calendar month at a time. For a given month, all of the base sequences' inflows for that calendar month (e.g., all January inflows) are scaled by that month's corresponding period mean *ratio* change in natural runoff within an assigned headwater tributary basin. Change in period mean January runoff is assessed by period-mean conditions in the natural runoff projections (Section 3.3) for the two projections periods considered in Section 2.2: 1971-2000 and 2011-2040. Table 3-3 shows how headwater tributary basins were assigned to CalSim II inflow variables. Sometimes multiple headwater basins were used to adjust a given CalSim II inflow variable, in which case a subjectively weighted average change-ratio was computed from the change-ratios of each assigned multiple headwater basin (e.g., adjustment to CalSim II inflow variable I200 "Kelly Ridge" is based on the monthly change-ratios computed as the weighted average of MRMC1 "Middle Fork Feather River" (50% weighted) and NBBC1 "North Yuba at New Bullards Dam" (50% weighted)). The subjective weights are generally based on geographic proximity. When multiple basins are assigned, the weights sum to 100% (i.e., sum across rows in Table 3-3 equals 100%). This month-specific scaling is then repeated for all calendar months, producing an adjusted reservoir inflow sequence that represents mean-monthly changes in natural runoff.

The second step introduces a full-period inflow adjustment designed to preserve annual runoff impacts from the natural runoff analysis. For a given reservoir inflow variable, the full-period base sequence of monthly inflows is considered. The entire sequence is scaled by corresponding *ratio* change in period mean-annual runoff from the assigned headwater tributary basin(s) (Table 3-3).

The second scaling is necessary to preserve consistency between long-term mean annual changes in "impaired reservoir inflow" and tributary "natural runoff." If adjustments stop after just the month-specific scaling, then mean annual changes in the CalSim II reservoir inflow variable won't be consistent because the mean annual natural runoff change in tributary basins were applied to monthly impaired inflow patterns.

After preparing monthly reservoir inflow time series for all inflow variables, consistent with a given climate projection and natural runoff response, subsequent adjustments are made to CalSim II inputs on "seasonal water supply forecast data" associated with each year's hydrology. These water supply forecasts inform the CalSim II simulation during January through May months, and determine simulated annual water delivery targets for the CVP and SWP systems. Adjustments were made so that relations between historical forecast data and historical inflows were preserved. Likewise, adjustments were made to the input hydrologic year-type classifications associated with each year's hydrology. The classifications are made relative to several classification systems featured in CalSim II. Adjustments were made so that relations between historical year-type classifications and historical inflows were preserved. The result is that the proportional split of classified drier to wetter year-types will change as the climate changes.

On the latter adjustment, a new year-type classification system is featured in these CalSim II studies relative to those featured in the CalSim II studies of Reclamation (2008a). The new system determines restoration flow releases, and depends on Friant inflow. Under the restoration settlement, six year types are defined according to the "annual unimpaired runoff at Friant for the water year (October - September)," where for each year-type there is a restoration release schedule specified in the SJRRP preferred action-alternative. The base sequence of unimpaired runoff at Friant was adjusted to reflect simulated changes in natural runoff above Millerton Lake using the same method used to adjust CalSim II reservoir inflow at Millerton Lake. This study did not presume to modify the restoration release allocation associated with perceived unimpaired runoff. So for each climate projection's "modified unimpaired inflow," the number of years that fell into each water year type category had the potential to change.

3.4.2 CalSim II Delta Representation of Sea Level Rise Assumptions

Sea level rise (SLR) assumptions were outlined in Section 2.3 (i.e., 1-foot SLR and 9% increase in tidal range, representing potential conditions by 2030). CalSim II represents sea level in how it represents Delta conditions and their constraints on CVP/SWP operations. The complexity of Delta hydrodynamics and salinity distribution are represented in CalSim II using a computationally efficient DSM2-emulator (Section 2.3). Development of this emulator is described in Reclamation (2008b) and is labeled here as the Delta Artificial Neural Network (Delta-ANN) module.

The Base and Alternative A versions of CalSim II feature a Delta-ANN module representing "current" sea level constraints on the Delta. All of the studies using climate change projections feature the Delta-ANN developed by DWR representing SLR assumptions listed above. Use of the Delta-ANN with SLR necessitated adjustment to CalSim II logic linking X2 assessment and constraint on upstream operations (i.e., how the location of the X2-defined salinity isohaline upstream of the Golden Gate changes and triggers different upstream operating decisions). Given SLR affecting X2 position and assessment, the Delta-ANN with SLR was used in the climate change studies to assess X2 during simulation instead of the Kimmerer-Monismith relationship used in the Base and Alternative A studies.

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4.0 Results

This section illustrates and summarizes key results on climate change implications for natural runoff and water supplies for the CVP/SWP and San Joaquin Basin reservoir systems. Discussion initially focuses on changes in natural runoff that affect surface water supplies. Discussion then switches to operations implications, and focuses on how future sea level and how regional climate assumptions influence measuring the effects of preferred SJRRP action-alternative (Alternative A) versus a future with no action (Base).

4.1 Natural Runoff and Reservoir Inflows

Expected results from the natural runoff analysis include the following:

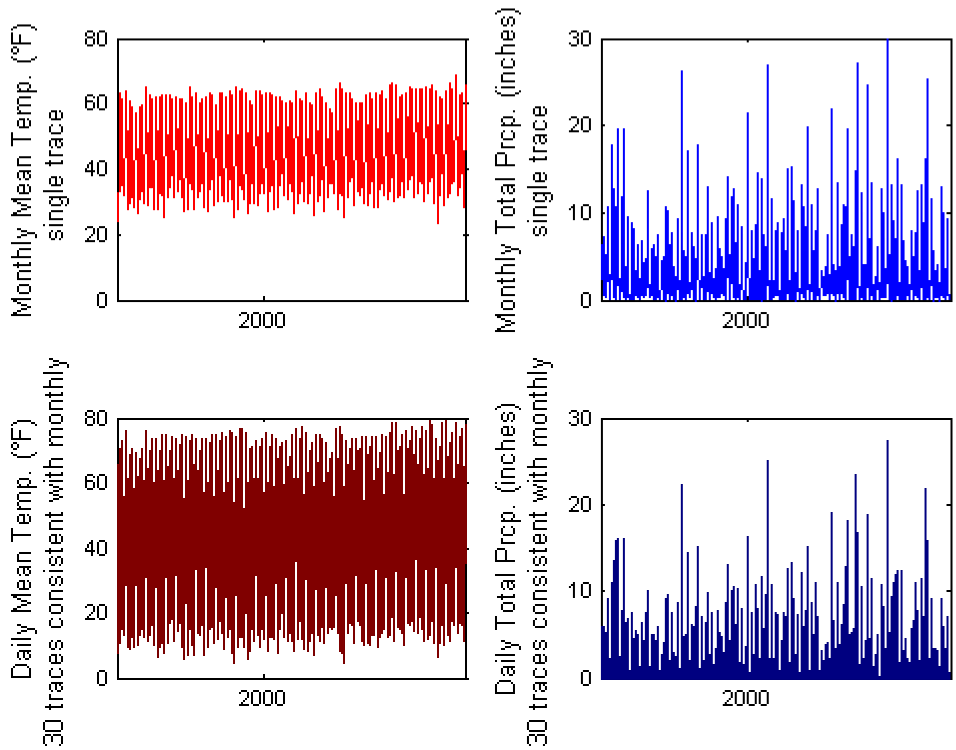
- Air temperature increase causing
  - More “wet season” rainfall precipitation rather than snow precipitation, where “wet season” is generally winter and spring.
  - Increased winter and early spring runoff due to more rainfall runoff.
  - Decreased late spring and summer runoff due to less snowpack development during winter and early spring.
- Annual precipitation change causing runoff increases or decreases depending on whether mean-annual precipitation increases or decreases.

To support discussion of natural runoff results for all basins and projections, an example is first provided, illustrating the set of inputs and outputs from the analysis over one basin involving one climate projection. The example basin is the San Joaquin River above Millerton Lake (FRAC1, Table 3-2), and the example projection is Projection No. 5 (i.e., *Central Projection*, Section 2.2.4).

Using the methodology described in Section 3.3.2, 30 sequences of 6-hourly T and P (i.e., weather “realizations”) were generated, consistent with the input requirements of the FRAC1 SacSMA/Snow17 model. Projection No. 5 monthly time series of T and P, averaged over the basin, is shown on the top panels of Figure 4-1. Daily time-series aggregates of those 6-hourly sequences consistent with the monthly time series (i.e., in terms of month-by-month mean air temperature and total precipitation) are plotted on the bottom panels of Figure 4-1.

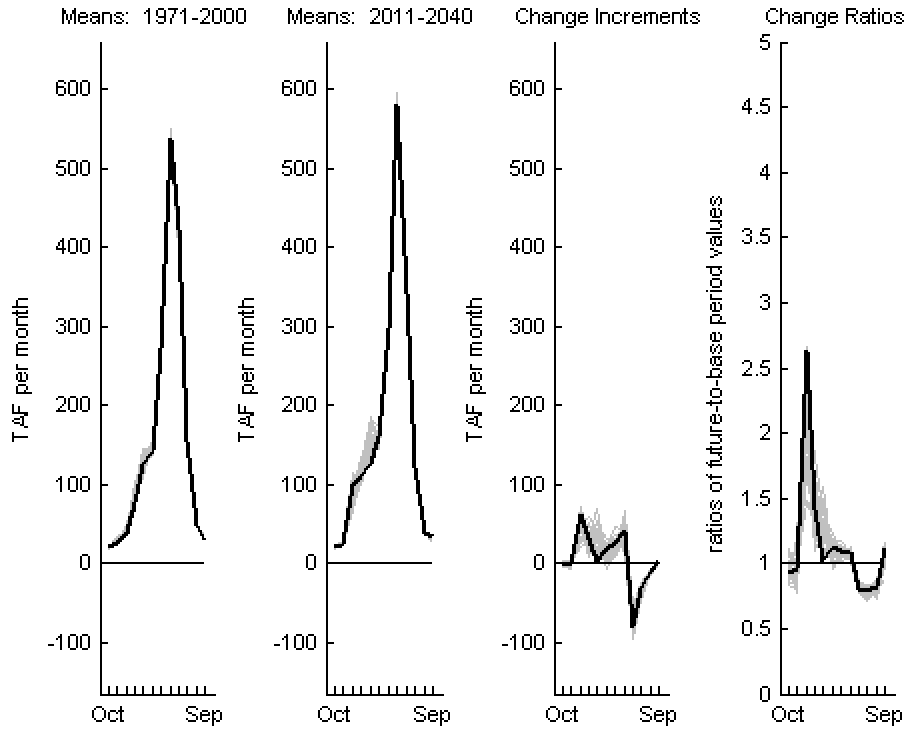
For each weather sequence, a runoff simulation is completed from 1971-2040. This results in 30 sequences of 6-hourly runoff from 1971-2040. Each output sequence was then surveyed for period mean-monthly runoff conditions during 1971-2000 and

2011-2040. Mean-monthly results for the historical and future periods are shown on the first and second panels of Figure 4-2. Realization-specific results are indicated by light-gray lines. The realization yielding median mean-annual change in runoff across the realizations is highlighted as the thick black line. Historical-to-future period changes in mean-monthly runoff are illustrated on the third and fourth panels. The third panel shows *incremental* change in mean-monthly runoff (panel 2 results minus panel 1 results, by sequence). The fourth panel shows *ratio* change in mean-monthly runoff (panel 2 results divided by panel 1 results, by sequence). Incremental change results suggest that for Projection No. 2, an increase in late-autumn through early-spring runoff would be expected in basin FRAC1, as well as a decrease in late-spring through summer runoff.



Note:
(top row) Climate-model "Projected" Monthly T and P, basin-area averaged, 1971-2040, from Projection No. 3 (Section 2.2.4); (bottom row): Daily weather traces re-generated 30 times (Section 3.4.1) to make 30 daily traces, or realizations, all consistent with the monthly times series in the top row.

Figure 4-1.
Runoff Simulation Setup Example – Monthly and Daily Climate and Weather Inputs for the SacSMA/Snow17 Application in the San Joaquin Basin Above Millerton Lake (FRAC1, Table 3-2)



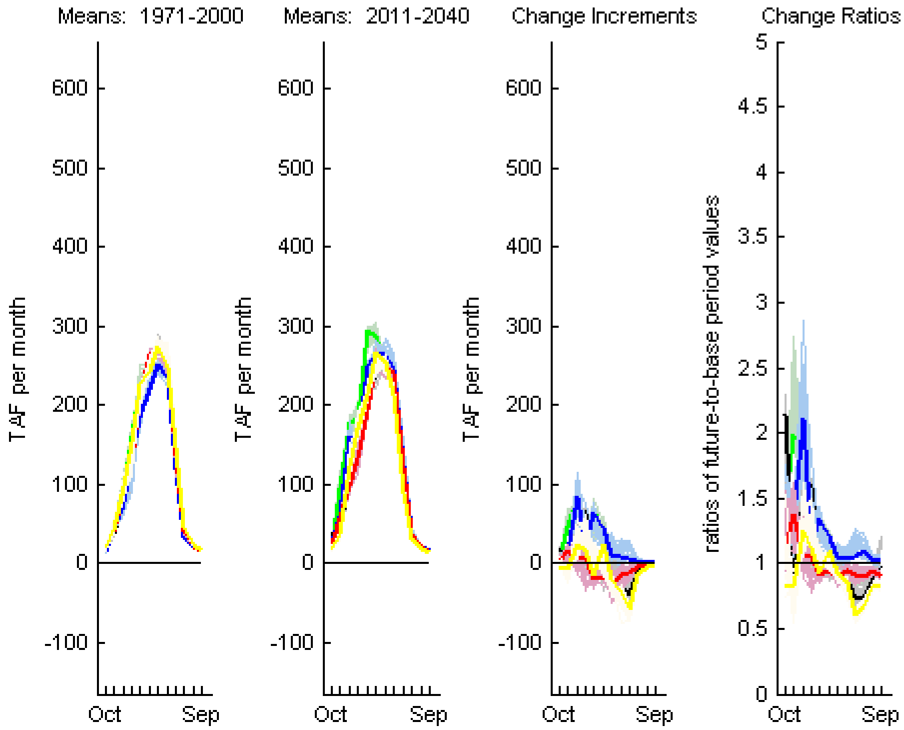
Note:
(1st panel) simulated mean-monthly runoff, 1971-2000, from each of the 30 realizations (Figure 4-1); (2nd panel) simulated mean-monthly runoff, 2011-2040, from each of the 30 realizations; (3rd panel) incremental change in mean-monthly runoff by realization, for 30 realizations; (4th panel) ratio change of future period to base period mean-monthly runoff by realization, for 30 realizations. Thicker line on each panel indicates results from the realization having the median ratio change in future-to-base period annual runoff among all realizations.

Figure 4-2.
Runoff Simulation Results Example – Monthly Runoff, Using SacSMA/Snow17 Application in the San Joaquin Basin Above Millerton Lake (FRAC1, Table 3-2)

As mentioned, the thick-line overlay on each panel of Figure 4-2 highlights the results from the weather sequence that produced the median change in mean-annual runoff. This sequence was chosen to provide natural runoff results for subsequent CVP/SWP operations analysis. The decision to choose results from one weather sequence (among the 30 sequence-specific sets of results) was motivated by the fact that only one CalSim II study was scoped to be completed per climate projection. This was because the uncertainty of monthly to annual changes in runoff due to different 6-hourly weather sequences appeared to be minor, based on simulation results, compared to the runoff uncertainty associated with the five climate projections, as will be shown on Figure 4-3 through Figure 4-11.

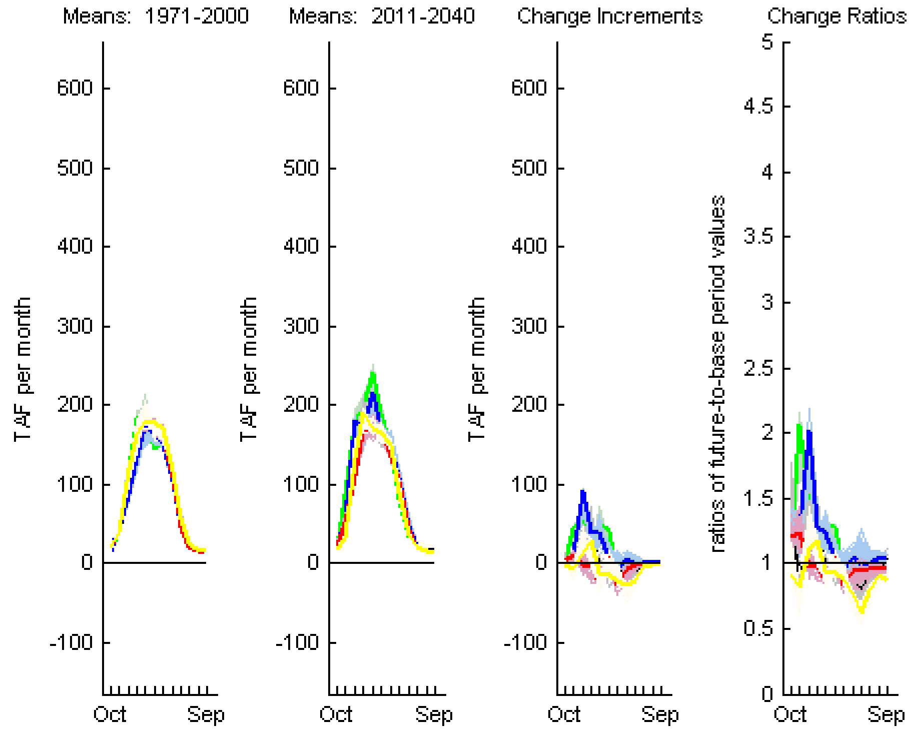
Results illustrated on Figure 4-2 are for one basin and one projection. In a similar fashion, basin-specific results for all five projections are illustrated, respectively, on Figure 4-3 to Figure 4-11, using different line color to indicate projection-specific results. Specifically, projections No. 1 through No. 5 are indicated by line colors green, blue, red, yellow, and black, respectively, and correspond to the projection labeling in Section 2.2.4.

Review of results across basins (Figure 4-3 to Figure 4-11) and across climate projections (line colors) shows that monthly runoff responses to climate change were generally similar in all basins (i.e., panels 1-3). Air temperature increase causes a shift towards an increased fraction of annual runoff occurring during winter and early-spring and a decreased fraction occurring during late-spring and summer. That annual runoff response is also affected by change in mean-annual precipitation. Review of ratio-changes in mean-monthly runoff (i.e., panel 4) shows that some basins have relatively large ratio changes during some months (e.g., October, HETC1 results shown on fourth panel of Figure 4-6). This does not mean that the incremental runoff change is large (see corresponding October results in the third panel of Figure 4-6). The large ratio changes usually occur when there’s a small denominator in the ratio (i.e., in this example, the October mean HETC1 runoff during 1971-2000).



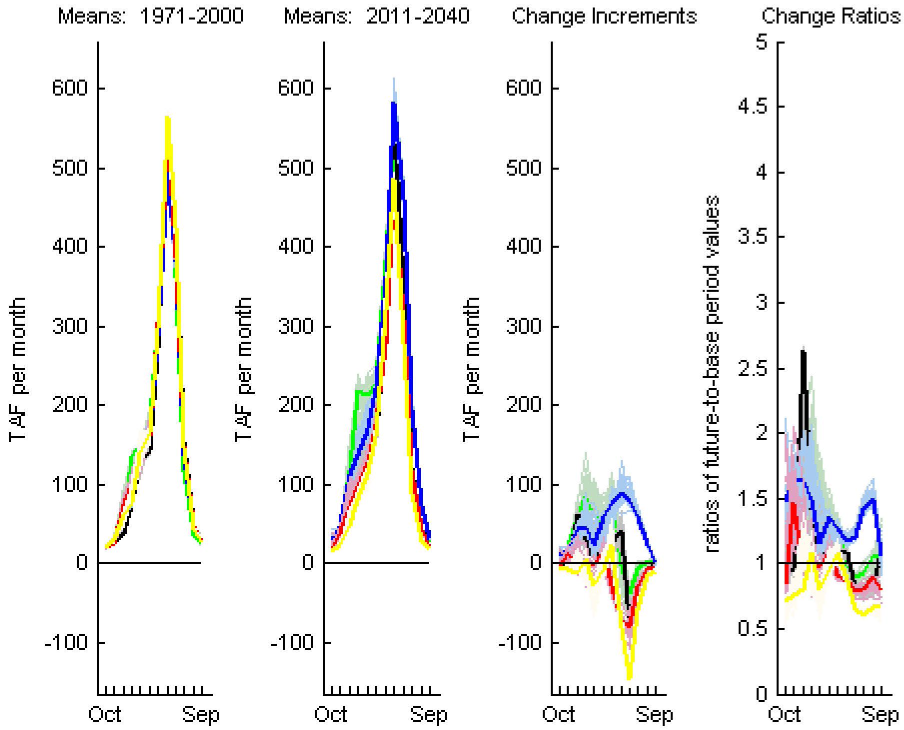
Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-3.
Simulated Monthly Runoff Response, Trinity at Trinity Reservoir
(CECG1, Table 3-2)



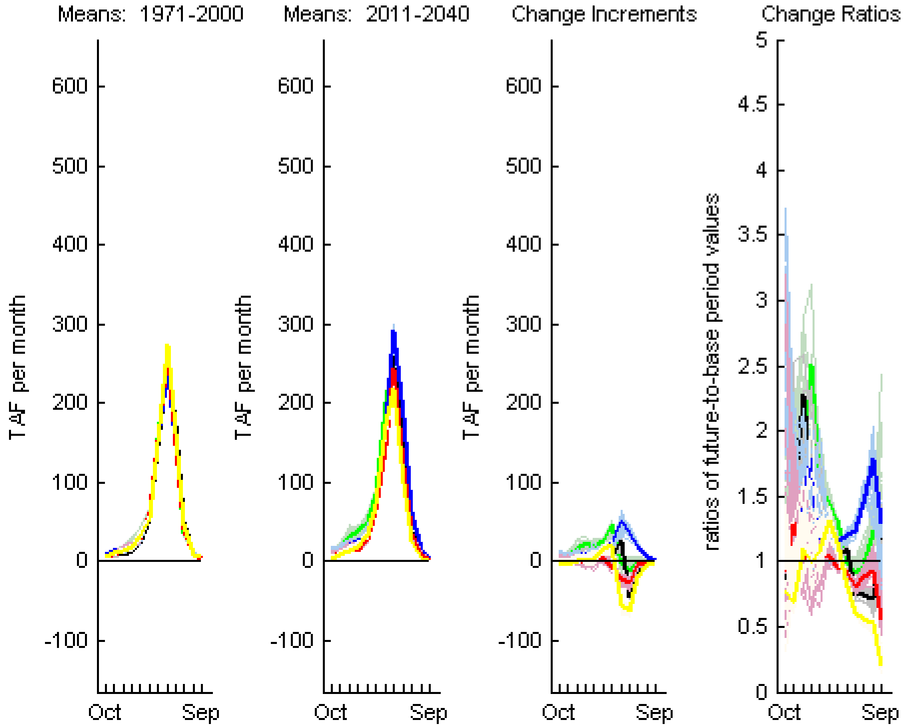
Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-4.
Simulated Monthly Runoff Response, Sacramento at town of Delta (DLTC1, Table 3-2)



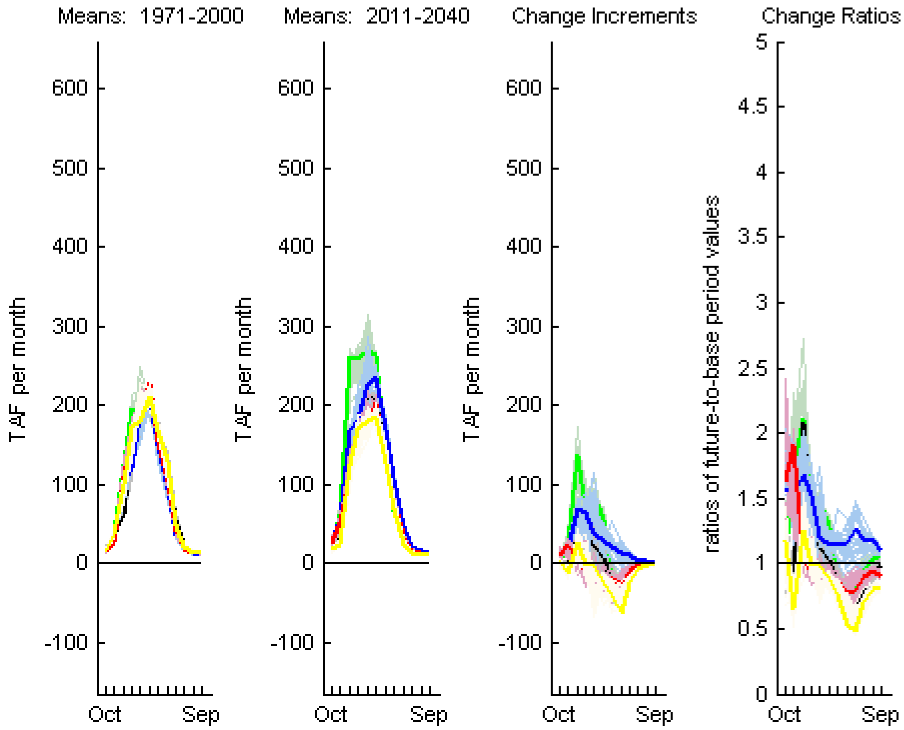
Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-5.
Simulated Monthly Runoff Response, San Joaquin at Millerton Lake
(FRAC1, Table 3-2)



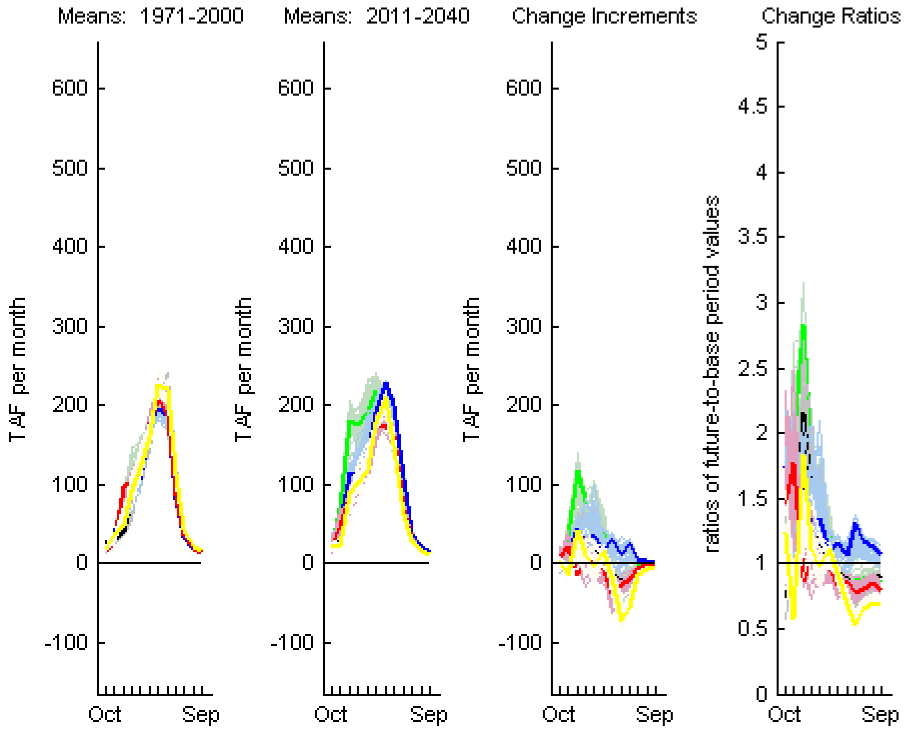
Note:
Similar to Figure 4-2 but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-6.
Simulated Monthly Runoff Response, Tuolumne at Hetch Hetchy Dam
(HETC1, Table 3-2)



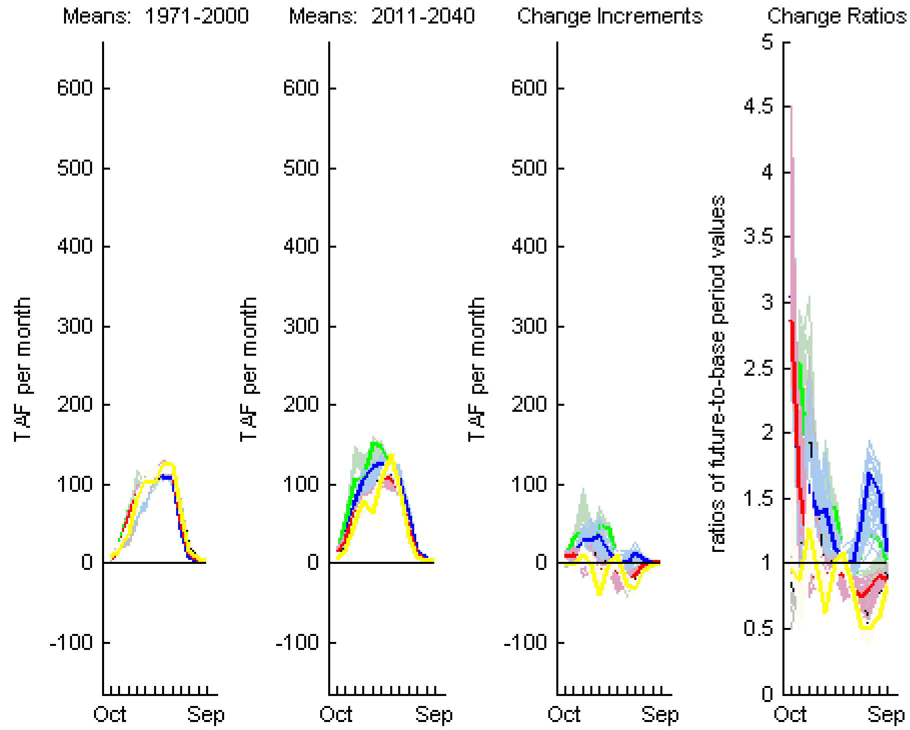
Note;
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-7.
Simulated Monthly Runoff Response, Feather, Middle Fork, at Merrimac (MRMC1, Table 3-2)



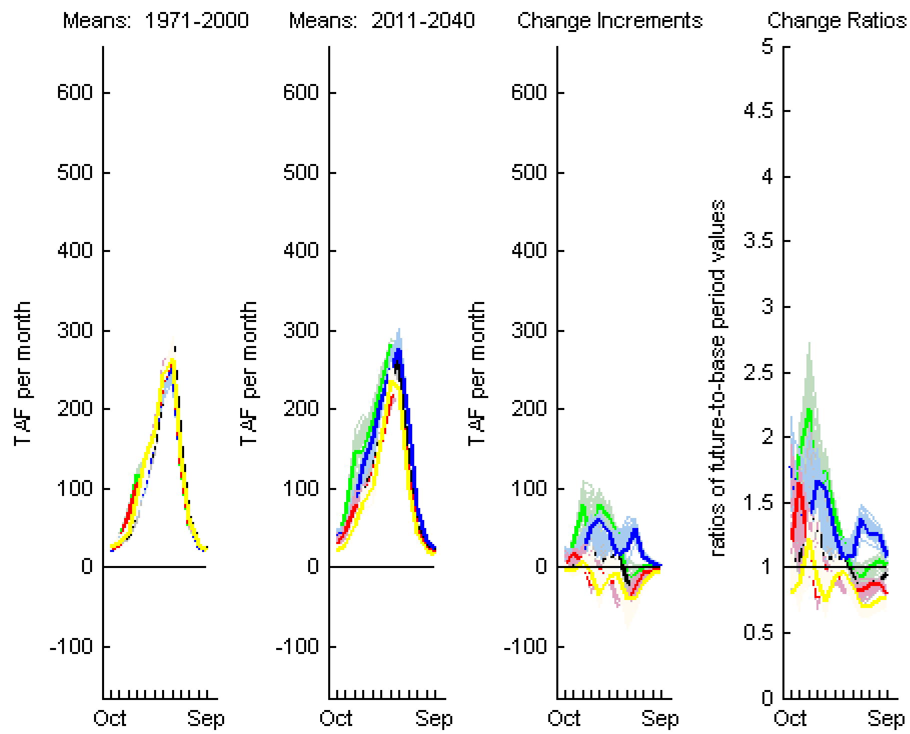
Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-8.
Simulated Monthly Runoff Response, North Yuba at New Bullards Bar Reservoir (NBBC1, Table 3-2)



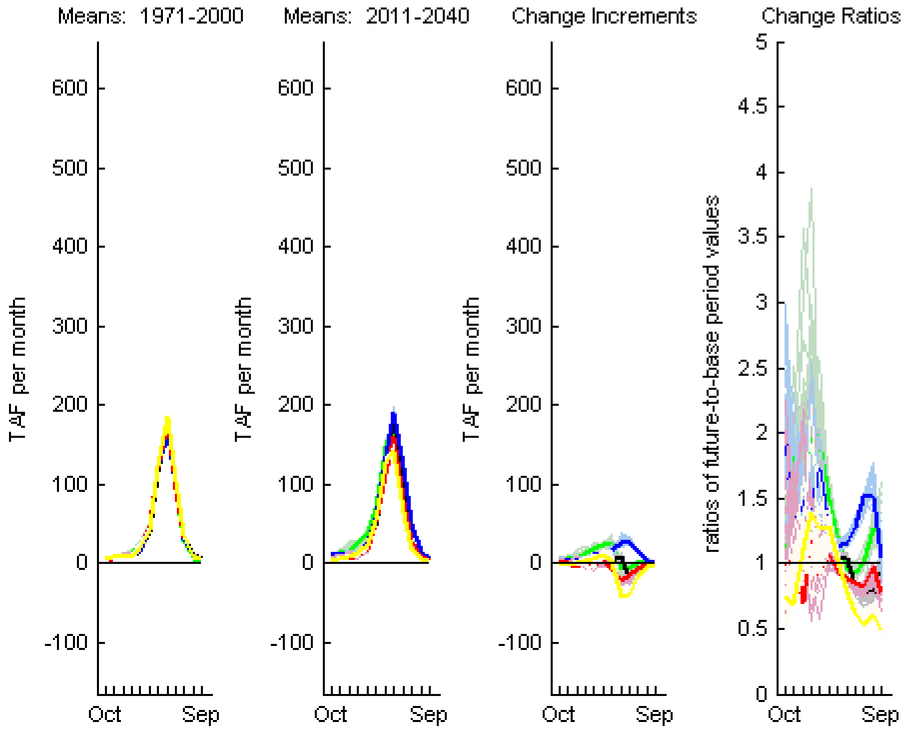
Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-9.
Simulated Monthly Runoff Response, American, North Fork, at North Fork Dam (NFDC1, Table 3-2)



Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

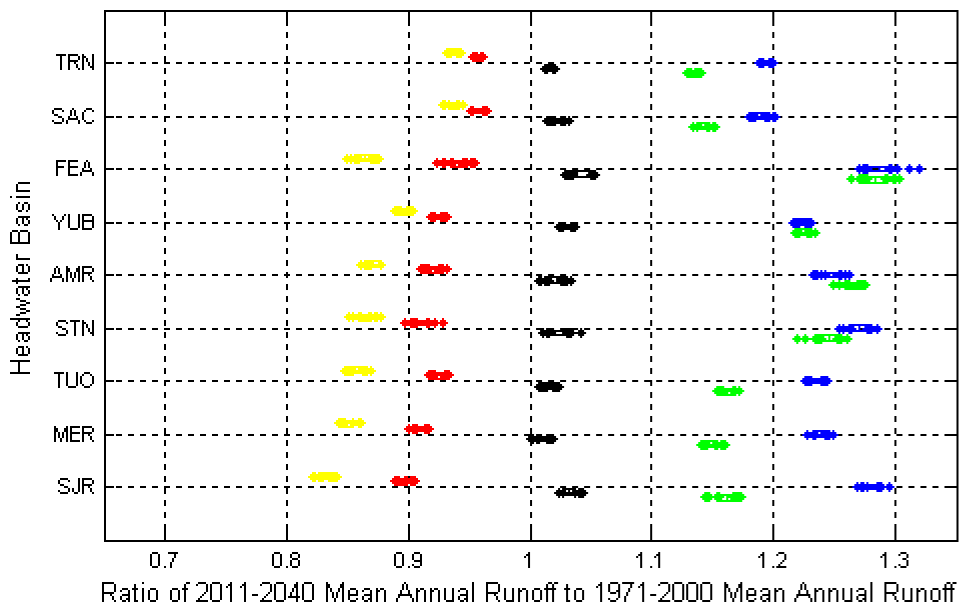
Figure 4-10.
Simulated Monthly Runoff Response, Stanislaus at New Melones Reservoir (NFDC1, Table 3-2)



Note:
Similar to Figure 4-2, but with results shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively.

Figure 4-11.
Simulated Monthly Runoff Response, Merced at Pohono Bridge
(POHC1, Table 3-2)

Switching to uncertainty in the mean-annual response, Figure 4-12 shows how the ratio-change in mean-annual runoff varies by climate projection. Results for Projections No. 1 through No. 5 are indicated by green, blue, red, yellow and black boxplots, respectively. A boxplot shows how the change in mean-annual runoff varied among the 30 weather realizations generated for the given projection. A boxplot's "box" indicates range from 25th percentile to 75th percentile change values; the mid-line through the box represents the median change. Figure 4-12 shows that the uncertainty introduced by weather-sequencing has very little effect on the ratio change in mean-annual runoff.



Note:
Results are shown for Projections No. 1 through No. 5, indicated by line colors green, blue, red, yellow, and black, respectively. For each set of results specific to basin and projection, there are 30 ratio values corresponding to the 30 different weather realizations simulated (each consistent with the given projection). The distribution of these 30 values is shown as a boxplot. Boxplot features are compressed at the chosen scale for the horizontal-axis, which was driven by the choice of highlighting results variation relative to projection choice.

Figure 4-12.
Simulated Annual Runoff Response, All Basins

Natural runoff changes were next translated into changes in reservoir inflows for CVP/SWP and San Joaquin Basin systems. Following the approach described in Section 3.4.1, CalSim II inflows were scaled on a monthly basis according to ratio changes in mean-monthly and mean-annual runoff (i.e., ratios indicated by "thick lines" on the fourth panels of Figure 4-3 through Figure 4-11; and boxplot medians from Figure 4-12, respectively, when using results from the SacSMA/Snow17 model). Resultant changes in mean-monthly and mean-annual inflows are summarized in Table 4-1 and Table 4-2 for major system reservoirs and the inflow point for the Yuba and Bear Rivers. Adjusted inflows and incremental differences from base inflows are summarized in Table 4-1 percentage differences from base are listed in Table 4-2. Figure 4-13 displays the ranges of the percent changes inflows at major inflow locations.

Table 4-1.
Average CalSim II Inflows and Incremental Differences By Climate Projection

Units = TAF[1]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Trinity Reservoir (CalSimII inflow variable I1)													
Base	19	52	100	130	151	178	210	244	129	40	14	10	1,277
Projection 1	26	100	178	145	198	211	202	213	115	36	13	10	1,448
Projection 2	26	67	199	147	200	212	218	252	136	44	15	11	1,525
Projection 3	21	70	103	135	136	166	188	229	116	36	14	9	1,223
Projection 4	16	43	123	143	142	196	196	211	79	27	12	9	1,197
Projection 5	39	47	141	198	146	172	198	214	92	29	13	10	1,298
Proj.1-Base	8	48	79	15	47	33	-8	-31	-14	-4	-1	-1	171
Proj.2-Base	7	15	99	17	49	35	8	8	7	3	0	0	247
Proj.3-Base	2	18	3	6	-15	-12	-22	-15	-13	-4	-1	-1	-54
Proj.4-Base	-3	-9	23	13	-9	18	-14	-32	-50	-13	-2	-2	-80
Proj.5-Base	20	-5	41	68	-5	-6	-13	-30	-37	-11	-2	0	21
(CVP) Lake Shasta (CalSimII inflow variable I4)													
Base	246	340	545	721	803	838	691	514	326	240	215	211	5,690
Projection 1	285	690	814	784	1019	1075	641	361	220	213	199	199	6,499
Projection 2	280	427	1080	920	989	870	654	542	322	238	227	219	6,769
Projection 3	291	413	522	693	679	874	567	475	301	227	203	198	5,446
Projection 4	230	284	609	852	765	787	618	401	208	192	199	187	5,331
Projection 5	297	314	696	947	775	778	641	465	264	215	204	221	5,818
Proj.1-Base	39	350	269	63	217	237	-50	-153	-106	-27	-16	-13	810
Proj.2-Base	35	87	535	198	186	32	-37	29	-4	-2	12	8	1,079
Proj.3-Base	46	73	-23	-28	-123	36	-124	-39	-24	-13	-12	-13	-244
Proj.4-Base	-16	-56	64	130	-38	-51	-73	-113	-118	-48	-17	-24	-359
Proj.5-Base	51	-26	151	226	-28	-60	-49	-49	-62	-25	-11	10	128
(SWP) Lake Oroville (CalSimII inflow variable I6)													
Base	124	185	343	477	511	567	562	506	280	159	137	119	3,967
Projection 1	141	338	747	667	809	784	530	370	257	167	153	133	5,096
Projection 2	194	281	564	721	621	653	647	587	357	190	161	130	5,105
Projection 3	194	337	339	431	481	494	482	387	220	140	126	104	3,735
Projection 4	148	124	434	480	524	521	446	281	144	116	114	99	3,430
Projection 5	113	177	683	575	583	590	490	361	182	127	130	118	4,129
Proj.1-Base	17	153	404	190	298	217	-32	-135	-23	8	16	14	1,128
Proj.2-Base	70	96	221	244	111	86	85	81	77	31	24	11	1,138
Proj.3-Base	70	151	-3	-46	-30	-72	-80	-119	-60	-19	-11	-15	-232
Proj.4-Base	25	-62	91	4	13	-46	-116	-225	-136	-44	-22	-20	-537
Proj.5-Base	-11	-8	341	98	72	24	-72	-144	-98	-32	-6	-1	162
Yuba/Bear River Inflows (CalSimII inflow variable I230)													
Base	52	74	156	221	200	212	173	242	189	122	97	51	1,789
Projection 1	42	134	387	362	270	253	153	197	162	104	84	42	2,191
Projection 2	88	100	241	280	261	228	197	253	243	139	106	53	2,189
Projection 3	73	126	131	224	193	200	140	206	144	96	80	39	1,654
Projection 4	62	40	261	228	188	227	158	162	100	78	66	34	1,604
Projection 5	35	71	295	303	216	198	153	208	140	98	81	44	1,842
Proj.1-Base	-10	60	231	141	70	41	-21	-45	-27	-17	-13	-9	402
Proj.2-Base	36	26	85	60	60	17	24	10	53	18	9	2	400
Proj.3-Base	21	52	-25	3	-7	-12	-33	-36	-45	-25	-17	-11	-135
Proj.4-Base	11	-34	105	8	-13	15	-16	-80	-89	-43	-31	-17	-185
Proj.5-Base	-17	-3	139	83	16	-14	-21	-34	-50	-23	-16	-7	53

Table 4-1.
Average CalSim II Inflows and Incremental Differences By Climate Projection (contd.)

Units = TAF[1]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Folsom Lake (sum of CalSimII inflow variables I8 and I300)													
Base	97	138	229	301	318	349	350	373	228	133	114	106	2,735
Projection 1	131	333	355	366	459	488	355	321	251	162	131	106	3,458
Projection 2	270	188	336	382	422	364	341	351	281	209	162	106	3,414
Projection 3	250	198	228	238	275	304	300	281	161	101	96	85	2,519
Projection 4	95	120	287	290	204	359	384	299	120	68	68	90	2,383
Projection 5	76	141	418	428	308	357	327	313	163	72	88	98	2,790
Proj.1-Base	34	195	126	66	141	139	4	-51	23	29	18	0	723
Proj.2-Base	173	50	107	81	104	15	-9	-21	53	77	49	0	679
Proj.3-Base	153	60	0	-62	-43	-45	-50	-92	-67	-32	-17	-21	-216
Proj.4-Base	-2	-18	58	-11	-114	10	34	-74	-108	-65	-45	-16	-352
Proj.5-Base	-21	3	190	128	-10	8	-23	-60	-65	-61	-25	-8	56
(CVP) Trinity Reservoir + Lake Shasta + Folsom Lake (main Sacramento Valley CVP reservoirs)													
Base	362	530	873	1152	1272	1365	1251	1130	683	413	343	328	9,702
Projection 1	442	1124	1347	1296	1676	1774	1198	895	586	411	344	314	11,405
Projection 2	576	682	1615	1449	1611	1447	1213	1145	739	491	404	336	11,708
Projection 3	563	681	853	1067	1091	1345	1055	984	579	363	313	293	9,187
Projection 4	340	447	1019	1284	1111	1342	1199	911	407	288	279	286	8,912
Projection 5	412	502	1256	1573	1228	1307	1166	991	520	316	305	329	9,906
Proj.1-Base	81	594	474	144	404	409	-54	-235	-97	-2	1	-14	1,704
Proj.2-Base	214	152	741	297	339	82	-38	15	56	79	61	8	2,006
Proj.3-Base	201	151	-20	-85	-181	-20	-196	-146	-104	-49	-30	-35	-514
Proj.4-Base	-21	-83	145	132	-161	-24	-52	-219	-276	-125	-64	-42	-790
Proj.5-Base	50	-28	382	421	-44	-58	-85	-139	-163	-97	-38	2	204
(CVP) New Melones Reservoir (CalSimII inflow variable I10)													
Base	34	41	62	85	95	112	128	204	164	75	47	39	1,087
Projection 1	37	75	135	106	165	156	154	199	158	77	50	41	1,353
Projection 2	58	57	81	136	147	136	134	220	220	91	57	42	1,380
Projection 3	40	66	68	66	95	101	116	169	134	64	41	31	990
Projection 4	28	37	75	79	71	105	127	177	121	53	37	30	939
Projection 5	35	43	94	110	101	119	138	192	134	64	42	38	1,110
Proj.1-Base	3	34	73	21	70	45	26	-5	-6	2	3	1	266
Proj.2-Base	24	16	19	51	52	25	6	16	55	16	10	2	293
Proj.3-Base	6	25	6	-19	1	-11	-12	-35	-30	-11	-6	-8	-97
Proj.4-Base	-6	-5	13	-6	-23	-7	-1	-27	-44	-21	-11	-9	-147
Proj.5-Base	1	2	32	25	6	7	10	-12	-31	-10	-5	-2	24

Table 4-1.
Average CalSim II Inflows and Incremental Differences By Climate Projection (contd.)

Units = TAF[1]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Millerton Lake (CalSimII inflow variable I18)													
Base	65	63	78	101	119	146	198	254	291	187	124	105	1,730
Projection 1	62	105	153	161	164	181	249	252	264	175	131	108	2,006
Projection 2	94	98	122	147	134	192	244	293	343	259	180	108	2,216
Projection 3	53	90	72	98	114	157	177	218	231	149	111	82	1,551
Projection 4	48	49	65	112	99	144	220	226	200	119	85	73	1,439
Projection 5	58	57	192	137	118	158	210	267	232	146	98	114	1,786
Proj.1-Base	-3	43	76	60	46	35	52	-2	-28	-12	7	3	276
Proj.2-Base	29	36	44	46	16	46	47	39	51	73	57	3	486
Proj.3-Base	-12	27	-6	-4	-4	11	-21	-36	-60	-38	-13	-24	-179
Proj.4-Base	-17	-14	-13	10	-20	-1	22	-28	-92	-68	-39	-32	-291
Proj.5-Base	-7	-6	115	35	-1	12	13	13	-60	-41	-26	8	56
Lake McClure (CalSimII inflow variable I20)													
Base	8	19	43	65	84	98	145	240	173	62	19	9	965
Projection 1	6	33	58	117	148	133	161	212	149	58	22	11	1,109
Projection 2	15	24	60	88	136	115	156	264	210	89	27	9	1,194
Projection 3	8	20	30	78	75	104	134	209	146	50	18	7	878
Projection 4	5	12	44	82	98	117	140	174	103	31	11	4	822
Projection 5	7	21	54	79	125	110	141	235	135	47	14	8	976
Proj.1-Base	-1	13	15	52	64	35	17	-27	-24	-4	4	2	144
Proj.2-Base	7	5	17	22	53	17	11	25	37	27	8	0	229
Proj.3-Base	0	1	-13	12	-8	6	-10	-30	-27	-12	-1	-2	-86
Proj.4-Base	-2	-7	1	17	14	19	-5	-66	-70	-31	-8	-5	-143
Proj.5-Base	-1	1	11	13	41	12	-4	-5	-38	-15	-5	-1	11
New Don Pedro Reservoir (CalSimII inflow variable I81)													
Base	20	37	90	123	160	186	200	308	294	107	31	29	1,586
Projection 1	17	48	144	261	227	240	233	271	242	92	34	33	1,843
Projection 2	23	37	128	208	162	224	223	361	352	150	53	37	1,958
Projection 3	17	45	92	114	170	189	188	278	236	93	28	16	1,467
Projection 4	14	24	93	116	165	235	220	238	175	59	16	5	1,361
Projection 5	13	45	172	172	191	200	188	304	200	73	20	34	1,611
Proj.1-Base	-2	11	54	138	67	53	33	-36	-52	-15	3	4	257
Proj.2-Base	3	1	38	85	2	37	23	53	58	42	22	7	372
Proj.3-Base	-2	9	2	-9	10	3	-13	-30	-59	-14	-3	-14	-118
Proj.4-Base	-5	-13	3	-7	5	49	20	-70	-119	-48	-15	-24	-224
Proj.5-Base	-7	8	82	49	31	14	-13	-3	-95	-34	-11	5	26

Note:
[1] Mean monthly or annual value during CalSim II simulation years, labeled 1922-2003 (82 years).
Key:
CVP = Central Valley Project
SWP = State Water Project
TAF = thousand acre-feet

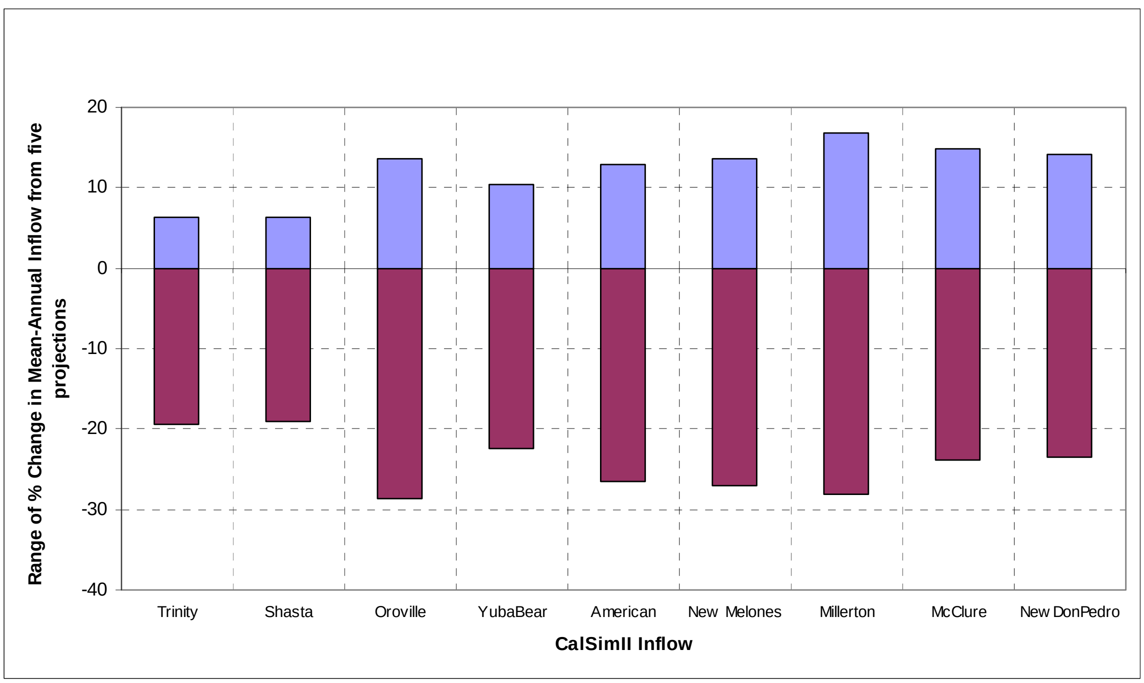
Table 4-2.
Percentage Departure from Average Historical CalSim II Inflows By Climate Projection

Units = TAF[1]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Trinity Reservoir (CalSimII inflow variable I1)													
Proj.1-Base	40	92	79	12	31	19	-4	-13	-11	-10	-7	-7	13
Proj.2-Base	36	28	99	13	32	19	4	3	5	9	1	2	19
Proj.3-Base	11	34	3	4	-10	-7	-11	-6	-10	-11	-6	-11	-4
Proj.4-Base	-15	-17	23	10	-6	10	-7	-13	-39	-32	-16	-17	-6
Proj.5-Base	106	-10	42	53	-4	-3	-6	-12	-29	-27	-11	-3	2
(CVP) Lake Shasta (CalSimII inflow variable I4)													
Proj.1-Base	16	103	49	9	27	28	-7	-30	-33	-11	-7	-6	14
Proj.2-Base	14	26	98	27	23	4	-5	6	-1	-1	6	4	19
Proj.3-Base	19	22	-4	-4	-15	4	-18	-8	-7	-6	-5	-6	-4
Proj.4-Base	-7	-16	12	18	-5	-6	-10	-22	-36	-20	-8	-11	-6
Proj.5-Base	21	-8	28	31	-4	-7	-7	-9	-19	-10	-5	5	2
(SWP) Lake Oroville (CalSimII inflow variable I6)													
Proj.1-Base	14	82	118	40	58	38	-6	-27	-8	5	12	12	28
Proj.2-Base	57	52	65	51	22	15	15	16	28	19	18	10	29
Proj.3-Base	57	82	-1	-10	-6	-13	-14	-23	-21	-12	-8	-12	-6
Proj.4-Base	20	-33	27	1	3	-8	-21	-44	-49	-27	-16	-17	-14
Proj.5-Base	-9	-4	100	21	14	4	-13	-29	-35	-20	-5	-1	4
Yuba/Bear River Inflows (CalSimII inflow variable I230)													
Proj.1-Base	-19	81	148	64	35	19	-12	-19	-14	-14	-13	-18	22
Proj.2-Base	69	35	55	27	30	8	14	4	28	15	9	4	22
Proj.3-Base	41	70	-16	2	-3	-6	-19	-15	-24	-21	-17	-22	-8
Proj.4-Base	21	-45	67	4	-6	7	-9	-33	-47	-36	-32	-34	-10
Proj.5-Base	-32	-4	89	37	8	-6	-12	-14	-26	-19	-17	-14	3
(CVP) Folsom Lake (sum of CalSimII inflow variables I8 and I300)													
Proj.1-Base	35	142	55	22	44	40	1	-14	10	22	15	0	26
Proj.2-Base	178	36	47	27	33	4	-3	-6	23	58	43	0	25
Proj.3-Base	158	44	0	-21	-14	-13	-14	-25	-29	-24	-15	-20	-8
Proj.4-Base	-3	-13	26	-4	-36	3	10	-20	-48	-49	-40	-15	-13
Proj.5-Base	-22	3	83	42	-3	2	-7	-16	-28	-46	-22	-8	2
(CVP) Trinity Reservoir + Lake Shasta + Folsom Lake (main Sacramento Valley CVP reservoirs)													
Proj.1-Base	22	112	54	12	32	30	-4	-21	-14	0	0	-4	18
Proj.2-Base	59	29	85	26	27	6	-3	1	8	19	18	2	21
Proj.3-Base	56	29	-2	-7	-14	-1	-16	-13	-15	-12	-9	-11	-5
Proj.4-Base	-6	-16	17	11	-13	-2	-4	-19	-40	-30	-19	-13	-8
Proj.5-Base	14	-5	44	37	-3	-4	-7	-12	-24	-23	-11	0	2
(CVP) New Melones Reservoir (CalSimII inflow variable I10)													
Proj.1-Base	8	83	117	25	74	40	20	-3	-4	3	6	3	25
Proj.2-Base	72	39	31	60	55	22	4	8	34	22	22	6	27
Proj.3-Base	16	60	10	-23	1	-10	-10	-17	-18	-14	-14	-22	-9
Proj.4-Base	-17	-11	21	-7	-25	-6	-1	-13	-27	-29	-23	-23	-14
Proj.5-Base	3	5	52	29	7	6	8	-6	-19	-14	-10	-5	2
(CVP) Millerton Lake (CalSimII inflow variable I18)													
Proj.1-Base	-4	68	98	59	38	24	26	-1	-10	-6	6	3	16
Proj.2-Base	44	57	57	45	13	32	24	15	18	39	46	3	28
Proj.3-Base	-18	43	-7	-4	-4	8	-10	-14	-21	-20	-11	-23	-10
Proj.4-Base	-27	-22	-17	10	-17	-1	11	-11	-31	-36	-31	-31	-17
Proj.5-Base	-11	-9	148	35	-1	9	6	5	-20	-22	-21	8	3

Table 4-2.
Percentage Departure from Average Historical CalSim II Inflows By Climate Projection (contd.)

Units = TAF[1]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Lake McClure(CalSimII inflow variable I20)													
Proj.1-Base	-16	69	34	80	77	35	11	-11	-14	-7	19	17	15
Proj.2-Base	91	23	40	34	63	17	8	10	22	44	42	-1	24
Proj.3-Base	-3	3	-31	19	-10	6	-7	-13	-16	-19	-3	-23	-9
Proj.4-Base	-29	-37	2	26	17	19	-3	-27	-41	-50	-40	-52	-15
Proj.5-Base	-10	7	26	20	50	12	-3	-2	-22	-24	-25	-11	1
New Don Pedro Reservoir (CalSimII inflow variable I81)													
Proj.1-Base	-12	30	60	112	41	29	16	-12	-18	-14	10	12	16
Proj.2-Base	18	2	43	69	1	20	11	17	20	40	72	24	23
Proj.3-Base	-11	24	2	-8	6	2	-6	-10	-20	-13	-9	-47	-7
Proj.4-Base	-26	-35	4	-5	3	26	10	-23	-41	-44	-49	-82	-14
Proj.5-Base	-36	22	91	40	19	7	-6	-1	-32	-32	-35	17	2

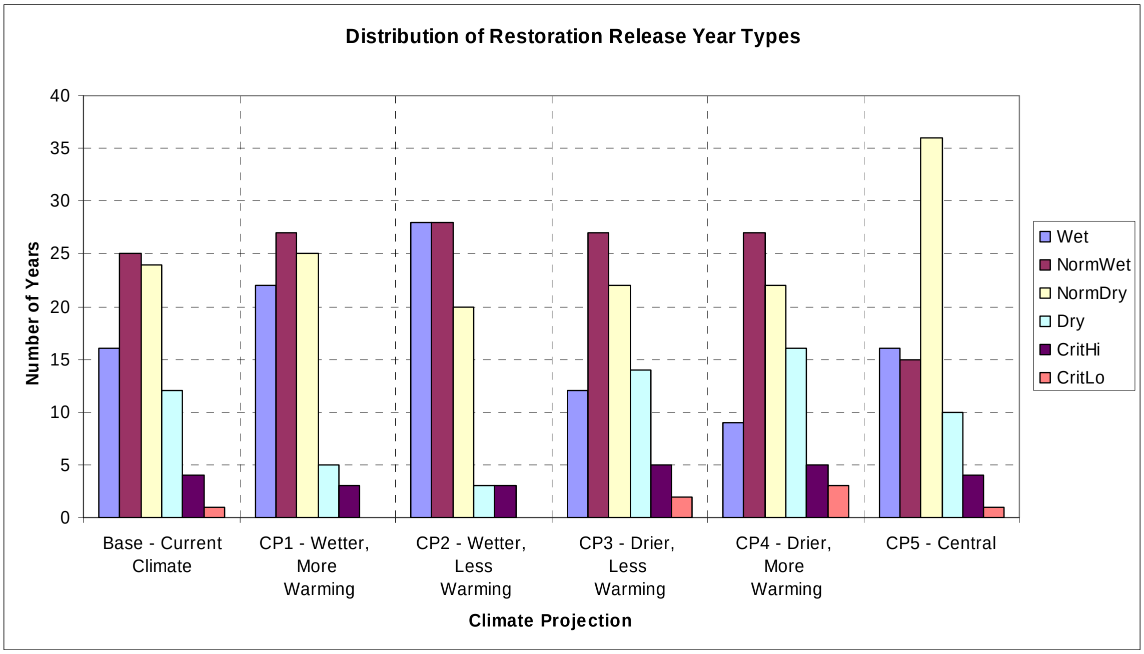
Note:
[1] Mean monthly or annual value during CalSim II simulation years, labeled 1922-2003 (82 years).
Key:
CVP = Central Valley Project
SWP = State Water Project
TAF = thousand acre-feet



Note:
Graph shows the maximum and minimum change in mean annual inflow among the 5 climate projections considered in the study.

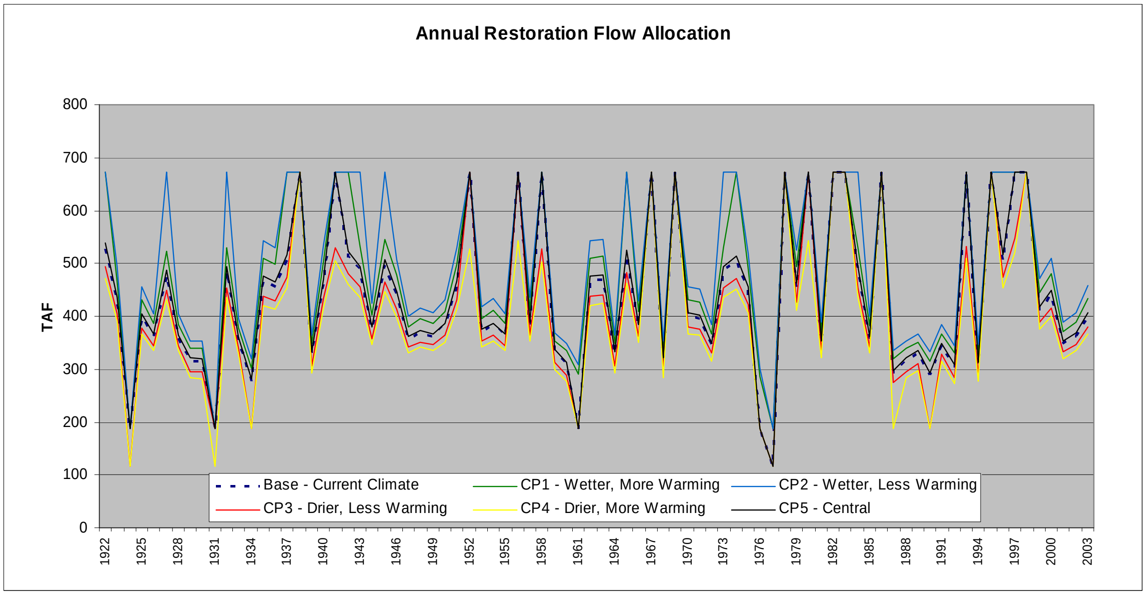
Figure 4-13.
Range of CalSimII Inflow Changes Associated with Regional Climate Assumptions

Lastly, other inflow-related CalSim II inputs were adjusted consistent with changes made to reservoir/headwaters inflows (summarized in Table 4-3). Specifically, adjustments were made to water supply forecasts and hydrologic year-type data associated with the various year-type classification systems, as described in Section 3.4.1. On the year-type classification adjustments, Figure 4-14 focuses on the system tied to restoration release schedules. As Figure 4-14 shows, the mix of classifications varies relative to the future regional climate assumption. Figure 4-15 is an additional view of how restoration release objectives would be sensitive to the regional climate assumption, showing how the resulting annual time series of restoration flow allocations varies among projections.



Note:
Shows the number of years that each of the 5 climate projections considered in the study fall into the 6 restoration year type categories.

Figure 4-14.
Distribution of San Joaquin River Restoration Year Type Classifications for Each Regional Climate Assumption



Note:
Shows the differences in annual restoration flow volumes under current climate and 5 climate projection conditions.

Figure 4-15.
Annual Allocation to Restoration Flows for Each Regional Climate Assumption

4.2 CVP/SWP Operations

Effects of the restoration releases under the five climate projection scenarios are compared to the effects seen between the Base and Alternative A scenarios using current climate data. The major categories of impacts to system operations due to restoration releases are deliveries to Madera and Friant Kern Canals, flows through the upper San Joaquin River system and at Vernalis, Delta operations including outflow and exports, and effects on NOD storage and reservoir releases. This section will focus on changes to impacts seen in these areas.

It is expected that differences in the impacts of restoration releases will be driven largely by the differences in the restoration releases caused by the changes to inflows at Friant. As demonstrated in Figure 4-15, higher overall restoration release allocations are seen in the two wetter climate projections (Projections No. 1 and No. 2), while the two drier projections result in lower overall allocations to restoration release (Projections No. 3 and No. 4). The annual releases under the centrally projected climate (Projection No. 5) are more similar to those under the historical climate, or “current climate.”

As an overview of results, Table 4-3 lists long term mean annual values for changes to storage results, key flow volumes, Delta parameters, and system deliveries during water years 1922-2003. Mean annual values for the dry period of 1929-1934 are also provided.

Table 4-3.
Summary of Operations Effects Variation with Regional Climate and Sea Level Scenarios

	Comparison 1: Current Climate		Comparison 2: CP1 - Wetter, More Warming		Comparison 3: CP2 - Wetter, Less Warming		Comparison 4: CP3 - Drier, Less Warming		Comparison 5: CP4 - Drier, More Warming		Comparison 6: CP5 - Central	
	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934
Effect of SJRRP on Mean End-of-September Storage (TAF)												
Trinity	11	9	2	9	3	9	6	9	2	9	1	9
Shasta	14	6	4	6	16	6	2	6	3	6	6	6
Oroville	26	39	33	39	22	39	17	39	19	39	8	39
Folsom	5	-1	4	-1	4	-1	1	-1	0	-1	1	-1
New Melones	16	31	11	31	12	31	13	31	14	31	15	31
CVP San Luis	-20	27	-14	27	-8	27	-6	27	-10	27	-6	27
SWP San Luis	16	9	18	9	20	9	12	9	29	9	24	9
Millerton	-16	-6	-13	-6	-20	-6	-12	-6	-8	-6	-11	-6
Total San Luis	-4	36	4	36	12	36	5	36	19	36	18	36
Effect of SJRRP on Mean-Annual River Flow Volumes (TAF)												
Trinity Release	1	0	1	0	5	0	0	-2	3	4	0	9
Keswick Release	-2	2	-2	-1	-2	2	-3	3	-5	-6	0	12
Nimbus Release	0	-2	0	-4	0	11	-1	-1	0	2	0	1
Flow Below Thermalito	0	-4	-2	-1	-1	-8	-4	-7	2	28	-1	-7
Friant Release	152	205	108	203	120	235	156	188	142	167	127	199
Main Friant Release	321	206	357	229	381	264	295	188	277	167	326	212
Friant Flood Release	-55	0	-124	-24	-99	-17	-56	0	-57	0	-97	-13
Friant Snowmelt Release	-113	-1	-125	-2	-161	-13	-83	0	-78	0	-102	0
Friant Kern Canal	-125	-161	-78	-166	-93	-195	-126	-148	-116	-132	-99	-155
Madera Canal	-25	-37	-28	-35	-26	-41	-28	-34	-25	-29	-27	-39
SJR to Mendota Pool	-68	0	-101	-14	-99	-22	-57	0	-58	0	-80	-10
Chowchilla Bypass	-78	0	-115	-8	-125	-1	-63	0	-59	0	-92	-1
Restoration Channel	239	137	272	157	294	190	216	122	200	106	244	141
DMC to Mendota Pool	34	0	52	5	57	17	25	0	25	0	38	4
Flow Below Mendota Pool	-35	0	-50	-9	-41	-4	-32	0	-32	0	-43	-6
Flow at Goodwin	0	-7	0	-5	0	-6	-1	-8	-1	-5	0	-9
New Don Pedro Release	0	-1	0	-1	0	0	0	-2	0	2	0	-1
McClure Release	0	7	0	3	0	1	0	-1	0	0	0	7

Table 4-3.
Summary of Operations Effects Variation with Regional Climate and Sea Level Scenarios (contd.)

	Comparison 1: Current Climate		Comparison 2: CP1 - Wetter, More Warming		Comparison 3: CP2 - Wetter, Less Warming		Comparison 4: CP3 - Drier, Less Warming		Comparison 5: CP4 - Drier, More Warming		Comparison 6: CP5 - Central	
	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934
Delta Parameters, Mean-Annual Condition												
SWP Banks (TAF)	45	77	29	55	42	99	32	84	22	55	42	60
CVP Banks (TAF)	9	4	9	-2	12	2	3	0	3	7	8	-2
Jones (TAF)	38	-2	62	7	57	21	34	2	24	-24	45	28
Total Banks (TAF)	53	76	41	53	53	100	35	84	22	58	51	59
Total Export (TAF)	91	74	103	60	110	121	69	86	46	33	96	88
Sac Flow at Freeport (TAF)	-15	-12	-17	-6	-9	14	-6	-10	-7	21	-15	-28
Excess Outflow (TAF)	27	41	0	57	13	62	38	9	64	86	12	-26
Required Outflow (TAF)	-3	-2	-6	8	-3	1	1	4	-5	6	-11	32
X2 Position (km)	0	0	0	0	0	0	0	0	0	0	0	0
Yolo Bypass (TAF)	11	-1	12	-1	4	0	0	0	7	0	10	-3
Flow at Vernalis (TAF)	120	126	102	132	124	171	114	113	105	105	102	122
Total Outflow (TAF)	24	39	-6	65	9	62	39	13	60	92	2	6
Total Inflow (TAF)	116	113	97	126	119	185	109	103	105	126	97	92
Old & Middle River (TAF)	-66	-34	-95	-26	-90	-70	-43	-47	-22	-2	-80	-48
QWEST (TAF)	26	51	-2	74	20	56	47	27	56	71	8	33

Table 4-3.
Summary of Operations Effects Variation with Regional Climate and Sea Level Scenarios (contd.)

	Comparison 1: Current Climate		Comparison 2: CP1 - Wetter, More Warming		Comparison 3: CP2 - Wetter, Less Warming		Comparison 4: CP3 - Drier, Less Warming		Comparison 5: CP4 - Drier, More Warming		Comparison 6: CP5 - Central	
	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934	1922-2003	1929-1934
Mean-Annual Deliveries Volumes (TAF)												
CVP North of Delta												
Agriculture	2	0	1	2	-1	1	1	0	0	0	1	0
Settlement Contracts	0	-1	0	5	0	3	0	0	-2	0	0	0
M&I	0	0	0	2	0	3	0	0	0	0	0	0
Refuge	0	1	0	-1	0	0	0	0	0	0	0	0
Total	1	0	1	7	-1	6	2	0	-1	0	2	0
CVP South of Delta												
Agriculture	15	0	21	10	9	3	14	0	3	0	15	0
Exchange	0	0	0	0	0	0	0	0	0	0	0	0
M&I	0	0	0	1	0	0	0	0	0	0	0	0
Refuge	0	0	0	0	0	0	0	0	-1	0	0	0
Total**	14	0	21	11	8	3	15	0	1	0	15	0
SWP												
Table A	23	31	14	53	29	36	21	0	-15	0	16	0
Article 56	-4	0	-2	-9	2	0	2	0	-4	0	-3	0
Article 21	25	42	19	23	9	53	8	0	38	0	29	0
Table A + Art 56	19	31	12	45	31	36	23	0	-19	0	13	0
Table A + Art 56 + Art 21	44	74	31	68	40	89	32	0	19	0	42	0
Allocations (%)												
Mean Annual Delivery Allocations (% of Demand)												
CVP North of Delta												
Agriculture	0.44%	0.22%	0.23%	0.72%	-0.16%	0.29%	0.30%	0.00%	0.03%	0.00%	0.32%	0.00%
M&I	-0.04%	0.22%	0.20%	0.59%	-0.24%	0.17%	0.02%	0.00%	0.00%	0.00%	0.19%	0.00%
CVP South of Delta												
Agriculture	1.11%	0.22%	1.30%	0.72%	0.74%	0.29%	0.76%	0.00%	0.22%	0.00%	0.98%	0.00%
M&I	-0.04%	0.22%	0.20%	0.59%	-0.24%	0.17%	0.02%	0.00%	0.00%	0.00%	0.19%	0.00%
SWP												
All SWC	0.67%	0.76%	0.34%	1.26%	0.75%	0.82%	0.58%	0.00%	-0.40%	0.00%	0.23%	0.00%

Note:
** CVP delivery increase does not match CVP export increase due to pass-through of exports to exchange delivery at Mendota Pool.
Key: TAF = thousand acre-feet

CalSimII modeling of the SJRRP alternatives, as described in the Modeling Technical Appendix to the SJRRP PEIS/R, demonstrated several effects of operating with the Restoration flow releases under Alternative A relative to the Base condition. The additional water emanating from the San Joaquin is treated as abandoned water in the Delta, which enables additional exports and creates conditions where flows from the Sacramento Basin can be decreased in some cases, resulting in a backup of water to NOD storage. Also, changes to flood and snowmelt release operations at Friant as a result of the restoration program play a role in the ultimate effect on flows at Vernalis.

The key impacts of restoration apparent under the historical climate condition include:

- A 150 TAF/year reduction in delivery to Friant Kern and Madera Canals
- Increased flows at Vernalis of 120 TAF/year
- Overall increase in Delta exports of 91 TAF/year
- Overall increase to Delta outflow of 24 TAF/year

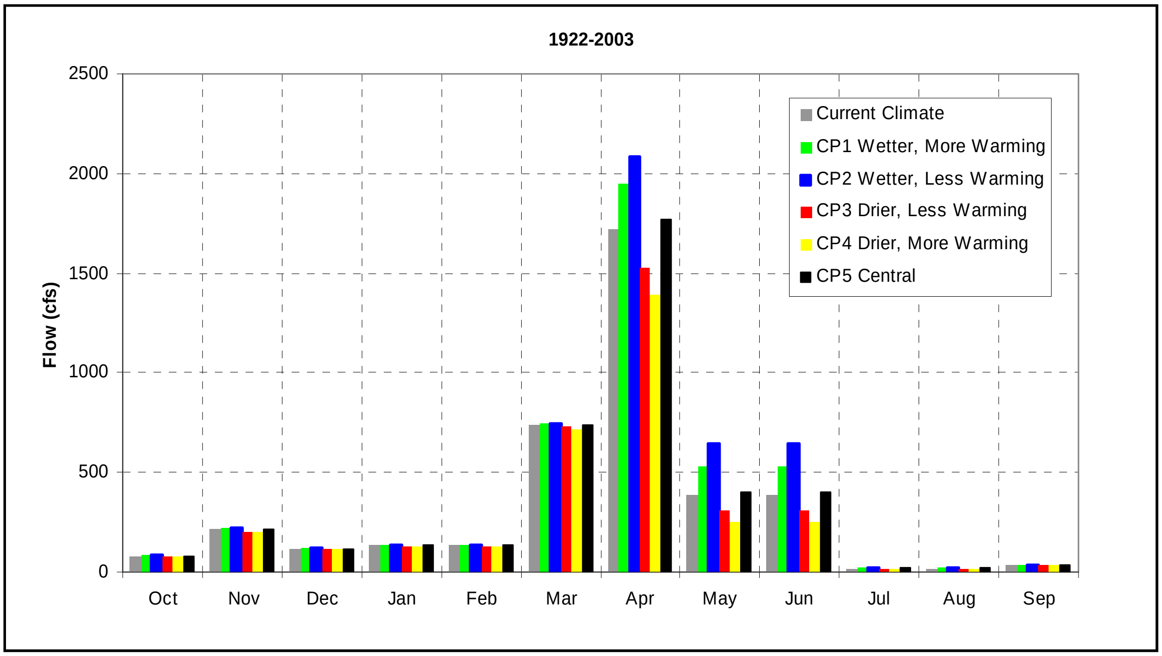
Upon conducting the same Base and Alternative A studies under the various regional climate change scenarios with sea level rise, these same effects varied as follows:

- Reduction to Friant Kern and Madera Canal deliveries was 126 TAF/year under the centrally projected climate change scenario, and varied from 106 to 154 TAF/year under the four bracketing climate change scenarios.
- The flow increase at Vernalis was 102 TAF/year under the centrally projected climate change, and varied from 102 to 124 TAF/year under the four bracketing climate change scenarios.
- Delta exports increased under the centrally projected climate scenario by 96 TAF/year, and increases varied from 46 to 110 TAF/year under the four bracketing climate change scenarios.
- Delta outflow increased under the centrally projected climate by 2 TAF/year, and overall average changes varied from -6 to 60 TAF/year under the four bracketing climate change scenarios.

The following sections provide more detailed discussion on how these and other operations effects are sensitive to the underlying climate assumption.

4.2.1 San Joaquin Basin Operations Effects:

Average monthly flows in the restoration channel are shown in Figure 4-16. Notable effects of climate projections occur in the months of April through June, when the restoration hydrograph targets higher (pulse) flows. Under the wetter climate projections, more years fall into the wetter restoration categories and this leads to higher average April-June flows. Under the drier projections, fewer years fall into the wetter categories than under the current climate, and this leads to lower average April-June flows.



Note:
Base scenarios have no restoration flows. The graph shows the quantity of the restoration release that flows through the restoration channel after losses in the upper San Joaquin River.

Figure 4-16.
Flow through the San Joaquin River Restoration Channel

The average annual impacts of the restoration flow releases (Alternative A relative to Base) on Friant Dam releases are shown in Figure 4-17. Under the Base scenario, Friant is operated to release water to meet downstream diversion requirements and related channel losses. Releases above this level are categorized as snowmelt-related or flood-related. Snowmelt releases are made in February-June, anticipating inflows that would exceed the capacity of the system to use or store them. In wet years, these planned releases may not accommodate all of the inflow, and flood releases are made to avoid violation of flood control rules for Friant storage.

Due to the higher required releases of the SJRRP, per Alternative A, snowmelt and flood releases may be reduced or even eliminated. The general trends in these impacts are seen for the current climate and in all of the climate change scenarios. Friant's main release increases to accommodate the additional restoration requirement, while flood and snowmelt releases decrease. Note that not all of the change in Friant's main release becomes restoration channel flow. This is due to channel losses in the San Joaquin River reaches between Friant and the restoration channel, where a flow increase also results in an increased volume of channel loss.

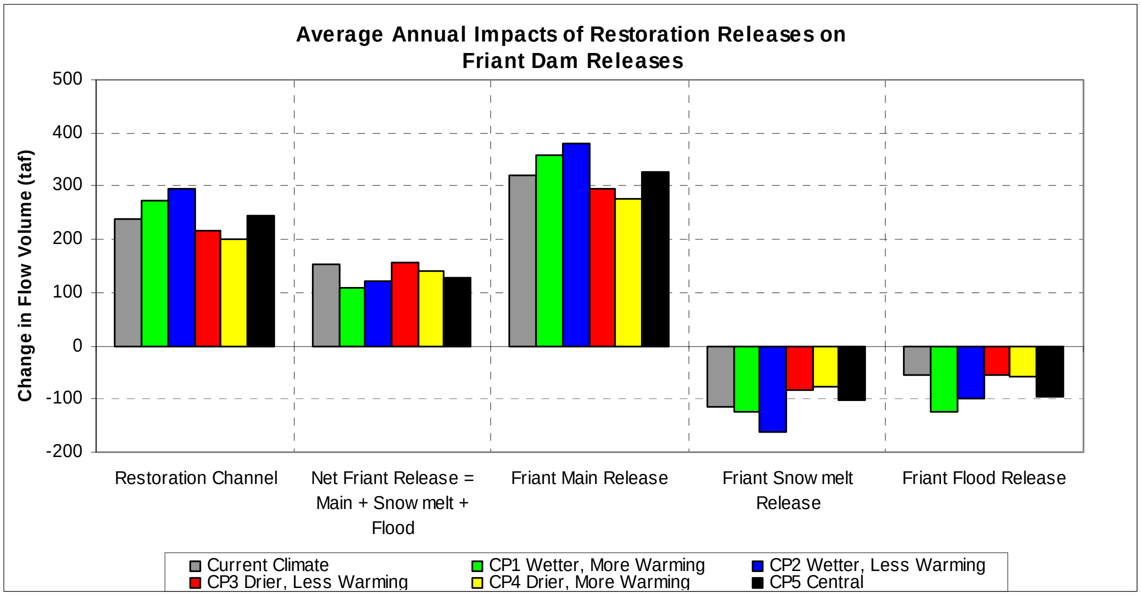


Figure 4-17.
Summary of Restoration Release Impacts to Friant Dam Releases under Current Climate and Five Climate Projection scenarios

The effect of the Restoration flow operation on deliveries to the Friant Kern and Madera Canals is a deliveries reduction under all climate scenarios (Figure 4-18)). (*Note that deliveries are not part of the downstream release from Friant Dam.*) More variability in delivery impacts are seen in the Friant Kern Canal, whereas Madera Canal impacts remain similar for all climate scenarios. The impact of the SJRRP to overall Friant delivery is tempered in Alternative A through the delivery of Paragraph 16(b) water as dictated in the Settlement. Because this water is often delivered to groundwater banks in the Friant service area at times when actual demand for water is low, and due to the prevalence of unstorable water in wet years, Alternative A delivery is actually higher than Base delivery in wet years but lower in other types of years, with the overall average effect of the delivery reduction.

On average, Friant delivery impacts are less severe for the wetter and central climate scenarios, and are not worsened for the drier climate scenarios. Wetter scenarios have additional unstorable water, enabling higher deliveries. Figure 4-19 demonstrates another difference between the historical climate scenario and wetter climate projections. While restoration allocation does increase overall for the wetter climates, there is a maximum allocation, and this is achieved more often. In the top plot of Figure 4-19, note that CP1 and CP2 have higher restoration flows and smaller (less negative) delivery impacts than for current climate except for the Wet restoration years, when the SJRRP release is capped at the maximum, enabling the delivery under the wetter climate scenarios of more unstorable (surplus) water. Under the drier climate projections, CP3 and CP4, impacts to delivery in all restoration year types track along the same trend as the difference in allocation to restoration flow.

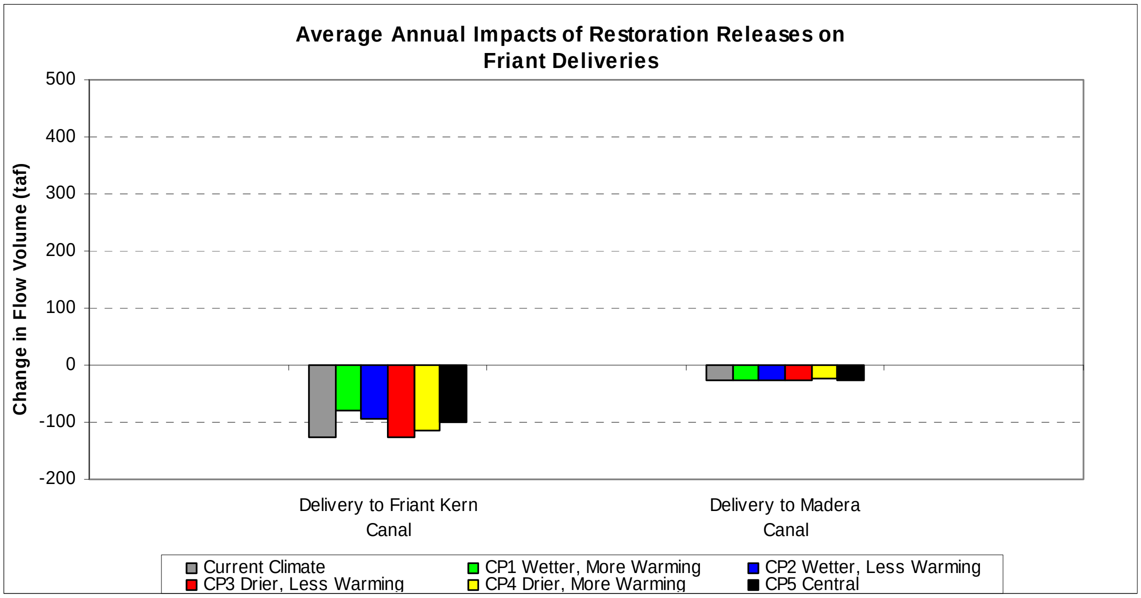


Figure 4-18.
Summary of Restoration Release Impacts to Friant Dam Deliveries Under Current Climate and Five Climate Projection Scenarios

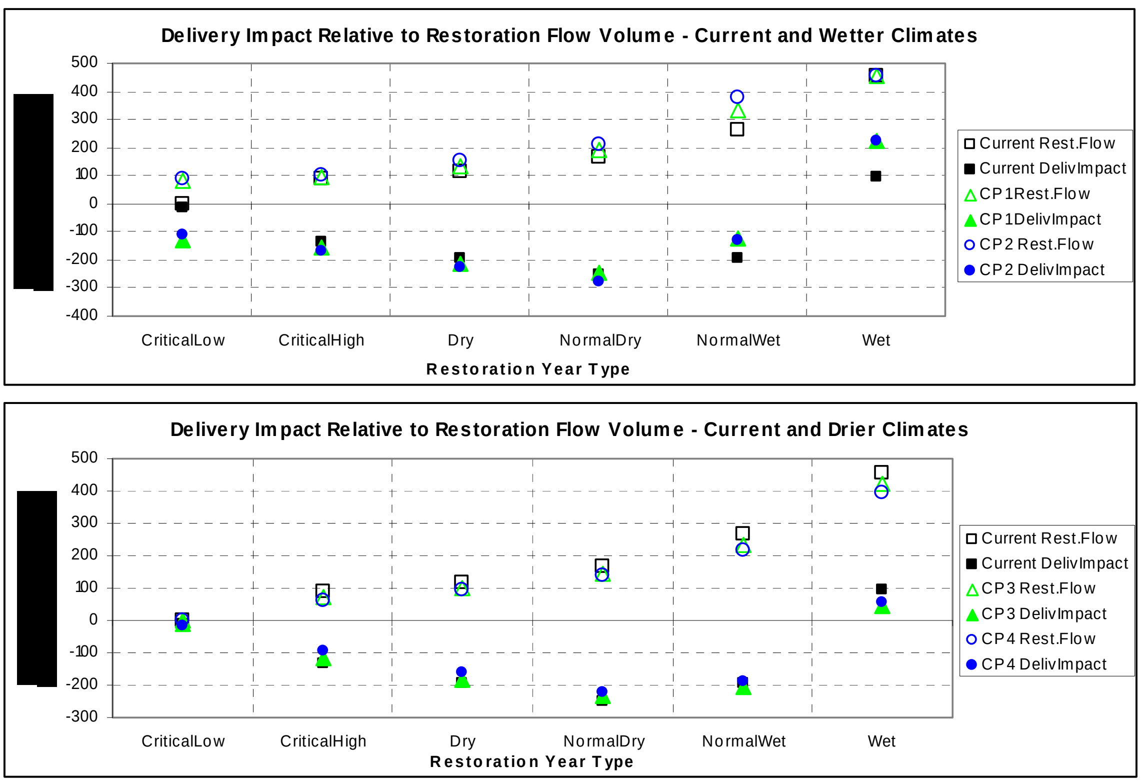


Figure 4-19.
Comparison of Water Year Type Variability in Impacts to Friant Delivery Under Current Climate and Wetter or Drier Climate Projection Scenarios

Elsewhere in the San Joaquin Basin, impacts of restoration releases maintain the same trends under climate change scenarios as were seen in the current climate impacts, with higher magnitudes in the wetter projections and lower magnitudes in the drier projections (Figure 4-20). For example, flows that reach Mendota Pool (driven by flood releases) decrease for all scenarios, but the reductions are more pronounced in the wetter climates and less pronounced in the drier climates. Downriver at Vernalis, the SJRRP impacts to flow continue to reflect the ensemble of changes to flood control release, delivery, and channel loss associated with each climate scenario. One additional effect to note is the limited effect of restoration operations on releases from other San Joaquin Basin tributaries; climate change does not appear to create or change the small effects on tributary operations (e.g., Flow at Goodwin).

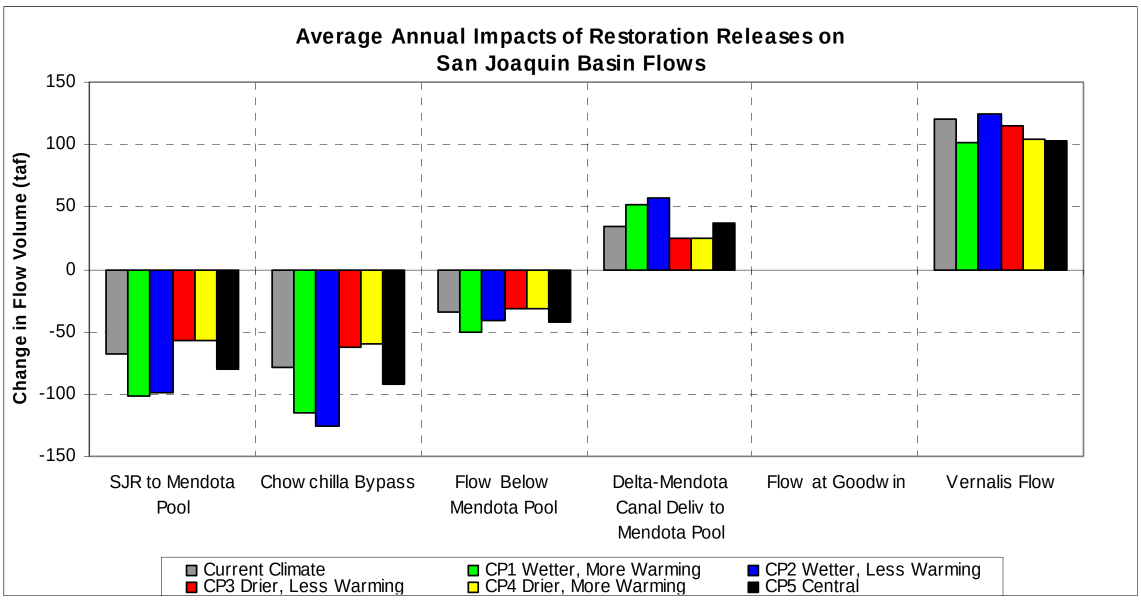


Figure 4-20.
Summary of Restoration Release Impacts to San Joaquin Basin Flows Under Current Climate and Five Climate Projection Scenarios

4.2.2 Delta Requirements and Operations Effects

The SJRRP action alternative results in additional water flowing to the Delta from the San Joaquin River. This water is treated as “abandoned” in that the CVP/SWP system is able to react opportunistically to its presence as long as existing Delta operations constraints are followed (minimum outflows, water quality standards, export restrictions). General trends in impacts of the SJRRP (Alternative A minus Base) are towards higher CVP and SWP exports, higher delta outflows, lower Sacramento River inflows, and higher Yolo Bypass flows, as seen in Figure 4-21. The balance of changes to Delta inflows is equivalent to the total change in exports and outflows.

The variation of these effects relative to the underlying climate assumption appears to show a shift towards more increase in export and less increase in Delta outflow for the wetter and central projections, and a shift towards less export and more delta outflow for the drier projections. Closer scrutiny of model results (not shown or tabulated here) suggest that the lower export increases for the drier climate projections, particularly Climate Projection No. 4, are often the result of a cap on exports that is imposed if the decision space of the water quality ANN is exceeded by the conditions presented in that month. These caps on exports force more water to delta outflow. The sea-level-rise ANN that was used, while the best available, appears to have limited capacity in handling the full range of Delta and hydrologic conditions forced by the collection of climate change scenarios considered in this study. Considering that limitation, results still seem to robustly support comparison of Delta effects associated with current climate, the wetter projections, and central projection because the export cap issue did not occur in those studies. Evaluation of the Delta effects sensitivity of the drier climate projections is questionable, however.

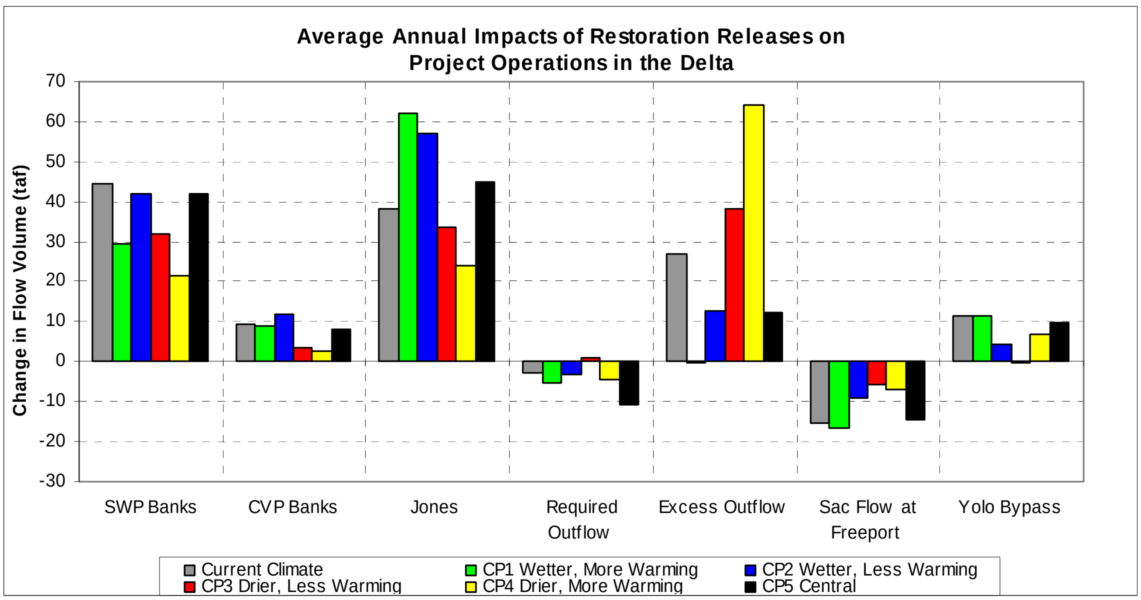


Figure 4-21.
Summary of Delta Operations Changes Under Current Climate Conditions and Five Climate Projection Scenarios

4.2.3 Other CVP/SWP System Effects – Delivery and Storage

Impacts to north of delta deliveries are small under the current climate condition and do not change notably for any of the five climate projections. Given the effects on project pumping at Banks and Jones, discussed in Section 4.2.2, SJRRP operations do have an effect on project deliveries in export areas south of the delta, with increases seen for both CVP and SWP. A summary of the increases is shown in Figure 4-22. Note that the CVP delivery increase does not track as high as the CVP export increase. This is because a portion of the export increase is routed to Mendota Pool to replace direct SJR deliveries. The exchange deliveries do not change measurably between the Base and Alternative A conditions, but the source of the water does.

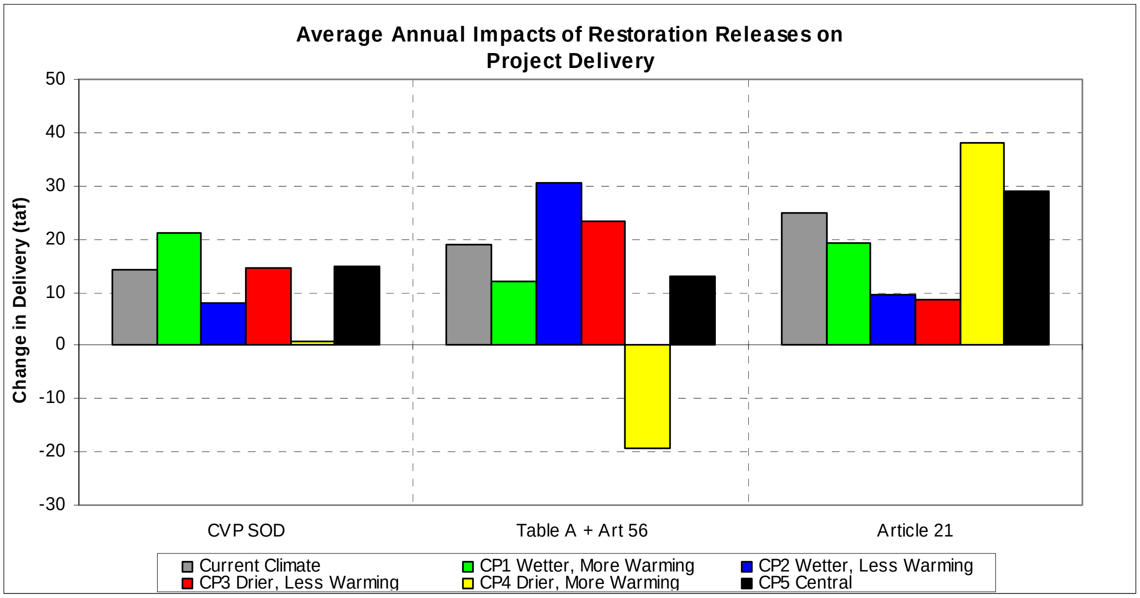


Figure 4-22.
Summary of SOD Delivery Changes Under Current Climate Conditions and Five Climate Projection Scenarios

As discussed above, particularly for Climate Projection 4 (drier, more warming) the results shown are affected by the cap placed on exports by the water quality ANN. This climate scenario shows a decrease in Table A and carryover deliveries with a simultaneous increase in Article 21 delivery. Interruptible deliveries are enabled in the model under conditions that include delta surplus, which is triggered due to the ANN export cap. A refinement of the water quality operation in the delta for each particular climate projection would likely clarify the effects of any given projection on the specific impacts of the SJRRP on delivery.

Under each climate condition, the SJRRP (Alternative A minus Base) leads to reduced Sacramento River flows at Freeport/Hood, and this effect is accompanied by increased north of delta carryover storage effects. These effects contribute partially to the influences on overall project export. San Luis operations are also affected by the overall increases in exports. Restoration release operations at Friant lead to an overall reduction in Millerton carryover storage, and also trigger occasional reductions in New Melones releases that lead to increased New Melones carryover storage. As shown in Figure 4-23, the trends towards an increase or decrease in carryover storage are maintained between the current climate and all of the climate projection scenarios.

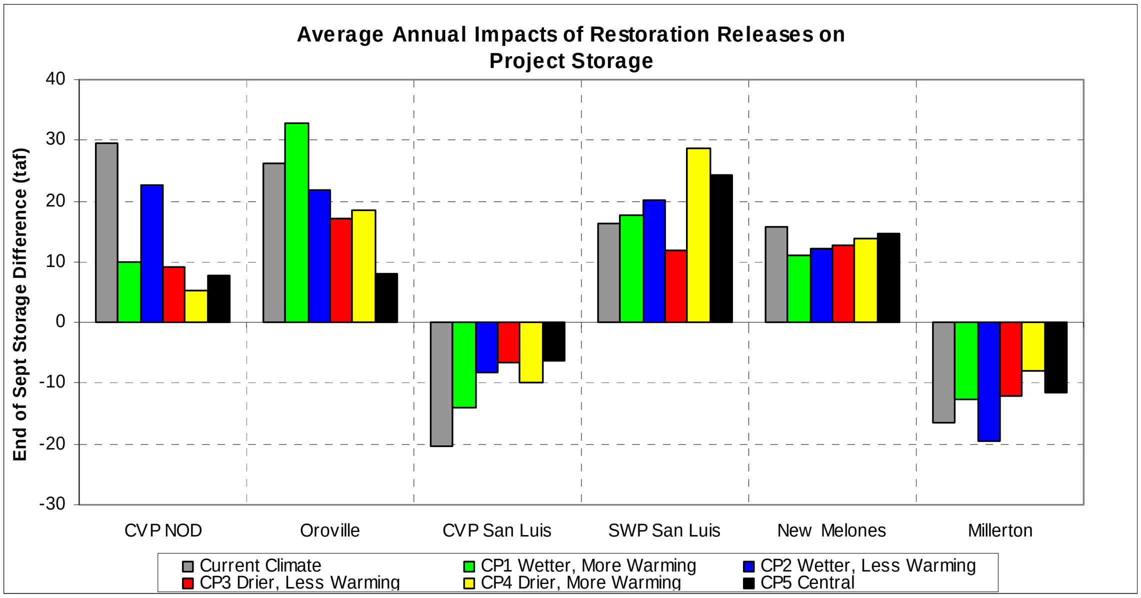


Figure 4-23.
Summary of End-of-Sept Carryover Storage Changes under Current Climate Conditions and Five Climate Projection Scenarios

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5.0 Uncertainties

This sensitivity analysis is designed to provide some quantitative illustration on how CVP/SWP water supply, operations, and operations-dependent conditions might respond to the range of future climate possibilities. The study was designed to take advantage of best available datasets and model tools, and to follow methodologies documented in peer-reviewed literature. However, there are a number of analytical uncertainties that are not reflected in study results, including uncertainties associated with the following analytical areas:

- **Global Climate Forcing –** Although the study considers climate projections representing a range of GHG emission paths, the uncertainties associated with these pathways are not represented in this analysis. Such uncertainties include those introduced by assumptions about technological and economic developments, globally and regionally; how those assumptions translate into global energy use involving GHG emissions; and biogeochemical analysis to determine the fate of GHG emissions in the oceans, land and atmosphere. Also, not all of the uncertainties associated with climate forcing are associated with GHG assumptions. Considerable uncertainty remains associated with natural forcings, with the cooling influence of aerosols being regarded as the most uncertain on a global scaled (e.g., Figure SPM-2 in IPCC 2007).

- **Global Climate Simulation –** While this study considers climate projections produced by state-of-the-art coupled ocean-atmosphere climate models (i.e., CMIP3 models discussed in Section 1.4), and these models have shown an ability to simulate the influence of increasing GHG emissions on global climate (IPCC 2007), there are still uncertainties about our understanding of physical processes that affect climate, how to represent such processes in climate models (e.g., atmospheric circulation, clouds, ocean circulation, deep ocean heat update, ice sheet dynamics, sea level, land cover effects from water cycle, vegetative and other biological changes), and how to do so in a mathematically efficient manner given computational limitations.

- **Climate Projection Bias-Correction –** This study is designed with the philosophy that climate model biases toward being too wet, too dry, too warm or too cool should be identified and accounted for as *bias-corrected* climate projections data prior to use in implications studies like this sensitivity analysis. Bias-correction of climate projections data affects results on incremental runoff and water supply response, as shown on a recent study of Colorado River Basin runoff impacts using both bias-corrected and non-bias-corrected versions of the same source climate projections (*D. Lettenmaier, presentation at Colorado State University "Hydrology Days 2008," March 26 2008*).

- **Climate Projection Spatial Downscaling –** This study uses the empirical BCSD technique to produce spatially disaggregated climate projections data on a monthly time-step. Although this technique has been used to support numerous water resources impacts studies in California (e.g., Van Rheenan et al. 2004, Maurer and Duffy 2005, Maurer 2007, Anderson et al. 2008), uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies require use of historical reference information on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which would presumably change with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have *stationarity*. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

- **Generating Weather Sequences Consistent with Climate Projections –** This study uses a technique to generate weather sequences consistent with the monthly downscaled climate projections. This technique has been used to support numerous water resources impacts studies (e.g., Van Rheenan et al. 2004, Maurer and Duffy 2005, Maurer 2007, Anderson et al. 2008). However, other techniques might have been considered. Preference among available techniques remains to be established.

- **Natural Systems Response –** This study analyzes natural runoff response to changes in precipitation and temperature while holding other watershed features constant. Other watershed features might be expected to change as climate changes and affect runoff (e.g., potential ET given temperature changes, vegetation affecting ET and infiltration, etc.). In the SacSMA/Snow17 model applications, potential ET estimates are inputs and were not adjusted, following the approach of Miller et al. 2003. In Reclamation (2008a), results from similar use of SacSMA/Snow17 were compared to those from use of another surface water hydrology model where potential ET change were automatically accounted for given changes in weather inputs. Similarity in model-specific results in Reclamation (2008a) suggested that potential ET adjustment (which differs from simulated *actual* ET) may not be a crucial aspect of runoff analysis for these Sierra Nevada basins. On the matter of land cover response to climate change, the runoff models' calibrations would have to change if land cover changed because the models were calibrated to represent the historical relationship between weather and runoff as mediated by historical land cover. Adjustment to watershed land cover and model parameterizations were not considered due to lack of available information to guide such adjustment.

- **Social Systems Response –** This study does not quantify the effects of changing water demands at the district or municipal scale. Such responses depend on demand management flexibility and socioeconomic drivers within these districts and municipalities. Model applications and methodologies for relating climate changes to demand management responses among CVP/SWP district customers under existing institutional and regulatory constraints remain to be established. Additionally, lack of available model applications and methodologies prevented quantitative treatment of other potential social responses to climate change that might translate into constraint changes for CVP/SWP operations (e.g., change in flood protection values below CVP/SWP reservoirs that determine reservoir flood control constraints on water supply storage; change in environmental management values that determine instream flow priorities by river tributary and during which times of the year; change in recreational values that determine water levels management at CVP/SWP reservoirs). In addition to how societal drivers could trigger changes in flood control, there could also be natural drivers associated with hydrologic response to climate change. For example, warming climate may affect storm-discharge relationships and reoccurrence expectations in watersheds above major CVP/SWP reservoirs, potentially necessitating flood control changes even if societal flood protection values do not change.

- **Discretionary Operators' Response –** This study reflects a simulated operator through rules and constraints defined in CalSim II. The simulated operator is generally “unresponsive” to the climate change, as simulated. The only responsive exception is that the CalSim II annual water allocation rules (i.e., “WSI-DI” curves) were adjusted to be consistent with inflow and inflow-related changes associated with Projection No. 1 through No. 4, which represents operators having an adjusted understanding of water supply possibility in any given year, and associated annual allocations that can be supported over the long term. In reality, just as external social systems might respond to a changing climate, it is reasonable to expect that CVP/SWP operators might react in other ways to a changing climate, within limitations permitted by current institutions, regulations, and contracts.

- **Water Temperature Analysis –** This study presumes that as climate changes, the current stream-temperature management paradigms constraining CVP and SWP operations will continue unchanged. In reality, it is questionable whether there might be shifts in multi-species management objectives in CVP and SWP tributaries, or shifts in objective priorities at various times during the calendar year.

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Attachment

San Joaquin River Underseepage Limiting Capacity Analysis

Draft
Supplemental Hydrologic and Water Operations Analyses Appendix

SAN JOAQUIN RIVER RESTORATION PROGRAM

Draft
April 2011

DRAFT
San Joaquin River Underseepage Limiting Capacity Analysis

March 30, 2011

1. INTRODUCTION

Tetra Tech, Inc., dba Mussetter Engineering, Inc. (Tt-MEI) performed an evaluation of the potential effects of restoration flows on levee underseepage in the 150-mile, mainstem portion of the San Joaquin River Restoration Reach and the Eastside Bypass between Friant Dam and the confluence with the Merced River.

Underseepage issues are most acute when a layer(s) of pervious material occurs below the levee foundation that extends both river- and land-side of the levee (USACE, 2000). These pervious layers allow seepage to occur below the levee structure where it often surfaces along the existing ground adjacent to the levee. This seepage can cause adverse impacts to adjacent landowners due to saturation of the ground surface, and can also lead to instability and failure of the levee.

To evaluate the potential impact of restoration flows on underseepage and saturation adjacent to the levees, elevations of land outside and adjacent to the levees were determined and compared to computed water-surface elevations over a range of flows. The evaluation was conducted using the HEC-RAS 1-D steady-state hydraulic models developed by Tt-MEI for the San Joaquin River Restoration Program (SJRRP), and initially consisted of a preliminary analysis of varying potential capacity thresholds and criteria (Tt-MEI, 2011). Based on the results of the preliminary analysis, a refined set of capacity criteria was established. This work was completed under the River Engineering Services for the San Joaquin River Restoration Program Contract, Task Order 48.

2. METHODOLOGY AND ASSUMPTIONS

The following sections describe the methodology and assumptions that were used in performing the analysis. The analysis specifically focused on identifying the discharge at which the water surface in the river would reach the outside ground elevation (i.e., in-channel flow capacity), and included a determination of the extent of each the reach where outside ground elevations are within 1 foot vertically of the water-surface for the identified in-channel capacity.

2.1. River Reaches

The seepage potential was evaluated for each subreach that is bounded by levees in Reaches 2A, 2B, 3, 4A, 4B2, 5, and the Eastside Bypass (**Figure 1**). As part of the project, new setback levees will be constructed in Reach 4B1 to safely convey the maximum releases under full restoration conditions. As a result, impacts associated with the full restoration releases were not evaluated in this reach. Setback levees will also be constructed in Reach 2B, but because interim-flow releases will be routed through this reach prior to construction, seepage potential along the levees upstream from the direct impacts of Mendota Pool was evaluated.

2.2. Hydraulic Models

Hydraulic models for the study reaches, which were initially developed based on 2-foot contour mapping developed by Ayres Associates (1998 and 1999) for the Sacramento and San Joaquin River Basins Comprehensive Study, have been recently updated using improved modeling techniques and the 2008 LiDAR mapping and bathymetry, where available. The models used for this analysis were further refined and the assumptions were defined as part of the evaluation of potential erosion and stability impacts to the levees associated with the proposed restoration flows (Tt-MEI, 2010). In addition, updates to the estimated pool elevation and rating curve at Mendota Dam that were made based on new information obtained after completion of the levee stability analysis (Tt-MEI, 2010) were incorporated into the Reach 2B hydraulic model.

Water-surface profiles used in the analysis were developed by running the refined models over a series of local discharges that were developed based on Friant Dam releases within the range of the Settlement Agreement Exhibit B flows, and adjusted for infiltration and diversion losses based on the curves used to develop the Exhibit B flows. The local discharges in Reach 3 include an additional 300 cfs to represent the average Arroyo Canal deliveries from Mendota Pool to the Arroyo Canal. These flows are then extracted at Sack Dam at the downstream end of Reach 3.

2.3. Outside Ground Elevations

Elevations of improved agricultural or urban land protected by the levees (outside ground) were identified as part of the levee stability analysis conducted by Tt-MEI (2010) to assess the potential for levee issues to affect land improvements along the reach. Elevations for each location were identified at each model cross section through inspection of the 2008 aerial photography, 2008 contour mapping, and cross-sectional topography. Actual elevations were determined from the topography used to develop the hydraulic model for each part of the reach (i.e., 2008 LiDAR mapping, supplemented with bathymetry from the 1998/1999 Ayres mapping, where necessary).

3. RESULTS

Computed water-surface profiles were compared to the ground elevations adjacent to both the left and right levees. The in-channel flow capacity of each reach was determined to be the highest flow rate through the reach where the water-surface elevation does not exceed the outside ground elevation. Approximate lengths of each site where the outside ground elevations are within 1 foot of the in-channel capacity discharge water-surface elevation were then estimated from the available mapping.

3.1. Reach 2A

Reach 2A is approximately 13 miles long and extends from Gravelly Ford (near the upstream end of the project levees) downstream to the Chowchilla Bypass Bifurcation Structure. Along both levees in Reach 2A, the highest local discharge for which the water surface is at or below the outside ground elevation is 1,060 cfs (**Figure 2**). A total of five locations with a combined length of approximately 1,980 feet were identified where the outside ground elevations are within 1 foot of the in-channel capacity water surface (**Figure 3 and Table 1**).

Table 1. Summary of approximate lengths of each location in each reach where the outside ground elevation is within one foot of the in-channel capacity discharge.

Reach	Site	Capacity Flow (cfs)	Length (ft)
Reach 2A	Site 1	1,060	1,120
Reach 2A	Site 2	1,060	380
Reach 2A	Site 3	1,060	350
Reach 2A	Site 4	1,060	40
Reach 2A	Site 5	1,060	90
Reach 2B	Site 1	810	1,240
Reach 3	Site 1	2,140	1,090
Reach 4A	Site 1	630	510
Reach 4A	Site 2	630	1,620
Reach 4A	Site 3	630	100
Reach 4B2	Site 1	990	510
Reach 4B2	Site 2	990	270
Reach 4B2	Site 3	990	320
Reach 4B2	Site 4	990	590
Reach 4B2	Site 5	990	300
Reach 4B2	Site 6	990	270
Reach 4B2	Site 7	990	370
Reach 4B2	Site 8	990	130
Reach 4B2	Site 9	990	440
Reach 4B2	Site 10	990	400
Reach 4B2	Site 11	990	350
Reach 4B2	Site 12	990	740
Reach 4B2	Site 13	990	540
Reach 5	Site 1	1,690	420
Reach 5	Site 2	1,690	440
Reach 5	Site 3	1,690	830
Eastside Bypass	Site 1	600	540
Eastside Bypass	Site 2	600	2,320
Eastside Bypass	Site 3	600	560

3.2. Reach 2B

Reach 2B is approximately 11 miles long and extends from the Chowchilla Bypass Bifurcation Structure downstream to Mendota Dam. Outside ground elevations along the lower portion of this reach (downstream from approximately Sta 4765+00) are generally lower than the normal pool elevation at Mendota Dam. As a result, Interim Flows will not significantly impact the potential for saturation of the outside ground in this area, and the existing flow capacity was evaluated only for the reach upstream from Sta 4765+00. Along both levees in Reach 2B, the highest local discharge for which the water surface is at or below the outside ground elevation is 810 cfs (**Figure 4**). One location of approximately 1,240 feet in length was identified where the outside ground elevations are within 1 foot of the in-channel capacity water-surface (Table 1 and **Figure 5**).

3.3. Reach 3

Reach 3 is about 22 miles long and extends from Mendota Dam downstream to Sack Dam. Considering both levees, the highest local discharge for which the water surface is at or below the outside ground elevation is about 2,140 cfs (**Figure 6**). The limiting area where the outside ground elevations are within 1 foot of the in-channel capacity flow water surface occurs near the downstream end of the reach near Sta 3385+20, just upstream from Sack Dam, and has an approximate length of 1,090 feet (Table 1 and **Figure 7**).

3.4. Reach 4A

Reach 4A is about 23 miles long and extends from Sack Dam downstream to the Sand Slough Control Structure. The computed water-surface profiles indicate that the highest local discharge for which the water surface is at or below the outside ground elevation is 630 cfs (**Figure 8**). A total of three locations with a combined length of approximately 2,230 feet were identified where the outside ground elevations are within 1 foot of the in-channel capacity water surface (Table 1 and **Figure 9**).

3.5. Reach 4B2

Reach 4B2 extends approximately 12 miles from the Mariposa Bypass downstream to the confluence with Bear Creek. The ground adjacent to the right levee in Reach 4B2 has several significant localized depressions near Sta 1068+30 and Sta 1072+20 (**Figure 10**). These local depressions limit the in-channel capacity discharge to about 190 cfs. However, aerial photographs and contour mapping indicate that these depressions are not on or adjacent to agricultural land, are relatively small, and can contain water even at low flows (Tt-MEI, 2011). If these local depressions are excluded from the analysis, the capacity along the reach increases to about 990 cfs (Figure 10). Based on the discharge of 990 cfs, a total of 13 locations with a combined length of approximately 5,230 feet were identified where the outside ground elevations are within 1 foot of the in-channel capacity water surface (Table 1 and **Figure 11**).

3.6. Reach 5

Reach 5 extends downstream from Bear Creek to the confluence with the Merced River, and along the left side of the river, the levee only exists within the upper portion of the reach (upstream from about Sta 660+00) (**Figure 12**). Along both levees in Reach 5, the highest local discharge for which the water surface is at or below the outside ground elevation is 1,690 cfs

(Figure 12). A total of three locations with a combined length of approximately 1,690 feet were identified where the outside ground elevations are within 1 foot of the in-channel capacity water surface (Table 1 and **Figure 13**). However, since much of the outside ground adjacent to the left levee is undeveloped and contains many local depressions (Tt-MEI, 2011), these results likely represent a conservative estimate of the in-channel discharge capacity in this reach.

3.7. Eastside Bypass

The Eastside Bypass extends downstream approximately 21 miles from the Sand Slough Control Structure to where it joins Bear Creek and then the San Joaquin River. The computed water-surface profiles indicate that the highest local discharge for which the water surface is at or below the outside ground elevation is 600 cfs (**Figure 14**). A total of three locations with a combined length of approximately 3,420 feet were identified where the outside ground elevations are within 1 foot of the in-channel capacity water surface (Table 1 and **Figure 15**).

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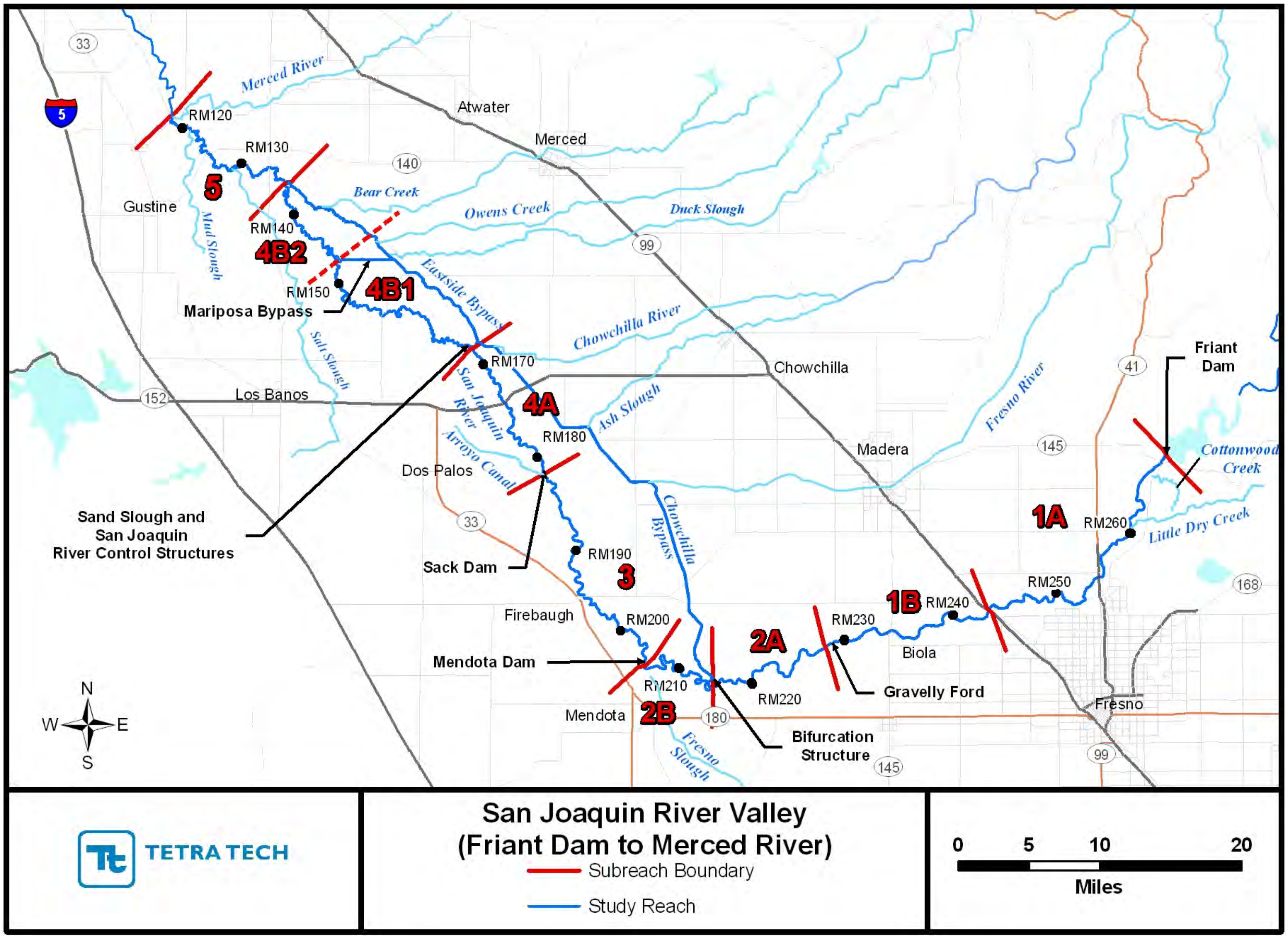

Figure 1. Map of the San Joaquin River Restoration Project Reach showing the subreach boundaries.

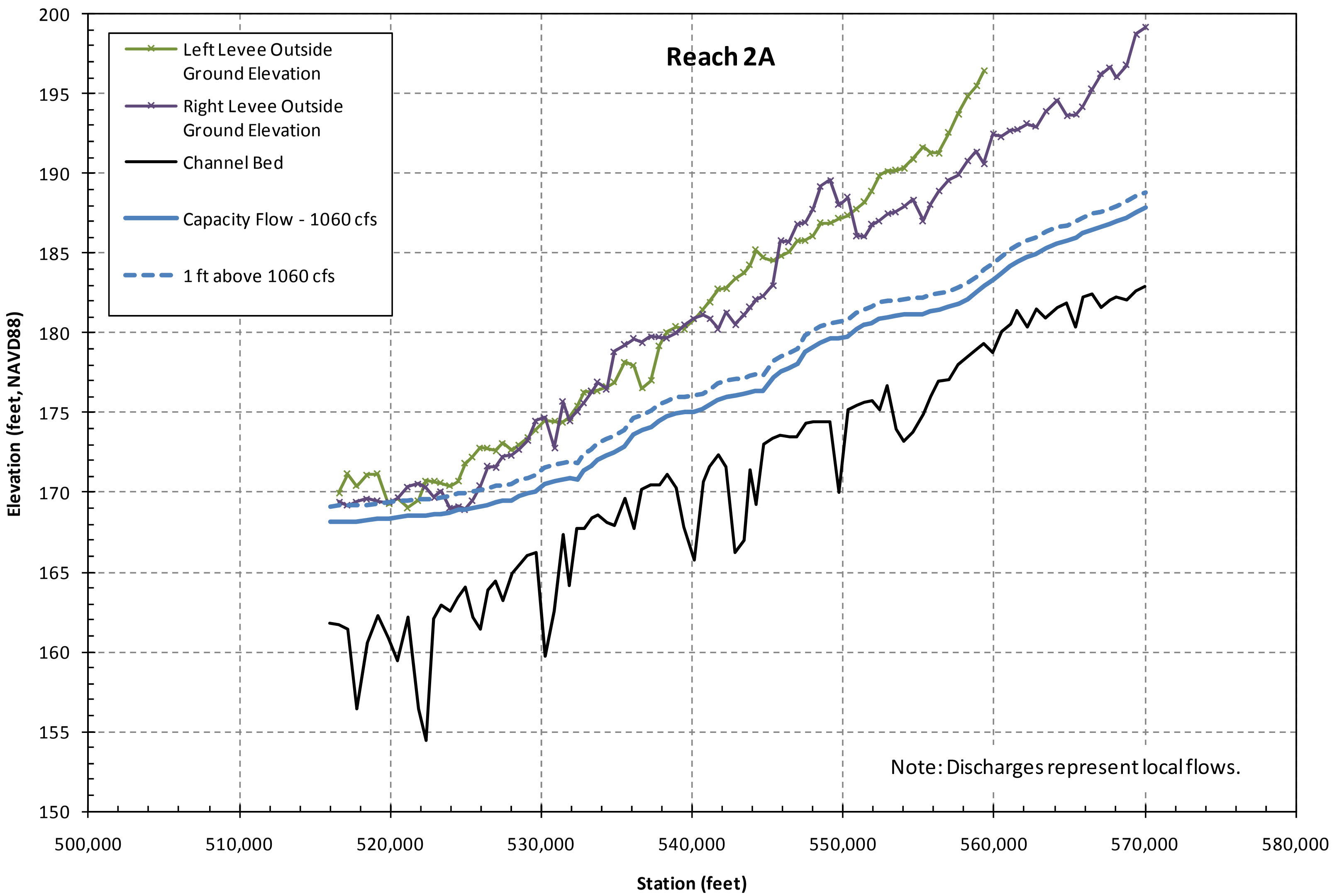

Figure 2. Outside ground elevations and computed water-surface profiles in Reach 2A at and 1 foot above the local discharge of 1,060 cfs.

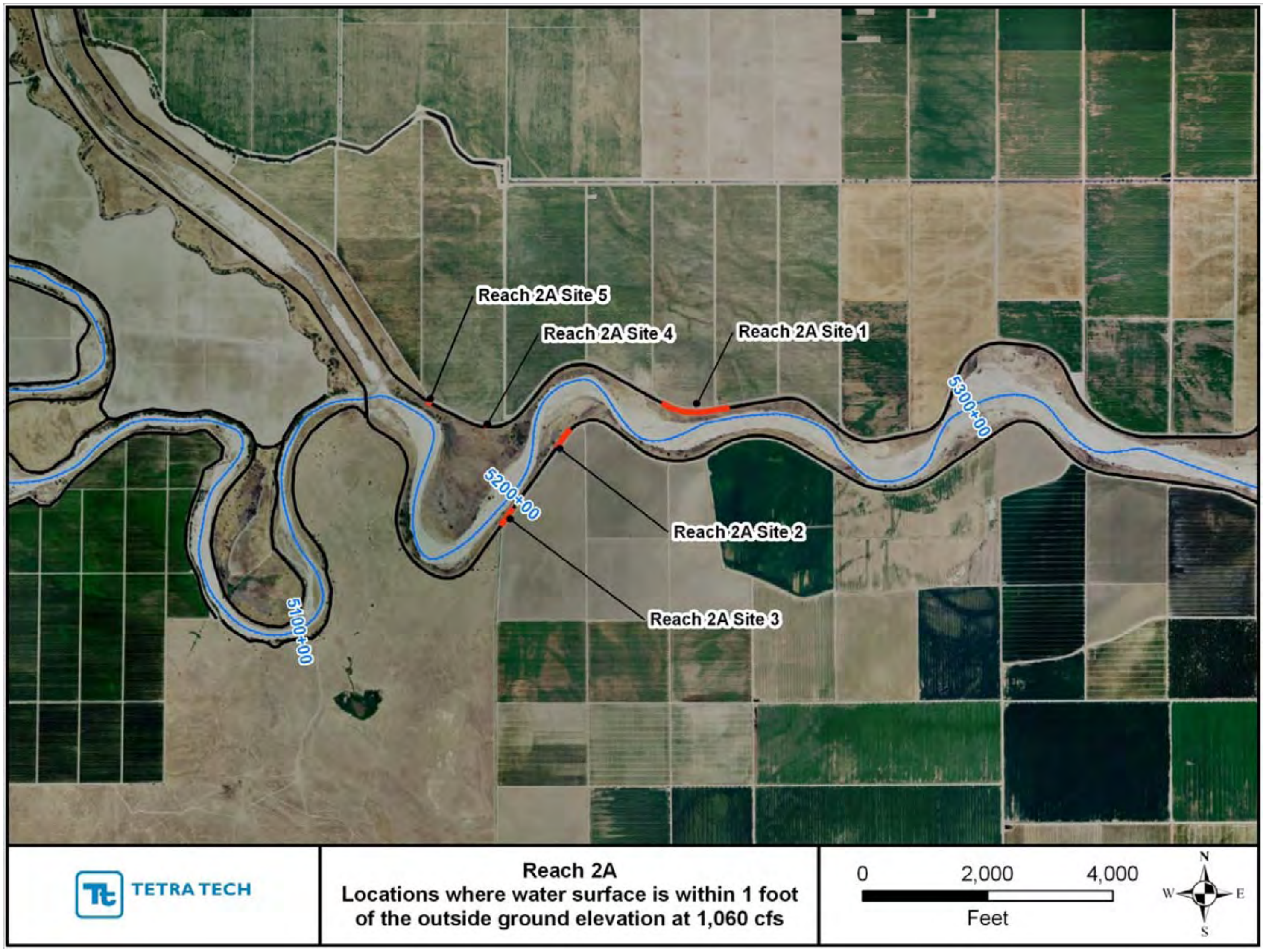

Figure 3. Map showing locations in Reach 2A where the 1,060-cfs water-surface elevation is within 1 foot of the outside ground elevation.

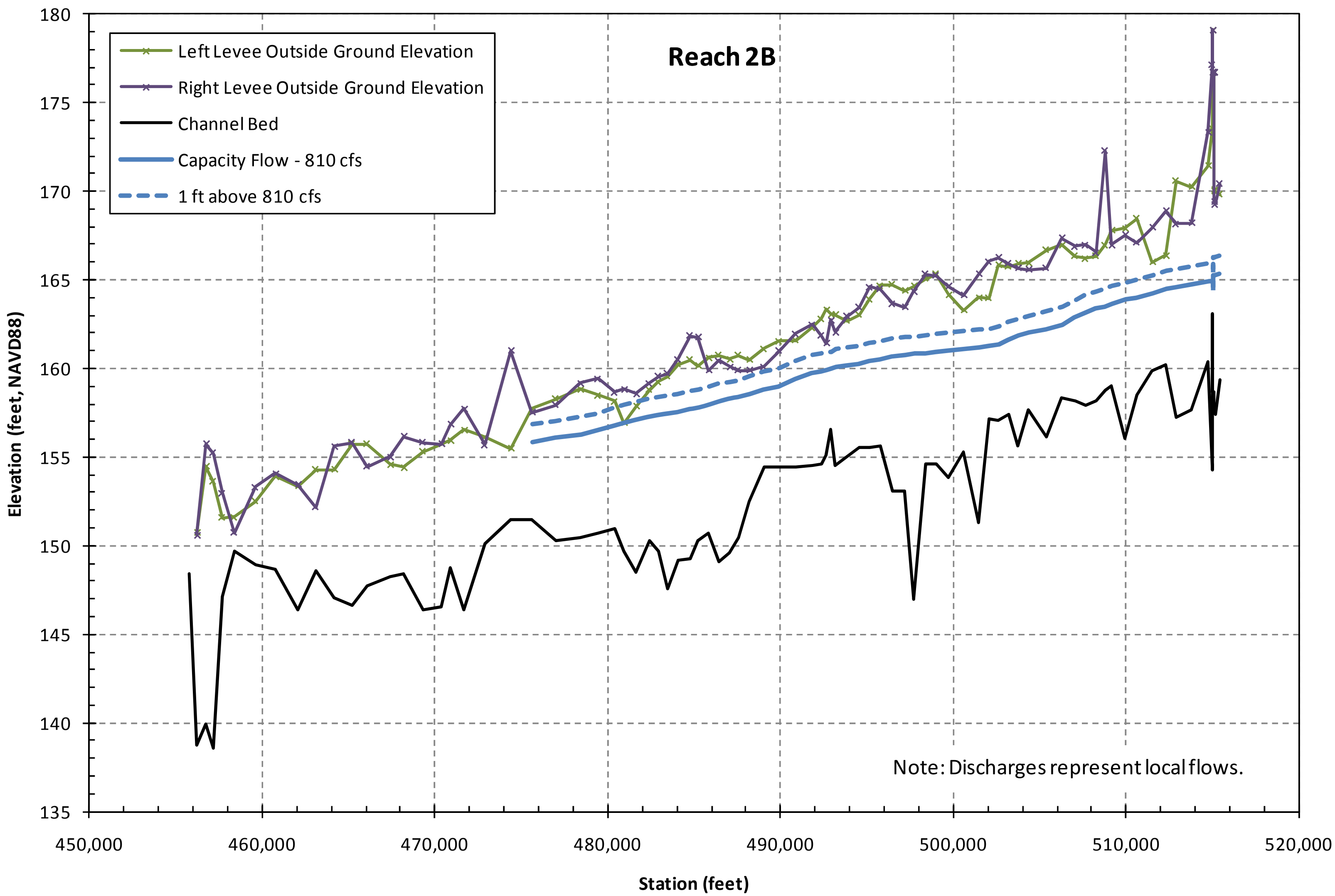

Figure 4. Outside ground elevations and computed water-surface profiles in Reach 2B at and 1 foot above the local discharge of 810 cfs.

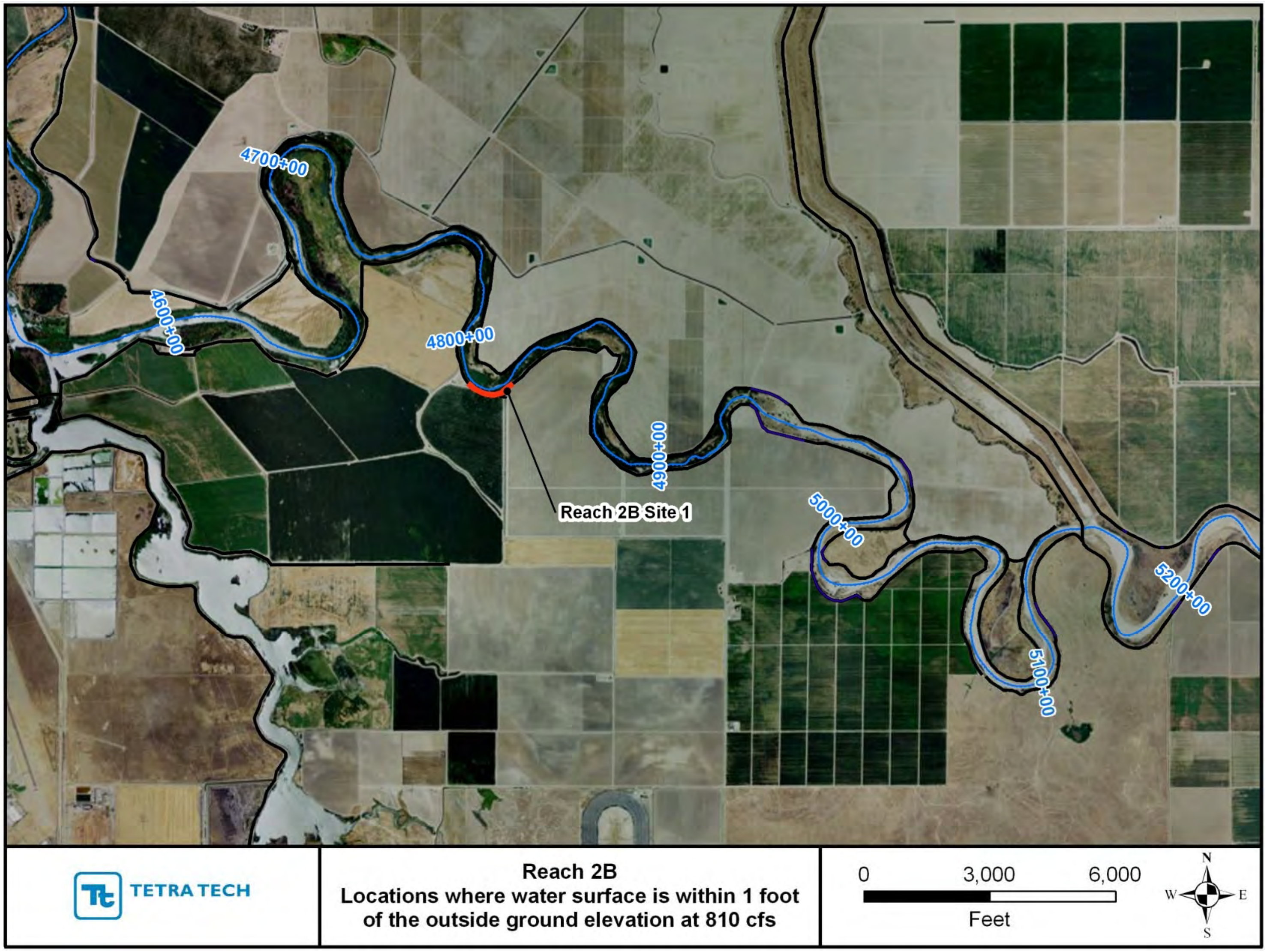

Figure 5. Map showing locations in Reach 2B where the 810-cfs water-surface elevation is within 1 foot of the outside ground elevation.

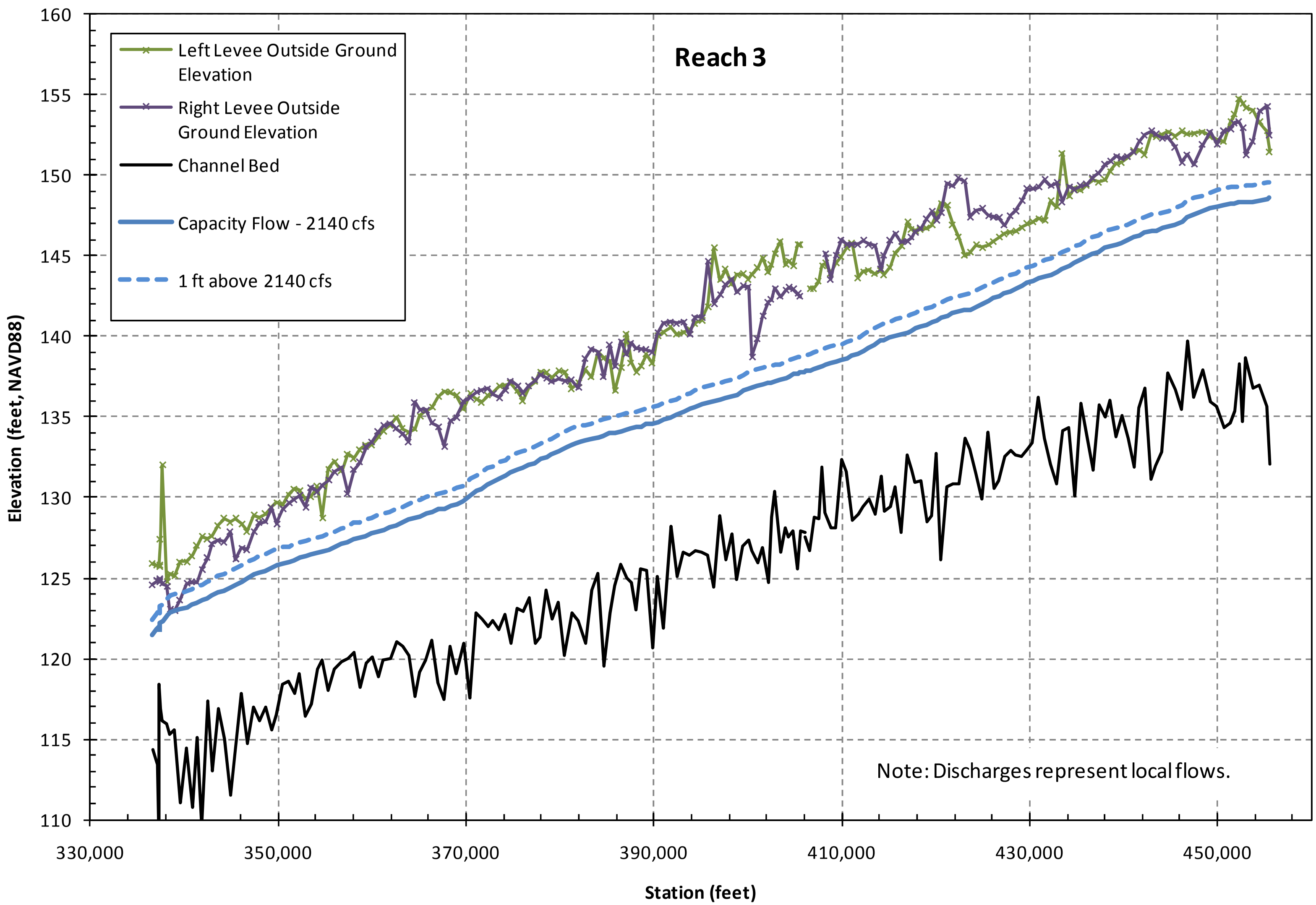

Figure 6. Outside ground elevations and computed water-surface profiles in Reach 3 at and 1 foot above the local discharge of 2,140 cfs.

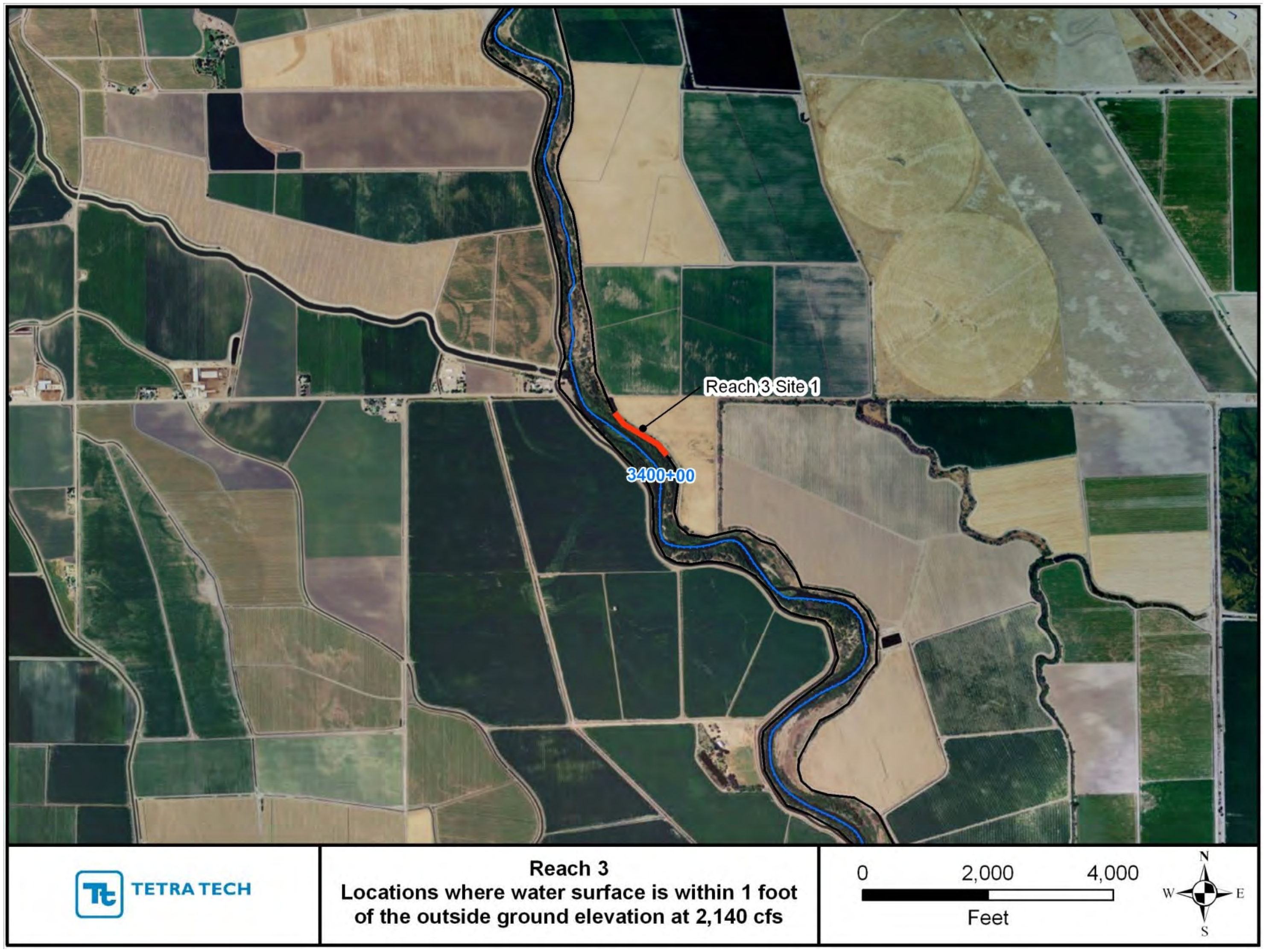

Figure 7. Map showing locations in Reach 3 where the 2,140-cfs water-surface elevation is within 1 foot of the outside ground elevation.

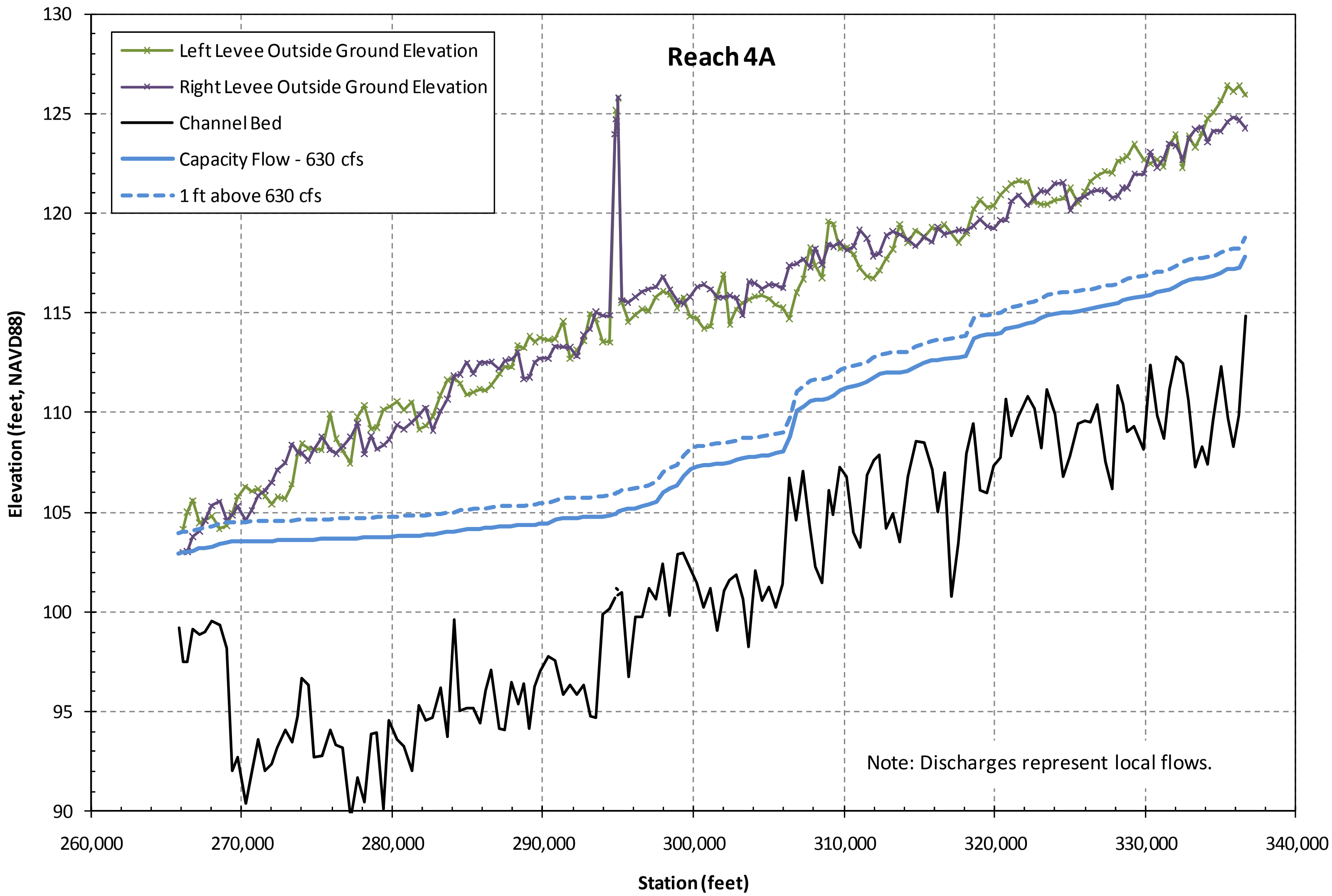

Figure 8. Outside ground elevations and computed water-surface profiles in Reach 4A at and 1 foot above the local discharge of 630 cfs.

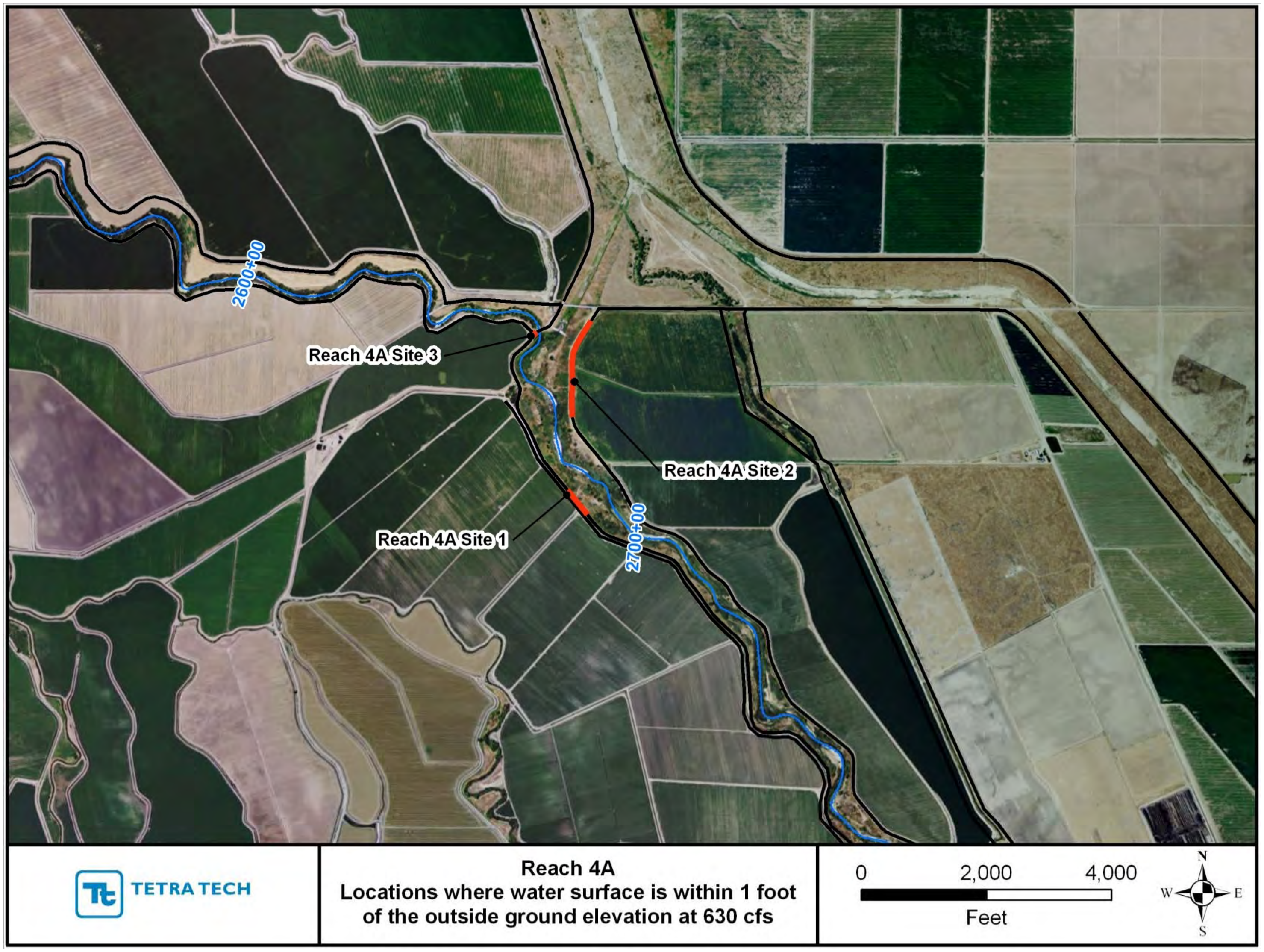

Figure 9. Map showing location in Reach 4A where the 630-cfs water-surface elevation is within 1 foot of the outside ground elevation.

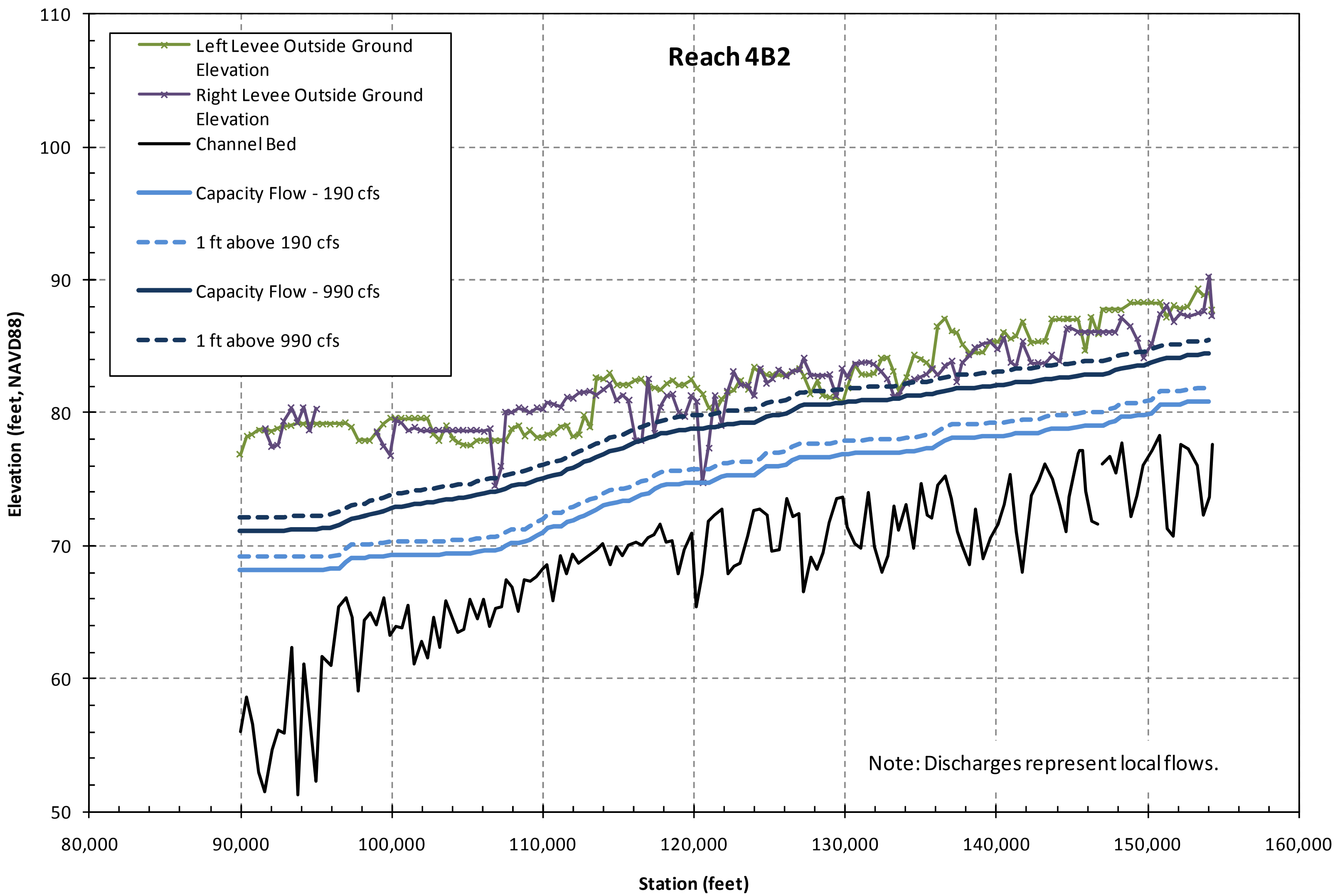

Figure 10. Outside ground elevations and computed water-surface profiles in Reach 4B2 at and 1 foot above the local discharges of 190 and 990 cfs.

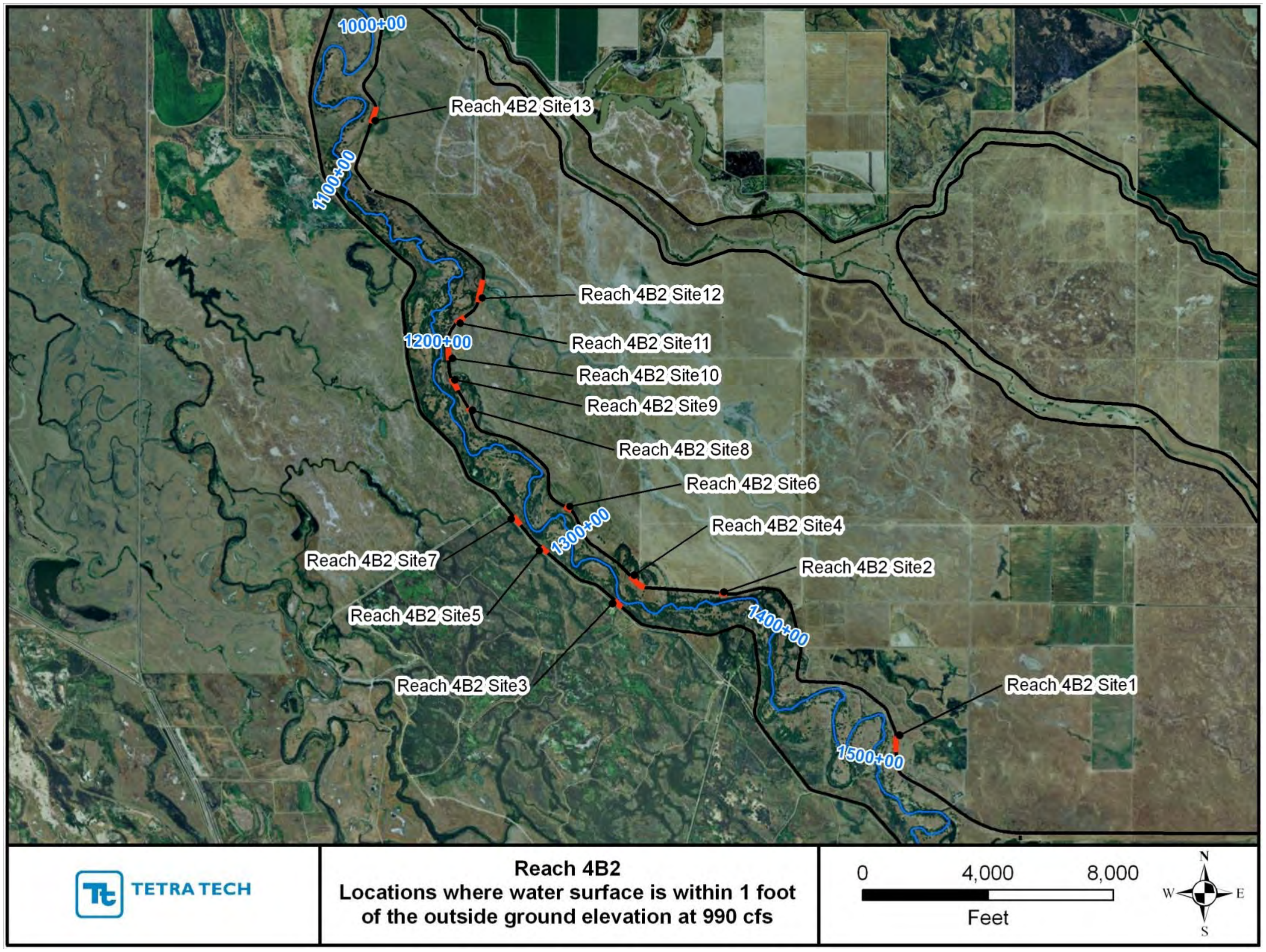

Figure 11. Map showing locations in Reach 4B2 where the 990-cfs water-surface elevation is within 1 foot of the outside ground elevation.

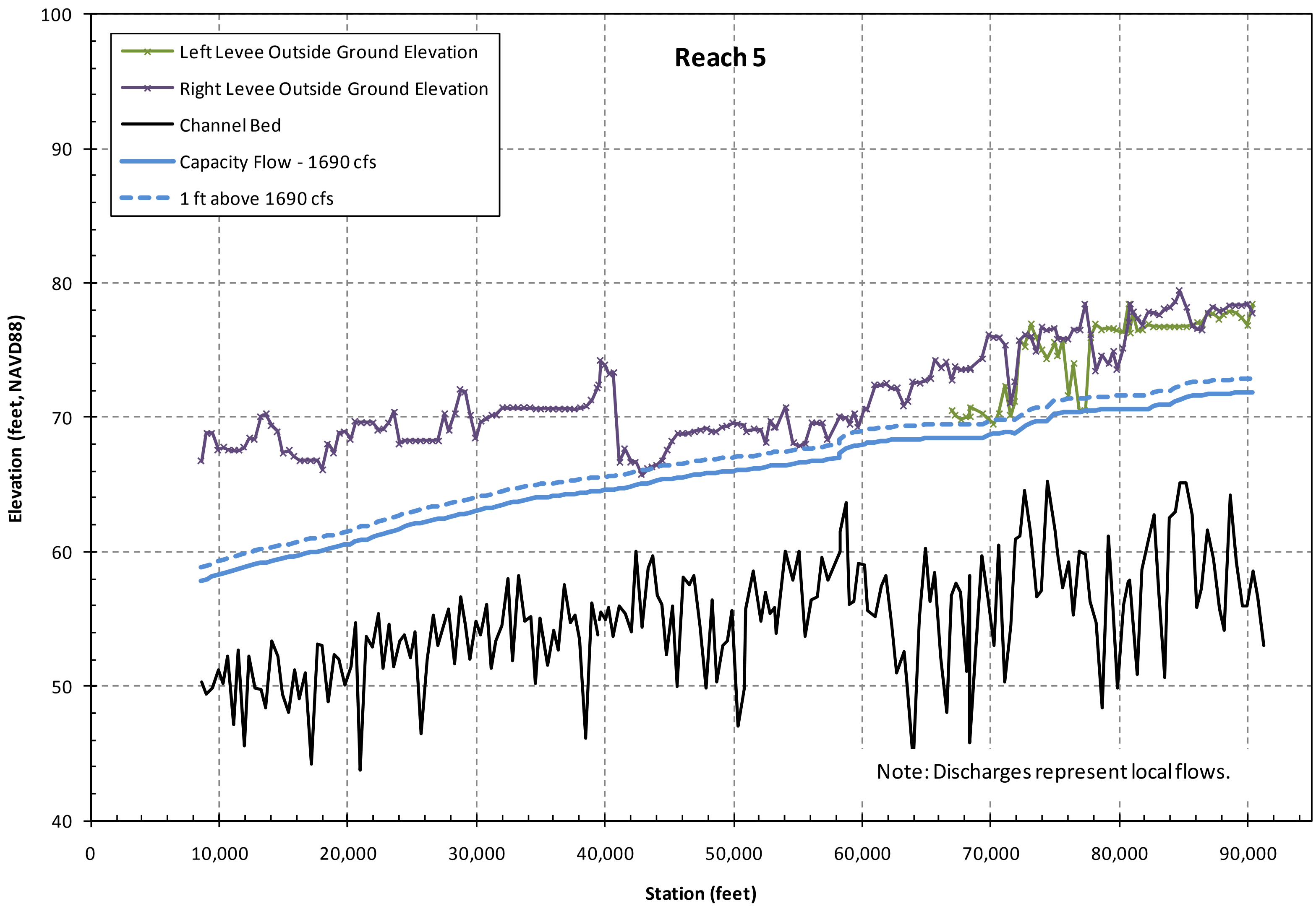

Figure 12. Outside ground elevations and computed water-surface profiles in Reach 5 at and 1 foot above the local discharges of 1,690 cfs.

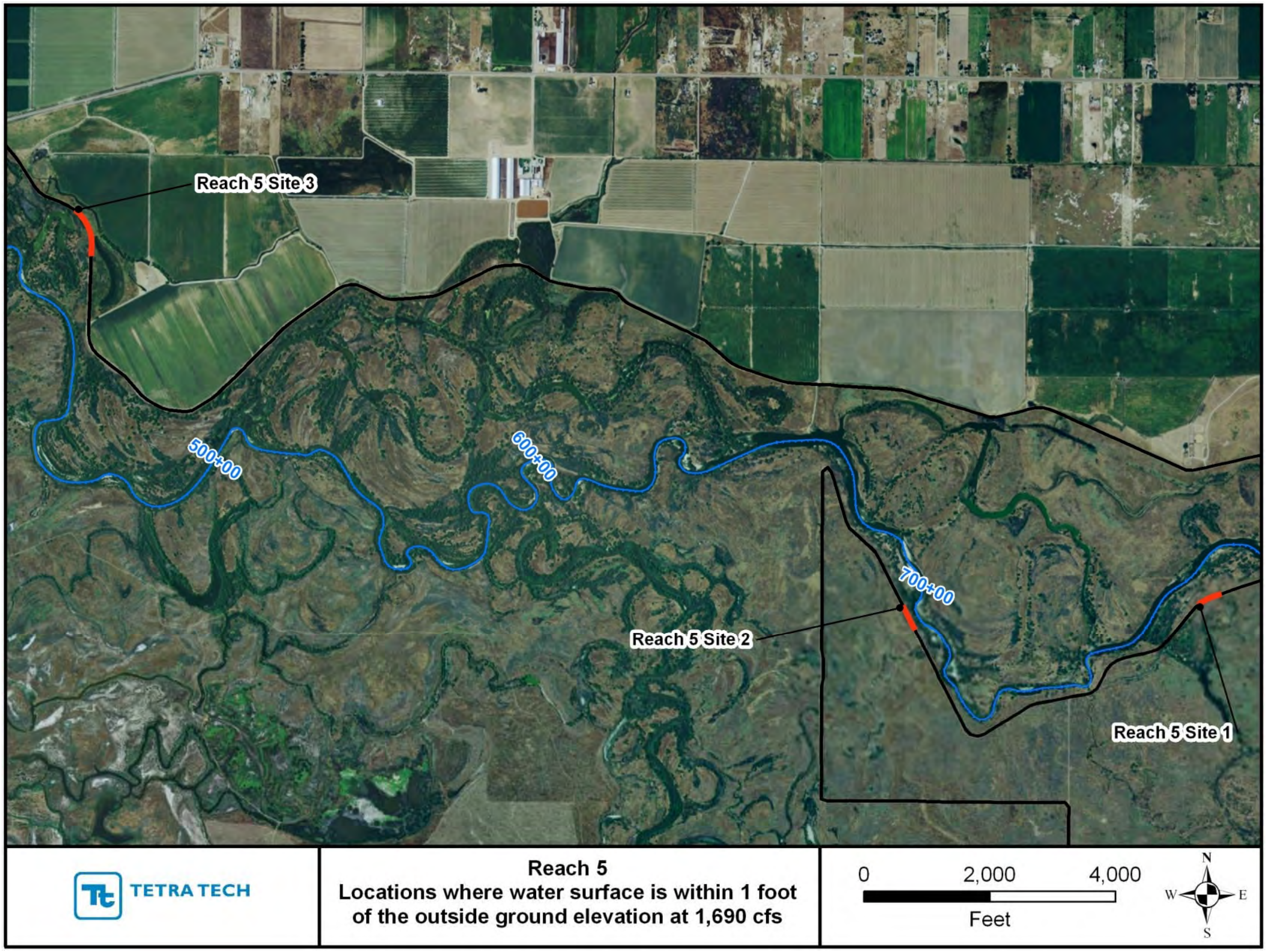

Figure 13. Map showing locations in Reach 5 where the 1,690-cfs water-surface elevation is within 1 foot of the outside ground elevation.

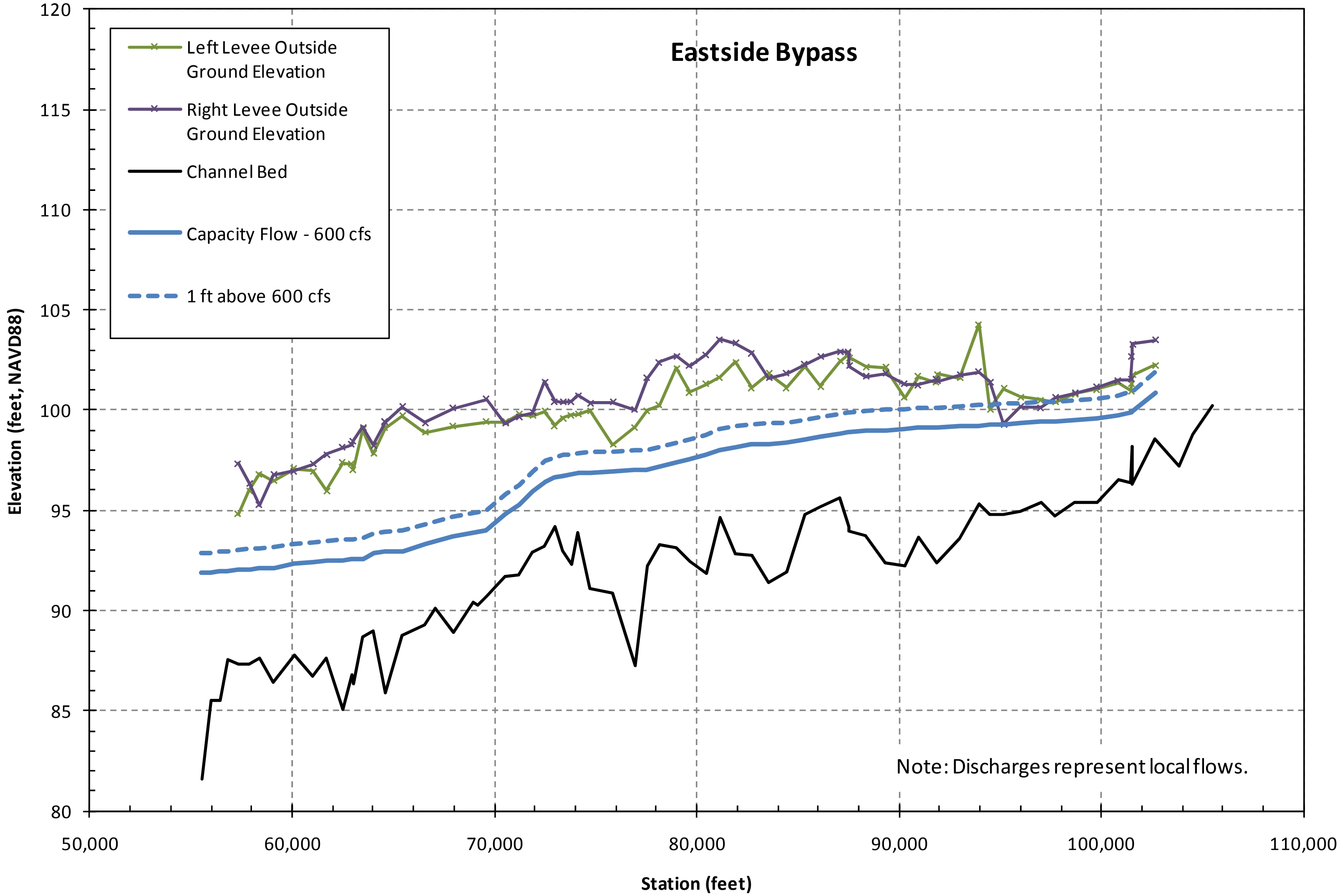

Figure 14. Outside ground elevations and computed water-surface profiles in the Eastside Bypass at and 1 foot above the local discharge of 600 cfs.

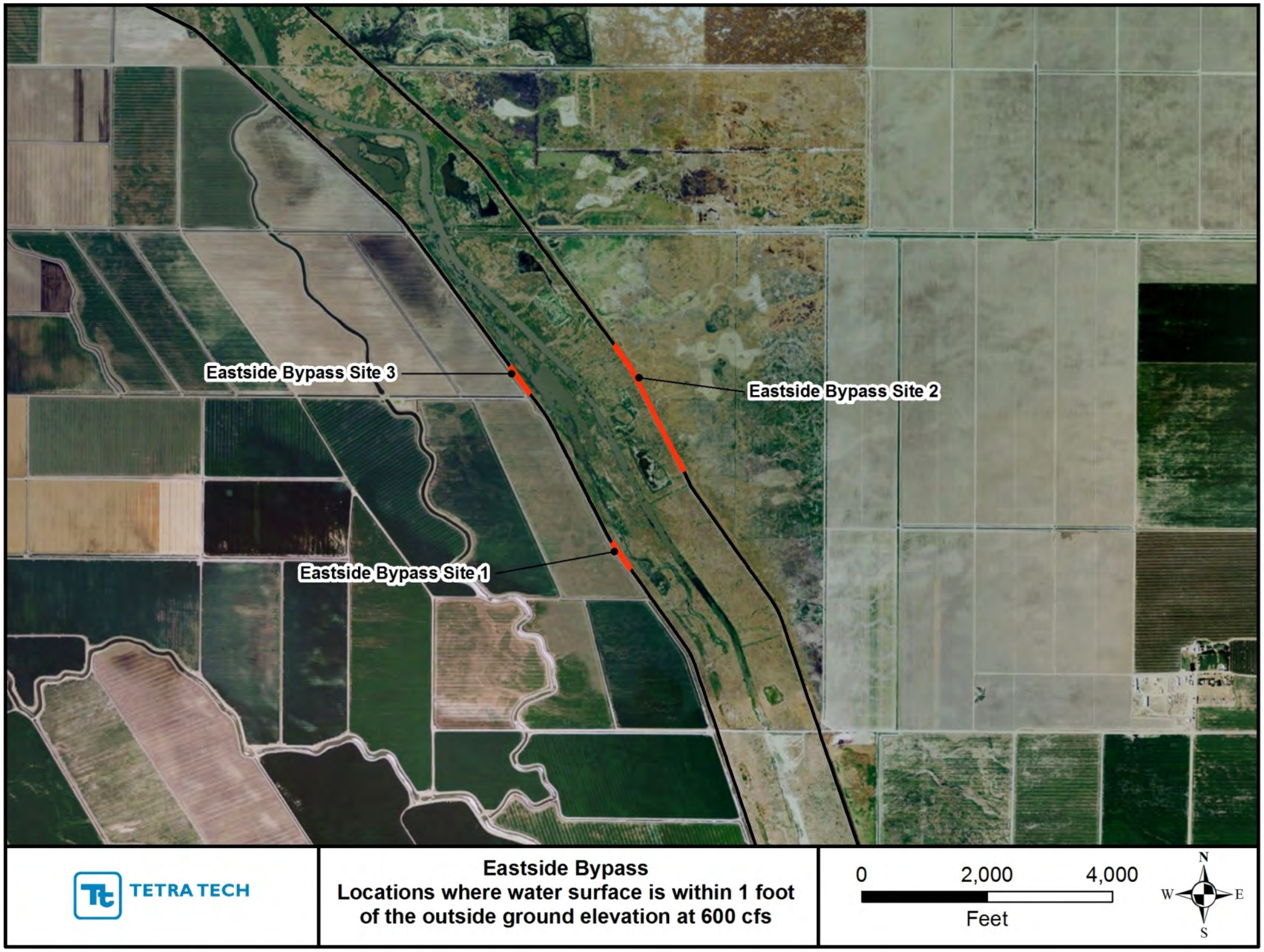

Figure 15. Map showing locations along the Eastside Bypass where the 600-cfs water-surface elevation is within 1 foot of the outside ground elevation.

Appendix J

Surface Water Supplies and Facilities Operations

Draft
Program Environmental Impact Statement/Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

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Attachments

List of Abbreviations and Acronyms

CVP	Central Valley Project
PEIS/R	Program Environmental Impact Statement/Report
SWP	State Water Project

1.0 Introduction

The Surface Water Supplies and Facilities Operations Appendix contains additional information to supplement the Affected Environment and Environmental Consequences sections of the Surface Water Supplies and Facilities Operations section of the Program Environmental Impact Statement/Report (PEIS/R). Each Attachment within this appendix is briefly described below.

- **Attachment – Additional Changes to Central Valley Project and State Water Project Operations:** contains information regarding changes to flows, storages, and diversions at select facilities within the Central Valley Project (CVP) and State Water Project (SWP). These results may be post-processed to meet the needs for analysis of significant impacts of Restoration flows in additional resource areas (e.g. impacts to Friant Division water supply in the Socioeconomics Appendix). These processes are described in the appropriate Appendix.

- **Attachment – Central Valley Project and State Water Project Contracts:** contains information regarding the total Friant Division long-term contracts, a summary of CVP contract amounts for service areas south of the delta, and maximum annual SWP Table A amounts.

- **Attachment – Diversions:** lists San Joaquin River diversions within the restoration area; diversions organized by reach and contain information regarding location, diversion and discharge type, screens, primary use, and estimated capacity.

- **Attachment – Exceedence Curves:** contains exceedence curves of all gages discussed in the Affected Environment section of the Hydrology - Surface Water Supplies and Facilities Operations chapter of the PEIS/R.

- **Attachment – Rating Tables:** contains rating tables of select gages discussed in the Affected Environment section of the Hydrology - Surface Water Supplies and Facilities Operations chapter of the PEIS/R.

- **Attachment – Water Year-Types:** explains water year-types referred to in the PEIS/R; includes Sacramento Valley, San Joaquin Valley, and San Joaquin River Restoration water year-types.

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Attachment

Additional Changes to Central Valley Project and State Water Project Operations

Draft
Surface Water Supplies and Facilities Operations Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

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Tables

Figures

Table 1.
Average Simulated Class I Delivery Flow Rates

Month	Existing Level[1] (2005)				Future Level[1] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2[2] (cfs)	Alt B1 and B2[2] (cfs)	Alt C1 and C2[2] (cfs)	No-Action Alt[2] (cfs)	Alt A1 and A2[3] (cfs)	Alt B1 and B2[3] (cfs)	Alt C1 and C2[3] (cfs)
Oct	458	438 (-4%)	438 (-4%)	438 (-4%)	458 (0%)	437 (-4%)	437 (-4%)	437 (-4%)
Nov	99	102 (2%)	102 (2%)	102 (2%)	98 (-1%)	101 (2%)	101 (2%)	101 (2%)
Dec	64	55 (-13%)	55 (-13%)	55 (-13%)	64 (0%)	55 (-13%)	55 (-13%)	55 (-13%)
Jan	63	54 (-13%)	54 (-13%)	54 (-13%)	63 (0%)	55 (-13%)	55 (-13%)	55 (-13%)
Feb	374	349 (-7%)	349 (-7%)	349 (-7%)	374 (0%)	349 (-7%)	349 (-7%)	349 (-7%)
Mar	423	409 (-3%)	409 (-3%)	409 (-3%)	423 (0%)	409 (-3%)	409 (-3%)	409 (-3%)
Apr	746	711 (-5%)	711 (-5%)	711 (-5%)	746 (0%)	711 (-5%)	711 (-5%)	711 (-5%)
May	1,199	1,153 (-4%)	1,153 (-4%)	1,153 (-4%)	1,199 (0%)	1,157 (-4%)	1,157 (-4%)	1,157 (-4%)
Jun	2,382	2,290 (-4%)	2,290 (-4%)	2,290 (-4%)	2,382 (0%)	2,289 (-4%)	2,289 (-4%)	2,289 (-4%)
Jul	2,910	2,779 (-5%)	2,779 (-5%)	2,779 (-5%)	2,910 (0%)	2,778 (-5%)	2,778 (-5%)	2,778 (-5%)
Aug	2,481	2,313 (-7%)	2,313 (-7%)	2,313 (-7%)	2,481 (0%)	2,312 (-7%)	2,312 (-7%)	2,312 (-7%)
Sep	1,273	1,173 (-8%)	1,173 (-8%)	1,173 (-8%)	1,273 (0%)	1,173 (-8%)	1,173 (-8%)	1,173 (-8%)

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_C1 + D18B_C1).
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] (%) indicates percent change from existing conditions.
[3] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 2.
Average Simulated Class I Delivery Flow Rates in Dry and Critical Years[1]

Month	Existing Level[2] (2005)				Future Level[2] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2[3] (cfs)	Alt B1 and B2[3] (cfs)	Alt C1 and C2[3] (cfs)	No-Action Alt[3] (cfs)	Alt A1 and A2[4] (cfs)	Alt B1 and B2[4] (cfs)	Alt C1 and C2[4] (cfs)
Oct	332	325 (-2%)	325 (-2%)	325 (-2%)	332 (0%)	324 (-2%)	324 (-2%)	324 (-2%)
Nov	88	103 (18%)	103 (18%)	103 (18%)	88 (0%)	103 (18%)	103 (18%)	103 (18%)
Dec	26	8 (-68%)	8 (-68%)	8 (-68%)	26 (0%)	8 (-68%)	8 (-68%)	8 (-68%)
Jan	26	8 (-68%)	8 (-68%)	8 (-68%)	26 (0%)	8 (-68%)	8 (-68%)	8 (-68%)
Feb	268	206 (-23%)	206 (-23%)	206 (-23%)	268 (0%)	205 (-23%)	205 (-23%)	205 (-23%)
Mar	416	314 (-24%)	314 (-24%)	314 (-24%)	416 (0%)	313 (-25%)	313 (-25%)	313 (-25%)
Apr	670	458 (-32%)	458 (-32%)	458 (-32%)	670 (0%)	457 (-32%)	457 (-32%)	457 (-32%)
May	1,099	751 (-32%)	751 (-32%)	751 (-32%)	1,099 (0%)	770 (-30%)	770 (-30%)	770 (-30%)
Jun	2,111	1,660 (-21%)	1,660 (-21%)	1,660 (-21%)	2,111 (0%)	1,656 (-22%)	1,656 (-22%)	1,656 (-22%)
Jul	2,425	1,996 (-18%)	1,996 (-18%)	1,996 (-18%)	2,425 (0%)	1,991 (-18%)	1,991 (-18%)	1,991 (-18%)
Aug	1,789	1,296 (-28%)	1,296 (-28%)	1,296 (-28%)	1,789 (0%)	1,293 (-28%)	1,293 (-28%)	1,293 (-28%)
Sep	806	611 (-24%)	611 (-24%)	611 (-24%)	806 (0%)	609 (-24%)	609 (-24%)	609 (-24%)

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_C1 + D18B_C1).
Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] (%) indicates percent change from existing conditions.
[4] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 3.
Average Simulated Class I Delivery Volumes

Month	Existing Level[1] (2005)				Future Level[1] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2[2] (TAF)	Alt B1 and B2[2] (TAF)	Alt C1 and C2[2] (TAF	No-Action Alt[2] (TAF)	Alt A1 and A2[3] (TAF)	Alt B1 and B2[3] (TAF)	Alt C1 and C2[3] (TAF)
Oct	28	27 (-4%)	27 (-4%)	27 (-4%)	28 (0%)	27 (-4%)	27 (-4%)	27 (-4%)
Nov	6	6 (2%)	6 (2%)	6 (2%)	6 (-1%)	6 (2%)	6 (2%)	6 (2%)
Dec	4	3 (-13%)	3 (-13%)	3 (-13%)	4 (0%)	3 (-13%)	3 (-13%)	3 (-13%)
Jan	4	3 (-13%)	3 (-13%)	3 (-13%)	4 (0%)	3 (-13%)	3 (-13%)	3 (-13%)
Feb	21	19 (-7%)	19 (-7%)	19 (-7%)	21 (0%)	19 (-7%)	19 (-7%)	19 (-7%)
Mar	26	25 (-3%)	25 (-3%)	25 (-3%)	26 (0%)	25 (-3%)	25 (-3%)	25 (-3%)
Apr	44	42 (-5%)	42 (-5%)	42 (-5%)	44 (0%)	42 (-5%)	42 (-5%)	42 (-5%)
May	74	71 (-4%)	71 (-4%)	71 (-4%)	74 (0%)	71 (-4%)	71 (-4%)	71 (-4%)
Jun	142	136 (-4%)	136 (-4%)	136 (-4%)	142 (0%)	136 (-4%)	136 (-4%)	136 (-4%)
Jul	179	171 (-5%)	171 (-5%)	171 (-5%)	179 (0%)	171 (-5%)	171 (-5%)	171 (-5%)
Aug	153	142 (-7%)	142 (-7%)	142 (-7%)	153 (0%)	142 (-7%)	142 (-7%)	142 (-7%)
Sep	76	70 (-8%)	70 (-8%)	70 (-8%)	76 (0%)	70 (-8%)	70 (-8%)	70 (-8%)
Total	756	717 (-5%)	717 (-5%)	717 (-5%)	756 (0%)	717 (-5%)	717 (-5%)	717 (-5%)

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_C1 + D18B_C1)
Notes:
1 Simulation period: October 1921 – September 2003.
2 (%) indicates percent change from existing conditions.
3 (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
TAF = thousand acre-feet

Table 4.
Average Simulated Class I Delivery Volumes in Dry and Critical Years[1]

Month	Existing Level[2] (2005)				Future Level[2] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2[3] (TAF)	Alt B1 and B2[3] (TAF)	Alt C1 and C2[3] (TAF)	No-Action Alt[3] (TAF)	Alt A1 and A2[4] (TAF)	Alt B1 and B2[4] (TAF)	Alt C1 and C2[4] (TAF)
Oct	20	20 (-2%)	20 (-2%)	20 (-2%)	20 (0%)	20 (-2%)	20 (-2%)	20 (-2%)
Nov	5	6 (18%)	6 (18%)	6 (18%)	5 (0%)	6 (18%)	6 (18%)	6 (18%)
Dec	2	1 (-68%)	1 (-68%)	1 (-68%)	2 (0%)	1 (-68%)	1 (-68%)	1 (-68%)
Jan	2	1 (-68%)	1 (-68%)	1 (-68%)	2 (0%)	1 (-68%)	1 (-68%)	1 (-68%)
Feb	15	11 (-23%)	11 (-23%)	11 (-23%)	15 (0%)	11 (-23%)	11 (-23%)	11 (-23%)
Mar	26	19 (-24%)	19 (-24%)	19 (-24%)	26 (0%)	19 (-25%)	19 (-25%)	19 (-25%)
Apr	40	27 (-32%)	27 (-32%)	27 (-32%)	40 (0%)	27 (-32%)	27 (-32%)	27 (-32%)
May	68	46 (-32%)	46 (-32%)	46 (-32%)	68 (0%)	47 (-30%)	47 (-30%)	47 (-30%)
Jun	126	99 (-21%)	99 (-21%)	99 (-21%)	126 (0%)	99 (-22%)	99 (-22%)	99 (-22%)
Jul	149	123 (-18%)	123 (-18%)	123 (-18%)	149 (0%)	122 (-18%)	122 (-18%)	122 (-18%)
Aug	110	80 (-28%)	80 (-28%)	80 (-28%)	110 (0%)	80 (-28%)	80 (-28%)	80 (-28%)
Sep	48	36 (-24%)	36 (-24%)	36 (-24%)	48 (0%)	36 (-24%)	36 (-24%)	36 (-24%)
Total	609	469 (-23%)	469 (-23%)	469 (-23%)	609 (0%)	469 (-23%)	469 (-23%)	469 (-23%)

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_C1 + D18B_C1)
Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] (%) indicates percent change from existing conditions.
[4] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
TAF = thousand acre-feet

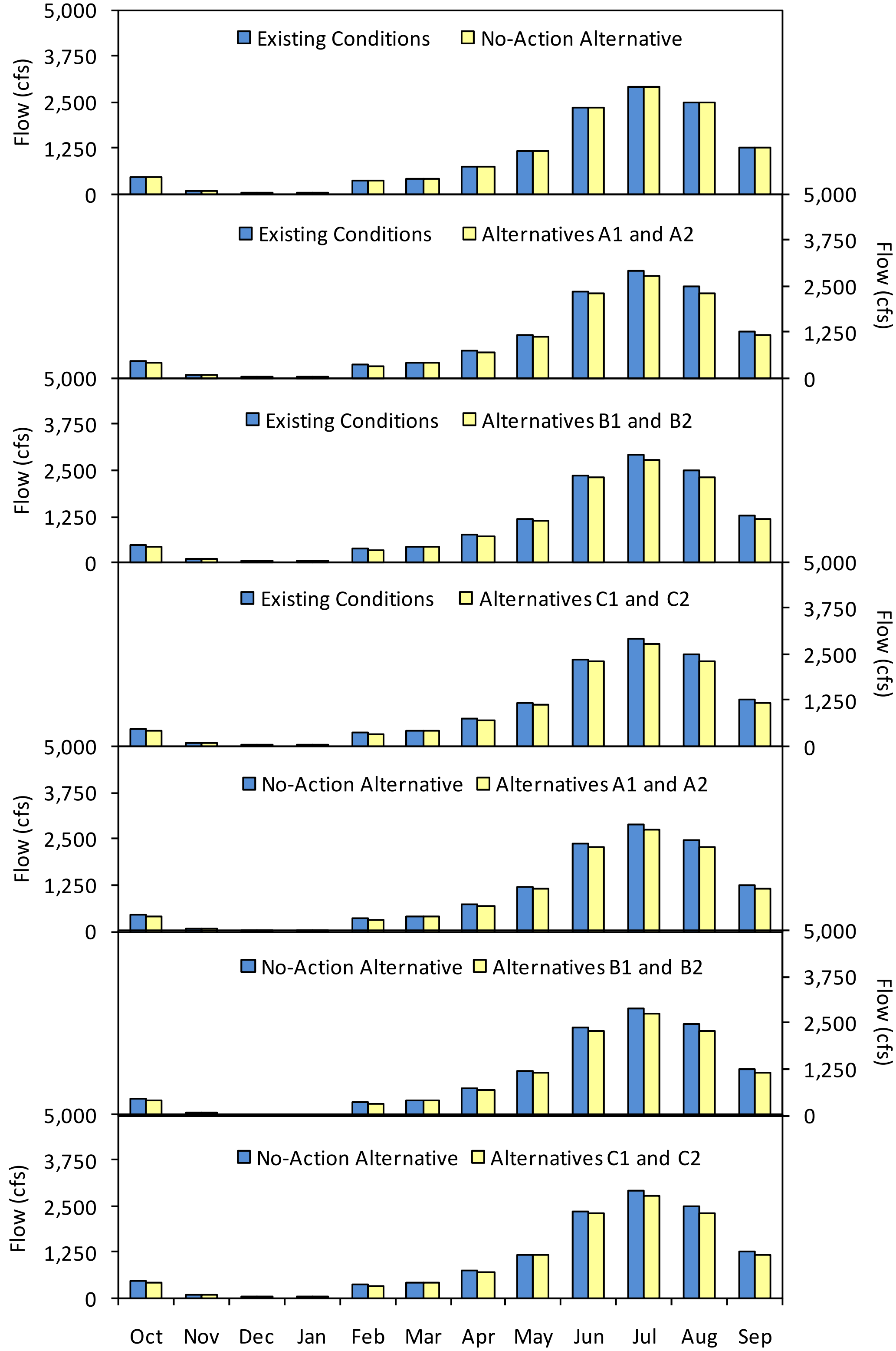

Figure 1.
Average Simulated Class I Delivery Flow Rates

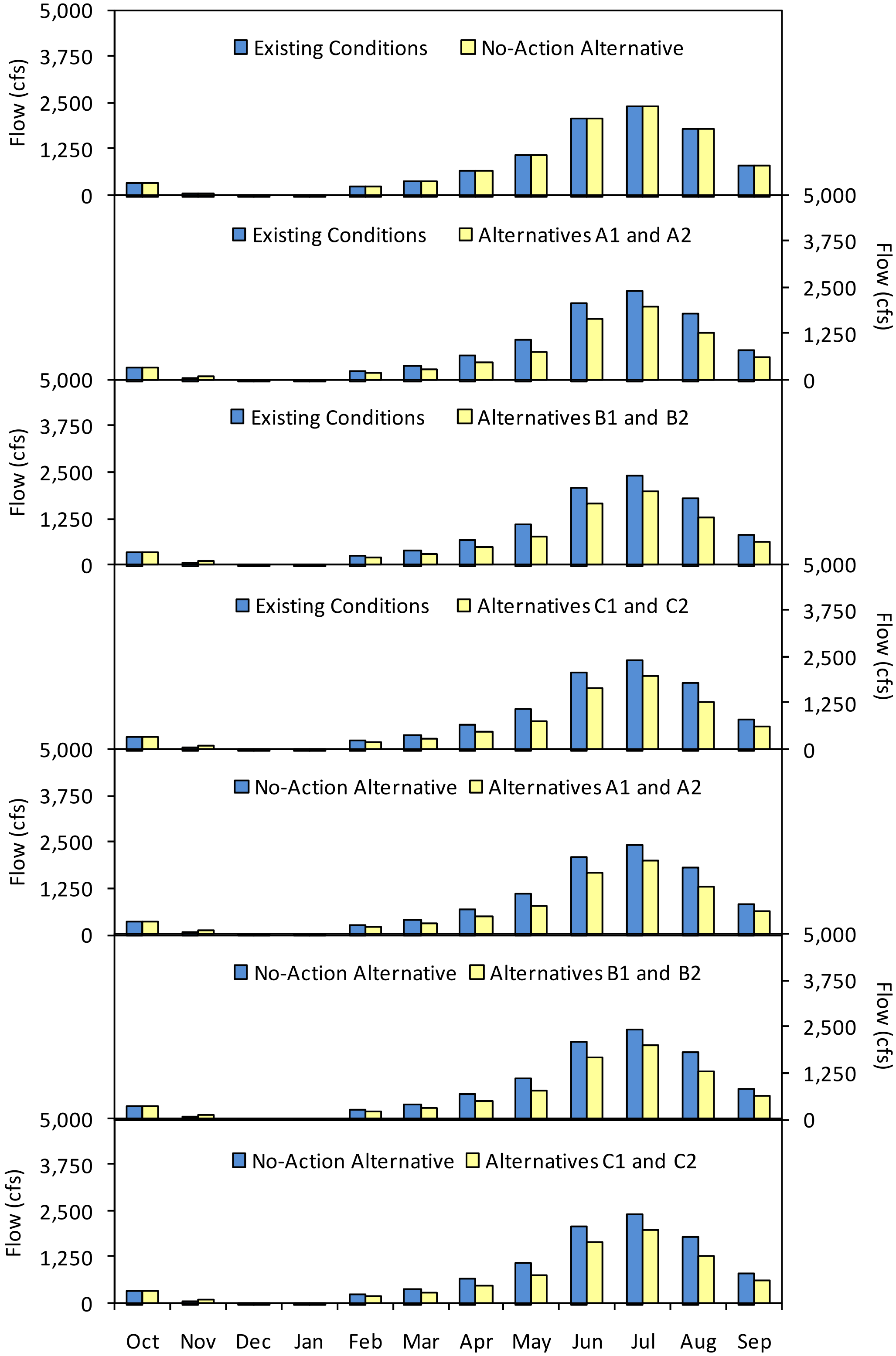

Figure 2.
Average Simulated Class I Delivery Flow Rates in Dry and Critical Years

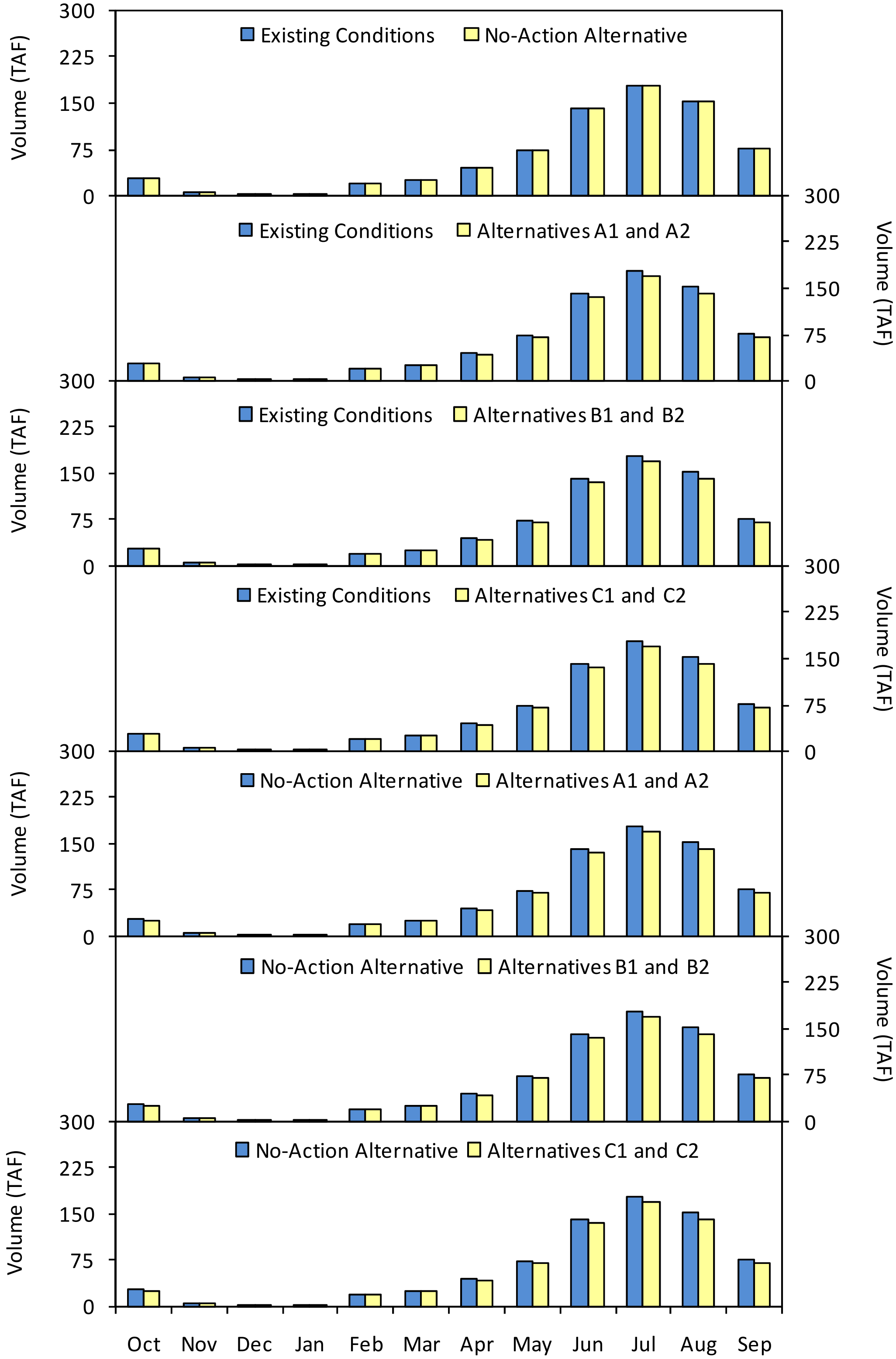

Figure 3.
Average Simulated Class I Delivery Volumes

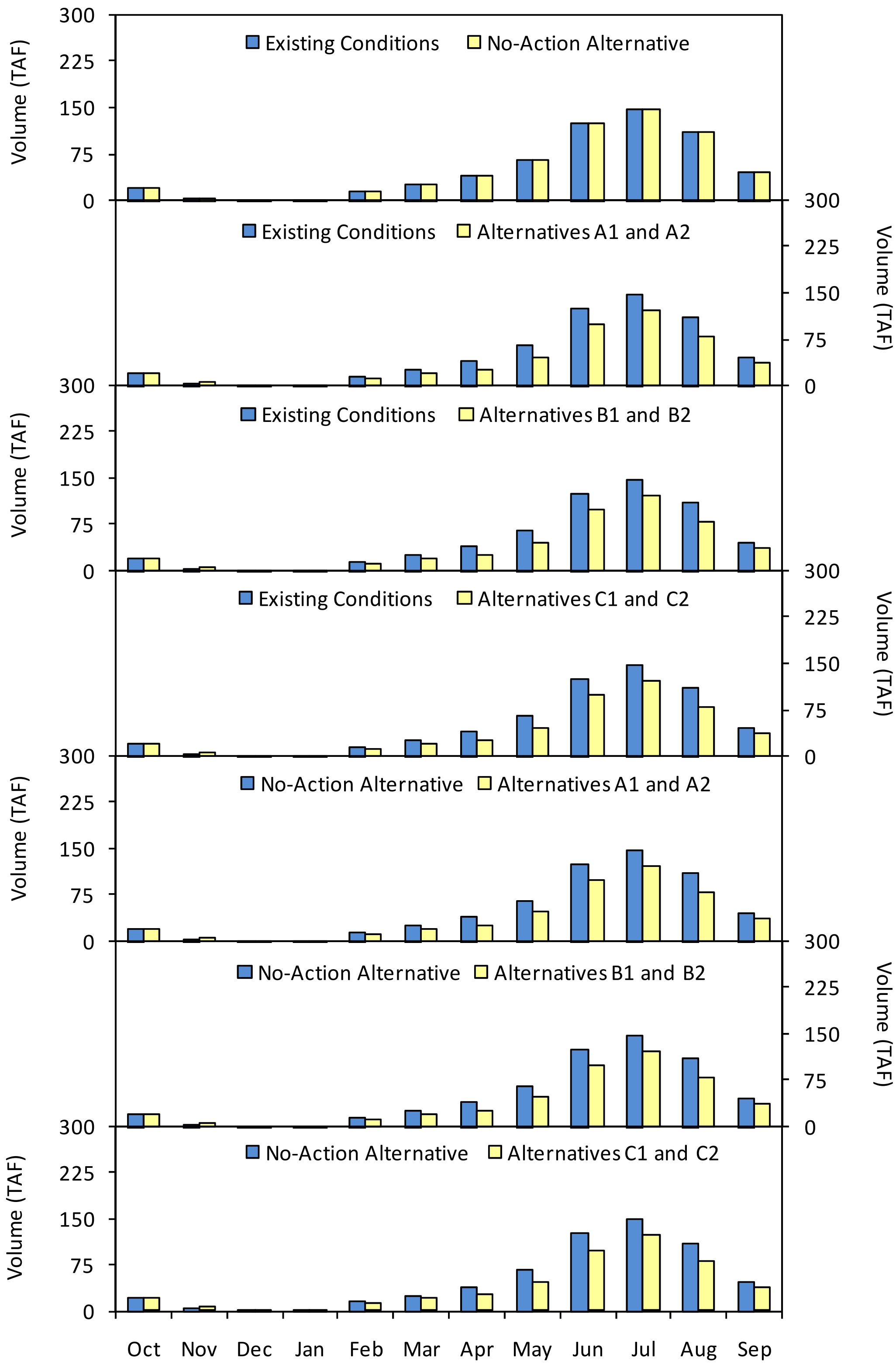

Figure 4.
Average Simulated Class I Delivery Volumes in Dry and Critical Years

Table 5.
Average Simulated Class II Delivery Flow Rates

Month	Existing Level[1] (2005)				Future Level[1] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2[2] (cfs)	Alt B1 and B2[2] (cfs)	Alt C1 and C2[2] (cfs)	No-Action Alt[2] (cfs)	Alt A1 and A2[3] (cfs)	Alt B1 and B2[3] (cfs)	Alt C1 and C2[3] (cfs)
Oct	133	109 (-18%)	109 (-18%)	109 (-18%)	132 (0%)	109 (-18%)	109 (-18%)	109 (-18%)
Nov	31	24 (-23%)	24 (-23%)	24 (-23%)	31 (0%)	23 (-23%)	23 (-23%)	23 (-23%)
Dec	44	36 (-18%)	36 (-18%)	36 (-18%)	44 (0%)	36 (-18%)	36 (-18%)	36 (-18%)
Jan	42	37 (-13%)	37 (-13%)	37 (-13%)	42 (0%)	37 (-13%)	37 (-13%)	37 (-13%)
Feb	265	214 (-19%)	214 (-19%)	214 (-19%)	265 (0%)	214 (-19%)	214 (-19%)	214 (-19%)
Mar	309	221 (-29%)	221 (-29%)	221 (-29%)	309 (0%)	220 (-29%)	220 (-29%)	220 (-29%)
Apr	710	523 (-26%)	523 (-26%)	523 (-26%)	708 (0%)	520 (-26%)	520 (-26%)	520 (-26%)
May	994	792 (-20%)	792 (-20%)	792 (-20%)	995 (0%)	792 (-20%)	792 (-20%)	792 (-20%)
Jun	1,045	841 (-20%)	841 (-20%)	841 (-20%)	1,045 (0%)	841 (-20%)	841 (-20%)	841 (-20%)
Jul	865	682 (-21%)	682 (-21%)	682 (-21%)	865 (0%)	683 (-21%)	683 (-21%)	683 (-21%)
Aug	758	608 (-20%)	608 (-20%)	608 (-20%)	758 (0%)	608 (-20%)	608 (-20%)	608 (-20%)
Sep	406	332 (-18%)	332 (-18%)	332 (-18%)	406 (0%)	332 (-18%)	332 (-18%)	332 (-18%)

Source; Summarized from CalSim II 2005 and 2030 simulations (Node D18A_C2 + D18B_C2).
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] (%) indicates percent change from existing conditions.
[3] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 6.
Average Simulated Class II Delivery Flow Rates in Dry and Critical Years[1]

Month	Existing Level[2, 3] (2005)				Future Level[2, 3] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)	No-Action Alt (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)
Oct	4	0	0	0	4	0	0	0
Nov	1	0	0	0	1	0	0	0
Dec	1	0	0	0	1	0	0	0
Jan	1	0	0	0	1	0	0	0
Feb	4	0	0	0	4	0	0	0
Mar	7	1	1	1	7	1	1	1
Apr	23	0	0	0	23	0	0	0
May	23	0	0	0	23	0	0	0
Jun	39	0	0	0	39	0	0	0
Jul	43	0	0	0	43	0	0	0
Aug	35	0	0	0	35	0	0	0
Sep	15	0	0	0	15	0	0	0

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_C2 + D18B_C2).
Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 7.
Average Simulated Class II Delivery Volumes

Month	Existing Level[1] (2005)				Future Level[1] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2[2] (TAF)	Alt B1 and B2[2] (TAF)	Alt C1 and C2[2] (TAF)	No-Action Alt[2] (TAF)	Alt A1 and A2[3] (TAF)	Alt B1 and B2[3] (TAF)	Alt C1 and C2[3] (TAF)
Oct	8	7 (-18%)	7 (-18%)	7 (-18%)	8 (0%)	7 (-18%)	7 (-18%)	7 (-18%)
Nov	2	1 (-23%)	1 (-23%)	1 (-23%)	2 (0%)	1 (-23%)	1 (-23%)	1 (-23%)
Dec	3	2 (-18%)	2 (-18%)	2 (-18%)	3 (0%)	2 (-18%)	2 (-18%)	2 (-18%)
Jan	3	2 (-13%)	2 (-13%)	2 (-13%)	3 (0%)	2 (-13%)	2 (-13%)	2 (-13%)
Feb	15	12 (-19%)	12 (-19%)	12 (-19%)	15 (0%)	12 (-19%)	12 (-19%)	12 (-19%)
Mar	19	14 (-29%)	14 (-29%)	14 (-29%)	19 (0%)	14 (-29%)	14 (-29%)	14 (-29%)
Apr	42	31 (-26%)	31 (-26%)	31 (-26%)	42 (0%)	31 (-26%)	31 (-26%)	31 (-26%)
May	61	49 (-20%)	49 (-20%)	49 (-20%)	61 (0%)	49 (-20%)	49 (-20%)	49 (-20%)
Jun	62	50 (-20%)	50 (-20%)	50 (-20%)	62 (0%)	50 (-20%)	50 (-20%)	50 (-20%)
Jul	53	42 (-21%)	42 (-21%)	42 (-21%)	53 (0%)	42 (-21%)	42 (-21%)	42 (-21%)
Aug	47	37 (-20%)	37 (-20%)	37 (-20%)	47 (0%)	37 (-20%)	37 (-20%)	37 (-20%)
Sep	24	20 (-18%)	20 (-18%)	20 (-18%)	24 (0%)	20 (-18%)	20 (-18%)	20 (-18%)
Total	339	267 (-21%)	267 (-21%)	267 (-21%)	338 (0%)	267 (-21%)	267 (-21%)	267 (-21%)

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_C2 + D18B_C2)
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] (%) indicates percent change from existing conditions.
[3] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
TAF = thousand acre-feet

Table 8.
Average Simulated Class II Delivery Volumes in Dry and Critical Years[1]

Month	Existing Level[2, 3] (2005)				Future Level[2, 3] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)	No-Action Alt (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)
Oct	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0
Apr	1	0	0	0	1	0	0	0
May	1	0	0	0	1	0	0	0
Jun	2	0	0	0	2	0	0	0
Jul	3	0	0	0	3	0	0	0
Aug	2	0	0	0	2	0	0	0
Sep	1	0	0	0	1	0	0	0
Total	12	0	0	0	12	0	0	0

Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_C2 + D18B_C2)
Notes:
1 Year-type as defined by the Restoration Year-Type.
2 Simulation period: October 1921 – September 2003.
3 Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
TAF = thousand acre-feet

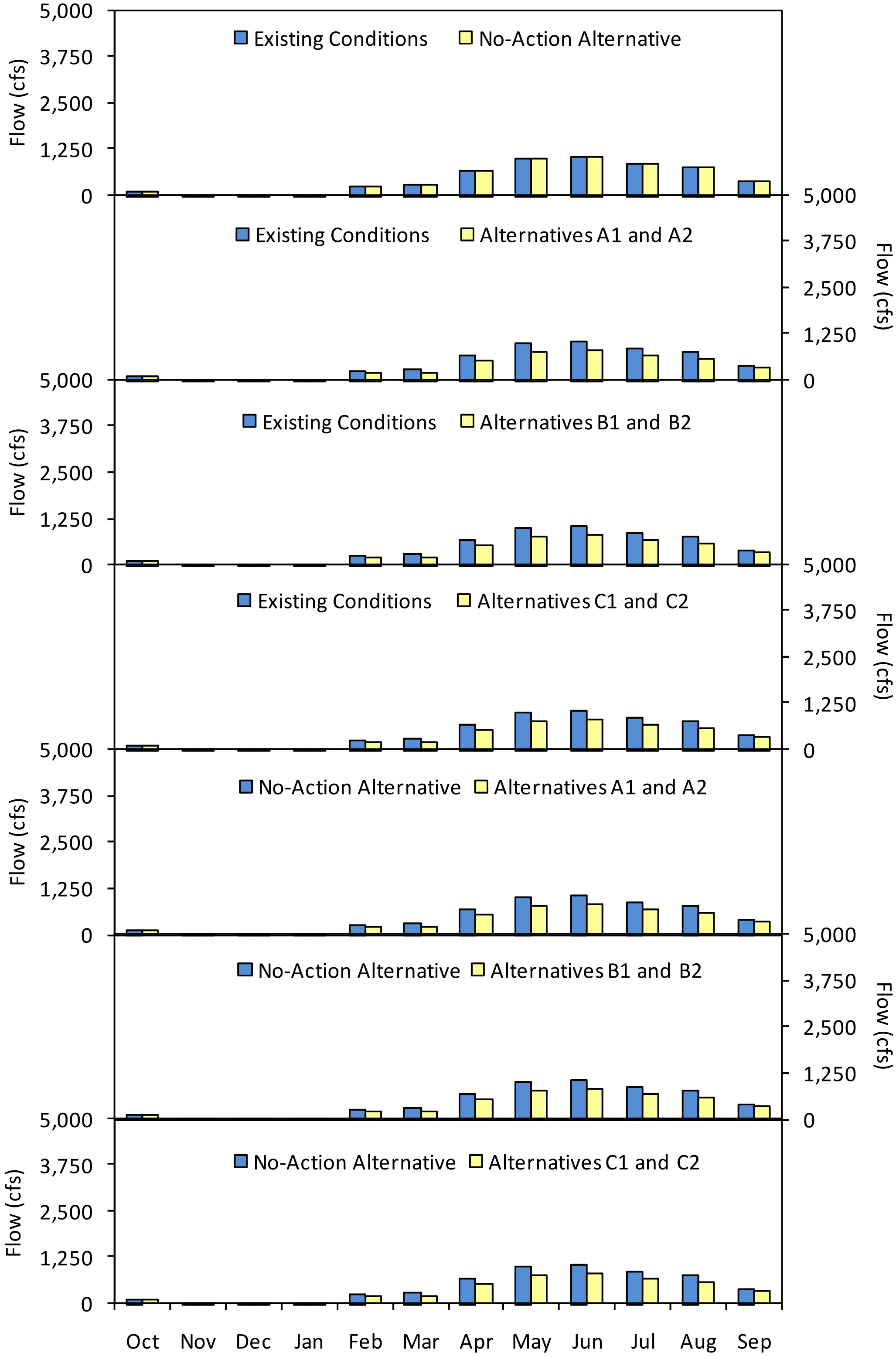

Figure 5.
Average Simulated Class II Delivery Flow Rates

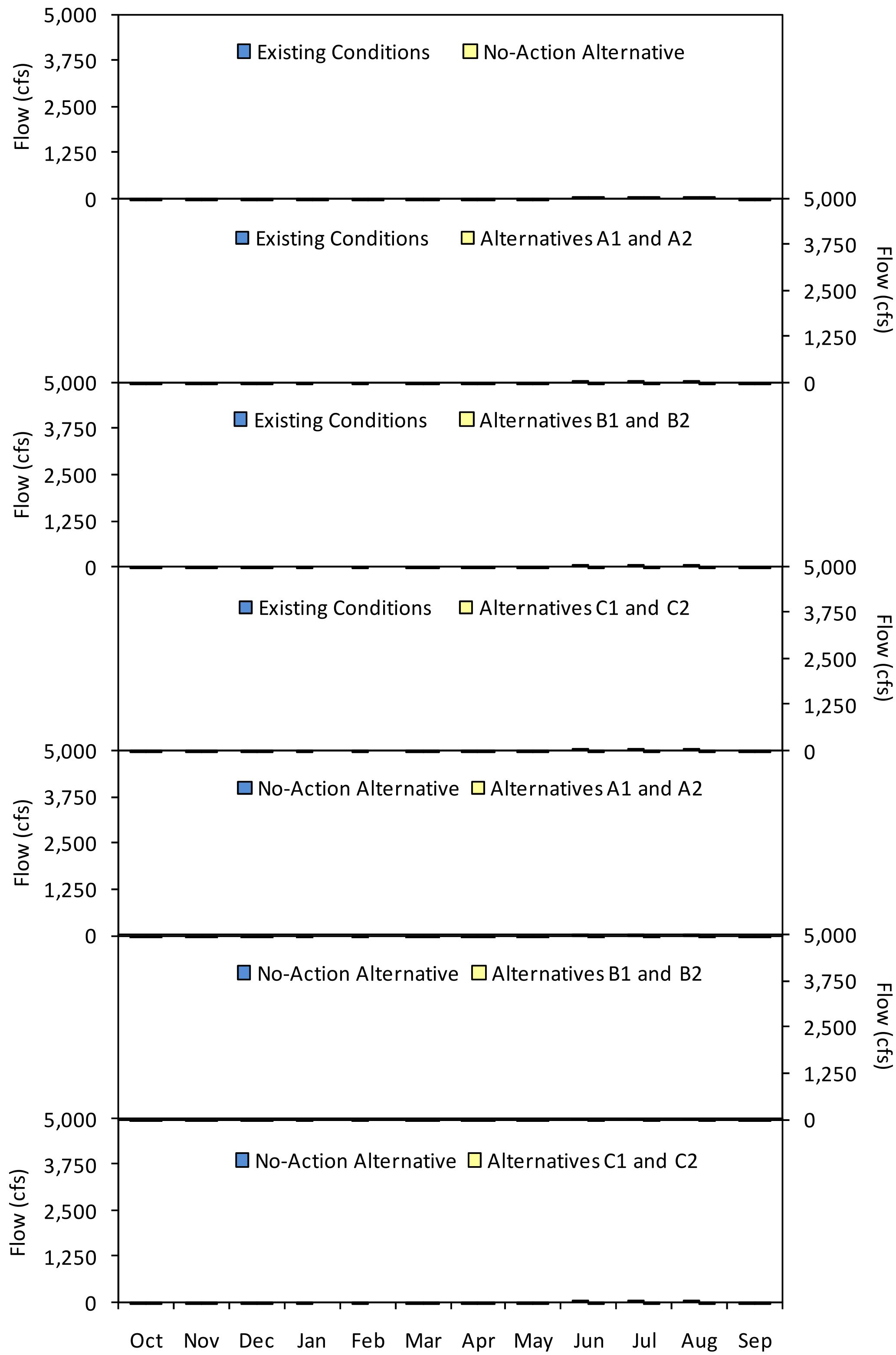

Figure 6.
Average Simulated Class II Delivery Flow Rates in Dry and Critical Years

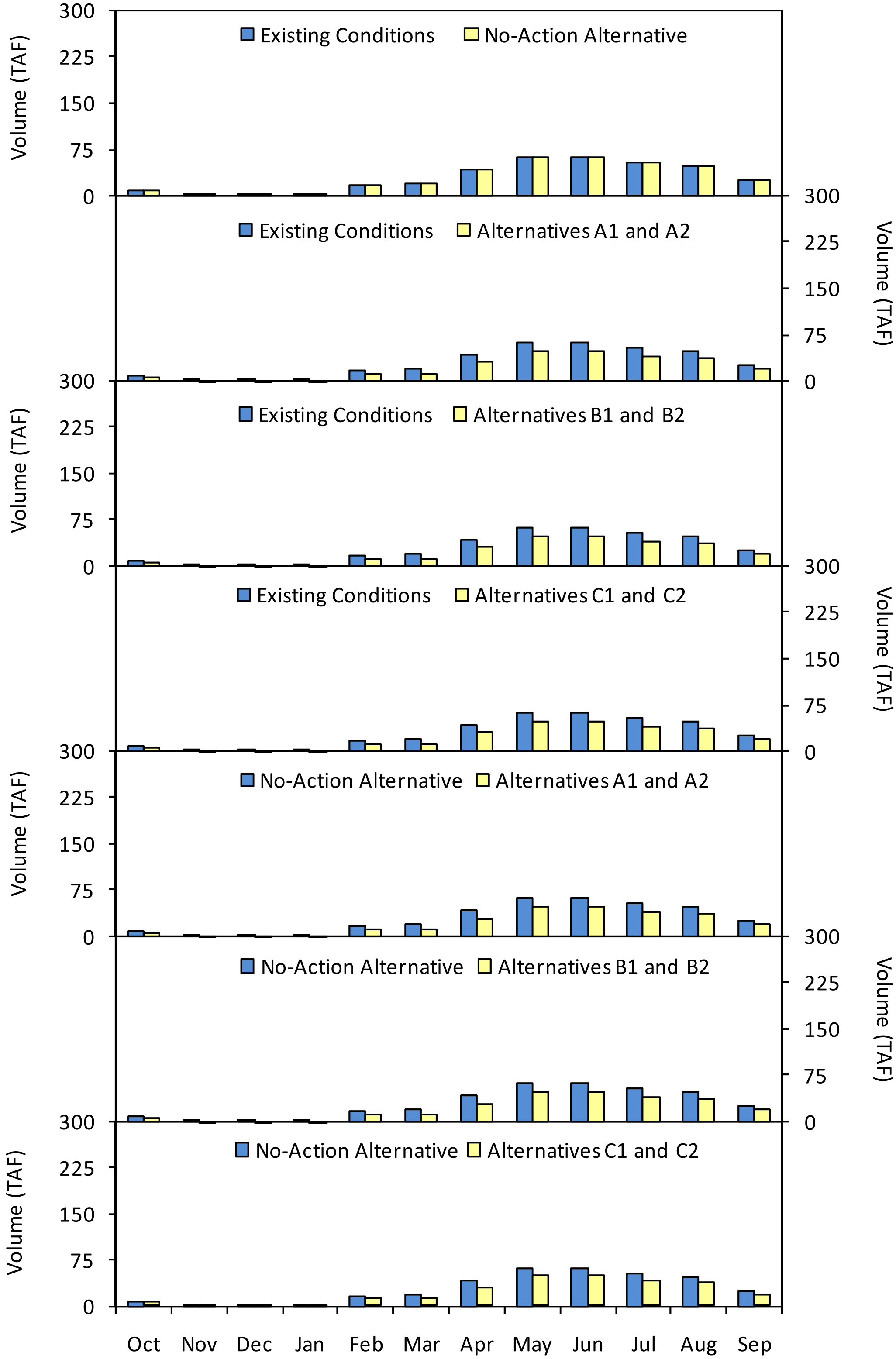

Figure 7.
Average Simulated Class II Delivery Volumes

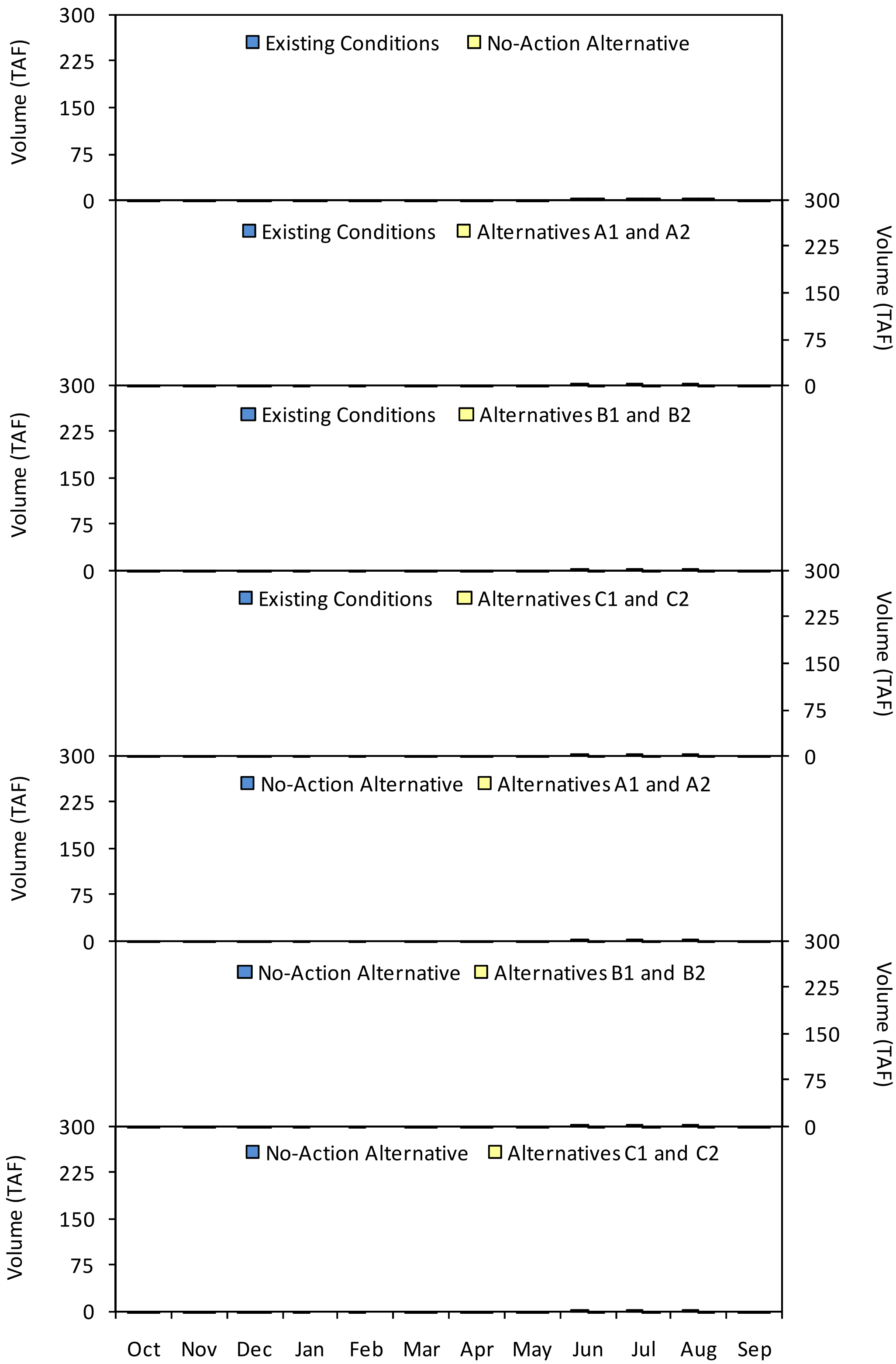

Figure 8.
Average Simulated Class II Delivery Volumes in Dry and Critical Years

Table 9.
Average Simulated 215 Delivery Flow Rates

Month	Existing Level[1, 2] (2005)				Future Level[1, 2] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)	No-Action Alt (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)
Oct	15	0	0	0	15	0	0	0
Nov	29	5	5	5	29	5	5	5
Dec	83	0	0	0	83	0	0	0
Jan	251	0	0	0	251	0	0	0
Feb	336	16	16	16	336	15	15	15
Mar	354	6	6	6	353	5	5	5
Apr	456	14	14	14	453	13	13	13
May	546	56	56	56	546	56	56	59
Jun	417	33	33	35	417	33	33	35
Jul	70	19	19	19	70	19	19	19
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_215 + D18B_215).
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 10.
Average Simulated 215 Delivery Flow Rates in Dry and Critical Years[1]

Month	Existing Level[2, 3] (2005)				Future Level[2, 3] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)	No-Action Alt (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)
Oct	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	132	0	0	0	132	0	0	0
Feb	228	7	7	7	228	7	7	7
Mar	141	2	2	2	141	2	2	2
Apr	98	8	8	8	99	8	8	8
May	5	0	0	0	5	0	0	0
Jun	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_215 + D18B_215).

Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.

Key:
Alt = Alternative
cfs = cubic feet per second

Table 11.
Average Simulated 215 Delivery Volumes

Month	Existing Level[1, 2] (2005)				Future Level[1, 2] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)	No-Action Alt (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)
Oct	1	0	0	0	1	0	0	0
Nov	2	0	0	0	2	0	0	0
Dec	5	0	0	0	5	0	0	0
Jan	15	0	0	0	15	0	0	0
Feb	19	1	1	1	19	1	1	1
Mar	22	0	0	0	22	0	0	0
Apr	27	1	1	1	27	1	1	1
May	34	3	3	3	34	3	3	4
Jun	25	2	2	2	25	2	2	2
Jul	4	1	1	1	4	1	1	1
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0
Total	154	9	9	9	153	9	9	9

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_215 + D18B_215)
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
TAF = thousand acre-feet

Table 12.
Average Simulated 215 Delivery Volumes in Dry and Critical Years[1]

Month	Existing Level[2, 3] (2005)				Future Level[2, 3] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)	No-Action Alt (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)
Oct	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	8	0	0	0	8	0	0	0
Feb	13	0	0	0	13	0	0	0
Mar	9	0	0	0	9	0	0	0
Apr	6	1	1	1	6	1	1	1
May	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0
Total	36	1	1	1	36	1	1	1

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_215 + D18B_215)
Notes:
1 Year-type as defined by the Restoration Year-Type.
2 Simulation period: October 1921 – September 2003.
3 Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
TAF = thousand acre-feet

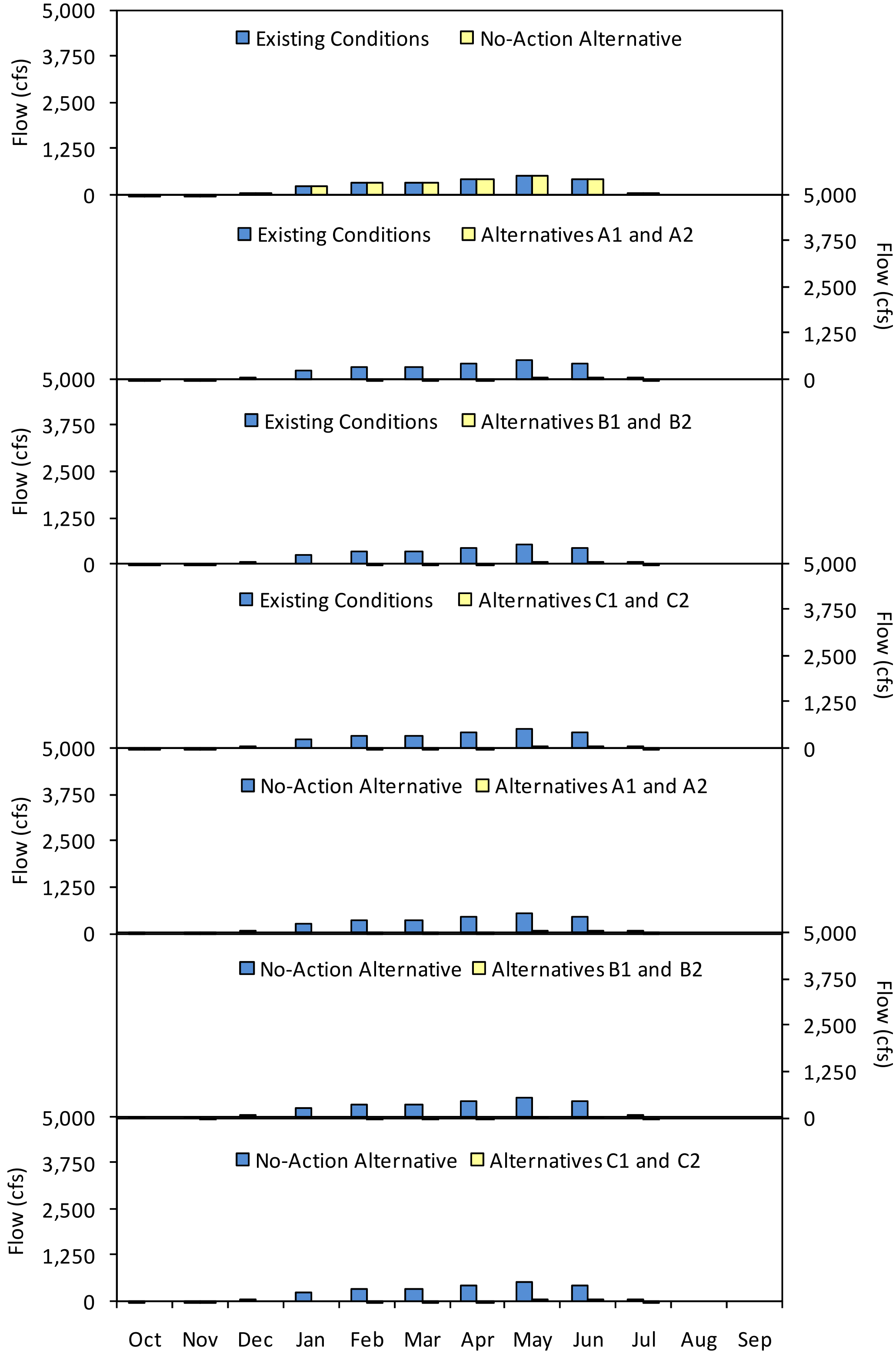

Figure 9.
Average Simulated 215 Delivery Flow Rates

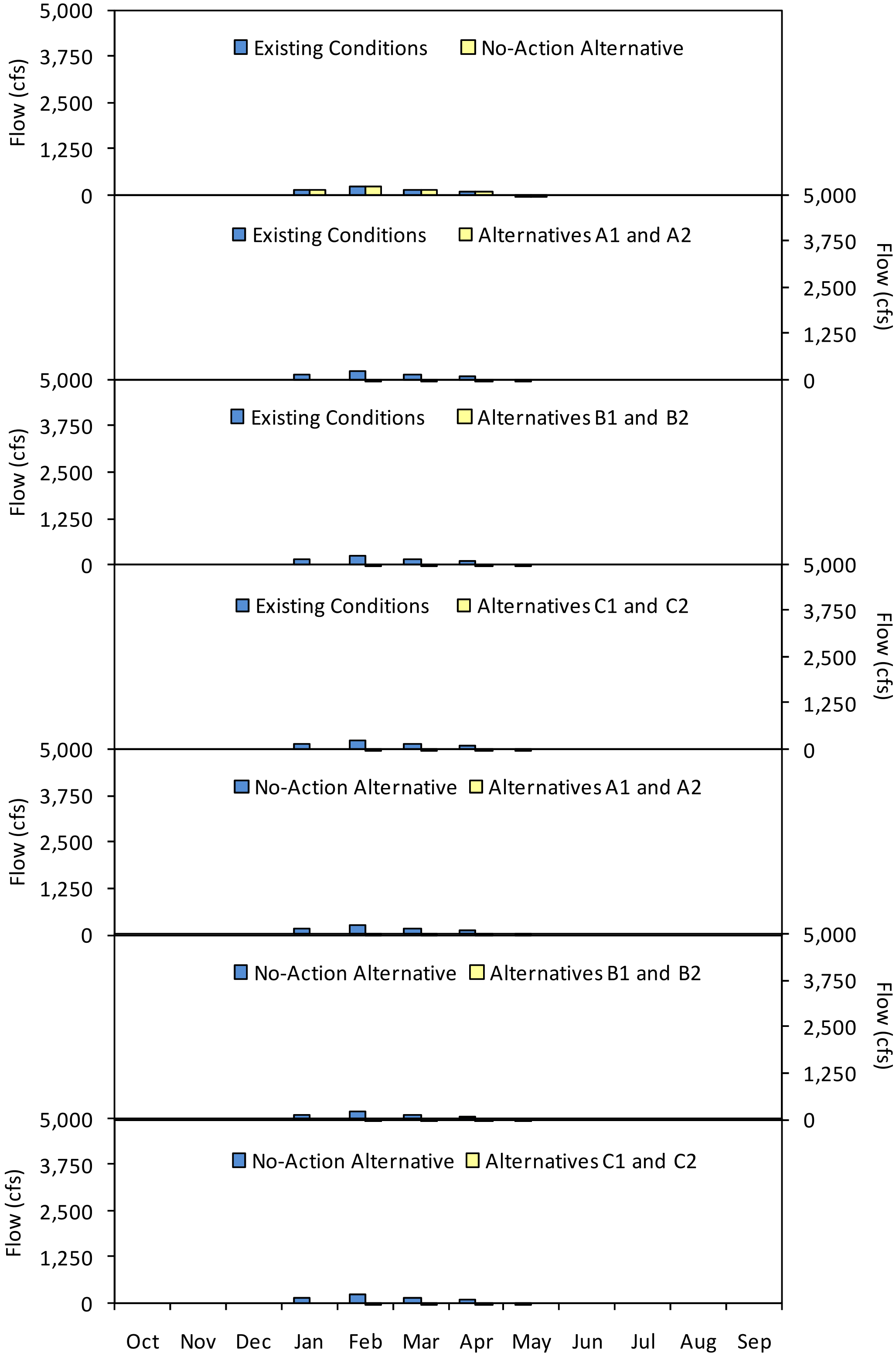

Figure 10.
Average Simulated 215 Delivery Flow Rates in Dry and Critical Years

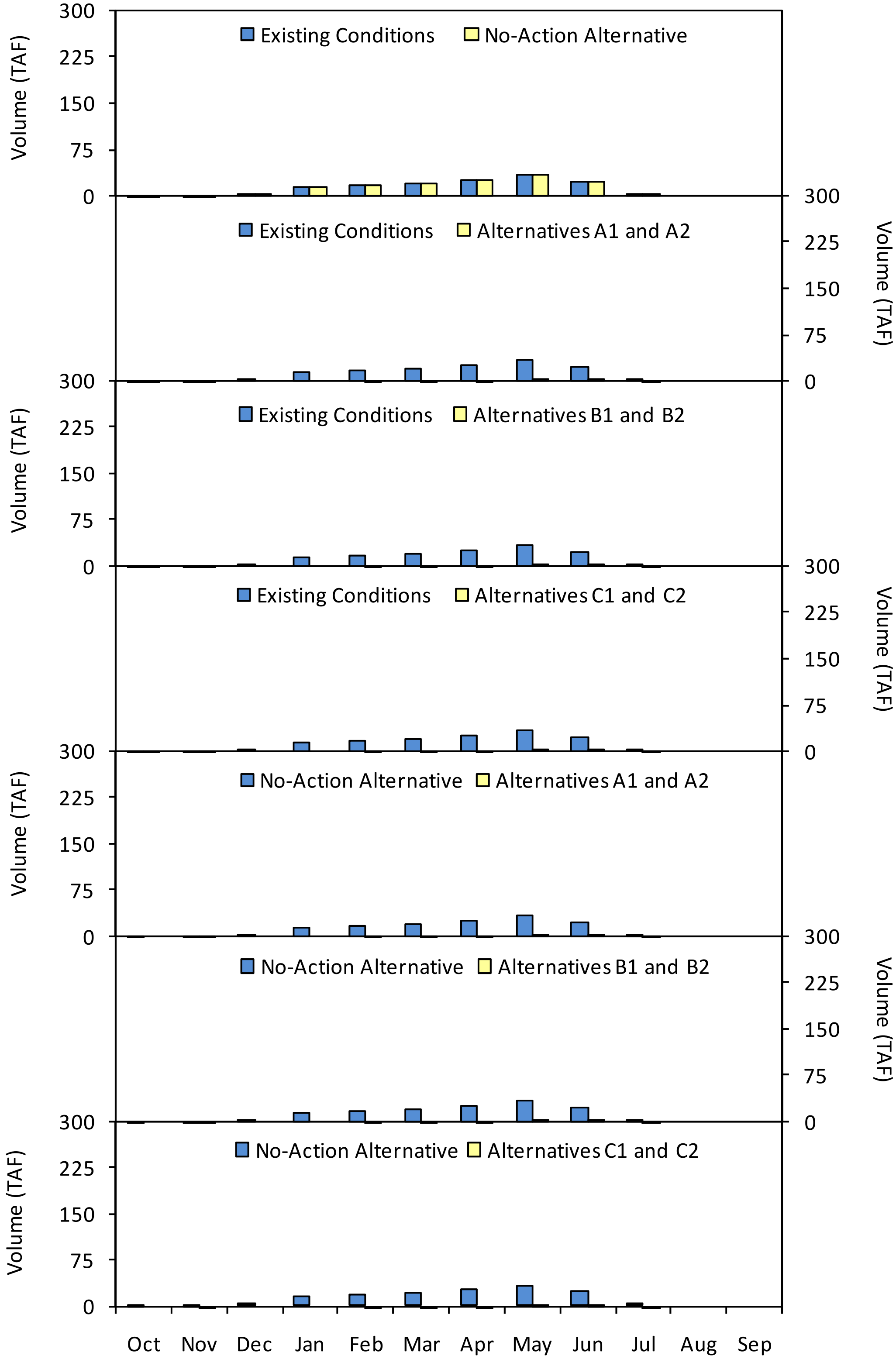

Figure 11.
Average Simulated 215 Delivery Volumes

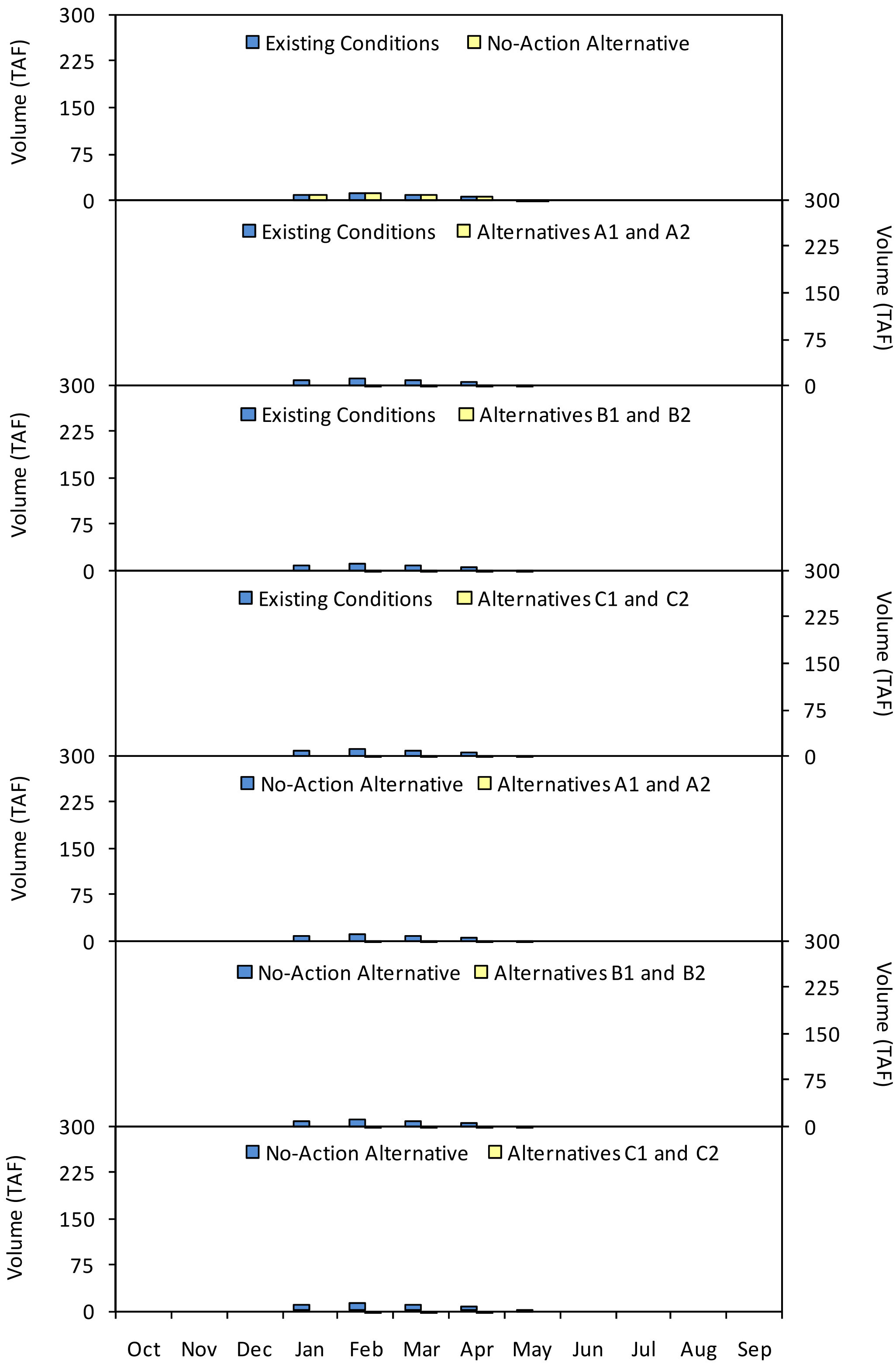

Figure 12.
Average Simulated 215 Delivery Volumes in Dry and Critical Years

Table 13.
Average Simulated Paragraph 16(b) Delivery Flow Rates

Month	Existing Level[1, 2] (2005)				Future Level[1, 2] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)	No-Action Alt (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)
Oct	0	24	24	24	0	24	24	24
Nov	0	40	40	40	0	40	40	40
Dec	0	102	102	102	0	102	102	102
Jan	0	214	214	214	0	214	214	214
Feb	0	352	352	352	0	352	352	352
Mar	0	238	238	238	0	239	239	239
Apr	0	236	236	236	0	238	238	238
May	0	286	286	286	0	286	286	281
Jun	0	253	252	250	0	253	253	251
Jul	0	42	42	42	0	42	42	42
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_16B + D18B_16B).
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 14.
Average Simulated 16(b) Delivery Flow Rates in Dry and Critical Years[1]

Month	Existing Level[2, 3] (2005)				Future Level[2, 3] (2030)			
	Existing Conditions (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)	No-Action Alt (cfs)	Alt A1 and A2 (cfs)	Alt B1 and B2 (cfs)	Alt C1 and C2 (cfs)
Oct	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	0	143	143	143	0	143	143	143
Feb	0	329	329	329	0	329	329	329
Mar	0	11	11	11	0	11	11	11
Apr	0	50	50	50	0	50	50	50
May	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0

Source: Summarized from CalSim II 2005 and 2030 simulations (Node D18A_16B + D18B_16B).
Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
cfs = cubic feet per second

Table 15.
Average Simulated 16(b) Delivery Volumes

Month	Existing Level[1, 2] (2005)				Future Level[1, 2] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)	No-Action Alt (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)
Oct	0	1	1	1	0	1	1	1
Nov	0	2	2	2	0	2	2	2
Dec	0	6	6	6	0	6	6	6
Jan	0	13	13	13	0	13	13	13
Feb	0	20	20	20	0	20	20	20
Mar	0	15	15	15	0	15	15	15
Apr	0	14	14	14	0	14	14	14
May	0	18	18	18	0	18	18	17
Jun	0	15	15	15	0	15	15	15
Jul	0	3	3	3	0	3	3	3
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0
Total	0	107	107	107	0	107	107	107

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_16B + D18B_16B)
Notes:
1 Simulation period: October 1921 – September 2003.
2 Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
TAF = thousand acre-feet

Table 16.
Average Simulated 16(b) Delivery Volumes in Dry and Critical Years[1]

Month	Existing Level[2, 3] (2005)				Future Level[2, 3] (2030)			
	Existing Conditions (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)	No-Action Alt (TAF)	Alt A1 and A2 (TAF)	Alt B1 and B2 (TAF)	Alt C1 and C2 (TAF)
Oct	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	0	9	9	9	0	9	9	9
Feb	0	18	18	18	0	18	18	18
Mar	0	1	1	1	0	1	1	1
Apr	0	3	3	3	0	3	3	3
May	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0
Total	0	31	31	31	0	31	31	31

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node D18A_16B + D18B_16B)
Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] Percent changes are not shown as these deliveries are typically near zero during all or part of the year in the existing conditions Alternatives simulations.
Key:
Alt = Alternative
TAF = thousand acre-feet

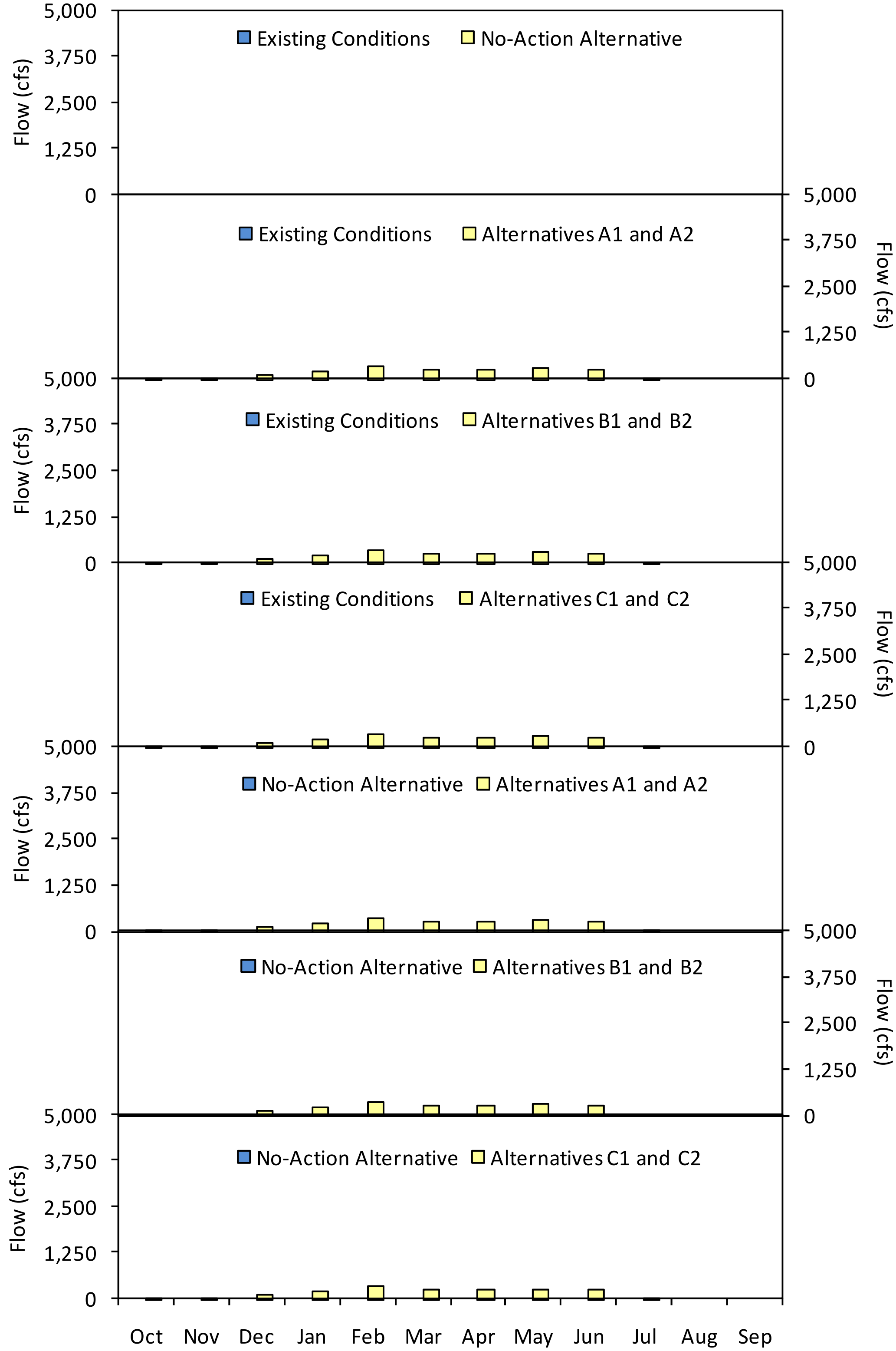

Figure 13.
Average Simulated 16(b) Delivery Flow Rates

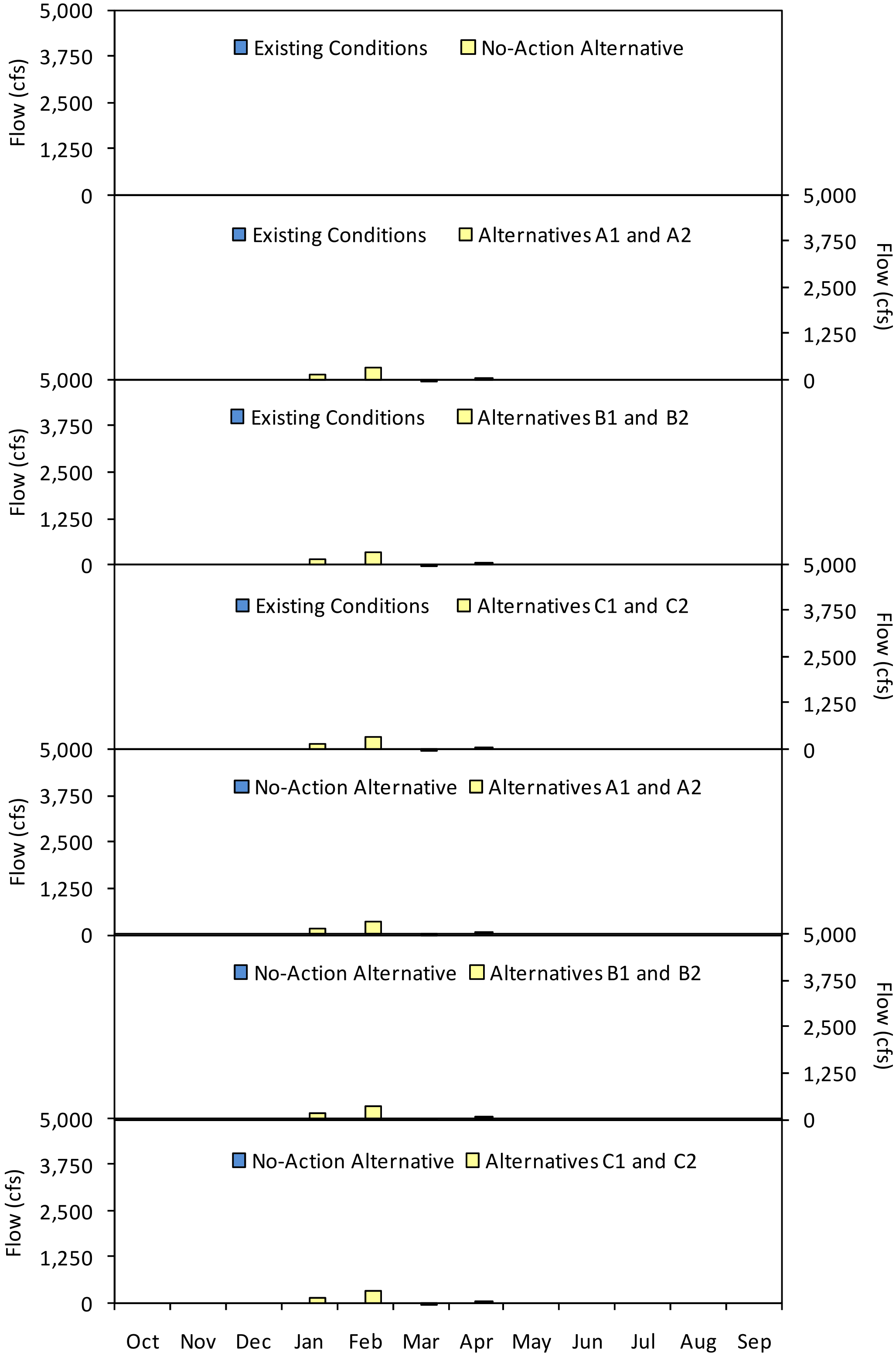

Figure 14.
Average Simulated 16(b) Delivery Flow Rates in Dry and Critical Years

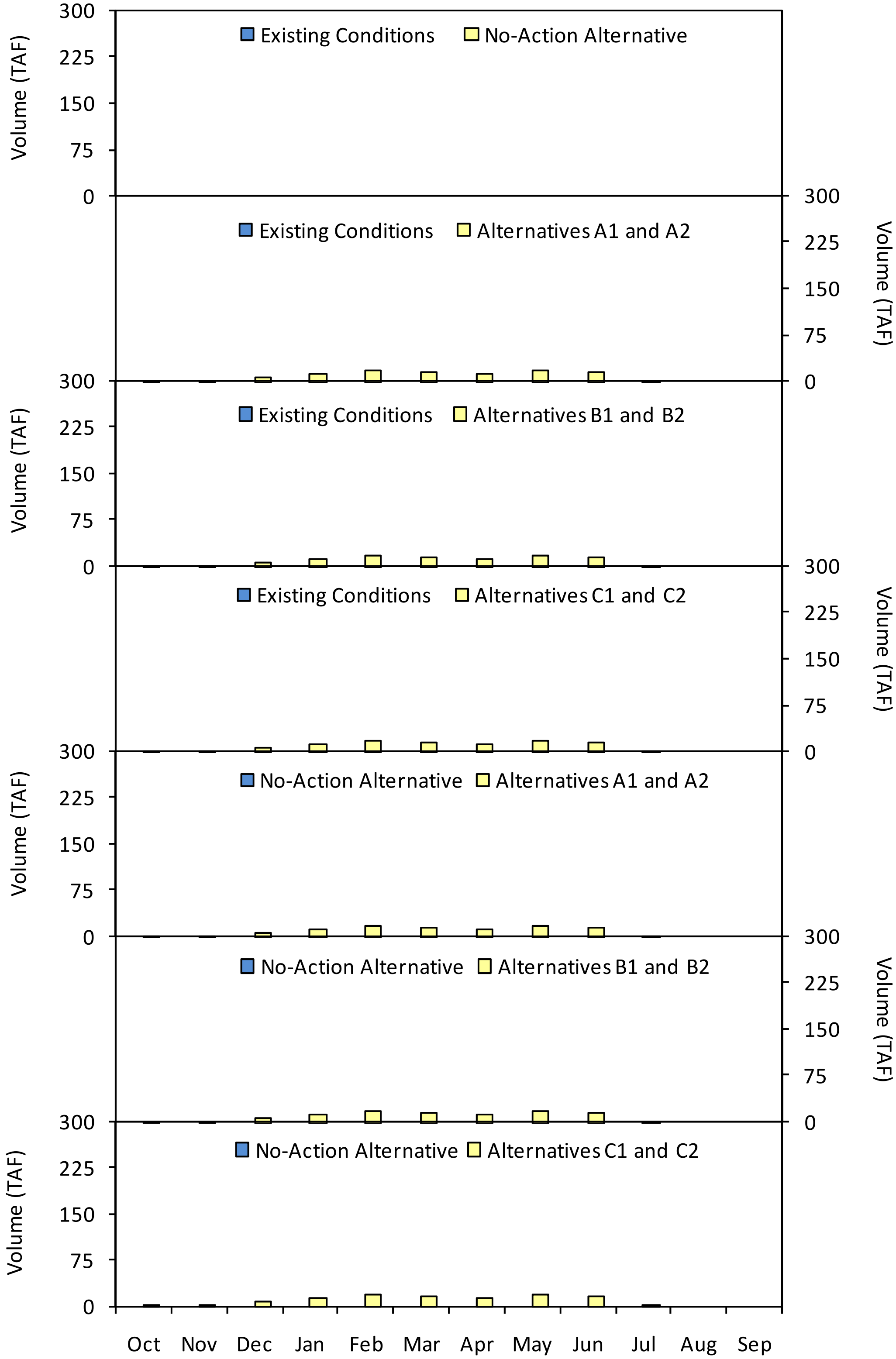

Figure 15.
Average Simulated 16(b) Delivery Volumes

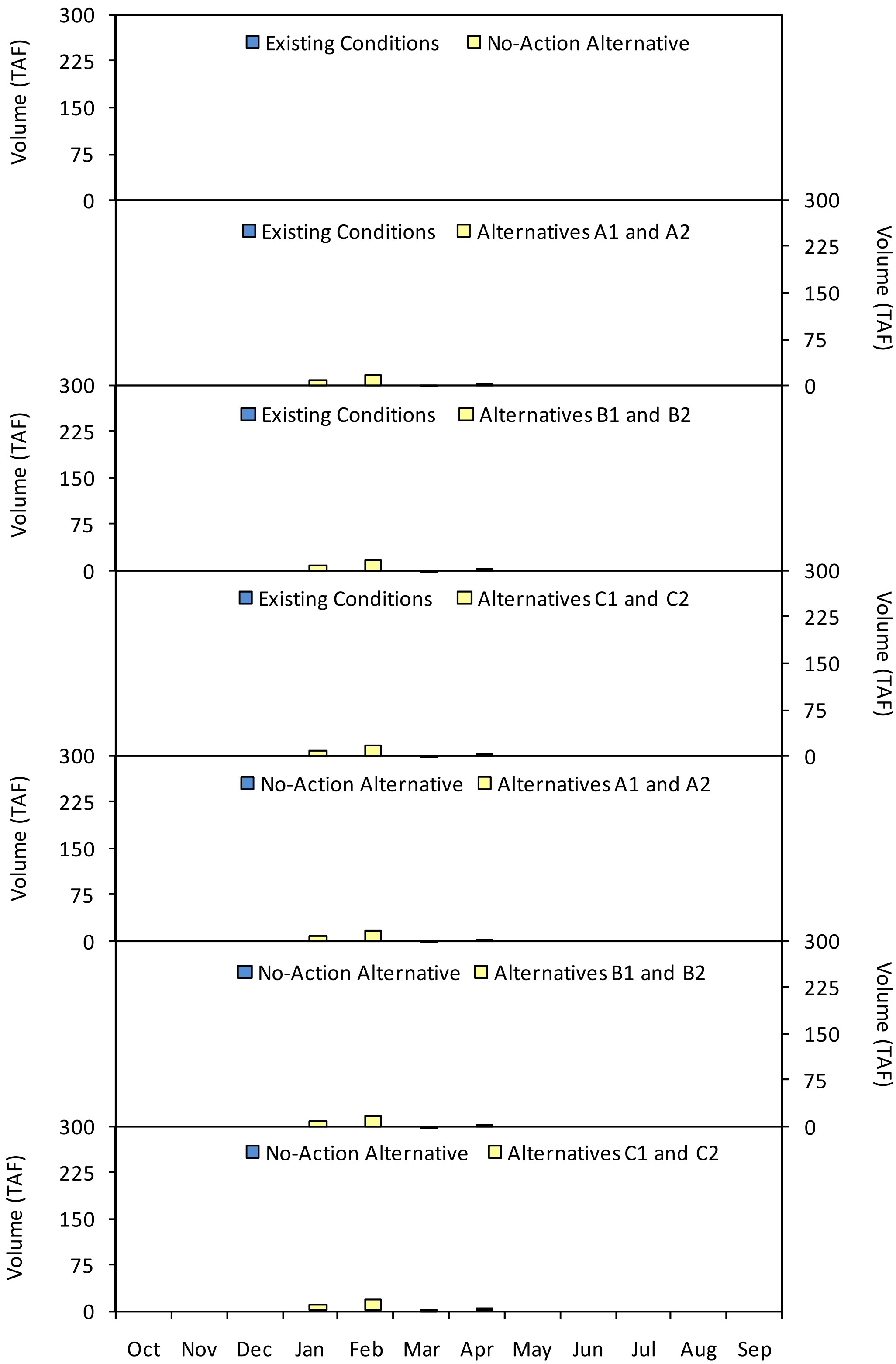

Figure 16.
Average Simulated 16(b) Delivery Volumes in Dry and Critical Years

Table 17.
Average Simulated End-of-Month San Luis Reservoir Storage

Month	Existing Level (2005)[1]				Future Level (2030)[1]			
	Existing Conditions (TAF)	Alt A1 and A2 (TAF)[2]	Alt B1 and B2 (TAF)[2]	Alt C1 and C2 (TAF)[2]	No-Action Alt (TAF)[2]	Alt A1 and A2 (TAF)[3]	Alt B1 and B2 (TAF)[3]	Alt C1 and C2 (TAF)[2]
Oct	885	876 (-1%)	873 (-1%)	875 (-1%)	943 (7%)	935 (-1%)	936 (-1%)	936 (-1%)
Nov	1,104	1,103 (0%)	1,099 (-1%)	1,101 (0%)	1,161 (5%)	1,157 (0%)	1,159 (0%)	1,158 (0%)
Dec	1,419	1,419 (0%)	1,415 (0%)	1,418 (0%)	1,474 (4%)	1,473 (0%)	1,474 (0%)	1,474 (0%)
Jan	1,732	1,728 (0%)	1,726 (0%)	1,727 (0%)	1,798 (4%)	1,795 (0%)	1,793 (0%)	1,794 (0%)
Feb	1,876	1,871 (0%)	1,869 (0%)	1,870 (0%)	1,932 (3%)	1,918 (-1%)	1,917 (-1%)	1,917 (-1%)
Mar	1,940	1,947 (0%)	1,947 (0%)	1,946 (0%)	1,979 (2%)	1,973 (0%)	1,972 (0%)	1,973 (0%)
Apr	1,846	1,874 (2%)	1,874 (1%)	1,871 (1%)	1,867 (1%)	1,887 (1%)	1,886 (1%)	1,883 (1%)
May	1,621	1,640 (1%)	1,639 (1%)	1,636 (1%)	1,615 (0%)	1,628 (1%)	1,627 (1%)	1,623 (1%)
Jun	1,257	1,261 (0%)	1,261 (0%)	1,258 (0%)	1,250 (-1%)	1,249 (0%)	1,248 (0%)	1,245 (0%)
Jul	981	979 (0%)	979 (0%)	977 (0%)	973 (-1%)	967 (-1%)	965 (-1%)	962 (-1%)
Aug	750	741 (-1%)	741 (-1%)	741 (-1%)	758 (1%)	751 (-1%)	750 (-1%)	748 (-1%)
Sep	771	761 (-1%)	758 (-2%)	760 (-1%)	811 (5%)	804 (-1%)	802 (-1%)	801 (-1%)

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node S11 + S12)
Notes:
[1] Simulation period: October 1921 – September 2003.
[2] (%) indicates percent change from existing conditions.
[3] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
TAF = thousand acre-feet

Table 18.
Average Simulated End-of-Month San Luis Reservoir Storage in Dry and Critical Years[1]

Month	Existing Level (2005)[2]				Future Level (2030)[2]			
	Existing Conditions (TAF)	Alt A1 and A2[2] (TAF)	Alt B1 and B2[3] (TAF)	Alt C1 and C2[3] (TAF)	No-Action Alt[3] (TAF)	Alt A1 and A2[4] (TAF)	Alt B1 and B2[4] (TAF)	Alt C1 and C2[4] (TAF)
Oct	812	821 (1%)	820 (1%)	818 (1%)	929 (14%)	925 (-1%)	924 (-1%)	922 (-1%)
Nov	992	1,016 (2%)	1,015 (2%)	1,013 (2%)	1,106 (11%)	1,113 (1%)	1,113 (1%)	1,111 (0%)
Dec	1,306	1,333 (2%)	1,332 (2%)	1,332 (2%)	1,419 (9%)	1,424 (0%)	1,425 (0%)	1,425 (0%)
Jan	1,634	1,655 (1%)	1,654 (1%)	1,653 (1%)	1,749 (7%)	1,754 (0%)	1,752 (0%)	1,752 (0%)
Feb	1,753	1,775 (1%)	1,774 (1%)	1,772 (1%)	1,858 (6%)	1,851 (0%)	1,852 (0%)	1,850 (0%)
Mar	1,829	1,855 (1%)	1,854 (1%)	1,853 (1%)	1,915 (5%)	1,911 (0%)	1,911 (0%)	1,910 (0%)
Apr	1,672	1,711 (2%)	1,710 (2%)	1,706 (2%)	1,750 (5%)	1,763 (1%)	1,762 (1%)	1,757 (0%)
May	1,405	1,442 (3%)	1,441 (3%)	1,437 (2%)	1,476 (5%)	1,492 (1%)	1,492 (1%)	1,486 (1%)
Jun	1,042	1,075 (3%)	1,076 (3%)	1,071 (3%)	1,118 (7%)	1,135 (2%)	1,134 (1%)	1,128 (1%)
Jul	850	875 (3%)	876 (3%)	872 (3%)	935 (10%)	945 (1%)	943 (1%)	937 (0%)
Aug	608	628 (3%)	628 (3%)	627 (3%)	734 (21%)	748 (2%)	743 (1%)	740 (1%)
Sep	591	607 (3%)	601 (2%)	606 (3%)	741 (26%)	753 (2%)	748 (1%)	746 (1%)

Source: Summarized from CALSIM II 2005 and 2030 simulations (Node S11 + S12)
Notes:
[1] Year-type as defined by the Restoration Year-Type.
[2] Simulation period: October 1921 – September 2003.
[3] (%) indicates percent change from existing conditions.
[4] (%) indicates percent change from No-Action Alternative.
Key:
Alt = Alternative
TAF = thousand acre-feet

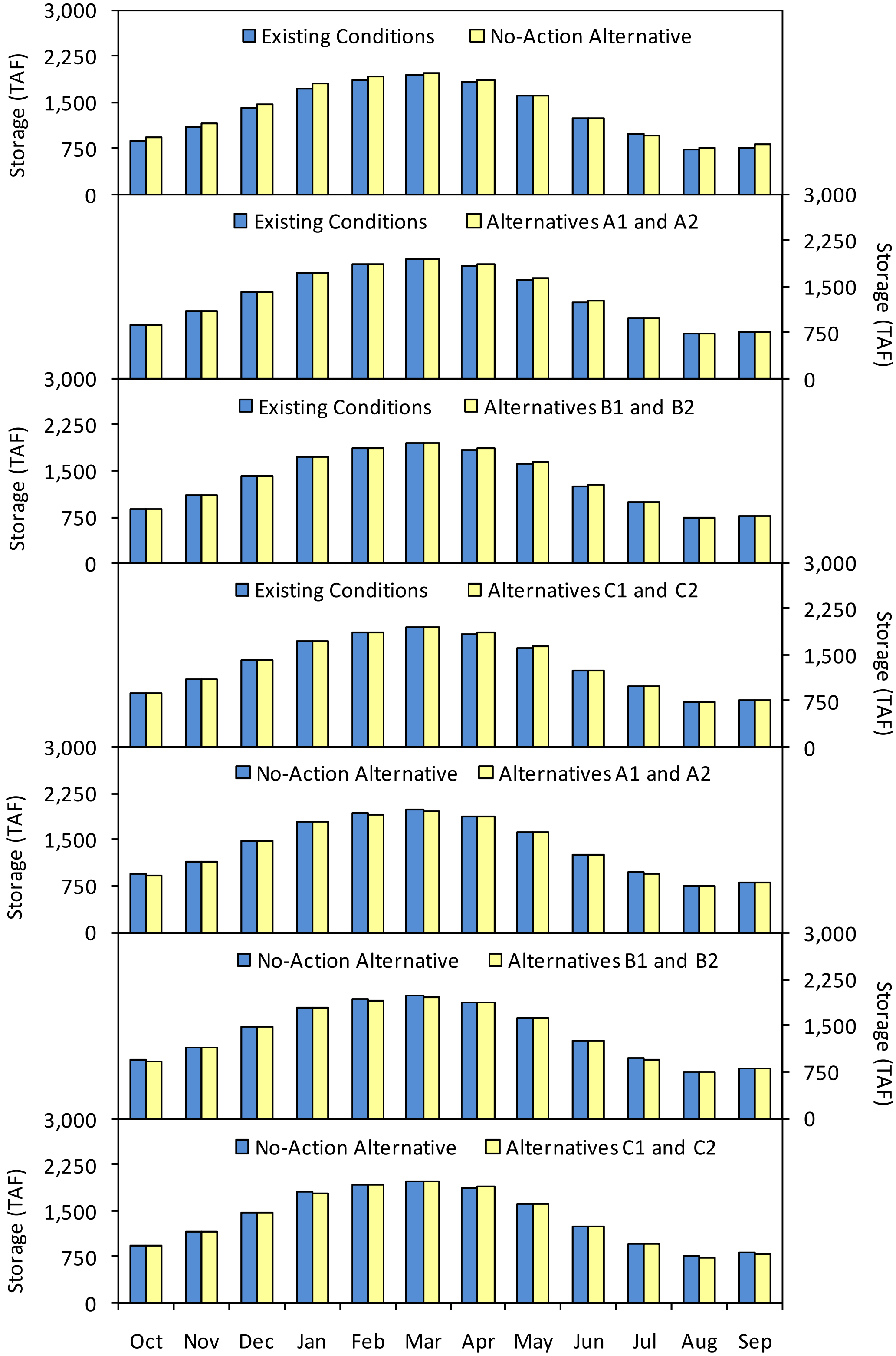

Figure 17.
Average Simulated End-of-Month San Luis Reservoir Storage

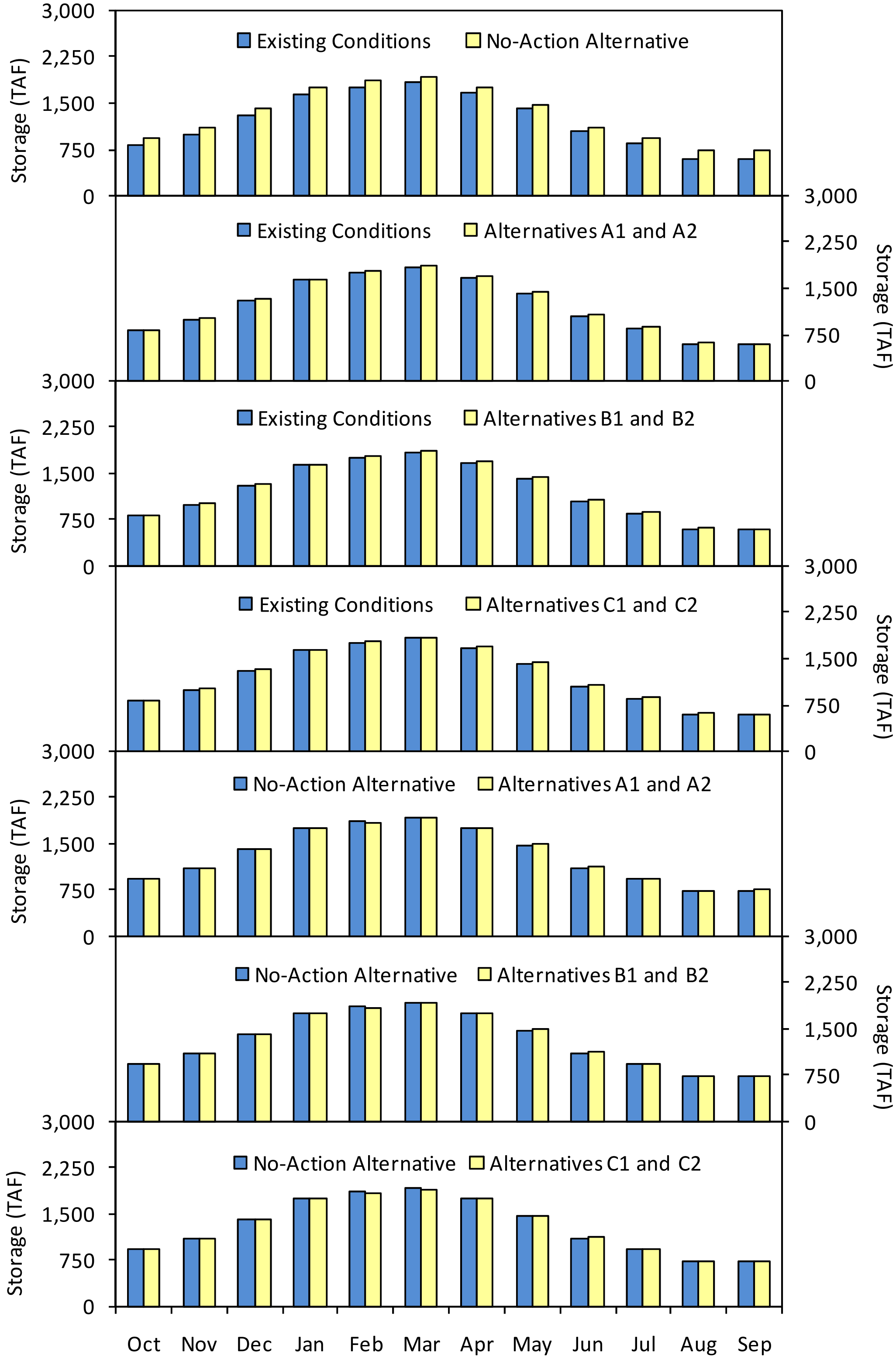

Figure 18.
Average Simulated End-of-Month San Luis Reservoir Storage in Dry and Critical Years

Attachment

Central Valley Project and State Water Project Contracts

Draft
Surface Water Supplies and Facilities Operations Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

Table 1.
Total Friant Division Long-Term Contracts

Contract Type/Contractor	Class 1 (acre-feet)	Class 2 (acre-feet)	Cross-Valley (acre-feet)
Friant Division Agriculture			
Madera Canal Agricultural			
Chowchilla WD	55,000	160,000	
Madera ID	85,000	186,000	
Total Madera Canal Agricultural	**140,000**	**346,000**	
San Joaquin River Agricultural			
Gravelly Ford WD	0	14,000	
Total San Joaquin River Agricultural	**0**	**14,000**	
Friant-Kern Canal Agricultural			
Arvin-Edison WSD	40,000	311,675	
Delano-Earlimart ID	108,800	74,500	
Exeter ID	11,500	19,000	
Fresno ID	0	75,000	
Garfield WD	3,500	0	
International WD	1,200	0	
Ivanhoe ID	7,700	7,900	
Lewis Creek WD	1,450	0	
Lindmore ID	33,000	22,000	
Lindsay-Strathmore ID	27,500	0	
Lower Tule River ID	61,200	238,000	
Orange Cove ID	39,200	0	
Porterville ID	16,000	30,000	
Saucelito ID	21,200	32,800	
Shafter-Wasco ID	50,000	39,600	
Southern San Joaquin MUD	97,000	50,000	
Stone Corral ID	10,000	0	
Tea Pot Dome WD	7,500	0	
Terra Bella ID	29,000	0	
Tulare ID	30,000	141,000	
Total Friant-Kern Canal Agricultural	**595,750**	**1,041,475**	
Total Friant Division Agricultural	**735,750**	**1,401,475**	
Friant Division M&I			
City of Fresno	60,000		
City of Orange Cove	1,400		
City of Lindsay	2,500		
Fresno County Waterworks District No. 18	150		
Madera County	200		
Total Friant Division M&I	**64,250**		
Total Friant Division Contracts	**800,000**	**1,401,475**	
Cross-Valley Canal Exchange			
Fresno County			3,000
Tulare County			5,308
Hills Valley ID			3,346
Kern-Tulare WD			40,000
Lower Tule River ID			31,102
Pixley ID			31,102
Rag Gulch WD			13,300
Tri-Valley WD			1,142
Total Cross-Valley Canal Exchange			**128,300**

Source: FWUA n.d.
Key:
ID = Irrigation District
M&I = municipal and industrial
MUD = Municipal Utility District
No. = number
WD = Water District
WSD Water Storage District

Table 2.
Summary of CVP Contract Amounts for Service Areas South of the Delta

Contractors	Central Valley Project Long-Term Contracts				Water Right, Annual Amount (acre-feet)
	Contract Number	Current Effective Periods	Annual Entitlements (acre-feet)	Types	
Delta-Mendota Canal					
Exchange Contractors	I1r-1144	-	**840,000**		
Central California Irrigation District, Columbia Canal Co., Firebaugh Canal Water District, San Luis Canal Co.				Exchange	
Refuges			**177,297**		
Grassland Water District	01-WC-20-1754	03/01/2001 – 02/28/2026	125,000[1]	Refuge	-
California Department of Fish and Game (total)	01-WC-20-1756	03/01/2001 – 02/28/2026	37,007[1]	Refuge	-
Volta Wildlife Management Area	01-WC-20-1756	03/01/2001 – 02/28/2026	13,000[1]	Refuge	-
Los Banos Wildlife Management Area	01-WC-20-1756	03/01/2001 – 02/28/2026	10,470[1]	Refuge	-
Salt Slough	01-WC-20-1756	03/01/2001 – 02/28/2026	6,680[1]	Refuge	-
China Island	01-WC-20-1756	03/01/2001 – 02/28/2026	6,857[1]	Refuge	-
National Wildlife Refuge in San Joaquin Valley	01-WC-20-1758	03/01/2001 – 02/28/2026	15,290[1]	Refuge	-
Kesterson National Wildlife Refuge	01-WC-20-1758	03/01/2001 – 02/28/2026	10,000[1]	Refuge	-
Freitas	01-WC-20-1758	03/01/2001 – 02/28/2026	5,290[1]	Refuge	-
Irrigation and M&I			**378,872**		
City of Tracy	Being Negotiated	-	10,000	Irrigation and M&I	-
Banta-Carbona Irrigation District	14-06-200-4305A-LTR1	03/01/2005 – 02/28/2030	20,000	Irrigation and M&I	-
West Side Irrigation District	7-07-20-W0045-LTR1	03/01/2005 – 02/28/2030	5,000	Irrigation and M&I	-
Del Puerto Water District	14-06-200-922-LTR1	03/01/2005 – 02/28/2030	140,210[2]	Irrigation and M&I	-
West Stanislaus Water District	14-06-200-1072-LTR1	03/01/2005 – 02/28/2030	50,000	Irrigation and M&I	-
Patterson Water District	14-06-200-3598A-LTR1	03/01/2005 – 02/28/2030	16,500	Irrigation and M&I	6,000
Centinella Water District	7-07-20-W0055-LTR1	03/01/2005 – 02/28/2030	2,500	Irrigation and M&I	-
Broadview Water District	14-06-200-8092-LTR1	03/01/2005 – 02/28/2030	27,000	Irrigation and M&I	-
Byron Bethany Irrigation District	NA	NA	20,600	NA	NA
Eagle Field Water District	14-06-200-7754-LTR1	03/01/2005 – 02/28/2030	4,550	Irrigation and M&I	-
Mercy Springs Water District	14-06-200-3365A-LTR1	03/01/2005 – 02/28/2030	2,842	Irrigation and M&I	-
Oro Loma Water District	14-06-200-7823-LTR1	03/01/2005 – 02/28/2030	4,600	Irrigation and M&I	-
DWR Intertie @ Mendota Pool	NA	NA	NA	Irrigation and M&I	-
Newman Wasteway Recirculation	NA	NA	NA	Irrigation and M&I	-
Panoche Water District	NA	NA	27,000	Irrigation and M&I	-
San Luis Water District	14-06-200-7773A-LTR1	03/01/2005 – 02/28/2030	45,080	Irrigation and M&I	-
Widren Water District	14-06-200-8018-LTR1	03/01/2005 – 02/28/2030	2,990	Irrigation and M&I	-
Total for Delta-Mendota Canal			**1,396,169**		6,000

Table 2.
Summary of CVP Contract Amounts for Service Areas South of the Delta (Contd.)

Contractors	Central Valley Project Long-Term Contracts				Water Right, Annual Amount (acre-feet)
	Contract Number	Current Effective Periods	Annual Entitlements (acre-feet)	Types (acre-feet)	
San Joaquin and Mendota Pool					
Exchange Contractors	I1r-1144		**840,000**	Exchange	-
Central California Irrigation District, Columbia Canal Co., Firebaugh Canal Water District, San Luis Canal Co.				Exchange	
Refuges			**218,098**		
Grassland Water District	01-WC-20-1754	03/01/2001 – 02/28/2026	125,000[1]	Refuge	-
California Department of Fish and Game	01-WC-20-1756	03/01/2001 – 02/28/2026	51,601[1]	Refuge	-
Los Banos Wildlife Management Area	01-WC-20-1756	03/01/2001 – 02/28/2026	10,470[1]	Refuge	-
Salt Slough	01-WC-20-1756	03/01/2001 – 02/28/2026	6,680[1]	Refuge	-
China Island	01-WC-20-1756	03/01/2001 – 02/28/2026	6,857[1]	Refuge	-
Mendota Wildlife Management Area	01-WC-20-1756	03/01/2001 – 02/28/2026	27,594[1]	Refuge	-
National Wildlife Refuge in San Joaquin Valley	01-WC-20-1758	03/01/2001 – 02/28/2026	41,497[1]	Refuge	-
San Luis National Wildlife Refuge	01-WC-20-1758	03/01/2001 – 02/28/2026	19,000[1]	Refuge	-
Kesterson National Wildlife Refuge	01-WC-20-1758	03/01/2001 – 02/28/2026	10,000[1]	Refuge	-
West Bear Creek	01-WC-20-1758	03/01/2001 – 02/28/2026	7,207[1]	Refuge	-
Freitas	01-WC-20-1758	03/01/2001 – 02/28/2026	5,290[1]	Refuge	-
Irrigation and M&I			**106,348**		
Fresno Slough Water District	14-06-200-4019A-LTR1	03/01/2005 – 02/28/2030	4,000	Irrigation and M&I	866
James Irrigation District	14-06-200-700-A-LTR1	03/01/2005 – 02/28/2030	35,300	Irrigation and M&I	9,700
Tranquility Irrigation District	14-06-200-701-A-LTR1	03/01/2005 – 02/28/2030	13,800	Irrigation and M&I	20,200
Hughes	14-06-200-3537A-LTR1	03/01/2005 – 02/28/2030	70[3]	Irrigation and M&I	93
Reclamation District 1606	14-06-200-3802A-LTR1	03/01/2005 – 02/28/2030	228	Irrigation and M&I	342
Dudley and Indart[4]	NA	NA	NA	Irrigation and M&I	2,280
Meyers, Marvin, Patricia [4]	NA	NA	NA	Irrigation and M&I	210
Laguna Water District	2-07-20-W0266-LTR1	03/01/2005 – 02/28/2030	800	Irrigation and M&I	-
Tranquility Public Utilities	NA	NA	70	Irrigation and M&I	-
Mid-Valley Water District (no contract)	NA	NA	NA	Irrigation and M&I	-
Terra Linda Farms (Coelho Family Trust)	NA	NA	2,080	Irrigation and M&I	-
Westlands Water District	NA	NA	50,000	Irrigation	-
Wilson, JW (no contract)	NA	NA	NA	Irrigation and M&I	-
Total San Joaquin and Mendota Pool			**1,164,446**		33,691

Table 2.
Summary of CVP Contract Amounts for Service Areas South of the Delta (Contd.)

Contractors	Central Valley Project Long-Term Contracts				Water Right, Annual Amount (acre-feet)
	Contract Number	Current Effective Periods	Annual Entitlements (acre-feet)	Types	
San Luis Canal / Cross Valley Canal					
Refuges			**64,601**		
California Department of Fish and Game	01-WC-20-1756	03/01/2001 – 02/28/2026	64,601[1]	Refuge	-
O'Neill Forebay Wildlife Refuge	NA	NA	NA	Refuge	-
Irrigation and M&I			**1,703,030**		
Broadview Water District	14-06-200-8092-LTR1	03/01/2005 – 02/28/2030	27,000	Irrigation and M&I	-
San Luis Water District	14-06-200-7773A-LTR1	03/01/2005 – 02/28/2030	80,000	Irrigation and M&I	-
Veterans Administration Cemetery	3-07-20-W1124-LTR1	03/01/2005 – 02/28/2045	850	Irrigation	-
Panoche Water District	14-06-200-7864A-LTR1	03/01/2005 – 02/28/2030	94,000	Irrigation and M&I	-
Pacheco Water District	6-07-20-W0469-LTR1	03/01/2005 – 02/28/2030	10,080	Irrigation and M&I	6,000
City of Avenal	14-06-200-4619-LTR1	03/01/2005 – 02/28/2045	3,500	M&I	-
City of Coalinga	14-06-200-4173A-LTR1	03/01/2005 – 02/28/2045	10,000	M&I	-
City of Huron	14-06-200-7081A-LTR1	03/01/2005 – 02/28/2045	3,000	M&I	-
Westlands Water District	14-06-200-495A-LTR1	03/01/2005 – 02/28/2030	1,150,000	Irrigation and M&I	-
County of Fresno	14-06-200-8292A-LTR1	03/01/2005 – 02/28/2030	3,000	Irrigation and M&I	-
Hills Valley Irrigation District	14-06-200-8466A-LTR1	03/01/2005 – 02/28/2030	3,346	Irrigation and M&I	-
Kern-Tulare Irrigation District	14-06-200-8601A-LTR1	03/01/2005 – 02/28/2030	40,000	Irrigation and M&I	-
Lower Tule River Irrigation District	14-06-200-8237A-LTR1	03/01/2005 – 02/28/2030	31,102	Irrigation and M&I	-
Pixley Irrigation District	14-06-200-8238A-LTR1	03/01/2005 – 02/28/2030	31,102	Irrigation and M&I	-
Rag Gulch Water District	14-06-200-8367A-LTR1	03/01/2005 – 02/28/2030	13,300	Irrigation and M&I	-
Tri-Valley Water District	14-06-200-8565A-LTR1	03/01/2005 – 02/28/2030	1,142	Irrigation and M&I	-
County of Tulare	14-06-200-8293A-LTR1	03/01/2005 – 02/28/2030	5,308	Irrigation and M&I	-
San Benito Country Water District	8-07-20-W0130-LTR1 (interim)	03/01/2001 – 02/28/2002	35,550[4]	Irrigation	-
			8,250[4]	M&I	-
Santa Clara Valley Water District	7-07-20-W0023-LTR1 (interim)	03/01/2001 – 02/28/2002	33,100[4]	Irrigation	-
			119,400[4]	M&I	-
Total for San Luis and Cross-Valley Canals			**1,767,631**		6,000
Totals for CVP South of Delta			**3,488,246**		45,691

Source: Reclamation 2005

Notes:
1 Level 2 contract amount.
2 Del Puerto contract includes Davis, Hospital, Kern Canon, Salado, Sunflower, Mustang, Orestimba, Foothill, Quinto, and Romero water districts.
3 CVPIA long-term contract information is not available. Present in historical delivery record.
4 Interim contract is based on the latest information available from the CVPIA.

Key:
- = 0
Co. = company
CVPIA = Central Valley Project Improvement Act
DWR = California Department of Water Resources
M&I = municipal & industrial
NA = not available

Table 3.
Maximum Annual SWP Table A Amounts

Contractors	Maximum Table A (acre-feet)	Maximum Table A Percent of Total
Feather River		
Butte County	27,500	0.66
Plumas County FC&WCD	2,700	0.06
Yuba City	9,600	0.23
Total for Feather River	**39,800**	**0.95**
North Bay		
Napa County FC&WCD	29,025	0.70
Solano County WA	47,756	1.14
Total for North Bay	**76,781**	**1.84**
South Bay		
Alameda County FC&WCD, Zone 7	80,619	1.93
Alameda County WD	42,000	1.01
Santa Clara Valley WD	100,000	2.40
Total for South Bay Aqueduct	**222,619**	**5.34**
San Joaquin Valley		
Oak Flat WD	5,700	0.14
Kings County	9,305	0.22
Dudley Ridge WD	57,343	1.37
Empire West Side ID	3,000	0.07
Kern County WA	998,730	23.93
Tulare Lake Basin WSD	95,922	2.30
Total for San Joaquin Valley	**1,170,000**	**28.04**
Central Coast		
San Luis Obispo County FC&WCD	25,000	0.60
Santa Barbara County FC&WCD	45,486	1.09
Total for Central Coast	**70,486**	**1.69**
Southern California		
Antelope Valley-East Kern WA	141,400	3.39
Castaic Lake WA	95,200	2.28
Coachella Valley WD	121,100	2.90
Crestline-Lake Arrowhead WA	5,800	0.14
Desert WA	50,000	1.20
Littlerock Creek ID	2,300	0.06
Mojave WA	75,800	1.82
MWDSC	1,911,500	45.81
Palmdale WD	21,300	0.51
San Bernardino Valley MWD	102,600	2.46
San Gabriel Valley MWD	28,800	0.69
San Gorgonio Pass WA	17,300	0.41
Ventura County FCD	20,000	0.48
Total for Southern California	**2,593,100**	**62.14**
Table A Total	**4,172,786**	**100.00**

Source: DWR 2006
Key:
FC&WCD = Flood Control and Water Conservation District
FCD = Flood Control District
ID = Irrigation District
MWD = Municipal Water District
MWDSC = Metropolitan Water District of Southern California
SWP = State Water Project
WA = Water Agency
WD = Water District
WSD = Water Storage District

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Attachment

Diversions

Draft
Surface Water Supplies and Facilities Operations Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

Table 1.
San Joaquin River Diversions Within the Restoration Area

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
267.6	**Reach 1A**							
267.1	Right	NA	Pump	Pipe	None	All year	AG	1
266.8	Left	NA	Pump	Pipe	Trash-rack	All year	AG	2
265.9	Left	NA	Submersible pump	Underground	None	All year	Recreation	4
265.4	Left	NA	Pump	Pipe	None	All year	Recreation	1
265.3	Right	NA	Vertical pump	Underground	Trash-rack	All year	AG	6
265.3	Right	NA	Vertical pump	Underground	None	All year	AG	4
265.3	Right	NA	Vertical pump	Underground	None	All year	AG	4
265.3	Right	NA	Vertical pump	Underground	None	All year	AG	4
264.9	Left	NA	Pump	Underground	None	All year	Recreation	1
263.6	Right	NA	Vertical pump	NA	None	All year	AG	NA
263.6	Right	NA	Vertical pump	Pipe	NA	All year	AG	4
263.6	Right	NA	Vertical pump	Pipe	Trash-rack	All year	AG	4
263.6	Right	NA	Vertical pump	Pipe	None	All year	AG	NA
263.6	Right	NA	Vertical pump	Pipe	None	All year	AG	NA
263.1	Left	NA	Centrifugal pump	Pipe	Trash-rack	Not in use	AG	NA
263.1	Left	NA	Vertical pump	Underground	None	All year	AG	4
262.8	Right	NA	Centrifugal pump	Pipe	None	All year	AG	1
262.5	Left	NA	Vertical pump	Underground	None	All year	AG	1
262.5	Left	NA	Centrifugal pump	Underground	None	All year	AG	3
262.4	Left	NA	Centrifugal pump	Underground	None	All year	AG	3
262.2	Right	NA	Vertical pump	Pipe	Trash-rack	All year	AG	35
262.2	Right	NA	Centrifugal pump	Underground	None	Not in use	AG	2
262.4	Left	NA	Pump	Na	None	All year	AG	NA

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
261.7	Left	NA	Pump	Underground	None	Not in use	NA	2
261.7	Left	NA	Centrifugal pump	Underground	Trash-rack	All year	NA	NA
261.7	Left	NA	Pump	Underground	None	Not in use	NA	NA
261.6	Left	NA	Centrifugal pump	Vertical concrete pipe	None	All year	Not in use	2
260.5	Na	Big Willow Unit	Weir	NA	NA	NA	NA	<5
260.5	Left	NA	Pump	NA	None	All year	AG	<1
261.2	Right	NA	Centrifugal pump	Underground	Trash-rack	All year	AG	4
261.1	Right	NA	Vertical pump	Under-ground	None	All year	AG	16
260.7	Left	RMC Lonestar Gravel Company	Vertical pump	NA	None	All year	Industrial	2
260.7	Left	RMC Lonestar Gravel Company	Vertical pump	NA	None	All year	Industrial	2
260.3	Right	NA	Vertical pump	Pipe	Trash-rack	All year	AG	1
260.3	Right	NA	Vertical pump	Pipe	Trash-rack	All year	AG	1
260.1	Na	Rank Island	Weir	NA	NA	NA	NA	5
260.1	Left	NA	Centrifugal pump	Pipe	Trash-rack	All year	AG	<1
259.9	Right	NA	Pump	NA	None	All year	NA	3
259.8	Left	NA	Centrifugal pump	Vertical concrete pipe	None	All year	AG	2
259.7	Left	NA	Vertical pump	Tank	None	All year	AG	3
259.5	Left	NA	Centrifugal pump	Underground	Trash-rack	All year	AG	1
259.6	Left	NA	Centrifugal pump	Vertical concrete pipe	Trash-rack	All year	AG	3
259.5	Right	NA	Vertical pump	NA	None	All year	Recreation	NA
259.5	Right	NA	Pump	NA	None	All year	AG	1
259.5	Left	NA	Centrifugal pump	Filter tank	Trash-rack	All year	AG	3

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
259.5	Left	NA	Centrifugal pump	Pipe	None	All year	Not in use	1
259	Right	NA	Centrifugal pump	Underground	None	All year	Recreation	<1
259	Left	NA	Centrifugal pump	Filter tank	Trash-rack	All year	AG	1
258.9	Right	NA	Centrifugal pump	Underground	None	All year	Recreation	4
258.7	Left	NA	Vertical pump	NA	None	Abandoned	Not in use	NA
258.7	Left	NA	Centrifugal pump	Underground	Trash-rack	All year	AG	4
257.8	Left	NA	Vertical pump	NA	None	All year	Industrial	NA
257.8	Left	NA	Pump	Water truck	None	All year	Industrial	NA
257.8	Left	NA	Vertical pump	NA	None	All year	Industrial	NA
257.6	Right	NA	Vertical pump	Pipe	Trash-rack	All year	AG	25
256.8	Left	NA	Centrifugal pump	Vertical concrete pipe	None	All year	AG	2
256.4	Right	D. Cobb	Centrifugal pump	NA	Trash-rack	Mar 1-Sept 30	AG	1
256.4	Right	D. Cobb	Centrifugal pump	NA	Trash-rack	Mar 1-Sept 30	AG	3
256.4	Left	NA	Vertical pump	Water truck	Trash-rack	All year	Domestic	<1
255.9	Left	NA	Vertical pump	Vertical concrete pipe	Trash-rack	All year	AG	NA
255	Right	NA	Pump	NA	None	All year	AG	1
255	Right	NA	Pump	Vertical concrete pipe	None	All year	AG	1
254.5	Left	NA	Vertical pump	NA	None	All year	AG	5
254	Left	NA	Vertical pump	Vertical concrete pipe	None	All year	AG	7
253	Right	NA	Pump	Water truck	Trash-rack	All year	Industrial	2
252.9	Both	NA	Culvert	San Joaquin River	None	All year	Road crossing	NA

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
252.9	Both	NA	Culvert	San Joaquin River	None	All year	Road crossing	NA
252.9	Both	NA	Culvert	San Joaquin River	None	All year	Road crossing	NA
252.6	Right	NA	Pump	Water truck	None	All year	Industrial	1
252.8	Right	NA	Pump	Pipe	None	All year	AG	6
252	Right	NA	Pump	NA	Trash-rack	All year	AG	2
251.8	Right	NA	Pump	NA	None	All year	AG	1
251.6	Left	NA	Pump	NA	None	All year	Domestic	NA
250	Right	NA	Centrifugal pump	Underground	Trash-rack	All year	AG	1
249.5	Left	NA	Pump	NA	None	Abandoned	Not in use	
248.1	Right	NA	Vertical pump	Underground	Trash-rack	All year	AG	35
247.4	Both	NA	Dam	San Joaquin River	None	All year	NA	<5
247.4	Right	NA	Vertical pump	Underground	Trash-rack	All year	AG	63
246.4	Right	NA	Pump	Underground	Trash-rack	All year	Not in use	NA
246.2	Left	NA	Culvert	Backwater	None	All year	NA	NA
246.2	Left	NA	Culvert	Backwater	None	All year	NA	NA
246.2	Left	NA	Culvert	Backwater	None	All year	NA	NA
245.7	Right	NA	Pump	Underground	None	Not in use	AG	NA
245.4	Right	NA	Vertical pump	Vertical concrete pipe	Trash-rack	All year	AG	35

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
243.1	**Reach 1B**							
242.5	Left	NA	Centrifugal pump	Vertical concrete pipe	None	All year	Not in use	NA
242.1	Left	NA	Centrifugal pump	NA	None	Abandoned	Not in use	NA
242	Right	NA	Culvert	Backwater	None	All year	NA	NA
241.5	Left	NA	Centrifugal pump	Vertical concrete pipe	None	All year	Not in use	1
240.7	Right	NA	Culvert	San joaquin river	None	All year	Road crossing	
240.5	Left	NA	Centrifugal pump	Pipe	None	All year	AG	4
239.6	Left	NA	Pump	Under-ground	None	Abandoned	Not in use	NA
230.9	Left	NA	Pipe	NA	None	All year	NA	1
230.1	Right	NA	Centrifugal pump	PIPE	Trash-rack	All year	AG	1
230.1	Right	NA	Pump	PIPE	None	All year	AG	3
230.1	Right	NA	Pipe	PIPE	None	All year	AG	3
229.9	Right	NA	Pump	Vertical pipe	None	All year	Not in use	3
229.5	Right	NA	Centrifugal pump	Pipe	Trash-rack	All year	AG	<1
229.3	Left	NA	Vertical pump	Pipe	Trash-rack	All year	AG	2
229.3	Left	NA	Vertical pump	Pipe	Trash-rack	All year	AG	2
229	**Reach 2A**							
228.9	Right	NA	Centrifugal pump	Vertical concrete pipe	None	All year	AG	4
228.8	Right	NA	Vertical pump	Earth ditch	Trash-rack	All year	AG	16
228.8	Right	NA	Vertical pump	Earth ditch	Trash-rack	All year	AG	16
227.8	Right	K. Emmert	Vertical pump	Vertical concrete box	Trash-rack	Feb 15-Nov 15	AG	3
223.4	Left	NA	Pump	Pipe	None	All year	Not in use	NA

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
223.1	Right	NA	Vertical pump	Vertical concrete pipe	Trash-rack	All year	AG	4
222.3	Right	NA	Floodgate	Earth ditch	None	All year	AG	NA
220.1	Left	NA	Floodgate	Earth ditch	None	All year	AG	NA
216	Right	Chowchilla Canal	Radial gates	Chowchilla canal	None	All year	AG	NA
216	Both	Bifuracation structure	Radial gates	Chowchilla canal	Trash-rack	All year	AG	NA
216	**Reach 2B**							
215.9	Right	Lone Willow Slough	Floodgate	Lone Willow Slough	None	All year	AG	NA
215.9	Right	Lone Willow Slough	Floodgate	Lone Willow Slough	None	All year	AG	NA
215.9	Right	Lone Willow Slough	Floodgate	Lone Willow Slough	None	All year	AG	NA
215.9	Right	Lone Willow Slough	Floodgate	Lone Willow Slough	None	All year	AG	NA
215.9	Right	Columbia Canal Company	Vertical pump	Vertical concrete pipe	None	All year	AG	NA
211.8	Both	NA	Culvert	San Joaquin River	None	All year	Road crossing	NA
211	Left	NA	Pipe	Earth canal	None	All year	AG	10
211	Left	NA	Pipe	Earth canal	None	All year	AG	10
210.8	Left	NA	Pipe	NA	None	All year	AG	3
210.6	Left	NA	Pipe	NA	None	All year	AG	3
209.7	Left	Logolusso Farms	Pipe	Earth ditch	None	All year	AG	11
209.7	Left	NA	Pipe	Earth ditch	None	All year	AG	7
209.7	Left	NA	Pipe	NA	None	All year	AG	7

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
209.7	Left	Logolusso Farms	Pipe	Earth ditch	None	All year	AG	3
209.7	Left	Logolusso Farms	Pipe	Earth ditch	None	All year	AG	3
208.9	Right	NA	Vertical pump	Pipe	Trash-rack	All year	AG	16
208.9	Right	NA	Vertical pump	NA	Trash-rack	All year	Not in use	NA
207.8	Right	NA	Vertical pump	Earth canal	NONE	All year	AG	4
207.2	Right	Columbia Pumping Plant USBR	Vertical pump	Concrete ditch	Trash-rack	Feb 2-Dec 1	AG	200
206.5	Left	Columbia Relift USBR	Vertical pump	Earth ditch	Trash-rack	All year	AG	4
206.5	Left	Columbia Relift USBR	Vertical pump	Earth ditch	Trash-rack	All year	AG	4
206	Right	NA	Vertical pump	Pipe	None	All year	AG	3
205.8	Right	NA	Pump	Na	None	All year	Flood control	NA
204.8	Right	Helm Canal	Weir	Helms canal	Trash-rack	All year	AG	NA
204.7	Left	Central CA Irrigation District	Floodgates	Helm's ditch	None	Jan 1-Nov 30	Multiple	10
204.9	Left	Fresno Slough Diversions	NA	NA	NA	NA	NA	300
204.9	Left	Firebaugh Canal Water District	NA	NA	NA	NA	NA	300
204.9	Left	Outside Canal	NA	NA	NA	NA	NA	300
204.85	Left	Main Canal	NA	NA	NA	NA	NA	1500

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
204.6	**Reach 3**							
202.1	Left	NA	Pump	NA	None	All year	AG	<1
202	Right	NA	Pump	NA	None	All year	Domestic	<1
195.4	Right	NA	Vertical pump	Underground	None	All year	Municipal	2
194.7	Left	NA	Pump	NA	None	Not in use	AG	NA
193.6	Right	NA	Vertical pump	Vertical concrete pipe	None	All year	AG	NA
192.9	Left	NA	Vertical pump	NA	None	All year	AG	NA
182	Left	Arroyo Canal	Floodgates	Arroyo Canal	None	All year	AG	600
182	**Reach 4A**							
180.8	Left	NA	Vertical pump	Poso canal	None	All year	AG	8
173.8	Right	Menefee River Ranch Company	Pump	Water tank	None	Jan 1-Oct 31	AG	1
170.8	Right	NA	Vertical pump	Under-ground	Trash-rack	All year	AG	3
170	Left	San Luis Ranching Company	Vertical pump	Earth ditch	None	Not in use	AG	NA
168.6	**Reach 4B1**							
168.4	Both	Sand Slough control structure	Dam	Mariposa Bypass	None	All year	AG	NA
168.4	Both	Lone Tree Mutual Water Company	Floodgate	Eastside Bypass	None	All year	AG	NA
168.4	Both	Lone Tree Mutual Water Company	Floodgate	Eastside Bypass	None	All year	AG	NA

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
168.4	Both	Lone Tree Mutual Water Company	Floodgate	Eastside Bypass	None	All year	AG	NA
168.4	Both	Lone Tree Mutual Water Company	Floodgate	Eastside Bypass	None	All year	AG	NA
168.4	Left	NA	Floodgate	Earth ditch	None	All year	AG	NA
165.8	Right	NA	Vertical pump	Earth ditch	None	All year	AG	NA
164.2	Right	NA	NA	NA	None	Abandoned	AG	NA
163	Both	NA	Culvert	San Joaquin River	None	All year	Road crossing	NA
159.7	Right	NA	Vertical pump	NA	None	All year	AG	3
159.5	Right	NA	Vertical pump	NA	Trash-rack	All year	AG	4
158.5	Right	NA	Vertical pump	Concrete distribution box	None	All year	AG	NA
158.5	Right	NA	Vertical pump	Underground	None	All year	AG	NA
158	Right	NA	Vertical pump	Vertical concrete pipe	None	All year	AG	NA
156.6	Right	NA	Pump	NA	None	All year	Domestic	1
156.5	Right	NA	Flash-board riser	NA	None	All year	AG	9
156.4	Right	NA	Pump	Filter tank	None	All year	Recreation	NA
156.4	Right	NA	Flash-board riser	NA	None	All year	NA	9
156.3	Right	NA	Floodgate	Earth ditch	None	All year	AG	NA
156.3	Both	NA	Floodgate	San Joaquin River	None	All year	Road crossing	NA
154.9	Left	NA	Pump	Concrete canal	None	All year	AG	3
154.3	Left	NA	Pump	Sprinklers	None	All year	AG	2
154.3	Left	NA	Pump	Concrete canal	None	All year	AG	2

Table 1.
San Joaquin River Diversions Within the Restoration Area (Contd.)

SJRRP River Mile	Bank Location	Diversion Name	Diversion Type	Discharge Type	Screen Type	Operation Status	Primary Use	Estimated Maximum Diversion Capacity (cfs)
153.8	Right	NA	Vertical pump	Vertical concrete pipe	None	All year	AG	NA
153.5	Both	NA	Culvert	San Joaquin River	None	All year	Road crossing	NA
147.3	**Reach 4B2**							
147.2	Right	D. & D. Land & Water Company	Vertical pump	Vertical concrete pipe	Trash-rack	Jan 15-Sept 1	Recreation	7
143.7	Right	San Luis Refuge	Vertical pump	Underground	None	All year	F/W Enhance	35
135.8	**Reach 5**							
131	Right	NA	Pump	Earth ditch	None	All year	Not in use	NA
130.4	Right	NA	Vertical pump	Vertical concrete pipe	None	All year	AG	9
125	Right	NA	Vertical pump	Concrete distribution box	None	All year	AG	7
118.8	Left	NA	Pump	Underground	None	Abandoned	Not in use	NA

Source: DFG, 2008; Reclamation, 2004

Key:
AG = agricultural
cfs = cubic feet per second
NA = not applicable
SJRRP = San Joaquin River Restoration Program

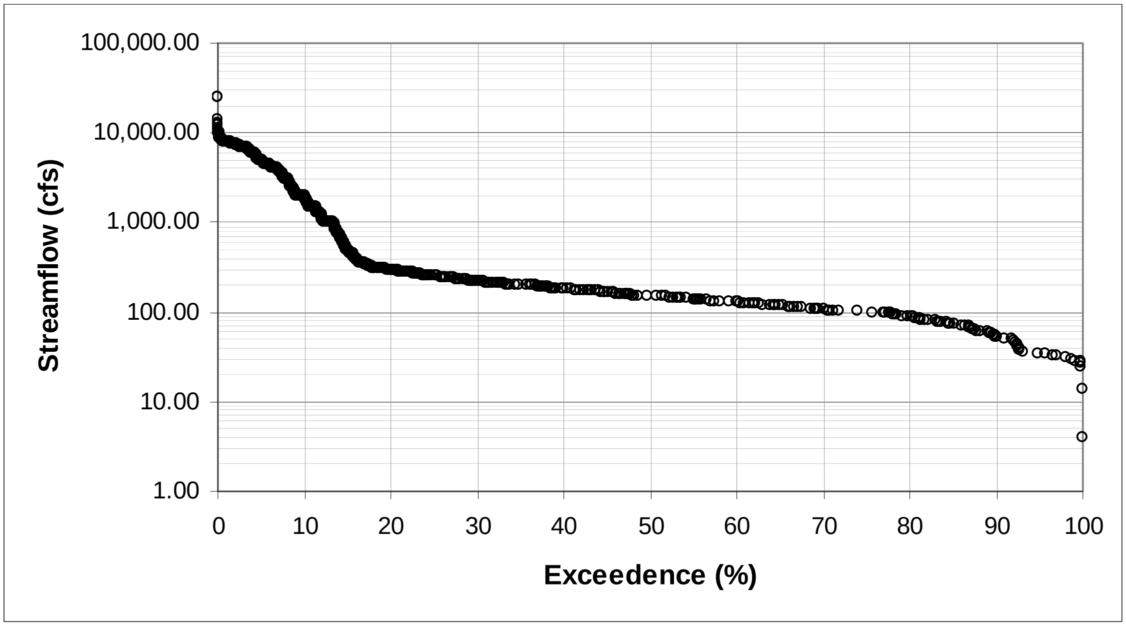
Attachment

Exceedence Curves

Draft
Surface Water Supplies and Facilities Operations Appendix

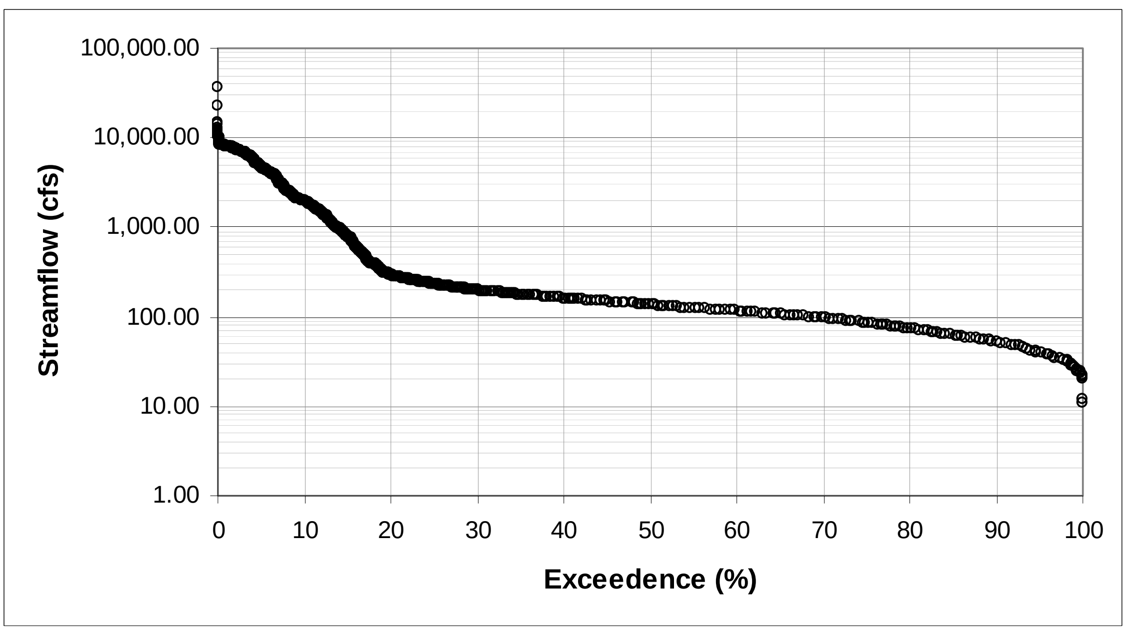
SAN JOAQUIN RIVER RESTORATION PROGRAM

Draft
April 2011



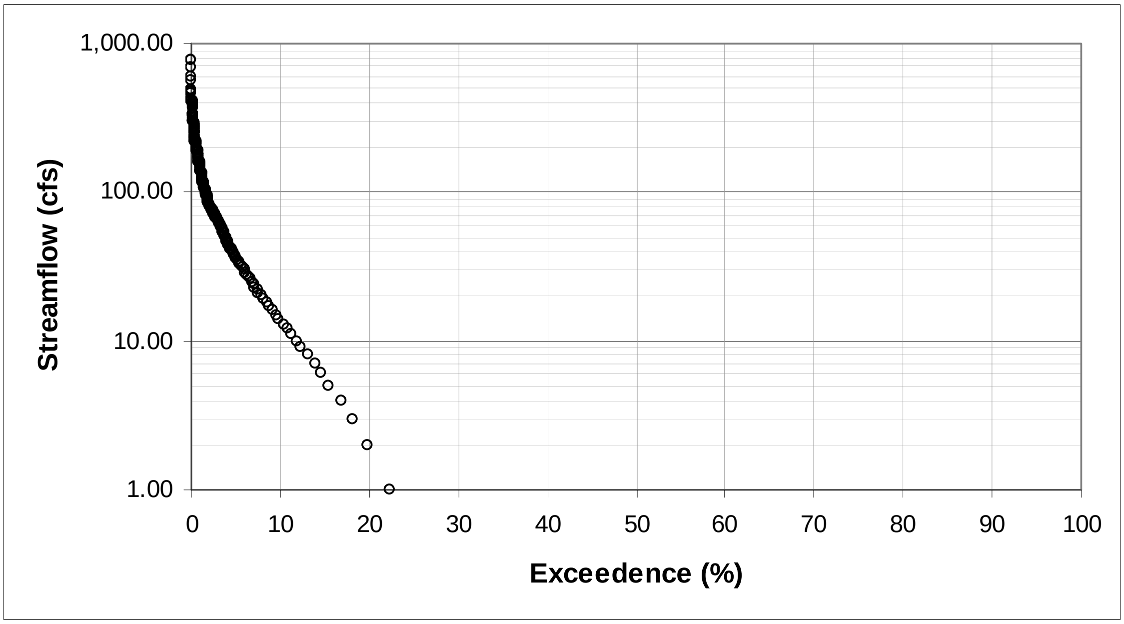
Key: cfs = cubic feet per second

Figure 1.
Flow Exceedence Curve for Friant Dam Releases



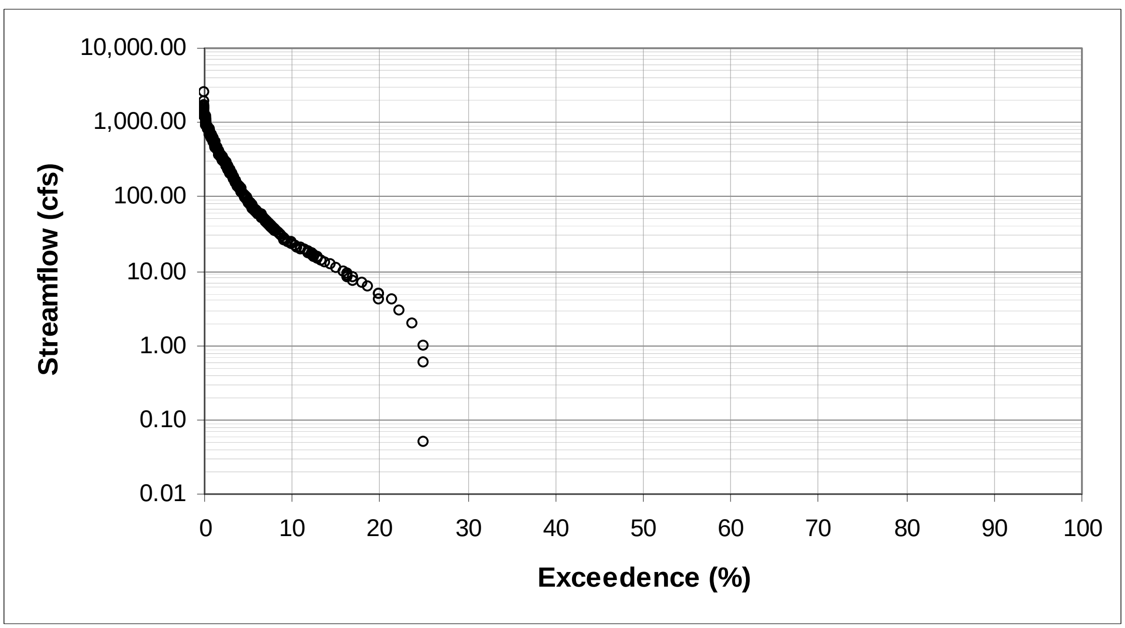
Key: cfs = cubic feet per second

Figure 2.
Flow Exceedence Curve for San Joaquin River Flow Below Friant Dam



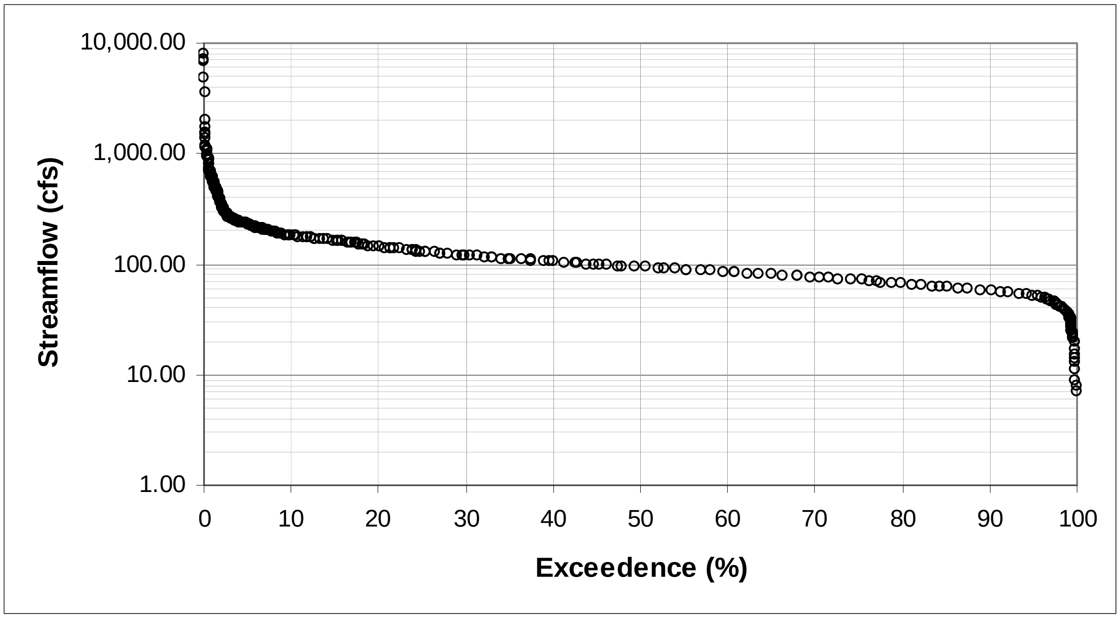
Key: cfs = cubic feet per second

Figure 3.
Historical Flow Exceedence Curve for Cottonwood Creek near Friant Dam



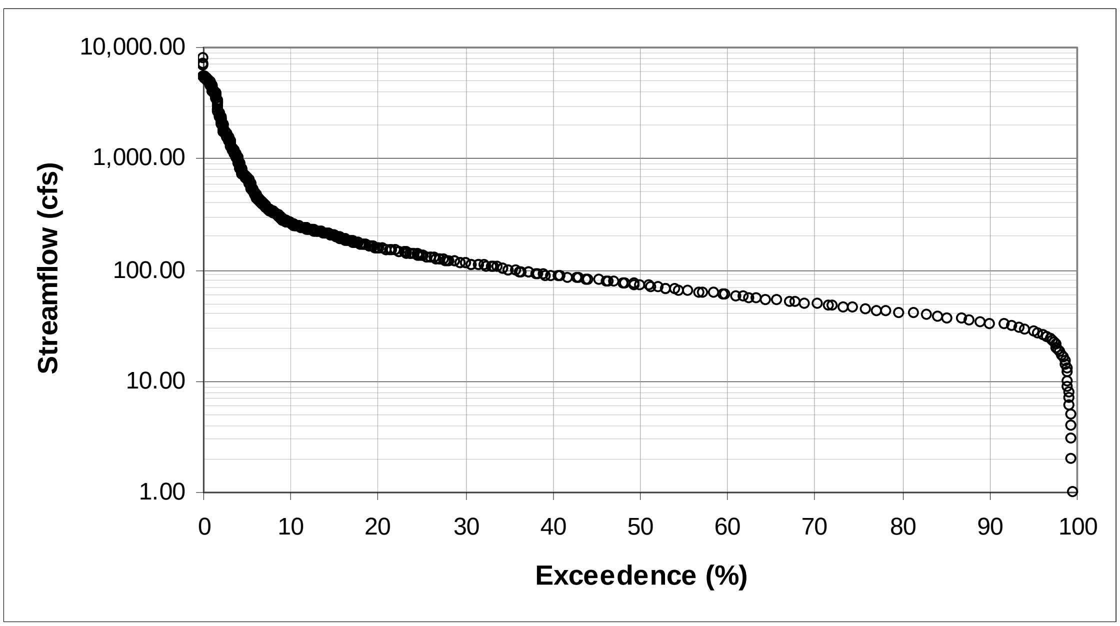
Key: cfs = cubic feet per second

Figure 4.
Historical Flow Exceedence Curve for Little Dry Creek near Friant Dam



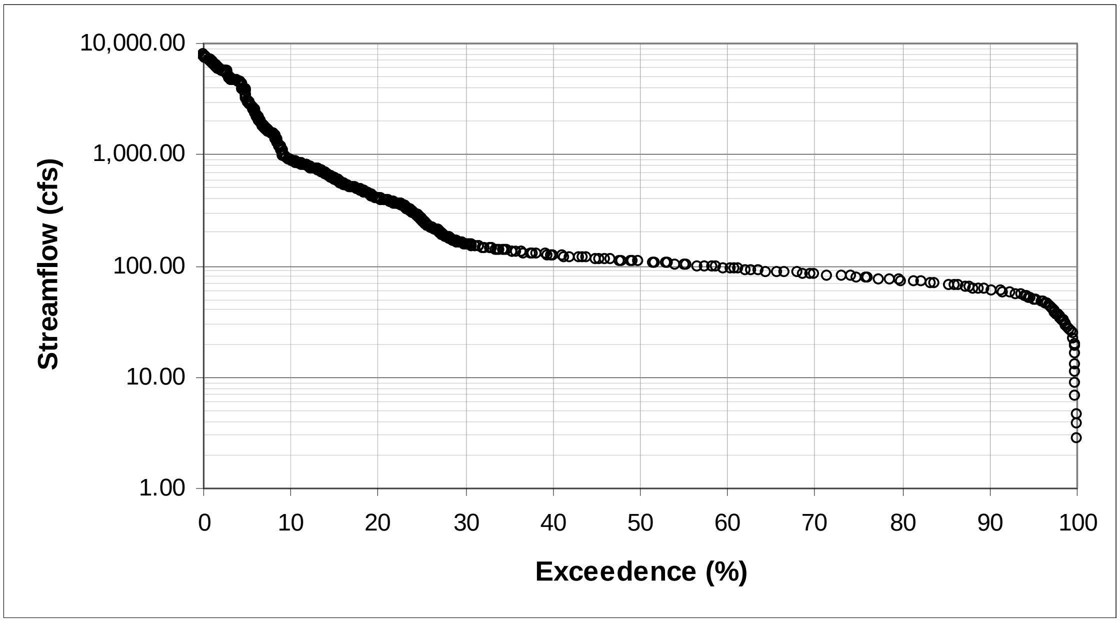
Key: cfs = cubic feet per second

Figure 5.
Flow Exceedence Curve for San Joaquin River at Donny Bridge



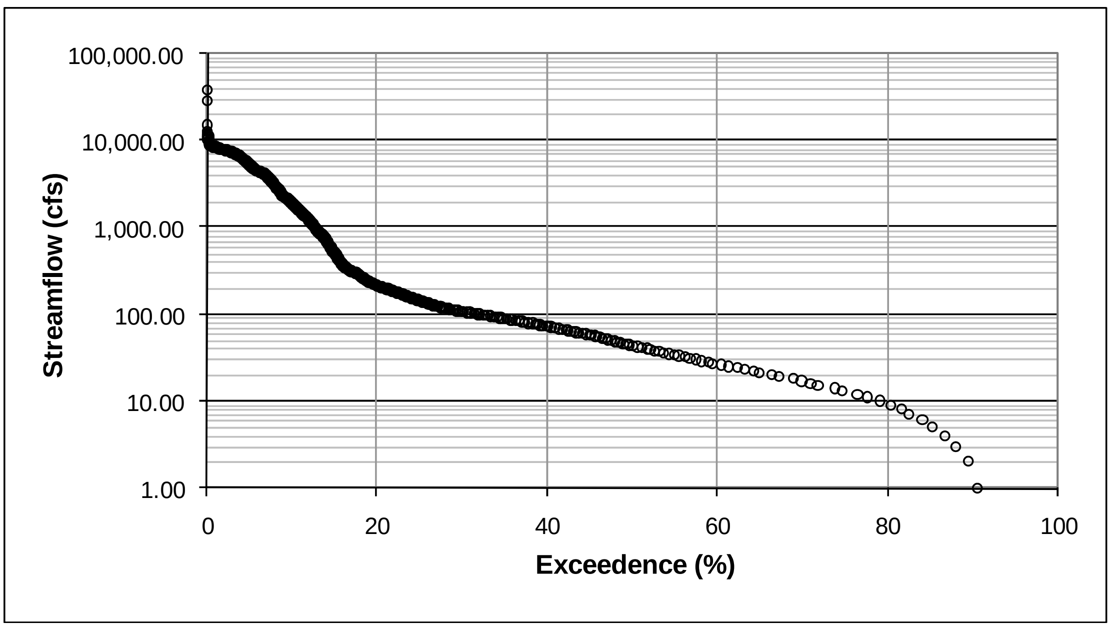
Key: cfs = cubic feet per second

Figure 6.
Flow Exceedence Curve for San Joaquin River at Skaggs Bridge



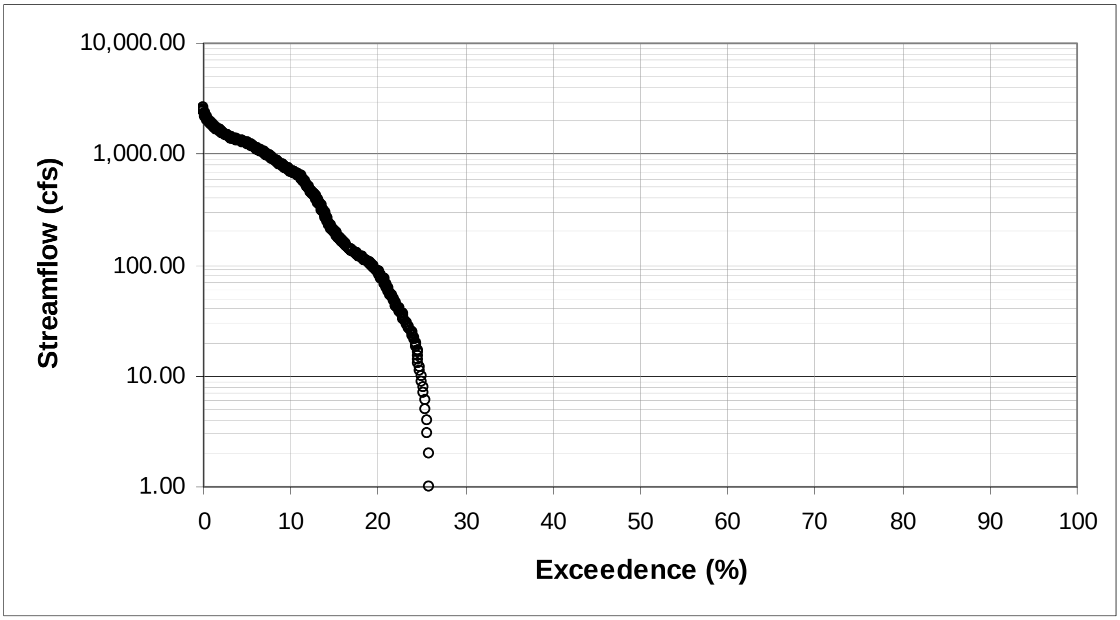
Key: cfs = cubic feet per second

Figure 7.
Flow Exceedence Curve for San Joaquin River near Biola



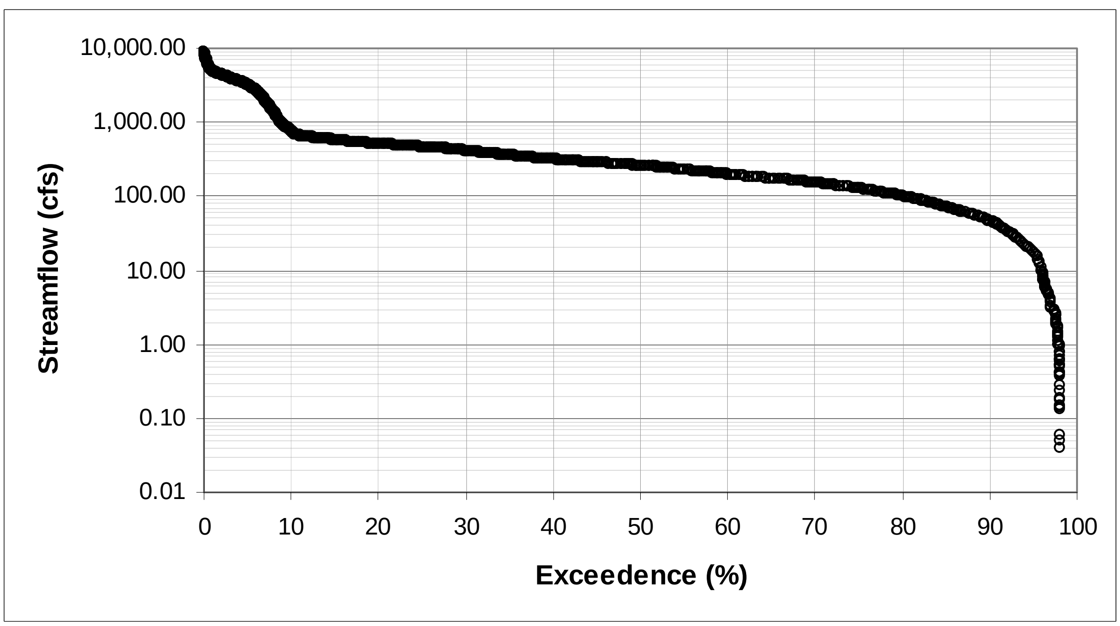
Key: cfs = cubic feet per second

Figure 8.
Flow Exceedence Curve for San Joaquin River at Gravelly Ford



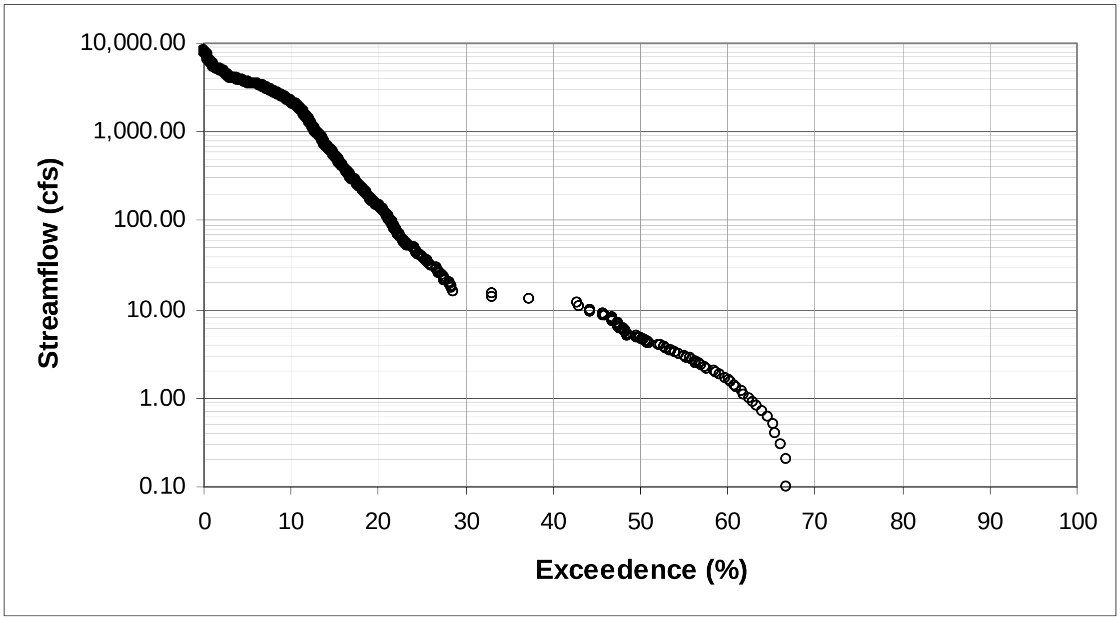
Key: cfs = cubic feet per second

Figure 9.
Flow Exceedence Curve for San Joaquin River Below Chowchilla Bypass Bifurcation Structure



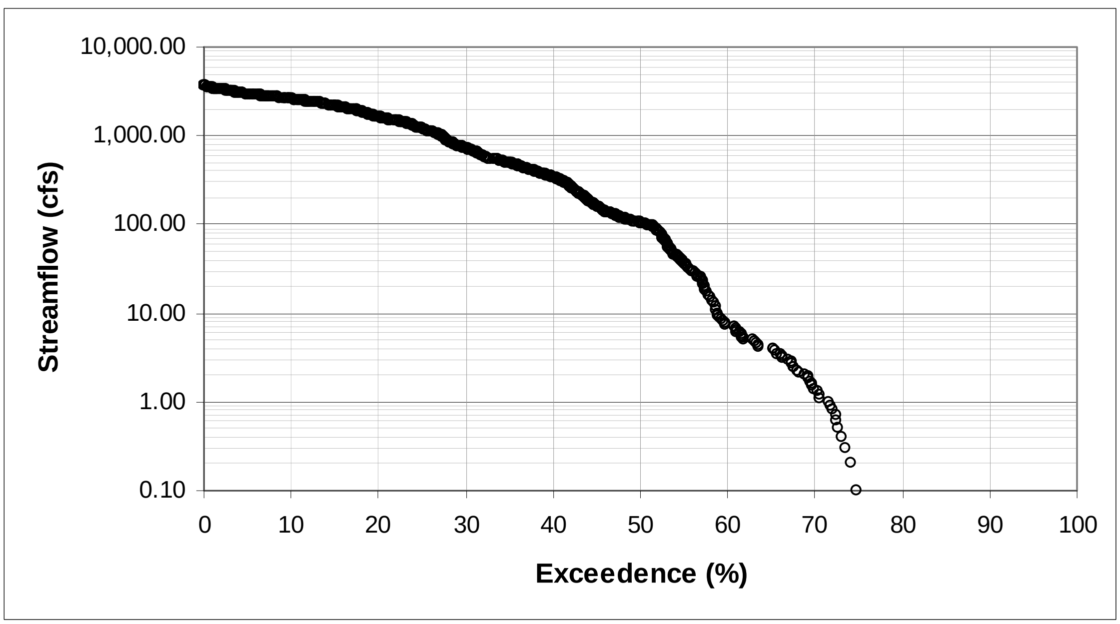
Key: cfs = cubic feet per second

Figure 10.
Flow Exceedence Curve for San Joaquin River near Mendota



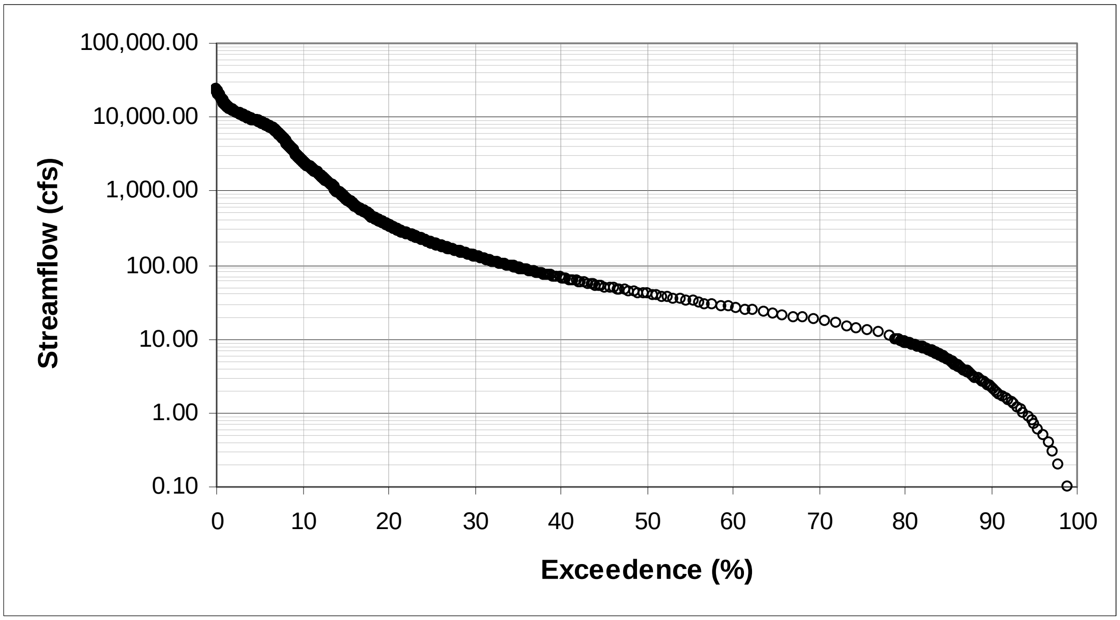
Key: cfs = cubic feet per second

Figure 11.
Flow Exceedence Curve for San Joaquin River near Dos Palos



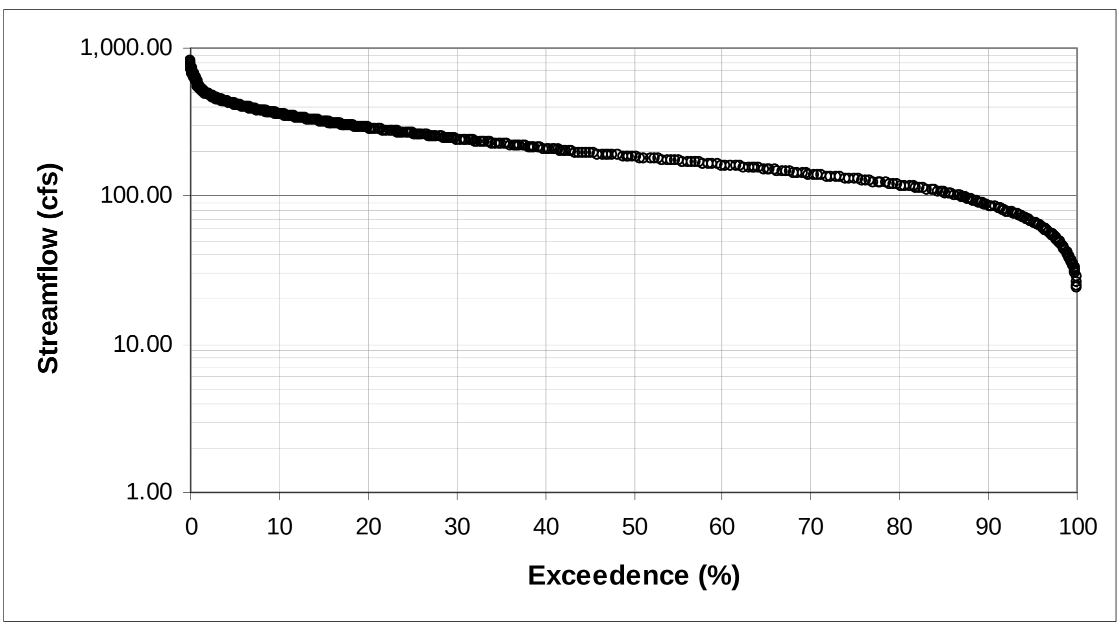
Key: cfs = cubic feet per second

Figure 12.
Flow Exceedence Curve for San Joaquin River near El Nido



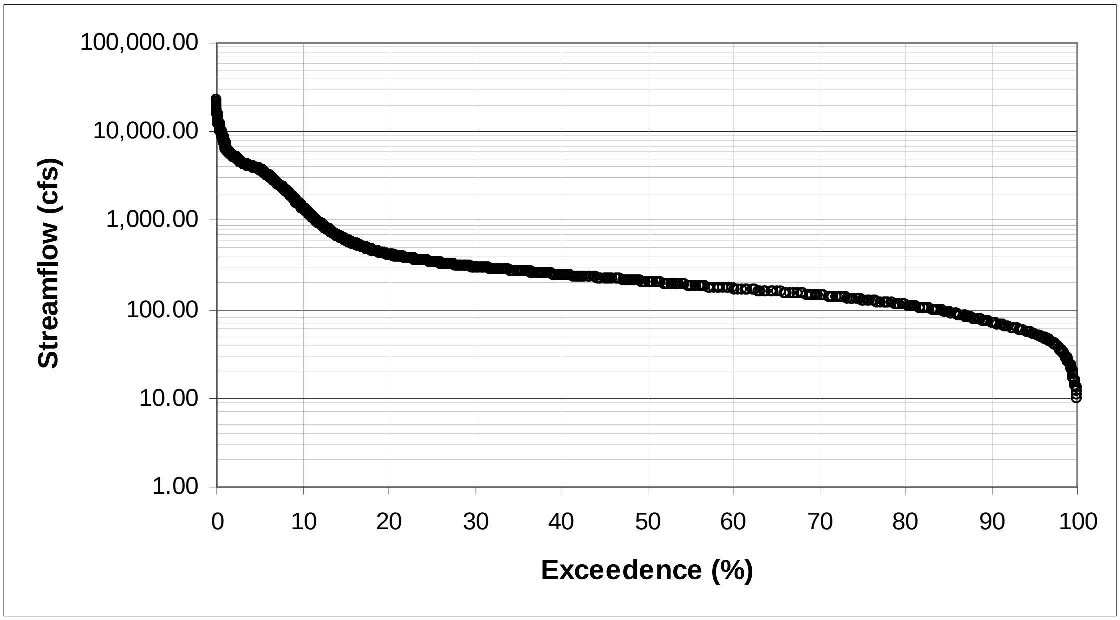
Key: cfs = cubic feet per second

Figure 13.
Flow Exceedence Curve for San Joaquin River near Stevinson



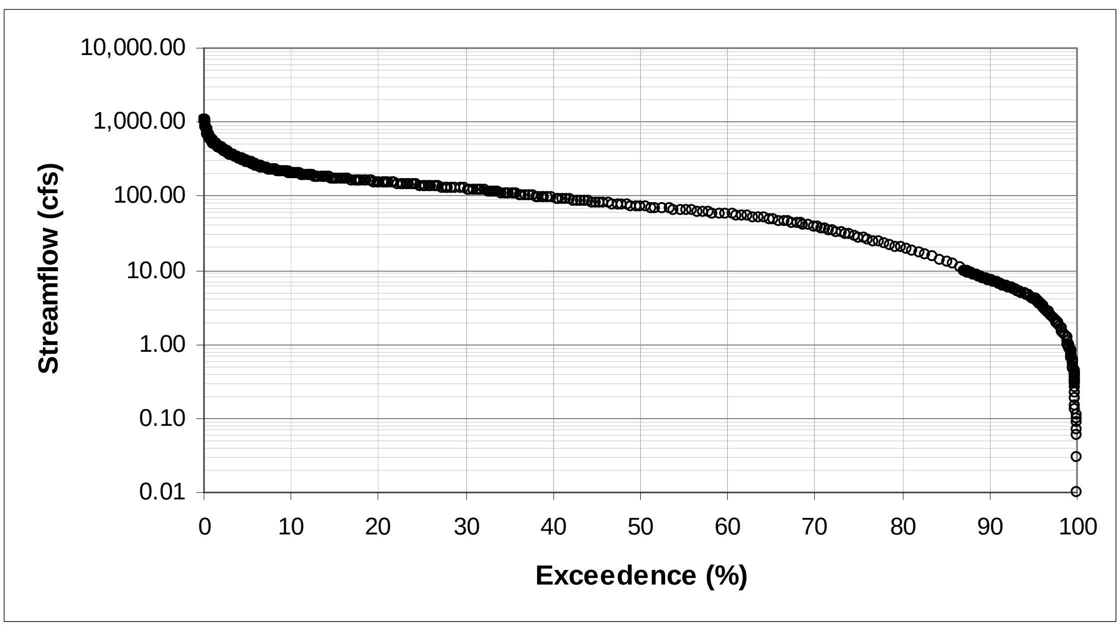
Key: cfs = cubic feet per second

Figure 14.
Flow Exceedence Curve for Salt Slough at Highway 165 near Stevinson



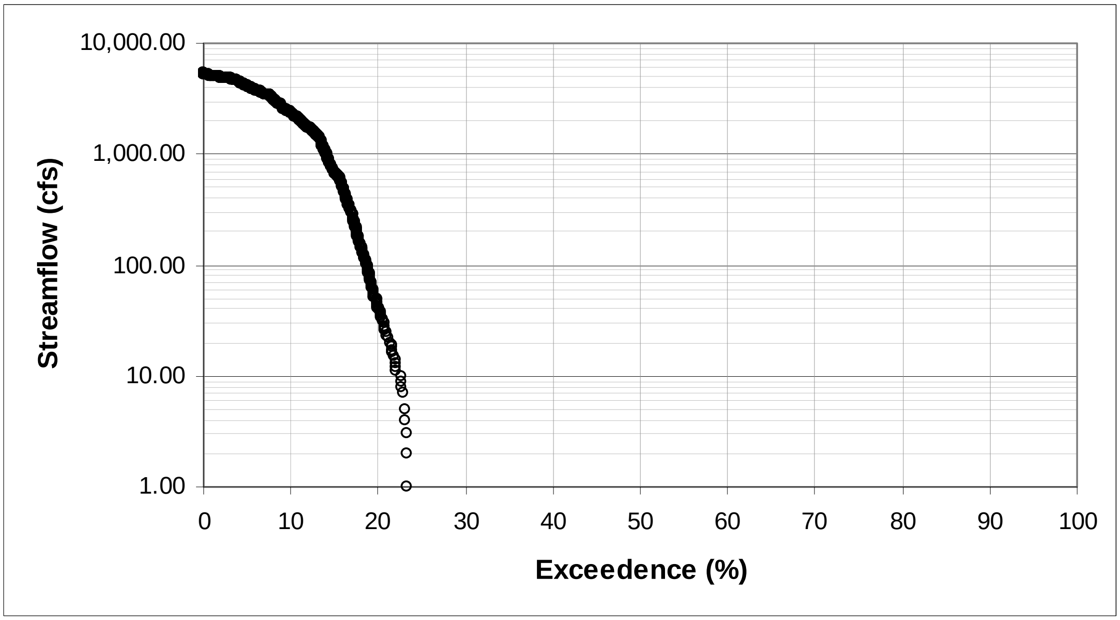
Key: cfs = cubic feet per second

Figure 15.
Flow Exceedence Curve for San Joaquin River at Fremont Ford Bridge



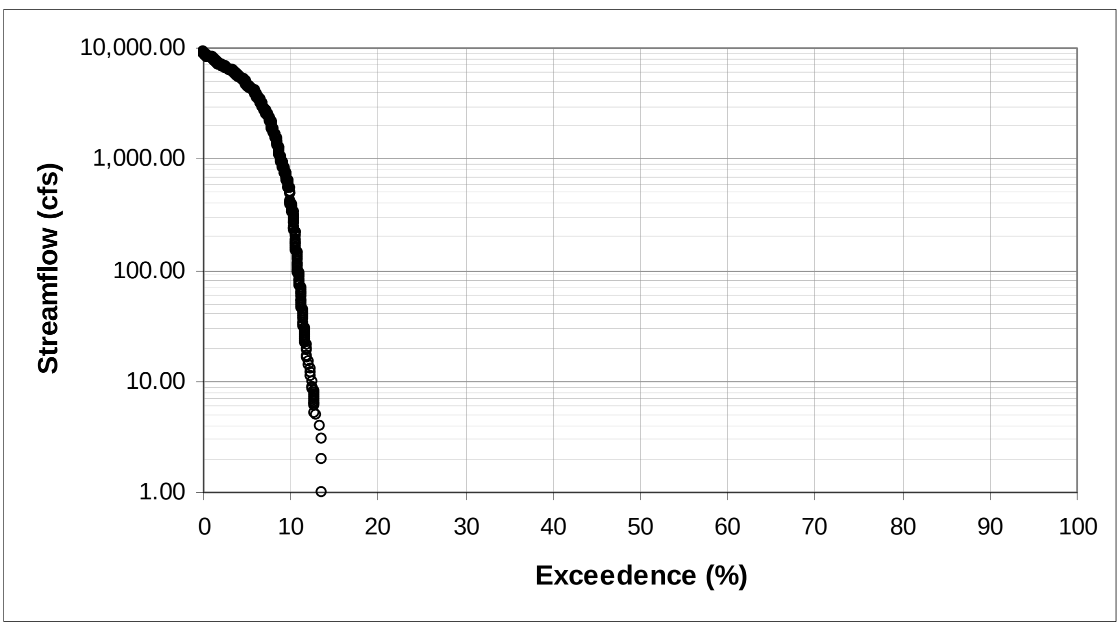
Key: cfs = cubic feet per second

Figure 16.
Flow Exceedence Curve for Mud Slough near Gustine



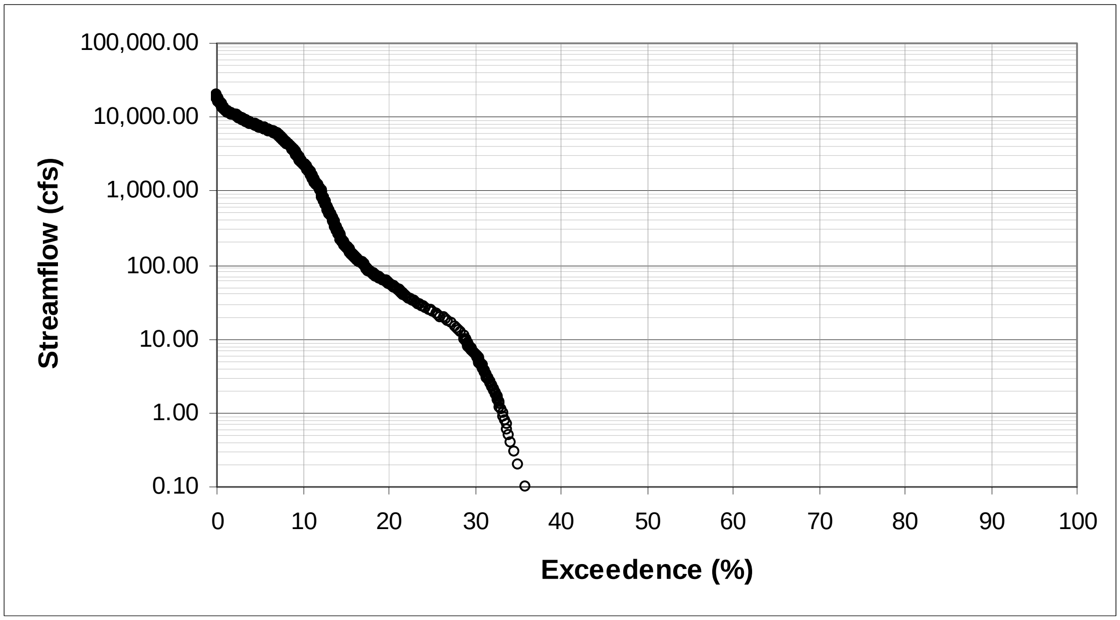
Key: cfs = cubic feet per second

Figure 17.
Flow Exceedence Curve for Fresno Slough/James Bypass near San Joaquin River



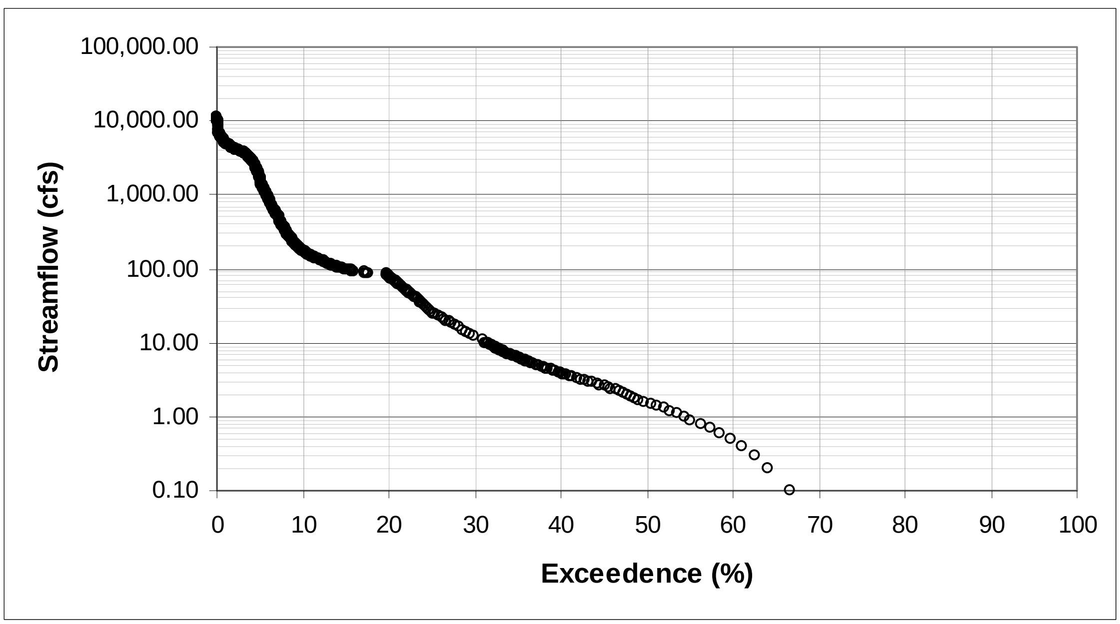
Key: cfs = cubic feet per second

Figure 18.
Flow Exceedence Curve for Chowchilla Bypass at Head



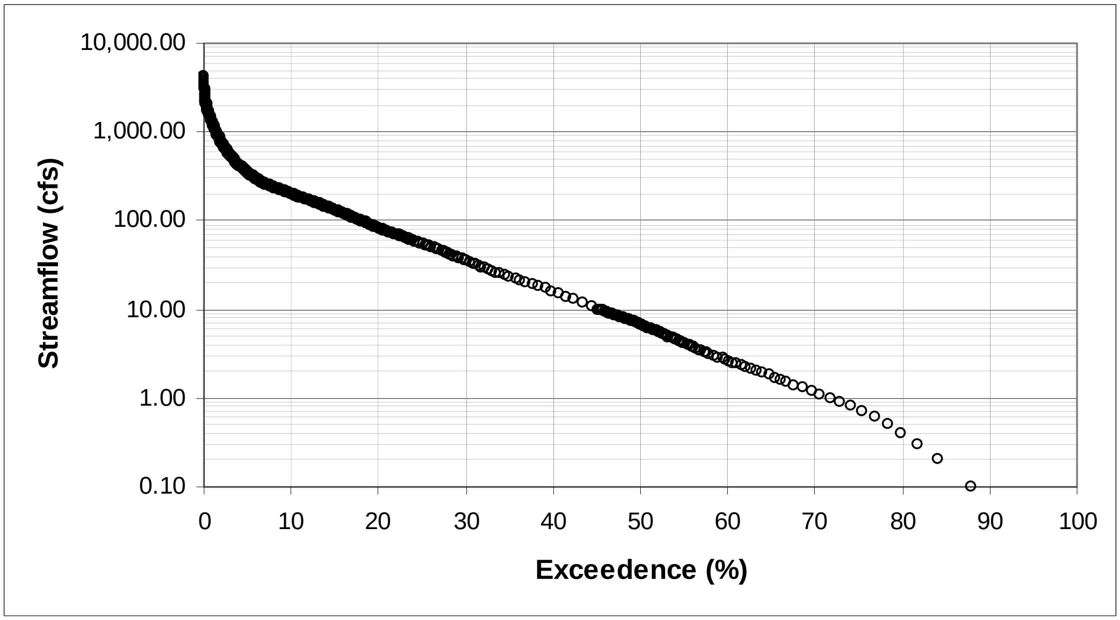
Key: cfs = cubic feet per second

Figure 19.
Flow Exceedence Curve for Eastside Bypass near El Nido



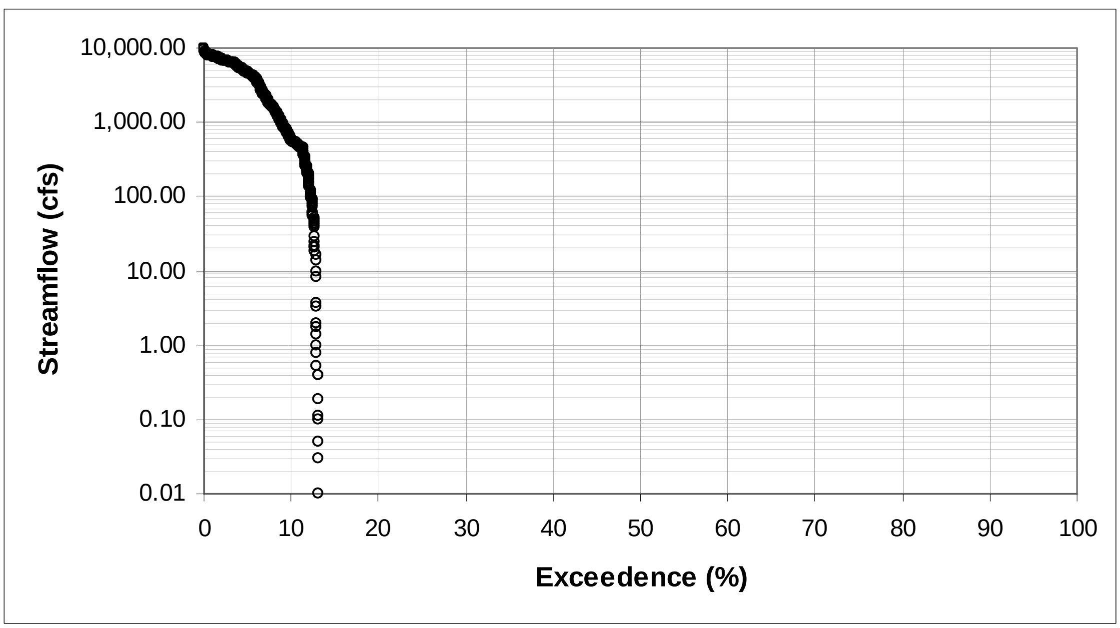
Key: cfs = cubic feet per second

Figure 20.
Flow Exceedence Curve for Eastside Bypass Below Mariposa Bypass



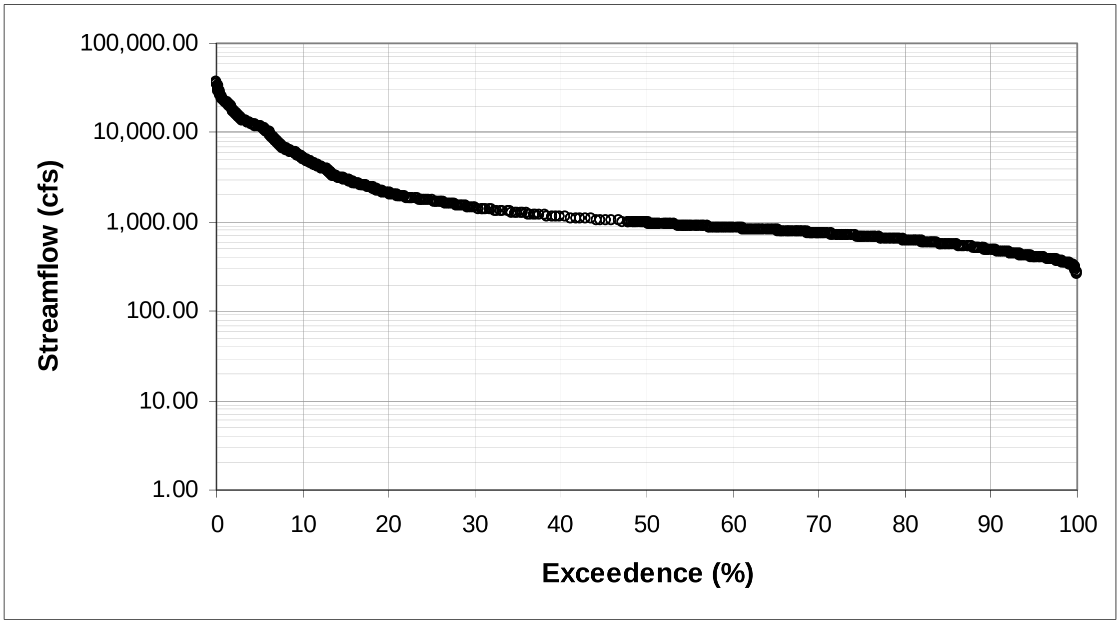
Key: cfs = cubic feet per second

Figure 21.
Flow Exceedence Curve for Bear Creek Below Eastside Bypass



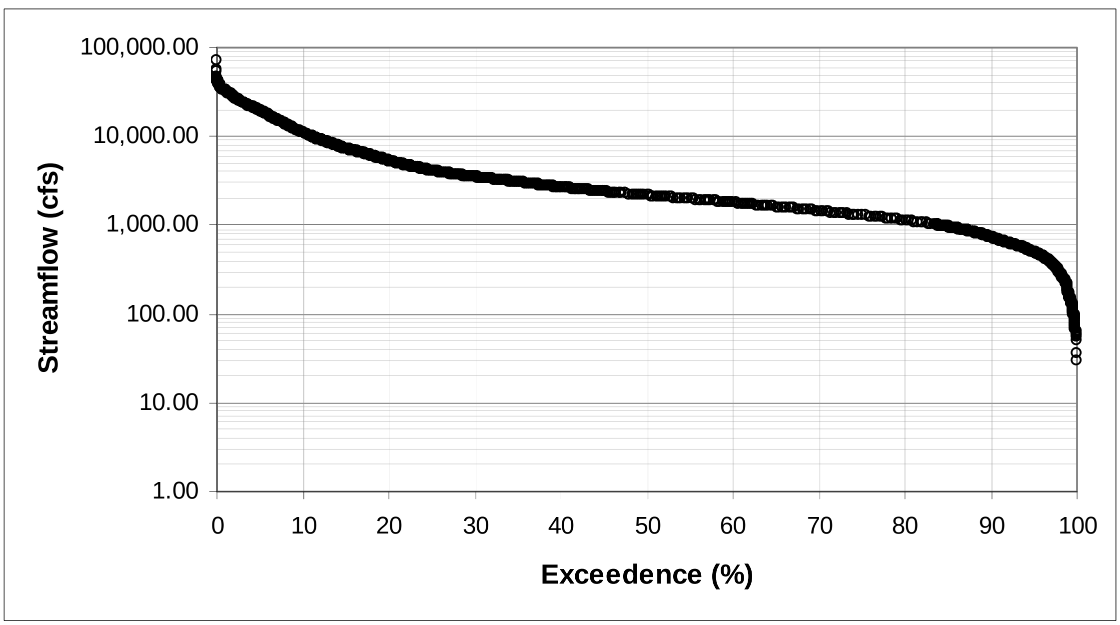
Key: cfs = cubic feet per second

Figure 22.
Flow Exceedence Curves for Mariposa Bypass near Crane Ranch



Key: cfs = cubic feet per second

Figure 23.
Flow Exceedence Curve for San Joaquin River near Crows Landing



Key: cfs = cubic feet per second

Figure 24.
Flow Exceedence Curve for San Joaquin River near Vernalis

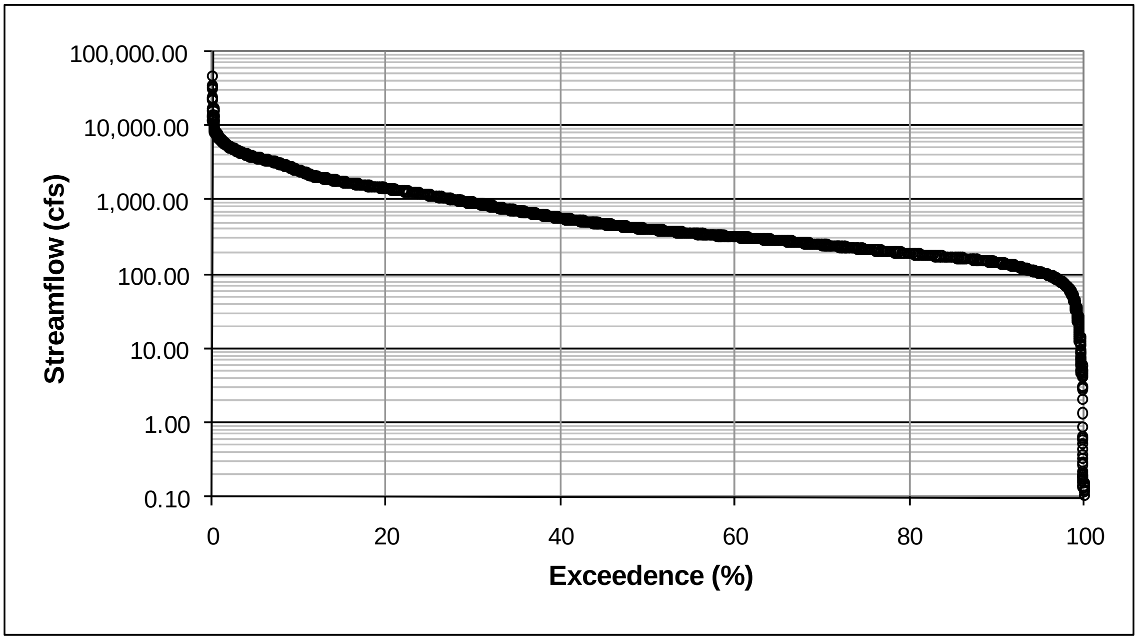
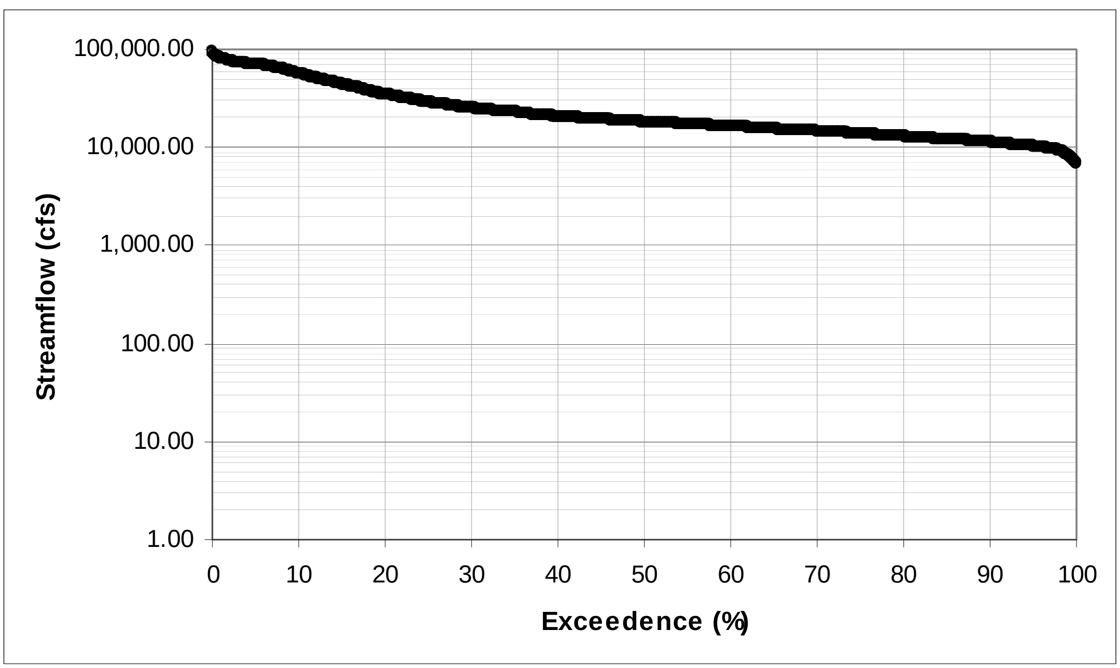
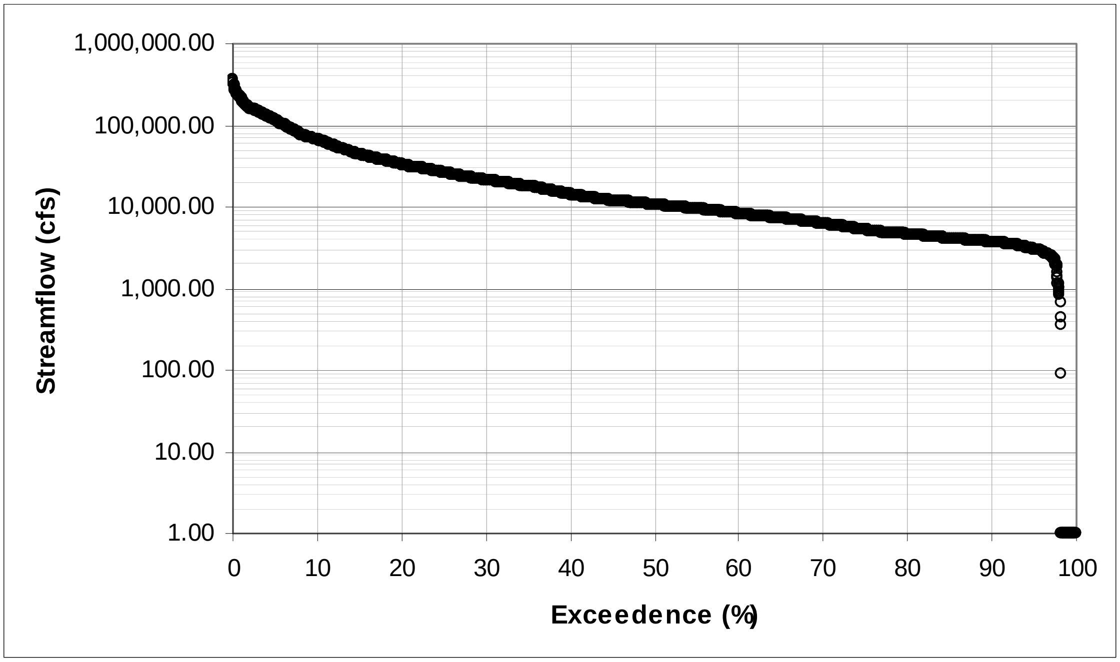


Figure 25.
Flow Exceedence Curve for Stanislaus River at Ripon



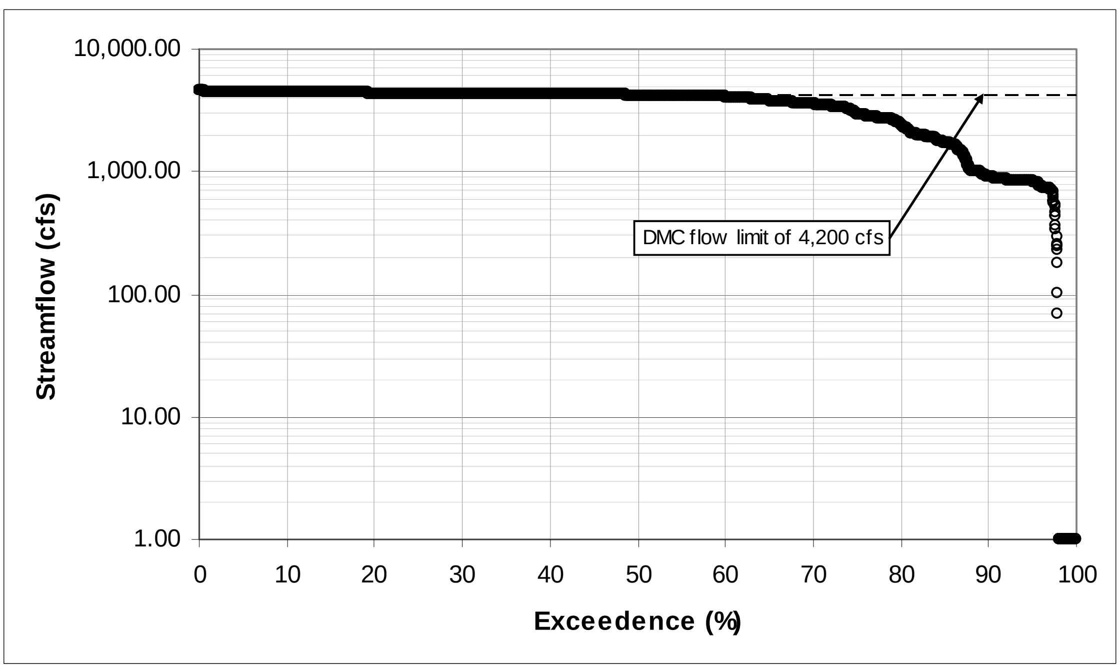
Key: cfs = cubic feet per second

Figure 26.
Flow Exceedence Curve for Sacramento River Flow at Freeport, 1998 – 2007



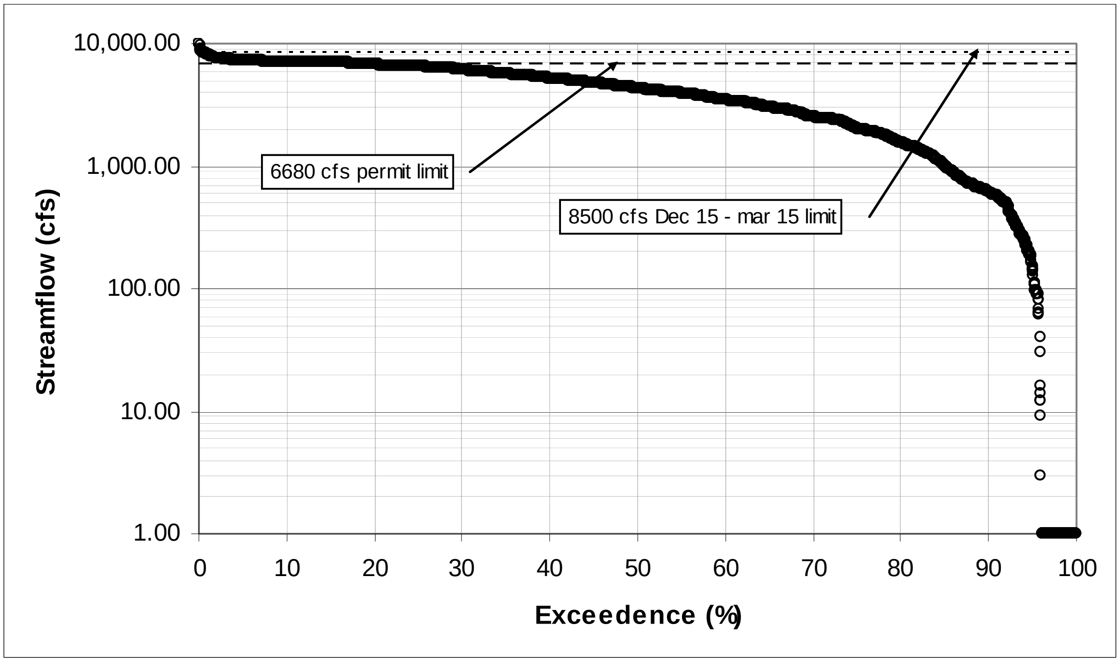
Key: cfs = cubic feet per second

Figure 27.
Flow Exceedence Curve for Total Delta Outflow, 1998 – 2007



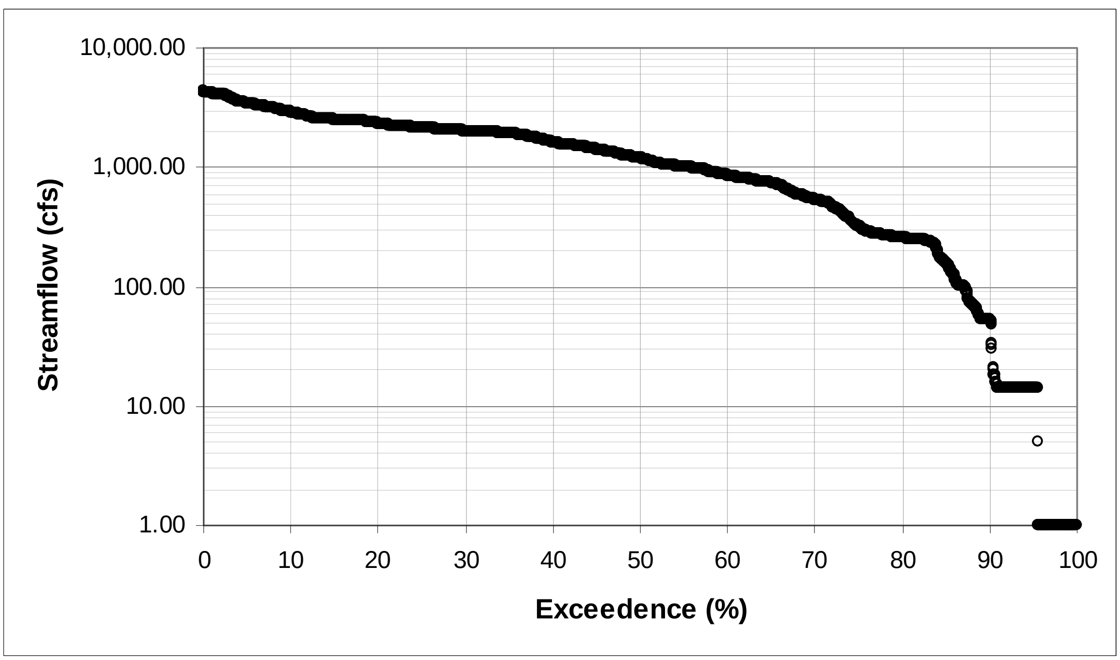
Key: cfs = cubic feet per second DMC = Delta-Mendota Canal

Figure 28.
Flow Exceedence Curve for Jones Pumping Plant, 1998 – 2007



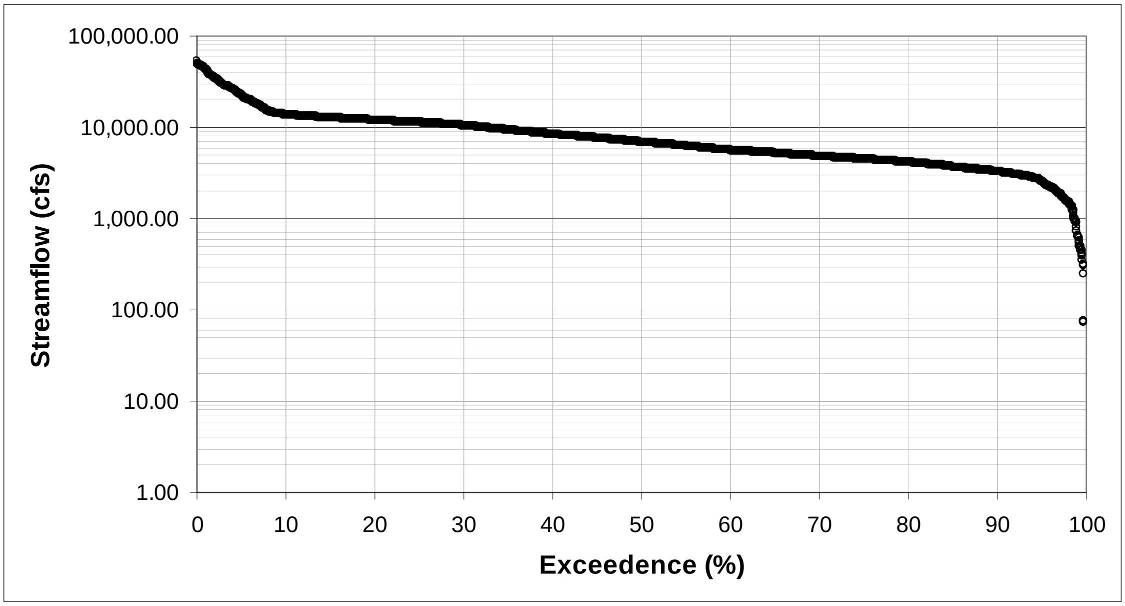
Key: cfs = cubic feet per second

Figure 29.
Flow Exceedence Curve for Banks Pumping Plant, 1998 – 2007



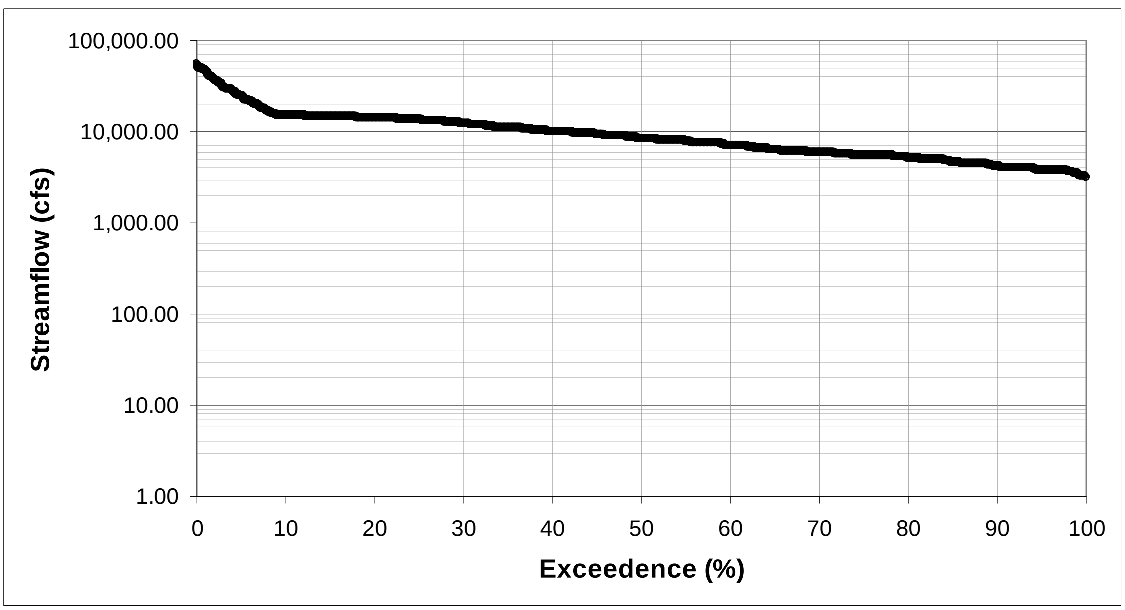
Key: cfs = cubic feet per second

Figure 30.
Flow Exceedence Curve for Trinity Exports to Sacramento Basin,
April 2000 – December 2007



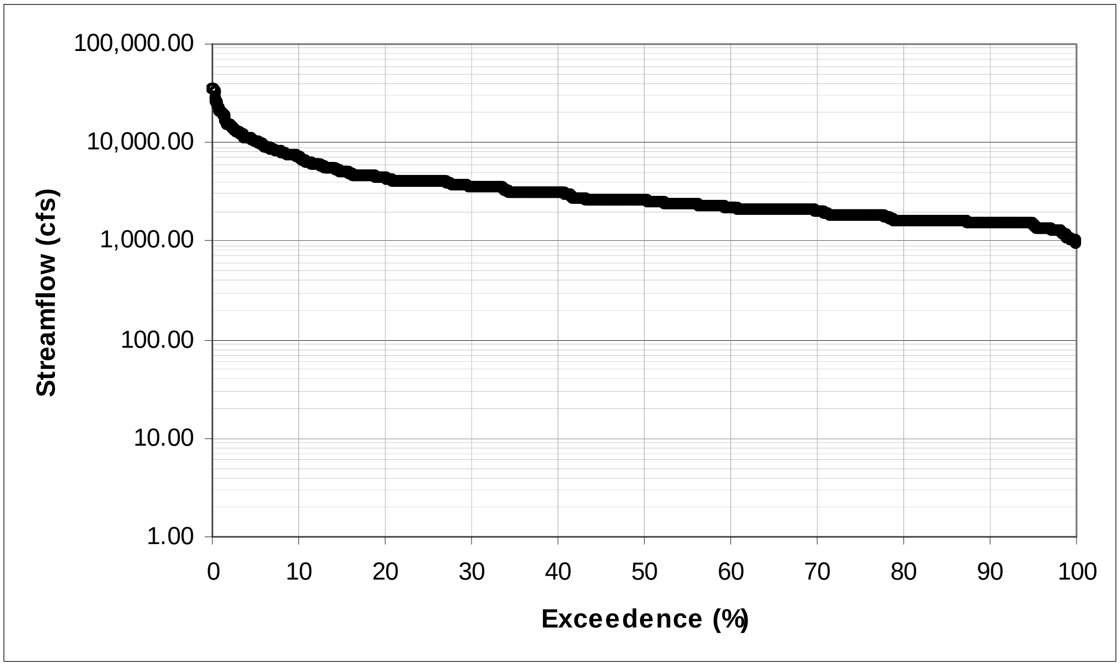
Key: cfs = cubic feet per second

Figure 2-31.
Flow Exceedence Curve for Shasta Lake Releases to Sacramento River, 1998 – 2007



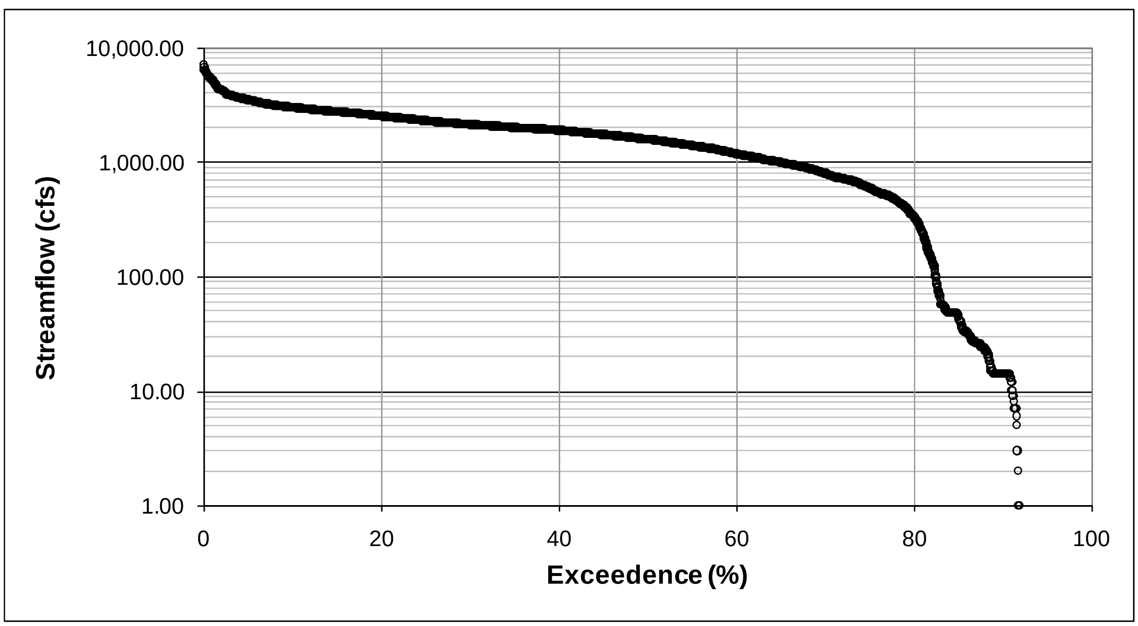
Key: cfs = cubic feet per second

Figure 32.
Flow Exceedence Curve for Keswick Reservoir Releases to Sacramento River, 1998 – 2007



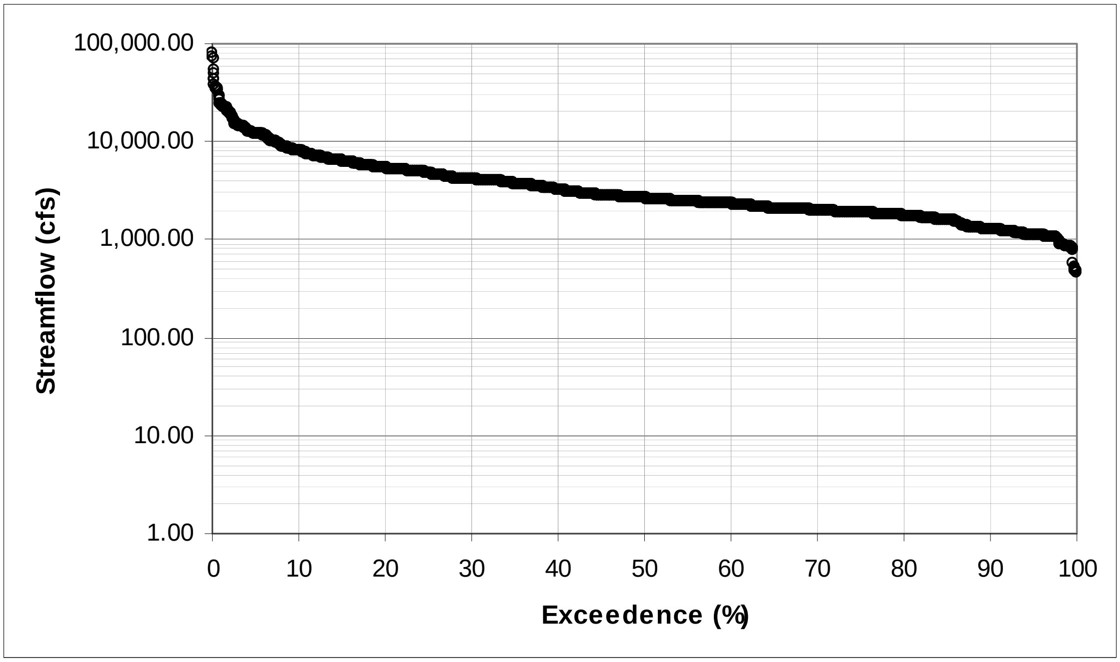
Key: cfs = cubic feet per second

Figure 33.
Flow Exceedence Curve for American River Below Nimbus, 1998 – 2007



Key: cfs = cubic feet per second

Figure 34.
Flow Exceedence Curve for New Melones Lake Releases, 1998 – 2007



Key: cfs = cubic feet per second

Figure 35.
Flow Exceedence Curve for Feather River at Gridley, 1998 – 2007

Attachment

Rating Tables

Draft
Surface Water Supplies and Facilities Operations Appendix

Draft
April 2011

Table 1.
Rating Table for San Joaquin River Below Friant Dam

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
1	NA	NA	NA	9	15	21	28	37	46	56
2	69	84	102	122	144	169	197	228	260	295
3	334	373	415	459	506	555	604	656	710	766
4	825	886	950	1,020	1,090	1,160	1,240	1,320	1,400	1,490
5	1,580	1,670	1,760	1,850	1,,950	2,050	2,140	2,250	2,350	2,460
6	2,570	2,680	2,790	2,900	3,010	3,130	3,250	3,370	3,490	3,620
7	3,750	3,870	3,990	4,110	4,240	4,370	4,500	4,630	4,760	4,900
8	5,030	5,170	5,320	5,460	5,610	5,760	5,910	6,060	6,210	6,370
9	6,530	6,690	6,850	7,020	7,190	7,360	7,530	7,700	7,880	8,060
10	8,240	8,420	8,600	8,790	8,980	9,170	9,370	9,560	9,760	9,960
11	10,200	10,400	10,600	10,800	11,000	11,200	11,400	11,600	11,900	12,100
12	12,300	12,500	12,800	13,000	13,200	13,500	13,700	14,000	14,200	14,400
13	14,700	14,900	15,200	15,500	15,700	16,000	16,200	16,500	16,800	17,000
14	17,300	17,600	17,900	18,100	18,400	18,700	19,000	19,300	19,600	19,900
15	20,100	20,400	20,700	21,000	21,400	21,700	22,000	22,300	22,600	22,900
16	23,200	23,600	23,900	24,200	24,500	24,900	25,200	25,500	25,900	26,200
17	26,600	26,900	27,200	27,600	28,000	28,300	28,700	29,000	29,400	29,800
18	30,100	30,500	30,900	31,200	31,600	32,000	NA	NA	NA	NA

Source: CDEC 2008, Gage ID SJF
Key:
cfs = cubic feet per second
NA = not available

Table 2.
Rating Table for San Joaquin River at Donny Bridge

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
1	0	0	0	0	0	0	1	2	6	12
2	26	34	43	52	63	74	86	99	114	130
3	148	165	184	204	225	248	270	294	319	345
4	373	400	429	459	490	523	554	587	621	656
5	692	724	757	791	826	862	895	928	962	997
6	1,032	1,065	1,099	1,133	1,167	1,202	1,235	1,269	1,303	1,337
7	1,372	1,406	1,439	1,474	1,508	1,543	1,578	1,614	1,649	1,686
8	1,722	1,757	1,792	1,827	1,863	1,899	1,935	1,971	2,008	2,045
9	2,082	2,118	2,154	2,191	2,227	2,264	2,301	2,339	2,376	2,414
10	2,452	2,491	2,531	2,570	2,610	2,650	2,691	2,731	2,772	2,813
11	2,855	2,896	NA	NA	NA	NA	NA	NA	NA	NA

Source: CDEC 2008, Gage ID DNB
Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 3.
Rating Table for San Joaquin River at Gravelly Ford

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
4	0	0	0	4	12	20	29	38	49	60
5	74	88	102	118	135	156	177	199	221	234
6	259	284	309	342	375	408	442	476	510	550
7	590	635	680	725	770	815	860	906	952	998
8	1,044	1,102	1,160	1,218	1,276	1,338	1,400	1,462	1,524	1,590
9	1,656	1,722	1,788	1,854	1,929	2,004	2,079	2,154	2,235	2,318
10	2,410	2,505	2,600	2,700	2,800	2,900	3,000	3,100	3,200	3,305
11	3,410	3,548	3,686	3,824	3,962	4,100	4,241	4,382	4,523	4,664
12	4,805	4,982	5,159	5,336	5,513	5,690	5,867	6,044	6,221	6,398
13	6,575	6,752	6,929	7,106	7,283	7,460	7,637	7,814	7,991	8,168
14	8,345	8,522	8,699	8,876	9,053	9,230	9,407	9,584	9,761	9,938
15	10,115	10,292	10,469	10,646	10,823	11,000	11,177	11,354	11,531	11,716
16	11,900	12,140	12,380	12,665	12,950	13,320	13,690	14,245	14,800	15,600
17	16,400	17,220	18,040	18,860	19,680	20,500	21,320	22,140	22,960	23,780
18	24,600	25,420	26,240	27,060	27,880	28,700	29,520	30,340	31,160	31,980
19	32,800	33,620	34,440	35,260	36,080	36,900	37,720	38,540	39,360	40,180
20	41,000	41,820	42,640	43,460	NA	NA	NA	NA	NA	NA

Source: CDEC 2008, Gage ID GRF

Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 4.
Rating Table for San Joaquin River Below Chowchilla Bypass Bifurcation Structure

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
163	0	6	15	25	35	47	60	75	90	107
164	124	143	163	184	205	227	250	274	299	325
165[1]	351	377	404	432	460	489	389	421	454	488
166	523	560	598	636	674	712	752	796	840	884
167	928	972	1,018	1,065	1,112	1,161	1,210	1,260	1,316	1,374
168	1,432	1,490	1,548	1,609	1,670	1,731	1,792	1,854	1,918	1,982
169	2,047	2,117	2,187	2,258	2,329	2,401	2,473	2,545	2,617	2,689
170	2,762	2,835	2,909	2,983	3,057	3,131	3,205	NA	NA	NA

Source: CDEC 2008, Gage ID SJB
Note:
[1] Values as reported by CDEC.

Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 5.
Rating Table for San Joaquin River near Mendota

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
1	NA	NA	NA	NA	NA	NA	NA	0	3	8
2	14	21	29	38	47	57	67	78	91	104
3	117	131	145	159	174	190	206	222	239	256
4	274	292	310	329	346	365	385	405	425	446
5	465	486	508	530	552	575	596	619	642	666
6	691	713	737	762	788	813	839	862	889	915
7	942	969	994	1020	1050	1080	1110	1130	1160	1190
8	1220	1250	1280	1310	1340	1370	1400	1430	1460	1490
9	1520	1550	1590	1620	1650	1680	1720	1750	1790	1820
10	1860	1890	1920	1960	1990	2030	2070	2100	2140	2180
11	2210	2250	2290	2330	2360	2400	2440	2480	2520	2560
12	2590	2630	2670	2710	2750	2790	2830	2870	2920	2960
13	3000	3040	3080	3120	3160	3210	3250	3290	3330	3380
14	3420	3460	3510	3550	3600	3640	3680	3730	3770	3820
15	3860	3910	3950	4000	4050	4090	4140	4180	4230	4280
16	4320	4370	4420	4470	4510	4560	4610	NA	NA	NA

Source: CDEC 2008, Gage ID MEN

Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 6.
Rating Table for San Joaquin River near Stevinson

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
60	0	0	1	2	3	5	7	9	13	16
61	20	24	29	34	39	45	52	58	66	73
62	81	85	90	103	118	128	139	150	161	173
63	186	199	212	226	240	255	270	285	301	317
64	335	352	369	387	407	425	445	465	486	506
65	527	549	572	594	616	640	664	690	714	739
66	764	791	819	845	872	900	929	959	987	1,017
67	1,047	1,078	1,110	1,141	1,172	1,205	1,238	1,272	1,307	1,341
68	1,375	1,410	1,446	1,483	1,521	1,557	1,594	1,632	1,670	1,710
69	1,750	1,788	1,827	1,867	1,908	1,949	1,992	2,035	2,079	2,124
70	2,170	2,258	2,,349	2,443	2,542	2,644	2,750	2,860	2,975	3,094
71	3,217	3,346	3,479	3,618	3,762	3,912	4,067	4,228	4,396	4,570
72	4,750	4,924	5,105	5,292	5,485	5,686	5,893	6,107	6,329	6,559
73	6,797	7,028	7,266	7,512	7,766	8,028	8,299	8,578	8,867	9,165
74	9,472	9,763	10,063	10,371	10,689	11,015	11,351	11,697	12,053	12,420
75	12,797	13,185	13,584	13,995	14,417	14,852	15,299	15,759	16,232	16,719
76	17,220	17,691	18,175	18,670	19,179	19,701	20,237	20,786	21,349	21,927
77	22,520	23,128	23,752	24,391	25,047	25,720	NA	NA	NA	NA

Source: CDEC 2008, Gage ID SJS

Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 7.
Rating Table for San Joaquin River at Fremont Ford Bridge

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
58	NA	NA	33	38	44	50	58	68	79	92
59	106	120	134	148	163	177	191	205	220	235
60	250	265	280	295	312	329	346	364	383	403
61	423	444	465	488	511	534	559	584	610	637
62	665	693	723	753	784	816	849	883	918	953
63	990	1,030	1,070	1,110	1,150	1,190	1,240	1,280	1,330	1,380
64	1,430	1,480	1,530	1,580	1,640	1,690	1,750	1,810	1,870	1,930
65	1,990	2,060	2,140	2,220	2,300	2,380	2,470	2,550	2,640	2,740
66	2,,830	2,950	3,070	3,190	3,320	3,450	3,590	3,730	3,880	4,030
67	4,180	4,350	4,520	4,700	4,880	5,070	5,260	5,460	5,670	5,880
68	6,100	6,320	6,550	6,790	7,040	7,290	7,540	7,810	8,080	8,360
69	8,650	8,990	9,340	9,710	10,100	10,500	10,900	11,300	11,700	12,100
70	12,600	13,100	13,600	14,100	14,700	15,200	15,800	16,400	17,000	17,600
71	18,300	19,000	19,800	20,500	21,300	22,100	23,000	23,800	24,700	25,600
72	26,600	NA	NA	NA	NA	NA	NA	NA	NA	NA

Source: CDEC 2008, Gage ID FFB

Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 8.
Rating Table for Chowchilla Bypass at Head

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
163	NA	NA	NA	NA	NA	NA	0	22	48	75
164	107	139	171	204	237	270	305	345	385	427
165	469	514	559	609	660	711	762	821	880	940
166	1,000	1,065	1,130	1,202	1,274	1,352	1,430	1,508	1,586	1,666
167	1,746	1,829	1,912	1,998	2,084	2,170	2,256	2,346	2,439	2,535
168	2,631	2,728	2,825	2,925	3,025	3,130	3,235	3,342	3,449	3,557
169	3,665	3,773	3,885	4,002	4,120	4,240	4,360	4,480	4,600	4,720
170	4,840	4,960	5,080	5,211	5,342	5,473	5,604	5,735	5,868	5,997
171	6,128	6,259	6,390	6,521	6,652	6,884	6,916	7,049	7,182	7,316
172	7,450	7,584	7,718	7,852	7,986	8,120	8,254	8,388	8,522	8,656
173	8,790	8,925	NA	NA	NA	NA	NA	NA	NA	NA

Source: CDEC 2008, Gage ID CBP

Key:
cfs = cubic feet per second
NA = not applicable/not available

Table 9.
Rating Table for Eastside Bypass near El Nido

Stage (feet)	Discharge (cfs)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
9	1	1	2	3	4	5	7	9	12	15
10	18	22	28	33	40	47	55	64	74	85
11	98	111	126	142	160	179	200	222	246	272
12	300	329	361	395	431	469	509	553	598	646
13	698	751	808	868	930	995	1,065	1,136	1,212	1,292
14	1,374	1,460	1,551	1,644	1,743	1,846	1,951	2,062	2,178	2,296
15	2,419	2,549	2,684	2,821	2,964	3,113	3,268	3,425	3,589	3,760
16	3,937	4,117	4,,303	4,497	4,698	4,902	5,113	5,332	5,559	5,788
17	6,026	6,271	6,525	6,782	7,047	7,322	7,605	7,892	8,187	8,492
18	8,807	9,124	9,451	9,787	10,134	10,491	10,850	11,219	11,599	11,990
19	12,391	12,795	13,210	13,637	14,074	14,524	14,977	15,441	15,917	16,405
20	16,906	16,906	16,906	16,906	16,906	16,906	16,906	16,906	16,906	16,906
21	16,906	NA	NA	NA	NA	NA	NA	NA	NA	NA

Source: CDEC 2008, Gage ID ELN

Key:
cfs = cubic feet per second
NA = not applicable/not available

Attachment

Water Year-Types

Draft
Surface Water Supplies and Facilities Operations Appendix

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List of Abbreviations and Acronyms

MAF	million acre-feet
PEIS/R	Program Environmental Impact Statement/Report
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet

1.0 Water Year-Types

Water year-types referred to in this Program Environmental Impact Statement/Report (PEIS/R) include Sacramento Valley, San Joaquin Valley, and San Joaquin River Restoration water year-types, as shown in Table 1-1 and described below.

1.1 Sacramento Valley Water Year-Types

The Sacramento Valley Water Year-Type is determined through the use of an index. The index is based on the sum of flows in the Sacramento River above Bend Bridge, Feather River inflow to Oroville Reservoir, flows in the Yuba River at Smartville, and American River inflow to Folsom Reservoir, in million acre-feet (MAF). This index is used to determine the Sacramento Valley Water Year-Type, as implemented in State Water Resources Control Board (SWRCB) Water Right Decision 1641. Final determination for year classification is made in May. Preliminary year classifications can be based on hydrologic conditions to date and runoff forecasts (SWRCB 2000).

1.2 San Joaquin Valley Water Year-Types

The San Joaquin Valley Water Year-Type is determined through the use of an index. The index is based on Stanislaus River inflows to New Melones Lake, Tuolumne River inflows to New Don Pedro Reservoir, Merced River inflows to Lake McClure, and San Joaquin River inflows to Millerton Lake, in MAF. This index is used to determine the San Joaquin Valley Water Year-Type, as implemented in SWRCB Water Right Decision 1641. Water year-types are set by first-of-month forecasts beginning in February. Final determination for San Joaquin River flow objectives is based on the May 1 75 percent exceedence forecast (SWRCB 2000).

1.3 San Joaquin River Restoration Water Year-Types

Total annual unimpaired runoff at Friant Dam for a water year (October through September) is the index by which the San Joaquin River Restoration Water Year-Type is determined. In order of descending wetness, the wettest 20 percent of the years are classified as Wet, the next 30 percent of the years are classified as Normal-Wet, the next 30 percent of the years are classified as Normal-Dry, the next 15 percent of the years are classified as Dry, and the remaining 5 percent of the years are classified as Critical. A subset of the Critical years, those with less than 400 TAF of unimpaired runoff, is identified as Critical-Low. Critical years with unimpaired runoff greater than 400 thousand acre-feet (TAF) are identified as Critical-High.

Table 1-1.
Sacramento Valley, San Joaquin Valley, and San Joaquin River Restoration Water Year-Types

Water Year	Sacramento Valley Year-Type	San Joaquin Valley Year-Type	San Joaquin River Restoration Year-Type
1921	Above-Normal	Above-Normal	Normal-Wet
1922	Above-Normal	Wet	Normal-Wet
1923	Below-Normal	Above-Normal	Normal-Wet
1924	Critical	Critical	Critical-High
1925	Dry	Below-Normal	Normal-Dry
1926	Dry	Dry	Normal-Dry
1927	Wet	Above-Normal	Normal-Wet
1928	Above-Normal	Below-Normal	Normal-Dry
1929	Critical	Critical	Dry
1930	Dry	Critical	Dry
1931	Critical	Critical	Critical-High
1932	Dry	Above-Normal	Normal-Wet
1933	Critical	Dry	Normal-Dry
1934	Critical	Critical	Dry
1935	Below-Normal	Above-Normal	Normal-Wet
1936	Below-Normal	Above-Normal	Normal-Wet
1937	Below-Normal	Wet	Normal-Wet
1938	Wet	Wet	Wet
1939	Dry	Dry	Dry
1940	Above-Normal	Above-Normal	Normal-Wet
1941	Wet	Wet	Wet
1942	Wet	Wet	Normal-Wet
1943	Wet	Wet	Normal-Wet
1944	Dry	Below-Normal	Normal-Dry
1945	Below-Normal	Above-Normal	Normal-Wet
1946	Below-Normal	Above-Normal	Normal-Wet
1947	Dry	Dry	Normal-Dry
1948	Below-Normal	Below-Normal	Normal-Dry
1949	Dry	Below-Normal	Normal-Dry
1950	Below-Normal	Below-Normal	Normal-Dry
1951	Above-Normal	Above-Normal	Normal-Wet
1952	Wet	Wet	Wet
1953	Wet	Below-Normal	Normal-Dry
1954	Above-Normal	Below-Normal	Normal-Dry
1955	Dry	Dry	Normal-Dry
1956	Wet	Wet	Wet
1957	Above-Normal	Below-Normal	Normal-Dry

Table 1-1.
Sacramento Valley, San Joaquin Valley, and San Joaquin River Restoration Water Year-Types (contd.)

Water Year	Sacramento Valley Year-Type	San Joaquin Valley Year-Type	San Joaquin River Restoration Year-Type
1958	Wet	Wet	Wet
1959	Below-Normal	Dry	Normal-Dry
1960	Dry	Critical	Dry
1961	Dry	Critical	Critical-High
1962	Below-Normal	Below-Normal	Normal-Wet
1963	Wet	Above-Normal	Normal-Wet
1964	Dry	Dry	Dry
1965	Wet	Wet	Normal-Wet
1966	Below-Normal	Below-Normal	Normal-Dry
1967	Wet	Wet	Wet
1968	Below-Normal	Dry	Dry
1969	Wet	Wet	Wet
1970	Wet	Above-Normal	Normal-Dry
1971	Wet	Below-Normal	Normal-Dry
1972	Below-Normal	Dry	Normal-Dry
1973	Above-Normal	Above-Normal	Normal-Wet
1974	Wet	Wet	Normal-Wet
1975	Wet	Wet	Normal-Wet
1976	Critical	Critical	Critical-High
1977	Critical	Critical	Critical-Low
1978	Above-Normal	Wet	Wet
1979	Below-Normal	Above-Normal	Normal-Wet
1980	Above-Normal	Wet	Wet
1981	Dry	Dry	Normal-Dry
1982	Wet	Wet	Wet
1983	Wet	Wet	Wet
1984	Wet	Above-Normal	Normal-Wet
1985	Dry	Dry	Normal-Dry
1986	Wet	Wet	Wet
1987	Dry	Critical	Dry
1988	Critical	Critical	Dry
1989	Dry	Critical	Normal-Dry
1990	Critical	Critical	Dry
1991	Critical	Critical	Normal-Dry
1992	Critical	Critical	Dry
1993	Above-Normal	Wet	Wet
1994	Critical	Critical	Dry

Table 1-1.
Sacramento Valley, San Joaquin Valley, and San Joaquin River Restoration Water Year-Types (contd.)

Water Year	Sacramento Valley Year-Type	San Joaquin Valley Year-Type	San Joaquin River Restoration Year-Type
1995	Wet	Wet	Wet
1996	Wet	Wet	Normal-Wet
1997	Wet	Wet	Wet
1998	Wet	Wet	Wet
1999	Wet	Above-Normal	Normal-Wet
2000	Above-Normal	Above-Normal	Normal-Wet
2001	Dry	Dry	Normal-Dry
2002	Dry	Dry	Normal-Dry
2003	Above-Normal	Below-Normal	Normal-Wet

Appendix K

Biological Resources - Fisheries

Draft
Program Environmental Impact Statement/Report

SAN JOAQUIN RIVER
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Attachments

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Attachment

Fishes of the San Joaquin River Restoration Area

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Biological Resources – Fisheries Appendix

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List of Abbreviations and Acronyms

°C	degrees Celsius
CESA	California Endangered Species Act
cm	centimeter
cm/s	centimeters per second
CNDDB	California Natural Diversity Database
Delta	Sacramento-San Joaquin Delta Delta
DFG	California Department of Fish and Game
DO	dissolved oxygen
DPS	distinct population segment
ESA	Federal Endangered Species Act
°F	degrees Fahrenheit
feet/s	feet per second
FL	fork length
ft^2	feet square
ft/s	feet per second
in	inch
kg	kilogram
km	kilometer
LWD	large woody debris
m	meter
m^2	meters squared
mg/L	milligram per liter
mm	millimeters
m/s	meters per second
NFH	Nimbus Fish Hatchery
NMFS	National Marine Fisheries Service
ppm	parts per million
ppt	parts per thousand
SJRRP	San Joaquin River Restoration Program
SL	standard length
TL	total length
U.C.	University of California
USFS	U.S. Forest Services
USFWS	U.S. Fish & Wildlife Service

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1.0 Introduction

Attachment A summarizes key aspects of the fish species in the San Joaquin River Restoration Program (SJRRP) Restoration Area (Restoration Area), as well as species that are not currently found in the Restoration Area, but are targeted for restoration (Chinook salmon and other native fishes) or have the potential to use the Restoration Area (Sacramento splittail, green and white sturgeon). These summaries provide an abbreviated description of the species' legal status, historical and present distributions, life history, habitat requirements, ecological interactions, and key ecological uncertainties.

Much of this information was originally prepared for the *San Joaquin River Restoration Study Background Report* (McBain & Trush 2002) and has been reproduced here in its original form or with modifications. Some of this information was originally paraphrased, by generous permission of the author, from *Inland Fishes of California* (Moyle 2002). Information from other literature sources is also included, particularly for the anadromous salmonid species, for which more expanded descriptions are provided.

It is important to note that the information provided here for Chinook salmon is not intended to represent the habitat requirements necessary for restoration or the life history traits likely to be exhibited by a restored population. Likewise, the ecological interactions and key uncertainties discussed herein for Chinook salmon are not necessarily those that will be most important for restoration to the Restoration Area. The information presented here represents a compendium of the best and most recent information available for the species in general, with a focus on Sacramento-San Joaquin basin populations. The environmental requirements and likely temporal occurrence of Chinook salmon in the Restoration Area, as well as factors likely to limit reintroduced populations of Chinook salmon, are described in detail in Appendix E, Fisheries Management Plan.

The fishes described in Attachment A are grouped into native and nonnative species. Within these two groups, species are presented alphabetically by family name.

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2.0 Native Species

Common Name	**Scientific Name (family)**
White sturgeon	*Acipenser transmontanus (*Acipenseridae)

Legal Status

Federal:	None
State:	None

2.1 Distribution

White sturgeon have a marine distribution spanning from the Gulf of Alaska south to Mexico, but a spawning distribution ranging only from the Sacramento River northward. Currently, self-sustaining spawning populations are only known to occur in the Sacramento, Fraser, and Columbia rivers. In California, primary abundance is in the San Francisco Estuary with spawning occurring mainly in the Sacramento and Feather rivers. They may have occurred historically in the Restoration Area based on habitat similarities with these other watersheds. Adult sturgeon were caught in the sport fishery industry in the San Joaquin River between Mossdale and the confluence with the Merced River in late winter and early spring, suggesting this was a spawning run (Kohlhorst 1976). Kohlhorst et al. (1991, as cited in USFWS 1995) estimated that approximately 10 percent of the Sacramento River system spawning population migrated up the San Joaquin River. Spawning may occur in the San Joaquin River when flows and water quality permit; however, no evidence of spawning is present (Kohlhorst et al.1976, Kohlhorst et al. 1991; both as cited in USFWS 1995). Landlocked populations are located above major dams in the Columbia River basin, and residual non-reproducing fish above the Shasta Dam and Friant Dam have been occasionally found. In the ocean, white sturgeon have been known to migrate long distances, but spend most of their life in brackish portions of large river estuaries. White sturgeon are occasionally noted in the San Joaquin River below the Restoration Area during California Department of Fish and Game (DFG) fall midwater trawls, DFG summer townet surveys, and University of California (U.C.) Davis Suisun Marsh fisheries monitoring (http://bdat.ca.gov/); however, only adults have been documented and no juveniles have been found, indicating a lack of spawning. Recent sampling efforts have not documented the current presence of white sturgeon in the Restoration Area (Brown and Moyle 1993, Schaffter 1997, Brown 1998, DFG 2007).

2.2 Life History

Reports of maximum size and age of white sturgeon are as great as 6-meter (m) fork length (FL) (820 kilograms (kg)) and greater than 100 years, although they generally do not exceed 2 m FL or 27 years of age. Males mature in 10 to 12 years (75 to 105 centimeters (cm) FL) and females in 12 to 16 years (95 to 135 cm FL). Maturation depends largely on temperature and photoperiod. Sturgeon migrate upstream when they are ready to spawn in response to increases of flow. Only a portion of the adult population spawns each year and is dependent on favorable conditions such as pulses of high flows, which appear to stimulate sizeable numbers of sturgeon to spawn. Because of this, successful year classes tend to occur at irregular intervals and therefore numbers of adult fish within a population can fluctuate significantly. Females are highly fecund, and average roughly 200,000 eggs each. Eggs become adhesive subsequent to fertilization, and adhere to the substrate until they hatch 4 to 12 days later, depending on temperature. The yolk sac is absorbed within 7 to 10 days, at which time they are free to move about the estuary. White sturgeon are benthic feeders and juveniles consume mainly crustaceans, especially amphipods and opossum shrimp. Adult diets include mainly fish and estuarine invertebrates, primarily clams, crabs, and shrimps.

2.3 Habitat Requirements

White sturgeon primarily live in brackish portions of estuaries where they tend to concentrate in deep sections having soft substrate. They move according to salinity changes, and may swim into intertidal zones to feed at high tide. Juvenile sturgeon are often found in upper reaches of estuaries in comparison to adults, which suggests that there is a correlation between size and salinity tolerance. Spawning occurs over deep gravel riffles or in deep pools with swift currents and rock bottoms between late February and early June when temperatures are between 8 and 19 degrees Celsius (°C).

2.4 Ecological Interactions

There are valuable commercial, sport, and Native American fisheries for white sturgeon in California. Although they may be vulnerable to overfishing, current management of this species is thought to allow for sustainable yield, and, in addition, white sturgeon are being cultured successfully. Another consequence of their life history is a heightened bioaccumulation potential of toxic substances such as polychlorinated biphenyls and selenium, which is thought to be passed on from the introduced overbite clam, a favorite food of sturgeon. Another possible hazard to these fish is alteration of estuarine habitat, such as in the Sacramento-San Joaquin Delta (Delta), which may decrease successful rearing.

2.5 Key Uncertainties

The potential to restore white sturgeon populations using cultured juvenile white sturgeon is not known.

Common Name	Scientific Name (family)
North American green sturgeon Southern DPS	*Acipenser medirostris* (Acipenseridae)
Legal Status	
Federal:	Threatened (ESA) (Effective list date: July 6, 2006)
State:	Species of Special Concern (DFG)

2.6 Distribution

Green sturgeon have been found from Mexico north to Canada, Russia, Korea, and Japan, although Asian populations are thought to belong to a separate species. In North America, green sturgeon reside in oceanic waters from the Bering Sea south to Mexico, and in rivers from British Columbia south to the Sacramento River. Currently, the only confirmed to spawn in the Sacramento, Klamath, Trinity, and Rogue rivers; however historic spawning rivers also included the Fraser, Columbia, Umpqua, Eel, and South Fork Trinity rivers. The southern Distinct Population Segment (DPS) includes all spawning populations south of the Eel River. Currently, the only known spawning population south of the Eel River is from the Sacramento River. Recent monitoring has documented a few individuals in the San Joaquin River as far upstream as the city of Stockton, but these fish returned to the Delta rapidly and did not remain in the river (J. Israel, U.C. Davis, pers. comm. with B. Chasnoff, Stillwater Sciences, April 2, 2008). Recent sampling efforts have not documented the current presence of green sturgeon in the Restoration Area (Brown 1998, Brown 2000, Moyle 2002, DFG 2007). No direct evidence exists that the southern DPS of North American green sturgeon were historically present in the Restoration Area, though modeling suggests historical habitat may have been suitable for the species (Mora et al. 2007). North American green sturgeon belonging to the southern DPS are present in the Delta well below the Restoration Area (DFG fall midwater trawl, U.C. Davis Suisun Marsh fisheries monitoring, both reported on http://bdat.ca.gov/).

2.7 Life History

Green sturgeon are anadromous, migrating from the ocean between March and July to spawn when temperatures are 8 to 14°C. Females produce 60,000 to 140,000 eggs that are broadcast in swift water and are then fertilized externally. Eggs hatch in about 8 days (at 12.7°C). Juveniles generally outmigrate in spring or autumn between Years 1 and 3. During this time, they remain in close proximity to estuaries, and subsequently migrate far distances as they grow. Males tend to grow slower and mature more rapidly than females, and consequently spend only 3 to 9 years at sea before returning, whereas females spend 3 to 13 years at sea before returning. Mature fish are typically 15 to 20 years old. Juveniles are known to consume small fish and amphipods, while adults often eat sand lances, callianassid shrimp, anchovies, and clams.

2.8 Habitat Requirements

Green sturgeon are assumed to have similar spawning and larval habitat requirements as white sturgeon. Green sturgeon have larger eggs with thinner chorions than white sturgeon, suggesting that green sturgeon may require colder, cleaner water for spawning than white sturgeon. Spawning occurs in fast, deep (greater than 3 m) water in substrates ranging from clean sand to bedrock, although large cobble is preferred. Small amounts of silt appear to increase egg survival by preventing eggs from adhering to each other.

2.9 Ecological Interactions

Green sturgeon in the Delta are caught by anglers that are targeting white sturgeon. Green sturgeon are caught less frequently than white sturgeon and are therefore considered to be more rare.

2.10 Key Uncertainties

Because of low abundance, limited spawning distribution, and low sport and commercial fishing value, the ecology, population dynamics, and life history of green sturgeon have not been well studied. Green sturgeon appear to be diminishing throughout their range. Effects of fisheries targeting this species are not understood, particularly in the Sacramento and Klamath River watersheds.

Common Name	**Scientific Name (family)**
Sacramento sucker	*Catostomus occidentalis* (Catostomidae)

Legal Status

Federal:	None
State:	None

2.11 Distribution

Sacramento suckers are common and have a wide distribution within Central and Northern California including streams and reservoirs of the Sacramento-San Joaquin watershed; on the coast in the Mad, Bear, Eel, Navarro, Russian, Pajaro, and Salinas rivers, and in Lagunitas Creek; and in watercourses within and surrounding the Morro Bay watershed from water transfers. They are also likely to be distributed within Southern California reservoirs that receive water from the California Aqueduct. Sacramento suckers can inhabit a wide array of habitats ranging from cool, high-velocity streams to warm sloughs to low-salinity portions of estuaries.

2.12 Life History

Sacramento suckers typically feed after dark on algae, detritus, and small benthic invertebrates. Sucker growth is highly variable, and includes one specimen from Crystal Springs measuring 560 millimeters (mm) FL and 30 years of age. They first spawn after 4 to 6 years, typically over gravel riffles during February through June when temperatures are approximately 12 to 18°C. Females can spawn annually up to 7 years, and may produce per spawning period between roughly 5,000 to 32,000 eggs that adhere to gravel bits or pieces of detritus. After embryos hatch in 2 to 4 weeks, larvae remain in association with the substrate until they are swept into warm shallow water or among flooded vegetation.

2.13 Habitat Requirements

Sacramento suckers are most commonly found in cold, clear streams and moderate elevation lakes and reservoirs. They choose microhabitats according to size, typically moving from shallow, low-velocity peripheral zones to areas of deeper water as the fish grow. Sacramento suckers can tolerate a wide range of temperature fluctuations from streams that rarely exceed 15 to 16°C to those that reach up to 29 to 30°C. They have also been observed to have high salinity tolerances, and have been found living in reaches where salinities surpass 13 parts per thousand (ppt). Due to their relatively high tolerances, Sacramento suckers have the ability to colonize new habitats readily.

2.14 Ecological Interactions

Sacramento suckers are generally associated with native minnows such as Sacramento pikeminnows, hardhead, and California roach, but can also be common in watercourses dominated by nonnative fishes.

2.15 Key Uncertainties

The ecology of Sacramento suckers is poorly understood, but may play major ecological roles that include keystone species with impacts on invertebrate communities, and high-energy food resources for juvenile salmonids and trout.

Common Name	**Scientific Name (family)**
Sacramento perch	*Archoplites interruptus* (Centrarchidae)

Legal Status

Federal:	None
State:	Species of Special Concern (DFG)

2.15.1 Distribution

The Sacramento perch historically occurred throughout the Central Valley, the Pajaro and Salinas rivers, and Clear Lake. Currently, they only reside in Clear Lake and Alameda Creek within their historical native distribution. Populations that presently occur outside of their native distribution within California include those in the upper Klamath basin and in the Cedar Creek, Mono Lake, Owens River, and Walker River watersheds. They are typically found in reservoirs and farm ponds, and are frequently associated with beds of rooted, submerged, and emergent vegetation, but may also be abundant in shallow, highly turbid environments with no aquatic vegetation.

2.16 Life History

Growth rates are highly variable and are influenced by both biotic and abiotic factors. They can live longer than 9 years, and in California have been known to exceed 1.5 kg (Moyle 2002). Breeding begins during their second or third year from March through early August. Fecundity varies with size, and can exceed 120,000 eggs per female. Spawning takes place in shallow water, generally 20 to 75 cm deep, where deposited eggs adhere to various substrates, including aquatic plants, algae, sticks, clay, and rocks (Mathews 1965, Murphy 1948, Moyle 2002). Initiation of spawning depends on water temperature reaching a suitable range (18 to 29°C; McCarraher and Gregory 1970). Males may create spawning nests out of shallow pits in the substrate, which they defend both before and after fertilization, until larvae are able to leave the nest. After living for 1 to 2 weeks as planktonic larvae, young-of-the-year descend into aquatic vegetation or shallow areas (Moyle 2002). The type of prey consumed by Sacramento perch is dependant upon size, food availability, and time of year. Prey items include small crustaceans, copepods, insect pupae and larvae, other fish including their own young-of-the-year, planktonic and surface organisms, and aquatic insects.

2.17 Habitat Requirements

Sacramento perch can tolerate variable environmental conditions including high turbidity, elevated salinity and alkalinity concentrations, and temperatures up to 30°C (Knight 1985). While they can tolerate temperatures as low as 6°C, low water temperatures might have a pronounced effect on activity and reproduction. They can survive and also reproduce in salinities up to 17 ppt and in sodium-potassium carbonate concentrations of over 0.8 ppt (McCarraher and Gregory 1970). Young-of-the-year tend to inhabit shallow, near-shore areas, often near overhanging vegetation or bed of aquatic plants (Moyle 2002).

2.18 Ecological Interactions

Sacramento perch are thought to be able to persist in their chosen habitats because of the absence of other centrarchids, especially black crappie and bluegill, which are usually excluded from these habitats because of high alkalinities or lack of introduction. When present, these nonnative species can successfully compete for food and space, and possibly prey on perch embryos and larvae. Decline of this species within its native range is assumed to be caused by such factors as interspecific competition, embryo predation, and habitat destruction, especially draining of lakes and sloughs and reduction of aquatic plant beds.

2.19 Key Uncertainties

Limited genetic lineage of populations may restrict the long-term survival potential of Sacramento perch. Reviews of their distribution and status are needed to be certain that populations are being protected.

Common Name	**Scientific Name (family)**
Prickly sculpin	*Cottus asper* (Cottidae)
Legal Status	
Federal:	None
State:	None

2.20 Distribution

Prickly sculpins residing on the coast can be found from the Kenai Peninsula, Alaska, down to the Ventura River in Southern California. Within California, there are also Central Valley populations in low elevations of most streams up to Keswick Dam on the Sacramento River, and in the San Joaquin Valley south to the Kings River. They have also been spread to reservoirs and associated streams within Southern California that receive water from the California Aqueduct. A separate form is also located in Clear Lake. Prickly sculpin can live in a multitude of environments that include fresh, brackish, and seawater, streams that range from small, cold, and clear to large, warm, and turbid, and lakes and reservoirs from small to large, and high level productivity (i.e., eutrophic) to intermediate level of productivity (i.e., mesotrophic).

2.21 Life History

Growth of prickly sculpin can vary greatly, and it is possible they can exceed 200 cm standard length (SL) and live longer than 7 years. Maturity occurs in 2 to 4 years, and spawning can last from February through June when water temperatures reach 8 to 13°C. During this period, sculpins will move into fresh water or intertidal reaches where males will dig nests by forming small hollows in the substrate underneath a rock. Depending on size, females will produce somewhere between about 300 to 11,000 eggs, and since males will mate with more than one female, up to 30,000 embryos can be found in one nest. Males protect the nest until embryos hatch. After hatching, larvae move down into large pools, lakes, and estuaries where they spend 3 to 5 weeks as planktonic fry. At this time, they begin to settle to the bottom, and start to move upstream or into shallow water of lakes or pools. The primary food items for prickly sculpin are large benthic invertebrates, but other aquatic insects, mollusks, isopods, amphipods, and small fish and frogs are also consumed.

2.22 Habitat Requirements

In the Central Valley, prickly sculpin are generally found in medium-sized, low-elevation streams with clear water and bottoms of mixed substrate and dispersed woody debris. The most vital habitat characteristic for sculpin residing in streams may be the presence of cover such as rocks, logs, and overhanging vegetation. In the San Joaquin Valley, they are absent from warm, polluted areas, which suggests their distribution is regulated by water quality. In the area near Friant Dam, prickly sculpin have been found in abundance in the cool flowing San Joaquin River, in the large, warm water Millerton Reservoir, and in the small, shallow Lost Lake where bottom temperatures exceed 26°C in the summer.

2.23 Ecological Interactions

Prickly sculpin are highly migratory, so many populations have been eradicated or reduced because of the construction of barriers on streams.

2.24 Key Uncertainties

The degree of genetic isolation of prickly sculpin populations due to the effects of barriers is unknown.

Common Name	**Scientific Name (family)**
Riffle sculpin	*Cottus gulosus* (Cottidae)
Legal Status	
Federal:	None
State:	None

2.25 Distribution

Riffle sculpin have a scattered distribution pattern throughout California that includes parts of the Sacramento-San Joaquin watershed, the San Francisco Bay Region, and coastal streams having historical connections to the Central Valley. They are also found in coastal streams from Puget Sound in Washington south to the Coquille River in Oregon. Their distribution indicates that they may have difficulties dispersing from one watershed to the next. They are most plentiful in headwaters or just below dams, where there are cold, permanent flows and an abundance of riffles and rocky substrates.

2.26 Life History

Riffle sculpins are benthic, opportunistic feeders. Most growth occurs in warmer months, and with fish rarely exceeding 100 mm total length (TL). Maximum age is not well studied, but is probably no more than 4 years. Sexual maturity is reached in the second year, with spawning occuring between February and April. Females can spawn more than 1,000 eggs, which they deposit on the underside of rocks in swift riffles or inside cavities of submerged logs. Males guard the embryos, which hatch in 11 to 24 days, as well as yolk-sac fry. When fry reach approximately 6 mm TL, they become benthic.

2.27 Habitat Requirements

Riffle sculpin prefer habitats that are fairly shallow and have moderately swift water velocities. They can also live in small pools as long as they are cool and contain adequate cover. They select for areas where water temperatures do not surpass 25 to 26°C, as temperatures greater than 30°C are generally lethal. Riffle sculpin are restricted to flowing water because of their requirement of oxygen levels near saturation.

2.28 Ecological Interactions

Although they cannot easily disperse to new locales, populations can recover from reductions that result from drought and exposure to toxic substances, albeit not quickly. Sculpin numbers can also be reduced when gold dredging practices destroy riffle habitats and loosen gravel used by the sculpin. Because they are sensitive to degradation of water and habitat quality, their presence is generally a sign of habitat healthy for salmonids. Although they generally do not interact with salmonids because of niche separation, they will occasionally prey upon one another. Sculpin can be fairly aggressive toward other benthic fishes, such as speckled dace, and may feed upon or even displace them.

2.29 Key Uncertainties

Little is known about the effects of isolation of populations and the potential for local extirpation.

Common Name	**Scientific Name (family)**
California roach	*Lavinia symmetricus* (Cyprinidae)
Legal Status	
Federal:	None
State:	Sacramento-San Joaquin subspecies - Species of Special Concern (DFG)

2.30 Distribution

California roach were first described from a specimen found in the San Joaquin River near Friant Dam. They are endemic to the Sacramento-San Joaquin Province and have distributions spanning the Sacramento-San Joaquin River watershed, including the Pit River and tributaries to Goose Lake. They also occur in coastal streams including the Navarro, Gualala, and Russian rivers, tributaries to Tomales Bay, Pescadero Creek, and several rivers within the Monterey Bay watershed. Introduced populations have been described in the Eel River, Soquel Creek, and the Cuyama River (although this population may be native). California roach are typically found in small tepid streams, and are most plentiful in mid-elevation streams in the foothills of the Sierras and lower portions of coastal streams.

2.31 Life History

California roach as old as 6 years have been reported but they seldom live longer than 3 years, and growth within this period is highly variable based on season and stream characteristics. Most growth occurs in early summer, and these fish rarely exceed 120 mm SL. Maturity occurs at approximately 45 to 60 mm SL (2 to 3 years). Spawning is regulated by water temperature, and occurs from March to July at temperatures above 16°C. Roach spawn in large aggregations in shallow areas where the dominant substrate is 3 to 5 cm gravel. Depending on their size, females will deposit from 250 to 2,000 adhesive eggs within interstices of the substrate. Hatching takes place in 2 to 3 days, and fry remain in crevices until they are able to actively swim. Roach are omnivores and will digest such items as terrestrial insects, filamentous algae, aquatic insect larvae and adults, crustaceans, and detritus.

2.32 Habitat Requirements

California roach are found in a broad variety of habitats within their wide distribution. They can be found in extreme conditions such as those with high temperatures (30 to 35°C) and low dissolved oxygen (DO) (1 to 2 parts per million (ppm)) as well as cold, clear, and well-aerated conditions. They have been noted from headwaters to lower reaches, including the main channel and highly modified reaches. Roach are unable to tolerate high salinities; mortality has been noted in the Navarro River when tidal influence increased salinity to 9 to 10 ppm.

2.33 Ecological Interactions

The presence of predatory fish can force roach from the open waters of sizeable pools to shallow areas at the periphery of pools and riffles, and totally exclude them from streams. Though the Sacramento-San Joaquin roach subspecies is abundant, it has been eliminated from certain areas where it traditionally occurred. Currently populations are often confined to reaches below barriers such as dams, diversions, and polluted waters containing predatory fishes, and are becoming increasingly more isolated. Additionally, much of their habitat is located within private lands where activities such as heightened grazing pressure leads to diminished stream flow and degraded habitat. Predatory fish are often introduced into remaining deep pools where roach can easily be eliminated.

2.34 Key Uncertainties

Although this subspecies is still abundant, it has disappeared from a portion of its range, and has not had a comprehensive study of its status, systematics, and distribution. The suitability of streams in the Pit and San Joaquin River watersheds that can be managed as refuges for local populations is not known.

Common Name	**Scientific Name (family)**
Hardhead	*Mylopharodon conocephalus* (Cyprinidae)
Legal Status	
Federal:	Sensitive (USFS)
State:	Species of Special Concern (DFG)

2.35 Distribution

Hardhead are endemic to the Sacramento-San Joaquin Province and occur in sections of the larger low- and mid-elevation streams of the Sacramento-San Joaquin watershed. They are largely absent from the lower Central Valley reaches. Hardhead are widely distributed in foothill streams and may be found in a few reservoirs such as Redinger and Kerkhoff reservoirs on the San Joaquin River, which are used for hydroelectric power generation. Their range extends from the Pit River system south to the Kern River. Hardhead also occur in the Russian River watershed.

2.36 Life History

Hardhead begin spawning at 3 years of age during the months of April and May. Spawning may continue through August. Fish in larger rivers or impoundments may migrate as far as 75 kilometers (km) to tributary streams for spawning. Spawning behavior is not known, however observed large aggregations during spawning season indicate behavior similar to hitch or pikeminnows. Females lay 7,000 to 24,000 eggs on gravel in riffles, runs, or the heads of pools. The early life history of hardhead is not well known. Hardhead can reach 30 cm SL in 4 to 6 years in the larger rivers but rarely exceed 28 cm SL in the smaller streams. The maximum size for hardhead is believed to be around 1 m TL and they may live longer than 10 years. Adult hardhead are bottom-feeding omnivores in deep pools. Juveniles may take insects from the surface. Prey items may include insect larvae, snails, algae and aquatic plants, crayfish, and other large invertebrates.

2.37 Habitat Requirements

In the Central Valley, hardhead occupy the relatively undisturbed reaches of low- and mid-elevation streams in the Sacramento-San Joaquin system. They also are known to occur in the mainstem Sacramento. Hardhead prefer water temperatures of above 20º C with optimal temperatures around 24 to 28º C. In the colder Pit River system, they prefer the warmest available water where temperatures peak at 17 to 21ºC. Their distribution is limited to well-oxygenated streams and the surface water of impoundments. They are often found in clear deep pools (greater than 80 cm) and runs with slower water velocities of 20 to 40 centimeters per second (cm/s). Hardhead distribution in streams appears to be limited by their poor swimming ability in colder waters. Larvae and post-larvae may occupy river edges or flooded habitat before seeking deeper low-velocity habitat once they have grown larger.

2.38 Ecological Interactions

Hardhead are often absent from streams where introduced species such as centrarchids are established. They are also usually absent from streams that have been heavily altered by human activity. Hardhead decline appears to be associated with habitat loss and predation by nonnative fishes. When present, hardhead are often found in association with Sacramento pikeminnow and Sacramento suckers which both have similar ecological requirements. Hardhead closely resemble the Sacramento pikeminnow but differ in the following morphological characteristics: the head is not as pointed and the body is deeper and heavier, the maxillary does not reach past the front margin of the eye, and a frenum, or small bridge of skin, connects the premaxillary bone, or upper lip, to the head.

2.39 Key Uncertainties

The decline of hardhead populations is similar to the decline of other native California fishes. Habitat alteration and predation by introduced species has adversely affected hardhead populations throughout their range. It is not known if hardhead populations can be stabilized. There are many information gaps in the life history and habitat requirements of hardhead. Spawning behavior has not been documented and early life history is poorly known.

Common Name	**Scientific Name (family)**
Central Valley hitch	*Lavinia exilicauda exilicauda* (Cyprinidae)

Legal Status

Federal:	None
State:	Sacramento-San Joaquin subspecies – None

2.40 Distribution

Hitch are endemic to the Sacramento-San Joaquin Province. There are three subspecies within this species: *L. e. chi* from Clear Lake (DFG Species of Special Concern), *L. e. harengus* from the Pajaro and Salinas watersheds, and *L. e. exilicauda* from the Sacramento-San Joaquin watershed (Lee et al. 1980). In addition to these regions, hitch are native to the Russian River, and are also found in the San Francisco Bay region and the Monterey Bay region. Additionally, they have been introduced into reservoirs within their native range, and have subsequently been carried via the California Aqueduct to several other reservoirs.

2.41 Life History

Hitch generally live for 4 to 6 years, reaching an ultimate size of up to 350 mm FL. Females grow larger and more rapidly than males, and growth is correlated with productivity and summer temperatures. Maturation can occur in 1 to 3 years for both sexes. Mass spawning migrations typically take place when flows increase from spring rains in locales such as rivers, sloughs, ponds, reservoirs, watershed ditches, and riffles of lake tributaries. Females will lay anywhere from 3,000 to 63,000 eggs, which sink to gravel interstices where they swell to approximately four times their preliminary size and remain lodged within the substrate. Hatching occurs in 3 to 7 days (15 to 22°C) and larvae take another 3 to 4 days to emerge. When they reach adequate size, they move into perennial water bodies where they will shoal for several months in association with aquatic vegetation or other complex vegetation before moving into open water. Hitch are omnivorous and feed in open waters on filamentous algae, aquatic and terrestrial insects, zooplankton, aquatic insect pupae and larvae, and small planktonic crustaceans.

2.42 Habitat Requirements

Hitch occur in warm, low-elevation lakes, sloughs, and slow-moving stretches of river, and in clear, low-gradient streams. Among native fishes, hitch have the highest temperature tolerances in the Central Valley. They can withstand high temperatures of up to 38°C, although they prefer temperatures of 27 to 29°C. Hitch also have moderate salinity tolerances, and can be found in environments with salinities up to 7 to 9 ppt. For spawning, hitch require clean, fine-to-medium gravel and temperatures of 14 to 18°C. When larvae and small juveniles move into shallow areas to shoal, they require vegetative refugia such as tule beds to avoid predators. Larger fish are often found in deep pools containing an abundance of aquatic and terrestrial cover.

2.43 Ecological Interactions

Hitch are declining in numbers, and some populations in streams of the San Joaquin Valley have recently become extirpated. Factors for decline include loss of adequate spawning flows because of dams and diversions, loss of summer rearing habitat, and predation by nonnative fishes. Besides piscine predators, hitch are preyed upon by avian predators, raccoons, mink, otter, and bears, especially during mass spawning migrations. In disturbed habitats, hitch are associated with introduced species such as catfish, centrarchids, and mosquitofish, whereas they are linked with Sacramento perch, Sacramento blackfish, thicktail chub, and splittail in less disturbed locales. When Sacramento blackfish share their same habitat, the two species often hybridize as a consequence of having to share spawning areas.

2.44 Key Uncertainties

Little is known about the abundance, distribution, status, and systematics of hitch.

Common Name	**Scientific Name (family)**
Sacramento blackfish	*Orthodon microlepidotus* (Cyprinidae)
Legal Status	
Federal:	None
State:	None

2.45 Distribution

Sacramento blackfish are assumed to be endemic to the Sacramento-San Joaquin Province, found primarily in Central and Southern California. They are being native to major tributaries and low-elevation reaches of the San Joaquin and Sacramento rivers, the Pajaro and Salinas rivers, and Clear Lake. Although they were abundant in the sizeable lakes of the historical San Joaquin Valley, they are currently common in sloughs and oxbow lakes of the Delta. They occur in a few Central California reservoirs (including Shasta, Alameda, and Lagoon Valley), the San Francisco Bay, Delta, and several Bay tributaries. Additionally, they have been transported via the California Aqueduct to reservoirs receiving water. They have also been introduced into the Lahontan Reservoir, and have consequently spread to lakes of Stillwater Marsh and the Humboldt River watershed.

2.46 Life History

Scale samples suggest that Sacramento blackfish live up to 5 years, although 7 to 9 years may be a better estimate based on inaccuracies associated with using scale samples to age cyprinids. They grow rapidly within their first and second years. In the third year, females tend to fractionally surpass the males in size, and each year thereafter, growth rates diminish. Blackfish seldom exceed 50 mm FL and 1.5 kg. Depending on environmental conditions, blackfish will mature in 1 to 4 years, although males tend to mature sooner. Fecundity is correlated with size, and a single female at lengths of 171 to 466 mm FL can produce about 14,700 to 346,500 eggs, respectively. Spawning occurs in shallow areas with dense aquatic vegetation between May and July when water temperatures range between 12 to 24°C. Fertilized eggs attach to substrate within this aquatic vegetation, and larvae are frequently found in similar shallow areas, although they have been noted in open water. Juvenile blackfish are often found in large schools within shallow areas associated with cover. Sacramento blackfish are generally suspension feeders on planktonic algae and zooplankton.

2.47 Habitat Requirements

Sacramento blackfish are frequently abundant in warm, typically turbid, and often highly modified habitats. They have been found in locations ranging from deep turbid pools with clay bottoms such as the Pajaro River to warm, shallow, seasonally highly alkaline, and greatly turbid environments such as the Lagoon Valley Reservoir. Blackfish have a remarkable ability to adapt to extreme environments such as high temperatures and low DO. Although optimal temperatures range from 22 to 28°C, adults can frequently be found in waters exceeding 30°C, and laboratory experiments have shown juveniles can survive in temperatures up to 37°C. Their ability to tolerate extreme conditions affords them survival during periods of drought or low flow.

2.48 Ecological Interactions

Through introductions and aqueduct linkage, blackfish have been and are continuing to be spread to a number of reservoirs and streams. At this time, consequences and possible impacts of this spread on other organisms is generally not known. In the Lahontan Reservoir, blackfish have replaced native tui chub as the most abundant species. When blackfish densities are elevated, algae blooms, increased nutrient levels, and other various lake ecosystem changes may occur as a result of selective consumption of algae-grazing zooplankton.

2.49 Key Uncertainties

Through introductions, Sacramento blackfish have spread to a number of waterbodies within California, and their complete distribution is not currently known. In turn, their impact on organisms within these areas is not known.

Common Name	**Scientific Name (family)**
Sacramento pikeminnow	*Ptychocheilus grandis* (Cyprinidae)

Legal Status

Federal:	None
State:	None

2.50 Distribution

Sacramento pikeminnow are endemic to the Sacramento-San Joaquin Province and are native to creeks and rivers in the Sacramento-San Joaquin watersheds, the Pajaro and Salinas rivers, the Russian River, the Clear Lake basin, and the upper Pit River. In the 1970s, Sacramento pikeminnow were spread throughout the State through introductions including via the aqueduct system. They are now found in Chorro and Los Osos creeks (tributaries to Morro Bay, San Luis Obispo County), Southern California reservoirs, and Pillsbury Reservoir and the Eel River (Mendocino and Humboldt counties).

2.51 Life History

Sacramento pikeminnow are sexually mature at 3 to 4 years old when they are 22 to 25 cm SL. Males mature before females. Sexually mature fish move upstream in April and May when water temperatures are 15 to 20ºC. Spawning occurs over gravel riffles or the base of pools in smaller tributaries. Spawning occurs at night and has not been well documented but is probably similar to the closely related northern pikeminnow (*P. oregonensis*). Males congregate and await females swimming past, attracting a number of males. The female releases a small number of eggs close to the bottom during a number of passes and the males fertilize the eggs. Fertilized eggs sink and adhere to the gravel. The number of eggs a female carries is related to size. A female 31 to 65 cm SL can spawn 15,000 to 40,000 eggs. Eggs probably hatch in 4 to 7 days at 18ºC. In approximately 1 week, larvae form shoals and occupy shallow areas before moving to deeper water and dispersing. Pikeminnow are slow growing and may live longer than 12 years. The largest known specimen was 115 cm SL and weighed 14.5 kg and was captured in the Kings River basin, Fresno County. Before the introduction of larger predatory fish such as basses, pikeminnows may have been the apex predator in the Central Valley. Pikeminnow prey includes insects, crayfish, larval and mature fish, amphibians, lamprey ammocoetes, and occasionally small rodents. Pikeminnow larger than 150 mm SL are primarily piscivorous.

2.52 Habitat Requirements

Sacramento pikeminnow prefer intermittent and permanent rivers and streams in low- to mid-elevation areas with clear water, deep pools, slow runs, undercut banks, and vegetation. They do not prefer turbid or polluted water or areas where centrarchids have become established. Sacramento pikeminnow prefer summer water temperatures above 15ºC with a maximum of 26ºC. Temperatures above 38ºC are usually lethal. Pikeminnow can tolerate salinities as high as 8 ppt but are rarely found in waters above 5 ppt.

2.53 Ecological Interactions

Sacramento pikeminnow prefer vegetated reaches of streams that are relatively undisturbed. In these types of habitats they are usually associated with other native fish species such as hardhead and Sacramento sucker. They are usually absent where centrarchid bass have become established. Pikeminnow may have adverse impacts on salmonids under some conditions. They opportunistically prey on juvenile salmonids in the Eel River, where pikeminnow were introduced, and in locations in the Sacramento River, where dams and diversions have altered natural habitat conditions, including flows. Sacramento pikeminnow have gained an undeservedly bad reputation because of their predatory nature. Pikeminnow have been implicated for predation on juvenile salmon and affecting their population numbers in the Central Valley system. Both species naturally occur there. Where habitat has been altered, such as the Red Bluff Diversion dam, both salmon and pikeminnow migrations have been delayed, which resulted in large pikeminnow adults preying on outmigrating juvenile salmonids. Efforts to improve fish passage reduced predation and improved the situation. In many instances, pikeminnow populations have suffered because of introduced predator species and adverse affects from altered habitat.

2.54 Key Uncertainties

Sacramento pikeminnow spawning behavior and early life history have not been well documented.

Common Name	**Scientific Name (family)**
Speckled dace	*Rhinichthys osculus* (Cyprinidae)
Legal Status	
Federal:	None
State:	None

2.55 Distribution

Speckled dace are native to all major western watershed systems from Canada south to Sonora, Mexico. They are widely distributed throughout many portions of California, but do not occur in most small coastal watersheds and various other watersheds and watercourses including the San Joaquin watershed, Clear Lake basin, Russian River, and Cosumnes River watershed. Dace are typically considered second or third order stream specialists, although they are known to occupy a variety of habitats such as springs, high-velocity brooks, pools in intermittent streams, higher order streams, and deep lakes. In some watersheds, however, speckled dace are potentially limited to small areas of suitable habitat, which may lead to extinction of these isolated populations.

2.56 Life History

Speckled dace generally live no longer than 3 years and seldom exceed 85 mm FL. Depending on environmental factors, population density, and food availability, speckled dace tend to grow 20 to 30 mm FL in their first year, and 10 to 15 mm in years thereafter;

females growing marginally faster than males. Maturation generally occurs in their second summer, and spawning generally occurs in the months of June and July. Females have been documented to spawn between roughly 200 to 800 eggs within crevices of gravel substrate where they adhere. Hatching occurs in about 6 days (at 18 to 19°C), after which larval fish will remain in the interstices for 7 to 8 days. Upon emergence, fry tend to seek warm shallow reaches associated with cover. Speckled dace are specialized to feed on small, benthic invertebrates living in riffles, but will also consume zooplankton and large terrestrial insects.

2.57 Habitat Requirements

Though speckled dace can occupy a wide variety of habitats, they each tend to have similar characteristics including clear, moving, well-oxygenated water, and plentiful deep cover such as submerged and overhanging vegetation, woody debris, and rocks. They prefer shallow (less than 60 cm) and rocky riffles and runs, and may actually be more abundant in channelized streams or those with reduced flows because of an increased quantity of preferred habitat. Certain populations of dace are tolerant of periodic extreme temperatures ranging from 0 to greater than 31°C, and DO levels as low as 1 ppm. If threshold levels are exceeded and local populations are eliminated or seriously depressed, dace have an extraordinary ability to recolonize and repopulate areas.

2.58 Ecological Interactions

Speckled dace tend to be more abundant in reaches where sculpin are absent because of overlapping food niches. They also display avoidance behavior in response to avian predators, often times being more nocturnally active. When avian predators are scarce, populations may be active during the day as well. Dace may also not be able to persist when there is an overabundance of nonnative predators. During spawning, dace may hybridize with Lahontan redside because they can spawn at the same time and place.

2.59 Key Uncertainties

Speckled dace may be present in headwaters of tributaries on the west side of the San Joaquin Valley but their presence has not been confirmed.

Common Name	**Scientific Name (family)**
Sacramento splittail	*Pogonichthys macrolepidotus* (Cyprinidae)

Legal Status

Federal:	None
State:	Species of Special Concern (DFG)

2.59.1 Distribution and Population Trends

Sacramento splittail are endemic to the Sacramento and San Joaquin river systems of California, including the Delta and the San Francisco Bay. Historically, splittail were found in the Sacramento River as far upstream as Redding, in the Feather River to Oroville, and in the American River upstream to Folsom. In the San Joaquin River they were once documented as far upstream as Friant (Rutter 1908, as cited in Moyle 2002). Splittail are thought to have originally ranged throughout the San Francisco Estuary, with catches reported by Snyder (1905, as cited in Moyle 2002) from southern San Francisco Bay and at the mouth of Coyote Creek.

In wet years Sacramento splittail have been found in the San Joaquin River as far upstream as Salt Slough (Baxter 2000, Baxter 1999, Brown and Moyle 1993, Saiki 1984) and in the Tuolumne River as far upstream as Modesto (T. Ford, Turlock and Modesto Irrigation Districts, pers. comm., 1998), where the presence of both adults and juveniles during wet years in the 1980s and 1990s indicated successful spawning.

When spawning, splittail can be found in the lower reaches of rivers and flooded areas. Otherwise they are primarily confined to the Delta, Suisun Bay, Suisun Marsh, the lower Napa River, the lower Petaluma River, and other parts of the San Francisco Estuary (Meng and Moyle 1995; Meng et al. 1994, as cited in Moyle 2002). In general, splittail are most abundant in Suisun Marsh, especially in drier years (Meng and Moyle 1995), and reportedly rare in southern San Francisco Bay (Leidy 1984). Splittail abundance appears to be highest in the northern and western Delta when population levels are low, and they are somewhat more evenly distributed throughout the Delta during successful year classes (Sommer et al. 1997, Turner 1966; both as cited in Moyle 2002).

Splittail are largely absent from the upper river reaches where they formerly occurred, residing primarily in the lower parts of the Sacramento and San Joaquin rivers and tributaries and in some Central Valley lakes and sloughs (Moyle 2002, Moyle et al. 2004). In wet years, however, they have been known to ascend the Sacramento River as far as the Red Bluff Diversion Dam and into the lower Feather and American rivers (Baxter 2000, Baxter 1999, Baxter et al. 1996, Sommer et al. 1997; all as cited in Moyle 2002). Currently the Sutter and Yolo bypasses along the lower Sacramento River appear to be important splittail spawning areas (Sommer et al. 1997). Splittail now migrate into the San Joaquin River only during wet years, and use of the Sacramento River and its tributaries is likely more important (Moyle 2002).

Accounts of early fisheries suggested that splittail had large seasonal migrations (Walford 1931, as cited in Moyle et al. 2004). Splittail migration now appears closely tied to river outflow. In wet years with increased river flow, adult splittail will still move long distances upstream to spawn, allowing juvenile rearing in upstream habitats. The upstream migration is smaller during dry years, although larvae and juveniles are often found upstream of the city of Sacramento to Colusa or Ord Bend on the Sacramento River (Moyle et al. 2004). Currently, the tidal upper estuary, including Suisun Bay, provides most juvenile rearing habitat, although young-of-the-year may rear over a broader area, including the lower Sacramento River. Brackish water apparently provides optimal rearing habitat for splittail.

The USFWS listed Sacramento splittail as a threatened species on March 10, 1999, because of the reduction in its historical range and because of the large population decline during the drought of 1987 to 1993 (Moyle et al. 1995, USFWS 1996, USFWS 1999a; all as cited in Moyle 2002; DFG 2008). On June 23, 2000, the Federal Eastern District Court of California found the final rule to be unlawful, and on September 22, 2000, remanded the determination back to the USFWS for a reevaluation of the final decision. After a thorough review, the USFWS removed the Sacramento splittail from the list of threatened species (DFG 2008). The DFG (1992) estimates that splittail during most years are only 35 to 60 percent as abundant as they were in 1940. DFG midwater trawl data indicate considerable fluctuations in splittail numbers since the mid-1960s, with abundance often tracking river and Delta outflow conditions. The overall trends include a decline from the mid-1960s to the late 1970s, somewhat of a resurgence through the mid-1980s, and another decline from the mid-1980s through 1994 (Moyle 2002). In 1995 and 1998, the population increased dramatically, demonstrating the extreme short-term and long-term variability of splittail recruitment success and the apparent correlation with river outflow (Sommer et al. 1997). In 2006, when spring outflows were the highest since 1998, beach seine surveys conducted by USFWS in the lower portion of the estuary recorded the highest number of 0+ fish individuals since the surveys began in 1992 (Greiner et al. 2007). Surveys in the upper portions of the estuary showed a drop in catches of splittail and many other Delta fish. These declines were coupled with declines in zooplankton, which are the primary food source for splittail (Hieb et al. 2004). It has been hypothesized that pesticide use in the Central Valley may be responsible for the decline in zooplankton, which is causing the widespread pelagic organism decline (POD) in the Delta (Oros and Werner 2005). Splittail may also be negatively affected by the introduction of the overbite clam (*Potamocorbula amurensis*) in the 1980s, which resulted in a collapse of opossum shrimp (*Neomysis mercedis*) populations, which were a primary source of food for splittail. The recent introduction of the Siberian prawn may similarly pose a threat to splittail food sources, as the Siberian prawns prey on mysid shrimp, which make up a large portion of spittail diets (Moyle et al. 2004). River outflow in February through May can explain between 55 percent and 69 percent of the variability in abundance of splittail young, depending on the abundance measure. Age -0 abundance of splittail declined in the estuary during most dry years, particularly in the drought that began in 1987 (Sommer et al. 1997). Not all wet years result in high splittail recruitment, however, since recruitment success is largely dependent on the availability of flooded spawning habitat. In 1996, for example, most high river flows occurred in December and January, before the onset of the splittail spawning season (Moyle 2002).

In summary, the long-term decline of splittail is most likely due to the following factors, in order of importance: (1) reduction in valley floor habitats, (2) modification of spawning habitat, (3) changed estuarine hydraulics, especially reduced outflows, (4) introduced species, (5) climatic variation, and (6) toxic substances.

2.60 Life History

Adult splittail move upstream beginning in late November to late January, foraging in flooded areas along the main rivers, bypasses, and tidal freshwater marsh areas of

Montezuma and Suisun sloughs and San Pablo Bay before the onset of spawning (Moyle et al. 2004). Feeding in flooded riparian areas before spawning may contribute to spawning success and survival of adults after spawning (Moyle et al. 2004). Splittail are adapted to the wet-dry climatic cycles of Northern California, and thus appear to concentrate their reproductive effort in wet years when potential success is greatly enhanced by the availability of inundated floodplain (Meng and Moyle 1995, Sommer et al. 1997). Splittail are thought to be fractional spawners, with individuals spawning over a protracted period—often as long as several months (Wang 1995). Older fish are believed to begin spawning first (Caywood 1974, as cited in Moyle 2002).

Females are typically highly fecund, with the largest individuals potentially producing 100,000 or more eggs (Daniels and Moyle 1983, Feyrer and Baxter 1998; both as cited in Moyle 2002). Fecundity has been found to be highly variable, however, and may be influenced by food supplies in the year before spawning (Moyle et al. 2004). The adhesive eggs are released by the female, fertilized by one or more attendant males, and adhere to vegetation until hatching (Moyle 2002). Splittail eggs, which are 0.4 to 0.6 inches (1.0 to 1.6 mm) in diameter (Wang 1986, Feyrer and Baxter 1998; both as cited in Moyle 2002), begin to hatch within 3 to 7 days, depending on temperature (Bailey 1994). Eggs laid in clumps hatch more quickly than individual eggs (Moyle et al. 2004). Within 5 to 7 days after hatching, swim bladder inflation occurs and larvae begin active swimming and feeding (Moyle 2002). Little is known regarding the tolerance of splittail eggs and developing larvae to DO, temperature, pH, or other water quality parameters, or to other factors such as physical disturbance or desiccation.

After emergence, most larval splittail remain in flooded riparian areas for 10 to 14 days, most likely feeding among submerged vegetation before moving off floodplains into deeper water as they become stronger swimmers (Sommer et al. 1997, Wang 1986; both as cited in Moyle 2002). Although juvenile splittail are known to rear in upstream areas for a year or more (Baxter 1999, as cited in Moyle et al. 2004), most move to tidal waters after only a few weeks, often in response to flow pulses (Moyle et al. 2004). The majority of juveniles apparently move downstream into shallow, productive bay and estuarine waters from April to August (Meng and Moyle 1995, as cited in Moyle 2002). Growth is likely dependent on the availability of high-quality food, especially in the first year of life (Moyle et al. 2004).

Non-breeding splittail are found in temperatures ranging from 5 to 24°C, depending on the season, and acclimated fish can survive temperatures up to 33°C for short periods (Young and Cech 1996, as cited in Moyle 2002). Juveniles and adult splittail demonstrate optimal growth at 20º C, and signs of physiological distress only above 29ºC (Young and Cech 1995, as cited in Winternitz and Wadsworth 1997).

Because splittail are adapted for living in brackish waters with fluctuating conditions, they are quite tolerant of high salinities and low DO levels. Splittail are often found in salinities of 10 to 18 ppt, although lower salinities may be preferred (Meng and Moyle 1995, as cited in Moyle 2002), and can survive low DO levels (0. 6 to 1. 2 milligrams per liter (mg/L) for young-of-the-year, juveniles, and subadults) (Young and Cech 1995, 1996). Because splittail have a high tolerance for variable environmental conditions

(Young and Cech 1996), and are generally opportunistic feeders (prey includes mysid shrimp, clams, copepods, amphipods, and some terrestrial invertebrates), reduced prey abundance will not likely have major population-level impacts. Year class success appears dependent on access and availability of floodplain spawning and rearing habitats, high outflow, and wet years (Sommer et al. 1997).

2.61 Habitat Requirements

Rising flows appear to be the major trigger for splittail spawning, but increases in water temperature and day length may also be factors (Moyle et al. 2004). Spawning typically takes place on inundated floodplains from February through June, with peak spawning in March and April. Available information indicates that splittail spawn in open areas with moving, turbid water less than 5 feet (1.5 meters) deep, amongst dense annual vegetation and where water temperatures are less than about 15°C (Moyle et al. 2004). Perhaps the most important spawning habitat in the eastern Delta is the Cosumnes River floodplain, where ripe splittail have been observed in flooded fields with cool temperatures less than 15° C, turbid water, and submerged terrestrial vegetation (Crain et al. 2004).

Splittail eggs are deposited in flooded areas amongst submerged vegetation, to which they adhere until hatching. Juveniles are strong swimmers and are usually found in shallow (less than 2 m (6. 6 feet) deep), turbid water (Young and Cech 1996). As their swimming ability increases, juveniles move away from the shallow areas near spawning sites into faster, deeper water (Moyle 2002). Floodplain habitat offers high food quality and production and low predator densities to increase juvenile growth.

Table 2-1 lists select habitat criteria for each Sacramento splittail life history stage based on a review of the scientific literature.

Table 2-1.
Life History Stage Habitat Criteria for Sacramento Splittail

Criteria	Adult Up-Migration and Spawning	Egg/Alevin Rearing	Juvenile Rearing	Adult
Water Temperature (°C)	Increase to 14 to 19°C may trigger spawning[1] spawn where water is <15°C[3]	≤ 18.5°C[3,5]	7 to 28°C; but 21 to 25°C preferred[4]	7 to 24°C[1,4]; but 19°C preferred[4]
Water Salinity (ppt)	≤ 18 ppt[2]		< 16 ppt[4]	10 to 18 ppt, but prefer lower[2]; can briefly tolerate up to 29 ppt[4]
Water Depth (cm)	50 to 200 cm for spawning[1]		< 200 cm[1]	<400 cm[3]
Water Velocity			tidal currents[1]	slow moving[1]
Substrate	spawn on floodplains with flooded vegetation[1]	floodplains with flooded vegetation	variable—may prefer soft bottoms with fine substrate and emergent vegetation[1,2]	variable—may prefer soft bottoms with fine substrate and emergent vegetation[1,2]

Sources:
[1] *Moyle 2002*
[2] *Meng and Moyle 1995*
[3] *Moyle et al. 2004*
[4] *Young and Cech 1996*
[5] *Bailey 1994*

Key:
< = less than
≤ = less than or equal to
°C = degrees Celcius
cm = centimenter
ppt = parts per thousand

2.62 Ecological Interactions

Human activities, such as extensive dam construction, water diversions, channelization, and agricultural watershed, have resulted in splittail disappearing as permanent residents from portions of the Sacramento and San Joaquin valleys. Much of the lowland habitat that they once occupied has been altered so that it is now inaccessible except during wet years. Splittail are preyed upon by striped bass and other piscivores.

2.63 Key Uncertainties

A variety of surveys have compiled splittail abundance data. None of these, however, was specifically designed to systematically sample splittail abundance, and definitive conclusions are therefore not possible (Moyle et al. 2004). Combined, the survey data indicate that some successful reproduction occurs on a yearly basis, but large numbers of juvenile splittail are produced only when outflow is relatively high. Thus, the majority of adult fish in the population probably result from spawning in wet years (Moyle et al. 2004). The stock-recruitment relationship in splittail is apparently weak, indicating that given the right environmental conditions, a small number of large females can produce many young (Sommer et al. 1997, Meng and Moyle 1995; both as cited in Moyle 2002). The effects of pesticides and other toxics on splittail are poorly known but are considered to be potentially negative. The effects of introduced species on splittail are poorly understood, although it is recognized that changes in the food web are likely to have negative consequences.

Common Name	**Scientific Name (family)**
Tule perch	*Hysterocarpus traski traski* (Embiotocidae)
Legal Status	
Federal:	None
State:	None

2.64 Distribution

Historically, the endemic Sacramento-San Joaquin subspecies of tule perch was widespread throughout the lowland rivers and creeks in the Central Valley. Currently in the San Joaquin watershed they occur in the Stanislaus River, occasionally in the San Joaquin River near the Delta, and the lower Tuolumne River. The other subspecies are *H. t. pomo* in the Russian River (listed by DFG as a State Species of Special Concern) and its lower tributaries, and *H. t. lagunae* in Clear Lake. In addition, tule perch have been carried via the California Aqueduct to Silverwood and Pyramid reservoirs in Southern California. They can be found in a number of lowland habitats including lakes, estuarine sloughs, and clear streams and rivers.

2.65 Life History

Tule perch generally search on the bottom or within aquatic plants for food items, but will also feed midwater. They are primarily adapted to feed on small invertebrates and zooplankton. They have been observed to ingest small amphipods, midge and mayfly larvae, small clams, brachyuran crabs, and mysid shrimp. Principal growth occurs within the first year, and a maximum length of 20 cm SL is rarely exceeded. They can live for up to 7 to 8 years, but more often do not survive past 5 years. Age at first maturity varies with environment, and number of young produced varies with size of the female. Females mate multiple times between July and September, and sperm is stored until January when internal fertilization occurs. Young develop within the female, and are born in June or July when food is most abundant. Juveniles begin to school soon after birth.

2.66 Habitat Requirements

Tule perch inhabiting rivers can usually be found within beds of emergent plants, in deep pools, and near banks with complex cover. They require cool, well-oxygenated water for their persistence, and tend not to be found in water exceeding 25°C for extended periods. They have a remarkable capability to tolerate high salinities, and can even persist at salinities of greater than 30 ppt.

2.67 Ecological Interactions

Tule perch that reside in lakes are commonly associated with bluegill and other alien centrarchids, but in streams they are associated primarily with other native fishes. The fact that they are viviparous lowers their vulnerability to competition and predation by nonnative fishes. They tend not to be found in environments dominated by exotic fishes, but this appears to be a result of poor water quality. Poor water quality and toxic chemical exposure seem to be responsible for their extirpation from the Pajaro and Salinas rivers, a majority of the San Joaquin basin, and various other smaller streams. They are rare in areas that have been greatly modified.

2.68 Key Uncertainties

Tule perch appear to have been extirpated from most of the San Joaquin basin, but the exact causes are not known.

Common Name	**Scientific Name (family)**
Threespine stickleback (resident subspecies)	*Gasterosteus aculeatus microcephalus* (Gasterosteidae)
Legal Status	
Federal:	resident subspecies – None
State:	resident subspecies – None

2.69 Distribution

Threespine stickleback populations are distributed in North America from the East Coast southward to Chesapeake Bay, and from the West Coast starting in Alaska southward as far as Baja California. They have resident partially armored (*G. a. microcephalus)*, anadromous fully armored (*G. a. aculeatus)*, and unarmored resident (*G. a. williamsoni*) subspecies, and are found in coastal streams, estuaries, and bays. In California, anadromous populations are present from the Oregon border south to Monterey Bay, while fully plated nonmigratory populations can occur southward as far as San Luis Obispo Creek. In the Central Valley, resident populations may be found from the lower Kings River to approximately Redding in the Sacramento River watershed, including the San Joaquin River where they are present below Friant Dam as well as a small stream above Kerckoff Reservoir. Unarmored threespine sticklebacks (listed as Endangered under the Federal Endangered Species Act (ESA) and California ESA (CESA)) are presently only found naturally in the upper Santa Clara River, San Antonio Creek, and Whitewater River.

2.70 Life History

Though the majority of threespine sticklebacks complete their life cycle within 1 year, there is evidence that they have the potential to survive for up to 2 or 3 years. In California, resident populations rarely exceed 50 mm TL whereas anadromous populations typically reach 80 mm TL, with females often larger than males. All forms of threespine stickleback breed in freshwater from April through July when daylight hours and water temperature increase, although anadromous forms tend to spawn earlier. Males construct nests out of algae, aquatic vegetation, and a sticky kidney secretion in which females will lay 50 to 300 eggs over several spawning periods. Males are responsible for protection and maintenance of the embryos, which hatch in 6 to 8 days at 18 to 20°C. Upon hatch, fry remain in the nest for several days while being cared for by the male, until they begin to swim in shoals.

2.71 Habitat Requirements

Preferred habitat for threespine sticklebacks includes shallow pools in calm water and backwaters containing vegetation, or associated with emergent plants at stream edges located above gravel, sand, and mud. This species requires water clarity that is great enough to allow growth of aquatic plants used for building nests, and because they are visual feeders. Anadromous forms are typically pelagic, but tend to stay close to shore.

This species generally requires cool water (less than 23 to 24°C) for long-term survival, and has broad salinity tolerances. Unless breeding, they shoal to more readily locate prey that consists of bottom-dwelling organisms, or those living in aquatic vegetation.

2.72 Ecological Interactions

Although these fish have spines and bony plates for armor and protection, the combination of their small size, sluggish motion, and preference for shallow water make them an ideal prey for both avian and piscine predators. The distribution of this species is largely determined by predation pressure; when predation is high, they will most likely be found in association with dense aquatic vegetation. They are considered an important prey item of salmonids, and it has been suggested that within Central Valley river systems, pikeminnow predation can eliminate sticklebacks. They act as a host for intermediate stages of bird tapeworm that causes the infected fish to turn white and swim slowly at the surface, increasing vulnerability to kingfishers and herons that then become the final hosts.

2.73 Key Uncertainties

The genetic relationships and taxonomy of threespine stickleback populations are complex and often equivocal, which makes identification of subspecies and legal status difficult. Sticklebacks are often important prey of salmonids, and it is uncertain how the San Joaquin River stickleback population will respond to salmon and steelhead reintroduction.

Common Name	**Scientific Name (family)**
Kern brook lamprey	*Lampetra hubbsi* (Petromyzontidae)

Legal Status

Federal:	None
State:	Species of Special Concern (DFG)

2.74 Distribution

Kern brook lampreys are endemic to the east portion of the San Joaquin Valley, and were first collected in the Friant-Kern Canal. They have subsequently been found in the lower Merced, Kaweah, Kings, and San Joaquin rivers. They are generally found in silty backwaters of rivers stemming from the Sierra foothills.

2.75 Life History

It is thought that this species undergoes metamorphosis in autumn, spawns in spring, and dies thereafter. Not much else is known about Kern brook lampreys, but they presumably have similar life histories to western brook lampreys.

2.76 Habitat Requirements

Ammocoetes are typically found in low velocity portions of shallow pools and along edges of runs. They prefer habitats with substrates of mud and sand, depths of 30 to 110 cm, and summer temperatures that do not exceed 25°C. Ammocoetes are often intermittently abundant in the siphons of the Friant-Kern Canal because this area meets the majority of habitat requirements. Adults tend to prefer riffles containing gravel for spawning, and rubble for cover.

2.77 Ecological Interactions

The Kern brook lamprey is a resident, nonpredatory species. Sculpin, salmonids, and even ravens may eat Kern brook lamprey eggs, spawning adults, and smaller ammocoetes. Some predators may demonstrate an aversion to eating larger ammocoetes, which may be due to secretion of granular cells in the skin.

2.78 Key Uncertainties

There is uncertainty about the potential for extirpation of populations within the San Joaquin watershed because they are largely isolated with most populations found below dams where flow regulation typically does not address lamprey needs. The effects of channelization, work on banks, and elimination or compaction of gravel beds from various management practices on habitats required by Kern brook lamprey are not well understood.

Common Name	**Scientific Name (family)**
Pacific lamprey	*Lampetra tridentata* (Petromyzontidae)
Legal Status	
Federal:	None
State:	None

2.79 Distribution

Pacific lampreys are anadromous fish that have Pacific coast distributions in streams from Hokkaido, Japan, through Alaska, and down to Rio Santo Domingo in Baja, California, although their distribution south of San Luis Obispo is intermittent. There are also landlocked populations from the Upper Klamath River, Goose Lake, and Clair Engle Reservoir on the Trinity River. Anadromous forms spend the predatory portion of their life in the ocean, and move into streams to spawn, while resident forms will spend this portion of their life in lakes and reservoirs before moving into spawning streams.

2.80 Life History

Depending on their location, Pacific lampreys will begin upstream migrations anywhere between January and September, and may spend up to a year maturing in freshwater until they are ready to spawn. Upstream migration seems to take place largely in response to high flows, and adults can move substantial distances unless blocked by major barriers such as the Friant Dam on the San Joaquin River. When they are ready to spawn both sexes will work together to build a nest. Females can produce 20,000 to 200,000 eggs that are released onto the gravel where they will adhere upon fertilization. Lampreys will typically die soon after spawning, though this is not always the case. Hatching occurs in approximately 19 days (at 15°C), and after spending a short period in the gravel, ammocoetes will move up into the current where they are swept downstream to an area with soft substrate where they bury themselves and filter feed on organic materials covering the substrate. Ammocoetes will move about, but will remain in this state for 5 to 7 years before beginning morphological changes enabling them to move into the ocean. When transformation is complete, downstream migration will take place during high-flow events.

2.81 Habitat Requirements

Nests are typically built in gravel-sized substrate, where water velocity is fairly rapid, depths are 30 to 150 cm, and water temperatures are generally 12 to 18°C. Ammocoetes occur in areas with soft substrate.

2.82 Ecological Interactions

While in their predatory phase, lampreys attack a multitude of fishes, including salmon and flatfishes in the ocean, and tui chub, suckers, and redband trout in lakes and reservoirs. Overall, their effect on fish populations is considered to be minimal. They are at times, prey of other organisms such as sharks and sea lions. Highly altered or polluted streams will often exclude Pacific lampreys from inhabiting an area.

2.83 Key Uncertainties

Little is known about the status and biology of this species, in particular if multiple spawning runs exist in some rivers as well as where landlocked forms exist.

Common Name	**Scientific Name (family)**
River lamprey	*Lampetra ayresi* (Petromyzontidae)
Legal Status	
Federal:	None
State:	Species of Special Concern (DFG)

2.84 Distribution

River lamprey can be found in large coastal streams from southwest Alaska to the San Francisco Bay. From what is known about this species, the region of primary abundance in California is in the lower Sacramento-San Joaquin watershed, especially the Stanislaus and Tuolumne rivers. They are additionally present in Sonoma, Salmon, and Alameda creeks, the Napa River, tributaries to the lower Russian River, and possibly the Eel River. Outside of California, their distributions are isolated and greatly scattered.

2.85 Life History

Spawning migrations occur in autumn, and spawning takes place in streams from February through May. One study in Cache Creek found females with fecundities of 11,400 to 37,300 eggs. After spawning, adults will die. After hatching, ammocoetes are hypothesized to spend 3 to 5 years in this stage before metamorphosis into adults. This transformation begins in the summer, and takes 9 to 10 months to complete. These lampreys will then enter the ocean at the end of spring where they spend 3 to 4 months.

During this period, they will display rapid growth while feeding on a variety of fishes such as herring and salmon.

2.86 Habitat Requirements

Nests are created by formation of depressions in gravel riffles. Ammocoetes occur in silty backwaters and eddies.

2.87 Ecological Interactions

River lamprey can have a substantial impact on prey populations, and in certain locations have been identified as a major source of salmon mortality. In laboratory studies, river lampreys are able to hybridize with western brook lamprey, though this has not been observed to occur in the wild.

2.88 Key Uncertainties

River lamprey population trends are unknown in the southern portion of its range, but it is probable they have declined in response to degradation of adequate spawning and rearing habitat in lower sections of large rivers. In California, the extent and timing of spawning migrations is not well known.

Common Name	**Scientific Name (family)**
Western brook lamprey	*Lampetra richardsoni* (Petromyzontidae)
Legal Status	
Federal:	None
State:	None

2.89 Distribution

The western brook lamprey is distributed from southwest Alaska to California including the Sacramento-San Joaquin system. They may occur further south in California in larger streams and rivers.

2.90 Life History

Western brook lampreys spawn in late April to early June when water temperatures exceed 10ºC. They construct nests in gravel riffles, which are occupied by two to four and as many as 12 individuals. Egg number varies from 1,100 to 3,700. Eggs are adhesive and hatch in approximately 10 days at 10 to 15.6ºC. In approximately 30 days ammocoetes burrow into the silt. Survival is apparently high as this species is one of the more abundant fish in the lower courses of streams in the northwestern United States.

Density can be as high as 170 per square meter. Western brook lampreys live 3 to 4 years in California and reach 13 to 18 cm in size. From August until November, the largest ammocoetes metamorphose into adults. These individuals overwinter without feeding, sexually mature in the spring, then spawn and die. The western brook lamprey is non-anadromous and is nonparasitic, consuming algae, including diatoms, and other organic matter.

2.91 Habitat Requirements

The species is abundant in freshwater streams and occupies backwaters and pools where silt and sand substrates exist. They may be restricted to the less disturbed sections of rivers and intolerant of high pollution levels.

2.92 Ecological Interactions

The species is probably more abundant than reported. Sculpin, salmonids, and even ravens may eat western brook lamprey eggs, spawning adults, and smaller ammocoetes. Some predators may demonstrate an aversion to eating larger ammocoetes, which may be due to secretion of granular cells in the skin. Western brook lampreys may compete with the Pacific lamprey, *L. tridentata*, and river lamprey, *L. ayresi*, for nesting space. However, brook lampreys usually nest in smaller streams and further upstream.

2.93 Key Uncertainties

Little work has been done on the biology of the western brook lamprey in California. The more isolated populations of this species may have unique characteristics and may be distinct species.

Common Name	**Scientific Name (family)**
Chinook salmon *Central Valley spring-run* *Central Valley fall-/late fall-run* *Sacramento River winter-run*	*Oncorhynchus tshawytscha* (Salmonidae)

Legal Status

Federal:	
Central Valley spring-run –	Threatened, Designated Critical Habitat
Central Valley fall/late-fall run –	Species of Concern
Sacramento River winter-run –	Endangered, Designated Critical Habitat
State:	
Central Valley spring-run –	Threatened
Central Valley fall-run –	None
Central Valley late fall-run –	Species of Special Concern
Sacramento River winter-run –	Endangered

2.94 Distribution and Population Trends

Chinook salmon are distributed in the Pacific Ocean throughout the northern temperate latitudes in North America and northeast Asia. In North America, they spawn in rivers from Alaska south to the San Joaquin River in California's Central Valley (Healey 1991). In California, populations are found in the Sacramento and San Joaquin basins. Chinook salmon are also widely distributed in smaller California coastal streams north of San Francisco Bay (Allen and Hassler 1986).

Four runs of Chinook salmon occur in California: fall, late fall, winter, and spring (Leet et al. 1992, Mills et al. 1997). Fall-run populations occur throughout the species' range and are currently the most abundant and widespread salmon runs in California (Mills et al. 1997). Winter-run populations are limited to the Sacramento River basin and were listed as endangered under the ESA in 1994. Two apparently distinct stocks of spring-run Chinook (or "spring Chinook") occur in California: a Sacramento-San Joaquin population and a Klamath-Trinity population (Moyle et al. 1995). Moyle et al. (1995) state that although other spring-run Chinook populations may have existed in smaller coastal streams between these two basins, such as the Eel River, they have since been extirpated and there is no evidence of recent spawning in these streams.

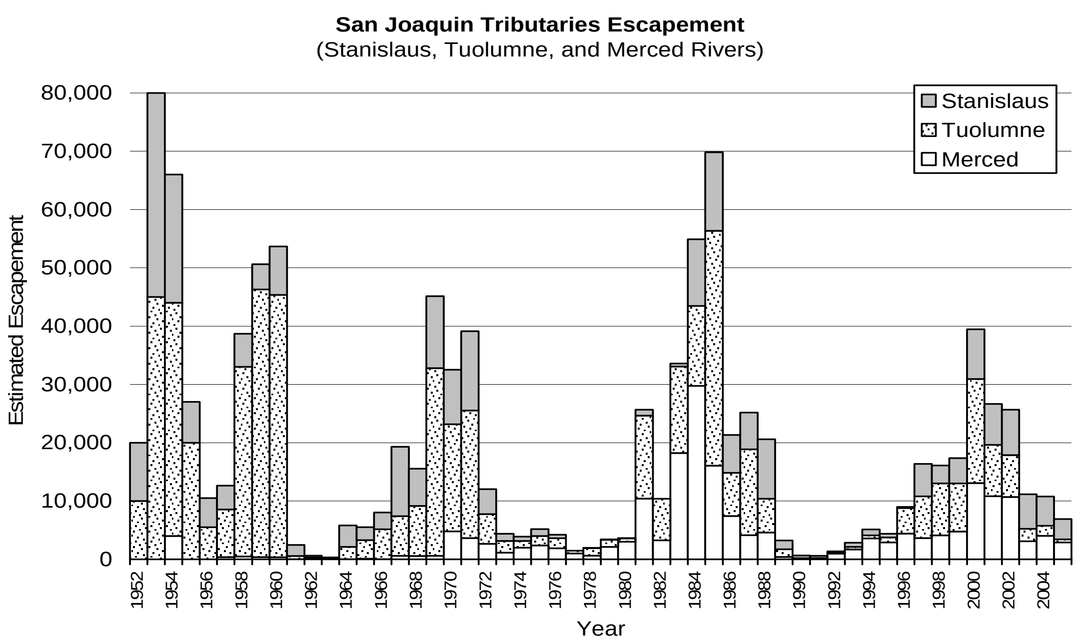
Central Valley spring-run Chinook are listed as threatened under the ESA and CESA. No late fall-run in San Joaquin River Basin fall-run Chinook belong to the Central Valley fall-run and late fall-run Evolutionary Significant Unit (ESU). The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin River basins and their tributaries, east of Carquinez Strait, California. NMFS (1999) determined that listing was not warranted for this fall-run ESU, but subsequently classified it as a Species of Concern on April 15, 2004, because of specific risk factors. Winter-run Chinook are not known to occur in the San Joaquin River basin.

The San Joaquin River system once supported large runs of both spring-run and fall-run Chinook salmon. In the San Joaquin River and its tributaries historic production is estimated to have approached 300,000 fish (Reynolds et al. 1993, as cited in Yoshiyama et al. 1998). The last large run observed in the San Joaquin River was more than 56,000 fish in 1945 (Fry 1961, as cited in Moyle et al. 1995). Adult spring-run Chinook salmon entered the system during periods of high spring snowmelt, held over in deep pools during the summer, then spawned in the upper reaches of the San Joaquin River and its major tributaries—the Stanislaus, Tuolumne, and Merced rivers—in the early fall. Locals living on the San Joaquin River mainstem before dam construction observed spring-run Chinook holding in the summer in pools near Friant Dam, and moving upstream into the gorge of the San Joaquin River to spawn (currently inundated by Millerton Lake) (California Fish and Game Commission 1921). Dam construction and irrigation diversions, which eliminated access to upstream spawning and holding areas, extirpated the spring-run from the basin by the late 1940s (Skinner 1962).

Fall-run Chinook salmon are currently the most abundant race of salmon in California (Mills et al. 1997). In the San Joaquin Basin, fall-run Chinook historically spawned in the mainstem San Joaquin River upstream of the Merced River confluence and in the mainstem channels of the major tributaries. Dam construction and water diversion dewatered much of the mainstem San Joaquin River, limiting fall-run Chinook to the three major tributaries where they currently spawn and rear downstream of mainstem dams.

Fall-run Chinook salmon estimates are available from 1940, but systematic counts of Chinook salmon in the San Joaquin Basin began in 1953, long after construction of large dams on the major San Joaquin basin rivers. Comparable estimates of population size before 1940 are not available. Since population estimates began, the number of fall-run Chinook returning to the San Joaquin Basin annually has fluctuated widely. Most recently, escapement in the Tuolumne River dropped from a high of 40,300 in 1985 to a low of about 100 resulting from the 1987 to 1992 dry period (EA 1997). With increased precipitation and improved flow conditions, escapement has increased to 3,300 in 1996 (EA 1997). From 1971 to 2007, hatchery production is estimated to have composed about 29 percent of the returning adult fall-run Chinook salmon in the San Joaquin basin (PFMC 2008). Figure 2-1 provides a summary of estimated escapement from 1953 to 2005 in the Stanislaus, Tuolumne, and Merced rivers.

Because of extensive hatchery introductions, most spring-run Chinook currently in Sacramento River mainstem have hybridized with fall-run fish, and are heavily introgressed with fall-run Chinook characteristics, particularly with regard to run timing (Yoshiyama et al. 1998). Deer, Mill, and Butte Creek stocks appear to have minimal to no hatchery influence.



Source: DFG grandtab spreadsheet

Figure 2-1.
Fall-run Chinook Salmon Escapement into San Joaquin Basin Tributaries 1952 to 2005

2.95 Life History

2.95.1 Overview

Chinook salmon vary in length of time of freshwater and saltwater residency, and in upstream and downstream migration timing (Healey 1991). Chinook salmon are the largest of the Pacific salmon species, reaching weights of up to 45 kg (99 lb). Chinook salmon have genetically distinct runs differentiated by the timing of spawning migration, stage of sexual maturity when entering fresh water, timing of juvenile or smolt outmigration, and other characteristics (Moyle et al. 1989).

Spring-run Chinook salmon typically spend up to 1 year rearing in fresh water before migrating to sea, perform extensive offshore migrations, and return to their natal river in the spring or summer, several months before spawning (these are also referred to as “stream-type” Chinook). Fall-run (or “ocean-type”) Chinook migrate to sea during their first year of life, typically within 3 months after their emergence from spawning gravels, spend most of their ocean life in coastal waters, and return to their natal river in the fall, a few days or weeks before spawning (Moyle et al. 1989, Healey 1991).

The following information focuses on the life history and habitat requirements of spring-run Chinook salmon although information on fall-run Chinook salmon is also included. Information specific to the San Joaquin River has been included where possible. Chinook salmon environmental requirements and likely temporal occurrence in the SJRRP Restoration Area have been summarized in the Fisheries Management Plan (FMP) (Appendix E). Exhibit A in Appendix E, Fisheries Management Plan has the likely timing and environmental requirements by life history stage for spring-run and fall-run Chinook salmon in the San Joaquin River Restoration Area based on historical information and recent information from Sacramento River basin populations.

2.95.2 Adult Upstream Migration and Spawning

Adult Chinook salmon migrate upstream from the ocean to spawn in their natal streams, although an unknown percentage may stray into other streams, especially during high-water years (Moyle et al. 1989). In the Sacramento system (the closest population of spring-run Chinook salmon to the San Joaquin River), adult spring-run Chinook salmon historically returned to fresh water between late-March and early July (DFG 1998). The spring-run populations in Mill (Johnson et al. 2006), Deer, and Butte creeks (Hill and Webber 1999, Ward et al. 2004) still exhibit this historical migration timing. However, since 1970, most spring-run salmon in the Sacramento River at the Red Bluff Diversion Dam, the Feather River, and the Yuba River migrate during the summer (DFG 1998). Upstream migration in the San Joaquin River historically occurred from March through June (CFGC 1921, Hatton and Clark 1942), and holding occurred from April though mid-July. Weir counts in the Stanislaus River suggest that adult fall-run Chinook salmon in the San Joaquin Basin typically migrate into the upper rivers between late September and mid-November (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007).

There are differences in run timing between basins within the Sacramento and San Joaquin rivers, which have been attributed to the timing of fall decreases in water temperature. Migration timing also appears to be based in part on snow melt flows (NMFS 1999). Therefore, it is likely that current run timing in the San Joaquin River would differ from historical timing. Fall-run Chinook salmon in the San Joaquin system typically enter spawning streams from September through November. The age of returning Chinook salmon adults in California ranges from 2 to 5 years.

Adult Chinook salmon appear to be less capable of passing fish ladders, culverts, and waterfalls during upstream migration than coho salmon or steelhead (Nicholas and Hankin 1989), due in part to slower swimming speeds and inferior jumping ability compared to steelhead (Reiser and Peacock 1985; Bell 1986, as cited in Bjornn and Reiser 1991). Cruising speeds, which are used primarily for long-distance travel, range from 0 to 1 meter per second (m/s) (0 to 3.3 feet per second (feet/s)) (Bjornn and Reiser 1991). Sustained speeds, which can be maintained for several minutes, range from 1 to 3.3 m/s (3.3 to 10.8 feet/s) (Bjornn and Reiser 1991). Darting speeds, which can only be sustained for a few seconds, range from 3.3 to 6.8 m/s (10.8 to 22.3 feet/s) (Bjornn and Reiser 1991). The maximum jumping height for Chinook salmon has been calculated to be approximately 2.4 m (7.9 feet) (Bjornn and Reiser 1991).

Spring-run Chinook spawning in the San Joaquin River historically occurred from late August to October, with peak spawning occurring in September and October (Clark 1942). Fall-run Chinook in the San Joaquin system typically spawn from October through December, with spawning activity peaking in early to mid-November. Upon arrival at the spawning grounds, adult females dig shallow depressions or pits typically 12 inches deep and 12 inches in diameter in suitably sized gravels (a redd), deposit about 1,500 eggs in the bottom during the act of spawning, and cover them with additional gravel. Over a period of 1 to several days, the female gradually enlarges the redd by digging additional pits in an upstream direction (Healey 1991). Redds are typically 10 to 17 meters squared (m^2) (108 to 183 feet square (ft^2)) in size, although they can range from 0.5 to 45 m^2 (5.4 to 484 ft^2) (Healey 1991). Spring-run Chinook redds in Deer Creek average 4 m^2 (42 ft^2) (Cramer and Hammack 1952, as cited in Moyle et al. 1995).

Spring-run Chinook spawners tend to congregate in high densities where stream reaches offer appropriate spawning habitat (Nicholas and Hankin 1989). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Briggs (1953) observed that the defended area could extend up to 6 m (20 feet) in all directions from the redd. Redds may be defended by the female for up to a month (Hobbs 1937). Males do not defend the redd but may exhibit aggressive behavior toward other males while defending spawning females (Shapovalov and Taft 1954). Generally, both male and female adults die within 2 weeks after spawning (Kostow 1995), with females defending the redd until they become too weak to maintain position over the redd or die.

2.95.3 Adult Carcasses

There is substantial evidence that adult salmon carcasses provide significant benefits to stream and riparian ecosystems. In the past, the large numbers of salmon that returned to streams contributed large amounts of nutrients to the ecosystem (Pearsons et al. 2007, Bilby et al. 1998, Hocking and Reimchen 2002). The carcasses provide nutrients to numerous invertebrates, birds, and mammals, and nutrients from decaying salmon carcasses are incorporated into freshwater biota (Helfield and Naiman 2001, Bilby et al. 1998), including terrestrial invertebrates (Hocking and Reimchen 2002). Helfield and Naiman (2001) found that nitrogen from carcasses is incorporated into riparian vegetation. Merz and Moyle (2006) found marine-derived nitrogen incorporated into riparian vegetation and wine grapes. Merz and Moyle (2006) also compared relative nitrogen contribution rates between salmon-abundant and salmon-deprived rivers. The results indicated that salmon-abundant rivers had much more marine-supplied nitrogen than non-salmonid rivers (Merz and Moyle 2006). This nutrient supply is a positive feedback loop in which nutrients from the ocean are incorporated into riparian growth that in turn provides ecosystem services by providing additional growth and development of the riparian system. Carcass nutrients are so important to salmonid stream ecosystems that resource managers spread ground hatchery salmon carcasses in Washington streams (Pearsons et al. 2007).

2.95.4 Spawning Gravel Availability and Redd Superimposition

Dams have reduced the supply of spawning gravels in the many rivers in the Sacramento-San Joaquin River basins. Limitations on spawning gravels often result in redd superimposition, whereby later arriving females dig redds on top of existing redds, causing substantial mortality of the previously deposited eggs (McNeil 1964, Hayes 1987). This has been found to be an important factor affecting Chinook populations in the Tuolumne River, and other rivers where gravel supplies may be limited by dams (EA 1992).

Clark (1942) conducted detailed surveys of the San Joaquin River for available spawning gravel. 417,000 ft^2 of suitable spawning gravel were found in 26 miles of channel between Lanes Bridge and the Kerchoff Powerhouse (upstream of Friant Dam). The Friant Dam inundated 36 percent of this area, leaving about 266,800 ft^2 of suitable spawning gravel in the channel below the dam, though it is not clear what criteria were used to determine suitability.

2.95.5 Egg incubation, Alevin Development, and Fry Emergence

In the Sacramento River, the egg incubation period for spring-run Chinook extends from August to March (Fisher 1994, Ward and McReynolds 2001), whereas the incubation period for fall-run Chinook salmon in the San Joaquin Basin extends from late October through February (Appendix E, Fisheries Management Plan). Egg incubation generally lasts between 40 to 90 days at water temperatures of 6 to 12°C (Bams 1970, Heming 1982; both as cited in Bjornn and Reiser 1991). At temperatures of 2.7°C, time to 50 percent hatching can take up to 159 days (Alderdice and Velsen 1978, as cited by Healey 1991). The alevins remain in the gravel for 2 to 3 weeks after hatching and absorb their yolk sac before emerging from the gravels into the water column during November to March in the Sacramento River basin (Fisher 1994, Ward and McReynolds 2001).

2.95.6 Juvenile Freshwater Rearing

The length of time spent rearing in freshwater varies greatly among spring-run Chinook juveniles. Chinook salmon may disperse downstream as fry soon after emergence; early in their first summer as fingerlings; in the fall as flows increase; or after overwintering in freshwater as yearlings (Healey 1991). Even in rivers such as the Sacramento River where many juveniles rear until they are yearlings, some juveniles probably migrate downstream throughout the year (Nicholas and Hankin 1989). Although fry typically drift downstream following emergence (Healey 1991), movement upstream or into cooler tributaries following emergence has been observed in some systems (Lindsay et al. 1986, Taylor and Larkin 1986).

Juveniles feed voraciously during summer, and display territoriality in feeding areas and are aggressive toward other juvenile Chinook (Reimers 1968, Taylor and Larkin 1986). Experiments conducted in artificial streams suggest that aggressive behavior among juvenile Chinook results in formation of territories in riffles and size hierarchies in pools having abundant food resources and relatively dense groupings of fish (Reimers 1968). Territorial individuals have been observed to stay closer to the substrate, while other individuals may school in hierarchical groups (Everest and Chapman 1972). At night, juveniles may move toward stream margins with low velocities and finer substrates or into pool bottoms, returning to their previous riffle/glide territories during the day (Edmundson et al. 1968; Don Chapman Consultants 1989, as cited in Healey 1991). Reimers (1968) speculated that intraspecific interactions or density-dependent mechanisms may cause downstream displacement of fry.

During winter, juveniles typically reduce feeding activity and hide in cover, conserving energy and avoiding predation and displacement by high flows (Chapman and Bjornn 1969, Meehan and Bjornn 1991). Juvenile Chinook that overwinter in fresh water either migrate downstream in the fall to larger streams that have suitable winter habitat or enter interstitial spaces among cobbles and boulders whereupon growth is suspended for the winter (Chapman and Bjornn 1969, Bjornn 1971, Everest and Chapman 1972, Carl and Healey 1984). Reductions in stream temperatures to 4 to 6°C typically cause downstream migration and/or movement into the interstices of the substrate (Morgan and Hinojosa 1996). In some areas, such as the mainstem Fraser River, juveniles have been observed to continue feeding in the winter (Levings and Lauzier 1991, as cited in Morgan and Hinojosa 1996). Morgan and Hinojosa (1996) suggested that juvenile Chinook may maintain territories in winter as well.

2.95.7 Floodplain Rearing

Juvenile salmonids larger than 2 inches (50 mm) in length in the Sacramento-San Joaquin system also rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook salmon juveniles that reared on the Yolo Bypass than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. Sommer et al. (2001) found that drifting invertebrates, the primary prey of juvenile salmonids, were more abundant on the inundated Yolo Bypass floodplain than in the adjacent Sacramento River. Bioenergetic modeling suggested that increased prey availability on the Yolo Bypass floodplain was sufficient to offset increased metabolic demands from higher water temperatures (5°C) higher than in the mainstem). Gladden and Smock (1990) estimated that annual invertebrate production on two Virginia floodplains exceeded river production by one to two orders of magnitude. In the Virginia study, annual production on the floodplain continuously inundated for 9 months was 3.5 times greater than on the floodplain inundated only occasionally during storms (Gladden and Smock 1990).

Sommer et al. (2001) suggested that the well-drained topography of the Yolo Bypass may help reduce stranding risks when floodwaters recede. Most floodplain stranding occurs in pits or behind structures (e.g., levees or berms) that impede watershed (Moyle et al. 2005). Additionally, research in the Cosumnes River (Moyle et al. 2005) and Tuolumne River (Stillwater Sciences 2007) suggests that flow-through of water on inundated floodplains appeared to be more important for providing suitable habitat for Chinook salmon and other native fish species than the duration of inundation or other physical habitat characteristics. Thus, configuration of restored floodplains to promote active flow-through of river water (i.e., creation of conveyance floodplains) would likely maximize habitat value for juvenile Chinook salmon.

2.95.8 Rearing Densities

Juvenile Chinook densities vary widely according to habitat conditions, presence of competitors, and life history strategies. Lister and Genoe (1970) reported maximum densities of fall-run Chinook emergent fry in stream margin habitats as 7.2 fish per m^2 (0.65 fish per ft^2) and in mid-channel habitats as 7.0 fish per m^2 (0.63 fish per ft^2). In the Red River, Idaho, densities of age 0+ Chinook in August averaged approximately 0.6 fish per m^2 (0.05 fish per ft^2) and declined to approximately 0.13 fish per m^2 (0.01 fish per ft^2) in November in low-gradient (1 to 2 percent) reaches (Hillman et al. 1987). Bjornn (1978, as cited in Bjornn and Reiser 1991) recorded late-summer age -0+ Chinook densities of up to 1.35 fish per m^2 (0.12 fish per ft^2) in a productive Idaho stream, and fewer than 0.8 fish per m^2 (0.07 fish per ft^2) in less productive third- and fourth-order streams. Densities in low-gradient (0.5 percent) reaches of Johnson Creek, Idaho, were more than 1.8 fish per m^2 (0.16 fish per ft^2) (maximum recorded density was 6. 5 fish per m^2 (0.59 fish per ft^2)) in early July, whereas densities in a higher gradient (1.3 percent) reach averaged 0.5 fish per m^2 (0.05 fish per ft^2) (maximum recorded density was 1.4 fish per m^2 (0.13 fish per ft^2)) in late July (Everest and Chapman 1972). Hillman et al. (1987) found that the addition of cobble substrate to heavily-sedimented glides in the fall substantially increased winter rearing densities, with Chinook using the interstitial spaces between the cobbles as cover. Fine sediment can act to reduce the value of gravel and cobble substrate as winter cover by filling interstitial spaces between substrate particles. This may cause juvenile Chinook to avoid these embedded areas and move elsewhere in search of suitable winter cover (Stuehrenberg 1975, Hillman et al. 1987).

2.95.9 Smolt Outmigration and Estuarine Rearing

Juvenile Chinook salmon in the Central Valley move downstream at all stages of their development: most as newly emerged fry dispersing to downstream rearing habitats and others that migrate toward the ocean as they undergo smoltification. Smoltification is the physiological process that increases salinity tolerance and preference, endocrine activity, and gill Na^+-K^+ ATPase activity. It usually begins in late March when the juveniles reach between 70 and 100 mm FL; however, a few fish delay smoltification until they are about 12 months old (yearlings) when they reach an FL between 120 and 230 mm (Appendix E, Fisheries Management Plan). Environmental factors, such as streamflow, water temperature, photoperiod, lunar phasing, and pollution can affect the onset of smoltification (Rich and Loudermilk 1991).

Rotary screw trap studies at the Parrott-Phelan Diversion Dam in Butte Creek probably provide the best available information on the migratory behavior of a natural spring-run salmon population in the Central Valley, because hatchery fish are not planted in Butte Creek and the fall-run salmon do not spawn above the study site. In Butte Creek, the fry primarily disperse downstream from mid-December through February, whereas the subyearling smolts primarily migrate between late-March and mid-June (Hill and Webber 1999; Ward and McReynolds 2001; Ward et al. 2004, Appendix E, Fisheries Management Plan). Spring-run yearlings in Butte Creek migrate from September through March (Hill and Webber 1999; Ward and McReynolds 2001; Ward et al. 2004). Juvenile emigration patterns in Mill and Deer creeks are very similar to patterns observed in Butte Creek, with the exception that Mill Creek and Deer Creek juveniles typically exhibit a later young-of-the-year migration and an earlier yearling migration (Lindley et al. 2004).

Fall-run salmon fry disperse downstream from early-January through mid-March, whereas the smolts primarily migrate between late-March and mid-June in the Stanislaus River, which is nearly identical to the timing of spring-run smolt outmigration in Butte Creek (Appendix E, Fisheries Management Plan). Fall-run yearlings are caught during all months that the rotary screw traps are operating at Oakdale on the Stanislaus River, which occurs from December through June, regardless of flow.

Juvenile Chinook feed and grow as they move downstream in spring and summer; larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989, Beckman et al. 1998), and it appears that in some systems juveniles that do not reach a critical size threshold will not outmigrate (Bradford et al. 2001). Juveniles that do not disperse downstream in their first spring may display high fidelity to their rearing areas throughout the summer rearing period (Edmundson et al. 1968). Nicholas and Hankin (1989) suggested that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures. Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Kjelson et al. (1981) observed peak seine catches of Chinook fry in the Delta correlated with increases in flow associated with storm runoff. Flow accounted for approximately 30 percent of the variability in the fry catch. Photoperiod may also be important, although the relative importance of various outmigration cues remains unclear (Bjornn 1971, Healey 1991).

2.95.10 Smoltification and Estuary Presence

In many systems, an important life history strategy of juvenile salmonids is to leave freshwater soon after emergence and take up residence in tidally functioning estuaries. While this is a common life history strategy among salmon on the Pacific Coast, fry often appear most abundant 2 to 3 months earlier in the Delta than in other Pacific Coast estuaries, perhaps in response to the warmer temperatures in the Delta (Healey 1980, Kjelson et al. 1982). Juvenile salmon less than 70 mm FL are abundant in the Delta from February to April (MacFarlane and Norton 2002). Work in other West Coast estuaries indicates estuarine rearing by fry is an important and critical life stage of salmon development (Levy and Northcote 1982). Fyke trapping and trawling studies conducted by the U.S. Fish and Wildlife Service (USFWS) in the Sacramento River and in the Delta suggest small juvenile Chinook salmon use the shoreline and larger juveniles typically use the center of the channel (USFWS 1994). Other studies along the Pacific Coast also indicate a preference for near-shore areas by less mature juvenile salmon (Dauble et al. 1989, Healey 1991). The diet of fry and juvenile Chinook salmon in the San Francisco Estuary consists of dipterans, cladocerans, copepods, and amphipods (Kjelson et al. 1982). Thus, the near-shore habitats in the Delta and San Francisco Bay are probably valuable to juvenile salmon for rearing purposes, whereas the main deepwater channels are used for migratory purposes.

Juvenile salmon undergo complex physiological changes, called smoltification, in preparation for their life in saltwater (summarized in Quinn 2005). As Chinook salmon begin smoltification, they prefer to rear further downstream where ambient salinity is up to 1.5 to 2.5 ppt (Healey 1980, Levy and Northcote 1982). Smolts enter the San Francisco Estuary primarily in May and June (MacFarlane and Norton 2002) where they spend days to months completing the smoltification process in preparation for ocean entry and feeding (Independent Scientific Group 1996). Within the estuarine habitat, juvenile Chinook salmon movements are dictated by the tidal cycles, following the rising tide into shallow water habitats from the deeper main channels, and returning to the main channels when the tide recedes (Levy and Northcote 1982, Healey 1991). Kjelson et al. (1982) reported that juvenile Chinook salmon demonstrated a diel migration pattern, orienting themselves to near-shore cover and structure during the day, but moving into more open, offshore waters at night. The fish also distributed themselves vertically in relation to ambient light. During the night, juveniles were distributed randomly in the water column, but would school during the day into the upper 3 meters of the water column.

In the San Francisco Estuary, insects and crustaceans dominate the diet of juvenile Chinook salmon (Kjelson et al. 1982, MacFarlane and Norton 2002). Larval fish become increasingly important in the diet as juvenile Chinook salmon approach and enter the ocean (MacFarlane and Norton 2002). Juvenile Chinook salmon spent an average of about 40 days migrating through the Delta to the mouth of San Francisco Bay in spring 1997, but grew little in length or weight until they reached the Gulf of the Farallon Islands (MacFarlane and Norton 2002). After passing through Suisun Bay, juvenile Chinook were primarily feeding on the hemipteran *Hesperocorixa* sp., the calanoid copepod *Eucalanus californicus*, the mysid *Acanthomysis* sp., fish larvae, and other insects (MacFarlane and Norton 2002). In San Pablo Bay, marine crustaceans in the order Cumacea were the dominant prey of juvenile salmon. In the Central Bay, they were feeding on insects, fish larvae, *Ampelisca abdita* (a gammaridean amphipod), and cumaceans (MacFarlane and Norton 2002). Based on the mainly ocean-type life history observed (*i.e.*, fall-run Chinook salmon), MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon show relatively little estuarine dependence and may benefit from expedited ocean entry. It is possible that the absence of extensive marsh habitats outside of Suisun and San Pablo bays and the introduction of exotic species of zooplankton limit important food resources in the San Francisco Estuary that are present in other Pacific Northwest estuaries (MacFarlane and Norton 2002).

2.95.11 Ocean Phase

When fall-run Chinook salmon produced from the Sacramento-San Joaquin system enter the ocean they appear to head north, and rear off the Northern California-southern Oregon coast (Cramer 1987, as cited in Maragni 2001). Fall-run Chinook typically rear in coastal waters early in their ocean life. Ocean conditions are likely an important cause of density-independent mortality and interannual fluctuations in escapement sizes. Central Valley Chinook salmon typically spend between 2 and 4 years at sea (Mesick and Marston 2007). Most mortality experienced by salmonids during the marine phase occurs soon after ocean entry (Pearcy 1992, Mantua et al. 1997).

Williams (2006) notes that in the summer, juveniles are found in slow eddies at either side of the Golden Gate, but that their distribution shifts north beyond Point Reyes later in the fall. Knowledge of California salmon life in the ocean is extremely limited. MacFarlane and Norton (2002) were the first to describe their physiology and feeding behavior in coastal waters of Central California. They compared the feeding rates and condition of fall-run Chinook salmon in the lower end of the Delta (Chipps Island), at the Golden Gate Bridge (representing the end of the Bay), and in the Gulf of the Farallones. Results indicated that feeding and growth were reduced in the Estuary, but increased rapidly in the coastal shelf in the Gulf of the Farallones (MacFarlane and Norton 2002). Fish larvae were the most important prey of juvenile Chinook salmon in the coastal waters of the Gulf of the Farallones (MacFarlane and Norton 2002). Euphausiids and decapod early life stages were also consumed in significant numbers.

Maturing Chinook salmon are abundant in coastal waters ranging from southeastern Alaska to California and their distribution appears to be related to their life history type (stream-type or ocean-type), race, as well as physical factors such as currents and temperature (Healey 1991, Williams 2006). Unfortunately, little information exists on the geographic distribution of Chinook salmon in the sea. Williams (2006) reported coded-wire-tag recoveries by fisheries management area from the Regional Mark Information System database. Results indicated that Central Valley Chinook salmon are primarily distributed between British Columbia and Monterey, California, with the highest percentages found off the San Francisco and Monterey regions.

Sub-adults feed on northern anchovy, juvenile rockfish, euphausiids, Pacific herring, osmerids, and crab megalopae along the Pacific Coast (Hunt et al. 1999). Northern anchovies and rockfish appear to be the most important prey items off the San Francisco coast (Hunt et al. 1999). It is likely that prey items change seasonally and salmon take advantage of such changes with opportunistic feeding (Williams 2006).

2.96 Habitat Requirements

2.96.1 Adult upstream Migration and Spawning

Adult spring-run Chinook require large, deep pools with moderate flows for summer holding during their upstream migration. Marcotte (1984) reported that suitability of pools declines at depths less than 2.4 m (7.9 feet) and that optimal water velocities range from 15 to 37 cm/s (0.5 to 1.2 feet/s). In the John Day River, Oregon, adults usually hold in pools deeper than 1.5 m (4.9 feet) that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986). Adult Chinook salmon require water deeper than 24 cm (0.8 feet) and water velocities less than 2.4 m/s (8 feet/s) for successful upstream migration (Thompson 1972, as cited in Bjornn and Reiser 1991). Water temperatures for adult Chinook holding and spawning are reportedly best when less than 16°C (60.8ºF), and lethal when greater than 27°C (80.6ºF) (Moyle et al. 1995). Spring-run Chinook in the Sacramento River typically hold in pools below 21 to 25ºC (69.8 to 77ºF).

In the Stanislaus River, fall-run Chinook salmon probably do not hold for more than 1 or 2 weeks before spawning, based on the time between when they pass the Riverbank weir (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007) and the initiation of spawning (DFG 2001, 2005).

In July 1942, Clark (1942) observed an estimated 5,000 spring-run Chinook holding in two large pools directly downstream of the Friant Dam. These fish appeared to be in good condition, and held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 22.2ºC (72ºF) in July. Fewer fish were seen in each subsequent visit in August, September, and October, and it was assumed they had moved downstream in search of spawning riffles. A seasonal sand dam was installed in late summer in the San Joaquin, blocking the migration of additional spring-run Chinook into the upper river. By September, fish were observed spawning 10 miles downstream of the Friant Dam. Although some fish may have held in pools downstream of Lanes Bridge, Clark (1942) concluded that the abundant spawning he observed in September and October on riffles between Friant Dam and Lanes Bridge were from fish that held in the pools below the dam and dropped back downstream to spawn.

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries 2 to 3 m (6.6 to 9.8 feet) in width (Vronskiy 1972) to large mainstem rivers (Healey 1991). Chinook prefer low-gradient (less than 3 percent) reaches for spawning and rearing, but will occasionally use higher gradient areas (Kostow 1995). Spawning site (redd) locations are mostly controlled by hydraulic conditions dictated by streambed topography (Burner 1951). Redds are typically located near pool tailouts (i. e., heads of riffles) where high concentrations of intragravel DO are available.

Chinook are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). Depths most often recorded over Chinook redds range from 10 to 200 cm (3.9 to 78 in) and velocities from 15 to 100 cm/s (0.5 to 3.3 feet/s), although criteria may vary between races and stream basins. Fall-run Chinook salmon, for instance, are able to spawn in deeper water with higher velocities, because of their larger size (Healey 1991); spring-run Chinook tend to dig smaller redds and use finer gravels than fall-run Chinook (Burner 1951). Similarly, 4- and 5-year-old fish are generally larger than the average 3-year-old fish, and can spawn in deeper, faster water with larger gravels and cobbles (Appendix E, Fisheries Management Plan).

Substrate particle size composition has been shown to have a significant influence on intragravel flow dynamics (Platts et al. 1979). Chinook salmon may therefore have evolved to select redd sites with specific particle size criteria that will ensure adequate DO delivery to their incubating eggs and developing alevins. In addition, salmon are limited by the size of substrate that they can physically move during the redd building process. Substrates selected likely reflect a balance between water depth and velocity, substrate composition and angularity, and fish size. As depth, velocity, and fish size increase, Chinook are able to displace larger substrate particles. Gravel that is suitable for spawning consists of a mixture of particle sizes from very coarse sand (0.04 0.1 to 6.0 in ((0.1 cm)) 0.25 to 15.24 cm)) to medium-diameter cobbles (6 in (15.2 cm)), with a median diameter (D_{50}) of 1 to 2 inches (2.54 to 5.08 cm) (Appendix E, Fisheries Management Plan). D_{50} values (the median diameter of substrate particles) found withinin a redd) for Chinook salmon redds have been found to range from 10.8 mm (0.43 in) to 78.0 mm (3.12 in) (Kondolf and Wolman 1993). Chinook in the Central Valley have been observed to spawn in substrate with D_{50} ranging from 31 to 66 mm (1.22 to 2.60 in) (Van Woert and Smith 1962, unpubl. data, as cited in Kondolf and Wolman 1993).

2.96.2 Egg incubation, Alevin Development, and Fry Emergence

Suitable water temperatures, DO delivery, and substrate characteristics are required for proper embryo development and emergence. Review of the literature suggests that 5.5 to 12.8°C (42 to 55°F) is the optimum temperature range for incubating Chinook salmon (Donaldson 1955, Combs and Burrows 1957, Combs 1965, Eddy 1972, Bell 1973, Healey 1979, Reiser and Bjornn 1979, Garling and Masterson 1985, Appendix E, Fisheries Management Plan). Sub-lethal stress and/or mortality of incubating eggs resulting from elevated temperatures would be expected to begin at temperatures of about 14.4°C (58°F) for constant exposures (Combs and Burrows 1957, Combs 1965, Healey 1979). A more recent thermal tolerance study of Sacramento River fall-run Chinook salmon eggs found that egg mortality began to occur as water temperature rose above 54°F (12.2°C) but was insignificant at temperatures from 52 to 56°F (11.1 to 13.3°C) (USFWS 1999b).

Delivery of DO to the egg pocket is the major factor affecting survival-to-emergence that is impacted by the deposition of fines in the spawning substrate. Several studies have correlated reduced DO levels with mortality, impaired or abnormal development, delayed hatching and emergence, and reduced fry size at emergence in anadromous salmonids (Wickett 1954, Alderdice et al. 1958, Coble 1961, Silver et al. 1963, McNeil 1964, Cooper 1965, Shumway et al. 1964, Koski 1981). Excessive concentrations of substrate fines smaller than 1 mm in diameter are usually correlated with reduced DO (Chapman

1988, Kondolf 2000). There is a strong possibility that turbidity also affects egg survival as a result of clay-sized particles adhering to the egg's membrane (Stuart 1953), reducing the egg's ability to absorb DO. This effect provides a good explanation of why salmonid eggs survive at high rates under low DO concentrations under clean laboratory conditions but not under natural settings with higher turbidity levels. Silver et al. (1963) found that low DO concentrations were related to mortality and reduced size in Chinook salmon and steelhead embryos. Data suggest that growth may be restricted at oxygen levels below saturation (Silver et al. 1963). Fine sediments in the gravel interstices can also physically impair the fry's ability to emerge through the gravel layer, trapping (or entombing) them within the gravel (Phillips et al. 1975, Hausle and Coble 1976). The DO requirement of Chinook salmon eggs has not been accurately determined under natural field conditions. The critical apparent velocity necessary for high rates of egg survival can vary from 0.65 feet/hr (20 cm/hr) to 50.9 feet/hr (1,550 cm/hr) depending on the DO concentration (Appendix E, Fisheries Management Plan).

2.96.3 Juvenile Freshwater Rearing

Juvenile Chinook salmon tend to use mainstem reaches and estuaries as rearing habitat more extensively than juvenile coho salmon, steelhead, and sea-run coastal cutthroat trout do. Spring-run Chinook typically rear in low-gradient reaches of mainstem rivers areas and large tributaries (Nicholas and Hankin 1989).

Following emergence, fry occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry grow, they move into deeper and faster water further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Everest and Chapman (1972) observed at least small numbers of Chinook fry in virtually all habitats sampled in early summer. Because Chinook fry tend to be larger than coho fry upon emergence, they may tend to use areas with higher water velocities than coho (Murphy et al. 1989, Healey 1991). Most researchers have not addressed fry habitat requirements separately from juvenile summer habitat requirements, but there seems to be consensus that Chinook fry prefer quiet, shallow water with cover. Everest and Chapman (1972) investigated habitat use of emergent Chinook fry; they found fry using depths less than 60 cm (24 in) and water velocities less than 15 cm/s (0.5 feet/s).

Substantial variability in the depth and velocity preferences of juvenile Chinook has been reported. Juvenile Chinook have been observed in virtually all depths and velocities where researchers have sampled (Hillman et al. 1987, Murphy et al. 1989). Lister and Genoe (1970) found that juvenile Chinook preferred slow water adjacent to faster water (40 cm/s (1.3 feet/s)).

2.96.4 Summer Rearing Habitat

Juvenile Chinook salmon appear to prefer pools that have cover provided by banks, overhanging vegetation, large substrates, or large woody debris (LWD). Juvenile densities in pools have been found to increase with increasing amounts of cover (Steward and Bjornn, unpubl. data, as cited in Bjornn and Reiser 1991). Water temperature may also influence juvenile habitat use. In the South Umpqua River basin, Roper et al. (1994)

observed lower densities of juvenile Chinook where water temperatures were higher. In areas where more suitable water temperatures were available, juvenile Chinook salmon abundance appeared to be tied to pool availability.

Temperatures also have a significant effect on juvenile Chinook growth rates. On maximum daily rations in laboratory experiments, growth rate increases with temperature to a certain point and then declines with further increases. Reduced rations can also result in reduced growth rates; therefore, declines in juvenile salmonid growth rates are a function of both temperature and food availability. Laboratory studies indicate that juvenile Chinook salmon growth rates are highest at rearing temperatures from 18.3°C to 21.1°C (65 to 70°F) in the presence of unlimited food (Clarke and Shelbourn 1985, Banks et al. 1971, Brett et al. 1982, Rich 1987), but decrease at higher temperatures, with temperatures greater than 23.3°C (74°F) being potentially lethal (Hanson 1990). Nicholas and Hankin (1989) suggest that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures.

2.96.5 Winter Rearing Habitat

Juvenile Chinook salmon rearing in tributaries may disperse downstream into mainstem reaches in the fall and take up residence in deep pools with LWD, interstitial habitat provided by boulder and rubble substrates, or along river margins (Swales et al. 1986, Healey 1991, Levings and Lauzier 1991). During high-flow events, juveniles have been observed to move to deeper areas in pools and they may also move laterally in search of slow water (Shirvell 1994, Steward and Bjornn 1987). Hillman et al. (1987) found that individuals remaining in tributaries to overwinter chose areas with cover and low water velocities, such as areas along well-vegetated, undercut banks. Lakes may occasionally be used by overwintering Chinook, but they appear to avoid beaver ponds and off-channel slough habitats (Healey 1991).

Considering the historical extent of floodplain inundation in the San Joaquin system, and tule (*Scirpus acutus*) marsh habitat along the San Joaquin River before land development, it is possible that juvenile Chinook salmon, as well as steelhead, reared on inundated floodplains in the San Joaquin River in Reaches 2 through 5. These downstream reaches were inundated for a good portion of the year in normal and wetter years, providing suitable water temperatures for juvenile rearing from January to at least June or July in most years, and perhaps extending into August in wetter years. As snowmelt runoff declined, and ambient temperatures increased, water temperatures in slow-moving sloughs and off-channel areas probably increased rapidly. The extent to which juvenile salmonids would have used the extensive tule marshes and sloughs historically found in Reaches 2, 3, 4, and 5, is unknown.

The quality of juvenile rearing habitat is highly dependant on the riparian vegetation. Riparian vegetation provides shading that lowers river temperatures, provides allochthonous organic matter that drives the salmon’s food web, contributes woody debris for aquatic habitat complexity, bank stability through root systems, and filtration of sediments and nutrients in storm runoff (Helfield and Naiman 2001).

Common Name	**Scientific Name (family)**
Steelhead	*Oncorhynchus mykiss* (Salmonidae)
Legal Status	
Federal:	Threatened (ESA), Designated Critical Habitat
State:	None

2.97 Designation

The Central Valley steelhead DPS includes naturally spawned steelhead occurring in the Sacramento and San Joaquin rivers and their tributaries and extends into the San Francisco Estuary to San Pablo Bay. Steelhead is the term commonly used for the anadromous form of rainbow trout *(Oncorhynchus mykiss)*. Only winter-run steelhead stocks are currently present in Central Valley streams (McEwan and Jackson 1996).

NMFS reaffirmed its listing of the Central Valley steelhead DPS as threatened on January 5, 2006. Critical habitat for this steelhead DPS was designated with an effective date of January 2, 2006. The DPS includes all naturally spawned anadromous *O. mykiss* (steelhead) populations below natural and manmade impassable barriers in the Sacramento and San Joaquin rivers and their tributaries, excluding steelhead from San Francisco and San Pablo bays and their tributaries, as well as two artificial propagation programs: the Coleman Nimbus Fish Hatchery (NFH), and Feather River Hatchery steelhead hatchery programs. Critical Habitat for Central Valley steelhead, which was effective on January 2, 2006, includes the San Joaquin Basin but excludes the Restoration Area. Central Valley steelhead are widely distributed throughout their range but are low in abundance, particularly in the San Joaquin Basin, and their abundance continues to decline (NMFS 2003). Microchemical analyses of otoliths taken from *O. mykiss* in the San Joaquin Basin have verified that the anadromous form of this species occurs in low numbers in the San Joaquin Basin (Zimmerman et al. 2009).

The National Marine Fisheries Service (NMFS) considered including resident *O. mykiss* in listed steelhead DPSs in certain cases, including (1) where resident *O. mykiss* have the opportunity to interbreed with anadromous fish below natural or artificial barriers, or (2) where resident fish of native lineage once had the ability to interbreed with anadromous fish but no longer do because they are currently above artificial barriers and are considered essential for the recovery of the DPS (NMFS 1998). The USFWS, which has authority under the ESA over resident fish, however, concluded that behavioral forms of *O. mykiss* can be regarded as separate DPSs and that lacking evidence that resident rainbow trout need ESA protection, only anadromous forms should be included in the DPS and listed under the ESA (NMFS 1998). The USFWS also did not believe that steelhead recovery would rely on the intermittent exchange of genetic material between resident and anadromous forms (NMFS 1998). In the final rule, the listing includes only the anadromous form of *O. mykiss* (NMFS 1998).

NMFS, however, considers all *O. mykiss* that have physical access to the ocean (including resident rainbow trout) to potentially be steelhead and will treat these fish as steelhead because (1) resident fish can produce anadromous offspring, and (2) it is difficult or impossible to distinguish between juveniles of the different forms.

Adult resident rainbow trout occurring in Central Valley rivers are often larger than Central Valley steelhead. Several sources indicate resident trout in the Central Valley commonly exceed 16 inches (406 mm) in length. Cramer et al. (1995) reported that resident rainbow trout in Central Valley rivers grow to sizes of greater than 20 inches (508 mm). Hallock et al. (1961) noted that resident trout observed in the Upper Sacramento River upstream of the Feather River were 14 to 20 inches (356 to 508 mm) in length. Also, at Coleman National Fish Hatchery, the USFWS found about 15 percent overlap in size distribution between resident and anadromous fish at a length of 22.8 inches (579 mm) (Cramer et al. 1995). Steelhead, therefore, have significant size overlap with resident rainbow trout occurring in Central Valley rivers, and many resident adult trout will be considered by NMFS to be steelhead.

2.98 Geographic Distribution

Steelhead are distributed throughout the North Pacific Ocean and historically spawned in streams along the west coast of North America from Alaska to northern Baja California and the east coast of Russia. The species is currently known to spawn only as far south as Malibu Creek in Southern California (Barnhart 1991, NMFS 1996a). Two major genetic groups exist in the Pacific Northwest, consisting of a coastal and an inland group separated by the Cascade Range crest (Schreck et al. 1986, Reisenbichler et al. 1992). Historic steelhead distribution in the upper San Joaquin River is not known, but in rivers where they still occur they are normally more widely distributed than Chinook (Voight and Gale 1998, as cited in McEwan 2001; Yoshiyama et al. 1996), and are typically tributary spawners. Therefore, it can be assumed steelhead would have been at least as far upstream as Mammoth Pool in the San Joaquin River, and probably in many smaller tributaries.

Lindley et al. (2006), using an Intrinsic Potential habitat model, predicted the historical distribution of steelhead in the Central Valley. They found that at least 81 independent populations of *O. mykiss* were widely distributed throughout the Central Valley, but were relatively less abundant in the San Joaquin River tributaries than the Sacramento River tributaries because of natural migration barriers. Also, many small tributaries to the major San Joaquin River tributaries are of too high gradient or too low flow to have supported *O. mykiss*, consequently steelhead were likely restricted to the mainstems and larger tributaries. Lindley et al. (2006) also found that about 80 percent of the historical spawning and rearing habitat is now behind impassable dams, and 38 percent of the populations identified by the model have lost all of their habitat.

2.99 Population Trends

The National Marine Fisheries Service (NMFS 1996a) has concluded that populations of naturally reproducing steelhead have been experiencing a long-term decline in abundance throughout their range. Populations in the southern portion of the range have experienced the most severe declines, particularly in streams from California's Central Valley and south, where many stocks have been extirpated (NMFS 1996a). During this century, 23 naturally reproducing populations of steelhead are believed to have been extirpated in the western United States. Many more are thought to be in decline in Washington, Oregon, Idaho, and California. Based on analyses of dam and weir counts, stream surveys, and angler catches, NMFS (1997) concluded that, of the 160 west coast steelhead stocks for which adequate data were available, 118 (74 percent) exhibited declining trends in abundance, while the remaining 42 (26 percent) exhibited increasing trends. From this analysis, the NMFS concluded that naturally reproducing populations of steelhead have exhibited long-term declines in abundance across their range. Steelhead stocks in California, however, have declined precipitously. The current population of steelhead in California is roughly 250,000 adults, which is nearly half the adult population that existed 30 years ago (McEwan and Jackson 1996). Current estimates of all steelhead adults in San Francisco Bay tributaries combined are well below 10,000 fish (Leidy 2001). Steelhead were historically in the San Joaquin River, though data on their population levels is lacking (McEwan 2001). Currently the steelhead population in the San Joaquin River is drastically reduced; however, there is evidence that small populations of steelhead persist in the lower San Joaquin River and tributaries (e.g., Stanislaus, Tuolumne, and possibly the Merced rivers) (McEwan 2001). In a review of factors affecting steelhead declines in the Central Valley, McEwan and Jackson (1996) concluded that all were related to water development and water management. Impassible dams have blocked access to historic habitat, forcing steelhead to spawn and rear in lower river reaches, where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001).

2.100 Life History

Steelhead is the term used for the anadromous form of rainbow trout, *Oncorhynchus mykiss*. Steelhead exhibit highly variable patterns throughout their range, but are broadly categorized into winter- and summer-run reproductive ecotypes. Winter steelhead, the most widespread reproductive ecotype, become sexually mature in the ocean, enter spawning streams in fall or winter, and spawn a few months later in winter or late spring (Meehan and Bjornn 1991, Behnke 1992). The general timing of winter steelhead in California is shown in Table 2-2. In the Sacramento River, steelhead generally emigrate as 2-year olds (Hallock et al. 1961) in winter and spring (McEwan 2001). Emigration appears to be more closely associated with size than age, with 6 to 8 inches being the size of most downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Microchemical analysis of Sr:Ca ratios in otoliths extracted from rainbow trout from Central Valley streams (including the mainstem San Joaquin and tributaries) provides evidence that at least some Central Valley rainbow trout populations are polymorphic (i.e., steelhead and resident forms interbreed; steelhead can produce resident progeny and resident adults can produce steelhead progeny). (McEwan 2001; Zimmerman et al. 2009). The decline of Central Valley steelhead may be due in part to the disruption of the ecological linkage between the two life history forms because of impassable dams that have modified the water temperature regime and block access to the majority of their historical habitat (McEwan 2001).

Table 2-2.
Central Valley Winter Steelhead Life History Timing

Life Stage	Month												Notes and Sources
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
Adult migration													Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult migration													Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult migration													Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult migration													Jones & Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning													Mills and Fisher 1994
Spawning													Peak spawning in California streams (McEwan 2001).
Spawning													Jones & Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) return to sea													Mills and Fisher 1994
Incubation													Reynolds et al. 1993

Table 2-2.
Central Valley Winter Steelhead Life History Timing (contd.)

Life Stage	Month	Notes and Sources
Emergence		Eggs hatch in 30 days at 51°F (Leitritz and Lewis 1980, as cited in McEwan 2001).
Emergence		Jones & Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).
Emergence		Jones & Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River Based on the results of emergence analysis for water temperature in SJR, Jones & Stokes estimated that emergence may occur between March 15 and August 30.
Rearing		In California scale analysis showed 70 percent reared for 2 years, 29 percent for 1 year, and 1 percent for 3 years (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration		Geographic area: Sacramento River Migrate downstream in every month of the year, with a peak in the spring, and a smaller peak in the fall (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration		Geographic area: lower Sacramento Migrated past Knights landing in 1998 from late December through early May, and peaked in mid-March (DFG unpublished data, as cited in McEwan 2001).
Outmigration		Reynolds et al. 1993
Outmigration		Jones & Stokes 2002 Foundation Runs Report Geographic area: Woodbridge Dam Outmigrating yearling and older steelhead detected January through July, and young of year detected April through July (Natural Resource Scientists 1998).

Key:

	Span of light activity		Span of moderate activity		Span of peak activity

2.100.1 Adult Upstream Migration and Spawning

In the Central Valley adult winter steelhead migrate upstream during most months of the year, beginning in June, peaking in September, and continuing through February or March (Hallock et al. 1961, Bailey 1954; both as cited in McEwan and Jackson 1996) (Table 2-2). Spawning occurs primarily from January through March, but may begin as early as late December and may extend through April (Hallock et al. 1961, as cited in McEwan and Jackson 1996). Sixty-six adult steelhead were observed at Dennett Dam on the Tuolumne River from October 1 through November 30, 1940, and five in late October 1942 (DFG unpubl. data, as cited in McBain & Trush 2002). In the Central Valley, adult winter steelhead generally return at ages 2 and 3 and range in size from 2 to 12 pounds (0.9 to 5.4 kg) (Reynolds et al. 1993). Some authors have suggested that increased water temperatures trigger movement, but some steelhead ascend into freshwater without any apparent environmental cues (Barnhart 1991). Peak upstream movement appears to occur in the morning and evening, although steelhead have been observed to move at all hours (Barnhart 1991). Steelhead are among the strongest swimmers of freshwater fishes. Cruising speeds, which are used for long-distance travel, are up to 1.5 m/s (5 feet/s); sustained speeds, which may last several minutes and are used to surpass rapids or other barriers, range from 1.5 to 4.6 m/s (5 to 15 feet/s), and darting speeds, which are brief bursts used in feeding and escape, range from 4.3 to 8.2 m/s (14 to 27 feet/s) (Bell 1973, as cited in Everest et al. 1985; Roelofs 1987). Steelhead have been observed making vertical leaps of up to 5.2 m (17 feet) over falls (W. Trush, pers. comm., as cited in Roelofs 1987).

During spawning, female steelhead create a depression in streambed gravels by vigorously pumping their body and tail horizontally near the streambed. Steelhead redds are approximately 10 to 30 cm (4 to 12 in) deep, 38 cm (15 in) in diameter, and oval in shape (Needham and Taft 1934, Shapovalov and Taft 1954). Males do not assist with redd construction, but may fight with other males to defend spawning females (Shapovalov and Taft 1954). Males fertilize the female's eggs as they are deposited in the redd, after which the female moves to the upstream end of the nest and stirs up additional gravel, covering the egg pocket (Orcutt et al. 1968). Females then move 2 to 3 feet upstream and dig another pit, enlarging the redd. Females may dig six to seven egg pockets, moving progressively upstream, and spawning may continue for several days to over a week (Needham and Taft 1934). A female approximately 85 cm (33 in) in length may lay 5,000 to 10,000 eggs, with fecundity being related to age and length of the adult female and varying between populations (Meehan and Bjornn 1991). A range of 1,000 to 4,500 eggs per female has been observed within the Sacramento watershed (Mills and Fisher 1994, as cited in Leidy 2001). In cases where spawning habitat is limited, late-arriving spawners may superimpose their redds atop existing nests (Orcutt et al. 1968).

Although most steelhead die after spawning, adults are capable of returning to the ocean and migrating back upstream to spawn in subsequent years, unlike most other Pacific salmon. Runs may include from 10 to 30 percent repeat spawners, the majority of which are females (Ward and Slaney 1988, Meehan and Bjornn 1991, Behnke 1992). Repeat spawning is more common in smaller coastal streams than in large watersheds requiring a lengthy migration (Meehan and Bjornn 1991). Hatchery steelhead are typically less likely than wild fish to survive to spawn a second time (Leider et al. 1986). In the Sacramento River, California, Hallock (1989) reported that 14 percent of the steelhead were returning to spawn a second time. Whereas females spawn only once before returning to the sea, males may spend 2 or more months in spawning areas and may mate with multiple females, incurring higher mortality and reducing their chances of repeat spawning (Shapovalov and Taft 1954). Steelhead may migrate downstream to the ocean immediately following spawning or may spend several weeks holding in pools before outmigrating (Shapovalov and Taft 1954).

2.100.2 Egg Incubation, Alevin Development, and Fry Emergence

Hatching of eggs follows a 20- to 100-day incubation period, the length of which depends on water temperature (Shapovalov and Taft 1954, Barnhart 1991). In Waddell Creek (San Mateo County), Shapovalov and Taft (1954) found incubation times between 25 and 30 days. Newly hatched steelhead alevins remain in the gravel for an additional 14 to 35 days while being nourished by their yolk sac (Barnhart 1991). Fry emerge from the substrate just before total yolk absorption under optimal conditions; later emerging fry that have already absorbed their yolk supply are likely to be weaker (Barnhart 1991). Upon emergence, fry inhale air at the stream surface to fill their air bladder, absorb the remains of their yolk, and start to feed actively, often in schools (Barnhart 1991, NMFS 1996b). Survival from egg to emergent fry is typically less than 50 percent (Meehan and Bjornn 1991), but may be quite variable, depending upon local conditions.

2.100.3 Juvenile Freshwater Rearing

Juvenile steelhead (parr) rear in freshwater before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require 3 or 4 years before smolting (Roelofs 1985).

Juveniles typically remain in their natal streams for at least their first summer, dispersing from fry schools and establishing feeding territories (Barnhart 1991). Peak feeding and freshwater growth rates occur in late spring and early summer. In Steamboat Creek, a major steelhead spawning tributary in the North Umpqua River watershed, juveniles typically rest in the interstices of rocky substrate in the morning and evening, and rise into the water column and orient themselves into the flow to feed during the day when water temperatures are higher (Dambacher 1991). In the Smith River of Oregon, Reedy (1995) suggested that rising stream temperatures and reduced food availability occurring in late summer may lead to a decline in steelhead feeding activity and growth rates.

Juveniles either overwinter in their natal streams if adequate cover exists or disperse as pre-smolts to other streams to find more suitable winter habitat (Bjornn 1971, Dambacher 1991). As stream temperatures fall below approximately 7°C (44.6°F) in the late fall to early winter, steelhead enter a period of winter inactivity spent hiding in the substrate or closely associated with instream cover, during which time growth ceases (Everest and Chapman 1972). Age 0+ steelhead appear to remain active later into the fall than 1+ steelhead (Everest et al. 1986). Winter hiding behavior of juveniles reduces their metabolism and food requirements and reduces their exposure to predation and high flows (Bustard and Narver 1975), although substantial mortality appears to occur in winter, nonetheless. Winter mortalities ranging from 60 to 86 percent for 0+ steelhead and from 18 to 60 percent for 1+ steelhead were reported in Fish Creek in the Clackamas River basin, Oregon (Everest et al. 1988, as cited in Dambacher 1991). Juveniles appear to compete for food and rearing habitat with other steelhead. Age 0+ and 1+ steelhead exhibit territorial behavior (Everest and Chapman 1972), although this behavior may dissipate in winter as fish reduce feeding activity and congregate in suitable cover habitat (Meehan and Bjornn 1991). Reedy (1995) found that steelhead in the tails of pools did not exhibit territorialism or form dominance hierarchies.

Parr outmigration appears to be more significant in smaller basins, when compared to larger basins (Dambacher 1991). In some areas juveniles migrate out of tributaries despite the fact that downstream rearing habitat may be limited and survival rates low in these areas, suggesting that migrants are responding to density-related competition for food and space, or to reduction in habitat quality in tributaries as flows decline (Dambacher 1991, Peven et al. 1994, Reedy 1995). In relatively small tributaries with good rearing habitat located downstream, early outmigration may represent an adaptation to improve survival and may not be driven by environment- or competition-related limitations (Dambacher 1991).

Steelhead may overwinter in mainstem reaches, particularly if coarse substrates in which to seek cover from high flows are available (Reedy 1995), or they may return to tributaries for the winter (Everest 1973, as cited in Dambacher 1991). Rearing densities for juvenile steelhead overwintering in high-quality habitats with cobble-boulder substrates are estimated to range from approximately 2.7 fish/m^2 (0.24 fish/ft^2) (W. Trush, pers. comm., 1997) to 5.7 fish/m^2 (0.53 fish/ft^2) (Meyer and Griffith 1997). Reedy (1995) observed higher densities of juvenile steelhead in the Middle Fork Smith River, California, than in the Steamboat Creek basin; he suggests that this may be due to the greater availability of large bed particles used for overwintering cover and velocity refuge in the Middle Fork Smith River than in Steamboat Creek. Everest and Chapman (1972) report age 0+ densities of 1.3 to 1.5 fish/m^2 (0.12 to 0.14 fish/ft^2) in preferred habitat in Idaho.

2.100.4 Smolt Outmigration and Estuarine Rearing

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 15 to 20 cm (5.85 to 7.80 in) (Meehan and Bjornn 1991). A length of 14 cm (5.46 in) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). Emigration appears to be more closely associated with size than age, with 6 to 8 inches (152 to 203 mm) being most common for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993). However, evidence suggests that photoperiod is the most important environmental variable stimulating the physiological transformation from parr to smolt (Wagner 1974). During smoltification, the spots and parr marks characteristic of juvenile coloration are replaced by a silver and blue-green iridescent body color (Barnhart 1991) and physiological transformations occur that allow them to survive in salt water.

Less is known regarding the use of estuaries by steelhead than for other anadromous salmonid species; however, the available evidence shows that steelhead in many systems use estuaries as rearing habitat. Smith (1990) concluded that even tiny lagoons unsuitable for summer rearing can contribute to the maintenance of steelhead populations by providing feeding areas during winter or spring smolt outmigration. Estuarine rearing may be more important to steelhead populations in the southern half of the species' range because of greater variability in ocean conditions and paucity of high-quality near-shore habitats in this portion of their range (Bond 2006, NMFS 1996a). Estuaries may also be more important to populations spawning in smaller coastal tributaries because of the more limited availability of rearing habitat in the headwaters of smaller stream systems (McEwan and Jackson 1996).

Most marine mortality of steelhead occurs soon after they enter the ocean and predation is believed to be the primary cause of this mortality (Pearcy 1992, as cited in McEwan and Jackson 1996). Because predation mortality and fish size are likely to be inversely related (Pearcy 1992, as cited in McEwan and Jackson 1996), the growth that takes place in estuaries may be very important for increasing the odds of marine survival (Bond 2006; Pearcy 1992, as cited in McEwan and Jackson 1996; Simenstad et al. 1982, as cited in NMFS 1996a; Shapovalov and Taft 1954).

Steelhead have variable life histories and may migrate downstream to estuaries as age 0+ juveniles or may rear in streams up to 4 years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Steelhead migrating downstream as juveniles may rear for 1 to 6 months in the estuary before entering the ocean (Barnhart 1991). Shapovalov and Taft (1954) conducted exhaustive studies of steelhead and coho salmon in Waddell Creek (Santa Cruz County, California) and found that coho salmon went to sea almost immediately after migrating downstream, but that some of the steelhead remained for a whole season in Waddell Creek lagoon or the lower portions of the stream before moving out to sea. Some steelhead individuals remained in the lagoon rather than moving out to sea and migrated back upstream and underwent a second downstream migration the following year. Coots (1973, as cited in McEwan and Jackson 1996) found that 34 percent of juvenile steelhead in San Gregorio Creek lagoon captured in summer were juveniles less than 100 mm (3.9 in) in length. Bond (2006) found that steelhead reared in the Scott Creek Lagoon, California, doubled in size during summer and composed 85 percent of the returning adult population, despite representing only 8 to 48 percent of the juvenile population. From these studies and others, it has been shown estuaries provide valuable rearing habitat to juvenile and yearling steelhead and not merely a corridor for smolts outmigrating to the ocean.

2.100.5 Ocean Phase

The majority of steelhead spend 1 to 3 years in the ocean, with smaller smolts tending to remain in salt water for a longer period than larger smolts (Chapman 1958, Behnke 1992). Larger smolts have been observed to experience higher ocean survival rates (Ward and Slaney 1988). Steelhead grow rapidly in the ocean in comparison to freshwater rearing habitats, with growth rates potentially exceeding 2.5 cm (0.98 in) per month (Shapovalov and Taft 1954, Barnhart 1991). Steelhead staying in the ocean for 2 years typically weigh 3.2 to 4.5 kg (7 to10 lbs) upon return to fresh water (Roelofs 1985).

Unlike other salmonids, steelhead do not appear to form schools in the ocean. Steelhead in the southern part of the species' range appear to migrate close to the continental shelf, while more northern populations of steelhead may migrate throughout the northern Pacific Ocean (Barnhart 1991).

2.101 Habitat Requirements

2.101.1 Adult Upstream Migration and Spawning

During their upstream migration, adult steelhead require deep pools for resting and holding (Puckett 1975; Roelofs 1983, as cited in Moyle et al. 1989). Deep pool habitat (greater than 1.5 m) (greater than 4.9 ft) is preferred by summer steelhead during the summer holding period.

Because adult winter steelhead generally do not feed during their upstream migration, delays experienced during migration may affect reproductive success. A minimum depth of about 18 cm (7 in) is required for adult upstream migration (Thompson 1972, as cited in Barnhart 1986); however, high water velocity and natural or artificial barriers are more likely to affect adult movements than depth (Barnhart 1986, as cited in McEwan and Jackson 1996). Velocities over 2.4 m/s (8 ft/s) may hinder upstream movement (Thompson 1972, as cited in Everest et al. 1985). Steelhead are capable of ascending high barriers under suitable flow conditions and have been observed to make vertical leaps of up to 5.1 m (17 ft) over waterfalls (W. Trush, pers. comm., as cited in Roelofs 1987). Deep pools provide important resting and holding habitat during the upstream migration (Puckett 1975; Roelofs 1983, as cited in Moyle et al. 1989).

Temperature thresholds for the adult migration and spawning life stages are shown in Table 2-3. These temperatures, however, are from the general literature and may not represent preferred or suitable temperature ranges for Central Valley steelhead stocks. For adult migration, temperatures ranging from 46 to 52°F (8 to 11°C) are considered to be preferred (McEwan and Jackson 1996), while temperatures exceeding 70°F (21°C) are stressful (Lantz 1971, as cited in Beschta et al. 1987). Preferred spawning temperatures range from 39 to 52°F (4 to 11°C) (McEwan and Jackson 1996, Bell 1973, 1991), with 68°F (20°C) being considered stressful and 72°F (22°C) considered lethal. Bell (1986) indicates that preferred temperatures for steelhead spawning range from 3.9º to 9.4ºC (39.0º to 48.9ºF). Steelhead may spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). In the Rogue River watershed, summer steelhead are more likely to spawn in intermittent streams, while winter steelhead typically spawn in permanent streams (Roelofs 1985).

Table 2-3.
Temperature Thresholds for Steelhead Adult Migration and Spawning

Life History Stage	Temperature	Comments	Source
Adult migration	46 to 52°F (8 to 11°C)	Preferred	McEwan and Jackson 1996
	>70°F (21°C)	Stressful (Columbia River)	Lantz 1971, as cited in Beschta et al. 1987
Spawning	39 to 49°F (4 to 9°C)	Preferred	Bell 1973, 1991
	39 to 52°F (4 to 11°C)	Preferred	McEwan and Jackson 1996
	68°F (20°C)	Stressful	FERC 1993
	>72 ºF (>22°C)	Lethal	FERC 1993
	75°F (24°C)	Upper lethal	Bell 1991

Key:
> = greater than
°C = degrees Celcius
°F = degrees Fahrenheit
FERC = Federal Energy Regulatory Commission

Areas of the stream with water depths from about 18 to 137 cm (7 to 53.4 in) and velocities from 0.6 to 1.2 m/s (2 to 3.8 ft/s) are typically preferred for spawning by adult steelhead (Moyle et al. 1989, Barnhart 1991). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). Values reported in the literature for average steelhead redd sizes are as high as 4.7 m2 (50 ft2) (4.64 meters squared) in large alluvial rivers (Bjornn and Reiser 1991) but patches as small as 0.37 m2 (4 ft2) are used, especially in streams where spawning gravel occurs in small isolated patches (Trush, B., McBain & Trush, pers. comm., 2004). D50 values (the median diameter of substrate particles found within a redd) for steelhead have been found to range from 10.4 mm (0.41 in) (Cederholm and Salo 1979, as cited in Kondolf and Wolman 1993) to 46.0 mm (1.8 in) (Orcutt et al. 1968, as cited in Kondolf and Wolman 1993). Steelhead pairs have been observed spawning within 1.2 m (3.9 feet) of each other (Orcutt et al. 1968).

2.101.2 Egg Incubation, Alevin Development, and Fry Emergence

Incubating eggs require DO concentrations, with optimal concentrations at or near saturation. Low DO increases the length of the incubation period and cause emergent fry to be smaller and weaker. Dissolved oxygen levels remaining below 2 ppm result in egg mortality (Barnhart 1991). Temperature thresholds for the incubation, rearing, and outmigration life history stages are shown in Table 2-4. Information available in the literature indicates preferred incubation temperatures ranging from 48 to 52°F (9 to 11°C) (McEwan and Jackson 1996, FERC 1993).

Table 2-4.
Temperature Thresholds for Incubation, Rearing, and Outmigration of Steelhead

Life History Stage	Temperature °F (°C)	Comments	Source
Incubation	50°F (10°C)	Preferred (hatching)	Bell 1991
	48 to 52°F (9 to 11°C)	Preferred (incubation and emergence)	McEwan and Jackson 1996 FERC 1993
	>55°F (>12.8°C)	Stressful	FERC 1993
	60°F (15.6°C)	Lethal	FERC 1993
Juvenile rearing	48 to 52°F (9 to 11°C)	Preferred (fry and juvenile rearing)	McEwan and Jackson 1996
	55 to 65°F (12.8 to 18.3°C)	Optimal	FERC 1993
	62.6 to 68°F (17 to 20°C)	Preferred (Central Valley Steelhead)	Myrick 1998 (p.134)
	50 to 59°F (10 to 15°C)	Preferred	Moyle et al. 1995
	68°F (20°C)	Sustained upper limit	Moyle et al. 1995
	77°F (25°C)	Lethal	FERC 1993
	80°F (27°C)	Lethal critical thermal maximum (Central Valley Steelhead - absolute maximum temperature tolerated)	Myrick 1998
Smolt outmigration	<57°F (14°C)	Preferred	McEwan and Jackson 1996
	>55°F (13°C)	Stressful (inhibit gill ATPase activity)	Zaugg and Wagner 1973, Adams et al., 1975, both as cited in ODEQ 1995

Key:
°C = degrees Celsius
°F = degrees Fahrenheit
FERC = Federal Energy Regulatory Commission
ODEQ = Oregon Department of Environmental Quality

2.101.3 Juvenile Freshwater Rearing Age 0+

After emergence from spawning gravels in spring or early summer, steelhead fry move to shallow-water, low-velocity habitats such as stream margins and low-gradient riffles and will forage in open areas lacking instream cover (Hartman 1965, Everest et al. 1986, Fontaine 1988). As fry increase in size in late summer and fall, they increasingly use areas with cover and show a preference for higher velocity, deeper mid-channel waters near the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). In general, age 0+ steelhead occur in a wide range of hydraulic conditions (Bisson et al. 1988), appearing to prefer water less than 50 cm (19.5 in) deep with velocities below 0.3 m/s (0.98 ft/s) (Everest and Chapman 1972). Age 0+ steelhead have been found to be relatively abundant in backwater pools and often live in the downstream ends of pools in late summer (Bisson et al. 1988, Fontaine 1988).

2.101.4 Age 1+ and Older Juveniles

Older age classes of juvenile steelhead (age 1+ and older) occupy a wide range of hydraulic conditions. They prefer deeper water during the summer and have been observed to use deep pools near the thalweg with ample cover as well as higher-velocity rapid and cascade habitats (Bisson et al. 1982, Bisson et al. 1988). Age 1+ fish typically feed in pools, especially scour and plunge pools, resting and finding escape cover in the interstices of boulders and boulder-log clusters (Fontaine 1988, Bisson et al. 1988). During summer, steelhead parr appear to prefer habitats with rocky substrates, overhead cover, and low light intensities (Hartman 1965, Facchin and Slaney 1977, Ward and Slaney 1979, Fausch 1993). Age 1+ steelhead appear to avoid secondary channel and dammed pools, glides, and low-gradient riffles with mean depths less than 20 cm (7.8 in) (Fontaine 1988, Bisson et al. 1988, Dambacher 1991). As steelhead grow larger, they tend to prefer microhabitats with deeper water and higher velocity as locations for focal points, attempting to find areas with an optimal balance of food supply versus energy expenditure, such as velocity refuge positions associated with boulders or other large roughness elements close to swift current with high macroinvertebrate drift rates (Everest and Chapman 1972, Bisson et al. 1988, Fausch 1993). Reedy (1995) indicates that 1+ steelhead especially prefer high-velocity pool heads, where food resources are abundant, and pool tails, which provide optimal feeding conditions in summer due to lower energy expenditure requirements than the more turbulent pool heads. Fast, deep water, in addition to optimizing feeding versus energy expenditure, provides greater protection from avian and terrestrial predators (Everest and Chapman 1972). Age 1+ steelhead appear to prefer rearing habitats with velocities ranging from 10 to 30 cm/s (0.33 to 0.98 ft/s) and depths ranging from 50 to 75 cm (19.5 to 29.3 in) (Everest and Chapman 1972; Hanson 1977, as cited in Bjornn and Reiser 1991).

During the juvenile rearing period, steelhead are often observed using habitats with swifter water velocities and shallower depths than coho salmon (Sullivan 1986, Bisson et al. 1988), a species they are often sympatric with. In comparison with juvenile coho, steelhead have a fusiform body shape that is better adapted to holding and feeding in swifter currents (Bisson et al. 1988). Where the two species coexist, this generally results in spatial segregation of rearing habitat that becomes most apparent during the summer months. While juvenile coho salmon are strongly associated with low-velocity habitats such as pools throughout the rearing period (Shirvell 1990), steelhead will use riffles (age 0+) and higher velocity pool habitats (age 1+) such as scour and plunge pools in the summer (Sullivan 1986, Bisson et al. 1982).

Preferred rearing temperatures range from 48 to 58°F (9 to 20°C), and preferred outmigration temperatures of less than 57°F (less than 13°C) (McEwan and Jackson 1996) (Table 2-4). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments used steelhead that were reared at the Mokelumne River Fish Hatchery from eggs collected at the NFH (American River). These experiments indicate that Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures ranging from 62.6 to 68°F (17 to 20°C) and a maximum temperature tolerated (lethal critical thermal maximum) of 80°F (27°C).

2.101.5 Winter Habitat

Steelhead overwinter in pools, especially low-velocity deep pools with large rocky substrate or woody debris for cover, including backwater and dammed pools (Hartman 1965, Swales et al. 1986, Raleigh et al. 1984, Fontaine 1988). Juveniles are known to use the interstices between substrate particles as overwintering cover. Bustard and Narver (1975) typically found age 0+ steelhead using 10 to 25 cm (3.9 to 9.7 in) diameter cobble substrates in shallow, low-velocity areas near the stream margin. Everest et al. (1986) observed age 1+ steelhead using logs, rootwads, and interstices between assemblages of large boulders (greater than 100 cm (39 in) diameter) surrounded by small boulder to cobble size (50 to 100 cm (19.7 to 39 in) diameter) materials as winter cover. Age 1+ fish typically stay within the area of the streambed that remains inundated at summer low flows, while age 0+ fish frequently overwinter beyond the summer low-flow perimeter along the stream margins (Everest et al. 1986). In winter, 1+ steelhead prefer water deeper than 45 cm (17.5 in), while age 0+ steelhead often occupy water less than 15 cm (5.8 in) deep and are rarely found at depths over about 60 cm (23.4 in) (Bustard and Narver 1975). Below 7°C (44.6°F), juvenile steelhead prefer water velocities less than 15 cm/s (0.5 ft/s) (Bustard and Narver 1975). Spatial segregation of stream habitat by juvenile coho salmon and steelhead is less pronounced in winter than in summer, although older juvenile steelhead may prefer deeper pools than coho salmon (Bustard and Narver 1975).

2.101.6 Ocean Phase

Little is known about steelhead use of ocean habitat, although changes in ocean conditions are important for explaining trends among Oregon coastal steelhead populations (Kostow 1995). Evidence suggests that increased ocean temperatures associated with El Niño events may increase ocean survival as much as twofold (Ward and Slaney 1988). The magnitude of upwelling, which determines the amount of nutrients brought to the ocean surface and which is related to wind patterns, influences ocean productivity with significant effects on steelhead growth and survival (Barnhart 1991). Steelhead appear to prefer ocean temperatures of 9 to 11.5ºC (48.2 to 52.7ºF) and typically swim in the upper 9 to 12 m (29.5 to 39.6 ft) of the ocean’s surface (Barnhart 1991).

3.0 Nonnative Species

Common Name	**Scientific Name (family)**
Inland silverside	*Menidia beryllina* (Atherinopsidae)

Legal Status

Federal:	None
State:	None

3.1 Distribution

Inland silversides appear to be native to estuaries and lower reaches of coastal rivers from Maine to Florida and along the Gulf Coast from Florida to Veracruz, Mexico. They occur in the Mississippi River from southern Illinois to the coast including Texas and Oklahoma. Inland silversides were introduced from Oklahoma to Blue Lakes and Clear Lake, Lake County, California, in 1967. The species rapidly spread through introductions, both illegal and those authorized by DFG. It was well established in the San Francisco Bay area by 1975, and spread further to the San Joaquin River, and then, via the aqueduct and reservoir system, to Southern California.

3.2 Life History

Silversides grow fast and have a short lifespan. Most fish reach 8 to 10cm TL in their first year and spawn and die during their first or second summer of life. Females grow faster and larger than males and may live a third year. Silversides are fractional spawners, meaning they can spawn using a fraction of their gonads on nearly a daily basis when temperatures reach 15 to 30°C. Females can produce 200 to 2,000 eggs per day during the California spawning season that runs from April to September. Fertilized eggs are adhesive and attach to substrate. Larvae hatch in 4 to 30 days, depending on water temperature. Because of their reproductive capacity, silversides are now the most abundant fish throughout much of their range in California, including the San Francisco Estuary.

3.3 Habitat Requirements

Silversides are most abundant in shallow areas of warm water lakes, reservoirs, and estuaries. Silversides typically shoal in large numbers, in or near protected areas with sand or gravel bottoms. They apparently move into open waters to feed on zooplankton and move into shallow water to avoid predation at night. They occur in waters of 8 to 34°C with optimal temperatures of 20 to 25°C. Optimal salinities appear to be 10 to 15 ppt, but they can survive salinities as high as 33 ppt. Larval survival is highest around 15 ppt.

3.4 Ecological Interactions

The rapid expansion of the silverside population has resulted in their becoming the most abundant fish throughout much of their range in California, including the San Francisco Estuary and the San Joaquin River. They occupy the same shallow water habitat that is important for rearing of juvenile salmon, splittail, and other fishes. Silversides have the potential to deplete zooplankton populations in these habitats that may influence growth and survival of juveniles of other species. Silversides may also prey on eggs and larvae of other species of fishes. Although other factors may also be important, delta smelt populations declined shortly after the introduction of silversides to the estuary.

3.5 Key Uncertainties

The ecological interactions between the introduced silversides and other species have not been well studied. Silversides may have adverse effects on native species through larvae and egg predation or competition for food.

Common Name	**Scientific Name (family)**
Black crappie	*Pomoxis nigromaculatus* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.6 Distribution

The natural range of the black crappie is in the fresh (and rarely brackish) waters of eastern and central North America from Quebec south to the Gulf Coast and from Virginia south to Florida and from Manitoba south to central Texas. Black crappie were probably introduced into California in 1908 when white crappies were also introduced. They were introduced to the Central Valley around 1916 to 1919, and are now well established throughout the state in reservoirs or where there is warm quiet water.

3.7 Life History

Black crappie mature in their second year at around 10 to 20 cm TL. Spawning begins when water temperatures reach 14 to 17ºC in March or April and may continue through July. Males construct 20 to 23 cm diameter nests in shallow water (less than 1 m) near cover such as overhanging banks or aquatic vegetation. Females can produce up to 188,000 eggs depending on the size of the fish. Males defend the nest and fry for a short period. Fry leave the nest and spend the next few weeks in the plankton before settling around structures. Young-of-the-year crappie grow rapidly and can reach 4 to 8 cm their first year. Black crappie can live 13 years and reach 2.2 kg in weight. Black crappie prey in midwater on zooplankton, dipteran larvae, aquatic insects, planktonic crustaceans, and on fish such as threadfin shad, inland silversides, and juvenile striped bass. They may be somewhat less piscivorous than white crappie.

3.8 Habitat Requirements

Black crappie prefer large warm water lakes and reservoirs and are usually associated with abundant aquatic vegetation and sandy/muddy bottoms. They prefer water that is less turbid than that preferred by white crappie. Preferred summer water temperatures are around 27 to 29ºC and temperatures over 37 to 38ºC are usually lethal. They can survive greater temperature extremes than the white crappie. Although their salinity (less than 10 ppt) and DO (greater than 1 to 2 mg/L) tolerances are similar to white crappie they are more abundant in the tidal sloughs of the San Francisco Estuary.

3.9 Ecological Interactions

Black crappie can show population fluctuations in relation to abundance of competing and prey species. Black crappie are ecologically similar to Sacramento perch, a native species. Once black crappie become established, they may displace Sacramento perch from breeding sites, and through predation and competition for food.

3.10 Key Uncertainties

When black crappie first became established in the Delta region in the 1920s the numbers of Sacramento perch declined. It is unclear why black crappie may displace the Sacramento perch.

Common Name	**Scientific Name (family)**
Bluegill	*Lepomis macrochirus* (Centrarchidae)

Legal Status

Federal:	None
State:	None

3.11 Distribution

Bluegill are native to the freshwaters of eastern and southern North America from the St. Lawrence and Mississippi watersheds south to Florida and northeastern Mexico. Bluegill were introduced to California in 1908, and became widely distributed throughout the state. They are probably the most widely distributed freshwater fish in California.

3.12 Life History

Spawning begins in spring when water temperatures reach 18 to 21ºC and may continue through the summer into September. Males construct nests in shallow waters that are approximately 20 to 30 cm in diameter. Females approach the male and deposit eggs in the nest as the male fertilizes them. Fertilized eggs adhere to debris at the bottom of the nest. Males and females spawn with multiple partners. Sunfish in general have a complex mating system. Females lay 2,000 to 50,000 eggs that hatch in 3 to 5 days. The nesting male may guard the newly hatched larvae for a short period until the next breeding cycle. Fry seek shelter in aquatic plants but may forage in the plankton before settling in plant beds near shore at 21 to 25 mm TL. Bluegill are opportunistic feeders, but because their mouths are relatively small they prey on a variety of smaller organisms including aquatic insects, fish, fish eggs, snails, zooplankton, and crayfish.

3.13 Habitat Requirements

Bluegill prefer warm, shallow lakes, reservoirs, ponds, streams, and sloughs but can survive as slow growing populations in colder systems. They are often associated with rooted plants and aquatic vegetation where they can hide and feed. Bluegill spend most of their lives in a small area where they become are able to find food and avoid predators. Bluegill prefer temperatures of 27 to 32ºC but can tolerate temperatures as low as 2 to 5ºC and as high as 40 to 41ºC. Preferred salinities are below 1 to 2 ppt but bluegill have been recorded in salinities up to 5 ppt in the San Francisco Estuary. Salinities of 12 ppt are lethal to bluegill. Maximum growth and reproduction occur in clear waters and DO of 4 to 8 mg/L.

3.14 Ecological Interactions

This species is known to hybridize with warmouth, green sunfish, and pumpkinseed sunfish. Bluegills are often associated with assemblages of other nonnative fishes such as largemouth bass, green sunfish, redear sunfish, catfish, golden and red shiners, carp, inland silverside, and western mosquitofish. Bluegill also sometimes serve as cleaner fish for other fishes (i.e., smallmouth bass). Because bluegill are so adaptive, aggressive, and prolific, they are an alien fish that limit native fish populations through predation on larvae and indirect effects that may make native fish more vulnerable to predators.

3.15 Key Uncertainties

The long-term effects of bluegill on native fishes are not known.

Common Name	**Scientific Name (family)**
Green sunfish	*Lepomis cyanellus* (Centrarchidae)

Legal Status

Federal:	None
State:	None

3.16 Distribution

The green sunfish is native to the fresh waters of east-central North America including the great Lakes and most of the Mississippi watershed. They now occur in every state in the United States including California because of introductions. They were first introduced to California in 1891, and have been spread throughout the state since then.

3.17 Life History

Spawning begins when water temperatures reach around 19°C. Males dig 15 to 38 cm diameter nests in 4 to 50 cm deep water. Females hover around the nests while males court and spawn with them. Males and females spawn with multiple partners. Females carry 2,000 to 10,000 eggs which when fertilized, adhere to the nest substrate, and are guarded by males. Eggs hatch in 5 to 7 days. Larvae feed on zooplankton for several days before seeking cover in vegetation. Green sunfish are opportunistic predators and feed on a wider spectrum of benthic invertebrates, zooplankton, and small fish than other species of sunfish. Green sunfish rarely grow larger than 15 cm SL although they can reach 30 cm SL and live 10 years. They often form stunted populations since they can reproduce at a small size (5 to 7 cm SL). Green sunfish are very aggressive and older fish can be territorial forming dominance hierarchies. This aggressiveness makes green sunfish susceptible to angling. They feed on invertebrates and small fish including insects, zooplankton, benthic invertebrates, crayfish, and fish larvae including their own.

3.18 Habitat Requirements

Green sunfish can survive temperatures greater than 38°C but prefer 26 to 30°C. They can withstand low oxygen levels (less than 1 mg/L) but avoid salinities higher than 1 to 2 ppt. They are good colonizers and can reoccupy dewatered stream reaches by surviving in intermittent pools. Green sunfish are found in small, warm, streams, ponds and lake edges. They usually are found associated with dense growths of emergent vegetation and brush piles. They are often the sole species in warm isolated pools in intermittent streams that have been affected by human disturbance. Green sunfish are capable of surviving where other species cannot.

3.19 Ecological Interactions

Water withdrawals may be enhancing intermittent pool-type habitat that this species prefers. They are part of the introduced predator species complex in California, and they are aggressive and form stunted populations that compete with or prey on native species such as the California roach, sticklebacks, and minnows. They prevent the reestablishment of native species if their habitat requirements are similar. They are known to hybridize with bluegill and pumpkinseed sunfish.

3.20 Key Uncertainties

It is not known how to prevent further spread or avoid creation of habitat beneficial to this species, or how to eradicate this species where it does the most harm.

Common Name	**Scientific Name (family)**
Largemouth bass	*Micropterus salmoides* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.21 Distribution

The native range of largemouth bass is from northeastern Mexico east to Florida, and north including the Mississippi River to Ontario and Quebec, and along the Atlantic seaboard to South Carolina. Largemouth bass were first introduced to California in 1891, from Illinois and were quickly distributed throughout California. A second introduction of Florida largemouth bass occurred in 1959, that also became widely distributed and promptly hybridized with the northern strain. Largemouth bass now occur throughout California in streams, lakes, and reservoirs.

3.22 Life History

Largemouth bass become sexually mature during their second or third year when they reach approximately 18 to 21 cm TL in males and 20 to 25 cm in females. Males construct nests in gravel or among aquatic vegetation in approximately 1 to 2 m of water when water temperatures reach 15 to 16º C. Females may lay eggs in multiple nests and may lay a total of 2,000 to 94,000 eggs. Eggs adhere to the substrate and hatch in 2 to 7 days depending on water temperature. Males guard the eggs and then the fry for up to 4 weeks. Fry form large schools that feed on zooplankton and patrol along vegetation and cover in shallower waters. Fry are vulnerable to predation at this time. Growth rates appear to be more variable for largemouth than for smallmouth bass. Many variables including genetics, food availability, water temperature, and competition may influence growth. Largemouth bass live to be greater than 4 years old and exceed 45 cm TL. The largest largemouth on record weighed 9.9 kg and was caught in Castaic Reservoir, Los Angeles County. The Florida strain of bass, or hybrid, appears to grow larger than the northern strain. Largemouth bass eat zooplankton and insects when they are fry and then aquatic insects, fish fry, and small crustaceans as they grow. Adult largemouth bass are adaptable predators and can feed on a variety of prey including larger invertebrates, amphibians, small mammals, and fish. Largemouth bass may also cannibalize young of their own species, including when they are fry and swim in large schools.

3.23 Habitat Requirements

Largemouth bass prefer warm, quiet water lakes, ponds, sloughs, abandoned gravel mine pits, and backwaters of low gradient streams, with relatively low turbidity, and with vegetative cover. Largemouth bass are frequently found in disturbed areas and in association with other nonnative species especially other centrarchids. Areas with current velocities less than 6 cm/s (0.2 feet/s) would constitute optimal habitat and velocities over 10 cm/s (0.34 feet/s) would likely be avoided. Adults prefer water temperatures of 25 to 30º C but can tolerate water temperatures of 37ºC. Juveniles may prefer slightly warmer waters (30 to 32ºC). Largemouth bass can tolerate DO as low as 1 mg/ and salinities as high as 16 ppt but they tend to avoid salinities over 5 ppt. Their adaptability to habitat extremes enables largemouth bass to survive in intermittent pools caused by drought or diversions. As a result they can persist in an area and their populations can quickly recover once flows resume. Habitat suitability for largemouth bass is not likely determined by depth as much as by velocity, temperature, and prey availability. In the Delta, largemouth bass and other centrarchid populations appear to be responding positively to increased habitat provided by an introduced aquatic plant, *Egeria densa*.

3.24 Ecological Interactions

Wherever largemouth bass are present they generally have adverse impacts on native species because of predation. In isolated water bodies they are capable of causing native species extirpations, and in larger systems they can effectively extirpate native species from certain areas. Largemouth bass can selectively feed on certain species to the point where they influence those populations. The reduction in a population of a native species, such as a planktivore, by largemouth bass can result in a cascade effect that may cause changes to not only species composition in a water body but water quality parameters as well.

3.25 Key Uncertainties

The predation dynamics associated with increased bass and other centrarchid populations on salmonids and other native species is poorly understood.

Common Name	**Scientific Name (family)**
Pumpkinseed	*Lepomis gibbosus* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.26 Distribution

Pumpkinseed are native to eastern North America from Canada to Georgia and in the upper Mississippi watershed west to South Dakota. They were apparently introduced to California in the early 1900s, and have been reported from the Klamath basin, Susan River, Sacramento-San Joaquin rivers, and Southern California. Due to illegal introductions, pumpkinseed can be expected throughout the state in cool, quiet waters.

3.27 Life History

Pumpkinseed mature in approximately 2 years. Spawning occurs when temperatures reach 13 to 17ºC from April through June. Males build nests on the bottom in less than one meter of water and defend the nest. Males and females spawn with multiple partners. Females lay 600 to 7,000 eggs that hatch in 3 to 5 days. Males defend the larvae for a short period before the young swim into open waters and feed on zooplankton. After several weeks the young settle out and associate with vegetation and structures. Pumpkinseed grow slowly but live relatively long: they rarely exceed 30 cm FL but can live 12 years. Pumpkinseed feed on hard-shelled invertebrates such as insects, snails, and bivalves that they pick from the bottom or from vegetation.

3.28 Habitat Requirements

Pumpkinseed prefer quiet, cool, clear or slightly turbid waters in lakes, ponds, sloughs, and sluggish streams. They are usually associated with aquatic vegetation or other structure. Ecologically they are similar to redear sunfish, but can withstand cooler water temperatures. They prefer water temperatures of 24 to 32ºC but can withstand high temperatures of up to 38ºC and lows down to 3 to 4º C. They can survive higher salinities up to 17 ppt and can withstand DO levels as low as 4 mg/L.

3.29 Ecological Interactions

Pumpkinseed have the potential to compete with and prey on native species. They have the potential to populate cooler waters including middle to higher elevation reservoirs and compete with native fishes there.

3.30 Key Uncertainties

Pumkinseed population dynamics are not known, but they appear to be spreading in Sacramento-San Joaquin rivers.

Common Name	**Scientific Name (family)**
Redear sunfish	*Lepomis microlophus* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.31 Distribution

Redear sunfish are native to the southeastern United States and from Florida to the Rio Grande including the lower Mississippi watershed. They were first recorded in California in 1951, and have since been introduced to Southern California, the Central Valley, the Russian River, and likely farm ponds and other waters throughout the state.

3.32 Life History

Redear sunfish usually mature by the second year and spawning occurs throughout the summer months when temperatures reach 21 to 24ºC. Males construct nests 25 to 62 cm in diameter, attract females and spawn much like other sunfishes. Females lay 9,000 to 80,000 eggs. Larvae appear to be planktonic before settling into aquatic vegetation. Redear sunfish feed on aquatic snails and hard-shelled invertebrates from the bottom and aquatic plants, and are known to feed on introduced mollusk species. They also feed on insect larvae and cladocerans.

3.33 Habitat Requirements

Redear sunfish prefer to inhabit deeper clear warm waters (greater than 2 m) of ponds, lakes, backwaters, and sloughs. They are most often found in aquatic vegetation, brush, stumps, logs and other cover. They are rarely found in the brackish waters of the San Francisco Estuary but can tolerate salinities up to 20 ppt, which makes them one of the more saline tolerant sunfishes. Turbid waters can inhibit redear sunfish reproduction. Turbid waters reduce light penetration to deeper water and decreases plant growth at depth, which forces redear sunfish into shallower waters where they are forced to compete with other species such as bluegill.

3.34 Ecological Interactions

Redear sunfish compete with bluegill, green sunfish, and pumpkinseed especially where turbid waters force them into the shallows where vegetation can grow. Other introduced sunfishes may have a greater impact on native fish species than redear sunfish do. Redear are not as common as bluegill and green sunfishes and their preferred diet of snails and bivalves often includes introduced species as well.

3.35 Key Uncertainties

Little is known about the ecology and dynamics of California populations of redear sunfish. Because of their relatively recent introduction in California, their role in the decline of native fishes is poorly understood.

Common Name	**Scientific Name (family)**
Smallmouth bass	*Micropterus dolomieu* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.36 Distribution

The native range of smallmouth bass is the eastern waters of North America from Minnesota and Quebec, south to Alabama, and west to Oklahoma. Smallmouth bass were first introduced to California in 1874, and are now widely distributed in rivers and reservoirs throughout California. Smallmouth bass now occur in most streams and reservoirs in the Central Valley, the Pit River, Russian River, Mad River, Freshwater Lagoon, Trinity River, Carmel River, Colorado River, Lake Tahoe, and other streams in Southern California.

3.37 Life History

Smallmouth bass become mature in their third or fourth year and begin to spawn when water temperatures reach 13 to 16ºC in May and June. Males construct nests in gravel in approximately 1 to 2 m of water with nests containing 2,000 to 21,000 eggs. Males and females are apparently monogamous. Males defend eggs and fry for up to 4 weeks when the fry reach 20 to 30 mm TL and disperse into shallower waters. Growth rates appear to be less variable for smallmouth than for largemouth bass because the parameters (temperature, salinity, DO) of their occupied habitats appear to be more uniform. Smallmouth bass live to be greater than 4 years old and may exceed 40 cm TL. Smallmouth bass eat zooplankton and insects when they are fry and then aquatic insects and small crustaceans as they grow. Adult smallmouth bass are predators on larger invertebrates, amphibians, small mammals, and fish. Adult smallmouth bass often feed on crayfish, which are frequently also introduced species. Smallmouth bass may also cannibalize young of their own species.

3.38 Habitat Requirements

Smallmouth bass prefer cool (20 to 27ºC), large, clear-water lakes and streams of moderate gradient with riffle-pool morphology, relatively low turbidity, and rocky substrates. Optimal stream reaches for adult smallmouth contain large pools, slow runs, eddies, or backwaters with abundant cover (e.g., boulders, rock ledges, undercut banks, and LWD) and prey (especially small fish and crayfish) and cobble-boulder substrates. In streams, larger adult smallmouth bass have been described variously as pool guild members, run or pool inhabitants, and habitat generalists. The biology of the smallmouth bass is quite similar to that of the largemouth bass; however, the smallmouth bass shows a somewhat greater preference for cooler streams with areas of swifter velocities. Water temperatures above 38ºC can be lethal. Smallmouth bass can tolerate DO as low as 1 to 3 mg/L but prefer oxygen levels above 6 mg/L.

3.39 Ecological Interactions

Smallmouth bass often exist with native species that have similar habitat requirements but their interactions are not well understood. Smallmouth bass may compete with hardheads for crayfish since they are a major component in the diet of both species. Smallmouth bass may also prey on juvenile Sacramento pikeminnow and hardhead and may adversely impact native frog populations. Under certain conditions, such as drought and warmer water conditions, smallmouth bass may have a reproductive advantage and have a greater impact on native fishes. Conversely, during cool years native fishes may spawn earlier and their juveniles may prey on smallmouth fry.

3.40 Key Uncertainties

Impacts on native fishes by smallmouth bass are not well known. However, impacts in water supply reservoirs may not be too severe where native fish are not very abundant. Methods to enhance native fish populations in relatively undisturbed areas where smallmouth bass coexist have not been established.

Common Name	**Scientific Name (family)**
Spotted bass	*Micropterus punctulatus* (Centrarchidae)

Legal Status

Federal:	None
State:	None

3.41 Distribution

The native range of spotted bass was the central and lower Mississippi River and along the Gulf coast from Texas to northwestern Florida. Spotted bass were introduced from Ohio to California in 1933. Spotted bass were introduced throughout Southern California and the Central Valley after 1974. They are now widely distributed in rivers and reservoirs throughout California, including those in the Central Valley.

3.42 Life History

Spotted bass become mature in their second year and begin to spawn when water temperatures reach 15 to 18ºC in late spring. Males construct nests in gravel in 0.5 to 4.6 m of water. Spawning continues until water temperatures reach 22 to 23ºC. Males and females are apparently monogamous but males may have more than one nest. Each nest contains 2,000 to 14,000 young, which are vigorously defended by the male for up to 4 weeks until the fry disperse when they are 30 mm TL. Growth rates are higher in warm-water reservoirs and slower in cool streams. Spotted bass can live to be 4 to 5 years old and may reach approximately 40 cm TL. Spotted bass are predators on larger invertebrates and fish, and larger fish eat larger prey. Fry eat zooplankton and insects and juveniles up to 75 mm eat aquatic insects and crustaceans. Fish over 75 mm eat fish, crustaceans, and aquatic and terrestrial insects. The most common fish prey species are sunfishes, crappie, and threadfin shad. Spotted bass may also cannibalize young of their own species.

3.43 Habitat Requirements

Spotted bass prefer clear, low-gradient waters in rivers and reservoirs. They inhabit slower more turbid water than smallmouth bass prefer, and faster water than largemouth bass. In rivers they occupy pools and avoid riffles and backwaters with heavy cover. In reservoirs they are found along steep, rocky underwater slopes, in the end where streams enter. Spotted bass prefer summer temperatures of 24 to 31ºC with adults just above the thermocline in moderate depths. Juveniles remain near shore in shallow water. They have a low salinity tolerance although they have been found in 10 ppt waters.

3.44 Ecological Interactions

Bluegills are common predators of spotted bass embryos and fry. Spotted bass may hybridize with smallmouth bass and redeye bass. Spotted bass may compete with, and prey on, native fishes under certain circumstances.

3.45 Key Uncertainties

Impacts on native fishes by spotted bass are unknown. However impacts may not be too severe in water supply reservoirs where native fish are not very abundant. Spotted bass are capable of swimming up reservoir tributary streams on a seasonal basis where they may compete with and prey on native fishes. The affects of hybridization with other species of bass are unknown.

Common Name	**Scientific Name (family)**
Warmouth	*Lepomis gulosus* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.46 Distribution

Warmouth are native to the Mississippi River watershed, the Rio Grande, Florida, and much of the Atlantic seaboard. Warmouth were introduced to California and were first mentioned in the 1930s. They are now found throughout the Central Valley and associated reservoirs. Although warmouth are established in California, they are relatively uncommon when compared to other sunfishes.

3.47 Life History

Warmouth live fairly long (6 to 8 years) but grow slowly. A 28 cm fish would be considered very large. They are known to have stunted populations where fish 10 cm TL are 4 to 6 years old. Warmouth mature in their second summer, and spawning occurs in late spring and early summer when water temperatures reach 21ºC. Males build nests near dense cover in 0.5 to 1.5 m deep water. Spawning behavior is similar to other sunfishes. Females produce 4,500 to 63,000 eggs depending on the size of the fish. Warmouth feed mainly on insects, snails, crayfish, and fish.

3.48 Habitat Requirements

Warmouth prefer abundant vegetation and cover in warm turbid, muddy bottom sloughs of the Central Valley, and they also do well in reservoirs. They are uncommon in tidal portions of the estuary. The preferred habitat parameters include summer water temperatures 22 to 28°C, salinities under 4 ppt, and oxygen levels above 4 mg/L, although they can withstand lower levels.

3.49 Ecological Interactions

Warmouth may hybridize with bluegill.

3.49.1 Key Uncertainties

The ecological role of warmouth in the sloughs and reservoirs of the Central Valley is poorly understood. Their interactions with other fish species are not well known.

Common Name	**Scientific Name (family)**
White crappie	*Pomoxis annularis* (Centrarchidae)
Legal Status	
Federal:	None
State:	None

3.50 Distribution

White crappie naturally occurred in the freshwaters of east central North America from southern Ontario and New York west of the Appalachian Mountains, south to the Gulf coast, and west to Texas and South Dakota. White crappie were apparently introduced to Southern California around 1908. They were not planted north of the Tehachapi Mountains until 1951, when they were also were introduced in the north from Oregon. They are now well established in all major river systems and reservoirs in California.

3.51 Life History

White crappie become mature in 2 to 3 years at 10 to 20 cm TL, and spawning usually begins in April and May when water temperatures reach 17 to 20ºC. Males construct either isolated nests or nests in colonies in waters that are usually less than 1 m deep but sometimes as deep as 6 to 7 m. Females may spawn in the nests of several different males. Eggs adhere to substrate in the nest, which is defended by the male. Females may have 27,000 to 68,000 eggs that hatch into planktonic larvae. Small juveniles feed in the plankton but return to protected areas near shore. White crappie can live longer than 7 to 8 years and reach a size greater than 35 cm FL.

3.52 Habitat Requirements

White crappie occur in warm, turbid, streams, lakes, ponds and slow moving rivers. They are apparently more tolerant of high turbidity, higher salinity, higher currents, and higher temperatures than the black crappie but have a lower tolerance of low DO levels. Black crappies displace white crappie in reservoirs that have oxygen levels less than 2 to 4 mg/L. White crappie also appear to tolerate a lack of aquatic vegetation and cover better than black crappie. Nests are constructed in hard clay bottoms close to bushes or overhanging branches. Optimal temperatures for white crappie range from 27 to 29º C with a maximum tolerance of around 31º C. White crappie are rare in estuaries but have been reported in salinities as high as 10 ppt. White crappie are shoaling fishes that congregate around structure during the day but move into open water to feed during evening and morning periods. White crappie eat a variety of prey including planktonic crustaceans, small fish, and aquatic insects. Fish and larger invertebrates are the preferred diet of fish larger than 140 mm FL. Threadfin shad are an important prey item.

3.53 Ecological Interactions

White crappie populations may interact with native and nonnative populations of fish through predation and competition. Inland silversides may compete for plankton with white crappie larvae and juveniles. Some populations of white crappie have demonstrated a boom-and-crash cycle in some locations (Clear Lake).

3.54 Key Uncertainties

How white crappie populations affect native fishes is not known. Effects may be minimal since most crappie populations are located in reservoirs or other highly disturbed areas where native fishes may not be present.

Common Name	**Scientific Name (family)**
American shad	*Alosa sapidissima* (Clupeidae)
Legal Status	
Federal:	None
State:	None

3.55 Distribution

American shad are anadromous and native to the Atlantic Coast from Labrador to Florida. They were introduced into the Sacramento River between 1871 and 1881. Once established, American shad spread quickly along the West Coast. Their current distribution extends from Todos Santos Bay, Baja California to Alaska and the Kamchatka peninsula, Russia. In California, American shad are found in the Sacramento River system, the Delta, and the San Joaquin River system, the Klamath River, the Eel River, and the Russian River. A unique and successfully reproducing landlocked population exists in Millerton Lake.

3.56 Life History

The anadromous American shad enter fresh water to spawn in the spring when water temperatures exceed 14º C although mature fish may occupy the estuary since the previous autumn. Males mature at 3 to 5 years and females at 4 to 5 years. Peak spawning occurs at temperatures around 18º C. The largest runs in the Sacramento are not seen until late May and early June. Fish spawn repeatedly over several days and eggs are fertilized in open water. Females can produce 20,000 to 150,000 eggs. Shad do not always die after spawning and surviving adults return downstream. Fertilized eggs are slightly negative buoyant, are not adhesive, and drift in the current. Eggs hatch in 8 to 12 days at 11 to 15º C but can hatch as quickly as 3 days at 24º C. Hatching success may be lower at higher temperatures. Larvae are 6 to 10 mm when they hatch and are planktonic for about 4 weeks. Juvenile shad can tolerate salinities of up to 20 ppt, and leave the estuary at 5 to 15 cm FL in September through November. However, some juveniles may use the estuary as a nursery for 1 to 2 years. Growth may be related to water temperature and the availability of prey. Shad are reported to live up to 7 years in California and males may reach 42 cm FL and females may reach 48 cm FL during that time. Young shad in the San Francisco Estuary feed on zooplankton, bottom organisms, and surface insects. Little is known about shad during their 3 to 5 years at sea, although emigrating fish tagged in the Sacramento River have been recaptured from Monterey to Eureka. Shad may live to be 7 years old.

3.57 Habitat Requirements

American shad spend most of their adult life at sea and may make extensive migrations along the coast. American shad are anadromous and need larger rivers for reproduction and juvenile rearing. They require spring water temperatures of 14 to 24º C for spawning to occur. Shad ascend freshwater rivers in the spring and migrate upstream, sometimes for considerable distances. Mass spawning occurs in the main channels of rivers in 1 to 10 m of water over a variety of substrates. Water velocity ranges from 31 to 91 cm/sec.

3.58 Ecological Interactions

Shad populations have been declining and are approximately one-third the number that they were 60 years ago. Dams and other obstructions impede juvenile and adult shad migration in many areas. Pollution, pesticides, and water diversions may also affect adult and juvenile shad populations.

3.59 Key Uncertainties

The affect of pesticides on larval shad and shad populations is not clear. The effects of changing ocean conditions on adult populations are not understood.

Common Name	**Scientific Name (family)**
Threadfin shad	*Dorosoma petenense* (Clupeidae)

Legal Status

Federal:	None
State:	None

3.60 Distribution

The native range of threadfin shad is from the Ohio River of Kentucky and southern Indiana, south to Texas and Florida including streams and rivers that flow into the Gulf of Mexico. Their range extends south to Guatemala and Belize. Threadfin shad were first introduced into California in San Diego County in 1953, and then were planted in reservoirs throughout the state and in the Sacramento-San Joaquin watershed in 1959. Threadfin shad are now well established in the Sacramento and San Joaquin rivers and the Delta and San Francisco Estuary. They also occur in the marine environment and have been recorded from Long Beach to Yaquina Bay, Oregon.

3.61 Life History

Spawning occurs in open water during spring when water temperatures exceed 21ºC. Eggs adhere to plants, floating or submerged objects, or under brush or logs. Threadfin shad may spawn at less than 1 year old. Females may release 900 to 21,000 eggs depending on the size of the female. Eggs hatch in 3 to 6 days and larvae immediately become planktonic. Larvae become juveniles in 2 to 3 weeks and form dense schools of similar size and age class. Threadfin shad grow fast and have short life spans, rarely living past 2 years and 10 cm TL. The largest California specimen was 22 cm TL. Like all clupeids, threadfin shad are planktivores and feed on zooplankton, phytoplankton, and detritus. They can strain food with their gill rakers or pick up individual organisms.

3.62 Habitat Requirements

Threadfin shad are found in lakes, ponds, larger rivers, estuaries, and reservoirs. They can also be found in the swifter waters of tailraces, near stream inlets and along dam faces, usually no deeper than 18m. They prefer summer water temperatures of 22 to 24ºC and waters that do not become colder than 7 to 14ºC in winter. Threadfin shad cannot endure temperatures below 4ºC for long periods. The Sacramento-San Joaquin populations experience die-offs when temperatures drop to 6 to 8ºC. Threadfin shad can survive and grow in seawater but apparently prefer fresh water and require it for successful reproduction.

3.63 Ecological Interactions

Threadfin shad were intentionally introduced into California as a forage fish for game fish. Their populations have the ability to rapidly increase when they are introduced into suitable habitat. At some locations the introduction has been a success with increased game fish growth rates. However, in some locations, threadfin shad proved to be unavailable as prey items to small warm water game fish because of their open water preference. In addition, threadfin shad may compete with and consume the planktonic larval stages of many warm water game fish, such as centrarchids (including the basses).

The growth and survival of larval centrarchids in some reservoirs may decrease when threadfin shad are present.

3.64 Key Uncertainties

The effect of threadfin shad on native species, especially those with planktonic larvae, is poorly understood. Threadfin shad numbers have slowly declined in the Delta in the last 20 years. This may indicate a general decline of planktonic fishes in the estuary. The ecological role of threadfin shad in this ecosystem is not well known.

Common Name	**Scientific Name (family)**
Common carp	*Cyprinus carpio* (Cyprinidae)
Legal Status	
Federal:	None
State:	None

3.65 Distribution

It is likely that carp evolved in the Caspian-Black Sea region. The Romans already cultured carp, which is now found in suitable waters worldwide. Due to their status as favorite food and sports fish in Europe, they were brought to California in 1872. By 1896, they were widely distributed. In California they are found in the Sacramento-San Joaquin watershed, the Salinas and Pajaro basins, the Russian River, Clear Lake, the Colorado River, some Lahontan watershed reservoirs and rivers, the Owens River, and along coastal Southern California.

3.66 Life History

Common carp live in the wild rarely longer than 12 to 15 years. Growth varies depending on environmental conditions, and they reach approximately 7 to 36 cm SL. During their second year, they double in length, growth slows down after the fourth year. Spawning occurs during any time of the day or night in spring and summer as soon as temperatures exceed 15°C, but especially when temperatures reach 19 to 23°C. The adhesive eggs attach to plants, roots, and bottom debris. Embryos hatch in 3 to 6 days and drop to the bottom or attach to vegetation where they stay until they have consumed the content of their yolk sac. After a few days they start feeding on zooplankton. Most carp fry move into protective beds of emergent and submerged vegetation by the end of the first week, which they will rarely leave until reaching 7 to 10 cm TL.

3.67 Habitat Requirements

Common carp are most abundant in warm, eutrophic lakes, reservoirs, and sloughs with silty bottoms and growths of submergent and emergent aquatic vegetation. They can also inhabit some trout streams and coldwater reservoirs. In streams they are found in deep pools with higher turbidity and soft bottoms. Carp are active between 2 to 24°C, can survive high turbidities, high temperatures (31 to 36°C), and low oxygen concentrations (0.5 to 3.0 ppm). They can survive salinities up to 16 ppt.

3.68 Ecological Interactions

Common carp are probably responsible for the reduction and displacement of native fish. Because of their foraging behavior, they may increase turbidity and prevent the growth of dense beds of aquatic vegetation. Young carp are preyed upon by game fish such as largemouth bass.

3.69 Key Uncertainties

It is uncertain how to prevent carp from spreading into watersheds that have not been populated.

Common Name	**Scientific Name (family)**
Fathead minnow	*Pimephales promelas* (Cyprinidae)
Legal Status	
Federal:	None
State:	None

3.70 Distribution

Fathead minnow are native to much of the eastern and midwestern portions of the United States and Canada, as well as parts of northern Mexico. They were introduced into much of the western United States as a bait and forage fish, including California (in the early 1950s) where they have been reared by both commercial breeders and DFG. This has lead to their establishment in the Sacramento-San Joaquin and Klamath basins, the Colorado watershed, a number of coastal watersheds, portions of Southern California, and potentially in any watersheds with adequate conditions for their survival. They can be found in an array of habitats, but appear to be most adapted to pools of small, turbid streams and in ponds where other fish are sparse.

3.71 Life History

Fathead minnow are opportunistic feeders who browse for filamentous algae, diatoms, small invertebrates, and organic matter located on the bottom, midwater, or amongst aquatic vegetation. Growth rates are extremely variable, and are largely dependent on temperature, availability of food, and population size. Maximum recorded length is 109 mm TL. First spawning can occur between a few months to 2 years of age, and the majority of fish die 1 to 2 months after the onset of spawning. Females can spawn throughout the summer season when temperatures are above 15 to 16°C and below 32°C, and can produce greater than 4,000 eggs. Males form nests by creating hollows in the substrate around some type of item such as a flat stone, branch, or root mass at a depth of 30 to 90 cm that the sticky eggs will adhere to. Males defend the nest and care for the embryos that hatch in 4 to 6 days (at 25°C).

3.72 Habitat Requirements

Fathead minnows are capable of surviving under extreme conditions such as, DO levels less than 1 mg/L, temperatures up to 33°C, high alkalinities, and high levels of organic pollution and turbidity. They are considered pioneer species because their ability to withstand environmental extremes allows them to inhabit and dominate temporary aquatic environments when they arise.

3.73 Ecological Interactions

When fathead minnows inhabit perennial environments, they are often poor interspecific competitors, especially with other cyprinids, but this is not always the case. In areas where they have become exceedingly abundant, such as the Upper and Lower Klamath lakes and in Tule Lake, they have been known to displace native cyprinids such as the blue chub in these locations.

3.74 Key Uncertainties

Fathead minnows are legal baitfish within California, and are easily moved to new locations where they have the potential to establish populations. It is unknown if this practice should be eliminated to safeguard native fishes that have similar habitat preferences, such as the California roach.

Common Name	**Scientific Name (family)**
Goldfish	*Carassius auratus* (Cyprinidae)
Legal Status	
Federal:	None
State:	None

3.75 Distribution

Goldfish naturally occur in eastern Europe and China. They have been spread by aquarists and bait fishermen throughout the world. Established in California since the 1860s, goldfish occur in large populations in Southern California reservoirs, in Clear Lake, as well as sloughs and reservoirs in the Central Valley. However, individuals and smaller populations can be found throughout the state where the water temperature is sufficiently warm.

3.76 Life History

Goldfish in the wild rarely live longer than 6 to 8 years, and growth during that time is variable, depending on environmental conditions. In California they usually reach 50 to 90 mm in their first year and can reach up to 20 cm TL. Females grow larger and live longer than males. Males mature during their second or third year. Goldfish are serial spawners and require temperatures of 16 to 26°C. Spawning takes place in May and April during sunrise on sunny days, over aquatic vegetation or flooded and emergent objects, such as leaves, roots, and grass. Eggs are adhesive and hatch within a week. Larvae and small juveniles seek cover among aquatic vegetation. Goldfish are omnivores feeding on algae, zooplankton, mollusks, crustaceans, organic detritus, and macrophytes. In the San Joaquin River, goldfish feed mostly on planktonic diatoms and strands of filamentous algae.

3.77 Habitat Requirements

Goldfish can survive in temperatures between 0 and 41°C, however populations generally establish in water with temperatures between 27 and 37°C. They prefer standing or slow moving water with heavy growth of aquatic vegetation but they can become established in colder lakes if there is a littoral area warm enough for breeding. They do well in disturbed and polluted areas, and can be found below reservoirs and in deep pools with dense cover in streams.

3.78 Ecological Interactions

In some areas their feeding behavior may lead to the elimination of aquatic plants and increase turbidity, especially in mud-bottomed ponds. They are often found in association with other nonnative fish, especially in disturbed and polluted areas.

3.79 Key Uncertainties

Goldfish occur widely throughout California, however, their ecological role is not well understood.

Common Name	**Scientific Name (family)**
Golden shiner	*Notemingonus crysoleucas* (Cyprinidae)

Legal Status

Federal:	None
State:	None

3.80 Distribution

Golden shiners are native throughout the majority of eastern North America from Quebec southward to Texas and Florida. In the late 1800s, they were introduced to California as a forage species, but did not have a large distribution until after 1955, when they were established as a legal baitfish. They are currently ubiquitous throughout the state. They generally inhabit warm, shallow ponds, lakes, and sloughs where they can be found in association with aquatic vegetation.

3.81 Life History

Golden shiners can obtain an ultimate length of up to 260 mm SL, and a maximum age of 9 years. They are sight feeders, and typically feed during the day on prey items such as mollusks, terrestrial and aquatic insects, small fish, aquatic insect larvae, filamentous algae, and large zooplanktons such as *Daphnia sp.* Breeding season in California lasts from March through September when water temperatures are in the region of 20°C. Females are fractional spawners, with initial fecundities of 2,700 to 4,700+ eggs. The adhesive eggs are deposited on submerged vegetation or bottom debris where males subsequently fertilize them. Hatching occurs in 4 to 5 days (at 24 to 27°C), upon which time emergent fry begin to shoal in large numbers, generally in association with near-shore aquatic vegetation.

3.82 Habitat Requirements

Golden shiners are most abundant in low-velocity, turbid environments with muddy bottoms such as low-elevation reservoirs and sloughs, but can also be present in coldwater lakes as long as there are warm, shallow areas for breeding and rearing their young. They can endure temperatures of up to 36 to 37°C, and DO concentrations less than 1 mg/L.

3.83 Ecological Interactions

Golden shiners can most often be found in areas having other introduced species such as largemouth bass, various sunfish species, and mosquitofish. In some locales, piscivorous fishes may limit their abundance. They shoal in littoral or pelagic areas to avoid predators, and if predation pressure is high, may become nocturnal feeders. In coldwater lakes, golden shiners have been known to reduce growth and survival of trout by reducing zooplankton populations.

3.84 Key Uncertainties

Golden shiners are one of three legal baitfish in California, and it is challenging to predict where populations could become established, and what problems could occur as a result of their colonization.

Common Name	**Scientific Name (family)**
Red shiner	*Cyprinella lutrensis* (Cyprinidae)
Legal Status	
Federal:	None
State:	None

3.85 Distribution

Red shiners are originally from streams in the western and central United States that drain into the Mississippi River and Rio Grande. They are used as a baitfish, and as a result have been planted in other regions, including California in 1954. DFG first planted them in the Sacramento-San Joaquin watershed and in Lake County ponds, but there is no evidence of a successful introduction. They can be anticipated to be present anywhere in the state, and are currently known to be found in the San Joaquin Valley, Coyote Creek, Sacramento Valley streams, the Colorado River watershed, Los Angeles County, San Juan, Big Tijunga, and Aliso creeks, and various coastal streams. They prefer habitats with turbid, alkaline, shallow, and slow-flowing water such as backwaters and sloughs.

3.86 Life History

Red shiners shoal in large groups and feed on the most plentiful organisms present, which may include crustaceans, aquatic insect larvae, surface insects, algae, and larval fish. They can obtain an ultimate size of 80 mm SL, and a maximum age of 2.5 to 3 years. They typically mature during the summer of their second year. Females are fractional spawners, and therefore fecundity among individuals will vary. Breeding season takes place when water temperatures are 15 to 30°C, and may be extended from May until October. Spawning takes place in slow-flowing water, and eggs will adhere to a plethora of substrates such as submerged vegetation, gravel and sand, root wads, woody debris, and active sunfish nests. Its early life history has not been described in literature.

3.87 Habitat Requirements

Favorable environments of red shiners include both unstable and highly disturbed environments such as intermittent streams, watershed ditches, and reservoirs. They avoid severe environmental conditions, but can tolerate pH values of 4 to 11, salinities up to 10 ppt, DO levels as low as 1.5 mg/L, and temperatures as high as 39.5°C. They are primarily found in water greater than 30 cm in depth, velocities of 10 to 50 cm/sec, and near submerged cover over fine substrate.

3.88 Ecological Interactions

Red shiners have a great capacity to spread within a region once they become established, and can displace native cyprinids whenever this occurs. They have been linked to declines of native fishes, such as the Virgin River spinedace, through their introduction.

3.89 Key Uncertainties

Red shiners are thought to be jeopardizing the future of native cyprinids in Southern and Central California, though there is no direct evidence to support this notion.

Common Name	**Scientific Name (family)**
Black bullhead	*Ameiurus melas* (Ictaluridae)
Legal Status	
Federal:	None
State:	None

3.90 Distribution

Black bullhead have native distributions spanning a great extent of the United States east of the Rocky Mountains and into southern Canada. Introductions have expanded them from their native range to locales within most western states. In California, black bullhead are quite common throughout the Central Valley, the San Francisco Estuary, and in coastal watersheds from San Luis Obispo County south to the Mexican border. They also have a presence in Monterey Bay tributaries, the lower Colorado River, and the Lost, Owens, and Russian River watersheds.

3.91 Life History

Adult black bullhead size can range from 17 to 61cm TL, dependant upon such factors as temperature, food availability, and degree of overcrowding. Black bullheads are omnivorous and feed on an array of organisms including aquatic and terrestrial insects, crustaceans, mollusks, earthworms, and both live and dead fish. Adults are nocturnal feeders whereas younger fish tend to have diurnal feeding habits. Spawning occurs in June and July when water temperatures exceed 20°C. Females create small hollows in the substrate as nests, and can lay between 1,000 to 7,000 eggs that form a cohesive yellow mass when fertilized. Parents care for their young from developing embryos to the time they are approximately 25 mm TL when young disperse to shallow reaches. Black bullhead are quite social, and can often be found shoaling together.

3.92 Habitat Requirements

Black bullhead have the ability to adapt to a wide range of environmental conditions, and have therefore been able to easily invade new areas. Their preferred habitats include sloughs and pools of low-gradient streams with muddy bottoms, slow velocities and warm, turbid water, river backwaters, and ponds and small lakes. They can be abundant in habitats such as ditches, brackish waters of estuaries, and temporary habitats such as intermittent streams. They can withstand temperatures up to 35°C, DO concentrations down to 1 to 2 mg/L, and salinities as high as 13 ppt.

3.93 Ecological Interactions

Black bullhead are becoming increasingly more prominent in highly disturbed lowland aquatic environments and can support small recreational fisheries. In California, they can oftentimes be found among other introduced species with similar habitat preferences including bluegill, green sunfish, inland silverside, carp, red shiner, fathead minnow, goldfish, channel catfish, and threadfin shad.

3.94 Key Uncertainties

The distribution of black bullhead appears to be expanding, and it is not known what effect this will have on other native and nonnative species.

Common Name	**Scientific Name (family)**
Brown bullhead	*Ameiurus nebulosus* (Ictaluridae)
Legal Status	
Federal:	None
State:	None

3.95 Distribution

Brown bullhead have a native range encompassing the majority of the United States east of the Great Plains and southeastern Canada, and have been introduced throughout most of southwestern Canada and the western United States where they exist in every major river system. In California, they are currently in the majority of larger coastal watersheds from the Klamath River to Southern California, the upper Klamath basin, all of the Sacramento-San Joaquin system, the Owens River, and potentially in California sections of the Truckee, Walker, and Carson rivers. Their greatest abundance is in large water bodies such as the sloughs of the Delta, Clear Lake, and foothill reservoirs though they have adapted to a variety of habitats ranging from warm, turbid sloughs to clear mountain lakes.

3.96 Life History

Brown bullhead can reach ultimate lengths of 53 cm TL and maximum weights of 2.2 kg, although commonly do not grow greater than 30 cm TL and 0.45 kg. Spawning usually begins in their third year, and in California takes place from May through July when water temperatures surpass 21°C. Females lay 2,000 to 14,000 eggs in batches within nests formed from hollows dug in sand or gravel that are closely associated with in-stream cover. Hatching occurs in 6 to 9 days, and yolk-sac fry will remain in the nest for roughly 1 week while being guarded by both parents. Smaller fish primarily consume chironomid midge larvae and small crustaceans, and graduate to larger insect larvae and fish as they grow. They are both omnivorous and opportunistic and will consume most organisms of adequate size.

3.97 Habitat Requirements

Habitat preference of brown bullheads includes the deep portion of the littoral zone in association with aquatic vegetation and soft substrate, and in sluggish, turbid, low-gradient reaches of rivers. They prefer temperatures between 20 to 33°C, but can tolerate temperatures of 0 to 37°C. They can withstand a wide span of salinities (greater than 13 ppt) and pH (greater than 9), and DO levels as low as 1 mg/L.

3.98 Ecological Interactions

Brown bullheads are most abundant in anthropogenically altered habitats and have become an important recreational fishery species.

3.99 Key Uncertainties

The effect of this introduced species on native fishes and introduced species is not known.

Common Name	**Scientific Name (family)**
Channel catfish	*Ictalurus punctatus* (Ictaluridae)

Legal Status

Federal:	None
State:	None

3.100 Distribution

Channel catfish originated in the Mississippi-Missouri River system and have been introduced throughout North America. It is assumed that the channel catfish population in the Central Valley originated from fish planted in the American River in the late 1920s.

Catfish have been reared in hatcheries since the 1960s, which widened their distribution to all public waters and private ponds and can be expected wherever suitable conditions are available.

3.101 Life History

Channel catfish are fast growing, reaching up to 53 cm TL at 10 years of age in California. They reach sexual maturity between 2 to 8 years at 18 to 56 cm. Spawning requires temperatures between 21 and 29°C (optimum 26 to 28°C). In California, they spawn between April and August using cave-like sites for nesting, including undercut banks, log jams, or old barrels. The male guards the nest and cares for the young, including aerating the embryos with movements of his body. The embryos hatch within 5 to 10 days and the young leave the nest after about a week. The young may stay together for another week or 2, then they disperse into shallow, flowing water. Channel catfish forage mainly on a wide variety of invertebrates and fish, but also maybe incidentally feed on detritus and plant material. Young catfish feed primarily on crustaceans and the larval aquatic insects.

3.102 Habitat Requirements

Catfish live in the mainstem of larger streams, spending days in deeper pools and foraging during the night in the water column. Young-of-year prefer living in riffles. Optimal stream habitat is characterized by clean, warm water with sand or gravel bottoms. They can survive temperatures of 36 to 38°C and oxygen minima of 1 to 2 mg/L. They can tolerate moderate salinities, but are not common in brackish water.

3.103 Ecological Interactions

They prey upon many native fish and fish larvae, as well as invertebrates and smaller mammals.

3.104 Key Uncertainties

The impacts of channel catfish on native fish, amphibians, and invertebrate assemblages are not known. However, because of their predatory behavior, it is assumed that it is negative.

Common Name	**Scientific Name (family)**
White catfish	*Ameiurus catus* (Ictaluridae)

Legal Status

Federal:	None
State:	None

3.105 Distribution

White catfish evolved in the lower reaches of streams of the Atlantic coast. In 1874, white catfish were planted in the San Joaquin River. They spread naturally throughout the Central Valley and were also planted in several lakes and reservoirs.

3.106 Life History

White catfish growth is variable, with the slowest populations found in the south and central Delta. Males grow faster and become larger than females and can reach up to 60 cm TL and 3 kg in their native streams and tend to be smaller in California. White catfish reach maturity when they are between 3 and 5 years old. Spawning occurs in June and July when water temperatures exceed 21°C. Eggs are spawned in a nest made by the male, who also cares for the young. Eggs hatch within a week at 24 to 29°C. White catfish are mainly piscivorous, but also feed on smaller organisms, such as amphipods, shrimp, and chironomid larvae. They forage mainly along the bottom.

3.107 Habitat Requirements

White catfish prefer areas of slow-velocity and avoid deep, faster velocity channel waters. During the day they avoid shallow vegetated areas; however, at night they move into shallow waters. They prefer temperatures exceeding 20°C and can survive temperature of 29 to 31°C and salinities as high as 11 to 14.5 ppt.

3.108 Ecological Interactions

White catfish can change species compositions in ecosystems where they are introduced because of their piscivorous feeding behavior. In Clear Lake, for example, they are responsible for the decline of native cyprinids.

3.109 Key Uncertainties

The extent that white catfish are predators on outmigrating salmonids is not known.

Common Name	**Scientific Name (family)**
Striped bass	*Morone saxatilis* (Moronidae)

Legal Status

Federal:	None
State:	None

3.110 Distribution

Striped bass originated from streams of the Atlantic coast. They were introduced into California in San Francisco Bay in 1879. They are found now in salt waters between Mexico and southern British Columbia, with the main breeding population still located in San Francisco Bay. They have also been raised in hatcheries and released into reservoirs and rivers flowing into the Central Valley.

3.111 Life History

Female striped bass can reach greater than 30 years in age. Growth is variable but rapid during the first 4 years, with the largest fish caught in California measuring 30.6 kg. Females mature between 4 and 6 years and can spawn every year. Spawning begins in April and requires temperatures above 14°C and below 21°C. Eggs slowly sink but even a slight current can keep them suspended. They hatch in about 2 days and feed off their yolk sac for up to 8 days. With increasing swimming abilities they start feeding on zooplankton. In the San Joaquin River embryos stay in the same general area in which spawning took place, as outflow is balanced by tidal currents. Larvae undergo vertical migrations to actively use riverine and tidal currents. Striped bass are pelagic, opportunistic predators, feeding on invertebrates and fishes.

3.112 Habitat Requirements

Striped bass are tolerant of wide range of environmental conditions, surviving temperatures up to 34°C, low DO levels between 3 to 5 mg/L, and high turbidity. They require a large cool river for spawning, a large body of water with large population of small fishes for foraging, and an estuary as a nursery ground for larvae and juveniles.

3.113 Ecological Interactions

It is possible that striped bass contributed to the decline of native fishes, including salmon, thicktail chub, and Sacramento perch, because of predation and competition. For example, striped bass consume up to 99 percent of juvenile salmon drawn to Clifton Court Forebay. However, other native fish, such as delta smelt and splittail, seem to be able to coexist with striped bass.

3.114 Key Uncertainties

It is unknown whether or not native fish species can recover in the presence of large striped bass populations.

Common Name	**Scientific Name (family)**
Bigscale logperch	*Percina macrolepida* (Percidae)
Legal Status	
Federal:	None
State:	None

3.115 Distribution

Bigscale logperch are found in numerous Gulf Coast river systems, and in 1954 were accidentally imported into lakes within Yuba County, California. They have since spread throughout the Sacramento-San Joaquin watershed, the San Joaquin Valley, reservoirs receiving water from the California Aqueduct, and other reservoirs within central and Southern California where they were potentially introduced by bait fishermen. They inhabit an array of lake and stream habitats, especially in “slower-moving stretches of warm, clear streams or in shallow waters of reservoirs on bottoms of mud, gravel, rocks, sticks, or large pieces of debris” (Moyle 2002).

3.116 Life History

Bigscale logperch can reach a maximum size of 125 mm SL at age 3+ years. They generally reach maturity in their second year, and during spawning females can produce 150 to 400 eggs. Spawning occurs between February and July in small gravel pits or within vegetation where the eggs are attached. Larvae are pelagic, and are consequently washed into side channels where they settle. Bigscale logperch are opportunistic, and their diet consists of whatever dominant insect larvae, amphipod, and planktonic crustaceans are present. They are benthic feeders, but will also rise from the bottom to collect free-swimming organisms.

3.117 Habitat Requirements

Bigscale logperch are generally inactive and reside along the edges of emergent vegetation or on the bottom, oftentimes in pits they have dug or buried within gravel substrate. They tend to prefer habitats with fine substrate and warm, turbid water. They have been found in waters with salinities of up to 4. 2 ppt.

3.118 Ecological Interactions

Exotic species such as the common carp, fathead minnow, various catfish species, inland silverside, bluegill, largemouth bass, and black crappie are primarily associated with bigscale logperch in addition to the native Sacramento blackfish.

3.119 Key Uncertainties

Native and desirable game fishes may be affected by bigscale logperch but the effects may be minimal because of their exclusive use of highly disturbed habitats.

Common Name	**Scientific Name (family)**
Mosquitofish	*Gambusia affinis* (Poeciliidae)
Legal Status	
Federal:	None
State:	None

3.120 Distribution

Mosquitofish are native to central North America, and have been introduced for mosquito control throughout the world. In 1922, they were introduced to California where they have rapidly spread throughout the state both through plantings and on their own. They are ubiquitous throughout portions of the state that do not have extended periods of cool water temperatures, and are still extensively planted.

3.121 Life History

Mosquitofish are omnivorous and opportunistic feeders on whatever organisms are most abundant. Growth is dependant upon factors such as sex, and various other environmental factors including productivity and temperature. Maximum size is 35 mm TL for males and 65 mm TL for females, and is typically achieved in one growing season. Fifteen months is generally the upper limit of survival for these fish because the majority die the same summer they reach maturity. Depending on genetics and environmental conditions factors such as time to maturity, gestation period, number of embryos per brood, and broods per season will vary. Under optimal conditions, females can contain up to 315 embryos, and 3 to 4 generations per year are feasible, though 50 embryos per brood and two generations per season are most common in the Central Valley. Mosquitofish are livebearers, and young are usually expelled in shallow water or among aquatic vegetation. Mosquitofish are omnivorous and besides consuming mosquito larvae and pupae, they will opportunistically feed upon such organisms as algae, zooplankton, terrestrial insects, diatoms, and various aquatic insects.

3.122 Habitat Requirements

In California streams, mosquitofish occur in disturbed portions of low-elevation streams, especially warm, turbid pools with beds of emergent aquatic plants. Within watersheds, mosquitofish can inhabit a wide array of habitats including brackish sloughs, salt marshes, warm ponds, lakes, and streams. They have a remarkable capability to withstand and even thrive under extreme environmental fluctuations. Though preferred conditions fall more centrally within the ranges, they can occur in temperatures of 0.5 to 42°C, pH of 4.7 to 10.2, salinities of 0 to 58 ppt, and DO levels of as low as 0.2 mg/L. They tend to be associated with aquatic vegetation, but will only be found along the periphery of plant growth if it is too thick.

3.123 Ecological Interactions

Although mosquitofish introduction can be used effectively as a biological control method for mosquito populations, plantings can have a negative effect on native populations of small fish, amphibians, and endemic invertebrates through predation on various life stages and harassment of adults that can keep breeding from occurring. They are thought to be responsible for eliminating or significantly reducing certain small fish species, such as the Amargosa pupfish, worldwide. Mosquitofish can also develop resistance to local pesticides, although low reproductive rates have directly correlated with high selenium levels from agricultural runoff in the San Joaquin Valley.

3.124 Key Uncertainties

Methods to control populations of mosquitofish where they currently coexist with native species are not well understood.

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Attachment

Fish Species Occurring Upstream or Downstream from the San Joaquin River Restoration Program Area

Draft

Biological Resources – Fisheries Appendix

Draft
April 2011

1.0 Introduction

A search of available data sources was conducted in 2008 to document the likely occurrence and distribution of Federal and State special-status fish species in the following sections of the San Joaquin River Restoration Program (SJRRP) Impact Area: upstream of Friant Dam, the San Joaquin River downstream of the Restoration Area (from the Merced River confluence to the Sacramento-San Joaquin Delta (the Delta)), and the Delta. Fish species occurring in the SJRRP Restoration Area (from Friant Dam downstream to the Merced River confluence), including special-status species, are addressed in the main body of the Technical Memorandum and in Attachment A and are not included here.

The special-status fish species appearing in this Attachment reflect the results of searches of the California Natural Diversity Database (CNDDB) (personal software edition (version 3.1.0), accessed on February 8, 2008) and the U.S. Fish and Wildlife Service (USFWS) species list using queries based on U.S. Geological Survey (USGS) quadrangles. Using a geographic information system (GIS), USGS quadrangles intersecting: (1) a 1,500-foot buffer on either side of the mainstem San Joaquin River, (2) Millerton Lake upstream of the Restoration Area, and (3) the Delta were selected for the special-status fish searches (Table 1-1).

Table 1-1.
Selection Criteria and Resulting USGS Quadrangles Used to Generate a Species List for Each Impact Area Subdivision

Subdivision of the Impact Area (Upstream to Downstream)	Selection Criteria	USGS Quadrangles	
San Joaquin River System – Upstream from Friant Dam	USGS quadrangles that overlap Millerton Lake	Millerton Lake West Millerton Lake East	
San Joaquin River System – Merced River to the Delta	USGS quadrangles that overlap a 1,500-foot buffer around the mainstem San Joaquin River from the confluence with the Merced River to the Delta	Brush Lake Crows Landing Hatch Holt Lathrop	Ripon Stockton West Terminous Vernalis Westley
Sacramento – San Joaquin Delta	USGS quadrangles that overlap the Delta	Antioch North Bouldin Island Honker Bay	Jersey Island Vine Hill
	TOTAL:	**17 quadrangles searched**	

Key:
USGS = U.S. Geological Survey

In addition, a search of the Bay Delta and Tributaries (BDAT) Project database (http://bdat.ca.gov/) yielded results from two California Department of Fish and Game (DFG) fisheries monitoring efforts (Fall Midwater Trawl and Summer Townet Survey) as well as results from the University of California (U.C.), Davis Suisun Marsh Fisheries

Monitoring program. These data were compiled to produce a comprehensive list of fish species likely to occur in the Sacramento–San Joaquin Delta.

Fish species occurring upstream or downstream of the Restoration Area or in the Delta are listed in Table 1-2, with the corresponding Impact Area region.

Table 1-2.
Fish Species Likely to Occur in the Impact Area Upstream or Downstream from the Restoration Area or in the Delta

Common name[1]	Scientific name	Status[2]		Native (N) Introduced (I)	Location[3 4]	Source
		Federal	State			
American shad	Alosa sapidissima			I	DE	BDAT 20085
Arrow goby	*Clevelandia ios*			I	DE	BDAT 20085
Bay pipefish (M)	*Syngnathus leptorhynchus*			N	DE	BDAT 20085
Bigscale logperch	*Percina macrolepida*			I	DE	BDAT 20085
Black bullhead	*Ameiurus melas*			I	DE	BDAT 20085
Black crappie	*Pomoxis nigromaculatus*			I	DE	BDAT 20085
Bluegill	*Lepomis macrochirus*			I	DE	BDAT 20085
Brown bullhead	*Ameiurus nebulosus*			I	DE	BDAT 20085
California halibut (M)	*Paralichthys californicus*			N	DE	BDAT 20085
Channel catfish	*Ictalurus punctatus*			I	DE	BDAT 20085
Chinook salmon (unspecified)	*Oncorhynchus tshawytscha*			N	DE	BDAT 20085
Chinook salmon, Central Valley Spring-run	*Oncorhynchus tshawytscha*	FT	ST	N	DE, DS	USFWS 20084
Chinook salmon, Sacramento River winter-run	*Oncorhynchus tshawytscha*	FE	SE	N	DE, DS	USFWS 20084
Common carp	*Cyprinus carpio*			I	DE	BDAT 20085
Delta smelt	*Hypomesus transpacificus*	FT	ST	N	DE, DS, US	CDFG 20086 BDAT 20085 USFWS 20084
Fathead minnow	*Pimephales promelas*			I	DE	BDAT 20085
Golden shiner	*Notemigonus crysoleucas*			I	DE	BDAT 20085
Goldfish	*Carassius auratus*			I	DE	BDAT 20085
North American green sturgeon—Southern DPS	*Acipenser medirostris*	FT	SSC	N	DE, DS	BDAT 20085 USFWS 2008
Green sunfish	*Lepomis cyanellus*			I	DE	BDAT 20085
Hardhead	*Mylopharodon conocephalus*		SSC	N	DE	BDAT 20085 USFWS 20084
Hitch	*Lavinia exilicauda*			N	DE	BDAT 20085
Inland silverside	*Menidia beryllina*			I	DE	BDAT 20085
Jacksmelt (M)	*Atherinopsis californiensis*			N	DE	BDAT 20085
Largemouth bass	*Micropterus salmoides*			I	DE	BDAT 20085
Longfin smelt	*Spirinchus thaleichthys*		SSC	N	DE	BDAT 20085
Northern anchovy (M)	*Engraulis mordax*			N	DE	BDAT 20085

Table 1-2.
Fish Species Likely to Occur in the Impact Area Upstream or Downstream from the Restoration Area or in the Delta (contd.)

Common name[1]	Scientific name	Status[2]		Native (N) Introduced (I)	Location[3 4]	Source
		Federal	State			
Pacific herring (M)	*Clupea pallasii pallasii*			N	DE	BDAT 2008[5]
Pacific lamprey	*Lampetra tridentata*			N	DE	BDAT 20085
Pacific pompano (M)	*Peprilus simillimus*			N	DE	BDAT 20085
Pacific staghorn sculpin	*Leptocottus armatus*			N	DE	BDAT 20085
Pacific tomcod (M)	*Microgadus proximus*			N	DE	BDAT 20085
Plainfin midshipman (M)	*Porichthys notatus*			N	DE	BDAT 20085
Prickly sculpin	*Cottus asper*			N	DE	BDAT 20085
Rainbow trout	*Oncorhynchus mykiss*			N	DE	BDAT 20085
Rainwater killifish	*Lucania parva*			I	DE	BDAT 20085
Redear sunfish	*Lepomis microlophus*			I	DE	BDAT 20085
River lamprey	*Lampetra ayresii*		SSC	N	DE	BDAT 20085
Sacramento blackfish	*Orthodon microlepidotus*			N	DE	BDAT 20085
Sacramento perch	*Archoplites interruptus*		SSC	N	DE	CDFG 20086 BDAT 20085
Sacramento pikeminnow	*Ptychocheilus grandis*			N	DE	BDAT 20085
Sacramento splittail	*Pogonichthys macrolepidotus*		SSC	N	DE, DS	CDFG 20086 BDAT 20085
Sacramento sucker	*Catostomus occidentalis*			N	DE	BDAT 20085
Shimofuri goby	*Tridentiger bifasciatus*			I	DE	BDAT 20085
Shiner perch (M)	*Cymatogaster aggregata*			N	DE	BDAT 20085
Shokihaze goby	*Tridentiger barbatus*			I	DE	BDAT 20085
Speckled sanddab (M)	*Citharichthys stigmaeus*			N	DE	BDAT 20085
Starry flounder (M)	*Platichthys stellatus*			N	DE	BDAT 20085
Steelhead, Central Valley	*Oncorhynchus mykiss*	FT		N	DE, DS, US	USFWS 20084
Striped bass	*Morone saxatilis*			I	DE	BDAT 20085
Surf smelt (M)	*Hypomesus pretiosus*			N	DE	BDAT 20085
Threadfin shad	*Dorosoma petenense*			I	DE	BDAT 20085
Threespine stickleback	*Gasterosteus aculeatus*			N	DE	BDAT 20085
Tidewater goby	*Eucyclogobius newberryi*	FE	SSC	N	DE	BDAT 20085
Topsmelt (M)	*Atherinops affinis*			N	DE	BDAT 20085
Tule perch	*Hysterocarpus traskii*			N	DE	BDAT 20085
Wakasagi	*Hypomesus nipponensis*			I	DE	BDAT 20085
Warmouth	*Lepomis gulosus*			I	DE	BDAT 20085
Western mosquitofish	*Gambusia affinis*			I	DE	BDAT 20085
White catfish	*Ameiurus catus*			I	DE	BDAT 20085
White crappie	*Pomoxis annularis*			I	DE	BDAT 20085
White croaker (M)	*Genyonemus lineatus*			N	DE	BDAT 20085
White sturgeon	*Acipenser transmontanus*			N	DE	BDAT 20085
Yellowfin goby	*Acanthogobius flavimanus*			I	DE	BDAT 20085

Table 1-2. Fish Species Likely to Occur in the Impact Area Upstream or Downstream From the Restoration Area or in the Delta (contd.)

Notes:
[1] (M) = marine species
[2] FE = Federal endangered, FT = Federal threatened, SE = CA State endangered, ST = CA State threatened, SC = CA State candidate, SSC = CA species of special concern
[3] DS = mainstem San Joaquin River downstream of Restoration Area, US = mainstem San Joaquin River upstream of Restoration Area, DE = Delta
[4] Locations in italics indicate records returned from a USGS quad-based search of the USFWS species list (accessed online at: http://www.fws.gov/sacramento/es/spp_list.htm), and indicate species that may be affected by projects in the SJRRP Impact Area. These records are presented here to document results of special-status species searches. They do not necessarily represent a complete or accurate account of species occurrence.
[5] Data accessed through the Bay Delta and Tributaries (BDAT) Project website (http://bdat.ca.gov/) on February 21, 2008. Selected fisheries monitoring projects include: CDFG Fall Midwater Trawl, CDFG Summer Townet Survey, and UC Davis Suisun Marsh Fisheries Monitoring.
[6] Data accessed through the California Natural Diversity Database (2008). These records are based on reported current or historical occurrences. They do not necessarily represent a complete or accurate account of species occurrence.

Attachment

Fish Species Water Temperature Suitability

Draft
Biological Resources – Fisheries Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

Table 1.
Suitable, Preferred, or Optimal-Water Temperature Ranges for Special-Status Fish Species in the San Joaquin River from Friant Dam to the Delta

Species	Spawning	Incubation and Emergence	Larval and Juvenile Rearing	Adults	Sources	Comments
Chinook salmon	≤57 to 59°F [a] (upper limit suitable)	39 to 55°F [b,c] (suitable)	55 to 64°F [d] (optimal)	≤66°F [a] (upper limit suitable)	[a] Williams (2006). [b] Myrick and Cech (2001) [c] McCullough (1999) [d] Marine (1997), as cited in Moyle (2002)	Includes fall-, winter- and spring-run Chinook salmon runs.
Central Valley steelhead	39 to 52°F [a] (preferred)	48 to 52°F [a] (preferred)	63 to 66°F [b] (preferred)	46 to 52°F [a] (preferred)	[a] McEwan and Jackson (1996) [b] Myrick and Cech (2001)	Data are for Central Valley steelhead.
Sacramento splittail	<59°F [a] (upper limit suitable)	≤65°F [a,d] (upper limit suitable)	45 to 82°F [b] (suitable)	45 to 75°F [b, c] (suitable)	[a] Moyle et al. (2004). [b] Young and Cech (1996). [c] Moyle et al. (2002). [d] Bailey et al. (2000), as cited in Moyle (2002).	
Hardhead	59 to 64°F [a] (suitable)	nd	nd	75 to 82°F [b] (preferred)	[a] Wang (1986) [b] Knight (1985), as cited in Moyle (2002)	
Kern brook lamprey	50 to 68°F [a, b,d] (suitable)	nd	≤77°F [c] (upper limit preferred)	≤77°F [c] (upper limit preferred)	[a] Vladykov (1973), as cited in Moyle (2002). [b] Brumo (2006) [c] Vladykov and Kott (1976)	[d] No data available for spawning stage for this species. Data provided are for western brook lampreys.
River lamprey	54 to 64°F [a,b,e] (suitable)	54 to 68°F [c,d,f] (suitable)	nd	nd	[a] Beamish (1980) [b] Moyle (2002); upper end of range is for Pacific lamprey [c] Meeuwig et al. (2005) [d] Brumo (2006)	[e] Data on upper end of range is for Pacific lamprey . [f] Data are for Pacific lamprey

Notes for analysis:
Lethal upper temperature limits have not been identified for most of the analysis species. The impact analysis is based on the assumption that water temperatures exceeding the suitable or optimal range result in physiological stress, impairment of essential behavior (e.g., feeding), and mortality if sustained.
General definitions of temperature criteria categories used:
Suitable = The range of temperatures at which a given life stage has been documented occurring under natural conditions.
Preferred = The range that a given life stage most frequently inhabits when allowed to freely select temperatures in a thermal gradient.
Optimal = The optimum temperature range for normal feeding activity, physiological response, and behavior. Some values are specifically optimums for growth.
Key:
< = less than
≤ = less than or equal to
°F = degrees Fahrenheit
nd = no data

Table 2.
Suitable, Preferred, or Optimal Water Temperature Ranges for Game Fish Species in the San Joaquin River from Friant Dam to the Delta

Species	Spawning	Incubation and Emergence	Larval and Juvenile Rearing	Adults	Sources	Comments
Rainbow trout	50 to 59°F [a] (preferred)	50 to 59°F [a] (suitable)	59 to 64°F [b] (optimal)	57 to 66°F [b] (optimal)	[a] Moyle (2002) [b] Myrick and Cech (2000)	Temperature range can vary with strain (Moyle 2002; Myrick and Cech 2000).
Largemouth bass	61 to 75°F [a] suitable	61 to 75°F [a,c] suitable	86 to 90°F [b] (preferred)	81°F [b] (preferred)	[a] Miller and Kramer (1971) as cited in Moyle (2002) [b] Coutant (1975), as cited in Moyle (2002)	[c] Based on spawning temperatures and short incubation time.
Smallmouth bass	55 to 61ºF [a] (lower limit suitable)	nd	84 to 88°F [b] (preferred)	68 to 81ºF [a] (preferred)	[a] Moyle (2002) [b] Coble (1975) as cited in Moyle (2002)	
Spotted bass	59 to 73 ºF[a] suitable	nd	nd	75 to 88ºF [b] (preferred)	[a] Aasen and Henry (1981) as cited in Moyle (2002) [b] Williams and Burgess (1999) as cited in Moyle (2002)	
Striped bass	59 to 68°F (optimal)	59 to 68°F [a] (optimal)	≤77°F (upper limit suitable)	≤77°F (upper limit suitable)	Moyle (2002)	[a] Based on spawning temperatures and short incubation time.

Notes for analysis:
Lethal upper temperature limits have not been identified for most of the analysis species. The impact analysis is based on the assumption that water temperatures exceeding the suitable or optimal range result in physiological stress, impairment of essential behavior (e.g., feeding), and mortality if sustained.
General definitions of temperature criteria categories used:
Suitable = The range of temperatures at which a given life stage has been documented occurring under natural conditions.
Preferred = The range that a given life stage most frequently inhabits when allowed to freely select temperatures in a thermal gradient.
Optimal = The optimum temperature range for normal feeding activity, physiological response, and behavior. Some values are specifically optimums for growth.
Key:
< = less than
≤ = less than or equal to
°F = degrees Fahrenheit
nd = no data

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Attachment

Species Life History Timing

Draft
Biological Resources – Fisheries Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

Table 1.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from Friant Dam to the Merced River. Presence in Restoration Area Reaches (1 through 5), if Known, is Indicated by Numbers in Each Cell

Life History Stage	Month																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Special-Status Species																								
Sacramento Splittail[1]																								
Adult instream migration	5	5																				5	5	5
Spawning			5	5	5	5	5	5	5	5	5	5												
Incubation and emergence				5	5	5	5	5	5	5	5	5	5											
Larval stage moving into deeper water				5	5	5	5	5	5	5	5	5	5	5										
Juvenile downstream migration							5	5	5	5	5	5	5	5	5	5								
Hardhead[2]																								
Adult migration						1	1	1	1	1	1	1	1	1	1									
Spawning							1	1	1	1	1	1	1	1	1	1								
Incubation and emergence	Not known																							
Larval stage	Larval and post larval fish remain in dense cover of flooded vegetation or fallen tree branches																							
Rearing or juveniles present	Move into deeper habitat																							
Kern Brook Lamprey[3]																								
Spawning					1	1	1	1																
Incubation and emergence	Not known																							
Larval stage	Not known																							
Rearing or juveniles present	Not known																							
Metamorphosis																			1	1	1	1		

Table 1.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from Friant Dam to the Merced River. Presence in Restoration Area Reaches (1 through 5), if Known, is Indicated by Numbers in Each Cell (contd.)

Life History Stage	Month																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Game Fish Species																								
Black Bass[3]																								
Spawning						1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5													
Incubation and emergence						1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5												
Larval stage						1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5												
Rearing or juveniles present							1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5	1,2, 3,5										
Striped Bass[3]																								
Adult migration						2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5														
Spawning							2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5												
Incubation and emergence							2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5												
Larval stage							2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5	2,3, 5												
Rearing or juveniles present	Juveniles quickly migrate downstream to estuary.																							

Table 1.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from Friant Dam to the Merced River. Presence in Restoration Area Reaches (1 through 5), if Known, is Indicated by Numbers in Each Cell (contd.)

Life History Stage	Month																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Game Fish Species (contd.)																								
Rainbow Trout[4]																								
Spawning	1	1	1	1	1	1	1	1																
Incubation and emergence	1	1	1	1	1	1	1	1	1	1	1	1												
Larval stage	Fry live in quiet waters before they move into deeper, faster flowing waters																							
Rearing or juveniles present					1	1	1	1	1	1	1	1	1	1										

Sources:
Reach Locations from: CDFG (2007) and McBain and Trush (2002).
[1] *Moyle et al. (2004)*
[2] *Grant and Maslin (1997), as cited in Moyle (2002)*
[3] *Moyle (2002)*
[4] *Moyle (2002), McEwan (2001)*

Probable span of life history activity	(light shading)
Peak of life history activity	(dark shading)

Table 2.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from the Merced River to the Delta and the Major San Joaquin River Tributaries (the Merced, Tuolumne, and Stanislaus rivers)

Life History Stage	Month																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Chinook Salmon (Fall-Run)[1]																								
Adult migration																								
Spawning																			TR	TR	TR	TR	TR	TR
Incubation and emergence	TR	TR	TR	TR	TR	TR													TR	TR	TR	TR	TR	TR
Rearing or juveniles present																								
Juvenile outmigration																								
Steelhead[2]																								
Adult migration																								
Spawning	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR							TR	TR	TR	TR	TR	TR
Incubation and emergence	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR							TR	TR
Rearing or juveniles present																								
Juvenile outmigration																								

Table 2.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from the Merced River to the Delta and the Major San Joaquin River Tributaries (the Merced, Tuolumne, and Stanislaus rivers) (contd.)

Life History Stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sacramento Splittail[3]												
Adult migration												
Spawning												
Incubation and emergence												
Larval stage moving into deeper water												
Juvenile downstream migration												
Hardhead[4]												
Adult migration												
Spawning												
Incubation and emergence	Not known											
Larval stage	Larval and post larval fish remain in dense cover of flooded vegetation or fallen tree branches											
Rearing or juveniles present	Move into deeper habitat											

Table 2.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from the Merced River to the Delta and the Major San Joaquin River Tributaries (the Merced, Tuolumne, and Stanislaus rivers) (contd.)

Life History Stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
River Lamprey[5]												
Adult migration												
Spawning												
Rearing or juveniles present	Remain in silty backwaters up to 5 years											
Metamorphosis												
Outmigration												
Ocean time	Up to 2 years											
Game Fish Species												
Black Bass[5]												
Spawning												
Incubation and emergence												
Larval stage												
Rearing or juveniles present												

Table 2.
Temporal Occurrence of Each Life Stage of the Representative Fish Species in the San Joaquin River from the Merced River to the Delta and the Major San Joaquin River Tributaries (the Merced, Tuolumne, and Stanislaus rivers). “TR” Indicates Life Stage Present Only in the San Joaquin River Tributaries (contd.)

Life History Stage	Month																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Striped Bass[5]																								
Adult migration						░	░	░	░	░														
Spawning							░	░	░	░	░	░												
Incubation and emergence							░	░	░	░	░	░												
Larval stage							░	░	░	░	░	░												
Rearing or juveniles present	Juveniles quickly migrate downstream to estuary.																							
Rainbow Trout[6]																								
Spawning	░	░	░	░	░	░	░	░																
Incubation and emergence	░	░	░	░	░	░	░	░	░	░	░	░												
Rearing or juveniles present					░	░	░	░	░	░	░	░	░	░										

Sources:
1 *Cramer Fish Sciences (2007), Ford and Brown (2001), Moyle (2002), Vick et al. (2000).*
2 *McEwan (2001)*
3 *Moyle et al. (2004)*
4 *Grant and Maslin (1997), as cited in Moyle (2002)*
5 *Moyle (2002)*
6 *Moyle (2002), McEwan (2001)*

Probable span of life history activity	░ (light grey)
Peak of life history activity	▓ (dark grey)

Key: TR = Species/lifestage is present in the major tributaries of the San Joaquin River (Merced, Tuolumne, and Stanislaus rivers).

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Attachment

Black Bass Spawning Production Model Description

Draft
Biological Resources – Fisheries Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

1.0 Model Description

The black bass spawning model is currently being used to estimate spawning production (i.e., total number of larvae leaving the nest) of largemouth and spotted bass in Millerton Lake. This is a spreadsheet model that combines habitat and life history information to simulate spawning production for largemouth bass and spotted bass. Habitat data include water temperatures, reservoir surface level fluctuations, and the surface areas of elevation contours. Life history information includes egg and larvae development time and in-nest survival rates. The life history parameters used in the model were derived primarily from studies of largemouth bass, but included one study of smallmouth bass. Comparable information for spotted bass is largely unavailable, but literature sources indicate that life history parameters for spotted bass are similar to those for largemouth bass, except for spawning depths, which are deeper for spotted bass (Greene and Maceina 2000, Reinart et. al. 1995, Aasen and Henry 1980, Vogele 1975). Therefore, except for spawning depths, the model uses the same life history parameters to simulate spawning production of largemouth bass and spotted bass. The principal sources for life history parameters and equations used in the model are Jackson and Noble (2000), Knoteck and Orth (1998), and Mitchell (1982).

Habitat data inputs for the model include yreservoir water temperatures, storage volumes and bathymetric relationships (storage volume versus surface area and elevation).

The input data used for the Millerton Lake simulations are derived from results of reservoir operations and temperature models. The Black Bass Spawning Production Model uses bathymetric data of the reservoir basin and a multi-year record of San Joaquin River basin hydrology to simulate reservoir storage volumes and water temperatures on a daily time step. The model uses quarter-month time steps (7 or 8 days each, depending on the month), averaging the storage and temperature values and computing water level change as the difference between the water level on the final day of the current time step and the water level on the final days of the previous time step. For processes such as development of eggs and larvae that, depending on water temperatures, may require more than one quarter-month time step for completion, the model employs overlapping time steps, simulating events of two quarter-months (the current and the next quarter month) during each step. Thus, the second quarter month of one time step becomes the first quarter month step of the next time step.

A summary outline of the 14 steps of the model follows:

- **Step 1 –** The average and final reservoir storage volumes are used for each time step to determine the equivalent elevations from lookup tables and surface areas for each one-foot depth interval.

- **Step 2 –** Average water temperatures for each time step are obtained.

- **Step 3 –** Egg incubation time is computed from simulated water temperatures using the following equation, as cited in Jackson and Noble (2000):

  I = 47.9 X exp(-0.13 x T)

  Where: I = incubation time in days and
  T = water temperature in degrees Celsius

  The model adds the development time from egg hatching to larvae leaving the nest to the incubation time. This assumption is supported by information in Knoteck and Orth (1998) and Mitchell (1982).

- **Step 4 –** Days available for incubation/development of eggs/larvae are set based on water temperature thresholds, with days available per time step set at 7.6. Days available is set to zero when water temperatures are less than 61°F (16°C) or greater than 76°F (24.5°C). Days available is also set to zero if the month is earlier than March or later than July because the eggs are not expected to be fully developed before March, and the females are assumed to be spawned out after July, regardless of water temperature. The spawning temperature thresholds were derived from Figure 3 in Mitchell (1982) for largemouth bass and are similar to spawning temperature thresholds given in other reports. If water temperature is between 61°F and 76°F during both quarter-month time steps, the model sets the number of days available for incubation/development to 15.2. If temperature during the first quarter-month time step is between 61°F and 76°F, but temperature during the second time step is greater than 76°F, the model sets the number of days available for incubation/development to 7.6 because incubation and development can occur only during the first time step. However, if water temperature is between 61°F and 76°F in first time step but is below 61°F during second time step, days available for incubation/development is set to zero, because the time needed to complete egg incubation plus larval development at 61°F and below (as computed in Step 3) is greater than 7.6 days, and incubation and egg development cease at the low water temperature of the second time step.

- **Step 5 –** The number of days during the current quarter-month time step that the bottom of the depth interval is inundated, given the rate and direction of reservoir surface elevation change of the time step is computed. If the direction of change is zero or positive, the number of days of inundation is 7.6. If the direction of change is negative, the number of days of inundation is the depth of the interval times the number of days required for one foot of elevation change.

- **Step 6 –** The potential number of completed nest cycles (spawning through departure of larvae) is computed for every two time steps (15.2-days). The potential number of nest cycles is a function of the development time (see Step 3) and the number of days during the time step available for egg and larval development (see Steps 4 and 5). It is computed as the days available for development (i.e., days that the bottom of depth interval is inundated and water temperatures are within the thresholds) divided by the development time. Partial nest cycles result in total mortality, so only the integer portions of computed values are used.

- **Step 7 –** The proportion of eggs spawned per nest that hatch and survive through development to the stage that the larvae leave the nest is computed. The assumed survival rate of eggs and larvae is 93 percent survival per day, based on Jackson and Noble (2000) for largemouth bass eggs and for larvae based on results for smallmouth bass in Knotek and Orth (1998). The proportion surviving was computed from the egg incubation/larval development time as follows:

  $S = 0.93^D$

  Where: S = proportion of eggs and larvae surviving in successful nests, and
  D = days for egg incubation plus larval development (see Step 3).

- **Step 8 –** A spawning depth suitability/nest density index value for each 1-foot depth interval from the reservoir surface to 15 feet for largemouth bass and from the surface to 22 feet for spotted bass is assigned. These indices were adopted from spawning habitat analyses reported in Jones and Stokes (1995) and Mitchell (2006). Depth ranges of 3 to 6 feet and 8 to 13 feet are considered optimal for largemouth bass and spotted bass spawning, respectively, and are assigned a value of 1.0. The surface layer and depths greater than 15 feet for largemouth bass and 21.5 feet for spotted bass are assigned a value of zero because wave action is assumed to destroy nests near the surface, and little or no spawning occurs below the maximum spawning depth. Suitability values for intermediate depths are computed by interpolation. The depth suitability value for every time step pair (15.2-days) and each depth interval was computed as the average of the values for the depths at the current and following time steps.

- **Step 9 –** This and the next two model steps compute three substrate conditioning factors based on the recent inundation and exposure history of the elevation contours. The first factor, exposure to air, improves spawning habitat quality because organic sediment material is decomposed and wind and storm runoff remove fine sediments. The second factor, terrestrial plant growth, results from exposure to air over succeeding weeks during the growing season. Inundated plants benefit spawning habitat because they provide cover for nests and larvae. The third substrate conditioning factor is sedimentation, which is a negative factor that results when an elevation contour sits in deep water, accumulating sediments for long periods of time. Step 9 computes the air exposure factor using three sub-steps. The first sub-step determines the number of time steps during the preceding three years that each elevation contour in the reservoir basin was above the current reservoir surface elevation. The second sub-step reduces this number by two for each time step preceding the current time step that the current surface elevation contour was submerged. This adjustment causes loss of habitat value by re-submergence to proceed at twice the rate as gain of habitat by exposure. Sub-step 3 aggregates the values in sub-step 2 by depth interval. Finally, these values are divided by the maximum possible value (144, the number of quarter-months in three years). The value of the exposure factor varies from 0 to 1. The value would be 0 if the elevation of the contour remained below the water surface for all 144 quarter-month time steps of the preceding three years, and it would be one if the contour of the depth interval had been above the water surface in all of the time steps of the preceding three years.

- **Step 10 –** Computes the terrestrial plant growth factor. This is the proportion of preceding time steps contiguous with the current time step that were above the current reservoir surface elevation contour during the preceding three years. This proportion is computed only for the growing season quarter-months, which are considered to be the 18 quarter-months from mid February through June. Thus, there are a maximum of 54 quarter-months for the three year period. The value of plants as cover for nests is considered to increase with the time available for their growth. Inundation is considered to terminate plant growth, but the cover value of previous plant growth remains for some time after inundation as the plants decompose. To account for this continuing but diminishing value of plants following inundation, the model removes two quarter-months for each time step following initial inundation of the contour.

- **Step 11 –** Sedimentation generally increases with the depth of a contour, and results in buildup of fine sediments and unoxidized organic material, adversely affecting spawning habitat suitability. Sedimentation is computed in three sub-steps. Sub-step 1 computes the average depth of each elevation contour over the three years prior to the current time step. Sub-step 2 subtracts this average depth from the maximum reservoir depth to minimum pool and divides this difference by this maximum depth. Sub-step 3 aggregates the computed sedimentation factors by depth intervals. The deeper the average depth of the elevation contour, the smaller the value of the factor, which reflects the reduced habitat suitability of substrate with fine sediment accumulations.

- **Step 12 –** The three substrate conditioning factors are combined after scaling them according to their relative importance. The terrestrial plant growth factor, which is considered the most important of the three, is multiplied by five, the air exposure factor is multiplied by three and the sedimentation factor is not changed. A “1” is added after multiplication for each of the factors to moderate their effects. Addition of “1” insures that the plant growth factor can modify the simulated spawning production no more than six-fold, the air exposure factor can modify simulated production no more than three-fold, and the sedimentation factor can modify simulated production no more than two-fold. If one were not added, the potential effect of the factors would approach infinity. Following addition of “1” to each of the scaled factors, the factors are summed and the sum is divided by eleven to make the maximum combined value equal to “1.”

- **Step 13 –** An index of spawning production density (i.e., production of larvae leaving the nest per unit area) is computed for each time step and depth interval as the product of the combined substrate conditioning factor (Steps 12), the depth suitabilities/nest densities (Step 8), proportion of eggs/larvae surviving per nest (Step 7), and complete nest cycles (Step 6).

- **Step 14** – An index of total spawning production is computed per time step and depth interval as the product of the production density (Step 13) and the total surface area of the depth interval in the reservoir (Step 1).

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