

# System Reoperation Study

## *Phase III Report: Assessment of Reoperation Strategies*



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## Acronyms and Abbreviations

BDCP	Bay Delta Conservation Plan
CM	Conjunctive Management
COA	Coordinated Operations Agreement
CVP	Central Valley Project
DWR	California Department of Water Resources
EOM	End-of-Month
EOS	End-of-September
FBO	Forecast-based Operations
MID	Merced Irrigation District
NDD	North Delta Diversion
SGMA	Sustainable Groundwater Management Act
SRS	System Reoperation Study
SWP	State Water Project
TTF	Target Threshold Frequency



## Executive Summary

The California Department of Water Resources (DWR) is conducting a System Reoperation Study (SRS) in cooperation with other State and federal agencies, local water districts, groundwater managers, and other stakeholders, to identify potential strategies for reoperation of the statewide flood protection and water supply systems. The opportunity to reoperate portions of California's statewide water system to yield increased water resources-related benefits was recognized by the State Legislature in Senate Bill X2 1 (SB X2 1) (Perata 2008).

In support of the legislative objectives, DWR developed the SRS to identify viable reoperation strategies and understand how integrated management can:

- Improve the reliability of municipal and irrigation water supply.
- Reduce flood hazards.
- Restore and protect ecosystems.
- Buffer the hydrologic variations expected from climate change.
- Improve water quality.

California's statewide water system is composed of a multitude of local, State, and federal projects. These projects include dams and reservoirs, hydropower plants, canals, and water diversion structures. Many of these facilities were developed in the early to mid-20th century, and were not designed, constructed, or operated as an integrated water supply and flood management system. Over time, operations of the two largest water supply projects, the State Water Project (SWP), operated by DWR, and the Central Valley Project (CVP), operated by the U.S. Department of the Interior's Bureau of Reclamation (Reclamation), have been integrated to a certain degree.

California's water supply and flood management infrastructure is physically interconnected to the extent that it is technically feasible to move water around the system, from Trinity County in the north to Imperial County in the south. However, the management of the water system is not as well integrated as it could be. The underlying logic of the SRS is that California can do much more with its existing water infrastructure by taking advantage of the physical interconnections (and enhancing them) while also operating the system in a coordinated manner to optimize the benefits.

The current focus of the SRS is the Central Valley, because this region has the highest integration of water supply and flood management facilities. Additionally, the greatest potential for ecosystem restoration through infrastructure reoperation is found in the Central Valley, because the existing infrastructure has had a profound effect on aquatic ecosystems. Figure ES-1 shows the location of the Central Valley and the study area for the SRS. Figure 1-1 also shows major features of the CVP and SWP.



Source: Department of Water Resources, CWP 2013

Figure ES-1: Location of Central Valley and Study Area for SRS

## Study Process

Development of the SRS is a multi-phased effort that includes:

- Phase I — Plan of Study.
- Phase II — Strategy Formulation and Refinement.
- Phase III — Assessment of Reoperation Strategies.

The next phase of SRS will consist of evaluation of the following:

- Potential for using flood water for managed groundwater recharge on farmland and working landscapes for flood protection, drought preparedness, aquifer remediation, and ecosystem restoration.
- Existing flood operating rules of the reservoirs under changing hydrology.
- Feasibility of existing reservoir spillways and outlets to pass floodwater safely with changing hydrology.
- Identification of system reoperation implementation challenges and opportunities.

This Phase III report summarizes the work that has been completed for the SRS since the completion of Phase II in February of 2014.

### Phase III Assessment of Reoperation Strategies

Phase III of the SRS evaluates the performance of the reoperation strategies. These strategies are comprised of reservoir reoperation strategies and a system integration strategy. These strategies, which were vetted and advanced from Phase II, include:

- Shasta Lake (Sacramento River) Reoperation.
- Lake Oroville (Feather River) Reoperation.
- Combined Reoperation of Shasta Lake and Lake Oroville (Sacramento and Feather rivers) with forecast-based operations (FBO) reoperation of Folsom Lake).
- Lake McClure (Merced River) Reoperation.
- Increased Integration of SWP and CVP (Operations as a Single Project).

All of the strategies evaluated in Phase III, except for the integration of SWP and CVP, are made up of the following components:

- Forecast-Based Operations.
- Conjunctive Management (CM).
- Supplemental Spring Flow.

For all strategies, baseline modeling was conducted to both evaluate the current level of performance and to establish a performance reference point to compare against the effects of reoperation. The SWP and CVP integration strategy investigates integration of the SWP and CVP. The Shasta Lake and Lake Oroville strategies were modeled using CalSim-II, HEC-ResSim, and HEC-RAS. Analysis of these three strategies included consideration of the impacts of potential implementation of the Bay-Delta Conservation Program (BDCP), North Delta Diversion (NDD), and climate change. The Lake McClure reoperation strategy and SWP and CVP integration strategy were modeled using spreadsheet models developed by MBK Engineers. The Lake McClure reoperation strategy considered climate change, but did not consider potential implementation of the BDCP NDD.

Modeling indicates that FBO have the potential to achieve many of the objectives of SRS. FBO can increase water supply through flexible flood control operation. Additionally, FBO has incidental effects on river flows below dams that may benefit ecosystems. FBO may also provide flood control benefits by temporarily increasing flood reservation space. When

combined with other reoperation components, like conjunctive management, the additional water held in storage with FBO can improve water supply reliability and provide water for ecosystem purposes.

For assessment of ecosystem benefits, the SRS team used surrogate supplemental spring flows to evaluate the potential to provide the benefits associated with increased flows to restore and protect ecosystems.

Conjunctive management is another reoperation component that can mitigate water supply and carry over storage impacts from supplemental spring flows. Expanded CM may also enhance water supply during dry and critical years by switching willing participants in the upper Sacramento and Feather river basins to groundwater during periods of reduced surface water availability. This in-lieu groundwater pumping results in increased storage in Shasta Lake and Lake Oroville in dry and critical years, which may aid with temperature management below the dams.

Although the NDD was not considered in the analysis of all scenarios, the analysis that was performed reveals similar performance effects between reoperation strategies, including the NDD facility vs. those only using existing infrastructure. Therefore, the reoperation strategies analyzed in Phase III are still considered beneficial with a potential new Delta conveyance. The NDD has the added flexibility to provide ecosystem benefits in rivers upstream of the Delta, but with less potential impact to CVP/SWP water supplies.

Similarly, climate-changed hydrology was considered for representative reoperation strategies and the performance of those strategies were similar to the non-climate changed evaluations. The modeling results reveal that reoperation strategies create changes in reservoir storage, river flow, and system-wide deliveries in trends similar to changes seen without climate change. This suggests that reoperation strategies are robust and can provide benefits under a range of potential future changes to hydrology.

The analysis of operating the SWP and CVP as a single project shows that water supply and ecosystem conditions may be improved through increased integration. Many of the potential benefits from fully integrating CVP and SWP operations can be possible within the context of the Coordinated Operations Agreement (COA), with additional agreements or arrangements as needed. Expanded joint point of diversion and sharing reservoir release obligations between the two projects are examples of how the benefits of increased integration may increase operational efficiency.

The important takeaway from the Phase III SRS analysis is that, while reoperation can provide potential benefits with minimal impacts to flood risk, the potential benefits to water supply, ecosystem, and flood management are limited as a result of reoperation. The incremental nature of the potential benefits identified in Phase III can be attributed to a few important aspects of California's water systems. Firstly, the SRS Phase III is attempting to optimize a highly constrained system to achieve new benefits. This creates a situation where achieving new benefits may create tradeoffs with other performance areas. Secondly, many system reoperation components evaluated in the SRS are already being implemented to some degree

in actual operations. Since the SRS evaluation assumes that these components have not been implemented, the actualized benefits associated with the reoperation strategies evaluated in Phase III would likely be less.

### Next Steps

Because of the limited benefits realized from this Phase III analysis, the next phase of SRS will consist of evaluation of the following:

- Potential for using flood water for managed groundwater recharge for farmland and working landscapes flood protection, drought preparedness, aquifer remediation, and ecosystem restoration.
- Existing flood operating rules of the reservoirs under changing hydrology.
- Feasibility of existing reservoir spillways and outlets to pass floodwater safely with changing hydrology.
- Identification of system reoperation implementation challenges and opportunities.

## Chapter 1. INTRODUCTION

California faces many challenges to its water management systems from growing population, unreliable water supply, future changes to climate, flood risk, and degraded ecosystems, compelling California to adopt a comprehensive and integrated water management policy. Mandated by Senate Bill X2 1, the California Department of Water Resources (DWR) has been leading the planning and studies to identify potential options for reoperating the State's flood protection and water supply systems to optimize the use of existing surface water storage and conveyance facilities, as well as groundwater storage capacity.

Under this system reoperation study (SRS), DWR is evaluating the potential benefits from changing operations and management of existing water supply, conveyance, and flood protection facilities to achieve improvements in water supply reliability, ecosystem protection/restoration, and flood hazard reduction. In addition, modifying the management of these objective priorities could also support water quality improvements. DWR is conducting the SRS in cooperation with other State and federal agencies, local water districts, groundwater managers, and other stakeholders to identify potential reoperation strategies.

Development of the SRS is a multi-phased effort. Phase I, Plan of Study, was completed in June 2011, and Phase II, Strategy Formulation and Refinement, in February of 2014. This report is to document the potential performance of reoperation strategies evaluated in Phase III.

As identified in Phase II, the SRS is evaluating potential strategies to simultaneously achieve the following water resources planning objectives:

- Improve the reliability of water supplies.
- Reduce flood hazards.
- Restore and protect ecosystems.

The SRS will also consider and evaluate potential water quality improvements and the potential to buffer climate change effects that can be supported with reoperation strategies.

### 1.1 Study Authorization

In September 2008, Senate Bill X2 1 (Perata)<sup>1</sup> was signed into law. Under this bill, Division 33, "Integrated Water Supply and Flood Protection Planning, Design, and Implementation," was added to the Water Code, commencing with Section 83000. Per Water Code Section 83002(b)(6)(B), DWR was required to conduct planning and feasibility studies to identify potential options for the reoperation of the State's flood protection and water supply systems that will optimize the use of existing facilities and groundwater storage capacity. The studies will incorporate appropriate climate change scenarios and be designed to determine the potential to achieve the following legislative objectives:

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<sup>1</sup> [http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb\\_0001-0050/sbx2\\_1\\_bill\\_20080930\\_chaptered.html](http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_0001-0050/sbx2_1_bill_20080930_chaptered.html)

- Integration of flood protection and water supply systems to increase water supply reliability and flood protection, improve water quality, and provide for ecosystem protection and restoration.
- Reoperation of existing reservoirs, flood facilities, and other water facilities in conjunction with groundwater storage to improve water supply reliability, flood control, ecosystem protection, and to reduce groundwater overdraft.
- Promotion of more effective groundwater management and protection, and greater integration of groundwater and surface water resource uses.
- Improvement of existing water conveyance systems to increase water supply reliability, improve water quality, expand flood protection, and protect and restore ecosystems.

## 1.2 Study Area

The legislatively mandated focus of this study is the “state’s flood protection and water supply systems.” The Central Valley (see Figure 1-1) has the State’s major flood management infrastructure and the greatest concentration of interconnected water supply systems, groundwater basins, and ecosystems; changes in operation of one component could potentially affect another. For this reason, the study area for identifying system reoperation opportunities is defined as the Central Valley, which includes the Sacramento, San Joaquin, and Tulare river basins. The SRS also recognizes that the approaches and strategies considered and evaluated in this study can be conceptually applied by local and regional water interests in other locations and with other facilities.

The State Water Project (SWP) and Central Valley Project (CVP) are the two main water storage and delivery systems in the Central Valley, operated by DWR and the U.S. Department of the Interior, Bureau of Reclamation (Reclamation), respectively. SWP and CVP have major reservoirs upstream of the Sacramento-San Joaquin Delta (Delta) to capture runoff; using the SWP and CVP pumping stations in the Delta, water is transported via natural watercourses and canal systems to urban and agricultural service areas south of the Delta.

SWP consists of 34 storage facilities (reservoirs and lakes) with a total storage capacity of 5.7 million acre-feet (maf), 20 pumping plants, four pumping-generating plants, five hydroelectric power plants, and about 700 miles of canals and pipelines. Project purposes include water supply, flood management, water quality maintenance, power generation, recreation, and fish and wildlife enhancement.

CVP consists of 20 reservoirs with a total storage capacity of more than 11 maf, 11 power plants, and more than 500 miles of canals and aqueducts. Project purposes include flood management; navigation; water supply; fish and wildlife protection, restoration, and enhancement; and power generation.

In the Central Valley, there are other storage facilities owned and operated by local agencies; for example, the New Bullards Bar Reservoir by Yuba County Water Agency, Camanche Reservoir by East Bay Municipal Utility District (EBMUD), and Lake McClure by Merced

Irrigation District. These facilities are part of multipurpose projects for flood protection; irrigation, municipal and industrial water supply; hydroelectric power; recreation; etc.

Over time, operations of SWP and CVP have been integrated to a certain degree. The current level of integration is based on the Coordinated Operations Agreement (COA) that was initiated in the 1970s and finalized in 1986 (United States Bureau of Reclamation 1986).



Image Source: California Dept. of Water Resources, CWP 2013

Figure 1-1: System Reoperation Study Area and Major Water Supply Facilities



### 1.3 Planning Principles

In development of the SRS, DWR has adopted a set of guiding principles drawn (with minor modifications) from *California Water Plan Update 2013*, as follows:

- Water supply benefits resulting from reoperation will be shared with the owners of the projects (as negotiated with the owners).
- Reoperation studies of regional and local projects will be performed with collaborative and voluntary participation of facilities' owners and operators.
- The priority of this study will be the reoperation opportunities that simultaneously reduce flood hazards, improve water supply reliability, and protect and restore ecosystems.

The above principles established the SRS study constraints. Phase III evaluation assumptions and strategy formulations also meet these principles through identification of willing infrastructure owners and operators and alternative configuration to provide net improvement in flood operations, water supply, and ecosystems.

### 1.4 Related Studies and Programs

There are several related studies and programs in the study area, which are ongoing and have the potential to affect the SRS (Table 1-1) or vice versa, SRS strategies may affect the related studies and programs. Depending on the particular goals, objectives, and status of each study and program, appropriate assumptions, results, and uncertainty have been addressed in the SRS.

Table 1-1. Studies and Programs Related to the System Reoperation Study

Study/Program	Partners	Status as of February 2016	Objective Themes	Relationship to System Reoperation Study
Shasta Lake Water Resources Investigation	<ul style="list-style-type: none"> <li>Reclamation.</li> </ul>	Final Feasibility Report. Final EIS.	<ul style="list-style-type: none"> <li>Ecosystem.</li> <li>Water Supply Reliability.</li> </ul>	Potential for Shasta FBO.
North-of-the-Delta Offstream Storage Investigation	<ul style="list-style-type: none"> <li>Reclamation, DWR, Sites JPA.</li> </ul>	Draft Environmental Impact Report /Environmental Impact Study (EIR/EIS) and Feasibility Report in progress.	<ul style="list-style-type: none"> <li>Water Supply Reliability.</li> <li>Renewable Power Integration.</li> <li>Ecosystem.</li> <li>Water Quality.</li> </ul>	Potential to affect future conditions.
Folsom Dam Joint Federal Project	<ul style="list-style-type: none"> <li>Reclamation, United States Army Corps of Engineers (USACE).</li> </ul>	Under Construction.	<ul style="list-style-type: none"> <li>Flood Protection.</li> </ul>	Potential for Folsom FBO.
Central Valley Flood Protection Plan	<ul style="list-style-type: none"> <li>DWR.</li> </ul>	Plan update in progress (2017).	<ul style="list-style-type: none"> <li>Flood protection.</li> <li>Ecosystem.</li> </ul>	2012 Plan includes Yuba-Feather FBO/FCO in State Systemwide Investment Approach.
Sacramento-San Joaquin Basins Study	<ul style="list-style-type: none"> <li>Reclamation.</li> <li>DWR.</li> <li>Stockton East Water District.</li> <li>El Dorado County Water Agency.</li> <li>Madera County Resources Management Agency.</li> </ul>	Strategy in progress.	<ul style="list-style-type: none"> <li>Water Supply Reliability.</li> </ul>	Addresses future uncertainties in climate, demographics, land use, and socioeconomic conditions and effects on water supply and demand.
Bay-Delta Conservation Plan (BDCP); In 2015, state and federal agencies added a new sub-alternative which separated the conveyance facility and habitat restoration	<ul style="list-style-type: none"> <li>DWR.</li> <li>Reclamation.</li> </ul>	<ul style="list-style-type: none"> <li>Draft EIR/EIS.</li> <li>Draft Biological Assessment.</li> <li>404 Permit Application Submitted.</li> </ul>	<ul style="list-style-type: none"> <li>Ecosystem.</li> <li>Water Supply Reliability.</li> </ul>	Potential to affect future conditions, addresses uncertainties in climate.

measures into two separate efforts: California WaterFix and California EcoRestore				
Delta Plan	<ul style="list-style-type: none"> <li>DWR.</li> </ul>	Plan completed in 2013.	<ul style="list-style-type: none"> <li>Ecosystem.</li> <li>Water Supply Reliability.</li> </ul>	Called for improvement of Delta conveyance and expansion of groundwater and surface storage.
San Joaquin River Restoration Program	<ul style="list-style-type: none"> <li>Reclamation.</li> <li>State Water Contractors.</li> </ul>	Construction and implementation.	<ul style="list-style-type: none"> <li>Ecosystem.</li> </ul>	Potential to affect future conditions in San Joaquin River Basin.
Upper San Joaquin River Basin Storage Investigation	<ul style="list-style-type: none"> <li>Reclamation.</li> <li>DWR.</li> </ul>	Draft Feasibility Report. Draft EIS.	<ul style="list-style-type: none"> <li>Water Supply Reliability.</li> <li>Ecosystem.</li> </ul>	Potential to affect future conditions in San Joaquin River Basin.
Cross Valley Canal Expansion Project	<ul style="list-style-type: none"> <li>Kern County Water Agency.</li> </ul>	Construction complete (2012).	<ul style="list-style-type: none"> <li>Water Supply Reliability.</li> </ul>	Included in baseline conditions.

### 1.5 Uncertainties in Future Conditions

California’s water resources future is uncertain. Water resources planning should recognize that conditions are changing and will continue to change (California Water Plan Update 2013). The SRS has identified two specific uncertainties that may influence potential reoperation strategies in the Central Valley: climate change effects, and potential new Delta conveyance. The SRS has included sensitivity analyses that include these potential uncertain futures to increase understanding of the future performance of system reoperation strategies.

California’s climate has been changing over the last century, with mean temperatures rising 1 to 2 degrees Fahrenheit, sea level rise of 7 inches along the California coast, and the precipitation mix between rain and snow in the Sierra Nevada has shifted to more rain and less snow (California Department of Water Resources 2014). In the face of expected continuing climate change, the historic hydrology might not be sufficient to represent the range of climate variation for future water resources planning. There is a need to address uncertainty from climate change in water resources planning.

Another uncertainty is conveyance in the Delta. The Bay Delta Conservation Plan (BDCP) was developed to address the Delta’s ecosystem<sup>2</sup>, water management, and water quality challenges within a regulatory framework. In April 2015, BDCP was revised and evolved into two efforts: California WaterFix<sup>3</sup> to protect water supplies and fish, and California EcoRestore to support a stronger Delta ecosystem. California WaterFix will change water management in California, and

<sup>2</sup> There are 56 covered species, including 11 fish species, 27 wildlife species, and 18 plant species, as well as 13 natural communities.

<sup>3</sup> <http://www.californiawaterfix.com/>

potential reoperation project performance should be evaluated with both existing and potential new Delta conveyance.

### 1.5.1 Climate Change

SRS has used a technical approach similar to that used by BDCP to evaluate the sensitivity of reoperation strategies under potential climate change conditions. This section provides an overview of these BDCP climate change assumptions for operational and water quality modeling. The SRS climate change sensitivity evaluation was based on modeling assumptions used by BDCP, which included climate change effects.

For the BDCP, future climate change projections are made primarily on the basis of Global Climate Model (GCM) simulations under a range of future emission scenarios. There are 112 future climate projections from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, and BDCP considered all these projections with subsequent bias-correction and statistical downscales to derive future Central Valley climate change. In BDCP, the reference climate period is 1970–2000<sup>4</sup>, with which projected temperature and precipitation of particular emission scenarios were compared. BDCP quantitative analyses were conducted for two 30-year future climate periods: (1) 2011–2040 as Early Long-Term (ELT), with the approximate midrange being 2025; and (2) 2046–2075 as Late Long-Term (LLT), with the approximate midrange being 2060.

At any selected 30-year future climatologic period, each projection represents one point of change among the others. A group of multi-model, multi-emission scenario projections is termed an *ensemble*, and individual model-emission scenario projections are termed *members of the ensemble*. Based on changes in annual temperature and annual precipitation from the median change (50th percentile), the state of climate change was represented by quadrants Q1 for drier, less warming; Q2 for drier, more warming; Q3 for wetter, more warming; and Q4 for wetter, less warming than the ensemble median. BDCP used Q5 as a midrange climate change scenario to describe samples from the 25th to 75th percentile of the full ensemble, and to also represent the best estimate of the consensus of climate projections. In each of the five regions, a sub-ensemble of climate change projections was identified, and then a climate change signal was incorporated into the natural variability observed in the historical record to project temperature and precipitation at localized areas. These data were then used as inputs to the Variable Infiltration Capacity (VIC) hydrology model to simulate runoff and other hydrologic variables for major rivers and streams in the Central Valley. Streamflow outputs from VIC were then applied as inputs to an operations model, like CalSim-II, and reservoir temperature models.

BDCP used the Rahmstorf method (Science 2007) for sea level rise estimates. The projected sea level rise at the ELT timeline (2025) is approximately 12–18 centimeters (cm) (5–7 inches). At the LLT timeline (2060), the projected sea level rise is approximately 30–60 cm (12–24

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<sup>4</sup> This period is the currently established climate norm used by National Oceanic and Atmospheric Administration and represents the most recent climate time period used for analyses (Bay Delta Conservation Plan 2013).

inches). Because of the considerable uncertainty in these projections and the state of sea level rise science, BDCP used the midrange of the estimates for each timeline: 15 cm (6 inches) by 2025 and 45 cm (18 inches) by 2060.

For the SRS, four climate change scenarios were selected to evaluate the sensitivity of Central Valley water resources systems and reoperations: ELT Q5, LLT Q5, LLT Q2, and LLT Q4. The ELT Q5 and LLT Q5 will represent the midrange climate change conditions for two different future climate periods. It is anticipated the LLT Q2 (drier, more warming) and Q4 (wetter, less warming) scenarios would likely capture the bounding conditions of climate change and sea level rise relevant to reoperation evaluated in this report.

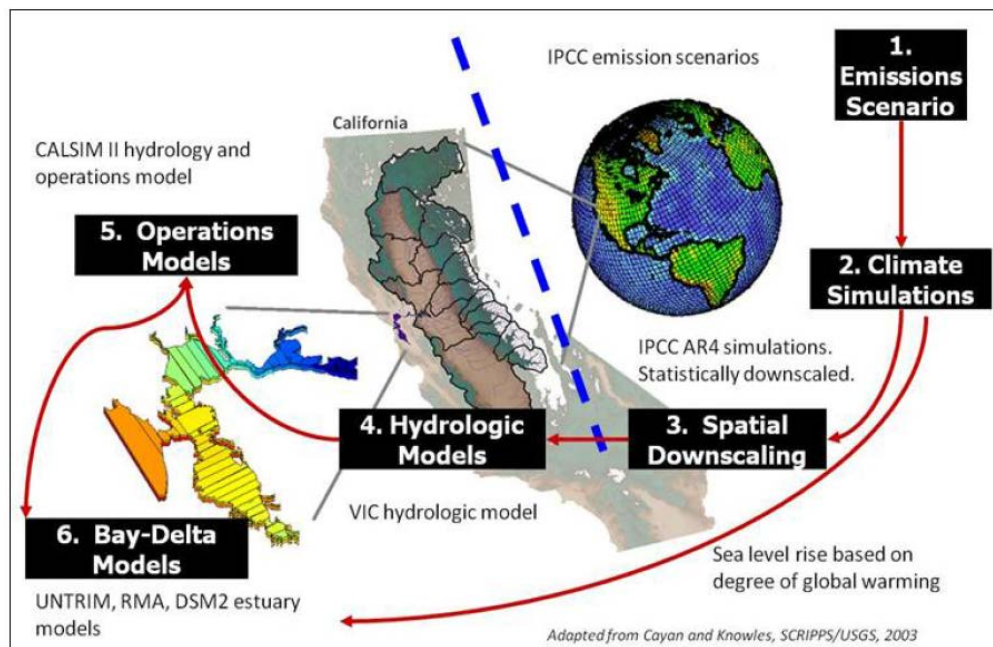


Figure 1-2: Graphical Depiction of the Analytical Process for Incorporating Climate Change into Water Planning

### 1.5.1 Bay-Delta Conservation Plan

Per its Executive Summary, BDCP proposed 22 different conservation measures for water flow and conveyance, natural community protection, natural community restoration, “other stressors,” and avoidance and minimization of incidental take (Bay Delta Conservation Plan 2013a). Subject to water flow and conveyance conservation measures, the new north Delta intake facilities along the Sacramento River will divert water through state-of-the-art positive barrier fish screens into an isolated tunnel/pipeline to the existing south Delta export facilities. It is anticipated that this new operation will improve conditions for covered fish species and protect the water supplies of the SWP and CVP.

Under BDCP Alternative 4, which was the Preferred Alternative for CEQA purposes, water would primarily be conveyed from the north Delta to the south Delta through 45 miles of pipelines/tunnels with a total of 9,000 cubic feet per second (cfs) capacity. Water would be diverted from the Sacramento River through three fish-screened intakes on the east bank of the Sacramento River between Clarksburg and Courtland. Water would travel in gravity collector pipelines from the intakes to a sedimentation basin before reaching the intake pumping plants. From the intake pumping plants, water would be pumped into short segments of conveyance pipelines, and then through an initial single-bore tunnel, which would lead to an intermediate forebay on Glannvale Tract. From the southern end of this forebay, water would pass through an outlet structure into a dual-bore tunnel where it would flow by gravity to the south Delta. Water would then be conveyed through a siphon under Italian Slough, and then into the north cell of the expanded Clifton Court Forebay, which would be dredged and redesigned to provide an area isolating water flowing from the new north Delta facilities. The expanded Clifton Court Forebay would be designed to provide water to Jones pumping plant 24 hours per day. Alternative 4 would also include the continued use of the SWP/CVP south Delta export facilities. Fremont Weir would be modified to improve fish passage by constructing an opening and installing operable gates and fish passage facilities. In addition, there would be a smaller opening with operable gates and fish passage enhancement for lower flow conditions (Bay Delta Conservation Plan 2013b).

Alternative 4 water conveyance operations would follow criteria for north Delta diversion bypass flows, south Delta OMR flows, south Delta export/inflow ratio, flows over Fremont Weir into Yolo Bypass via operable gates, Delta inflow and outflow, Delta Cross Channel gate operations, additional Rio Vista minimum flow requirements, operations for Delta water quality and residence (per State Water Resources Control Board [SWRCB] Decision 1641 [D-1641]), and water quality for agricultural and municipal/industrial diversions (per D-1641). Delta outflow would be determined by the outcome of a decision tree process being used to account for potential uncertainties related to flow requirements (Bay Delta Conservation Plan 2013b).

Note that in April of 2015, State agencies announced a modified preferred alternative, Alternative 4A under California WaterFix, in replacement of BDCP Alternative 4 to address concerns like the impacts of large-scale habitat restoration efforts and the 50-year permit

duration. Alternative 4A will be evaluated in the Recirculated Draft EIR/Supplemental Draft EIS (RDEIR/SDEIS) that is currently under development. As a result of the timing of the new California WaterFix Alternative 4A, this SRS Phase III analysis evaluates Alternative 4 of the BDCP to consider the potential performance of Reoperation strategies with new Delta conveyance. The California WaterFix program has found that modeling results of Alternative 4 and 4A are similar. This sensitivity analysis and results are described in the “Uncertain Futures” section of Chapter 5 in this report.

Consistent with the revised proposed project, the California WaterFix RDEIR/SDEIS includes analysis of two other sub-alternatives that do not include habitat restoration measures beyond those needed to provide mitigation under CEQA, NEPA, ESA, and CESA. The potential environmental impacts of the proposed project and other sub-alternatives were evaluated in the RDEIR/SDEIS released for public review and comment in July of 2015.

## Chapter 2. CALIFORNIA CENTRAL VALLEY WATER RESOURCES BACKGROUND AND SETTING

### 2.1 Introduction

Water resource facilities in California utilize time management to control water resources, primarily to provide flood protection for the Central Valley and secondarily to address issues of timing and distribution of water resources within the state. California has a Mediterranean climate consisting of cool, wet winters and warm, dry summers. This climate creates natural time-management considerations regarding the availability and utilization of water resources. Water must be captured when and where it is available, to be delivered to locations when and where it is needed. Runoff from both intense winter storm precipitation and spring snowmelt from the Sierra Nevada mountain range can exceed the capacity of the Central Valley river system. Numerous surface water reservoirs in Northern California were constructed to control, capture, and store water when it is available in the wet winter and spring for use elsewhere in the state during the dry summer and fall. In California, water is stored primarily in aquifers, mountain snowpack, and surface water reservoirs. Important considerations when assessing how the system may be reoperated, as well as the potential effects of such a reoperation on other beneficial uses, are the interdependencies among the meteorological, hydrological, and climatological systems; the water uses and demands in the state; and the water resource facilities and facilities management.

### 2.2 Basin Characteristics

The precipitation in California's Mediterranean climate typically occurs in a highly variable pattern during the winter and spring seasons, and primarily in the mountainous regions of Northern California. Figure 2-1 illustrates the average annual precipitation in California. The average annual precipitation varies from over 160 inches per year near the coast in Northern California, to less than 6 inches per year in the southern San Joaquin Valley. Three general measures of precipitation in California are the *Northern Sierra 8-Station Index*, the *San Joaquin 5-Station Index*, and the *Tulare Basin 6-Station Index*. These indices log the average precipitation at key stations in their respective basins, and provide an indication of the season's general wetness. Historical average annual precipitation indices are shown on Figure 2-2. The average Northern Sierra 8-Station Index is 52 inches, the average for the San Joaquin 5-Station Index is 41 inches, and the average for the Tulare Basin 6-Station Index is 29 inches. The wettest index is in the northern part of the state, and the indices get dryer toward the southern part of the state. The historical average monthly 8-Station index, 5-Station index, and 6-Station index data are shown in Figure 2-3. On average, the bulk of the precipitation falls between November and March, with the wettest months occurring in December and January. In a Mediterranean climate, precipitation can vary greatly from week-to-week, between seasons, from year-to-year, and over a period of years.



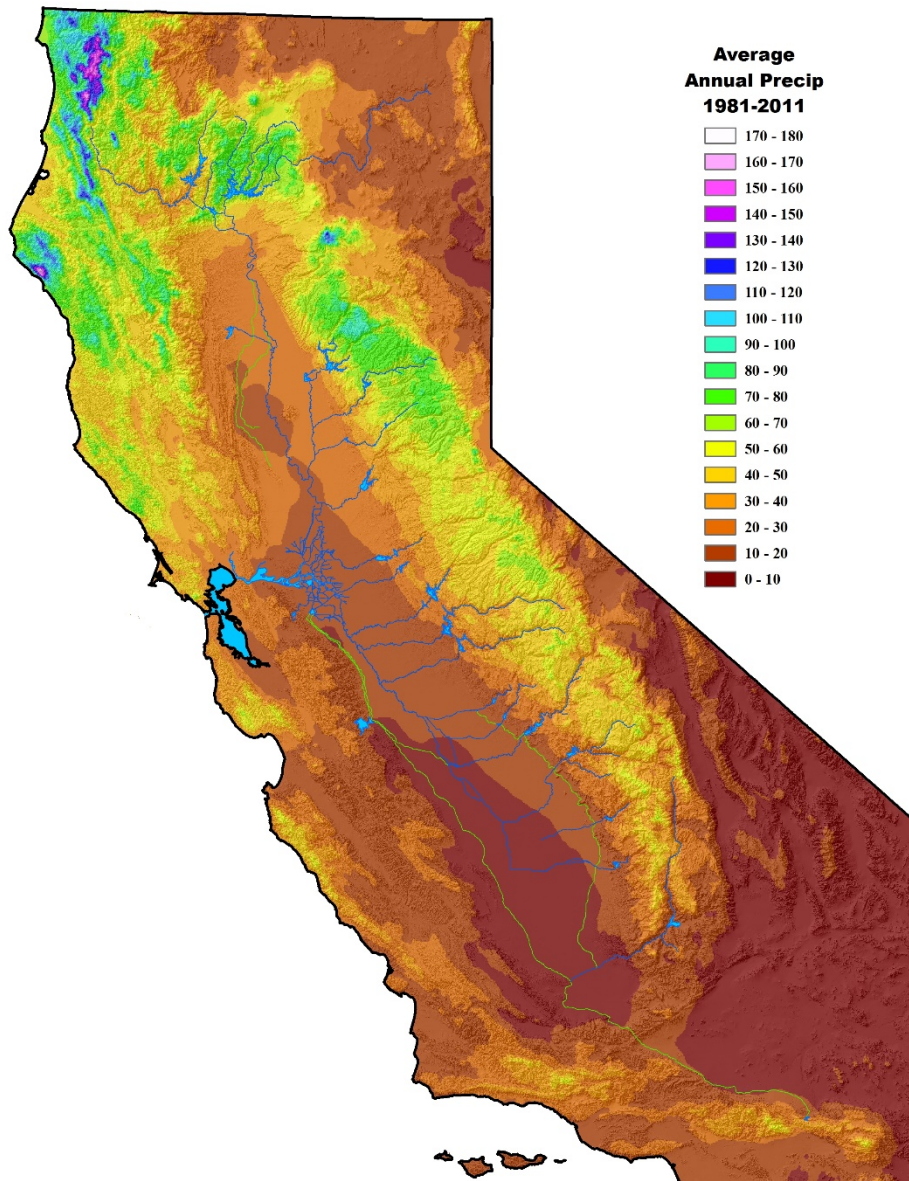


Figure 2-1: Average Annual Precipitation in California

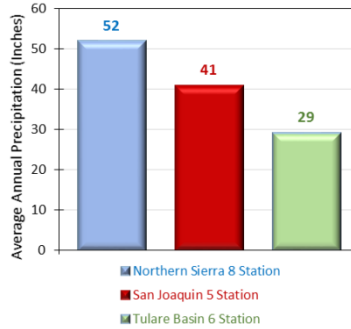


Figure 2-2: Average Annual Precipitation Indices

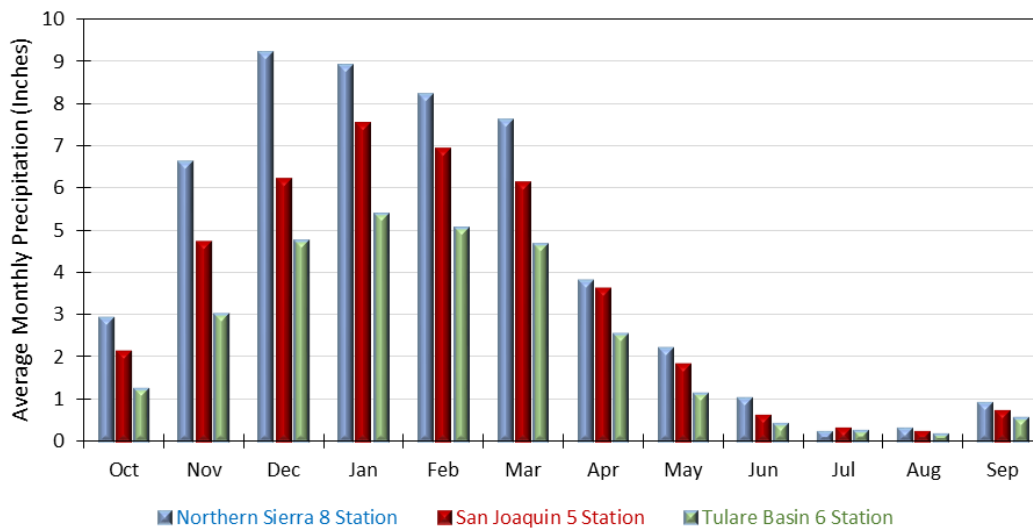


Figure 2-3: Average Monthly Precipitation Indices

Runoff into the Central Valley follows the same general patterns as precipitation, although there are variations resulting from basin geomorphic characteristics and snow accumulation effects. The major runoff basins in the mountainous regions in the northern Central Valley are the Upper Sacramento, Feather, Yuba, and American. In the southern Central Valley region, the major basins are the Stanislaus, Tuolumne, Merced, and Upper San Joaquin. Located between these two regions is the Eastside Basin that flows directly into the Sacramento-San Joaquin Delta (Delta) region. Downstream of the mountainous runoff basins and draining the Central Valley, are the Sacramento Valley and San Joaquin Valley basins. The major drainage basins feeding the Delta and the average annual runoff from each basin are shown in Figure 2-4. Reflective of the wetter conditions in the northern half of the state, the Sacramento River contributes, on average, about three-quarters of the total inflow to the Delta, roughly 22 million acre-feet (maf). The San Joaquin River contributes just less than one-quarter of the flow, approximately 6 maf, with local precipitation and the Delta Eastside streams comprising of the Cosumnes, Mokelumne, and Calaveras rivers making up the difference, approximately 2 maf.

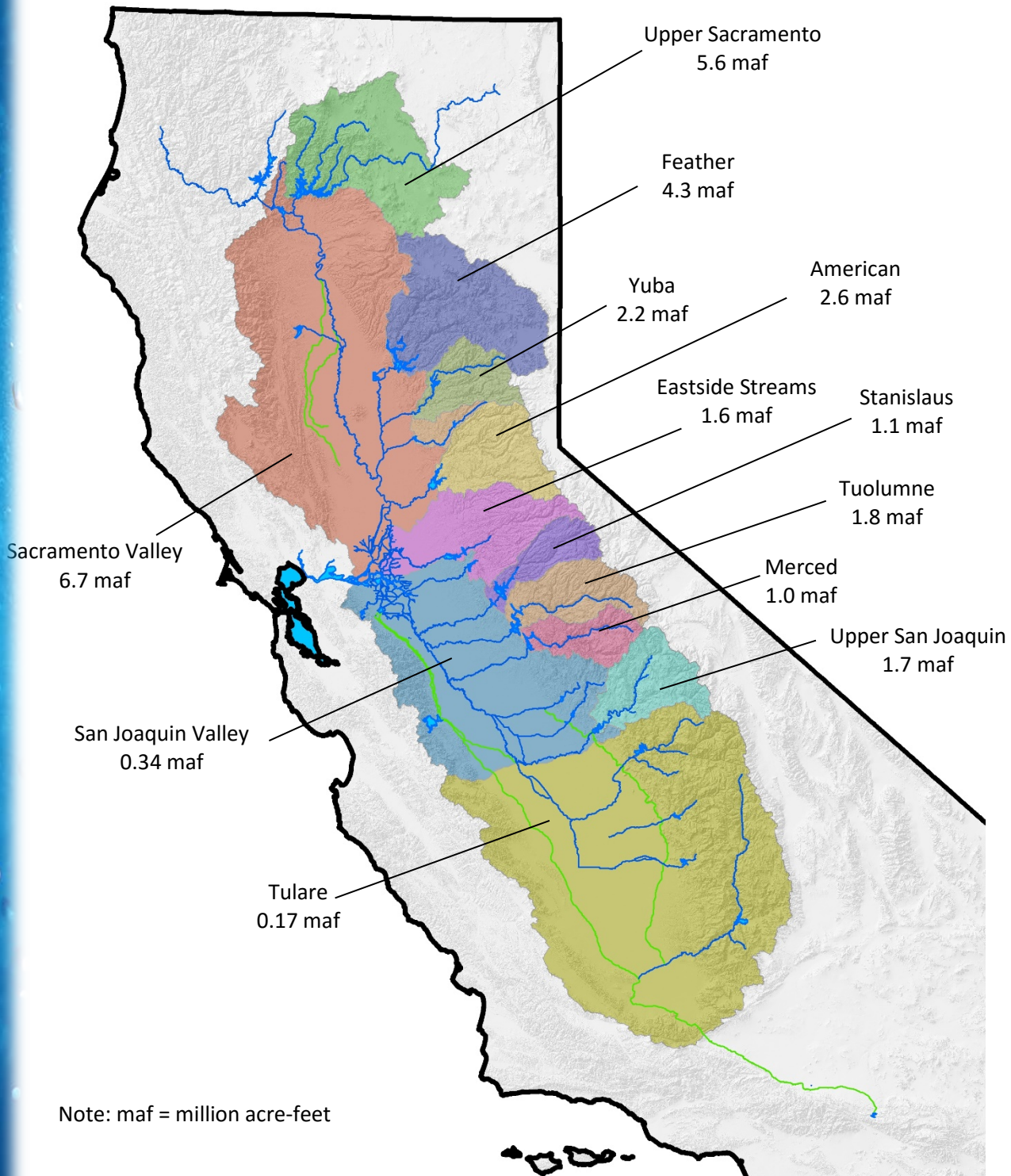


Figure 2-4: Drainage Basins and Average Annual Unimpaired Runoff in the Central Valley

As shown in Figure 2-4, the runoff in the Sacramento Valley, downstream of the Northern Sierra Nevada drainage basins, can produce a significant volume of flow. This area can generate, on average, over 6 maf of runoff annually. The basin is at a lower elevation, and the runoff is driven

primarily by rainfall rather than snowmelt. At the south end of the San Joaquin Valley, the rivers and streams flow into the Tulare Basin. The runoff from this basin typically does not contribute to the Delta inflow except in the wettest years, when excess runoff can flow over to the San Joaquin River.

Figure 2-5 and Figure 2-6 show the average monthly inflow to Shasta Reservoir, which is representative of the typical runoff in Northern California. Large winter storms, associated snowpack, and runoff create high flow and potential flooding conditions in both the Central Valley and the Delta during the winter and the spring. As the storm season ends and natural hydrologic conditions become dry, natural low-flow conditions exist in the summer and fall. Based on the inflow records from 1943 through 2015, the average peak runoff at Shasta Reservoir occurs in March. Nonetheless, as shown in Figure 2-6, there is a large variability in the monthly inflow, and in California’s Mediterranean climate, the peak month can occur anytime from December through April in any given year.

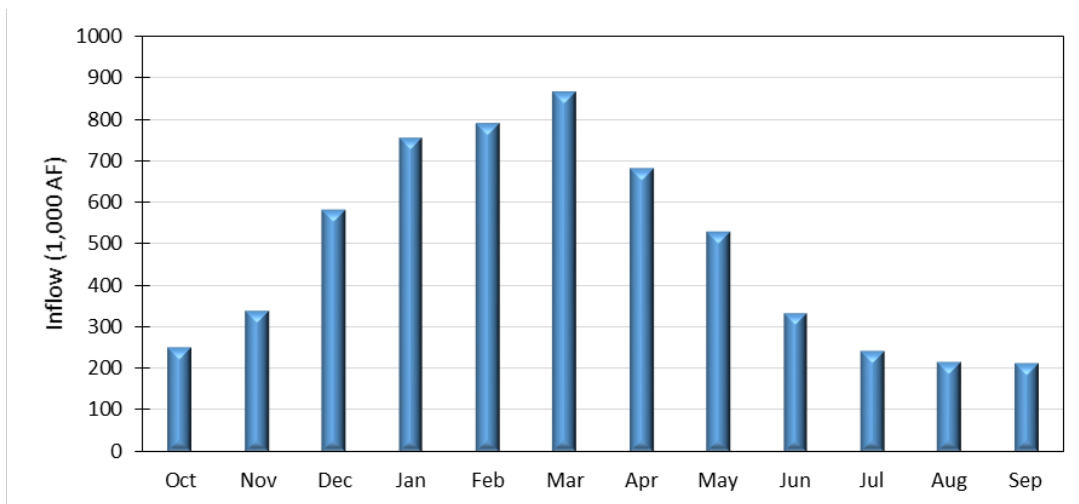


Figure 2-5: Average Monthly Shasta Reservoir Inflow (1943 through 2015)

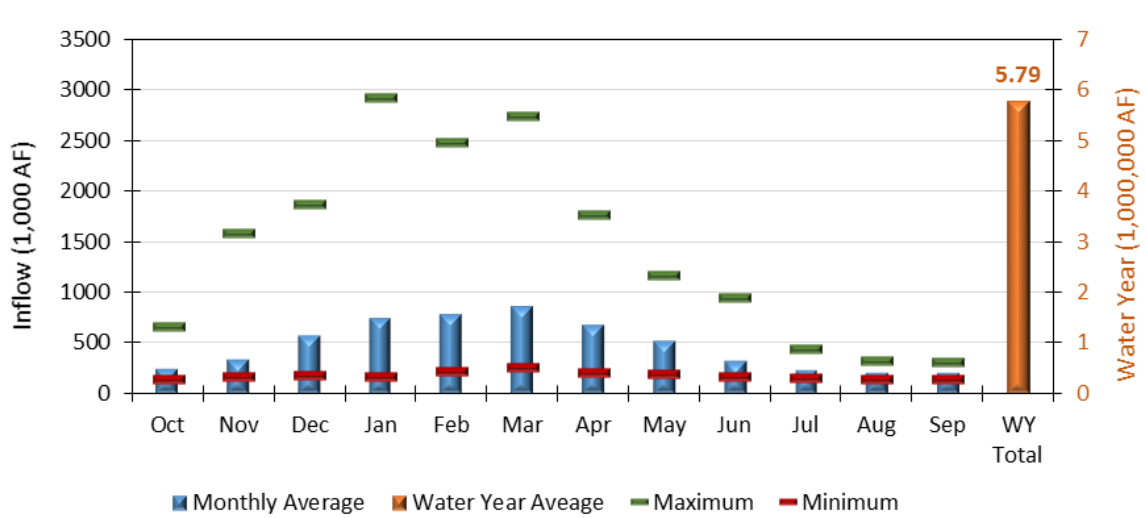


Figure 2-6: Average Monthly Shasta Reservoir Inflow with Maximum, Minimum, and Annual Total (1943 through 2015)

Figure 2-7 shows the average monthly Sacramento Valley accretion of water. Rainfall runoff during winter months is the primary source of valley water accretion, along with minor amounts of snowmelt. Because this accretion occurs below the reservoirs within the Sacramento River basin, this runoff is uncontrolled and enters the Delta via a natural runoff pattern. As the storm season ends and natural hydrologic conditions become dry, natural low-flow conditions exist in the summer and fall. As shown in Figure 2-7, there is a large variability in the monthly inflow, and in California’s Mediterranean climate, the peak month can occur at any time from January through March in any given year.

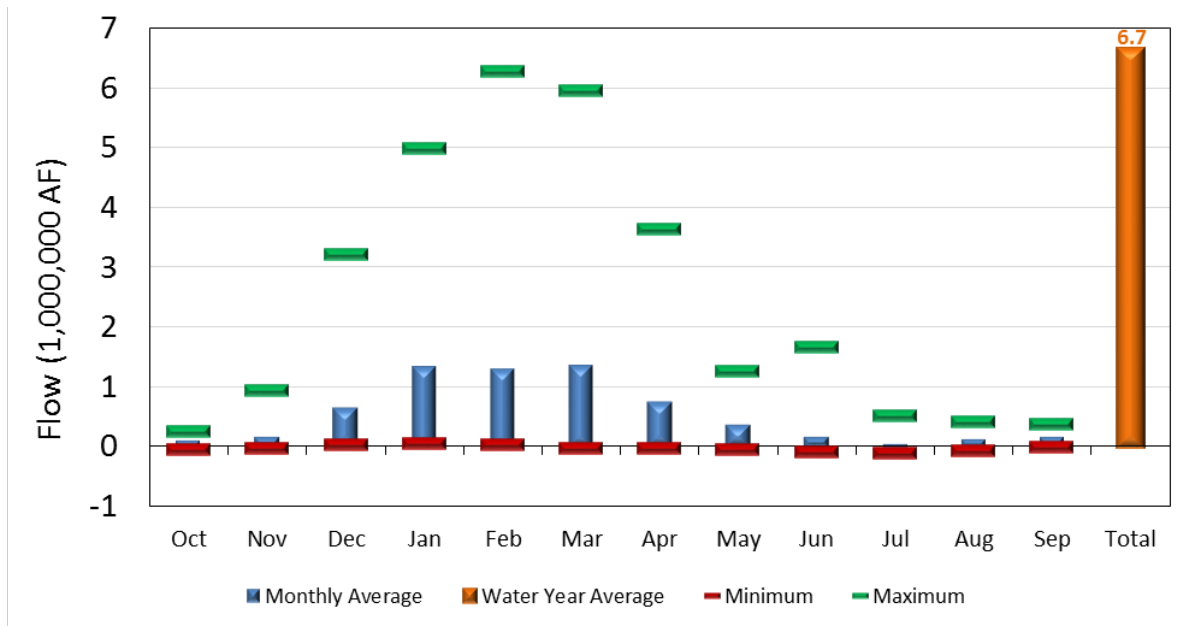


Figure 2-7: Average Monthly Sacramento Valley Accretion with Maximum, Minimum, and Annual Total (1970 through 2014)

California’s precipitation and runoff pattern is primarily driven by winter storms coming from the Pacific Ocean. On average, five to seven larger storms contribute to most of the precipitation that falls in California, and a few of these larger storms can be the difference between a wet water year and a dry water year. Figure 2-8 shows the average number of wet days per year that provide up to half of an area’s total annual precipitation. In the southern part of California, very few storms make up the water supply, while in Northern California, 10 to 15 days of precipitation contribute up to half of the year’s water supply. Studies have shown that California has the largest year-to-year variability in seasonal precipitation in the continental United States.

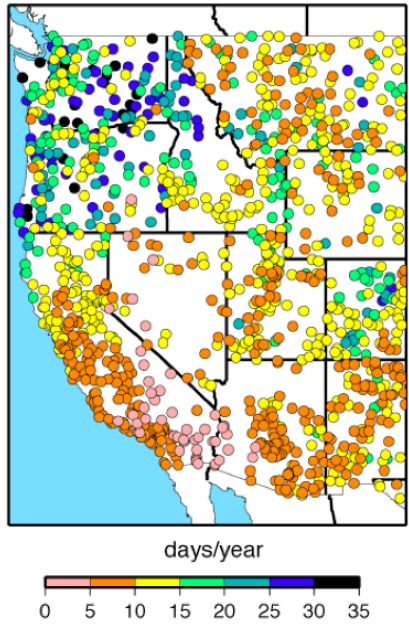


Figure 2-8: Average Number of Wet Days/Year to Obtain Half of Total Annual Precipitation (Water Years 1951 through 2008)

California's Mediterranean climate is subject to large annual variations in precipitation and runoff, as illustrated in Figure 2-9. This figure shows the Sacramento River Index (SRI) from 1906 through 2015. The SRI is the sum of the full natural flow of the Sacramento River at Bend Bridge, the Feather River at Oroville, the Yuba River at Smartsville, and the American River at Folsom. The SRI varies from a low of 5.12 maf in 1977 to a high of 37.68 maf in 1983. Figure 2-9 also shows the average SRI and the 5-year running average SRI. The 5-year running average provides a drought indicator by providing the accumulated water deficit over any 5-year period.

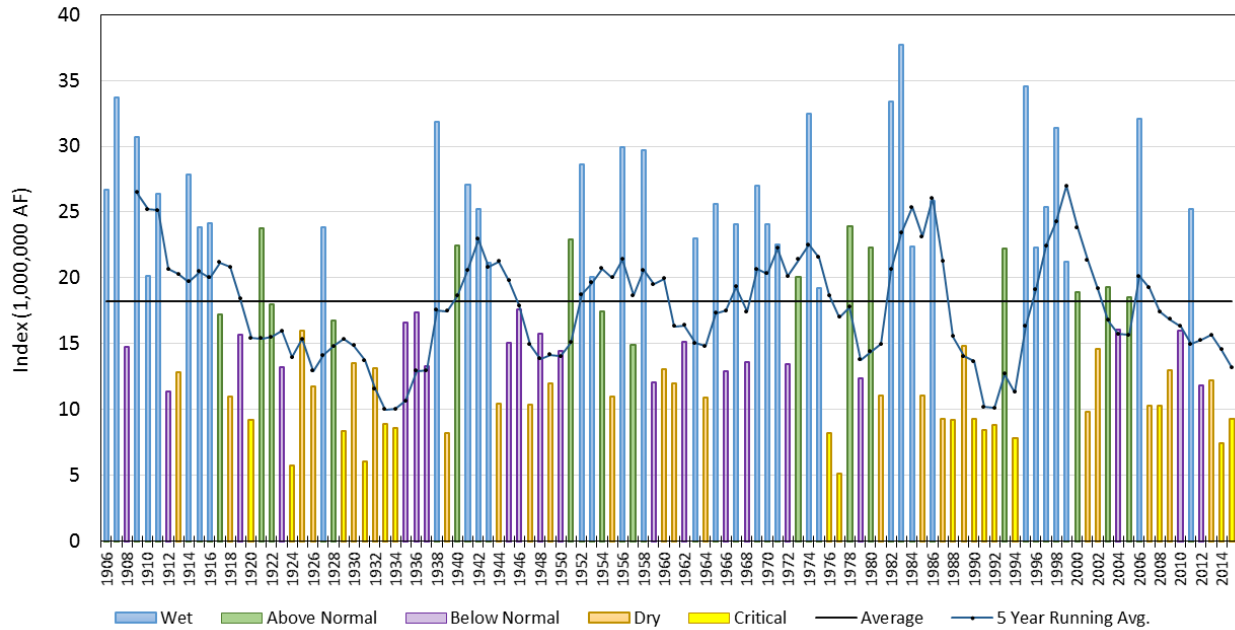


Figure 2-9: Sacramento River Index and 5-Year Running Average (1906 through 2015)

## 2.3 Water Management Facilities

### 2.3.1 Reservoirs

The Mediterranean climate and drought/flood cycles in California instilled the need for water management facilities to help control the availability and timing of California’s natural water resources. Dams were constructed in the natural canyons in the foothills surrounding the Central Valley (rim reservoirs) to control the variable California hydrology and protect life and property from potential flooding. Reservoir operations have been environmentally engineered to provide this primary function as well as other multiple benefits, including water supply, downstream water quality, power generation, recreation, and fishery protection. Offstream reservoirs store water by diverting runoff entering the Central Valley drainage downstream of the rim reservoirs, in addition to capturing flows passing through the rim reservoirs.

To divert and export water from the Sacramento Valley, diversion and export facilities were environmentally engineered to distribute water to specific land areas and uses with secondary facilities, such as fish screening and salvage facilities utilized to environmentally engineer fish protection considerations. These types of facilities were designed to manage water resources within the variability of California’s climatic and hydrologic conditions, and provide for the diversion, storage, re-regulation, conveyance, and delivery of the water for a variety of purposes. Figure 2-10 shows the major reservoirs above the Central Valley watershed, highlighting the storage capacities and average annual unimpaired basin runoff for each reservoir.



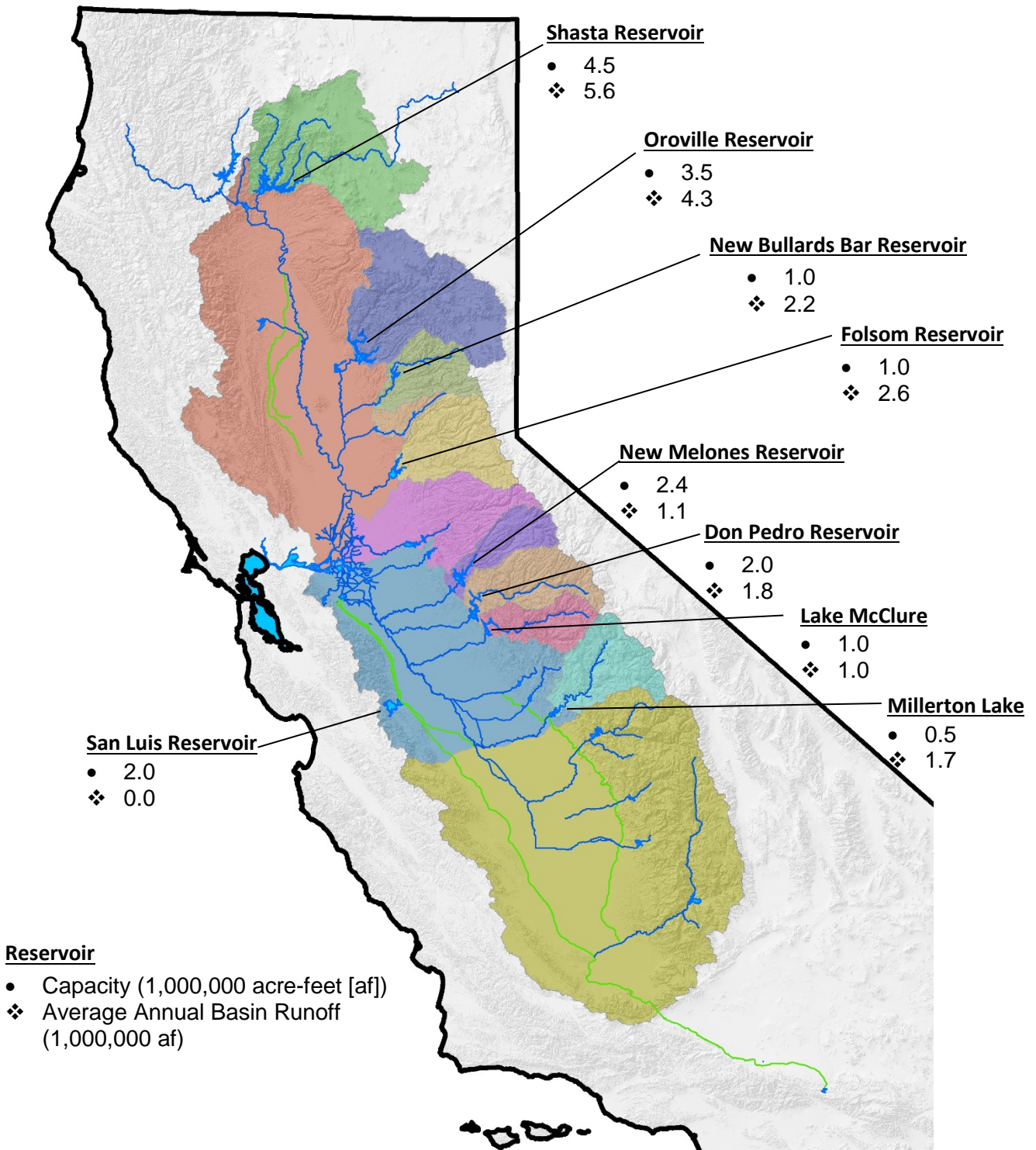


Figure 2-10: Central Valley Reservoirs showing Storage Capacity and Average Annual Unimpaired Basin Runoff

Rim reservoirs, located at the upper rim of California's valley regions, control and store the flood flows at the bottom of the drainage basins. The primary purpose of the rim reservoirs is to

reduce downstream flooding from storm and snowmelt events by capturing the peak storm and snowmelt runoff for release later in the season when the flood threats have subsided. Reservoir management operations flatten the peak unimpaired runoff flows in the winter, and augment river flows in the summer and fall. Figure 2-11 and Figure 2-12 show the average monthly inflow and releases at Shasta Reservoir and Folsom Reservoir, respectively. The timing of the reservoir releases (storage management) is coordinated to achieve environmental instream flow and temperature objectives.

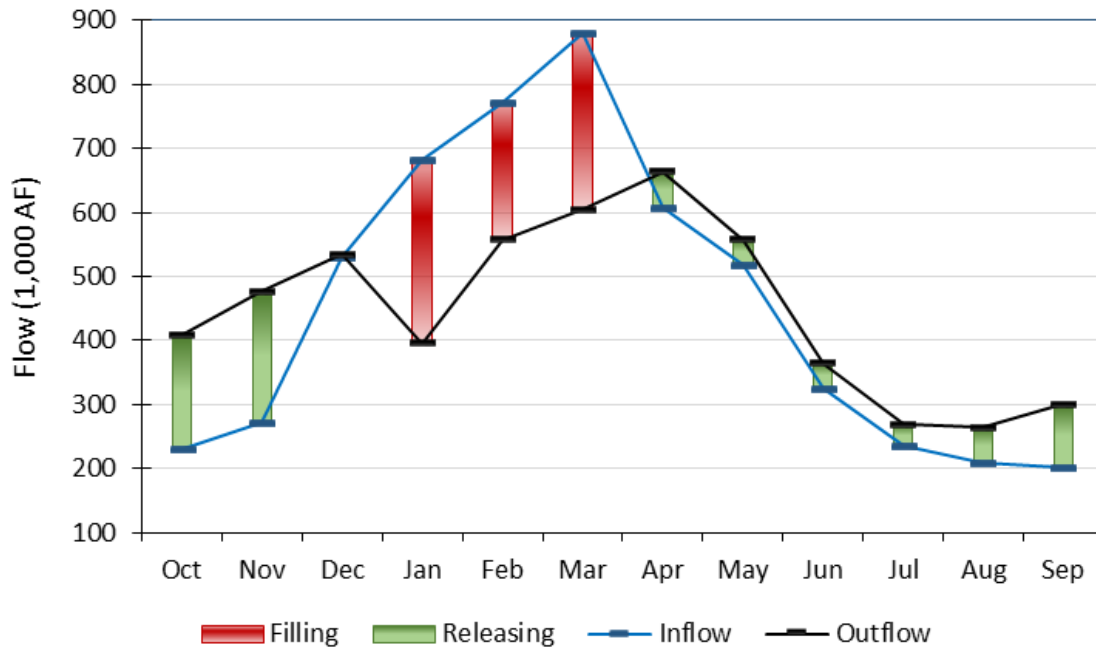


Figure 2-11: Shasta Reservoir Average Monthly Inflow and Release

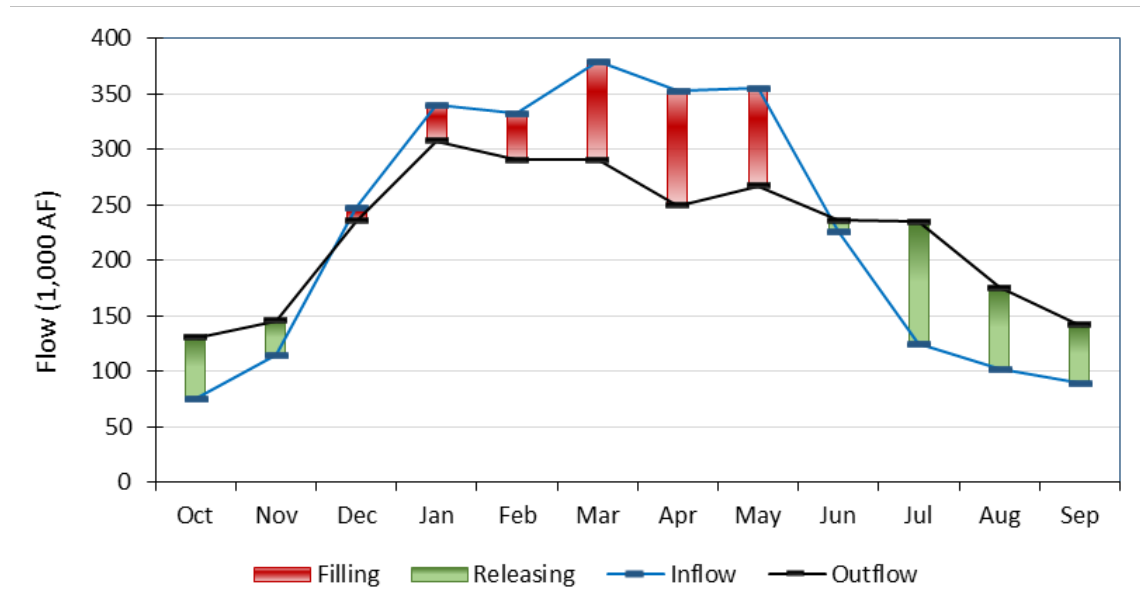


Figure 2-12: Folsom Reservoir Average Monthly Inflow and Release

Runoff basins in the southern Central Valley have different hydrologic characteristics than the northern Central Valley. Winter storms in the southern Central Valley have more variety in intensity and duration. Southern Central Valley basins originate at higher elevations, producing more snow and runoff timing variability. Snowmelt generally occurs later in the season farther south, and the runoff generated from the snowmelt can create more flooding concerns than in Northern California. Reservoirs in the Sierra Nevada that feed into the San Joaquin River generally have a larger storage capacity for the drainage area than reservoirs in the Northern Sierra that feed into the Sacramento River Basin; that is, the ratio of the reservoir storage capacity to unimpaired basin runoff volume is larger (Figure 2-10). Larger flood storage capacity in the San Joaquin Basin is also needed to manage reservoir releases in highly constrained flood-control river corridors. Reservoirs in the San Joaquin Basin have greater storage retention potential, with operations geared more toward multi-year drought protection concerns. The hydrologic system in the San Joaquin Basin is highly engineered and there are fewer periods when flow in excess of San Joaquin Valley demands is available.

*Offstream reservoirs* are located “off” of the major rivers and streams, and are environmentally engineered to augment the ability to divert and capture runoff in the Central Valley. Water is pumped into storage when flow is available, and it is released later in the season when demands are high. In addition to adding the ability to divert and capture unstored flow that may be available from the rivers and the Delta, the offstream reservoir operations provide the opportunity to re-divert and export previously stored water for later use.

### 2.3.2 Sacramento — San Joaquin River Delta Salinity and Flow

Runoff and inflow to the Delta help repel salinity intrusion from San Francisco Bay. Salinity reaches farther inland during the lower flow periods in the summer and fall, and is pushed out

toward the western edge of the Delta when flows are higher in the winter and spring months. Flood control management of the water facilities affects the timing and volume of unimpaired runoff into the Delta, and reduces extent of the seasonal salinity intrusion. Historically, higher salinity reached far into the interior Delta in drought years prior to the construction and operations of the State and federal water projects.

Figure 2-13 and Figure 2-14 show the maximum salinity intrusion in the Delta before and after the construction of the major water resource projects.

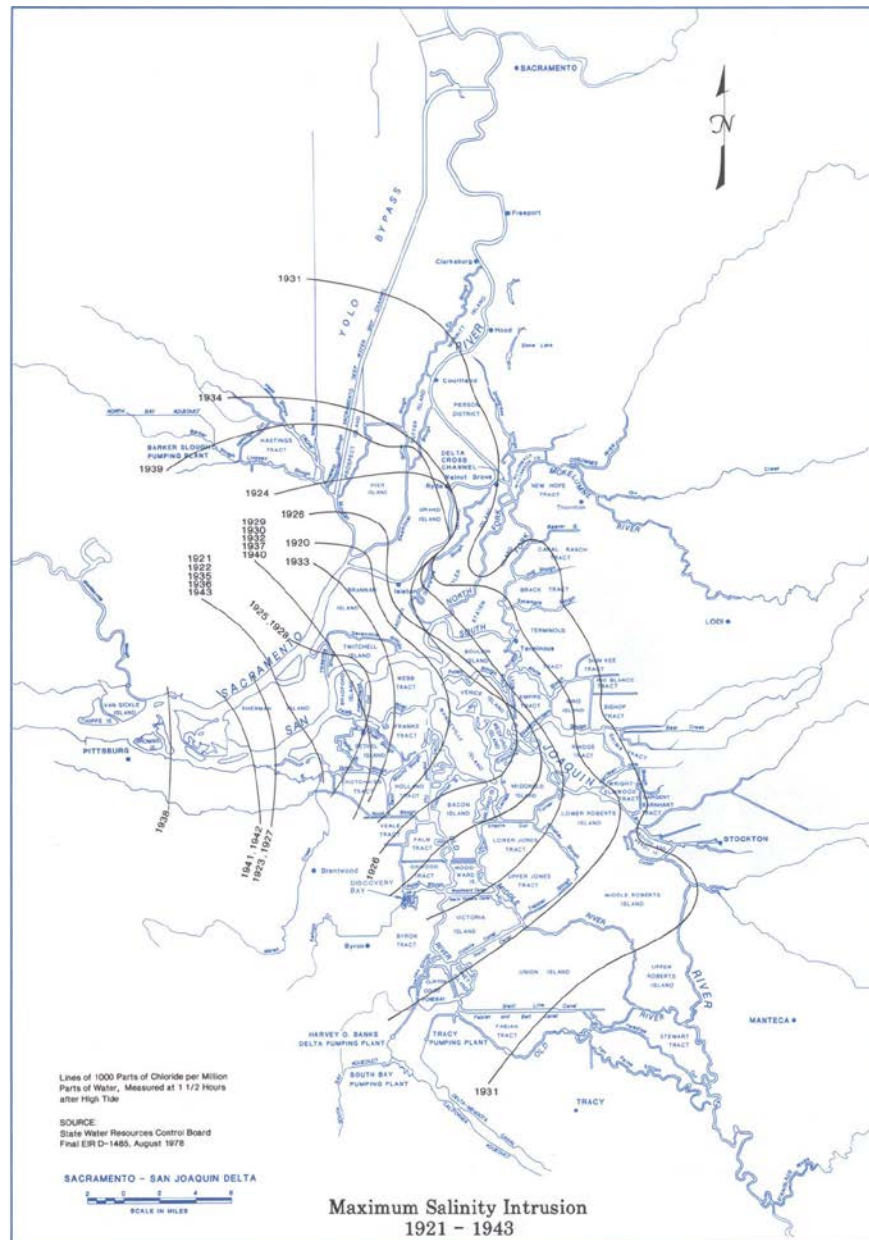


Figure 2-13: Delta Water Quality Pre-project

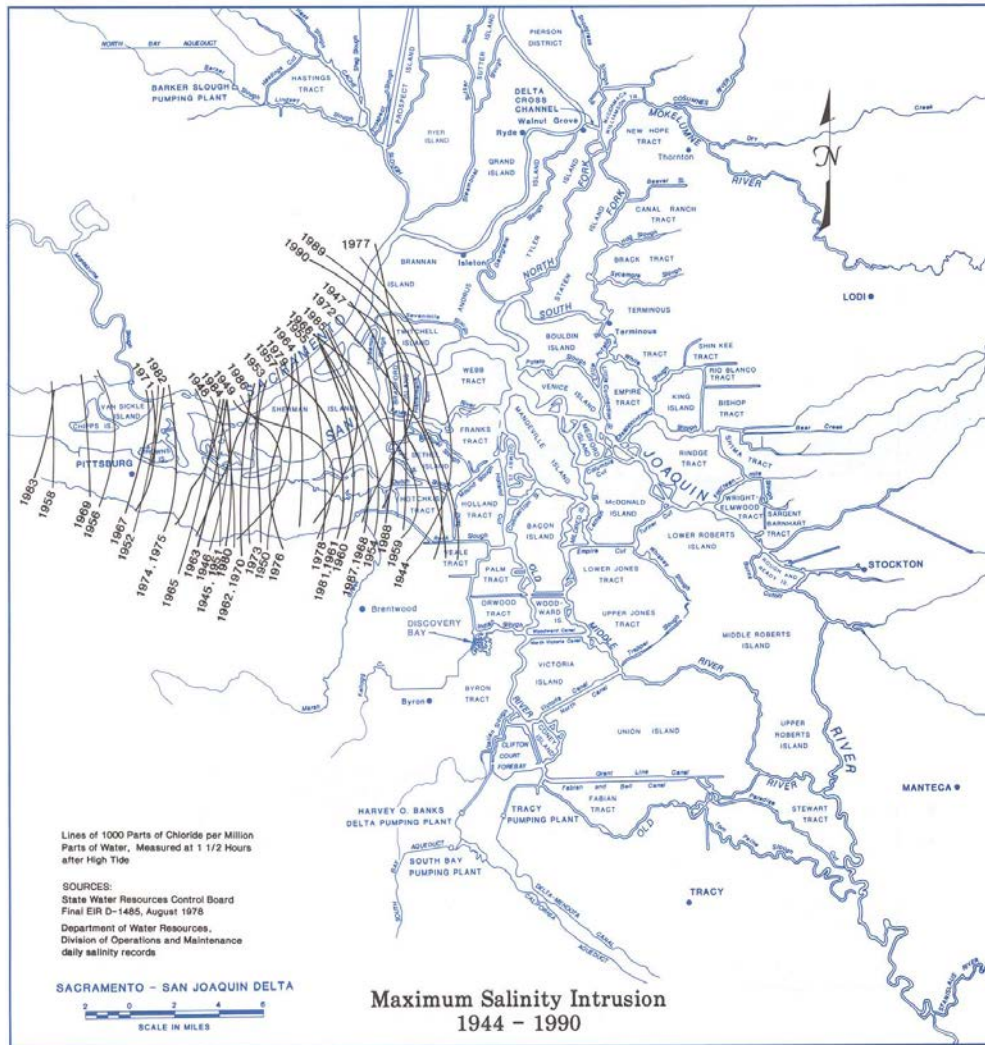


Figure 2-14: Delta Water Quality Post-project

California's climate and population distribution creates the need to convey water from the wetter northern part of California to the drier San Joaquin Valley and farther south where the demand exists. Export facilities were constructed in the Southern Delta and on upstream rivers to pump water into canals and pipelines for conveyance to other basins. Because of the environmental effects associated with exporting water from a river and from the Delta, export facilities were engineered to minimize impacts on the environment at both locations. Fish screening and collection are especially difficult in the tidal Delta environment, and the pumping of water can alter the natural flow pattern in the Delta channels, affecting fish movement and water quality. Exports from the South Delta affect the channel flow in the Delta, and the net tidal flow reverses as water is drawn toward the pumps. Figure 2-15 shows typical Delta net channel flow before and after the export facilities were constructed in the South Delta. For diversions along a river, fish screening is easier, but the changes in channel flow and velocities, and added conveyance distances can be challenging.

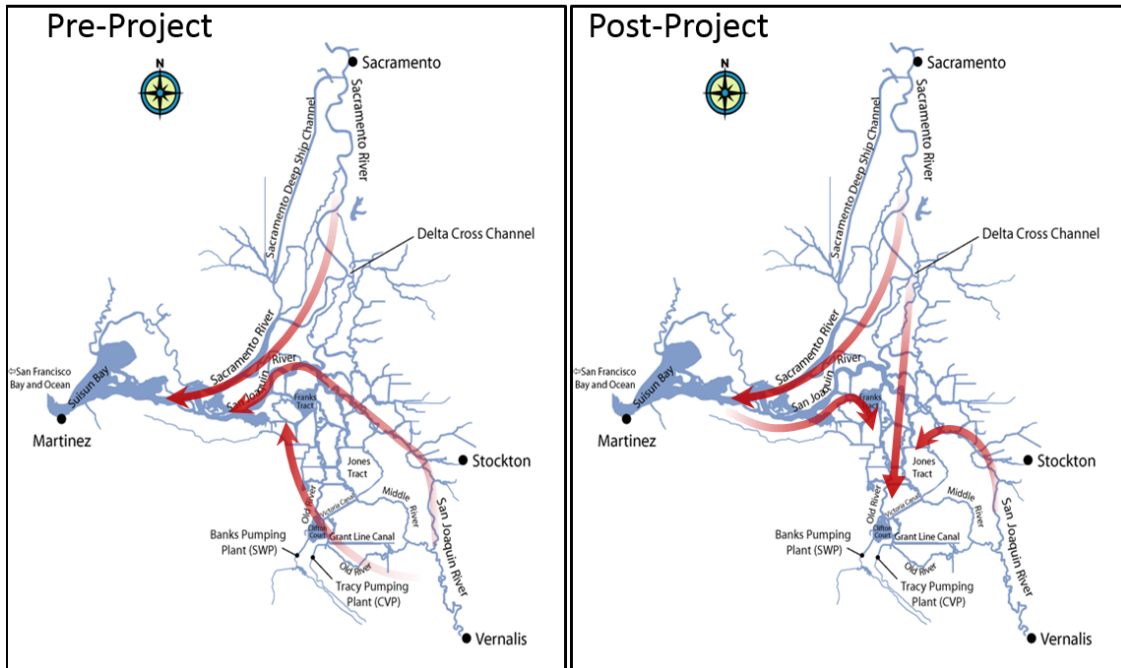


Figure 2-15: Net Delta Flow Pre-project and Post-project

### 2.3.3 Water Demands

Water resources are utilized for agricultural, municipal, and industrial uses; wildlife refuges; environmental flows in the rivers and Delta; and water quality and temperature management. California’s Mediterranean climate influences the timing and distribution of these demands.

The climate and geography of California contributed to the development of demands for water far from areas of the state where water supply is available. Generally, the northern portions of California receive more precipitation and water supply. Fertile soils and warmer climates in the San Joaquin Valley and Tulare Lake region provide prime areas for agriculture and the associated demands for irrigation water. Additionally, the climate and coastal areas of southern California have attracted people and the associated development of significant urban demands, despite limitations on locally available water. Figure 2-16 shows the areas in the state with the highest population and the largest agricultural use.



Figure 2-16: Major Areas of Agricultural and Municipal Water Demand

The long, dry summers provide for optimum conditions for agriculture, but create a mismatch with the time when precipitation is available. Figure 2-17 illustrates the general demand pattern for agriculture in the San Joaquin Valley and the average runoff pattern in Northern California. The high-summer water demand for agriculture is met through water released from the rim and offstream reservoirs, and is supplemented by groundwater pumping.

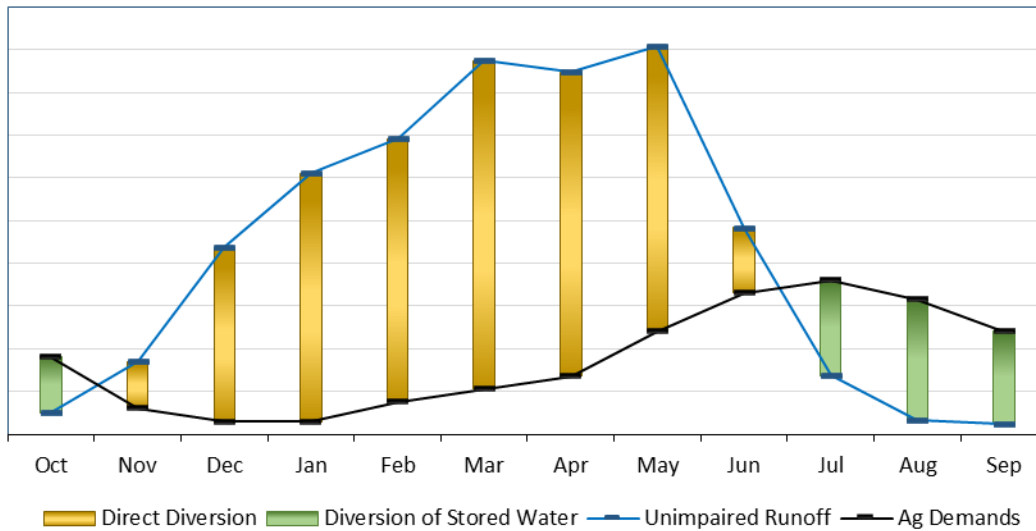


Figure 2-17: Typical Unimpaired Runoff and Agricultural Demand

Other water supply demands in California include water for the wildlife refuges; Delta water quality maintenance; and environmental uses for instream flows, river temperatures, and Delta outflow and water quality. The water management system is environmentally engineered to control runoff and convey water to meet beneficial uses. Secondary or incidental project benefits include recreation and power generation.

### 2.3.4 Surface Water Availability and Time Management

Surface water availability in the Central Valley comes either directly from storm and snowmelt runoff or from water previously stored in reservoirs and re-released at a later time. The fate of surface water and whether it may be stored, exported to another basin, or used to meet in-basin demands depends on the time of year and the water demands (for environmental flow and human uses) at that specific point in time versus gross surface-water availability.

In-basin demands include the legal uses of water in the Sacramento River Basin, plus the flow needed to meet current Delta water quality and flow objectives. Throughout any given year, California's water "system" status falls into two broad categories, *balanced conditions* and *excess conditions*. *Balanced conditions* are periods when the releases from the upstream reservoirs and unregulated flow approximately equal the water supply needed to meet in-basin uses in the Sacramento Valley, plus exports. *Excess conditions* are periods when releases from reservoirs, plus unregulated flow exceed the Sacramento Valley in-basin uses, plus exports. This can also be stated as surplus unregulated flow to the San Francisco Bay. The use of surface water under balanced conditions can be illustrated by showing the sources and uses of runoff through a typical year. Figure 2-18 illustrates system water uses in balanced conditions.



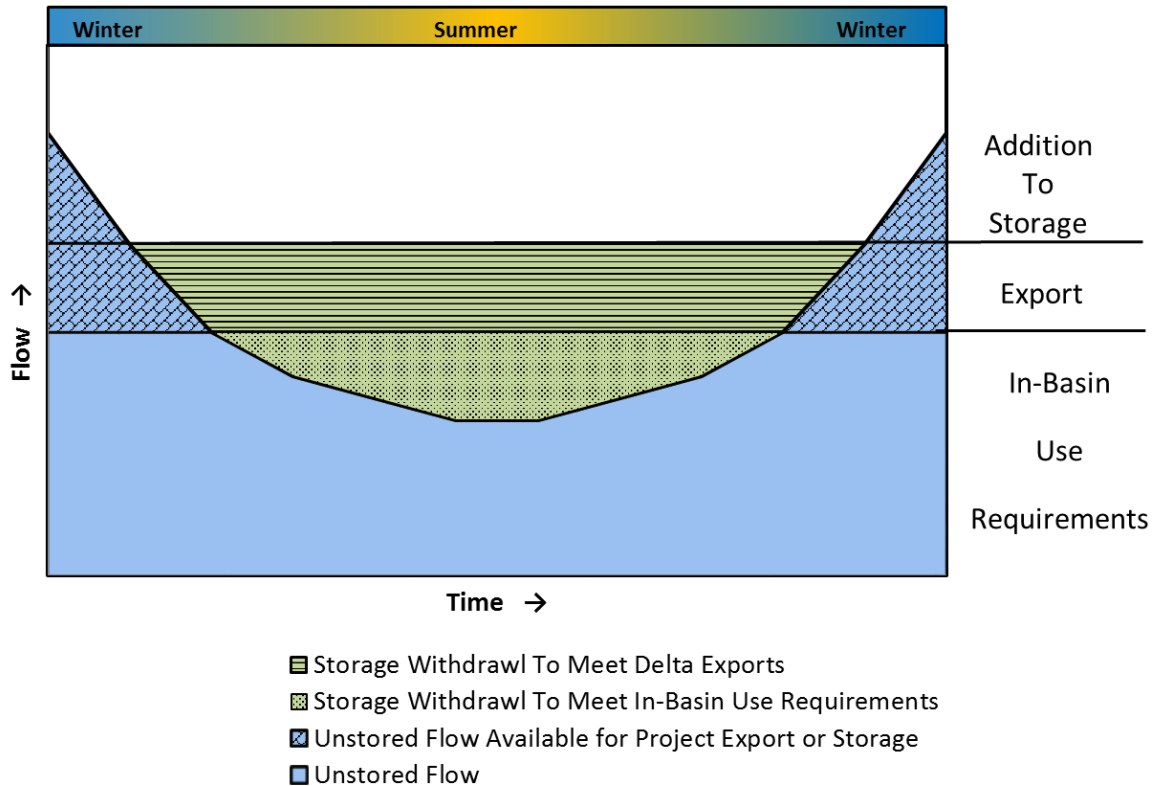


Figure 2-18: System Water Uses in Balanced Conditions

As an example, in the winter there may be runoff from precipitation to meet the in-basin uses, divert to reservoir storage, fully export water from the Delta, and still have supply in excess of the regulatory requirements. As the season progresses, runoff typically decreases to a point when excess water is no longer flowing from the “system” and all of the unstored flow is used to meet in-basin demands, diverted to reservoir storage, or is exported; this denotes the shift from excess conditions to balanced conditions. Moving into the summer season, the runoff subsides and unstored flow may still meet the in-basin uses, but additional releases from reservoir storage would become necessary to meet export demands. By the middle of summer in California, the conditions are typically dry enough that releases from reservoir storage would be necessary to meet the export demands as well as portions of the in-basin demands. In the fall, as precipitation returns with surface runoff and the in-basin demands subside, the process reverses back to having excess flow in the system.

Under excess conditions, all water rights are being satisfied and additional water may be available for diversion and use. Under balanced conditions, all of the water flowing in the system is used to meet a beneficial use, and any change in a use or supply would result in an impact on one or more of the other uses. A change in the source of the supply or use would be offset concurrently by a similar response elsewhere in the system, or the system will compensate later in the current year, or potentially in a subsequent year. All the facilities act together as a system to balance effects.

Water resource management in this Mediterranean climate centers on the time management of resources. Reservoir management decreases peak river flows to protect against flooding, to provide more flow in the summer and fall when water is needed for ecosystem needs, and to meet demands. Downstream diversions and export facilities were designed to take advantage of the timing patterns of unstored flow and reservoir releases to meet water supply needs. Additionally, offstream reservoirs were constructed to utilize the export facilities that were sized to capture available runoff downstream of the reservoirs for use later in the year; San Luis Reservoir is an example of this type of reservoir. These facilities were environmentally engineered to manage the resources for all beneficial uses of water. As water uses changed over the decades, the integrated facility management responded with seasonal timing shifts in operations.

An example of evolving demands is the increased desire for more Delta outflow during winter and spring months. This change in demand for the Delta environment affects the volume of water available to export for downstream water supply and water available for export to fill offstream reservoirs. The unmet water demand is partially met by timing changes in reservoir releases; by increased exports in the subsequent summer; or by relying on other sources, such as groundwater or other local reservoir storage. Demands may also shift seasonally to reduce the summer demand. Therefore, a shift in Delta demands in the winter can lead to a shift in more exports in the summer and fall, different seasonal Delta water quality, higher summer and fall reservoir releases, more draw on upstream storage, flattened water use demands, or a reoperation of offstream facilities. Figure 2-19 illustrates the reoperation of reservoirs and exports resulting from a winter action to increase Delta outflow.

Winter action to increase Delta outflow: Decrease in exports reduces south of Delta supply and decreases off stream storage.

Spring reoperation to recover supply: South of Delta demand begins source shifting.

Summer reoperation: Increase exports, increase rim reservoir releases reducing storage, increase releases from off stream storage, continue demand source shifting.

Fall reoperation: Begin reducing rim reservoir releases to recover storage, manage exports corresponding with rim reservoir reoperation, continue demand source shifting.

Figure 2-19: Example of Reoperation of Facilities Resulting From a Winter Action to Increase Delta Outflow

The potential changes to facility operations resulting from a change in winter Delta demands, as described in the preceding example of evolving demands, are shown in Figure 2-20. As exports are further restricted from January through June, Delta outflow increases. This operation prevents south-of-Delta offstream storage from filling through diversion of excess flow, and causes this operation to deviate from the original design. To compensate for the inability to divert excess winter flow, export of stored water is increased during summer months, resulting in decreases in rim reservoir storage. This changes temperature management, fall and winter reservoir releases, and the balance of beneficial uses throughout the California water system.

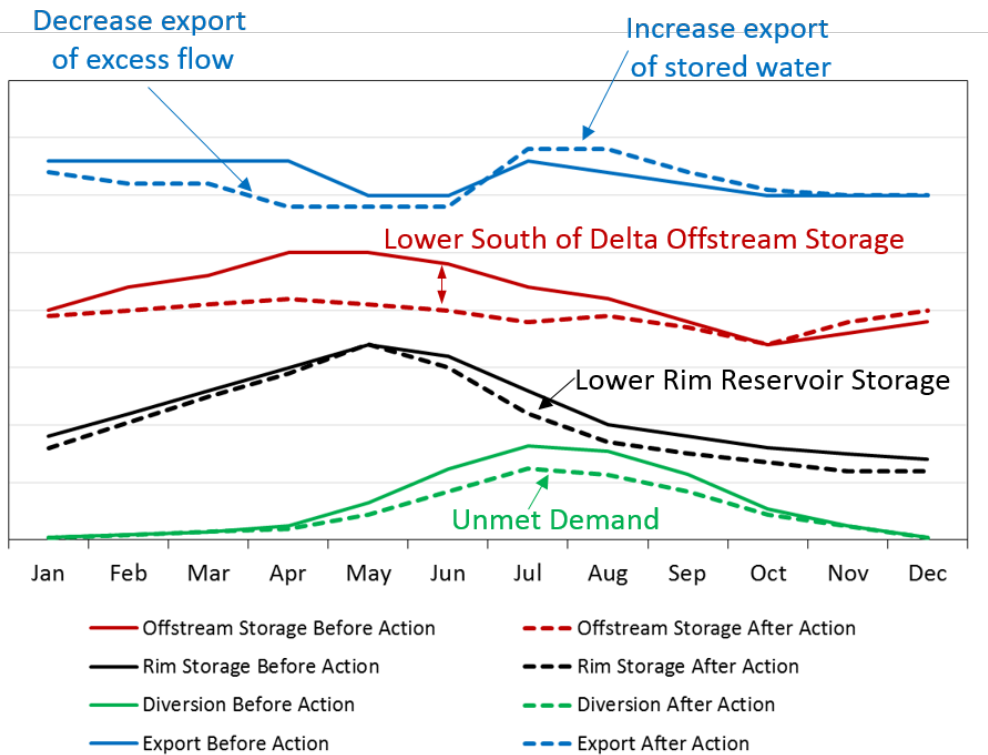


Figure 2-20: Conceptual Changes in Facility Operation Based on Example of Increased Delta Demand

## Chapter 3. PHASE I AND PHASE II SRS SUMMARY

As previously described, development of this study is a multi-phased effort that included:

- Phase I, Plan of Study (completed March 2011).
- Phase II, Strategy Formulation and Refinement (completed February 2014).
- Phase III, Assessments of Strategies.

The next phase of SRS will consist of evaluation of the following:

- Potential for using flood water for managed groundwater recharge on farmland and working landscapes for flood protection, drought preparedness, aquifer remediation, and ecosystem restoration.
- Existing flood operating rules of the reservoirs under changing hydrology.
- Feasibility of existing reservoir spillways and outlets to pass floodwater safely with changing hydrology.
- Identification of system reoperation implementation challenges and opportunities.

This chapter summarizes the Phase I and Phase II activities to provide background for the Phase III assessments.

### 3.1 SRS Phase I — Plan of Study

Phase I, Plan of Study, provided early direction and scope for the SRS through mission, goals, and objectives, followed by the identification of problems and opportunities. Constraints were then derived from legislation (SB X2 1), the Study Team, and California Water Plan Update 2009 to frame the development of the reoperation strategies as follows:

- Identified measures that could be assembled into reoperation strategies.
- Established a framework for the identification, development, and comparative evaluation of reoperation strategies.
- Presented an initial roster of reoperation concepts for further study.

The Plan of Study laid out the preliminary process to assess reoperation measures to improve performance for the three mission objectives: (1) water supply reliability, (2) flood hazard reduction, and (3) ecosystem protection and restoration. The initial challenge for the SRS was to formulate reoperation strategies to simultaneously achieve all three of these study objectives. Given the scale and complexity of the Central Valley water and flood systems, this may appear to be a daunting challenge. Yet, in practice, water system optimization studies conducted in river basins around the world have identified a limited universe of physical and operational changes in existing infrastructure which, if combined in clever ways, provide all the possible permutations for constructing optimization strategies. The Plan of Study identified nine general “building blocks” for physical and operations changes to optimize existing water systems.

- Reoperate reservoirs by changing storage and discharge regime.

- Integrate management of groundwater and surface water by utilizing dewatered aquifer space for storage in conjunction with reservoir reoperation.
- Transfer water among willing parties to reallocate limited supplies from existing water rights holders to uses bearing a higher/different economic or social value.
- Change stream flow patterns to improve magnitude, duration, frequency, timing, and location of both high- and low-flow events below reservoirs to restore more natural flow conditions conducive to ecosystem health and productivity.
- Expand through-valley flood conveyance and reactivate floodplains via levee set-backs, expanded flood bypasses, increased transitory storage, easements, and similar actions.
- Retrofit dams by expanding outlets, adding or relocating outlets, increasing the spillway size, retrofitting sluice gates, and other physical alterations that allow changes in reservoir flow releases.
- Change points, timing, and/or volume of diversions to reduce or alter diversions (e.g., the isolated conveyance facility proposed within the BDCP).
- Improve conveyance and interconnections to increase flexibility of water storage and delivery in the Central Valley.
- Improve fish passage by, for example, installing fish passage facilities around dams.

With these nine building blocks, the Plan of Study conceptually developed potential reoperation components for consideration through an iterative process for further study in Phase II.

### 3.2 SRS Phase II - Strategy Formulation and Refinement

Potential reoperation strategies were considered and formulated through two Phase II refinement processes. First, the SRS completed an outreach and vetting that identified willing study participants. Also, the SRS completed a tradeoff analysis that included a cursory evaluation of specific reoperation components to determine the effects, positive and negative, of a limited number of components on specific important metrics. These cursory analyses helped formulate the appropriate size of specific reoperation components, based upon a review of each component's effects.

The reoperation components evaluated in the tradeoff analysis are:

- Increase integration of flood and conservation storage operations at reservoirs.
- Increase integration of groundwater and surface water conjunctive operations associated with groundwater basins in proximity to reservoirs.
- Provide supplemental spring flows to support aquatic and riparian habitats downstream of reservoirs.

#### 3.2.1 Outreach and Vetting Process

A vetting process on various reoperation measures was conducted through a months-long series of consultations with 28 water management entities whose infrastructure or water management policies could be impacted by any of the potential reoperation strategies (see

Table 3-1). Through this process, these 28 entities provided DWR with additional information necessary to develop reoperation strategies for which the potential implementation entities would be willing to participate. As a result of these consultations, Merced Irrigation District (MID) expressed interest in participating in the SRS Phase III evaluation.

Table 3-1. Water Management Entities Consulted in the Phase II Vetting Process

Arvin-Edison Water Storage District	Northern California Water Association
Calleguas Municipal Water District	Orange County Water District
Central Valley Flood Protection Project managers	Raymond Basin Management Board
East Bay Municipal Utility District	Reclamation District 108
Friant Water Users Authority	San Gabriel Basin Water Quality Authority
Glenn Colusa Irrigation District	San Luis Delta Mendota Water Authority
Inland Empire Utilities Agency	Semitropic-Rosamond Water Bank
Kern County Water Agency	Study team for Sacramento Valley Conjunctive Water Management Program (Shasta and Oroville reoperations)
Kern Water Bank Authority	The Nature Conservancy
Madera Irrigation District and Madera Ranch Water Bank	Three Valleys Municipal Water District
Merced Irrigation District	Turlock Irrigation District
Metropolitan Water District of Southern California	U. S. Bureau of Reclamation
Modesto Irrigation District	U.S. Army Corps of Engineers
National Marine Fisheries Service	Water Replenishment District

### 3.2.2 Tradeoff Analysis

A reconnaissance-level tradeoff analysis was performed to identify potential options for reservoir reoperation strategies and to improve understanding of existing system constraints. The analysis is referred to as a “tradeoff analysis” in recognition of the fact that the existing water supply and flood management system is highly integrated and currently operated to meet water supply, flood management, and ecosystem purposes. Therefore, reoperation components designed to meet one of the three objectives of the SRS frequently create tradeoffs with the other objectives. For example, reductions in required reservoir space for flood management may improve water supply reliability, but also increase risk of flood damage.

The SRS team identified the potential to reoperate reservoirs to improve flow conditions downstream of existing dams. For these tradeoff analyses and assessment of strategies, the SRS team used surrogate supplemental spring flows to evaluate the potential to provide benefits associated with increased flows to restore and protect ecosystem function and habitat conditions. The first tradeoff analysis focused on two reoperation components that could be part of strategies associated with Shasta Lake and Lake Oroville, (1) Supplemental Spring Flow releases ranging between 25 to 500 thousand acre-feet (taf) per year from March–May for ecosystem benefits<sup>5</sup>, and (2) expanded conjunctive management (CM) in the Sacramento Valley through additional groundwater pumping of up to 100 taf per year from May–August, when surface water is limited. A total of 26 different tradeoff scenarios with different

<sup>5</sup> A water supply index was developed to guide operational decisions and limit the risk to carryover storage at Oroville and Shasta reservoirs. This index characterizes available water supply through September in Oroville and Shasta reservoirs with estimates made from March–May.

combinations of the two options were developed and evaluated using CalLite<sup>6</sup>, the Central Valley Water Management Screening Model.

When dedicating a supplemental flow for ecosystem purposes, ecosystem flow-only scenarios could reduce reservoir carryover storages, impacting both cold-water resources (that support river water temperature management below reservoirs) and water supply in subsequent years. Conjunctive management-only scenarios, in contrast, could reduce downstream flows that may impact habitat and temperature conditions for fish. However, combining conjunctive management with supplemental spring flows may be more synergistic because of the system effects of each. Conjunctive management, in dry and critical years, could increase reservoir carryover storages, improving cold-water pools and water supply. Under supplemental flow with conjunctive management scenarios, the two components could complement each other and mitigate some of the tradeoffs.

### 3.2.3 Forecast-Based Operations Analysis

Tradeoff analysis was also completed for Forecast-Based Operations (FBO). FBO can be applied as a component of a reservoir reoperation strategy, and Phase II included quantitative evaluations of these reoperations. FBO incorporates weather forecasts into reservoir operations to enhance flexibility in management of the flood control and conservation pools. This increases opportunities for additional water supply and flood risk reduction (see **Error! Reference source not found.**). With recent improvements in technology, modern weather forecasts are very accurate, and there is a very high correlation between forecast five-day inflows and observed five-day inflows (see Attachment A). With such high accuracy, reservoir operators could preserve water encroached into the flood control pool and defer release until the next storm event is forecasted. The increase in storage, especially during the end of the reservoir refill period, could consequently increase water supply for various downstream purposes without increasing flood risks. For events of high inflow forecasts, reservoir operators could evacuate the reservoir through early releases to provide additional flood control storage for capturing the anticipated high flood inflow. Therefore, the downstream river stage could be further reduced, and thus could lower downstream flood risk.

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<sup>6</sup> <http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalLite/index.cfm> CalLite simulates the hydrology of the Central Valley, reservoir operations, delivery allocation decisions, Delta salinity, and habitat-ecosystem flow indices over an 82-year planning period from water year 1922–2003. CalLite maintains the hydrologic, operational, and institutional integrity of CalSim-II.

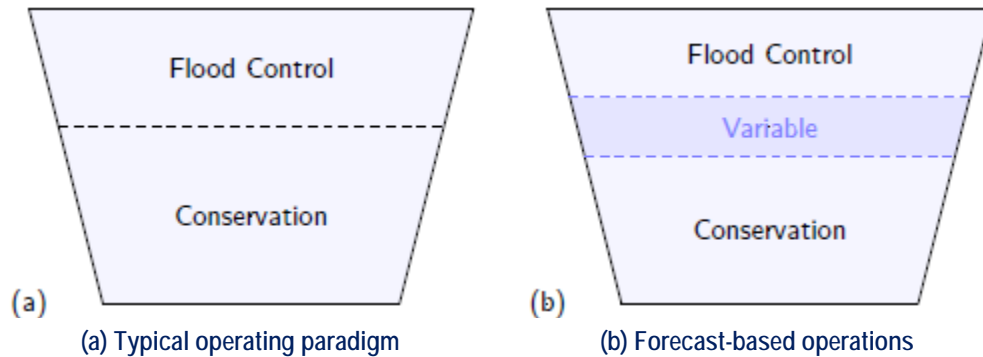


Figure 3-1: Depiction of reservoir space allocations under typical and FBO operations

Phase II of SRS included quantitative FBO evaluations of water supply enhancement on four reservoirs in the Central Valley, (1) Shasta Lake on the Sacramento River, (2) Lake Oroville on the Feather River, (3) Folsom Lake on the American River, and (4) New Bullards Bar Reservoir on the North Yuba River. These tradeoff evaluations were conducted at two levels, (1) individual reservoir using daily model with historical daily inflow, outflow, and storage data as inputs; and (2) system-wide effects using CalLite.

A daily FBO model with perfect foresight of historical inflow values was developed for each reservoir. Reservoir storage was allowed to encroach into the flood pool, limited to one quarter of the available flood space. This essentially resulted in a modified top of conservation pool operation, and thus altered storage and outflow conditions. The number of years with increase in storage through FBO was 15 out of 57 years for Shasta Lake, 10 out of 42 years for Lake Oroville, five out of 40 years for New Bullards Bar Reservoir, and 12 out of 55 years for Folsom Lake. The number of years with spring refill also increased with FBO. Specifically, spring refill increased by two more years for Shasta Lake, four more years for Lake Oroville, four more years for New Bullards Bar Reservoir, and five more years more for Folsom Lake.

A CalLite model run was performed to demonstrate the potential effects of FBO reoperation system-wide on the carryover storage and water supply of the SWP and CVP. Daily reoperation assumptions developed for the daily model were approximated through iterations into monthly reoperation assumptions. Note that New Bullards Bar Reservoir is not dynamically modeled in CalLite, so its reoperation was not assessed. Table 3-2 summarizes the simulated long-term average annual changes in end-of-September carryover storage at Shasta, Trinity, Folsom, and Oroville reservoirs; Delta inflow and outflow; and SWP and CVP exports and project deliveries with FBO reoperation. All changes were less than 5 percent, except Folsom Lake end-of-September storage, which was 5.42 percent. Changes of exports at the Jones and Banks pumping plants were less than 1 percent.

Phase II also included a qualitative flood control enhancement evaluation gained from implementing FBO on these four reservoirs in terms of flood space, outlet capacity, and channel capacity. The evaluation concluded that Lake Oroville and Folsom Lake have adequate release capacity to implement FBO. However, Shasta Lake's release capacity is limited by the



downstream channel capacity of 100,000 cfs at Bend Bridge. Similarly, the limited outlet capacity at New Bullards Bar Reservoir limits its ability for pre-event flood releases. The outlet and downstream capacity limitations reduce the effectiveness of FBO at these two reservoirs.

Table 3-2. Summary of Effects on SWP and CVP Carryover Storage and Water Supply from FBO Reoperation

	Long-Term Average End-of-September Carryover Storage (1,000 acre-feet)				Long-Term Average Annual Amount (taf)							
	Shasta Lake	Trinity Lake	Folsom Lake	Oroville Lake	Delta Inflow	Delta Outflow	Jones Pumping Plant	Banks Pumping Plant	CVP North-of-Delta Agricultural Deliveries	CVP North-of-Delta Municipal and Industrial Deliveries	SWP Table A Deliveries	SWP Article 21 Deliveries
Baseline	2,680	1,396	517	1,836	17,913	15,802	2,252	2,630	233	85	2,179	63
Changes (FBO minus Base)	60	20	28	-21	-16	-28	18	-5	11	1	-1	-3
Change in Percentage	2.24	1.43	5.42	-1.14	-0.09	-0.18	0.80	-0.19	4.72	1.18	-0.05	-4.76
Keys: FBO = Forecast-based operations CVP = Central Valley Project SWP = State Water Project												

Table 3-3. Phase II Qualitative Evaluation of Flood Control Enhancement for Watershed Flood Control System Components with Regard to Ability to Implement Forecast-Based Operations

Reservoir	Flood Space	Outlet Capacity	Channel Capacity
Shasta Lake	Adequate	Adequate	Limited
Lake Oroville	Adequate	Adequate	Adequate
New Bullards Bar Reservoir	Adequate	Limited	Adequate
Folsom Lake	Adequate	Adequate*	Adequate
* With the consideration of Joint-Federal Project completion in 2017.			

### 3.3 Lake McClure Strategy Formulation and Refinement

Merced Irrigation District owns and operates New Exchequer Dam on the Merced River for flood control, water supply, ecosystem benefits, hydropower production, and recreation. New Exchequer Dam impounds Lake McClure (1,024 taf Capacity). The average annual runoff of the Merced River at the dam is approximately 975 taf. The dam releases water directly into Lake McSwain, which then releases to Merced Falls Reservoir where water is eventually impounded behind Crocker-Huffman Diversion Dam — where MID's Main Canal diverts water.

MID operates New Exchequer Dam for flood control and the USACE Water Control Manual mandates a maximum flood space of 350 taf. Water is also released to meet water rights settlement agreements with riparian water users along the Merced River and for deliveries to Stevinson Water District. In addition, MID is required to provide 15 taf annually to the Merced National Wildlife Refuge as a condition of their Federal Energy Regulatory Commission (FERC) license. MID does not have discretion over water supplied to these three users. Further, New Exchequer Dam is also operated to meet FERC and Davis-Grunsky Act instream flow requirements. Davis-Grunsky Act flows are for the November–March period, and FERC flows are met from April–October. Further, MID provides 12.5 taf in fall releases for fish each year as a condition of its water right licenses. MID also owns, operates, and maintains 239 deep irrigation wells, of which 170 are currently active. These surface water and groundwater facilities allow MID to conjunctively manage both types of water resources.

MID suggested that DWR evaluate reoperation of up to 15 taf at Lake McClure as part of the Phase III SRS. Part of this analysis included a tradeoff analysis of FBO and conjunctive management, applied separately, at Lake McClure. Since these analyses are in line with the strategy formulation and refinement objective of Phase II, the discussion of the preliminary tradeoff analyses for Lake McClure is presented here.

Analysis of New Exchequer Dam for all scenarios was performed using a monthly spreadsheet model that simulates operations for flood control, water supply, hydropower production, and flows on the Merced River downstream of the dam. The monthly model simulates an 82-year historical hydrology from water year 1922–2003, consistent with CalSim-II. Model operations depict current MID demand for surface water and regulatory requirements. All results presented in this report are from the monthly spreadsheet model.

#### 3.3.1 Lake McClure Conjunctive Management Tradeoff Analysis Assumptions

Three conjunctive management scenarios were developed to illustrate tradeoffs in water supply, river flows, reservoir storage, hydropower generation, and groundwater effects associated with Lake McClure. The first conjunctive management scenario examined effects of reduced levels of conjunctive management operations within MID. Current MID conjunctive management practices increase surface water deliveries, and in so doing reduce groundwater pumping by approximately 45 taf annually in years when surface water is available. Analysis of this conjunctive management scenario involved reducing surface water deliveries and increasing

MID groundwater pumping such that conjunctive management is effectively eliminated from MID operations. This scenario established a no-CM baseline.

The second conjunctive management scenario examined the effects of expanding MID's conjunctive management operations beyond existing conditions. To increase CM, this scenario assumed an additional 15 taf of surface water would be delivered, when available, to offset a like amount of groundwater pumping. For this scenario, available water supply (storage + runoff) in April must exceed 760 taf to trigger additional surface water deliveries. Additionally, if Lake McClure had not refilled from CM in prior years, no additional releases could be made. This second requirement limits Lake McClure drawdown to a maximum of 15 taf as a result of additional CM deliveries. This increased CM scenario seeks to reduce the use of groundwater within MID's sphere-of-influence. Groundwater levels vary across Merced County, with areas under MID and its sphere-of-influence providing recharge that helps limit the effect of local cones of depression on the western and southern edges of the county.

A third conjunctive management scenario evaluated how a groundwater reserve could be used to backstop more aggressive reservoir operations, with the dual purpose of increased Merced River spring flows and additional surface water deliveries from the lower San Joaquin River. This scenario begins with an additional 15 taf of surface water delivered in-lieu of pumping groundwater. The delivery creates a credit in the aquifer that could be pumped in future years, if needed. For the purposes of this analysis, it was assumed that the 15 taf remained in the groundwater system with no loss over time.

After a 15 taf credit is established in the groundwater system and Lake McClure has refilled, a modified reservoir operation will be initiated to release an additional 15 taf annually, when surface water is available. The additional release serves two purposes. First, it is released during spring months to increase Merced River flows for ecosystem benefits. Second, the additional release is assumed to be re-diverted from the lower San Joaquin River to provide additional water supply to service areas outside of MID. Similar to the tradeoff reoperation analyses described above, the SRS is using supplemental ecosystem flows to evaluate the potential to provide benefits associated with increased flows to restore and protect ecosystems. Release and flow pattern targets to support specific ecosystem functions have not been identified or modeled.

### 3.3.2 Lake McClure FBO Tradeoff Analysis Assumptions

The required flood control space, release capacity, and downstream channel capacity for Lake McClure and the Merced River downstream of New Exchequer Dam were reviewed to develop rules for FBO. To simulate FBO at Lake McClure, the SRS assumed that up to 50 taf of the existing required flood control space could be varied based on future inflow forecasts. The assumption of 50 taf was made to be conservative and minimize the risk associated with imperfect forecasts.

Two FBO scenarios for Lake McClure were explored: FBO for water supply, and FBO for both supplemental ecosystem flows and water supply. FBO simulations were performed using the daily reservoir operations model of Lake McClure and New Exchequer Dam that were developed for FERC relicensing. Historical hydrology from 1970–2006 was applied to the modeled scenarios. The daily operations model uses a perfect foresight forecast of reservoir inflow. FBO rain flood space requirements from the daily model were compared with historical monthly inflow volumes to develop rules for FBO application in all scenarios.

For the first scenario, FBO is applied to MID's existing operations. Additional water held in Lake McClure was available during multiyear periods of below average inflow to meet demands within MID, and this resulted in reductions in groundwater pumping. For the second scenario, FBO is used to support both environmental flow and water supply releases to the Merced River. To accomplish these actions, water stored in Lake McClure above existing flood control levels without FBO was simulated as an asset. This stored water could later be released to support supplemental spring flows on the Merced River and additional surface water deliveries from the lower San Joaquin River.

### 3.3.3 Results of Lake McClure Preliminary Strategy Tradeoff Analysis

The table below provides summary metrics of average annual changes in MID water supply, hydropower generation, and Merced River flows for the FBO- and CM-modeled scenarios, when compared to existing MID operations (i.e., Baseline Conditions). The tabulated values illustrate tradeoffs between preliminary reoperation strategies.

Table 3-4. Summary of Average Annual Change in Key System Metrics for CM & FBO Scenarios

	MID Surface Water Delivery (taf)	MID SOI Surface Water Delivery (taf)	Lake McClure Carryover Storage (taf)	Merced River Project Hydro. Generation (GWhrs)	Merced River Flow near Cressey (taf)	Additional Release for CM or River & Water Supply (taf)	Number of Years with Additional Release
<b>Baseline Conditions</b>	414	14	507	349	447	N/A	N/A
<b>Scenario</b>	<i>Changes from Baseline Conditions</i>						
<b>Reduced CM</b>	-21	-14	+28	0	+33	N/A	N/A
<b>Increased CM for Groundwater Management</b>	0	+8	-3	0	-8	+8	45
<b>Increased CM for Ecosystem and Water Supply</b>	0	+1	-3	0	0	+3	19*
<b>FBO for MID Water Supply</b>	+2	0	+39	+2	-4	N/A	N/A
<b>FBO for Ecosystem and Water Supply</b>	+2	0	+35	+2	-4	+3	18

*\*Number of years include both conjunctive management releases to establish GW credit and environmental/water supply releases.*

Modeling results indicate FBO may provide small benefits to MID water supply and hydropower generation, even when combined with operations to increase conjunctive management or provide additional releases for environmental/water supply purposes. Increased storage or increased deliveries, including deliveries to increase conjunctive management or establish a groundwater reserve for making environmental releases, decreases average annual Merced River flow in all tradeoff scenarios with FBO or increased CM. This type of fundamental tradeoff is found in all systems.

### 3.4 Strategies Advanced to Phase III

Based on the SRS Phase II vetting process and tradeoff analyses results, reoperation of Shasta Lake, Lake Oroville, and Lake McClure, as well as the integrated operation of SWP and CVP, will be advanced to Phase III for further development and assessment. The Phase III reoperation strategies incorporated FBO, conjunctive management, and supplemental spring flow releases to support benefits in all three objective categories simultaneously. Phase II modeling results from the FBO analysis and the tradeoff analysis established a reasonable set of risk mitigation formulation guidance for the selected Phase III strategies.

The strategies advanced for further analysis in the SRS Phase III are:

- Shasta Lake (Sacramento River) Reoperation.
- Lake Oroville (Feather River) Reoperation.
- Combined Reoperation of Shasta Lake and Lake Oroville (Sacramento and Feather Rivers), with FBO reoperation of Folsom Lake.
- Lake McClure (Merced River) Reoperation.
- Increased Integration of SWP and CVP (Operations as a Single Project).

For all but the last strategy, a series of scenarios with different levels of FBO, conjunctive management and supplemental spring flow releases were evaluated to support (1) water supply reliability, (2) flood hazard reduction, and (3) ecosystem protection and restoration. Chapter 4 discusses the modeling approach for Phase III and the tools used to conduct the various analyses. Chapter 5 describes the reoperation components applied to model the strategies. In Chapter 6, the performance of each reoperation strategy is compared against baseline conditions to quantify potential net improvements in flood management, water supply reliability, and ecosystem functions. In general, each improvement was evaluated from a system-wide perspective, except for the Lake McClure reoperation analysis, which focuses on local effects on the Merced River.

Chapter 6 also presents an analysis of the increased integration of the SWP and CVP, which is different from the aforementioned reservoir reoperation strategies. The objective of the increased integration of the SWP and CVP is to evaluate the additional benefits that might be obtained through operating the SWP and CVP as a single integrated project. This includes identifying operations that could improve overall performance of both projects. To complement the evaluation of SWP and CVP integration, Chapter 7 discusses reoperation principles and integration efforts between the SWP and CVP that have already been incorporated into real-time operations to some degree. Chapter 8 presents the relevant findings of the SRS Phase III and the recommendations for the next phase.

## Chapter 4. PHASE III EVALUATION APPROACH

This chapter discusses the operational components, evaluation metrics, and modeling tools used in the formulation and evaluation of the Phase III SRS reoperation strategies. The strategies employ integrated reservoir operations, groundwater conjunctive management, ecosystem enhancement, and water supply system integration as operational components. These components apply quantitative or qualitative metrics, which are used in conjunction with modeling tools to evaluate performance.

The System Reoperation Study is using the following terms and meanings for the purposes of this document:

**Component:** a single, unique reoperation element that can be used to support one or more of the SRS planning objectives. As noted below, Phase III components include Forecast-Based Operations, Conjunctive Management, Supplemental Spring Flow, and Water Resources System Integration. Components are combined to create a full reoperation strategy.

**Strategy:** a set of reoperation components combined and formulated to achieve SRS planning objectives. In addition, the formulation may be designed to ensure that a particular component's negative effects to one or more SRS objectives are limited.

**Scenario:** SRS developed potential alternative future assumptions to better understand the performance effects on reoperation strategies posed by uncertain future conditions. The SRS Phase III analysis has considered two potential uncertain futures, climate change and new Delta conveyance. In order to better understand the sensitivity and performance of specific reoperation strategies, the Phase III strategies were also combined with uncertain future scenarios. In addition, the term "scenario" is also used to describe tradeoff evaluations discussed previously.

### 4.1 Operational Components

The SRS integrates reservoir operations with system reoperation components as described in the following paragraphs. In each case, the operation of a reservoir must be modified to support the integration of the reoperation components in support of achieving benefits, such as water supply reliability, ecosystem protection and restoration, and flood hazard reduction. Modifications to operations have been designed to provide benefits in all three categories simultaneously. In addition, operational safeguards have been incorporated to reflect risk management considerations to ensure that existing purposes are not adversely affected by these reoperational components.

#### 4.1.1 Forecast-Based Operations

Forecast-Based Operations (FBO) incorporates weather forecasts into reservoir operations to enhance flexibility in management of flood control pools and conservation pools. For the SRS,

modeling analysis assumed that reservoir operators would allow encroachment into the flood control pool as long as low inflow is forecasted. However, if forecasts project high inflows, reservoirs would be evacuated through early releases to provide additional flood control storage, reducing peak flows downstream.

#### 4.1.2 Groundwater Conjunctive Management

Groundwater conjunctive management is simulated in the SRS as groundwater substitution. Additional groundwater would be extracted from the groundwater basins during dry conditions to supplement surface water. Conjunctive management is already being used by local water users in the vicinity of the reservoirs considered in SRS Phase III. The conjunctive management operations in these Phase III strategies reflect an increase in integrated conjunctive operation.

#### 4.1.3 Supplemental Spring Flow

A single operational flow release component from March to May, identified as a supplemental spring flow, was included in the reoperation strategies to evaluate ecosystem benefits and water supply in combination with conjunctive use and forecast-based operations (FBO). This supplemental flow is being used as a surrogate for potential specific ecosystem function flow regime improvements that could be supported with the supplemental flow quantity of water. For example, the supplemental flow could be used to support a pulse flow in the spring to support anadromous fish migration.

#### 4.1.4 Water Resources System Integration

The SRS predominately applies this component to the SWP and CVP integration strategy, which is evaluated independently of the reservoir reoperation strategies. The basic premise of system integration is based on the physical makeup of the SWP and CVP. The CVP has greater upstream storage capacity than the SWP, and the SWP has greater downstream conveyance capacity. By combining the resources of the projects, water stored in upstream CVP reservoirs can be conveyed through SWP facilities. A simple approach to system integration is to assume expanded joint point of diversion (JPOD) for Delta exports, but a more comprehensive approach is to assume the SWP and CVP are operating as a single project (consolidating place of use under the water rights permits).

### 4.2 Evaluation Metrics

Metrics for water supply, ecosystem, and flood risk reduction are employed as yardsticks to measure the performance of the modeled Phase III SRS strategies. This section briefly describes these metrics.

#### 4.2.1 Water Supply

Water delivery reliability is usually defined as the annual amount of water that can be expected to be delivered with a certain frequency. While long term delivery is important, some water users



prefer the reliability of dry year delivery. Different metrics for measuring improvements in water deliveries reliability reflect the needs of different water users. For example, municipal and industrial (M&I) water users without their own storage frequently place a higher value on dry year reliability than on average annual deliveries; whereas M&I water users that have adequate water storage capacities will place a higher value on average annual deliveries. In most cases, agricultural water users, especially those with permanent crops and limited access to groundwater, will prefer higher dry year reliability. For the SRS Phase III evaluation, water supply reliability is shown as the average increase in deliveries, expressed in thousands of acre-feet.

#### 4.2.2 Ecosystem

The primary metrics for ecosystem benefits are the quantity of additional flow provided by the supplemental spring flow, and additional water in storage at the reservoirs. The average annual supplemental flow is expressed in thousands of acre-feet over the March to May period. The additional water in storage is reported as increased end-of-September (EOS) storage.

Previous studies (Vogel 2011) have emphasized the importance of a spring pulse flow because of its benefits for reducing salmonid predation risk. Specifically, pulse flows can transport wild and hatchery-reared fall run salmon juveniles relatively quickly downstream, rather than spending additional time in the river exposed to non-native predators. Benefits of a supplemental spring flow could also include salmonid rearing (if flows are great enough to inundate floodplains), splittail spawning and rearing, bank swallow nest preparation, and delta smelt spawning (Alexander et al. 2014). Analyzing specific biological or ecological flow metrics for the supplemental spring flow scenario provides a reference point for the potential modeled outcomes of redesigned flow release patterns in the Sacramento River/Delta system. Given that the ecosystem supplemental spring flow is a simplified hydrologic regime, this approach should not be construed as a comprehensive evaluation of alternative flow release patterns. More specifically, a project analysis should identify specific ecosystem flow actions (such as those described above) and then evaluate their effects to both the water resources system and to species.

The approach to this ecosystem evaluation consisted of using a suite of ecosystem evaluation metrics drawn from well-vetted efforts (DWR 1999; TNC and American Rivers 2013; Alexander et al. 2014). The Nature Conservancy's Ecological Flows Tool (EFT) (Alexander et al. 2014) provides a suite of peer-reviewed species sub-models of 25 key life-history performance indicators (metrics), each of which is driven by relevant measures of flow, water temperature, channel migration, salinity and/or stage at a daily timescale. A subset of EFT metrics was used for this study's flow-ecosystem benefit evaluation. The following metric screening criteria were used to select EFT metrics for this evaluation:

- Principally dependent on flow (vs. other physical variables).
- Experts comfortable with metric during peer review (Clint Alexander, personal communication).

- Portable to monthly CalSim-II model.

All metrics chosen for this evaluation are capable of evaluating flow scenarios using multiple species' life history needs, such as requirements for flow timing, duration, and frequency (or recurrence interval).

For an evaluation of a system reoperation project, it may be appropriate to consider additional metrics. For example, the SRS has noted that the ecosystem metrics used in this evaluation were associated with the environment and the focal species that occur in the Sacramento River and Sacramento-San Joaquin Delta, spanning the area from Keswick Dam in the north to Mallard Island in the Delta. The metrics were used to evaluate flow scenarios and were linked to biophysical processes and species life history needs, such as requirements for flow timing, duration, and frequency (or recurrence interval). Metrics included special status species in the system, as well as fundamental habitat forming or maintenance processes critical to the success of these species. The majority of metrics were drawn from The Nature Conservancy's (TNCs) EFT (Alexander et al. 2014), and these metrics were chosen based on three EFT screening criteria (see "Evaluation Approach" above). Two additional metrics were developed for this evaluation, including an "OMR Entrainment" metric based on work by TNC and American Rivers (2013) and a "Geomorphic Process" metric based on work by DWR (1999). The metrics can be grouped into the following four categories: salmonids, non-salmonids, geomorphic process (instream), and riparian (Table 4-1). The flow frequency criteria from EFT (Alexander et al. 2014) were termed, for this evaluation, Target Threshold Frequencies (TTFs) (see Appendix D, Tables 2 thru 5 for more information) to measure the outcome of CalSim-II model results for each reoperation strategy. The TTF criteria were applied to the model runs of the baseline, and each reoperation strategy to identify improvements or impacts to metric values.

Table 4-1: Summary of Suite of Ecosystem Evaluation Metrics, Including Locations, Species, and Literature Sources.

Category	Metric	Location	Species	Literature Source
Salmonid	Spawning WUA	Keswick	All Runs	Alexander et al. 2014 (EFT CS1)
	Rearing WUA	Keswick	All Runs	Alexander et al. 2014 (EFT CS2)
	Redd Scour	Keswick	All Runs	Alexander et al. 2014 (EFT CS5)
	Yolo Growth	Yolo	All Runs	Alexander et al. 2014 (EFT CS7)
	Predation Risk	Hood	All Runs	Alexander et al. 2014 (EFT CS9)
	Temperature/Route	Hood	All Runs	Alexander et al. 2014 (EFT CS10)
Non-Salmonid	Spawning	Yolo	Splittail	Alexander et al. 2014 (EFT SS1)
	Spawning Success	Mallard Is.	Delta Smelt	Alexander et al. 2014 (EFT DS1)
	Habitat Suitability	X2	Delta Smelt	Alexander et al. 2014 (EFT DS2)
	Entrainment Risk	OMR	Delta Smelt	Alexander et al. 2014 (EFT DS4)
	OMR Entrainment	OMR	DS, LFS, SH	TNC and American Rivers 2013
Instream	Geomorphic Process	Red Bluff	N/A	DWR 1999
Riparian	Peak flow	Hamilton City	Bank Swallow	Alexander et al. 2014 (EFT BASW2)
	Initiation	Hamilton City	Cottonwood	Alexander et al. 2014 (EFT FC1)
	Scour	Hamilton City	Cottonwood	Alexander et al. 2014 (EFT FC2)

### 4.2.3 Flood Risk Reduction

Reduction in flood risks to properties and lives is one of the objectives in the SRS. Engineers and hydrologists usually use stage and flow to measure the flood risk in a region. However, in areas with frequent levee breaks, the number of levee breaks and the extent of the inundated area are sometimes used in measuring flood risk. For project-level evaluations, the flood risk will need to be measured in terms of loss of lives and property damage.

## 4.3 Evaluation Tools

Several modeling applications were used to evaluate the Phase III SRS strategies and their effects to water supply, the ecosystem, and flood risks. This section describes the modeling applications used in this study and how they are used to evaluate the performance of the reoperation strategies.

### 4.3.1 CalSim-II Model

CalSim-II is a computer simulation model that was jointly developed by DWR and the U.S. Bureau of Reclamation for water resources planning. It is widely used to simulate existing and future operations of the SWP and CVP, and also other water supply features in the Central Valley and Sacramento-San Joaquin Delta. The hydrology used by this model was developed by adjusting the monthly historical flow record for the period of October 1921 through September 2003 (i.e., water year 1922 to 2003) to account for the influence of changes in land uses and regulation of upstream flows.

CalSim-II represents water resource systems, consisting of reservoirs and channels (natural and artificial), as a network of nodes and arcs. Nodes in the network may represent reservoirs, groundwater basins, junction points of two or more flows, or simply a point of interest on a channel. Arcs represent water flows between nodes, or out of the system, and may be inflows, channel flows, return flows, or diversions. Constraints are applied to reflect operations criteria, regulatory requirements, etc.

For each reservoir, storage zones are specified to represent volumes between physical and operational levels. The zones are weighted and dynamically bounded to insure proper filling of the reservoir, meeting target storage levels, and minimizing encroachment in the flood pool.

#### 4.3.2 Merced River Water Allocation Spreadsheet Models

Analysis of Lake McClure operations for all scenarios and strategies was performed using a monthly spreadsheet model developed by MBK Engineers. This model simulates operations for flood control, water supply, and hydropower production and flows on the Merced River, downstream of New Exchequer Dam, to approximately the confluence with the San Joaquin River. The model simulates an 82-year historical hydrology period from water year 1922 to 2003, which is consistent with CalSim-II. Model operations depict current MID demand for surface water and regulatory requirements.

Modeled releases from the New Exchequer Dam include the following:

- Water rights settlement with riparian water users.
- Water rights settlement with Stevinson Water District.
- Davis-Grunsky Act flows from November–March.
- FERC flow requirements from April–October provide minimum flows (from 40 to 180 cfs as measured at Shaffer Bridge depending on time of year and water year type).
- 15 taf to Merced National Wildlife Refuge during irrigation season (April–October).
- 12.5 taf for fisheries purposes in fall.
- Irrigation water to lands within Merced Irrigation District’s boundaries.
- Irrigation water to lands within Merced Irrigation District’s sphere of influence (SOI).

Forecast-based flood control operations were initially analyzed in a daily operations model developed by MID for use during FERC relicensing. Forecast-based operational decisions are made on a daily basis and consequently were simulated using the daily model. Based on results of the daily model, rules were developed to approximate forecast-based operations in the monthly model and these scenarios were re-run in the monthly model. All results presented in this report are from the monthly spreadsheet model.

#### 4.3.3 SWP and CVP Integration Spreadsheet Model

A spreadsheet model of the SWP and CVP was developed to analyze potential benefits of system integration. The spreadsheet uses hydrology and operational parameters from CalSim-

It along with simplified operations logic to evaluate system integration. The model has similar resolution as CaLite, but with more simplified operations logic. The model can either be run based on existing COA accounting or be run assuming the CVP and SWP operating as a single project.

#### 4.3.4 HEC-ResSim

The Reservoir System Simulation (HEC-ResSim) software developed by the U.S. Army Corps of Engineers (USACE), Institute for Water Resources, Hydrologic Engineering Center is used to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints. It represents reservoir systems through a network of elements (junctions, routing reaches, diversion, and reservoirs), a user-defined network configuration, physical properties, operational rules, etc. HEC-ResSim can be applied to evaluate reservoir operations for flood management, low flow augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support. Users define the simulation period, such as a single event or a full period, using available time-steps.

Under the Central Valley Hydrology Study (CVHS) effort led by DWR and USACE, HEC-ResSim models were developed in 2013 to represent the reservoir system, operations, and flood events in the Sacramento River Basin and San Joaquin River Basin, respectively. This Study applied the CVHS HEC-ResSim models for use in modeling reservoir reoperation.

#### 4.3.5 HEC-RAS

The Hydrologic Engineering Center of USACE also developed the Hydrologic Engineering Centers River Analysis System (HEC-RAS) to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS system contains four one-dimensional river analysis components for (1) steady flow water surface profile computations, (2) unsteady flow simulation, (3) movable boundary sediment transport computations, and (4) water quality analysis. Its geometric data consist of connectivity of the river system, cross-section data, junction information, hydraulic structure data (bridges, culverts, dams, weirs, etc.), and cross section interpolation.

Under the ongoing 2017 Central Valley Flood Protection Plan (CVFPP) effort, two HEC-RAS models for the Sacramento River Basin and San Joaquin River Basin were used as a tool to evaluate flood risk and support the flood management planning effort. These models were used in the analysis of the Phase III SRS strategies.

#### 4.3.6 Palantir

Palantir is a web-based data analysis tool that advances the capabilities of spreadsheet software and allows for integration of multiple datasets as well as exploratory and structured data analysis. For this evaluation, Palantir was used for the ecosystem analysis, and facilitated the analysis and the target threshold frequency criteria with CalSim-II baseline and strategy runs to identify improvements or impacts to metric values.

## Chapter 5. PHASE III REOPERATION COMPONENTS, STRATEGIES AND BASELINE CONDITIONS

This chapter describes the reoperation components used to formulate the reoperation strategies and the baseline model assumptions. Components of full reoperation strategies include forecast-based operations (FBO), conjunctive management, supplemental spring flows, and water resources system integration. The first three components apply largely to the analysis of the reservoir reoperation strategies. The SWP and CVP integration strategy includes only the water resources system integration component.

### 5.1 Phase III Reoperation Components

The intent of Phase III is to perform an assessment of reoperation strategies. The strategies were formulated using FBO, conjunctive management, supplemental spring flow, and water resources system integration. This section discusses each of these components and how they were applied in modeling. Where project-specific details for these components are necessary, such as FBO encroachments at specific reservoirs, they are included in the discussion of the component.

#### 5.1.1 Forecast-Based Operations

As described in Section 3.2.3, FBO incorporates weather forecasts into reservoir operations to enhance flexibility in management of the flood control pool and the conservation pool. For the SRS, the analysis assumed that reservoir operators would allow encroachment into the flood control pool as long as low inflow is forecasted. However, if forecasts project high inflows, reservoirs would be evacuated through early releases to provide additional flood control storage, reducing peak flows downstream. The following sections discuss the specific FBO rules applied to each of the reservoirs included in the SRS. Additional detail on the formulation and development of specific trigger inflows for advance releases is provided in Attachment A to the SRS Phase II Report. Much of the FBO formulations in the sections below reflect operational safeguards added to manage the risk associated with uncertain future hydrology, where larger and more damaging flows are possible. The operational safeguards for FBO at all reservoirs were formulated with consideration of the Folsom Dam Water Control Manual Update, which is ongoing.

##### 5.1.1.1 *Shasta Lake FBO*

FBO will allow up to 25 percent encroachment in Shasta Lake's flood control space when low volumes of inflow are forecasted. Risk is minimized by releasing storage ahead of a forecasted damaging storm. The modified operational rule to allow FBO at Shasta Lake was to make advance storage releases when the five-day cumulative inflow volume exceeded 900 taf or when monthly inflows exceed 30,000 cfs.

#### 5.1.1.2 Lake Oroville FBO

FBO will allow up to 25 percent encroachment in Lake Oroville's flood control space when low volumes of inflow are forecasted. Risk is minimized by releasing storage ahead of a forecasted damaging storm. The modified operational rule to allow FBO at Lake Oroville was to make advance storage releases when the five-day cumulative inflow volume exceeded 1,100 taf or when monthly inflows exceed 32,500 cfs.

#### 5.1.1.3 Lake McClure FBO

The Water Control Manual for New Exchequer states that the downstream channel capacity on the Merced River is approximately 6,000 cubic feet per second (cfs). A maximum release of 6,000 cfs from New Exchequer Dam for a five-day period could evacuate about 60 taf. Based on this finding, FBO will allow up to 50 taf of encroachment into the flood control space for Lake McClure. The assumption of 50 taf, instead of the full 60 taf, was made to be conservative and provide a buffer against imperfect forecasts. Risk is minimized by releasing storage ahead of a forecasted damaging storm.

#### 5.1.1.4 Folsom Lake FBO

FBO will allow up to 25 percent encroachment in Folsom Lake's flood control space when low volumes of inflow are forecasted. Risk is minimized by releasing storage ahead of a forecasted damaging storm. The modified operational rule to allow FBO at Folsom Lake was to make advance storage releases when the five-day cumulative inflow volume exceeded 900 taf or when monthly inflows exceed 15,200 cfs.

### 5.1.2 Conjunctive Management

Conjunctive management, a practice to integrate operations between surface water systems and groundwater basins, was identified as an option to help meet the SRS objectives. As a result of the differences in aquifer characteristics and how they are currently managed, conjunctive management assumptions in the Sacramento Valley Groundwater Basin were different from the San Joaquin Valley Groundwater Basin. Conjunctive management operational assumptions were designed to protect existing system uses.

#### 5.1.3 Sacramento Valley Groundwater Basin

A prior conjunctive management study in the Sacramento Valley, conducted by the Natural Heritage Institute (NHI) and Glenn-Colusa Irrigation District (GCID) in 2011, revealed that while groundwater levels are drawn down during the irrigation season in many areas, levels recover during the precipitation season, except during prolonged droughts (i.e., multiple dry years). Cones of depression (dewatered aquifer) generally do not persist over multiple years to provide space for groundwater banking; so, additional water recharge could induce additional groundwater discharge to the streams. Consequently, the study determined that traditional conjunctive management operations that bank groundwater when surplus surface water is

available and extract groundwater when surface supplies are limited is ineffective in the Sacramento Valley. This 2011 study evaluated annual groundwater pumping capacity of up to 200 taf from GCID<sup>7</sup> and up to 100 taf from the Butte Basin<sup>8</sup> to integrate with the surface water system.

For the Sacramento Valley, the Phase III SRS conjunctive management component is to pump groundwater in-lieu of surface water diversions from May–August during periods of limited surface water availability. Additional groundwater would be extracted, by willing participants, to meet a portion of reservoir release obligation and help maintain storage in Shasta and Oroville lakes. Again, risk mitigation criteria have been established to avoid potential negative effects associated with the conjunctive management component. The assumptions are:

- Maximum annual groundwater extraction of 100 taf (monthly extraction of 25 taf between May–August) to reduce surface water diversions from the Sacramento River<sup>9</sup>, and consequently to prevent Shasta Lake end-of-September carryover storage from falling below 2.2 million AF, and to provide sufficient cold water to meet the Balls Ferry temperature compliance point in the following year per National Marine Fisheries Service (NMFS) 2009 Biological Opinion (National Marine Fisheries Service 2009).
- Maximum annual groundwater extraction of 100 taf (monthly extraction of 25 taf between May–August) to reduce surface water diversion from the Feather River<sup>10</sup>, and consequently to prevent Lake Oroville end-of-September carryover storage from falling below 1.5 million AF.

During drier years, the ability to reduce reservoir releases can be constrained by temperature management operations. Managing cold water for stream temperature is a priority during summer in the upper Sacramento River. Reductions in reservoir releases associated with increased groundwater pumping will also reduce stream flow below reservoirs, which can reduce available habitat with suitable temperatures. The effects of reduced releases on stream temperature were analyzed in the tradeoff analysis conducted for Phase II.

#### 5.1.3.1 San Joaquin Valley Groundwater Basin

The majority of the Merced Irrigation District (MID) service area is above the sub-basins of the San Joaquin Valley Groundwater Basin, which provides groundwater as a major source of water supply for agricultural and municipal uses. MID has been practicing conjunctive use to in-lieu recharge the groundwater basin, to provide surface water when available to reduce groundwater pumping, and to rely on more groundwater during dry conditions. However, the San Joaquin Valley has experienced varying degrees of groundwater level decline. Where groundwater

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<sup>7</sup> GCID is a CVP contractor.

<sup>8</sup> Groundwater pumping was assumed to be from Western Canal Water District and Richvale Irrigation District, who are SWP contractors.

<sup>9</sup> It is assumed groundwater pumping would occur in Colusa Basin and reduce Sacramento River diversion between Red Bluff and Wilkins Slough.

<sup>10</sup> It is assumed groundwater pumping would occur in SWP Feather River Service Area and reduce surface water diversion from Thermalito Afterbay.



pumping exceeds recharge, groundwater overdraft remains a recurring problem in certain areas of Eastern Merced County. Since 1980, average groundwater levels in the Merced Subbasin have declined about 14 feet, and there are cones of depression in the aquifer (Merced Area Groundwater Pool Interests 2008). As of 2007, the Merced Subbasin is in a state of groundwater-level decline with a cumulative decrease in storage of approximately 720 taf from 1980 to 2007, or about 26 taf per year, on average.

Unlike the Sacramento Valley conjunctive management measures, the Phase III SRS component for Lake McClure is to further expand existing MID conjunctive management practice by providing an additional 15 taf of surface water delivery for in-lieu recharge to the aquifer when:

- Available water supply at Lake McClure in April exceeds 760 taf.
- Lake McClure refilled from a prior year's conjunctive management release.

#### 5.1.4 Supplemental Spring Flow

As described in Chapter 4, a supplemental spring flow is a component of the reoperation strategies to support ecosystem protection and restoration benefits. In the Phase III SRS, the supplemental spring flow reoperation component in the Sacramento River Basin is to release water of up to 200 taf per year, from a single reservoir, March–May. Supplemental spring flows are only made when:

- The anticipated reservoir end-of-September carryover storage is above a specific target using a water supply index<sup>11</sup>.
- The reservoir is not making flood releases in that month (i.e., to maintain storage below flood pool).

The end-of-September carryover storage target is 2.4 million AF for Shasta Lake and 1.5 million AF for Lake Oroville. These operational rules for the supplemental spring flow component have been developed to manage risk associated with negative effects in objective categories such as water supply and ecosystem protection associated with cold-water pool maintenance. These risk mitigation rules were developed based upon the supplemental spring flow component performance in the Phase II tradeoff analysis. There are six potential supplemental spring release patterns (Table 5-1) and the selection is based on whether supplemental spring flow release was made in the current and previous months, as well as system metrics associated with the above risk mitigation rules.

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<sup>11</sup> Details see Attachment B of Phase II SRS Report.

Table 5-1. Supplemental Spring Flows by Fraction of the Annual Target Amount

Pattern	March	April	May	Total
1	1/3	1/3	1/3	1
2	1/3	1/3	0	2/3
3	1/3	0	0	1/3
4	1/3	0	1/2	5/6
5	0	1/2	1/2	1
6	0	0	1/2	1/2

For the San Joaquin River Basin, specifically at Lake McClure, the supplemental spring flow component of reoperation for the Phase III SRS is different from the components applied to the Sacramento River Basin. The supplemental spring flow for Lake McClure reoperation was limited to 15 taf, as directed by MID, and the limit of 15 taf in volume released was reached in May.

### 5.1.5 Water Resources System Integration

The basic premise of system integration is based on the physical makeup of the SWP and CVP. The CVP has greater upstream storage capacity than the SWP, but the CVP has less conveyance capacity downstream in the Delta than the SWP. By combining the projects, water stored in upstream CVP reservoirs can be conveyed through SWP facilities. A simple approach to system integration is to assume expanded joint point of diversion (JPOD) for Delta exports, and a more comprehensive approach is to assume the SWP and CVP operating as a single project (consolidating place of use under the water rights permits).

## 5.2 Baseline Modeling Assumptions

Baseline modeling assumptions are used to assess the performance of the reservoirs and water resources systems without a project, or in this case, without a reoperation strategy. The Phase III SRS reoperation strategies and modeling results are presented in Chapter 6. Modeling baseline system operations establishes a reference indicator of performance, which is used to comparatively and quantitatively evaluate the benefits of reoperation performance. The Shasta Lake and Lake Oroville, Lake McClure, and SWP and CVP integration strategies each employ specific baselines to determine strategy performance.

The baseline conditions of the SRS assumed a 2030 level-of-development with current regulatory requirements, including the 2008 and 2009 Biological Opinions from NMFS and the United States Fish and Wildlife Service (USFWS). The modeled differences between baseline and reoperated strategy performance represent the quantified effects of that strategy.

### 5.2.1 Shasta Lake and Lake Oroville Reoperation Baseline Modeling Conditions

Several baseline model runs were developed for comparison with the various reoperation strategies presented in Chapter 6. One baseline depicts the current regulatory requirements, existing infrastructure, and historical hydrology of the CVP/SWP network without any reoperation components placed into the system. This baseline is used for comparison with the performance of Reoperation Strategies 1–6, which involve reoperation of Shasta Lake, Lake

Oroville, and combined reoperation of Shasta Lake and Lake Oroville. Another scenario baseline was developed that includes the North Delta Diversion (NDD) as proposed in the BDCP, and now considered as part of California WaterFix. This baseline is used for comparison with the performance of reoperation strategies 6A, 6B, and 6C, which depict different levels of system reoperation in conjunction with the NDD.

A baseline for each climate change scenario was also developed. Each of these climate-changed baselines depict current regulatory requirements and infrastructure, but apply a specific climate-changed hydrology and sea level rise. These four climate-changed baselines are used to quantify the effects of climate-changed conditions considered in strategies 6 ELT-Q5, 6 LLT-Q2, 6 LLT-Q4, and 6 LLT-Q5.

### 5.2.2 Lake McClure Reoperation Baseline Modeling Conditions

Similar to the baselines established for Shasta Lake and Lake Oroville reoperations, the Lake McClure reoperation baselines depict MID's current operations, regulatory requirements, existing infrastructure, and historical hydrology. This baseline is used to evaluate the performance of the two strategies for Lake McClure described in Chapter 6.

A baseline for each climate change scenario was also developed. Each of these climate-changed baselines depicts current regulatory requirements and infrastructure, but applies a specific climate-changed hydrology and sea level rise. These four climate-changed baselines are used to quantify the effects of climate-changed reoperation of Lake McClure for ecosystem benefit and water supply.

### 5.2.3 Increased Integration of SWP and CVP Baseline Modeling Conditions

As noted in Chapter 4, the SWP and CVP integration reoperation analysis uses the SWP and CVP Integration Spreadsheet model rather than the CalSim-II model, as applied to the Shasta Lake and Lake Oroville reoperations. For the integration model, a baseline operation was developed by including operating assumptions in the model with existing contracts, operational criteria, and existing COA. Reoperation strategies were evaluated by running the model with existing contracts, operational criteria, and replacing existing COA with integrated operations logic. Strategies' model runs were then compared to the baseline model run to determine benefits. Benefits identified from the modeling analysis may be overstated, because the baseline does not contain the level of system integration that already occurs in real-time operations as described in Chapter 7.

## Chapter 6. REOPERATION STRATEGIES AND MODELING RESULTS

This Chapter describes the Phase III SRS reoperation strategies and presents the modeling results of the evaluation. The purpose of the evaluation is to determine the potential for additional benefits to the water supply, the ecosystem, water quality, and flood control that can be gained from reoperating these existing facilities by employing various reoperation components. Discussion of modeling results includes specific discussion on the effects to water supply, the ecosystem, flood protection, and uncertain futures, such as climate change and new Delta conveyance. This section also presents an analysis of SWP/CVP Integration, a reoperation of California's two largest water projects, as distinguished from the reservoir reoperation strategies described previously. The objective of the SWP/CVP integration strategy is to evaluate the potential benefits that might be obtained through operating the SWP and CVP as a single integrated project.

### 6.1 Overview of Modeling Operations and Results

#### 6.1.1 Shasta Lake and Lake Oroville Reoperation Strategies Overview

The SRS evaluates strategies that cover reoperation of Shasta Lake, Lake Oroville, as well as a combination of Shasta Lake and Lake Oroville. Reservoir reoperation strategies include the following components: conjunctive management, forecast-based operations, and release of supplemental spring flows (March to May). The SRS also considers the potential effects associated with uncertain futures, including potential climate change effects and proposed new Delta conveyance on system reoperation strategies. Therefore, scenarios were developed that include new Delta conveyance facilities (as proposed in the BDCP and now known as California WaterFix) and climate change effects. The following table summarizes the reoperation strategies and uncertain future scenarios considered for Shasta Lake and Lake Oroville.

Table 6-1. Summary of Shasta Lake and Lake Oroville Reoperation Strategies

Strategy	Reservoir(s) Reoperated	Sacramento River Supplemental Spring Flow <sup>1</sup>	Feather River Supplemental Spring Flow <sup>1</sup>	Operations of North Delta Diversion (NDD)	Sacramento River Basin CM <sup>2</sup>	Feather River Basin CM <sup>2</sup>	Forecast Based Operations	Flood Hazard Reduction
1	Shasta	50 taf	No Pulse.	No NDD.	50 taf	No CM	Up to 25% encroachment in reservoir flood space.	Advance releases ahead of a damaging storm <sup>3</sup> .
2		200 taf			100 taf			
3	Oroville	No Pulse	50 taf	No NDD.	No CM	50 taf	Up to 25% encroachment in reservoir flood space.	Advance releases ahead of a damaging storm <sup>3</sup> .
4			200 taf			100 taf		
5		50 taf	50 taf		50 taf	50 taf		
6								
6A				As described in BDCP EIR/EIS				
6B	Shasta + Oroville (w/FBO at Folsom)	150 taf	150 taf	As described in BDCP EIR/EIS + supplemental spring flows are not diverted.	100 taf	100 taf	Up to 25% encroachment in reservoir flood space.	Advance releases ahead of a damaging storm <sup>3</sup> .
6C				As described in BDCP EIR/EIS + all supplemental spring flows are diverted.				
6-ELT-Q5								
6-LLT-Q2				No NDD.				
6-LLT-Q4								
6-LLT-Q5								

<sup>1</sup>Supplemental spring flows are defined as a targeted volume from March to May. These volumes are not necessarily provided every year.

<sup>2</sup>Conjunctive management is defined as an annual volume from May to August. Pumping is typically at these levels during Dry or Critical years as defined by the Sacramento River Index (SRI).

<sup>3</sup>Flood hazard reduction is also studied in this phase, but is evaluated in a separate analysis.

Reoperation Strategies 1 and 2 focus on improving water supply reliability, enhancing upper Sacramento River aquatic ecosystems, and improving flood management by reoperating Shasta Lake. Shasta Lake is reoperated by providing springtime supplemental flows, irrigation season CM through groundwater pumping in lieu of surface water diversions, and FBO. Supplemental spring flows from the reservoir are released from March to May. Strategies 1 and 2 are designed to analyze the effects of two different magnitudes of reoperation. Strategy 1 is a more modest reoperation with supplemental spring flows of up to 50 taf annually and CM pumping of up to 50 taf annually. Strategy 2 is a more aggressive reoperation with supplemental spring flows of up to 200 taf and CM of up to 100 taf annually. The FBO for both Strategies 1 and 2 allow up to 25 percent encroachment during relatively dry conditions and allow for advance releases during potential damaging storms.

Strategies 3 and 4 focus on similar objectives as Strategies 1 and 2, but instead reoperate Lake Oroville. These strategies are also designed to analyze the effects of both a modest and more aggressive reoperation of Oroville. Strategy 3 is a more modest reoperation with supplemental spring flows of up to 50 taf annually and CM pumping of up to 50 taf annually. Strategy 4 is a more aggressive reoperation with supplemental spring flows of up to 200 taf annually and CM of up to 100 taf annually. The FBO component of strategies 3 and 4 again allow up to 25 percent encroachment during relatively dry conditions and allow for advance releases during potential damaging storms.

Strategies 5 and 6 reoperate both Shasta Lake and Lake Oroville in combination. In addition, Strategies 5 and 6 also include FBO at Folsom Lake. Strategy 5 reoperates both Shasta Lake and Lake Oroville to provide supplemental spring flows and improved management of surface water from in-lieu groundwater pumping in the Sacramento and Feather river basins. In this strategy, system-wide supplemental spring flow volumes can be as high as 100 taf annually (50 taf in Sacramento River and 50 taf in Feather River) and conjunctive management volumes can reach 50 taf annually in both the Sacramento and Feather river basins. Strategy 6 expands the magnitude of reoperation at both Shasta Lake and Lake Oroville.

Strategies 6A, 6B, and 6C employ the same reoperation components as Strategy 6, but also include the effects of potential new Delta conveyance facilities. New Delta conveyance facilities, also known as the North Delta Diversion (NDD), include three intakes on the Sacramento River near Hood with a combined capacity of 9,000 cfs, designed to move water from the Sacramento River to existing export pumps in the south Delta. This analysis evaluates a range of reoperation with new Delta conveyance scenarios.

Three North Delta Diversion (NDD) operational scenarios were developed to assess the effects of a potential new Delta conveyance on Strategy 6. In Strategy 6A (i.e., Strategy 6 and BDCP-reoperation scenario A), water is diverted from the NDD using bypass flow requirements established in BDCP Alternative 4. This bypass flow requirement is documented in Chapter 3.4.1.2 of the BDCP Draft Environmental Impact Report/Environmental Impact Study (EIR/EIS). Strategy 6B includes the NDD and the reoperation components used in Strategy 6; however, supplemental spring flows released from Shasta Lake and Lake Oroville are not diverted at the NDD, but are instead allowed to flow through the Delta and to San Francisco Bay. Finally, in Strategy 6C, supplemental spring flows made from reoperating Shasta Lake and Lake Oroville are diverted at the NDD to the maximum extent possible, subject to available diversion capacity at the NDD.

Strategies 6 ELT-Q5, 6 LLT-Q2, 6 LLT-Q4, and 6 LLT-Q5 evaluate reoperation in the context of potential climate change. In these scenarios, Shasta Lake and Lake Oroville are reoperated using the same reoperation components as Strategy 6, but each scenario uses a different climate-changed hydrology. Climate change scenarios cover two different planning horizons of early long-term (ELT) and late long-term (LLT) and different climate change projections. Additional detail is provided in the subsequent section that presents results from these scenarios.

Sections 6.1 to 6.4 summarize the modeling results for each strategy. The key results presented include changes in reservoir storage, river flows, and water deliveries. Some results are presented as a comparison of the simulated values for each strategy, including the baseline (i.e., without reoperation strategy). Other results are presented as changes in simulated values between the strategies and the baseline.

### 6.1.2 Lake McClure Reoperation Strategy Overview

For the Phase III SRS, DWR worked with MID to develop several reoperation strategies designed to achieve one or more of the goals of the SRS. The reoperation strategies for Lake McClure are similar to those for Shasta Lake and Lake Oroville, including FBO, conjunctive management, and supplemental spring flows applied to Lake McClure operations. Analysis of Lake McClure is performed as an isolated system and does not include any reoperation of Shasta Lake, Lake Oroville, or Folsom Lake.

A specific analysis of climate change on the expanded conjunctive management with FBO was also conducted using the same climate change assumptions that were applied to Shasta Lake and Lake Oroville. The specific Phase III strategies explored for reoperation of Lake McClure are:

#### Combined FBO + Conjunctive Management Strategies

- Increased Conjunctive Management and Forecast-Based Operations for Groundwater Management (CM & FBO — GW Mngmt).
- Increased Conjunctive Management and Forecast-Based Operations for Supplemental Spring Flows and Water Supply (CM & FBO — River & WS).

#### Climate Change and new Delta conveyance Strategies

- Increased Conjunctive Management and Forecast-Based Operations for Ecosystem Supplemental Spring Flows and Water Supply under BDCP climate change scenarios ELT Q5, LLT Q2, LLT Q4, and LLT Q5.

Strategies include components to create both additional yield and support other water resources objectives. Each strategy evaluates tradeoffs in water supply, river flows, reservoir storage, hydropower generation, and approximate effects on groundwater that result from changes in operations. Combined conjunctive management and FBO strategies were designed to meet objectives of more effective groundwater management, ecosystem improvement, and water supply reliability. Section 6.3 describes strategy operations, assumptions, and results in detail.

### 6.1.3 Increased Integration of SWP and CVP Strategy Overview

In addition to evaluating potential benefits that may be possible by reoperating specific reservoirs (i.e., Strategies 1–6), the SRS also evaluated how integrated operations of the state and federal water projects in California may increase water supply and enhance ecosystem function and habitat. The Central Valley Project (CVP) generally has more storage and less conveyance flexibility, while the opposite is generally true for the State Water Project (SWP). The operation of the two projects is coordinated in accordance with the 1986 Coordinated Operations Agreement and other agreements. Though operation is coordinated, the SWP and CVP generally operate as two separate projects — each having different contractual obligations

and operating constraints. SWP and CVP also generally share a common water supply source (i.e., the Delta and its tributaries) and some conveyance facilities. Increased integration of the projects may result in benefits that support the objectives of the SRS and the projects themselves. Accordingly, the purpose of this analysis is to assess potential benefits of operating the SWP and CVP as a single, more integrated project.

This reoperation analysis focuses on the major CVP and SWP storage facilities in the Sacramento River Basin, Delta export facilities, joint use SWP/CVP San Luis Reservoir, and components of the Bay-Delta watershed affected by these projects. The CVP has a storage capacity of about 8 million acre-feet (maf) in the Sacramento River Basin while the SWP storage capacity is about 3.5 maf. The CVP has a maximum Delta export capacity of about 4,600 cubic feet per second (cfs), while the SWP has a maximum export capacity of about 10,300 cfs. These capacities are often restricted by regulations that limit diversions from the Delta.

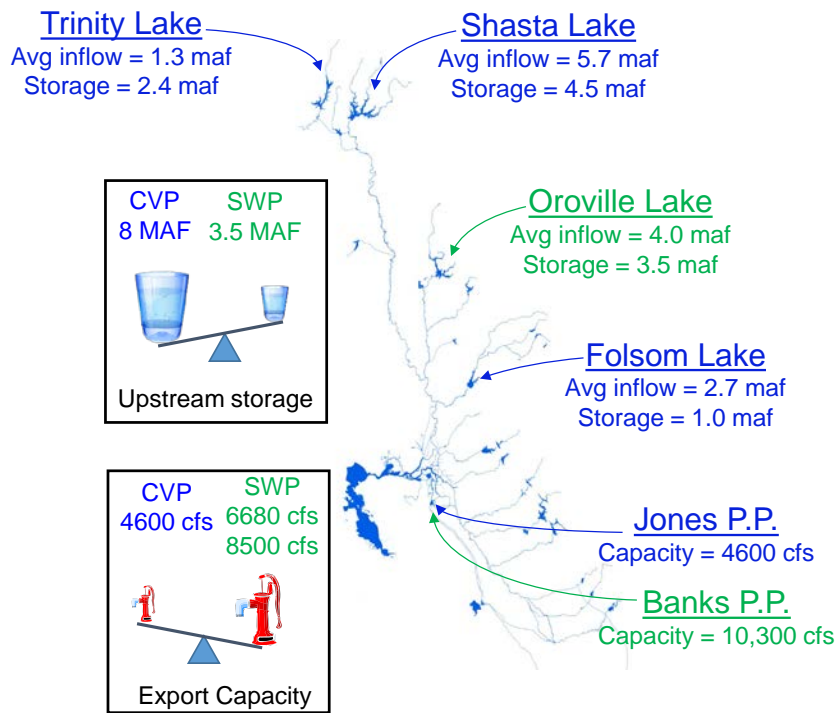


Figure 6-1: Major Components of the CVP and SWP

CVP and SWP operations are constrained by a myriad of requirements, including State Water Resources Control Board (SWRCB) orders and decisions, U.S. Army Corps of Engineers (USACE) requirements, National Marine Fisheries Service (NMFS) biological opinions (BO) for protection of salmon, the U.S. Fish and Wildlife Service (USFWS) biological opinion for protection of delta smelt, and numerous other agreements and requirements. These requirements generally specify operational limits such as minimum and maximum allowable storage, minimum river flows, maximum diversions, minimum water quality, and other criteria. In addition to criteria that set flow and reservoir requirements, the Coordinated Operations



Agreement (COA) is foundational to how the CVP and SWP share obligations for meeting Delta requirements and sharing water supplies.

CVP and SWP operations upstream of, and in the Delta, are coordinated and linked through the COA. The COA is both an operations agreement and a water rights settlement. The purpose of the COA is to ensure that the CVP and the SWP each obtains its appropriate share of water from the Delta and that each bears its share of obligations to protect the other beneficial uses of water in the Delta and the Sacramento Valley. This coordinated operation based upon agreed-upon criteria provides a foundation of integration that can increase the efficiency of both the CVP and the SWP.

*In summary, the COA:*

- Defines the project facilities and their water supplies.
- Sets forth procedures for coordination of operations.
- Identifies formulas for sharing responsibilities for meeting Delta standards and other legal uses of water.
- Identifies how unstored flow will be shared.
- Sets up a framework for exchange of water and services between the SWP and CVP.
- Provides for periodic review every five years, though it has not been updated since it was signed in 1986.

The analytical approach for this reoperation strategy evaluates how the CVP and SWP could operate to meet the project's objectives and the SRS goals without the constraints of the COA. For the purpose of this analysis, all flow and water quality requirements will be met. Further, contractual obligations that DWR and Reclamation have with the SWP and CVP contractors will be honored. It is important to emphasize that by the definitions outlined in the COA, the CVP and SWP are already operating in an integrated manner. To operate in a more integrated manner, COA accounting of water is performed on a daily basis and a cumulative account is maintained where COA debt, by either project, may be accumulated over several months. Project operators meet regulatory requirements and contractual obligations to the best of their ability and then tabulate COA accounting. COA debt is then repaid based on mutual agreement between the project operators.

The fundamental objectives of this reoperation strategy are for the projects to benefit from unconstrained sharing of available conveyance capacity and variations in sharing of reservoir release obligations. This analysis initially reviewed and evaluated historical operations to assess the degree of past integration of the projects and to illuminate the potential that may have existed to increase past operational efficiency (See Chapter 7 for this historical analysis). Then, after establishing a baseline, a simplified modeling analysis was conducted where the CVP and SWP are operated as a single project. Section 6.6 discusses the results of this integration analysis.

## 6.2 Shasta Lake and Lake Oroville Reoperations Strategies

### 6.2.1 Shasta Lake Reoperation Strategies (Strategies 1 & 2)

Strategies 1 and 2 evaluate reoperating Shasta Lake to enhance water supply, reduce flood hazards, and restore and protect upper Sacramento River ecosystems. Strategy 1 implements more modest reoperation components, while Strategy 2 implements those same components more aggressively. The following table summarizes the components of the two Shasta Lake reoperation strategies.

Table 6-2: Shasta Lake Reoperation Strategies

Components	Strategy 1 Assumptions	Strategy 2 Assumptions
<b>Sacramento River Supplemental Spring Flow Target</b>	<i>50 taf</i>	<i>200 taf</i>
<b>Sacramento River Basin CM</b>	<i>50 taf</i>	<i>100 taf</i>
<b>Forecast-Based Operations</b>	<i>Up to 25% encroachment in reservoir flood space. Advance releases ahead of a damaging storm.</i>	

#### 6.2.1.1 Findings & Results of Shasta Lake Reoperation Strategies

The following table presents the effects of reoperating Shasta Lake according to the modeling assumptions of Strategies 1 and 2. This table presents results as compared against baseline conditions, where the baseline conditions depict current operations and regulatory requirements, existing infrastructure, and historical hydrology. Also, a reoperation at Shasta Lake that only included FBO was performed to demonstrate that FBO is the primary driver of increased Shasta Lake storage.

Table 6-3: Modeling Results Summary — Shasta Lake Reoperation Strategies

	Baseline	Baseline + FBO	Strategy 1	Strategy 2
	Annual Volume (taf)	Change in Volume Compared to Baseline (taf)		
Supplemental Spring Flow Target	--	--	50	200
Additional CM Volume Target	--	--	50	100
Supplemental Spring Flow	--	--	21	62
Expanded Groundwater Pumping	--	--	9	19
Shasta EOS Storage	2,660	48	45	38
Trinity EOS Storage	1,401	6	4	-8
Folsom EOS Storage	519	3	6	1
Oroville EOS Storage	1,713	-17	-20	-20
Delta Inflow from Sacramento River	17,854	-11	1	14
Delta Outflow	15,644	-13	-6	11
CVP Export at Jones Pumping Plant	2,247	7	9	8
SWP Export at Banks Pumping Plant	2,738	-4	-2	-5
CVP North-of-Delta Deliveries (Agricultural/Municipal & Industrial)	440	7	8	6

Note: Targets are maximum volumes of water that can be provided in any year. All results are average annual volumes of water.

Modeling reveals that reoperation of Shasta Lake with FBO, CM, and supplemental spring flows (i.e., ecosystem releases) may provide incremental benefits to Shasta Lake storage, river flow and Delta inflow, CVP Delta exports and north-of-Delta deliveries, and incremental decreases in Lake Oroville storage and SWP Delta exports. Strategy 2 increases the amount of supplemental spring flow releases, relative to Strategy 1, which reduces the amount of water available for reservoir storage and delivery while also increasing groundwater pumping. The larger supplemental spring flows of Strategy 2 also provide an increase in Delta outflow. The following sections discuss the potential benefits and effects of these reoperation strategies.

#### 6.2.1.2 Water System Effects Associated with Reoperation

Analysis of End-of-Month (EOM) storage exceedances over an 82-year simulation period reveals that increased storage from FBO tends to outweigh storage reductions from supplemental spring flow releases. EOM storage is frequently higher in all months compared to the baseline, which is primarily driven by relaxed flood control reservation space requirements under FBO.

As Lake Oroville is not reoperated in these strategies, Lake Oroville EOS storage decreased in the summer — primarily in wet year types defined by the SRI. The largest modeled EOS decrease for a single year was 259 taf. The modeled EOS decreases at Lake Oroville are a result of increased Lake Oroville releases to compensate for reduced releases at Shasta Lake.

Since Shasta Lake is reoperated with FBO, it now holds water that previously spilled to meet flood control reservation space requirements.

During years of low storage in the system, FBO and conjunctive management help Shasta Lake retain higher storage levels during summer and fall. The increased storage levels in Shasta Lake also give CVP the flexibility to make releases from Shasta Lake to meet downstream requirements, which consequently relieves release burdens from Folsom Lake. Increases in Folsom EOM late summer and early fall storage during years of relatively low storage demonstrates the improved operational flexibility associated with this type of reoperation.

Average Monthly Changes (AMC) in flow are used to characterize downstream effects from reoperated reservoirs. AMC are the difference between reoperation strategies and a baseline (strategy minus baseline), averaged by month for an 82-year simulation period. The following figures illustrate AMC in the Sacramento River below Keswick and in the Feather River below Thermalito Afterbay. Increases in lower Feather River flows are primarily driven by Lake Oroville meeting SWP demands that were previously met in the baseline with unused federal water from the Delta during wetter years.

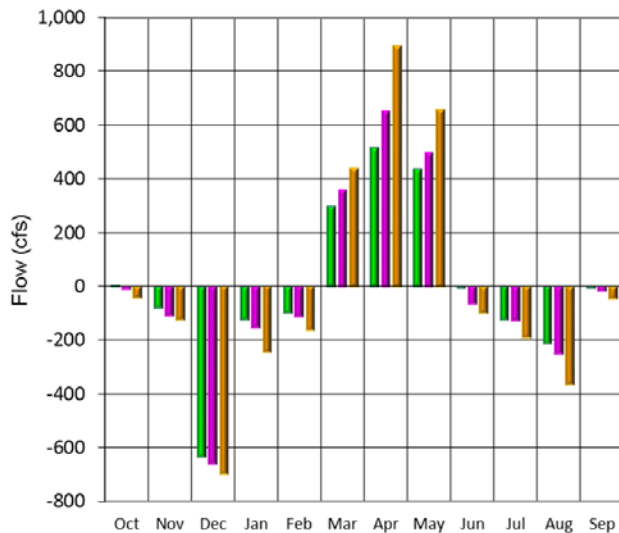


Figure 6-2: Changes in Sacramento River Flow below Keswick Dam (Strategies 1 & 2)

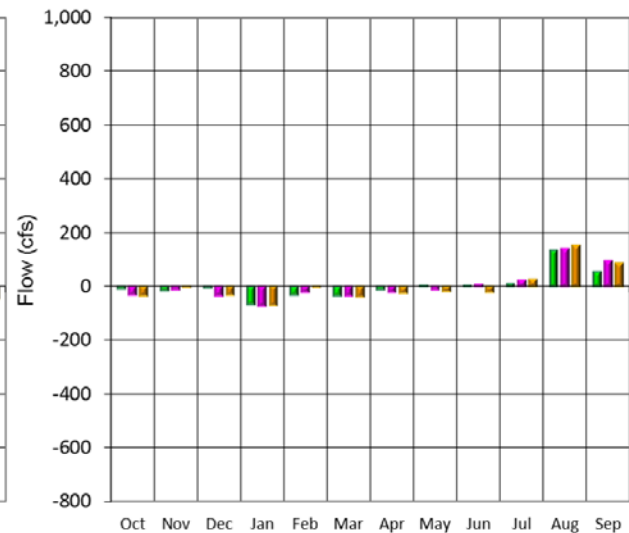
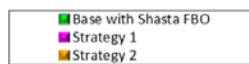


Figure 6-3: Changes in Feather River Flow below Thermalito Afterbay (Strategies 1 & 2)

For all strategies, modeling shows that FBO is a dominant driver of changes in reservoir operations and river flows throughout the system. Between November and December, Shasta Lake releases are reduced as a result of additional storage space created by FBO. In January and February, reduced releases are caused by FBO, and refilling of storage space vacated by supplemental spring flow releases from preceding springs. From March to May, Shasta Lake increases releases primarily for supplemental spring flows and to maintain flood space reservation. In Strategies 1 and 2, end-of-May storage in Shasta Lake during dry and critical years increases on average by about 40 taf. These reoperation strategies also improve end-of-

September carryover storage, particularly during dry years with conjunctive management. EOS storage in Shasta Lake increased on average by about 40 taf in both Strategy 1 and Strategy 2. During dry and critical years, EOS storage in Shasta Lake increased on average by 60 taf and 112 taf in Strategy 1 and Strategy 2, respectively.

Higher spring releases occur in the FBO-only scenario when additional water held in storage in fall and winter keeps Shasta Lake higher. As a result, during large spring runoff events, Shasta Lake must operate to current flood control levels, and must make increased releases in these months when compared with the baseline.

### 6.2.1.3 Water Supply Analysis

Increased storage in Shasta Lake as a result of FBO creates higher allocations to CVP water service contractors. However, while FBO increases CVP deliveries, higher supplemental spring flow releases under Strategy 2 reduces some of the water supply benefits created with FBO.

Figure 6-4 illustrates average annual changes in north-of-Delta (NOD) CVP deliveries under FBO-only, Strategy 1, and Strategy 2.

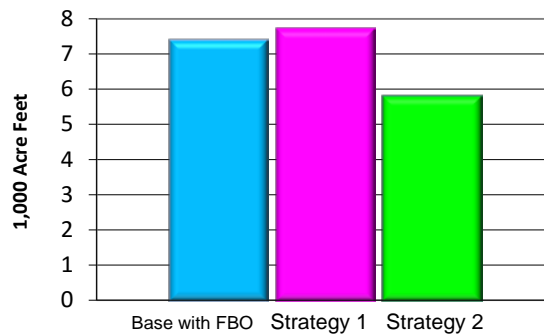


Figure 6-4: Changes in NOD CVP Deliveries (Strategies 1 & 2)

The effects of Strategies 1 and 2 on south-of-Delta (SOD) exports are minimal because increases in Delta inflow in the spring is not captured at SOD export pumps because of flow restrictions in the Old and Middle rivers from March–June. The average annual exports at Jones Pumping Plant increase by less than about 10 taf for both strategies. At Banks Pumping Plant, average annual exports decrease by up to about 5 taf for both strategies.

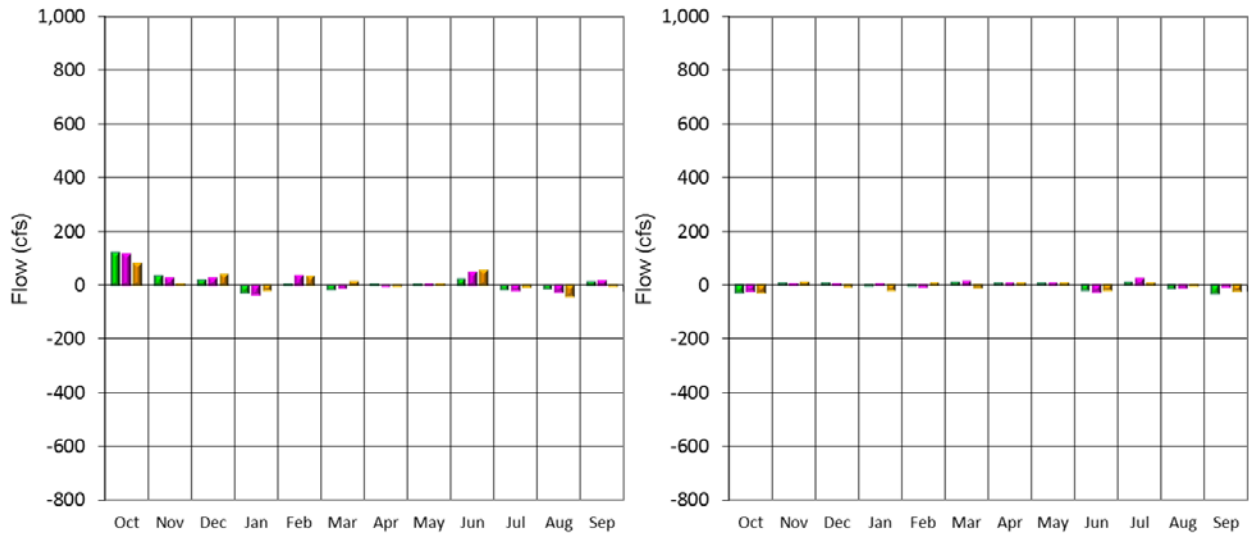
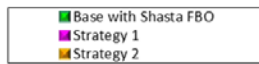


Figure 6-5: Changes in Exports at Jones Pumping Plant (Strategies 1 & 2)

Figure 6-6: Changes in Exports at Banks Pumping Plant (Strategies 1 & 2)



#### 6.2.1.4 Ecosystem

As shown in Table 6-3, the Shasta Lake reoperation can provide supplemental spring flows and improve the cold water pool associated with Shasta Lake. However, there is a reduction in storage in Lake Oroville. Reoperation yields minor improvements in specific ecosystem metrics compared to baseline model runs (Appendix D). Also, the small benefits from the supplemental spring flows to some ecosystem metrics may be associated with negative impacts to other ecosystem metrics.

For Strategies 1 and 2, on average, March to May EOM storage decreased as a result of supplemental spring flow releases. This effect continues through September. Average annual supplemental spring flows for Strategies 1 and 2 are 21 taf and 62 taf, respectively.

While average storage conditions are reduced, storage during dry and critical years is improved. This improvement in end-of-May storage in Shasta Lake in dry and critical years (about 40 taf) is a result of conjunctive management. This implies increased cold water storage during these important periods increases the ability to maintain suitable salmonid habitat downstream of Keswick Dam. A more detailed ecosystem analysis for these strategies is contained in Appendix D.

#### 6.2.1.5 Flood Protection

For Strategies 1 and 2, the use of FBO necessitates changes in flood control operational rules in order to maintain safety. As a part of these strategies, FBO allows stored water to encroach into a maximum of 25 percent of a reservoir’s available flood control reservation space. Flood risk is reduced by also allowing the release of water ahead of a forecasted damaging storm.

Strategies 1 and 2 involve reoperation of Shasta Lake only. The modified operational rule to allow FBO at Shasta Lake was to make advance storage releases when the forecasted five-day cumulative inflow volume exceeds 900 taf.

With an early trigger release in Shasta Lake of 900 taf, the model results show peak surface water elevation increases of approximately 0.1 feet in the American, Feather, and Sacramento rivers during the 100-year event, with an increase of approximately 0.3 feet during the 200-year event. The peak surface water elevation increase may be due to the change in timing of releases coinciding with local inflows. These results indicate no flood control benefit resulting from the Shasta Lake reoperation strategies.

#### 6.2.1.6 *Other Effects*

Reoperation under Strategy 1 and Strategy 2 also has effects on groundwater pumping and Delta flows. Groundwater pumping increases in response to supplemental spring flows that diminish reservoir storage. Strategy 2 has higher supplemental spring flow targets than Strategy 1, which results in a greater change in average annual groundwater pumping (an increase of 19 taf for Strategy 2 vs. 9 taf for Strategy 1).

Changes in operations from upstream reservoirs persist into the Delta. The AMC in Delta inflow from the Sacramento River and Yolo Bypass are approximately equal to the AMC below Keswick, Thermalito, and Nimbus, minus any increase in NOD CVP deliveries. As a result, changes in Delta inflow persist as changes in Delta outflow.

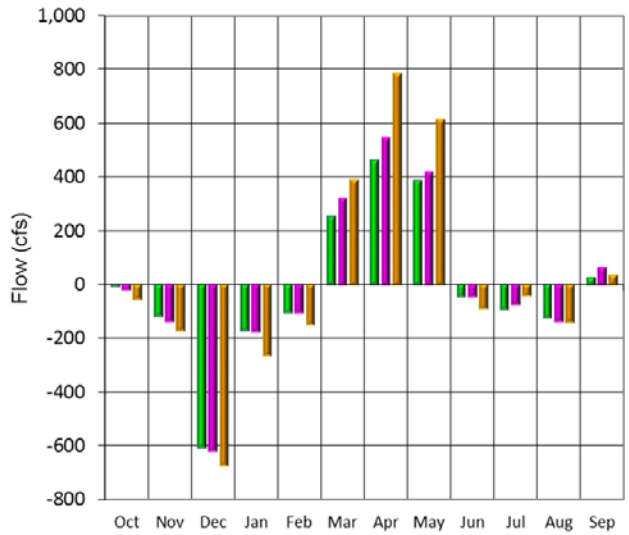


Figure 6-7: Changes in Delta Inflow from Sacramento River (FBO and Strategies 1 & 2)

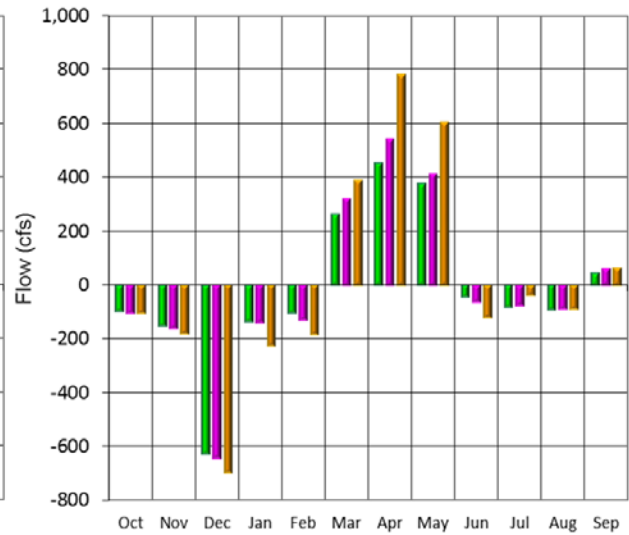
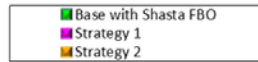


Figure 6-8: Changes in Delta Outflow (FBO and Strategies 1 & 2)

### 6.2.2 Lake Oroville Reoperation Strategies (Strategies 3 & 4)

Strategies 3 and 4 focus on reoperating Lake Oroville with reoperation components similar to those evaluated in Strategies 1 and 2 for Shasta Lake. Lake Oroville can release, as supplemental spring flows, up to 50 taf in Strategy 3 and 200 taf in Strategy 4. Additional CM in the Feather River Basin of 50 taf is included in Strategy 3 and 100 taf in Strategy 4.

Table 6-4. Lake Oroville Reoperation Strategies

Components:	Strategy 3 Assumptions	Strategy 4 Assumptions
Feather River Supplemental Spring Flow Target	50 taf	200 taf
Feather River Basin CM	50 taf	100 taf
Forecast-Based Operations	Up to 25% encroachment in reservoir flood space; advance releases ahead of a damaging storm.	

#### 6.2.2.1 Findings & Results of Lake Oroville Reoperation

The following table presents the effects of reoperating Lake Oroville according to the modeling assumptions of Strategies 3 and 4. This table presents results as compared against baseline conditions, where the baseline conditions depict current regulatory requirements, existing infrastructure, and historical hydrology. A reoperation that only included FBO at Lake Oroville was also performed, demonstrating that FBO is the primary driver of increased Lake Oroville storage.



Table 6-5. Modeling Results Summary — Lake Oroville Reoperation Strategies

	Baseline	Baseline + FBO	Strategy 3	Strategy 4
	Annual Volume (taf)	Change in Volume Compared to Baseline (taf)		
Supplemental Spring Flow Target	--	--	50	200
Additional CM Volume Target	--	--	50	100
Supplemental Spring Releases	--	--	9	33
Expanded Groundwater Pumping	--	--	18	35
Shasta EOS Storage	2,660	0	1	6
Trinity EOS Storage	1,401	-2	-1	-1
Folsom EOS Storage	519	0	1	3
Oroville EOS Storage	1,713	14	15	8
Delta Inflow from Sacramento River	17,854	0	17	34
Delta Outflow	15,644	-5	2	19
CVP Exports at Jones Pumping Plant	2,247	0	1	-3
SWP Exports Banks Pumping Plant	2,738	5	14	17
CVP north-of-Delta Deliveries (Agricultural/Municipal/Industrial)	440	0	0	0

Note: Targets are maximum volumes of water that can be provided in any year. All results are average annual volumes of water.

Modeling reveals that reoperation of Lake Oroville with FBO, CM, and supplemental spring flows may provide incremental benefits to Lake Oroville storage, Delta inflow and outflow, the ecosystem, and SWP Delta exports. Strategy 4 increases the amount of supplemental spring flows relative to Strategy 3, which may reduce the amount of water available for reservoir storage and delivery while also increasing groundwater pumping. The higher supplemental spring flows of Strategy 4 also provide an expected increase in Delta flows compared to Strategy 3. The following sections discuss the potential benefits and effects of these reoperation strategies.

#### 6.2.2.2 Water System Effects Associated with Reoperation

As was the case in Strategies 1 and 2 at Shasta Lake, EOM storage at Lake Oroville is frequently higher in all months when compared to the baseline for Strategies 3 and 4. This is primarily driven by relaxed flood control reservation space requirements under FBO. Conjunctive management improves storage during dry years. EOS storage in Lake Oroville during dry and critical years increased on average by 18 taf and 38 taf in Strategy 3 and Strategy 4, respectively.

Reduced releases from Lake Oroville with reoperation are mostly caused by filling additional storage space under FBO and recovery of storage vacated by the release of supplemental spring flows from March to May. Increases in Lake Oroville releases and Feather River flows occur in April and May from both increased spills under FBO and the release of supplemental

spring flows. Reduced releases from Lake Oroville from November to March are mostly caused by filling additional storage available under FBO.

6.2.2.3 Water Supply Analysis

Generally, improved Lake Oroville storage from reoperation will increase SWP allocations and SOD exports and filling the SWP portion of San Luis Reservoir — this is the case in July and August.

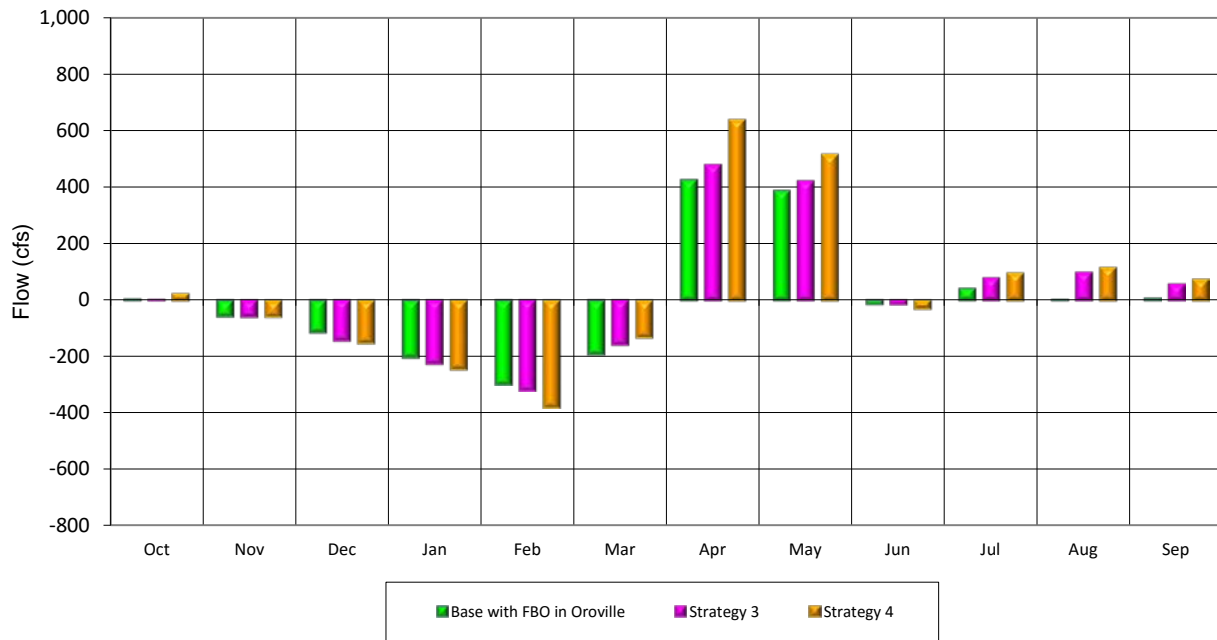


Figure 6-9: Changes in Feather River Flow below Thermalito Afterbay (Strategies 3 & 4)

The effects of these reoperation strategies on SOD exports are minimal, because increases in March to May Delta inflow is generally not captured at SOD export pumps because of the flow restrictions in the Old and Middle rivers. Using only FBO reoperation at Lake Oroville has little to no effect on CVP exports at Jones Pumping Plant. Strategies 3 and 4 increase average annual CVP exports at Jones Pumping Plant by about 2 taf. Average annual SWP exports at Banks Pumping Plant increased in Strategies 3 and 4 by about 15 taf. Using only FBO reoperation at Lake Oroville increases SWP SOD exports by about 5 taf.

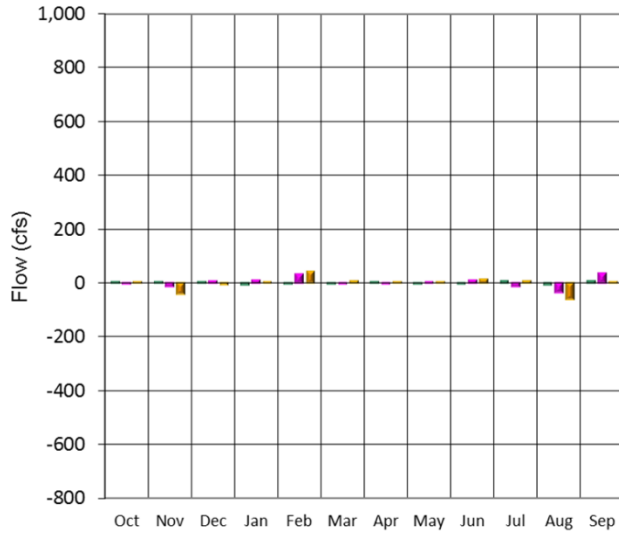


Figure 6-10: Changes in Exports at Jones Pumping Plant (Strategies 3 & 4)

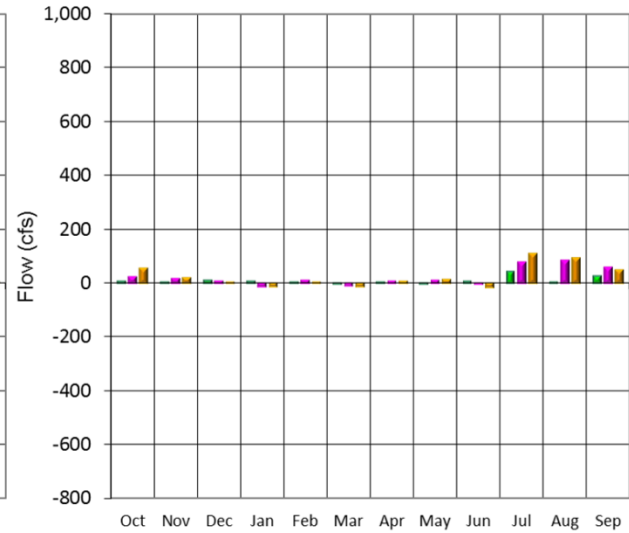
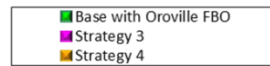


Figure 6-11: Changes in Exports at Jones Pumping Plant (Strategies 3 & 4)

#### 6.2.2.4 Ecosystem

As shown in Table 6-5, the Lake Oroville reoperation can provide supplemental spring flows and improve the cold water pool associated with Lake Oroville. Reoperation strategies yielded minor improvements in specific ecosystem metrics compared with baseline model runs (Appendix D); the small benefits from the supplemental spring flows to some ecosystem metrics may also be associated with negative impacts to other ecosystem metrics. Figure 6-9 shows changes in flows in the Feather River below Thermalito Afterbay as a result of the Lake Oroville reoperation strategies.

The average annual release of supplemental spring flows for Strategy 3 and Strategy 4 are 9 taf and 33 taf, respectively. In comparison with an FBO-only reoperation, March to May EOM storages at Lake Oroville for Strategies 3 and 4 are reduced as a result of the release of supplemental spring flow, and this effect persists through September. A more detailed ecosystem analysis for these strategies is contained in Appendix D.

#### 6.2.2.5 Flood Protection

For Strategies 3 and 4, the use of FBO necessitates changes in flood control operational rules in order to maintain safety. As operated in these strategies, FBO allows stored water to encroach into a maximum of 25 percent of the reservoir’s flood control reservation space. Flood risk is minimized by allowing the release of water ahead of a forecasted damaging storm. These strategies reoperate Lake Oroville only. The modified operational rule to allow FBO at Lake Oroville was to make advance storage releases when the forecasted five-day cumulative inflow volume exceeded 1,100 taf.

With an early trigger release in Lake Oroville of 1,100 taf, model results show stage decreases of approximately 0.1 and 0.2 feet during the 50-year event, and between 0.1 and 0.2 feet decreases in the 100-year event along the Feather River. The American River and Sacramento River show less than a tenth of a foot stage differences.

6.2.2.6 Other Effects

Reoperation under Strategy 3 and Strategy 4 has effects on groundwater pumping and Delta flows. Groundwater pumping does increase through reoperation as a result of the release of supplemental spring flows. Strategy 4 has higher supplemental spring flow targets than Strategy 3, which results in a greater change in average annual groundwater pumping than Strategy 3 (an increase of 35 taf for Strategy 4 vs. 18 taf for Strategy 3). Changes in operations from upstream reservoirs persist into the Delta. Changes in Delta inflow also persist as Delta outflow. For these strategies, March to May Delta inflows and outflows increased as a result of the additional release of supplemental spring flows.

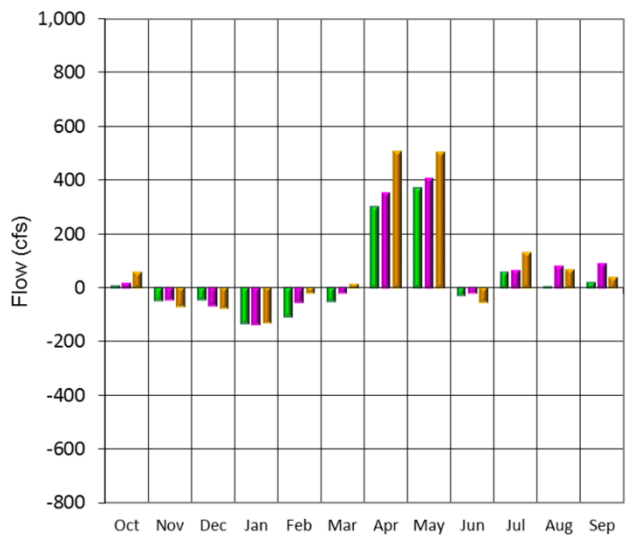


Figure 6-12: Changes in Delta Inflow from Sacramento River (FBO and Strategies 3 & 4)

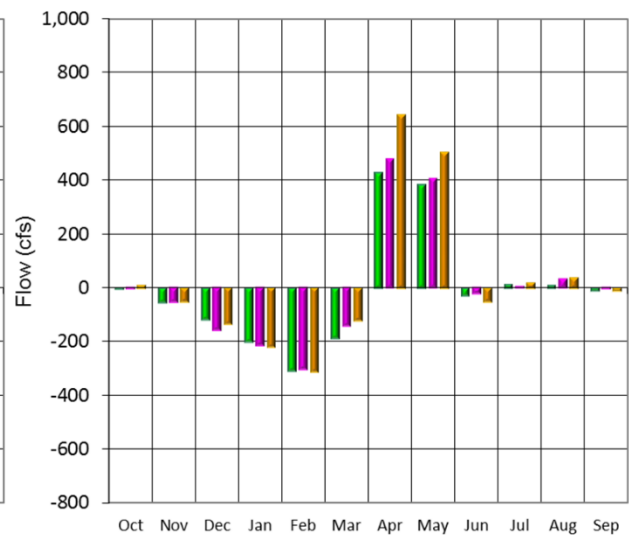
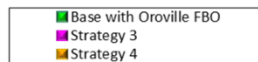


Figure 6-13: Changes in Delta Outflow (FBO and Strategies 3 & 4)

### 6.2.3 Combine Reoperation of Shasta Lake and Lake Oroville Strategies (Strategies 5 & 6)

Two reoperation strategies that include reoperation of Shasta Lake and Lake Oroville in combination (Strategies 5 and 6) were evaluated. Both strategies also include FBO at Folsom Lake. Strategy 5 reoperates both Shasta Lake and Lake Oroville to provide supplemental spring flows and improve management of surface water from in-lieu groundwater pumping in the Sacramento and Feather river basins. System-wide supplemental spring flow volumes can be as high as 100 taf annually (50 taf in the Sacramento River and 50 taf in the Feather River), and conjunctive management volumes can reach 50 taf annually each in the Sacramento and Feather river basins. Strategy 6 reoperates Shasta Lake and Lake Oroville similar to Strategy 5, but annual volume of supplemental spring flows can be as high as 300 taf system-wide (150 taf in the Sacramento River and 150 taf in the Feather River), and additional groundwater pumping can be as high as 100 taf each in the Sacramento and Feather river basins.

Table 6-6. Combine Reoperation of Shasta Lake and Lake Oroville Strategies

	Strategy 5 Assumptions	Strategy 6 Assumptions
Sacramento River Supplemental Spring Flow Target	50	150
Feather River Supplemental Spring Flow Target	50	150
Sacramento River Basin CM	50	100
Feather River Basin CM	50	100
Forecast-Based Operations	<i>Up to 25% encroachment in reservoir flood space. Advance releases ahead of a damaging storm</i>	
Folsom Dam Reoperation	<i>FBO-Only</i>	

#### 6.2.3.1 Findings & Results of Combine Reoperation of Shasta Lake and Lake Oroville

The following table presents the effects of jointly reoperating Shasta Lake and Lake Oroville according to the modeling assumptions of Strategies 5 and 6. Both strategies also include FBO at Folsom Lake. This table presents results as compared with baseline conditions, where the baseline conditions depict current regulatory requirements, existing infrastructure, and historical hydrology. A reoperation that included FBO-only at all reservoirs was also performed to demonstrate that FBO is the primary driver of increased reservoir storage.

Table 6-7. Modeling Results Summary — Combine Reoperation of Shasta Lake and Lake Oroville Strategies

	Baseline	Baseline + FBO	Strategy 5	Strategy 6
	Annual Volume (taf)	Change in Volume Compared to Baseline (taf)		
Supplemental Spring Flow Target	--	--	100	300
Additional CM Volume Target	--	--	100	200
Supplemental Spring Flow Releases	--	--	29	80
Expanded Groundwater Pumping	--	--	27	55
Shasta EOS Storage	2,660	53	60	51
Trinity EOS Storage	1,401	5	6	-2
Folsom EOS Storage	519	15	15	16
Oroville EOS Storage	1,713	-12	-10	-10
Delta Inflow from Sacramento River	17,854	-17	9	39
Delta Outflow	15,644	-25	-8	12
CVP Deliveries at Jones Pumping Plant	2,247	10	14	14
SWP Deliveries at Banks Pumping Plant	2,738	-3	3	12
North-of-Delta CVP Deliveries (Agricultural/Municipal/Industrial)	440	12	12	11

Note: Targets are maximum volumes of water that can be provided in any year. All results are average annual volumes of water.

Modeling reveals that joint reoperation of Shasta Lake and Lake Oroville with FBO, CM, and supplemental spring flows may provide incremental benefits to Shasta Lake and Folsom Lake storage, Delta inflow, the ecosystem, and water deliveries, with an incremental decrease in Lake Oroville storage. Strategy 6 increases the amount of supplemental spring flow releases relative to Strategy 5, which may reduce the amount of water available for reservoir storage and delivery while also increasing groundwater pumping. The higher ecosystem flows of Strategy 6 also provide an expected increase in Delta outflows compared with Strategy 5. The following sections discuss the potential effects and benefits of these reoperation strategies. An analysis of uncertain futures, specifically the potential effects of climate change and implementation of new Delta conveyance, was performed using the reoperation components associated with Strategy 6. The analysis and results of these uncertain futures is discussed in Section 6.2.3.6.

#### 6.2.3.2 Water System Effects Associated with Reoperation

In general, EOM storage in Shasta Lake is increased in all months when compared with the baseline, as a result of relaxed flood control reservation space requirements under FBO. Conjunctive management improves storage during drier year types. EOS storage in Shasta Lake during dry and critical years increased on average by 49 taf and 6 taf in Strategy 5 and

Strategy 6, respectively. EOM storage in Folsom Lake increases are primarily caused by relaxed flood control reservation space requirements under FBO.

The following figures illustrate AMC in the Sacramento River below Keswick and in the Feather River below Thermalito Afterbay.

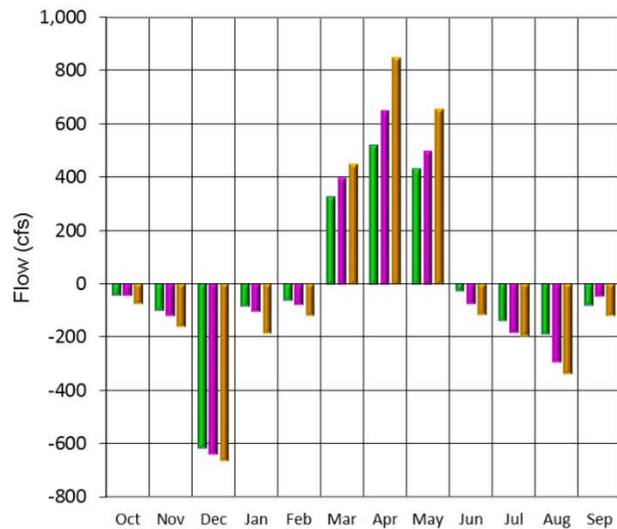


Figure 6-14: Changes in Sacramento River Flow below Keswick Dam (Strategies 5 & 6)

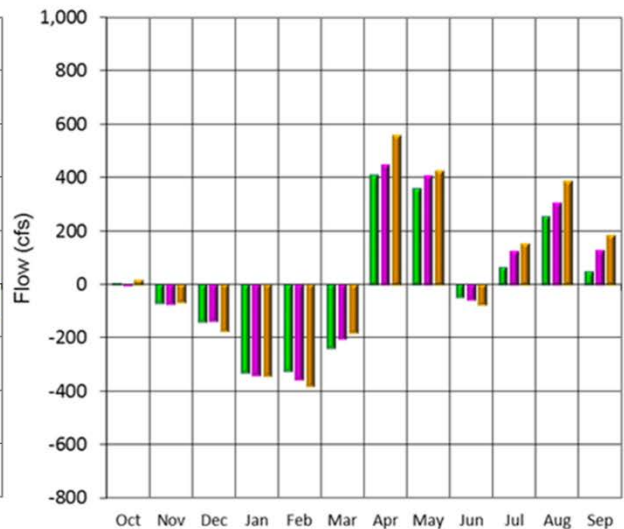


Figure 6-15: Changes in Feather River Flow below Thermalito Afterbay (Strategies 5 & 6)

### 6.2.3.1 Water Supply Analysis

Increased storage in Shasta Lake and Folsom Lake resulting from FBO can result in higher allocations to CVP water service contractors.

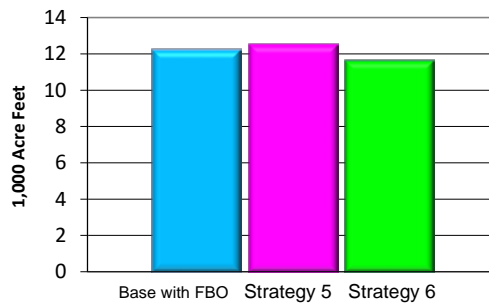


Figure 6-16: Changes in CVP NOD Diversions (Strategies 5 & 6)

The effects of these strategies on SOD exports are minimal because increases in Delta inflow during the spring are not captured at SOD export pumps as a result of flow restrictions in Old and Middle rivers. Average annual water supplies are improved by 29 and 37 taf for Strategies 5 and 6, respectively.

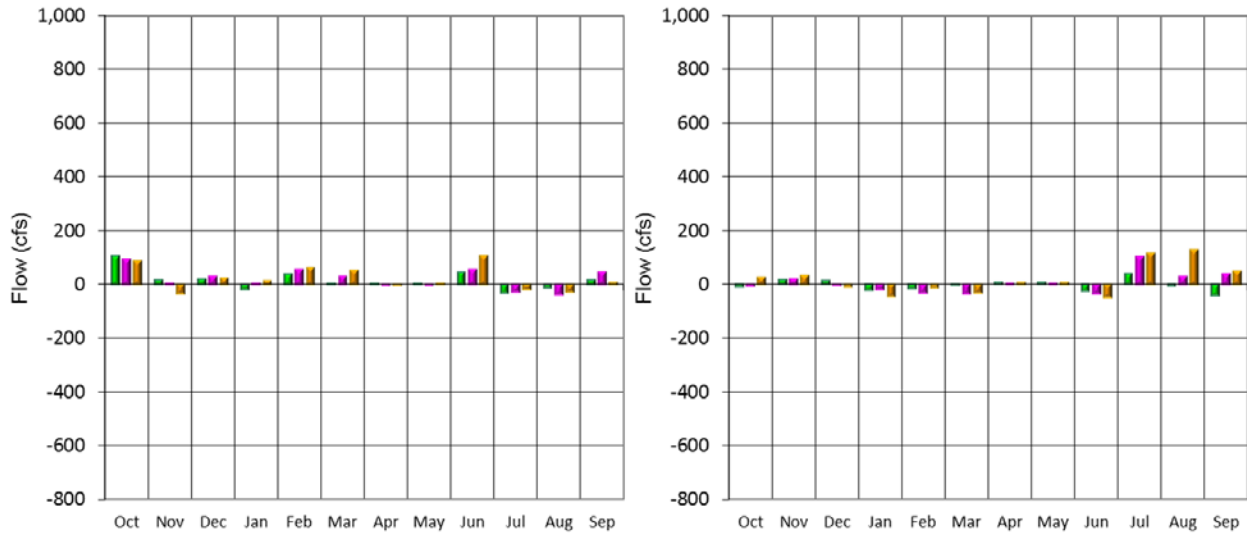


Figure 6-17: Changes in CVP Exports at Jones Pumping Plant (Strategies 5 & 6)

Figure 6-18: Changes in SWP Exports at Banks Pumping Plant (Strategies 5 & 6)

### 6.2.3.2 Ecosystem

As shown in Table 6-7, the combined reoperation of Shasta Lake and Lake Oroville can provide supplemental spring flows and improve the cold water pools associated with Shasta Lake and Folsom Lake; conversely, there is a lesser reduction in carry-over storage in Lake Oroville. Reoperation yielded minor improvements in specific ecosystem metrics compared with baseline model runs (see Modeling Results Summary below); the small benefits from the supplemental spring flows to some ecosystem metrics may also be associated with negative impacts to other ecosystem metrics. Note the flow volume results of the Combined Reoperation of Shasta Lake and Lake Oroville Strategy in the following paragraph.

From March to May, supplemental spring flows are released when conditions allow. The average annual release of supplemental spring flows for Strategy 5 and Strategy 6 are 29 taf and 80 taf, respectively. In comparison with an FBO-only reoperation, March to May EOM storages in Shasta Lake and Lake Oroville are reduced after ecosystem releases, and this effect persists through September. However, in comparison with the baseline, storage is still higher during these months, indicating supplemental spring flows may be provided from additional water gained under FBO. EOM storage in Folsom Lake is increased on average, primarily caused by relaxed flood control reservation space requirements under FBO. A more detailed ecosystem analysis for these strategies is contained in Appendix D.

### 6.2.3.3 Flood Protection

For Strategies 5 and 6, the use of FBO necessitates changes in flood control operational rules in order to maintain safety. As operated in these strategies, FBO allows stored water to encroach into a maximum of 25 percent of available reservoir flood control reservation space.



Flood risk is minimized by allowing the release of water from storage ahead of a forecasted damaging storm. FBO operations at Shasta Lake, Lake Oroville, and Folsom Lake are included in these strategies. The modified operational rules to allow FBO at Shasta Lake, Lake Oroville, and Folsom Lake were to make advance storage releases when the forecasted five-day cumulative inflow volume exceeded 900 taf, 1,100 taf, and 900 taf, respectively.

With an early trigger release to Shasta Lake of 900 taf, to Lake Oroville of 1,100 taf, and to Folsom Lake of 900 taf, the Sacramento River shows a peak water surface elevation decrease downstream of the Fremont Weir of greater than 0.1 feet during the 100-year event. The American River shows a peak water surface elevation decrease of approximately 1.5 feet during the 100-year event. For the 50-year and 200-year events along the American River, there were minor differences.

6.2.3.4 Other Effects

Reoperation under Strategy 5 and Strategy 6 has effects on groundwater pumping and Delta outflows as well. Groundwater pumping increases through reoperation to compensate for the release of supplemental spring flows. Strategy 6 has higher ecosystem release targets than Strategy 5, which results in a greater change in average annual groundwater pumping (an increase of 55 taf vs. 27 taf).

Changes in operations from upstream reservoirs persist into the Delta. Changes in Delta inflow also persist as Delta outflow. For these strategies, March to May Delta inflows and outflows increased as a result of the supplemental spring flows.

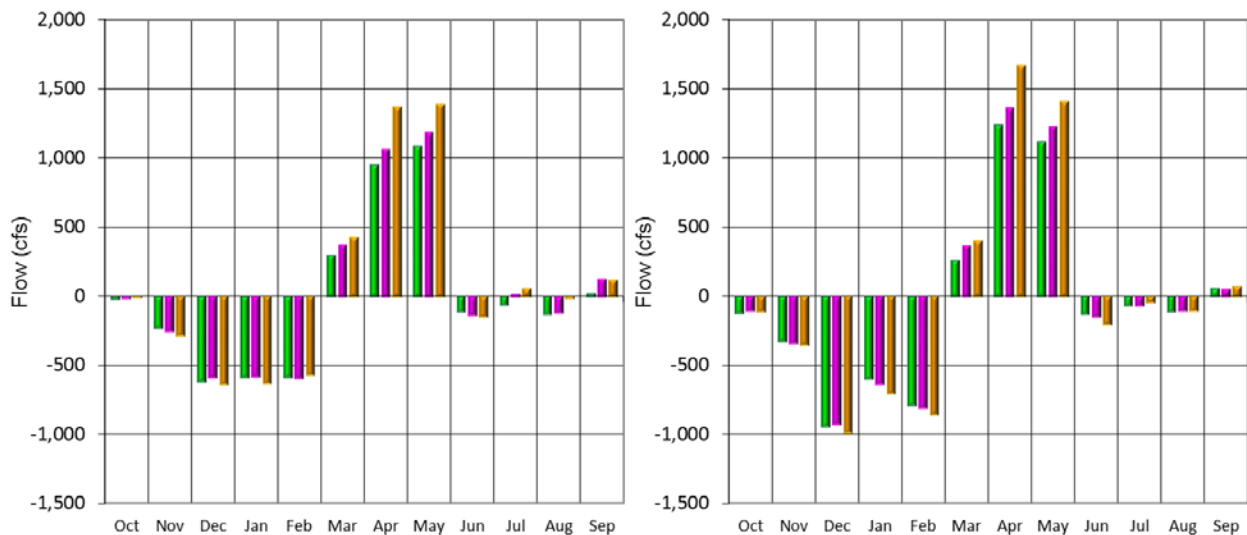


Figure 6-19: Changes in Delta Inflow from Sacramento River (FBO and Strategies 5 & 6)



Figure 6-20: Changes in Delta Outflow (FBO and Strategies 5 & 6)

6.2.3.5 *Uncertain Futures — Considerations for New Delta Conveyance and Climate Change*

Additional sensitivity analyses were conducted to understand the potential effects from new Delta conveyance and climate change. These analyses were conducted using the modeling assumptions from Strategy 6 — the combined reoperation of Shasta Lake and Lake Oroville (with FBO at Folsom Lake). Three scenarios (6A, 6B, and 6C) are used to portray how a NDD facility affects reoperation strategies, including recapture of ecosystem pulses. Four climate change scenarios (6-ELT-Q5, 6-LLT-Q2, 6-LLT-Q4, and 6-LLT-Q5) are used to describe the range of potential climate change in the early long-term and late long-term. The following sections each describe the results of sensitivity analyses for new Delta conveyance and climate change considerations.

6.2.3.6 *Uncertain Futures: New Delta Conveyance*

Three North Delta Diversion (NDD) operational scenarios (6A, 6B, and 6C) were developed to evaluate the potential effects of new Delta conveyance on Strategy 6, the combined reoperation of Shasta Lake and Lake Oroville. In Strategy 6A, water is diverted from the NDD using bypass flow requirements established in the BDCP Alternative 4. Strategy 6B includes the NDD as part of the CVP/SWP and the reoperation strategies used in all Strategy 6 options; however, supplemental spring flows released from Shasta Lake and Lake Oroville are not diverted at the NDD and instead provide ecosystem benefits in the lower reach of the Sacramento River through the Delta. Finally, in Strategy 6C, supplemental spring flows from reoperating Shasta Lake and Lake Oroville are diverted at the NDD to the maximum extent possible, subject to available diversion capacity at the NDD. These three operational scenarios for Strategy 6 were developed to bookend how an NDD facility affects reoperation strategies, including recapture of supplemental spring flows. The table below summarizes reoperation strategies under Strategies 6A, 6B, and 6C.

Table 6-8. Modeling Assumptions for New Delta Conveyance Considerations

	Strategy 6A	Strategy 6B	Strategy 6C
<b>Sacramento River Supplemental Spring Flow Target (taf/yr)</b>	150	150	150
<b>Feather River Supplemental Spring Flow Target (taf/yr)</b>	150	150	150
<b>Sacramento River Basin CM Target (taf/yr)</b>	100	100	100
<b>Feather River Basin CM Target (taf/yr)</b>	100	100	100
<b>Forecast-Based Operations</b>	Up to 25% encroachment in reservoir flood space. Advance releases ahead of a damaging storm.	Up to 25% encroachment in reservoir flood space. Advance releases ahead of a damaging storm.	Up to 25% encroachment in reservoir flood space. Advance releases ahead of a damaging storm.
<b>Folsom Dam Operations</b>	FBO-Only.	FBO-Only.	FBO-Only.
<b>NDD Operations</b>	As described in Chapter 3.4.1.2 of BDCP EIR/EIS.	As described in Chapter 3.4.1.2 of BDCP EIR/EIS (With <b>NO</b> ecosystem pulses diverted at the NDD).	As described in Chapter 3.4.1.2 of BDCP EIR/EIS (With ecosystem pulses diverted at the NDD).

Results presented for these strategies are changes in Delta inflow, outflow, and exports.

Table 6-9. Modeling Results Summary — New Delta Conveyance Considerations

	Baseline	Strategy 6	Strategy 6A	Strategy 6B	Strategy 6C
	Annual Volume (taf)	Change in Volume Compared to Baseline (taf)			
Supplemental Spring Flow Target, Sacramento and Feather rivers	--	300	300	300	300
Additional CM Volume Target, Sacramento and Feather River basins	--	200	200	200	200
Supplemental Spring Flow Releases	--	<b>80</b>	<b>73</b>	<b>74</b>	<b>73</b>
Expanded Groundwater Pumping	--	<b>55</b>	<b>43</b>	<b>39</b>	<b>43</b>
Shasta EOS Storage	2,638	<b>51</b>	<b>23</b>	<b>20</b>	<b>27</b>
Trinity EOS Storage	1,397	<b>-2</b>	<b>-5</b>	<b>-7</b>	<b>-4</b>
Folsom EOS Storage	518	<b>16</b>	<b>5</b>	<b>2</b>	<b>6</b>
Oroville EOS Storage	1,766	<b>-10</b>	<b>13</b>	<b>6</b>	<b>17</b>
Delta Inflow from Sacramento River	17,868	<b>39</b>	<b>-1</b>	<b>-1</b>	<b>-2</b>
Delta Outflow	14,671	<b>12</b>	<b>-68</b>	<b>-54</b>	<b>-86</b>
CVP Exports at Jones Pumping Plant	2,446	<b>14</b>	<b>41</b>	<b>28</b>	<b>52</b>
SWP Exports at Banks Pumping Plant	3,522	<b>12</b>	<b>25</b>	<b>23</b>	<b>30</b>
North-of-Delta CVP Deliveries (Agricultural/Municipal/Industrial)	454	<b>11</b>	<b>7</b>	<b>6</b>	<b>7</b>

Note: Targets are maximum volumes of water that can be provided in any year. All results are average annual volumes of water.

Strategy 6, combined reoperation of Shasta Lake and Lake Oroville, contributes to a small increase in Delta inflow (about 0.2 percent). However, with the combined reoperation of reservoirs using new Delta conveyance, Delta inflow is virtually identical with or without reoperation. Figure 6-21 shows that Delta inflow from the Sacramento River is reduced in the winter months and increases in March to May when flood releases made under baseline operations are now stored in the reservoirs under FBO. In the spring, Delta inflow is increased as a result of supplemental spring flows being released from Shasta Lake and Lake Oroville, in addition to water held in storage under FBO from previous months that may spill.

In general, Delta outflow increases are greatest in Strategy 6, without an NDD. With an NDD, a portion of the increase in March to May and September inflows to the Delta are diverted at the NDD. This is illustrated as the difference between the AMC in Delta outflow under Strategy 6 compared to Strategies 6A, 6B, and 6C.

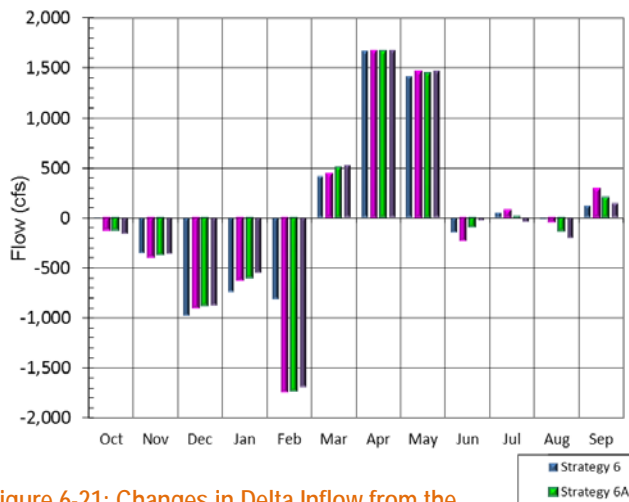


Figure 6-21: Changes in Delta Inflow from the Sacramento River (Strategies 6, 6A, 6B, & 6C)

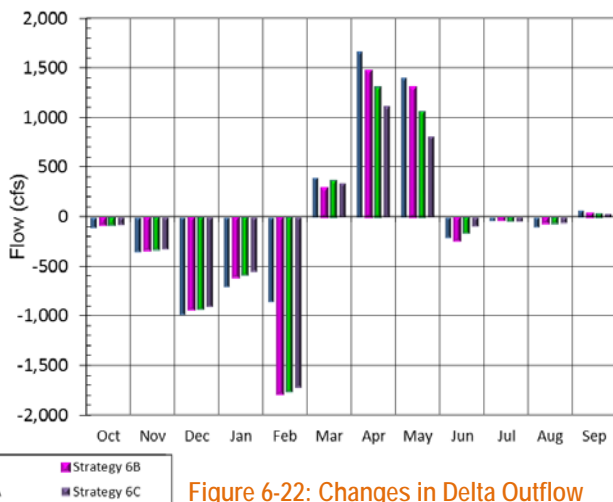


Figure 6-22: Changes in Delta Outflow (Strategies 6, 6A, 6B, & 6C)

Average monthly exports at both Banks and Jones pumping plants increase in March to May in Strategies 6A, 6B, and 6C, primarily from diversion of reoperation supplemental spring flows at the NDD. Strategy 6C has the largest potential increase in diversions and Strategy 6B has the smallest. Overall, SOD exports increase in Strategies 6, 6A, 6B, and 6C.

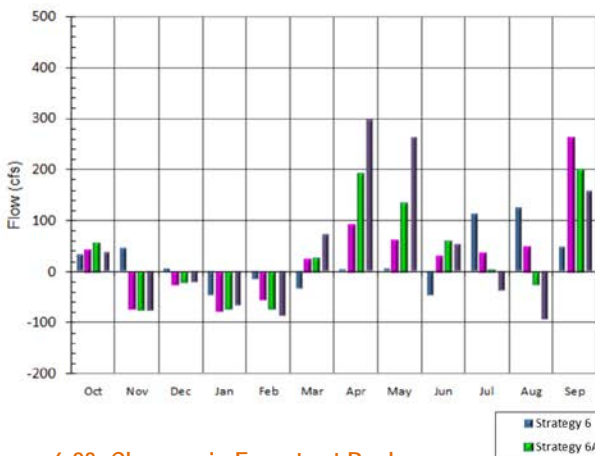


Figure 6-23: Changes in Exports at Banks Pumping Plant (Strategies 6, 6A, 6B, & 6C)

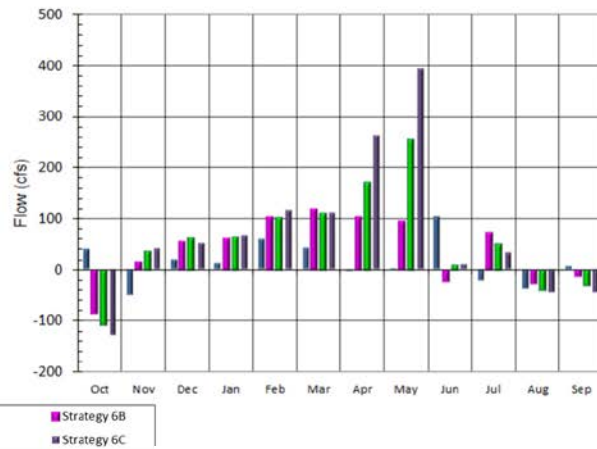


Figure 6-24: Changes in Exports at Jones Pumping Plant (Strategies 6, 6A, 6B, & 6C)

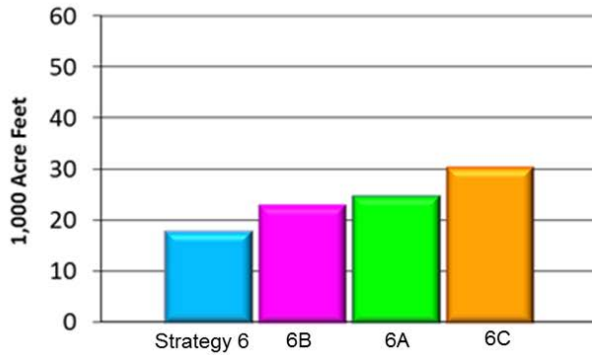


Figure 6-25: Average Annual Change in Banks Pumping Plant (Strategies 6, 6A, 6B, & 6C)

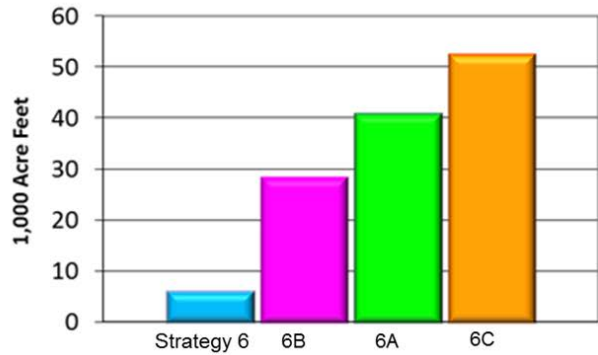


Figure 6-26: Average Annual Change in Jones Pumping Plant (Strategies 6, 6A, 6B, & 6C)

### 6.2.3.7 Uncertain Futures: Climate Change Considerations

There is a general consensus that climate warming will induce changes in hydrology. Current operational decisions and approaches, which largely rely on historically informed hydrology, may not be appropriate under the projected climate changes. Moreover, projected sea level rise could potentially degrade water quality in the Delta through intrusion of salt water, which can require increased releases from upstream reservoirs. Thus, there is merit in understanding the sensitivity of benefits and effects of proposed reoperation strategies under climate change and sea level rise conditions.

Climate change simulations consider many global processes at a scale larger than the regional or watershed level. In the BDCP draft EIR/EIS, five downscaled general circulation model (GCM) climate projections were developed. The five models can be broadly categorized as Q1) drier, less warming; Q2) drier, more warming; Q3) wetter, more warming; Q4) wetter, less warming; and Q5) 25th to 75th percentile (“median”) level of warming and wetness trends. ELT describes a future climate period from 2011–2040. LLT describes a future climate from 2046–2075. The technical description of these climate projections can be found in Section A, Appendix 5A of the BDCP Draft EIR/EIS. This Phase III study applies ELT Q5, LLT Q2, LLT Q4, and LLT Q5 climate change assumptions to Strategy 6. The following table summarizes the climate changed reoperation scenarios that were evaluated to consider the effects of climate change.

Table 6-10. Modeling Assumptions for Climate Change Considerations

	Strategy 6-ELT-Q5	Strategy 6-LLT-Q2	Strategy 6-LLT-Q4	Strategy 6-LLT-Q5
<b>BDCP Climate Model Analyzed (Timeline of Analysis)</b>	<i>Drier, less warming (2011 to 2040)</i>	<i>Drier, more warming (2046 to 2075)</i>	<i>Wetter, less warming (2046 to 2075)</i>	<i>Median warming and wetness (2046 to 2075)</i>
Sacramento River Spring Flow Target (taf/yr)	150			
Feather River Spring Flow Target (taf/yr)	150			
Sacramento River Basin CM Target (taf/yr)	100			
Feather River Basin CM Target (taf/yr)	100			
Forecast-Based Operations	<i>Up to 25% encroachment in reservoir flood space.</i>			
	<i>Advance releases ahead of a damaging storm.</i>			
Folsom Dam Operations	<i>FBO-Only.</i>			
NDD Operations	<i>No NDD.</i>			

To evaluate the effects of climate change on reoperation for each of the four strategies outlined previously, a climate-changed baseline was established for each reoperation strategy. These baselines depict current regulatory requirements and infrastructure while using a climate-changed hydrology and rise in sea level. The difference between proposed strategies and the relevant baselines for metrics such as water deliveries, reservoir storage, and river flows were calculated to illustrate effects of reoperation. The results of climate change analysis are presented in the following table.

Table 6-11: Modeling Results Summary for Climate Change Considerations

	Base ELT-Q5	Strategy 6-ELT-Q5	Base LLT-Q2	Strategy 6-LLT-Q2	Base LLT-Q4	Strategy 6-LLT-Q4	Base LLT-Q5	Strategy 6-LLT-Q5
	Annual Volume (taf)	Change from Baseline (taf)	Annual Volume (taf)	Change from Baseline (taf)	Annual Volume (taf)	Change from Baseline (taf)	Annual Volume (taf)	Change from Baseline (taf)
Supplemental Spring Flow Releases	--	75	--	48	--	93	--	74
Expanded Groundwater Pumping	--	74	--	123	--	57	--	90
Shasta EOS Storage	2,463	12	1,731	47	2,622	-5	2,233	23
Trinity EOS Storage	1,280	-1	843	29	1,444	-11	1,719	2
Folsom EOS Storage	465	6	347	-1	462	4	408	-5
Oroville EOS Storage	1,541	42	1,200	70	1,616	16	1,382	63
Delta Inflow from Sac. River	18,085	54	15,490	66	20,800	43	18,080	57
Delta Outflow	16,101	9	13,531	-7	19,222	4	16,257	-13
CVP Exports at Jones Pumping Plant	2,124	12	1,716	26	2,212	5	1,986	21
SWP Exports at Banks Pumping Plant	2,659	31	2,227	46	2,744	34	2,478	46
North-of-Delta CVP Deliveries (Agricultural/Municipal/Industrial)	401	11	287	13	464	6	368	15

The most pronounced climate change effect observed during analysis of EOM storage is the reduced storage levels in the LLT Q2 scenario. The LLT Q2 scenario represents a drier, warmer climate projection. Average annual inflow into Shasta Lake for LLT Q2 is projected to be 779 taf less than using historic hydrology. Moreover, average annual inflow into Lake Oroville and Folsom Lake, and flow from other major tributaries are a combined 1,907 taf less when compared to historically informed inflows. This overall reduction of water in the upstream reservoirs means less water is available to meet downstream demands, minimum flow requirements, and maintain water quality in the Delta. The effects on storage from the other three climate change scenarios are smaller, and vary by month.

The following figures illustrate average monthly flow changes in the Sacramento River below Keswick Dam, in the Feather River below Thermalito Afterbay, and in the American River below Nimbus Dam, respectively. Changes shown for each scenario are the differences between a baseline operation and the reoperation strategies with the same hydrology.

Figure 6-27: Changes in Sacramento River Flow below Keswick Dam



Figure 6-28: Changes in the Feather River Flow below Thermalito Afterbay

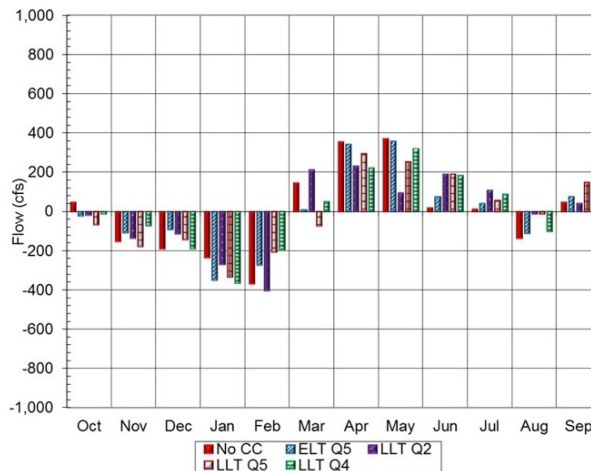


Figure 6-29: Changes in American River Flow below Nimbus Dam

In general, even under climate change, the system reacts similarly to reoperation strategies defined under Strategy 6. In winter months, releases from Shasta Dam are reduced in comparison to their no-action baseline scenario as a result of the increased conservation storage allowed with FBO. Most of this increased conservation storage is filled with flood releases that were made in a no-action baseline. In the spring, reservoirs have less space to capture snowmelt since the conservation pool is mostly filled in the winter, and therefore additional releases are made to maintain storage at flood control levels. Also, a small portion of the additional releases in spring are due to supplemental spring flows.

Flows in upstream river systems persist into the Delta as a change in inflow from the Sacramento River. With the existing regulatory requirements and Delta conveyance, most of these changes in inflows occurring from fall through spring contribute to increased Delta outflows.



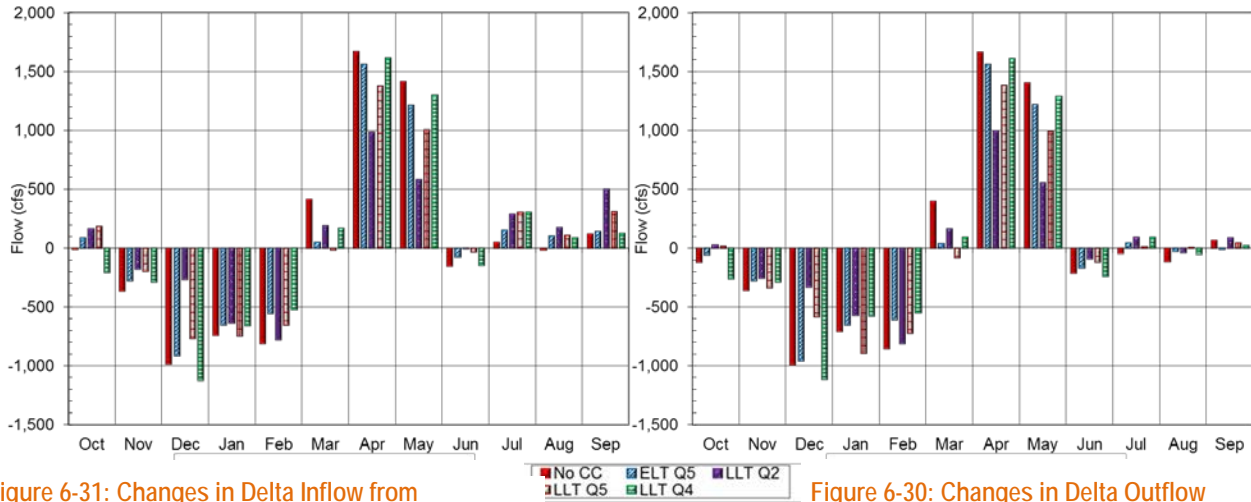


Figure 6-31: Changes in Delta Inflow from Sacramento River (Strategy 6 with and without Climate Change)

Figure 6-30: Changes in Delta Outflow (Strategy 6 with and without Climate Change)

Delta inflow is increased from summer through fall to support increased levels of exports and meet water quality standards. Changes in exports at Banks and Jones pumping plants are presented below.

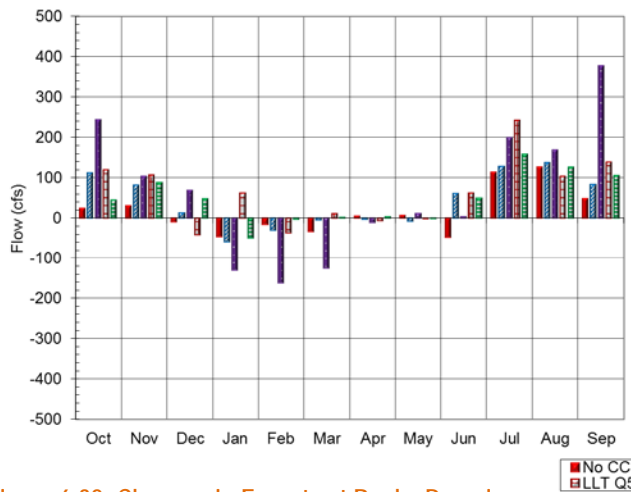


Figure 6-32: Changes in Exports at Banks Pumping Plant (Strategy 6 with and without Climate Change)



Figure 6-33: Changes in Exports at Jones Pumping Plant (Strategy 6 with and without Climate Change)

### 6.3 Lake McClure Reoperation Strategies

This section presents the modeling results for reoperation of Lake McClure. Reoperation strategy effects on water supply, river flows, reservoir storage, hydropower generation, and groundwater were analyzed by simulating MID dam operations for each reoperation strategy. Modeling results are compared against the results of MID's baseline dam operations to illustrate the effects of reoperation. Two Lake McClure reoperation strategies are presented here as Strategies 7 and 8.

Analysis of Lake McClure for all strategies was performed using a monthly spreadsheet model that simulates operations for flood control, water supply, hydropower production, and flows on the Merced River downstream of the dam. The monthly model simulates an 82-year historical hydrology from water year 1922–2003, consistent with CalSim-II. Model operations depict current MID demand for surface water and regulatory requirements. All results presented in this report are from the monthly spreadsheet model.

The Phase III SRS evaluates combined FBO and CM reoperation of Lake McClure to meet one or more objectives of the SRS. Specifically, two strategies analyze the combination of expanded conjunctive management and FBO for different purposes. The first strategy combined the two components for the purpose of improved groundwater management. The second strategy, to support both the environment and water supply, combined these components to provide additional Merced River releases. In order to simulate FBO in Lake McClure, it was assumed that up to 50 taf of the existing required flood control reservation space could be varied based on future inflow forecasts. The assumption of 50 taf, instead of the full 60 taf, was conservative and provides a buffer against imperfect forecasts.

#### *Strategy 7: Increased Conjunctive Management and Forecast-Based Operations for Groundwater Management (Abbreviated as CM & FBO — GW Mngmt)*

In this strategy, FBO is applied and the current CM is expanded by delivering an additional 15 taf of surface water, when available, to offset a like amount of groundwater pumping. Available water supply (Lake McClure storage + Merced River runoff) in April must exceed 760 taf to trigger these additional surface water deliveries. For this strategy, CM drawdown in Lake McClure is limited to a maximum of 15 taf.

#### *Strategy 8: Increased Conjunctive Management and Forecast-Based Operations for Ecosystem and Water Supply (Abbreviated as CM & FBO — River & WS)*

The second combined strategy performed an evaluation using a groundwater reserve to backstop more aggressive reservoir operations for the dual purposes of increased Merced River flows and additional surface water deliveries from the lower San Joaquin River. In this strategy, MID's existing conjunctive management is expanded by up to 15 taf annually and FBO is applied to reservoir operations.

This strategy begins with an additional 15 taf of surface water delivered in-lieu of pumping groundwater. The additional surface water delivery creates a credit in the aquifer that could be pumped in future years, if needed, with no net effect to the groundwater system, in theory. For the purposes of this simplified analysis, it was assumed that the 15 taf remained in the groundwater system with no loss over time.

After a 15 taf credit is established in the groundwater system and Lake McClure has refilled, a more aggressive reservoir operation is triggered to release an additional 15 taf annually when surface water is available. The additional 15 taf of release is intended to serve two purposes. First, it is released during spring months to increase flows in the Merced River for ecosystem benefits. Second, the additional release is assumed to be sold and re-diverted from the lower San Joaquin River to provide additional water supply to areas outside of MID.

*Summary of Modeling of Lake McClure Strategies*

The following table summarizes the key modeling assumptions applied to the two Lake McClure combined (CM + FBO) strategies. The effects of climate change on reoperation of Lake McClure are considered in later analysis and are discussed in Section 6.3.6.

Table 6-12: Lake McClure Reoperation Strategy Assumptions

	Strategy 7 CM & FBO — GW Mngmt	Strategy 8 CM & FBO — River & WS
Merced River CM Operations	+15 taf, when available.	+15 taf, when available, to establish a groundwater credit.  +15 taf, when available, the credit above is then used for ecosystem flows and water supply after a groundwater credit is established.
Purposes of Merced River CM	To offset groundwater pumping.	To establish a groundwater credit and provide flows for ecosystem and water supply after a credit is established.
Lake McClure Drawdown Limit	15 taf.	
Forecast-Based Operations	Up to 50 taf encroachment in reservoir.	
	Advance releases ahead of a damaging storm.	

### 6.3.1 Findings and Results

Table 6-13 provides summary metrics of the average annual changes in water supply, hydropower generation, and Merced River flows for the modeled strategies, when compared to existing MID operations.

Table 6-13. Summary of Average Annual Change in Key System Metrics for Lake McClure Strategies

		Strategy 7 CM & FBO — GW Mngmt	Strategy 8 CM & FBO — River & WS
	Baseline Conditions	<i>Changes from Baseline Conditions</i>	
MID Surface Water Delivery (taf)	414	+2	+2
MID SOI Surface Water Delivery (taf)	14	+9	0
Lake McClure Carryover Storage (taf)	507	+34	+35
Merced River Project Hydro. Generation (GWHrs)	349	+2	+2
Merced River Flow near Cressey (taf)	447	-12	-3
Additional Release for CM or River & Water Supply (taf)	N/A	+8	+4
Number of Years (out of 82) with Additional Release*	N/A	46	23*

\*Number of years include both conjunctive management releases to establish GW credit and environmental/water supply releases.

Modeling results indicate FBO may provide small benefits to water supply and hydropower generation, even when combined with operations to increase conjunctive management or provide additional releases for environmental/water supply purposes. Increased deliveries, including deliveries to increase conjunctive management or establish a groundwater reserve for making environmental releases, decrease average annual Merced River flow. This is a fundamental tradeoff in this kind of reoperation generally. However, some of these operations change the timing to increase flows during periods when flows are relatively low by reducing flood control releases from New Exchequer Dam when Merced River flows are relatively high. These timing changes may provide an environmental benefit.

The tabulated values in the table above provide a means of understanding key effects across strategies. The following sections provide more detailed information on how the individual strategies affect water supply, river flows, reservoir storage, and hydropower generation.

### 6.3.2 Water Supply

#### 6.3.2.1 Water Supply Analysis of Strategy 7: CM & FBO — GW Mngmt

Modeling this first strategy illustrates that FBO increased the water supply in some years; however, when Lake McClure doesn't refill from the prior year's conjunctive management release, the additional 15 taf release is not made. Increased surface water deliveries to MID occur in four years as a result of higher reservoir storage with FBO. Carryover storage in Lake McClure is generally higher with FBO, even when making additional conjunctive management

releases. Yet, while end-of-October storage is higher in approximately 90 percent of years, storage later in the winter may be the same as under existing operations if inflow is forecasted to be high.

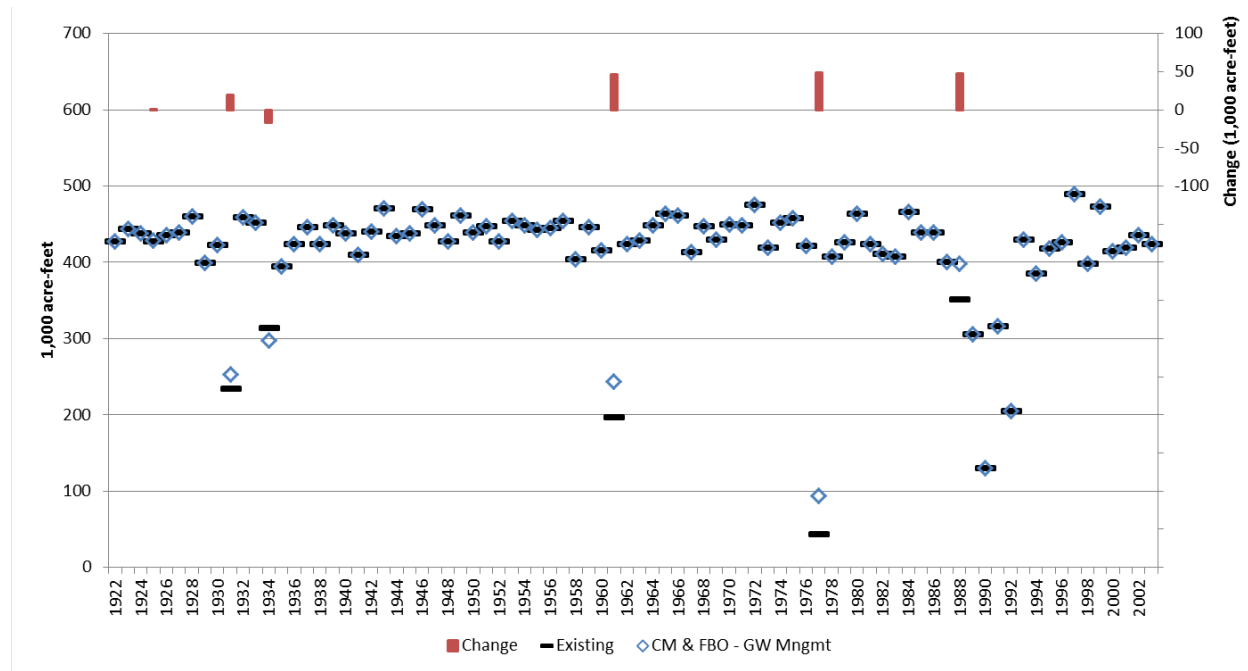


Figure 6-34: Strategy 7: Increased CM & FBO for Groundwater Management — MID Surface Water Deliveries

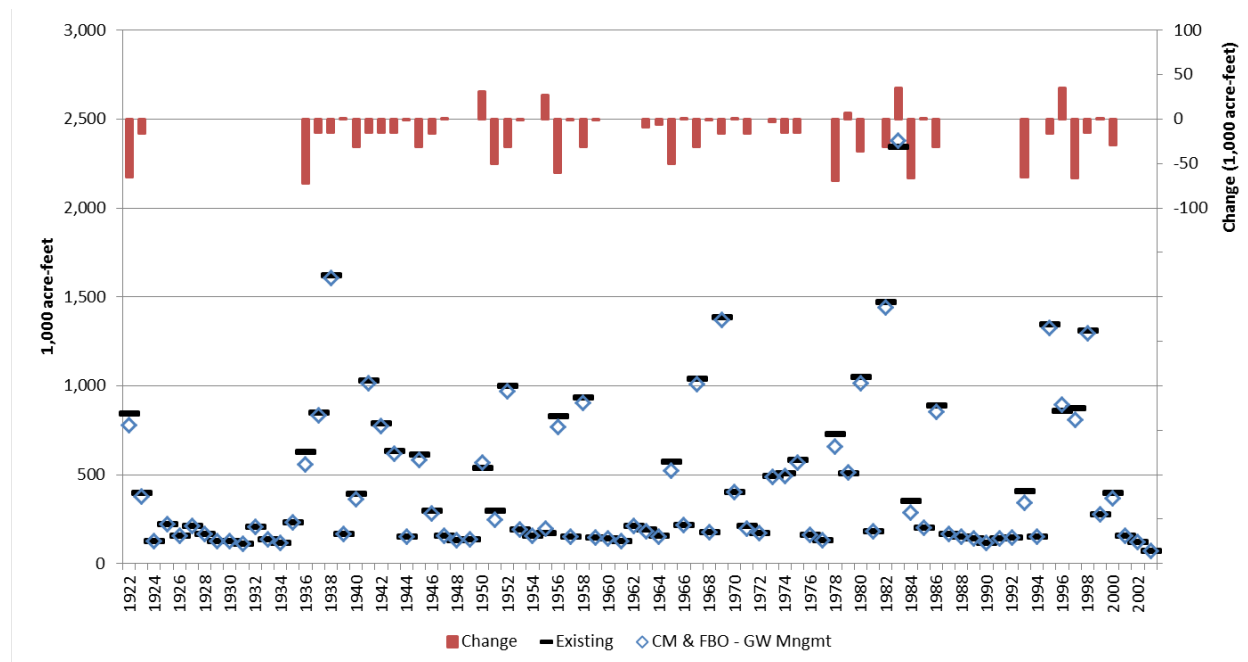


Figure 6-35: Strategy 7: Increased CM & FBO for Groundwater Management — Merced River Flows near Cressey

MID surface water deliveries are increased in four out of 82 years and reduced in one year under this strategy. Increased surface water deliveries to MID under the aegis of conjunctive

management reduced flow on the Merced River — particularly during periods when New Exchequer Dam makes flood control releases under existing operations.

6.3.2.2 Water Supply Analysis of Strategy 8: CM & FBO — River & WS

In this strategy, FBO can increase reservoir storage and provide additional water supply. In the first year of the simulation, MID delivers 15 taf of additional surface water and establishes a credit of 15 taf in the GW account to be called upon in future years if Lake McClure becomes lower than under existing operations.

Environmental/water supply releases of 15 taf in May are made in 22 years during the simulation, or approximately one in four years (See Figure 6-36). These releases increase Merced River flow and re-diversion from the lower San Joaquin River for water supply. The releases are more frequent with the combination of increased conjunctive management and FBO than with either component alone. Carryover storage in Lake McClure is higher, relative to existing operations, as a result of FBO.

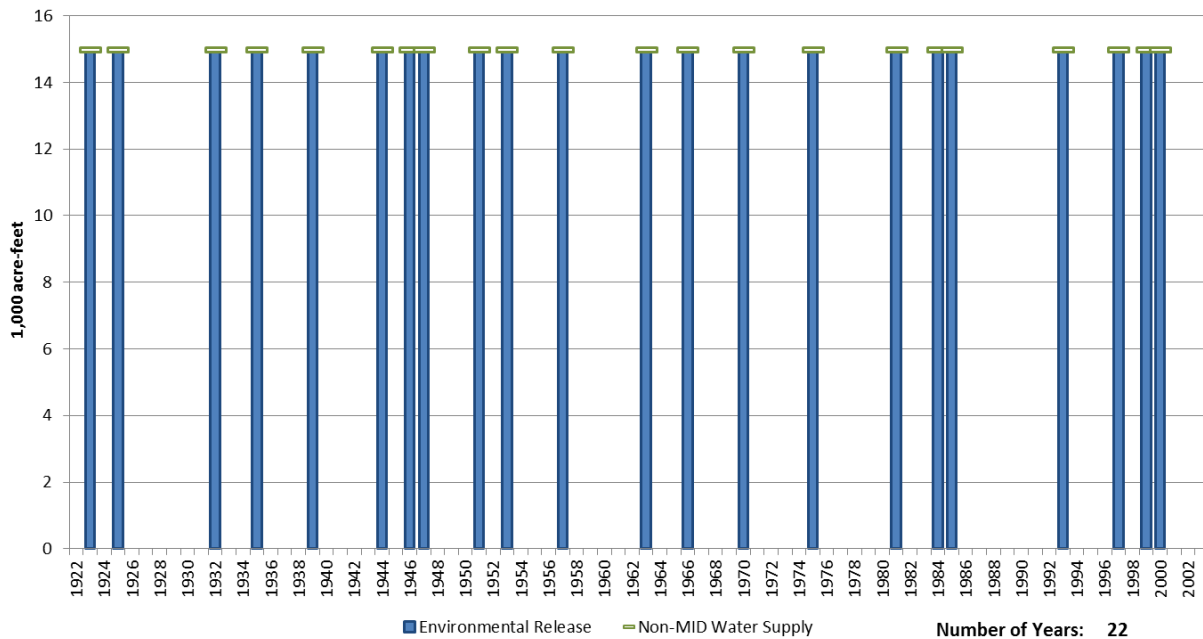


Figure 6-36: Strategy 8: Increased CM & FBO for Ecosystem and Water Supply — Ecosystem /Water Supply Releases

Figure 6-37 illustrates that MID surface water deliveries are increased in four years and decreased in one year, starting in simulation year 1934.

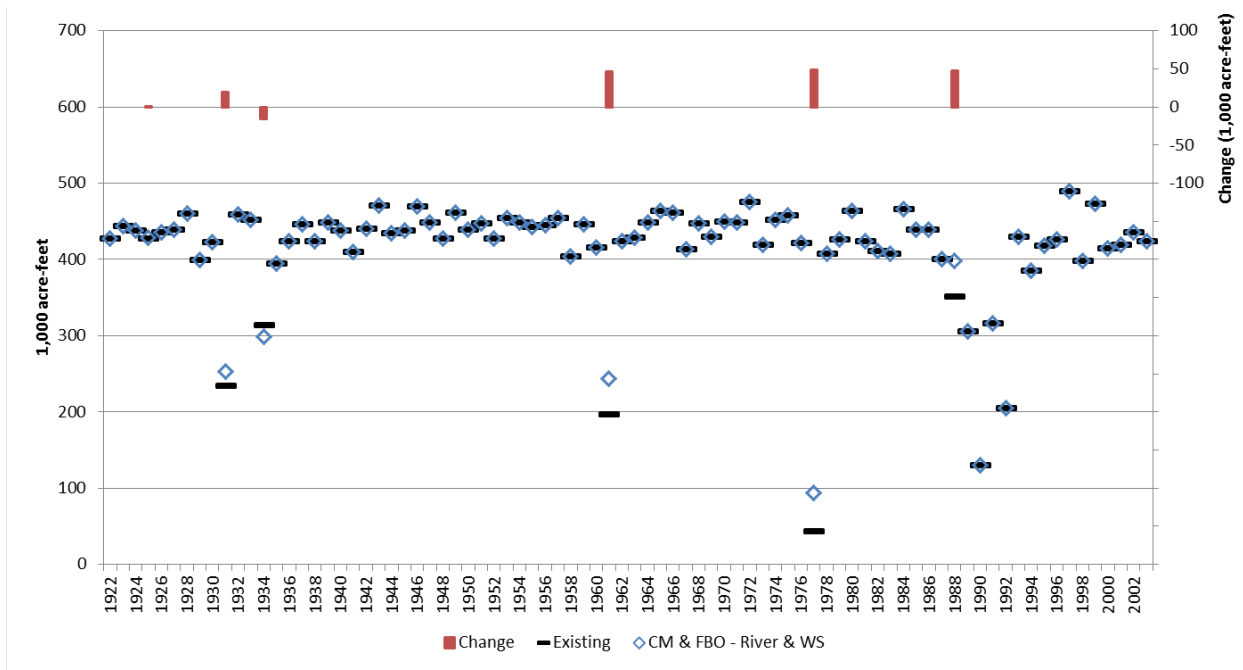


Figure 6-37: Strategy 8: Increased CM & FBO for Ecosystem and Water Supply — MID Surface Water Deliveries

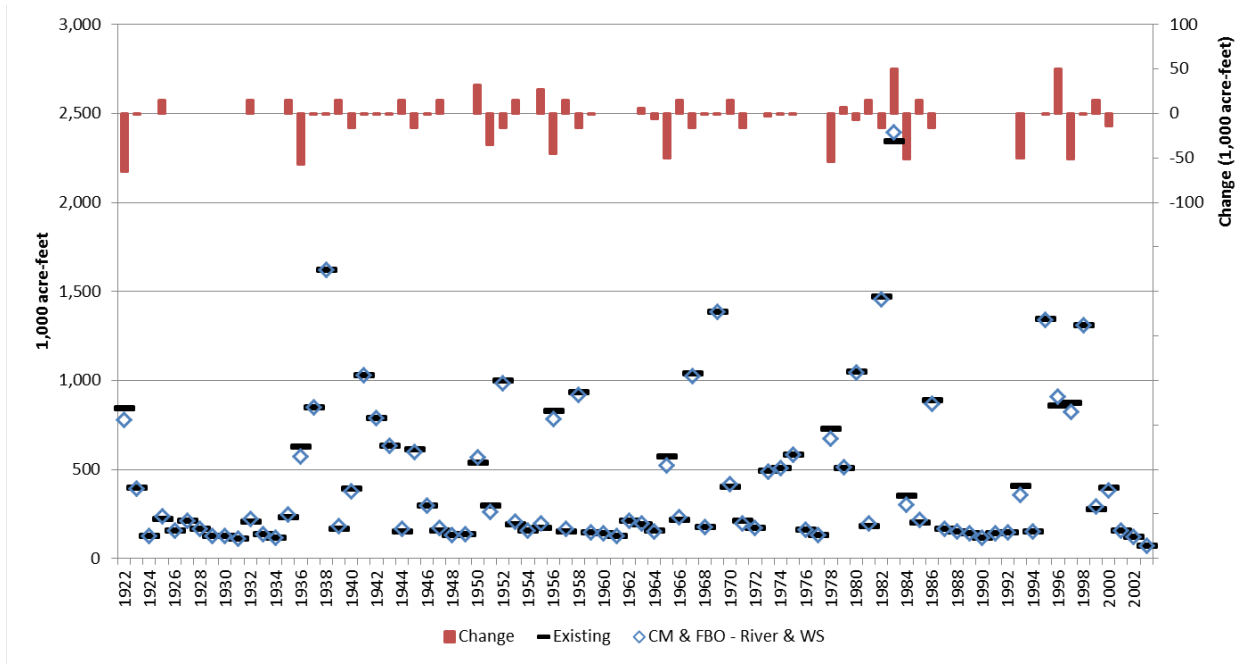


Figure 6-38: Strategy 8: Increased CM & FBO for Ecosystem and Water Supply — Merced River Flows near Cressey

Additional releases from Lake McClure for environmental/water supply do not change the average annual flow in the Merced River, but additional MID surface water deliveries do. Environmental releases increase Merced River flows in May when flows under existing

operations are lower; however, when Lake McClure is making flood control releases, releases for supplemental spring flows are reduced (See Figure 6-38 above).

### 6.3.3 Ecosystem

#### *Ecosystem Effects of Strategy 8: CM & FBO — GW Mngmt*

Ecosystem flows are not a component of Strategy 7, CM & FBO — GW Mngmt. They are, however, a component in the Strategy 8, CM & FBO — River & WS. In Strategy 8, after a 15 taf credit is established in the groundwater system and Lake McClure has refilled, a more aggressive reservoir operation begins, releasing an additional 15 taf annually when surface water is available. This additional 15 taf is released during the spring months to increase flows in the Merced River for ecosystem benefits.

A specific ecological objective for the environmental release was not defined. Instead, it was assumed that a spring release, simulated to occur in May, could provide some ecological benefit. This assumption is based on the historical period for increased San Joaquin River (SJR) tributary flows under the Vernalis Adaptive Management Plan (VAMP) and the State Water Resources Control Board's recent interest in increased SJR tributary flows during the February to June period. Results for a similar volume of release in other spring months are expected to be similar.

Since a specific ecological objective was not defined, there was no effort to shape or disaggregate the monthly volume to a smaller time-step. It is recognized that an additional release may provide an increased ecological benefit if released on a specific pattern, but the pattern has little effect on the metrics evaluated in this analysis. Therefore, it was assumed that the 15 taf was released at a constant rate of approximately 250 cfs for the entire month of May. Changing the pattern of release can affect the ability to meet the dual objectives of ecological benefit and water supply. There is approximately 300 cfs of capacity to divert increased releases from the lower SJR and move the water, either directly or through exchange, into the upper Delta-Mendota Canal. Environmental/water supply releases greater than approximately 300 cfs may exceed the capacity for diversion from the lower SJR, but may still be re-diverted at CVP/SWP Delta export facilities. However, diversions at CVP/SWP Delta export facilities are more constrained by regulatory requirements such that not all of the water may be available for export re-diversion.

### 6.3.4 Flood Protection

#### *Flood Management Effects of Strategies 7 and 8: CM & FBO — GW Mngmt*

Merced ID operates New Exchequer Dam for flood control according to the United States Army Corps of Engineers water control manual. The water control manual includes requirements for a maximum of 350 taf of mandatory rain flood space and recommendations for conditional or snowmelt space based on the forecasted spring runoff.

For the Lake McClure (New Exchequer Dam) reoperation strategies, the use of FBO necessitates changes in flood control operational rules in order to maintain safety. The Water



Control Manual for New Exchequer states that the downstream channel capacity on the Merced River is approximately 6,000 cubic feet per second (cfs). Inflow forecasts for Lake McClure from the National Weather Service's California Nevada River Forecast Center cover a five-day period into the future. Therefore, a maximum release of 6,000 cfs from New Exchequer for a five-day period could evacuate approximately 60 taf of flood space if an inflow forecast showed a significant inflow event on the horizon. In order to simulate FBO for Lake McClure, it was assumed that up to 50 taf of the existing required flood control space could be varied based on future inflow forecasts. The assumption of 50 taf, instead of the full 60 taf, was made to be conservative and provide a buffer against imperfect forecasts. Flood risk is minimized by releasing storage ahead of a forecasted damaging storm. Under Lake McClure FBO, it was assumed that early release would be triggered when the five-day forecasted cumulative inflow volume exceeds 239 taf, which is equivalent to the peak five-day cumulative volume for a 50-year event.

Modeling of the FBO for the 50-year, 100-year, and 200-year events in HEC-ResSim concluded that FBO did not change Lake McClure's operation under the 50-year event, while the 100-year and 200-year events triggered early releases to lower the peak reservoir storage. Therefore, it is concluded that Lake McClure FBO had no change in peak river stage downstream from New Exchequer Dam.

### 6.3.5 Other Effects

#### 6.3.5.1 *Effects on Groundwater and Hydropower: Strategy 7, CM & FBO — GW Mngmt*

For this strategy, additional MID surface water delivery of 15 taf decreases GW pumping by an equivalent volume in 46 of the 82 years simulated. GW pumping increased in simulation year 1934 as a result of additional surface water deliveries made in prior years, making less surface water available in that year. Cumulative reduction in GW pumping over the 82-year period is approximately 850 taf. This long-term reduced pumping is assumed to improve groundwater management in the area.

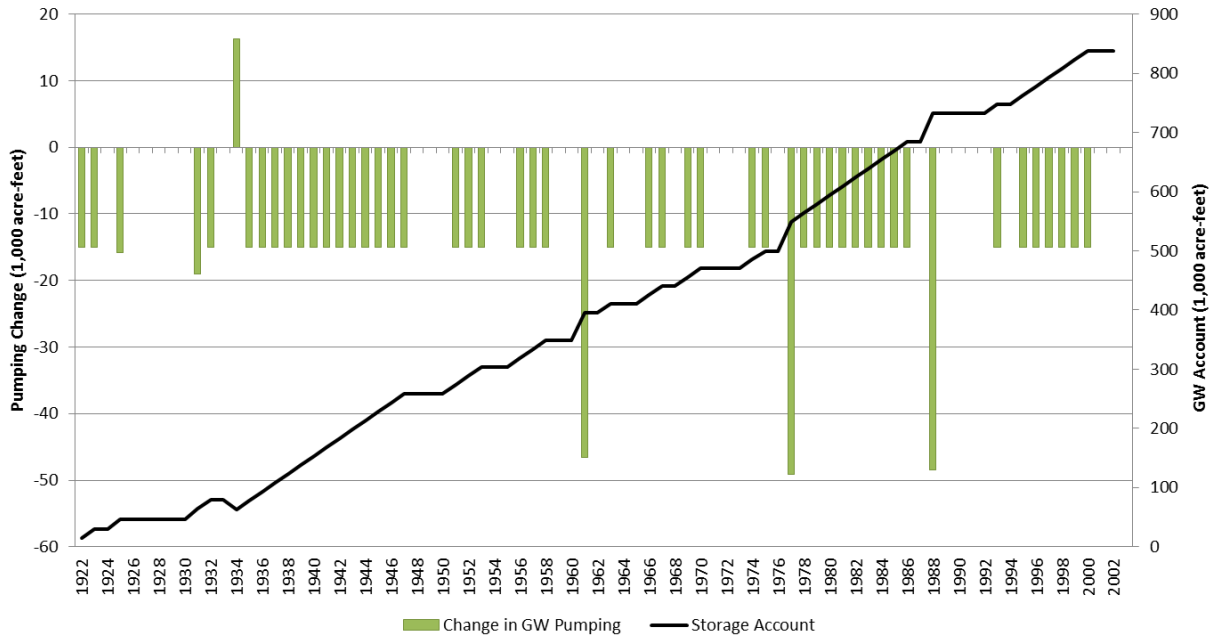


Figure 6-39: Increased CM & FBO for Groundwater Management — Groundwater Summary

Changes in flow regime increase average annual hydropower generation by approximately 3 gigawatt-hours. This strategy’s annual hydropower generation fluctuates between approximately -5 and 35 percent of annual generation under existing operations.

6.3.5.2 *Effects on Groundwater and Hydropower: Strategy 8, CM & FBO — River & WS*

The following highlights are noted to illustrate how the reoperation strategy works over time. In the first year of the simulation, MID delivers 15 taf of additional surface water and establishes a credit of 15 taf in the GW account that can be called upon in future years if Lake McClure is lower than it is under existing operations. In simulation year 1931, FBO provides for additional MID surface deliveries, which reduces GW pumping. In simulation year 1934, GW pumping increases to meet MID demand and compensate for an additional environmental/water supply release made in 1932. GW pumping is reduced in 1961, 1977, and 1988 due to additional storage from FBO, which also provided additional surface water deliveries in these years.

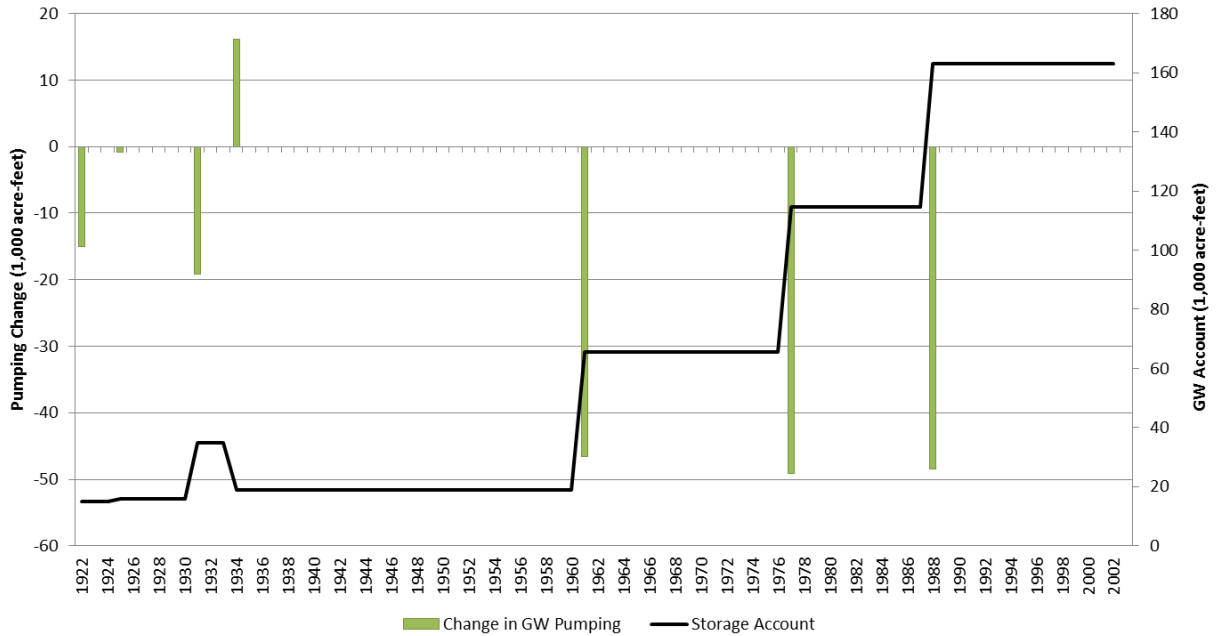


Figure 6-40: Increased CM and FBO for Ecosystem and Water Supply — Groundwater Summary

Changes in flow regime increased average annual hydropower generation by approximately 3 gigawatt-hours under this strategy. Changes in annual hydropower generation fluctuate between approximately -5 and 35 percent of annual generation under existing operations.

### 6.3.6 Uncertain Futures: Climate Change Considerations

As was done for the modeling of Shasta Lake and Lake Oroville reoperations, a climate change assessment of Lake McClure reoperations was performed to better understand the magnitude of these potential effects, and how the proposed reoperation strategies will perform under a range of climate change scenarios.

The analysis for the MID system also applied downscaled BDCP General Circulation Models for climate change. Specifically, this study applies ELT Q5, LLT Q2, LLT Q4, and LLT Q5 climate change assumptions to the Merced River. The two Q5 scenarios serve as median climate projections that bookend the range of potential climate change in the early long term (year 2011 to 2040) and late long term (year 2046 to 2075).

For this assessment, it was assumed that requirements that are currently based in part on inflow, such as minimum instream flow requirements in MID’s existing FERC license or water right agreements for downstream users, would not change as a result of changes in inflow to Lake McClure. No changes were assumed for flood space requirements, irrigation demands, minimum pool requirements, or minimum flow requirements (such as the Davis-Grunsky Act Contract). It was assumed that all existing regulatory requirements would remain in place in future climate-changed conditions to provide a standard basis of comparison against non-climate changed strategies.

This analysis evaluates how expanding MID’s current conjunctive management programs by up to 15 taf annually, in combination with FBO for the purpose of increased Merced River flow and water supply, may operate with climate change. The following table summarizes the climate change scenarios modeled. Each climate-change scenario applies the reoperation assumptions from the Lake McClure reoperation strategy CM & FBO — River & WS (Increased Conjunctive Management and Forecast-Based Operations for Ecosystem and Water Supply).

Table 6-14. Merced River (Lake McClure) Climate Change Scenario and Reoperation Strategy Assumptions

	Strategy 8 CM & FBO — River & WS w/ELT-Q5	Strategy 8 CM & FBO — River & WS w/LLT-Q2	Strategy 8 CM & FBO — River & WS w/LLT-Q4	Strategy 8 CM & FBO — River & WS w/LLT-Q5
BDCP Climate Model Analyzed (Timeline of Analysis)	<i>Drier, less warming (2011 to 2040)</i>	<i>Drier, more warming (2046 to 2075)</i>	<i>Wetter, less warming (2046 to 2075)</i>	<i>Median warming and wetness (2046 to 2075)</i>
Merced River CM Operations	<i>+15 taf, when available, to establish a groundwater credit.</i>			
	<i>+15 taf, when available, the credit above is used for ecosystem flows and water supply.</i>			
Purposes of Merced River CM	<i>To establish a groundwater credit and provide flows for ecosystem and water supply after a credit is established.</i>			
Lake McClure Drawdown Limit	<i>15 taf.</i>			
Forecast-Based Operations	<i>Up to 50 taf encroachment in reservoir.</i>			
Flood Hazard Reduction	<i>Advance releases ahead of a damaging storm.</i>			

The first step in this analysis is to determine the range of climate-changed hydrology on the Merced River and compare it with historical hydrology. Figure 6-41 compares average annual inflow to Lake McClure by San Joaquin Valley Water Year Type for the historical hydrology and the four climate change scenario projections.

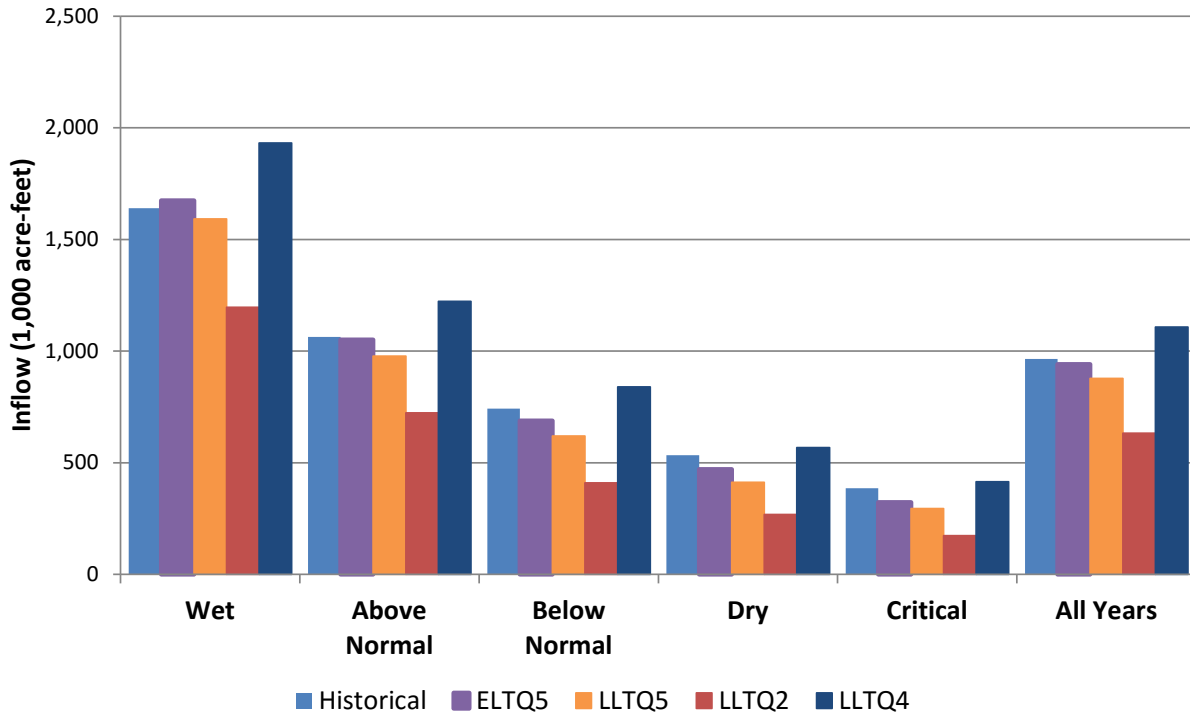


Figure 6-41: Avg. Annual Lake McClure Inflow by San Joaquin Water Year Type

Note: For this graphic, the San Joaquin Valley Water Year Type is based only on historical hydrology, i.e., it is not recalculated for the climate-changed hydrology so that the average annual inflow by year type is calculated from the same years for all scenarios.

Modeled average annual inflows display several noteworthy trends. Q5 projections at both the ELT and LLT have relatively small changes in average annual inflow in wetter years, but relatively larger reductions in drier-year inflow. LLT Q2 projections show significantly less inflow in all year types, with the largest volumetric reductions in wet years (approximately 440 taf), but the largest percent reduction from existing hydrology in dry and critical years (approximately 50 percent). LLT Q4 projections show increases in average annual inflows across all years; however, the majority of the increases come in wetter years when Lake McClure typically fills and spills under existing operations and historical hydrology. This can indicate that additional inflow will result in increased spill, but not necessarily increased water supply. Increases in dry and critical year inflow under LLT Q4 are smaller in terms of both the volume and the percentage increase from historical hydrology.

The second step in this climate change analysis is to use the projected climate-change average annual inflows (above) to create baseline scenarios that evaluate the range of effects from climate change on current operations. Establishing these baselines allows quantification of the effects of reoperation with climate change. The range in climate-changed hydrology illustrates that availability of surface water for MID may decrease significantly or potentially increase slightly, with corresponding changes in carryover storage, hydropower generation, and flows downstream (see Table 6-15).

Table 6-15. Baseline Climate Change Scenarios - Average Annual Changes in Merced River Operations

	MID Surface Water Delivery (taf)	MID SOI Surface Water Delivery (taf)	Lake McClure Carryover Storage (taf)	Merced River Project Hydro. Generation (GWHRs)	Merced River Flow near Cressey (taf)
Baseline Hydrology (No Climate Change)	414	14	507	349	447
	Change from Existing (Baseline) Hydrology.				
Base ELT Q5	-14	-1	-47	-18	-4
Base LLT Q2	-122	-6	-232	-150	-182
Base LLT Q4	+7	0	+23	+36	+133
Base LLT Q5	-27	-2	-106	-47	-47

Under baseline scenario LLT Q2, there are significant reductions in deliveries in approximately 40 percent of simulated years and carryover storage is at or near the current regulatory minimum pool of 115 taf approximately 55 percent of the time. Conversely, under the LLT Q4 scenario of wetter, less warming conditions, MID water supply may improve when compared to the historical hydrology. However, the median scenario (LLT Q5) from the range of potential future climate change projections shows more frequent reductions in MID surface water deliveries and significantly lower carryover storage in approximately 65 percent of all years at both the ELT and LLT horizons.

The final step in this climate change analysis is to model the four climate-changed inflows under the reoperation assumptions of Strategy 8: CM & FBO — River & WS (Increased Conjunctive Management and Forecast-Based Operations for Ecosystem and Water Supply). The effects of climate change on reoperation were determined by comparing climate-changed reoperation scenario performance against its respective baseline. Table 6-16 summarizes annual changes in water deliveries, carryover storage, hydropower generation, Merced River flow, and ecosystem releases for each climate-change scenario. Results for the No Climate Change hydrology are presented in Section 6.3.1 for Strategy 8: CM & FBO for river flows and water supply. Accordingly, these results are again included here for comparison with results from the climate-changed scenarios.

Table 6-16. Summary of Average Annual Change in Key System Metrics for Climate Change Scenarios and CM & FBO for River and non-MID Water Supply

Reoperation Strategy 8: CM & FBO — River & WS (with Climate Scenario as described below)	MID Surface Water Delivery (taf)	MID SOI Surface Water Delivery (taf)	Lake McClure Carryover Storage (taf)	Merced River Project Hydro. Generation (GWHrs)	Merced River Flow near Cressey (taf)	Additional Release for CM or River & Water Supply (taf)	Number of Years with Additional Release*
<i>Presented as changes from baseline scenarios (As shown in Table 6-15)</i>							
No Climate Change	+2	0	+35	+2	-3	+4	23
(w/ELT Q5)	+1	+1	+30	+1	-4	+3	18
w/LLT Q2	+3	0	+13	+1	-4	+2	11
w/LLT Q4	+2	+1	+34	0	-3	+4	23
w/LLT Q5	0	+1	+26	+1	-2	+3	19

\*Number of years includes both conjunctive management releases to establish GW credit and environmental/water supply releases.

The results of modeling illustrate that a combined reoperation strategy of FBO, a groundwater reserve, and more aggressive reservoir operations create similar changes in performance with climate-changed hydrology as with the historical hydrology. Reoperation provides a small increase in average annual water supply and higher carryover storage in Lake McClure. There are minimal changes in average annual hydropower generation. Average annual Merced River flow decreases, but there is an increase in spring flows (provided by the supplemental spring flow) which may create an environmental benefit. There is a reduction in the frequency of additional conjunctive management and environmental/water supply releases under the Q2 and Q5 climate change scenarios. This occurs because there is less inflow to Lake McClure and lower storage under these scenarios and therefore less water available for making these discretionary releases.

#### 6.4 Increased Integration of SWP and CVP Strategy

Review of historical operations clearly demonstrates that the CVP and SWP are currently operated in an integrated manner, as described in the COA. Even though the projects are operated in an integrated manner, it is possible to increase water supply and ecosystem benefits by operating both projects as a single project. Therefore, a modeling analysis was performed to estimate the potential benefits from operating the CVP and SWP as a single project.

The basic premise of this analysis is to treat CVP and SWP exports as a single project diversion and balance upstream project reservoirs as though they belong to the same project rather than assign release responsibility based on the COA. For the purposes of this analysis, CVP and SWP export operations are combined, and changes in exports cannot be attributed to either project, only as a total. Currently, each project’s obligation to satisfy Delta requirements is determined by COA sharing; in this analysis, a reservoir’s release obligation is determined based on the status of each reservoir relative to the status of all project reservoirs and system-wide conditions.

The objective of the single project integrated reoperation analysis is to improve ecosystem function and habitat conditions and improve the reliability of municipal and irrigation water

supply. The primary improvement to the ecosystem is generated by rebalancing reservoir release obligations to protect reservoir cold water pools, river temperature, and changes in annual and seasonal river flow regimes. Water supply benefits are increased by expanded use of JPOD and changes in upstream releases made possible by JPOD and reservoir balancing. It is expected there will be little reduction of flood hazards through this type of reoperation.

Operating the CVP and SWP as a single project increases operational flexibility, allowing operators to more easily rebalance system benefits. In addition to reallocating reservoir release obligations, there is increased opportunity to either draw reservoirs down to lower levels to increase average annual water supply, or hold reservoirs higher and decrease average deliveries while increasing dry-year reliability. This tradeoff between higher average annual deliveries and dry-year reliability is formally referred to as *hedging*. Increasing operational flexibility may be the most significant benefit of system integration; however, the benefits derived from this flexibility are dependent on how operators choose to operate. For the purpose of this analysis, hedging rules were used to create a range of potential benefits.

A spreadsheet model using hydrology and operational parameters from CalSim-II was developed to analyze potential benefits of SWP and CVP integration. A baseline operation was developed by operating the model with existing contracts, operational criteria, and COA. Reoperations were evaluated by running the model with existing contracts and operational criteria, and replacing existing COA with integrated operations logic. To derive benefits, alternative model runs were compared to the baseline model. Benefits derived from this analysis may be overstated because the baseline does not account for the level of system integration that already occurs informally in actual operations.

Depending on hedging assumptions, average annual water supply benefits ranged from about 100 taf to 150 taf. Reoperations with more aggressive allocation rules (greater reservoir drawdown) increased yield by about 150 taf; while less aggressive rules, with higher reservoir storage targets, increased yield by just over 100 taf. System integration that increases project yield will likely decrease total upstream reservoir storage (Trinity, Shasta, Oroville, and Folsom) in all but the driest of years. This is a result of the increased ability to deliver additional supplies through JPOD and integrated reservoir operations. Increased reservoir drawdown in wet years is minimal because of the surplus conditions prevalent in these years. In above-normal, below-normal, and dry years, total reservoir drawdown ranges from about 100 taf to 150 taf because of JPOD and reservoir integration. In critical years, when upstream ecosystems are in need, total reservoir storage increases ranged from about 20 taf to 300 taf, depending on hedging rules. With increased flexibility for reservoir balancing, there are increased storage levels when specific reservoirs reach low levels. These increases in storage during dry hydrologic conditions are likely to benefit instream temperature conditions below the dams.



### 6.5 Modeling Results Summary

This section summarizes the modeling results from the Shasta Lake reoperation, Lake Oroville reoperation, combined Shasta Lake and Lake Oroville reoperation, and Lake McClure reoperation. Detailed discussion on the modeling and findings of these SRS strategies can be found in sections 6.2 and 6.3, respectively. Tabulated results for the SWP/CVP integration strategy are not provided here because the modeling results may be overstated when considering that baseline modeling for this strategy does not reflect the level of system integration that occurs in actual operations. Please refer to Section 6.4 for discussion of the results of this Strategy.

**Table 6-17. Summary of Reservoir Reoperation Strategies**

Strategy	Reservoir(s) Reoperated	Sacramento River Spring Pulse <sup>1</sup>	Feather River Spring Pulse <sup>1</sup>	Operations of North Delta Diversion (NDD)	Sacramento River Basin CM <sup>2</sup>	Feather River Basin CM <sup>2</sup>	Merced River CM <sup>2</sup>	Forecast Based Operations	Flood Hazard Reduction	
	Shasta	50 taf 200 taf	No Pulse.	No NDD.	50 taf 100 taf	No CM.	No CM.	Up to 25% encroachment in reservoir flood space.	Advance releases ahead of a damaging storm <sup>3</sup> .	
	Oroville	No Pulse.	50 taf 200 taf		No CM. 100 taf	50 taf 100 taf				
	Shasta + Oroville (w/FBO at Folsom)	50 taf	50 taf		50 taf	50 taf	No CM.	Up to 25% encroachment in reservoir flood space.	Advance releases ahead of a damaging storm <sup>3</sup> .	
				As described in BDCP EIR/EIS.						
				As described in BDCP EIR/EIS + no ecosystem pulses.						
			150 taf	150 taf	As described in BDCP EIR/EIS + all ecosystem pulses.	100 taf				100 taf
					No NDD.					
ELT-Q5*										
LLT-Q2*										
LLT-Q4*										
LLT-Q5*										
CM & FBO — GW Mngmt							+15 taf to offset groundwater pumping.			
CM & FBO — River & WS							+15 taf to establish a groundwater credit.			
CM & FBO — River & WS w/ELT Q5	Lake McClure	N/A	N/A	N/A	N/A	N/A	+15 taf for ecosystem flows and water supply after a groundwater credit is established.	Up to 50 taf encroachment in reservoir.		
CM & FBO — River & WS w/LLT Q2										
CM & FBO — River & WS w/LLT Q4										
CM & FBO — River & WS w/LLT Q5										

<sup>1</sup> Supplemental Spring Flows are defined as a targeted volume from March to May. These volumes are not necessarily provided every year.

<sup>2</sup> Conjunctive management is defined as an annual volume from May to August. Pumping is typically at these levels during Dry or Critical years as defined by the Sacramento River Index (SRI).

<sup>3</sup> Flood hazard reduction scenarios are studied in this phase, but are performed in a separate analysis.

Table 6-18. Modeling Results Summary — Shasta Lake and Lake Oroville Reoperation

	Shasta Reservoir Reoperation				Oroville Reservoir Reoperation			Oroville-Shasta Combine Reoperation (w/FBO at Folsom)		
	Baseline	Baseline + FBO	Strategy 1	Strategy 2	Baseline + FBO	Strategy 3	Strategy 4	Baseline + FBO	Strategy 5	Strategy 6
	Annual Volume (taf)	Change in Volume Compared to Baseline (taf)								
Target Additional Pulse Volume	--	--	50	200	--	50	200	--	100	300
Target Additional CM Volume	--	--	50	100	--	50	100	--	100	200
Supplemental Spring Flows	--	--	21	62	--	9	33	--	29	80
Expanded Groundwater Pumping	--	--	9	19	--	18	35	--	27	55
Shasta Avg. Annual EOS Storage	2,660	48	45	38	0	1	6	53	60	51
Trinity Avg. Annual EOS Storage	1,401	6	4	-8	-2	-1	-1	5	6	-2
Folsom Avg. Annual EOS Storage	519	3	6	1	0	1	3	15	15	16
Oroville Avg. Annual EOS Storage	1,713	-17	-20	-20	14	15	8	-12	-10	-10
Avg. Annual Delta Inflow from Sac. River	17,854	-11	1	14	0	17	34	-17	9	39
Avg. Annual Delta Outflow	15,644	-13	-6	11	-5	2	19	-25	-8	12
Avg. Annual Flow to Jones Pumping Plant	2,247	7	9	8	0	1	-3	10	14	14
Avg. Annual Flow to Banks Pumping Plant	2,738	-4	-2	-5	5	14	17	-3	3	12
Avg. Annual CVP Deliveries (Agricultural/Municipal/Industrial)	440	7	8	6	0	0	0	12	12	11

Table 6-19. Modeling Results Summary — Strategy 6, Oroville-Shasta Combine and Uncertain Futures (BDCP & Climate Change Scenarios)

	Oroville-Shasta Combine Reoperation (w/FBO at Folsom)												
	Baseline (No BDCP)	Strategy 6	BDCP ANALYSIS			CLIMATE CHANGE ANALYSIS							
	Annual Volume (taf)	Change from Baseline (taf)	Strategy 6A	Strategy 6B	Strategy 6C	Base ELT-Q5	Strategy 6-ELT-Q5	Base LLT-Q2	Strategy 6-LLT-Q2	Base LLT-Q4	Strategy 6-LLT-Q4	Base LLT-Q5	Strategy 6-LLT-Q5
			Change from Baseline (taf)			Annual Volume (taf)	Change from Base ELT-Q5	Annual Volume (taf)	Change from Base LLT-Q2	Annual Volume (taf)	Change from Base LLT-Q4	Annual Volume (taf)	Change from Base LLT-Q5
Target Additional Pulse Volume	--	300	300	300	300	--	300	--	300	--	300	--	300
Target Additional CM Volume	--	200	200	200	200	--	200	--	200	--	200	--	200
Supplemental Spring Flows	--	80	73	74	73	--	75	--	48	--	93	--	74
Expanded Groundwater Pumping	--	55	43	39	43	--	74	--	123	--	57	--	90
Shasta Avg. Annual EOS Storage	2,638	51	23	20	27	2,463	12	1,731	47	2,622	-5	2,233	23
Trinity Avg. Annual EOS Storage	1,397	-2	-5	-7	-4	1,280	-1	843	29	1,444	-11	1,719	2
Folsom Avg. Annual EOS Storage	518	16	5	2	6	465	6	347	-1	462	4	408	-5
Oroville Avg. Annual EOS Storage	1,766	-10	13	6	17	1,541	42	1,200	70	1,616	16	1,382	63
Avg. Annual Delta Inflow from Sac. River	17,868	39	-1	-1	-2	18,085	54	15,490	66	20,800	43	18,080	57
Avg. Annual Delta Outflow	14,671	12	-68	-54	-86	16,101	9	13,531	-7	19,222	4	16,257	-13
Avg. Annual Flow to Jones Pumping Plant	2,446	14	41	28	52	2,124	12	1,716	26	2,212	5	1,986	21
Avg. Annual Flow to Banks Pumping Plant	3,522	12	25	23	30	2,659	31	2,227	46	2,744	34	2,478	46
Avg. Annual CVP Deliveries (Agricultural/Municipal/Industrial)	454	11	7	6	7	401	11	287	13	464	6	368	15

Note: The BDCP and Climate Change scenarios employ the reoperation assumptions from Strategy 6.

Table 6-20. Modeling Results Summary — Lake McClure Reservoir Reoperation, Including Climate Change Considerations

	Baseline Conditions	Strategy 7 CM & FBO — GW Mngmt	Strategy 8 CM & FBO — River & WS	CLIMATE CHANGE ANALYSIS							
				Base ELT Q5	Base LLT Q2	Base LLT Q4	Base LLT Q5	Strategy 8 w/ELT Q5	Strategy 8 w/LLT Q2	Strategy 8 w/LLT Q4	Strategy 8 w/LLT Q5
		<i>Changes from Baseline Conditions</i>		<i>Changes from Baseline Conditions</i>				<i>Changes from Baseline Conditions</i>			
MID Surface Water Delivery (taf)	414	+2	+2	-14	-122	+7	-27	+1	+3	+2	0
MID SOI Surface Water Delivery (taf)	14	+9	0	-1	-6	0	-2	+1	0	+1	+1
Lake McClure Carryover Storage (taf)	507	+34	+35	-47	-232	+23	-106	+30	+13	+34	+26
Merced River Project Hydro. Generation (GWhrs)	349	+2	+2	-18	-150	+36	-47	+1	+1	0	+1
Merced River Flow near Cressey (taf)	447	-12	-3	-4	-182	+133	-47	-4	-4	-3	-2
Additional Release for CM or River & Water Supply (taf)	N/A	+8	+4	N/A	N/A	N/A	N/A	+3	+2	+4	+3
Number of Years with Additional Release	N/A	46	23*	N/A	N/A	N/A	N/A	18	11	23	19

**Note:** The Climate Change scenarios employ the reoperation assumptions from Strategy 8 CM & FBO — River & WS reoperation.  
 \*Number of years include both conjunctive management releases to establish GW credit and environmental/water supply releases.

## 6.6 Ecosystem Results

### Shasta Lake and Lake Oroville

**Baseline Conditions Results:** Results showed that baseline conditions do not achieve TTFs for 24 of 31 ecosystem metrics. Juvenile salmonid growth, spawning, and growth flows have TTFs of 67 percent (two out of every three years), yet baseline conditions did not meet TTFs (range: 1 percent for flows into Yolo Bypass to benefit spring-run salmon, up to 54 percent for in-river flows to benefit winter-run spawning). Salmonid juvenile thermal stress has a TTF of 33 percent, yet baseline conditions are 31 percent. Cottonwood initiation flows have a TTF of 12 percent (one out of every eight years), yet baseline conditions are only 1 percent. Geomorphic process flows have TTFs of 33 percent (one out of every three years), yet baseline conditions are only 16 percent for a 14-day flow duration, 22 percent for a seven-day duration, and 29 percent for a three-day duration.

In contrast, three of 31 metrics achieved TTFs with baseline conditions (the four Delta metrics, including salvage of delta smelt and longfin smelt, do not have TTFs). Geomorphic process flows for a one-day duration (36 percent) exceeded the 33 percent TTF. Salmonid predation risk (45 percent) exceeded the 33 percent TTF. Bank swallow nest inundation avoidance (100 percent) exceeded the 33 percent TTF.

**Reoperation Strategy Results:** The Shasta Lake and Lake Oroville reoperation strategies provided up to 80 taf of supplemental spring flows (Table 6-7) but yielded only minor improvements in specific ecosystem metrics compared with baseline model runs (see Appendix D, Table 10). Most improvements in ecosystem metrics showed very small (< 3 percent) increases in the frequency with which important ecological flow conditions are improved. Also, results showed that the small benefits from the supplemental spring flows to some ecosystem metrics may be associated with negative impacts to other ecosystem metrics. For example, three metrics that showed slight benefits included salmonid predation risk (up to 3 percent), winter-run rearing (up to 2 percent), and steelhead spawning habitat (up to 6 percent). In contrast, fall run spawning showed a decreasing trend (<6 percent decline) relative to baseline.

The negligible increase in winter-run rearing (up to 2 percent) occurred despite CalSim-II modeling results that showed end-of-September storage improvements of up to 51 taf in Shasta Lake (Table 6-7).

### Merced River (Lake McClure)

For the Merced River (Lake McClure) analysis, ecosystem flows are one component of Strategy 8 CM & FBO — River & WS. The ecosystem analysis contained in Appendix D does not include analysis of the effects and benefits of Merced River reoperation. As part of the CM & FBO — River & WS strategy, 15 taf is released during spring months to increase flows in the Merced River for ecosystem benefits. An exact ecological objective for the environmental release was not defined. Instead, it was assumed that a spring release, simulated to occur in May, would provide some ecological benefit. This assumption is based on the historical period for increased San Joaquin River (SJR) tributary flows under the Vernalis Adaptive Management Plan (VAMP)

and the State Water Resources Control Board's recent interest in increased SJR tributary flows during the February to June period.

Uncertain future scenarios, including potential new Delta conveyance and climate change scenarios, were not evaluated using the ecosystem analytical tools. Also, the analysis of SWP and CVP Integration did not include an ecosystem objective.

## Chapter 7. REOPERATION TECHNIQUES CURRENTLY BEING APPLIED BY THE CENTRAL VALLEY PROJECT AND STATE WATER PROJECT

Historical operations were assessed to identify periods where reoperation components associated with Phase III SRS are already being employed by operators to improve system performance. This review focused on use of forecast-based operations as well as integrated operations of the SWP and CVP, as presented in this Phase III SRS.

### 7.1 Assessment of Historical Operations at Shasta, Oroville, and Folsom Dams

For FBO, our approach analyzes how encroached flood space was used in Shasta Lake, Lake Oroville, and Folsom Lake for the past 15 years and whether the encroachment was used for flood control, water supply conservation, or other beneficial uses. Once the purpose for the release is identified, it is compared against the operation strategies proposed by the SRS. The SRS approach to FBO includes using the flood control pool to hold additional water to enhance water supply or ecosystems, and evacuating the flood pool when a flood damaging inflow is forecast. This review is made in hindsight and Delta excess or balanced conditions are considered in this assessment.

Analysis of historical operations reveals that the CVP and SWP occasionally hold water in the flood control pool in a manner similar to the one detailed in this SRS. However, historical operations indicate that smaller flood encroachments and releases are more typical under the prescribed rules taken from the CVP or SWP water control manuals. Water is evacuated during periods when the Delta is in excess condition, and so releases were not made for beneficial use. Under the proposed FBO strategy, water is held in storage during the winter and spring. Conversely, if encroached water is held through the spring and into the summer, hydropower operations will more likely coincide with other beneficial uses; whereas historically, this water was evacuated during times when the Delta was in excess and downstream needs and requirements were already fully met.

#### 7.1.1 Shasta Dam Historical Operations

Lake Shasta conservation pool volume is established by using the accumulation of seasonal inflow. If accumulated seasonal inflow is less than 110,000 cfs by March 20, then there will be no flood control reservation after March 20th. This allows the conservation pool to fill the entire reservoir during low runoff years. If accumulated seasonal inflow exceeds 530,000 cfs, then the flood control reservation is required until June 15th. Determining whether these conservation pool operations are employed is based on observed inflow and not on forecasts.

In an analysis performed as part of the Yuba-Feather Forecast Coordinated Operations (FCO) and the *Folsom Dam Water Control Manual* update, an ensemble of historical basin conditions

was used to produce a series of five-day runoff forecasts for Shasta Lake. This was done to characterize the range of inflow that the forecast models would produce. A relationship between observed five-day inflow and forecast five-day inflow was developed and can be used to summarize the uncertainty in a five-day forecast. Figure 7-1 illustrates this relationship.

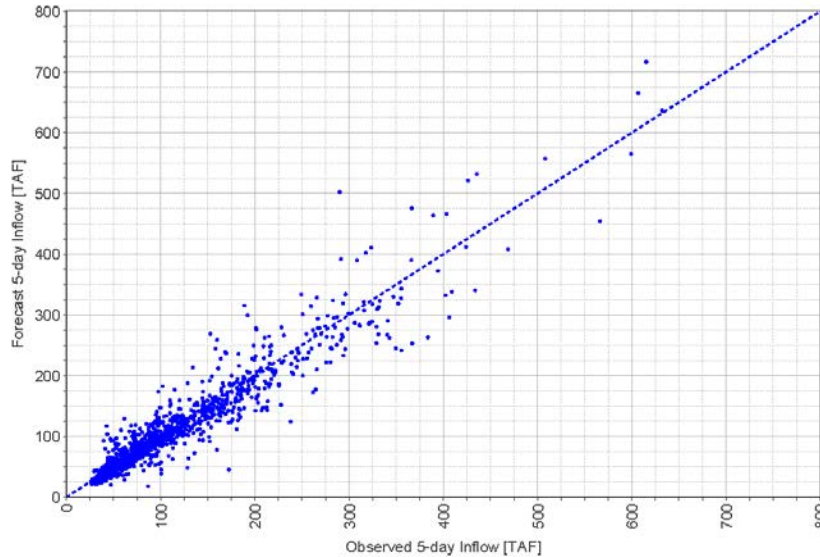


Figure 7-1: Observed versus Forecast Inflow in Shasta Lake

The relationship reveals that there is a high correlation between forecast five-day inflows and observed five-day inflows. Based on this correlation, analysis of historical operations reveals four periods from 2000 to 2015 with the potential for using FBO as proposed in this Phase III SRS. These periods are identified in March 2000, late February to early March of 2004, mid-December to January of 2011, and early April 2011.

### 7.1.2 Oroville Dam Historical Operations

The State Water Project does not separate daily releases by powerhouse, spills, or outlets at Lake Oroville. Thermalito power canal has a channel capacity of 16,900 cfs. Using the operations of April 1, 2012 to May 1, 2012 as example operations, this event similarly aligns with how the SRS will hold water in the flood pool during periods of low inflow. The Delta was in excess conditions and water was held in the flood pool for about a month. On average, the flood control pool was encroached by about 10 percent for the month of April. At the end of May, the entire reservoir became the conservation pool. In contrast to this operation, the SRS would take more risk by allowing 25 percent of the flood space to hold water for beneficial uses. Further, if encroached water from reoperation is held through the spring and into the summer, hydropower operations will more likely coincide with other beneficial uses.

### 7.1.3 Folsom Dam Historical Operations

Folsom Dam provides flood protection to urban areas in and surrounding Sacramento. Operators may be apprehensive about using encroached flood space for purposes other than



flood control because there is insufficient release capacity to evacuate the reservoir in a reasonable forecast window. However, after the completion of the Joint-Federal Project (JFP) spillway, release will not be as constrained. Therefore, this analysis summarizes historical operations and evaluates how operations may have differed under system reoperation, while assuming Folsom Dam will have the release capacity from the JFP.

Folsom Lake operates by holding water in the flood pool during the spring and making releases for power production. This encroached volume is typically less than 100 taf. By May, the operable portion of the reservoir is reserved for conservation, and water that is held in the flood pool during the winter and early spring becomes part of the conservation pool.

Historical opportunities for Folsom FBO operation are limited due to the constrained release capacity described above. However, the release capacity offered by the JFP could allow additional opportunities to hold water in the flood control space. The SRS proposes using 25 percent of the allocated flood space to hold water for purposes other than flood control.

This assessment has confirmed that some FBO concepts are already used in real-time operations, usually at a lesser scale than proposed by SRS. Since operations analyses assume that each reservoir is operated according to its respective water control manual, the quantity of benefits that would result from implementation of FBO is probably less than that shown in the SRS evaluations.

## 7.2 Historical CVP/SWP Integration Operations

Review of historical operations provides insight into how the two projects operate in an integrated manner, and how they may have been able to operate more efficiently. The focus of this assessment is historical sharing of Delta export facilities and sharing of reservoir release obligations. To perform this assessment, historical project operations data was collected and evaluated. Evaluation of the historical data can inform how the projects have operated in an integrated fashion, and speculate how they may have been able to increase benefits.

With highly variable hydrology, changing regulatory conditions, and nuances specific to each year of operation, it is difficult to interpret historical operations data and speculate how operators could have operated more efficiently. Therefore, it is important to consider that speculating how operators could have been more efficient is done without knowing all of the constraints and considerations that existed historically. Consequently, this evaluation may overestimate efficiency gains or benefits of more integrated operations.

### 7.2.1 Historical Sharing of Delta Export Facilities

Sharing of Delta export facilities has occurred frequently since both the SWP and CVP began operation in the early 1970s. Because the SWP export facility (Banks Pumping Plant) has more capacity than the CVP facility, most of the export sharing in the past has been done by the CVP

using SWP facilities to convey CVP supplies. Sharing of Delta export facilities is commonly known as Joint Point-of-Diversion (JPOD).

Prior to the mid-1990s, federal pumping at Banks occurred in significant quantities in most years, but has decreased considerably as regulatory requirements have increased. In addition to the CVP using SWP Banks to convey supplies to contractors from the Delta-Mendota Canal and the California Aqueduct, the SWP conveys CVP water to the Cross Valley Canal (CVC); the quantity of CVC water exported at Banks is displayed in Figure 7-2. Although CVC exports at Banks comprise an important water supply, additional deliveries to CVC contractors are not considered in this analysis.

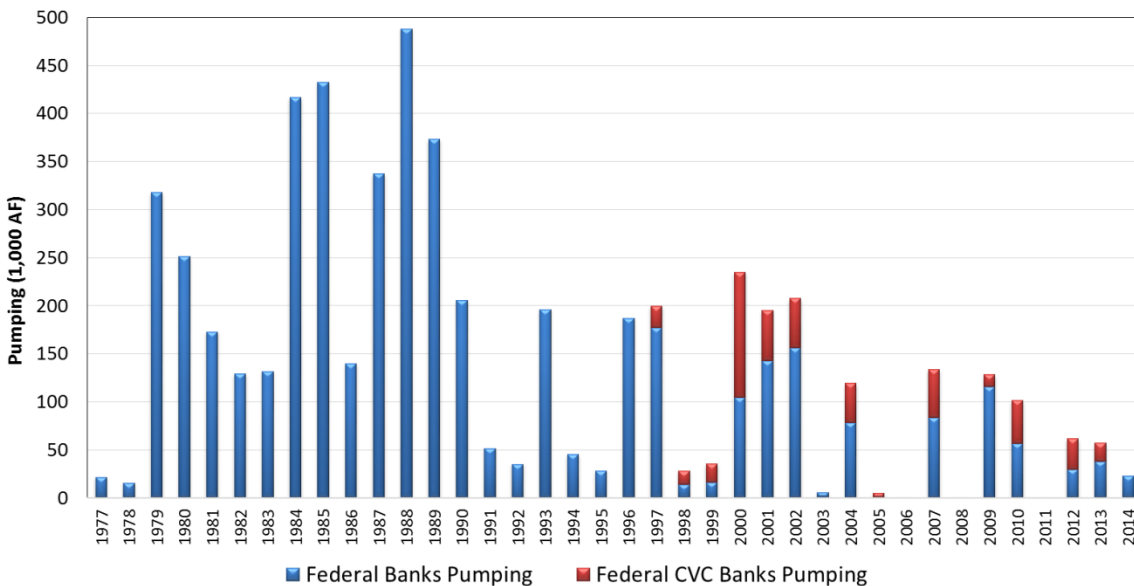


Figure 7-2: Historical JPOD — Federal Pumping at Banks Pumping Plant

The opportunity to increase Delta exports through export sharing can be estimated by assessing historical unused capacity at Banks. Figure 7-3 shows historical annual pumping at Banks and unused capacity from 1985 to 2014. Unused capacity is tabulated for July to October because this is when JPOD may have been used. In many years, there has been available capacity to export additional supply from the Delta.

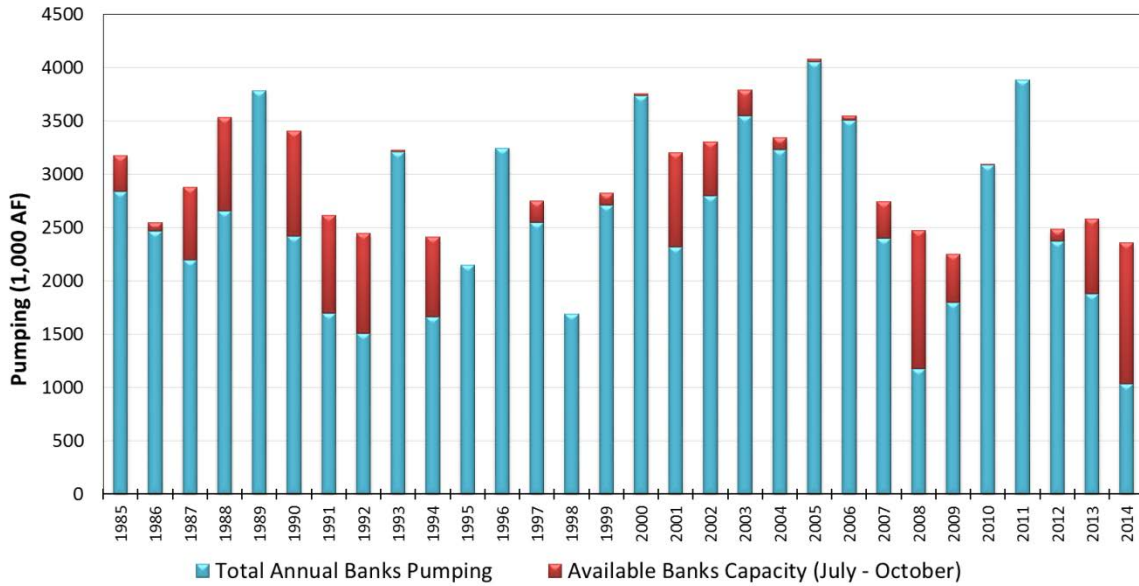


Figure 7-3: Banks Pumping and Available Capacity

The ability to export additional supply is a key component in estimating how much JPOD use could have been expanded historically, but availability of supply must also be considered. Estimation of available water supply can be made by taking historical carryover storage in upstream CVP reservoirs and assuming they could have been drawn to lower levels to increase water deliveries. Figure 7-4 and Figure 7-5 contain a chart of historical end-of-September (carryover) storage in Shasta Lake and Folsom Lake, respectively. Available supply is estimated by assuming that when Shasta Lake carryover was above 3 maf and Folsom Lake carryover was above 450 taf, that these reservoirs could be drawn down to increase water deliveries. The volume of available supply is shown in Figures 7-4 and 7-5 as red bars.

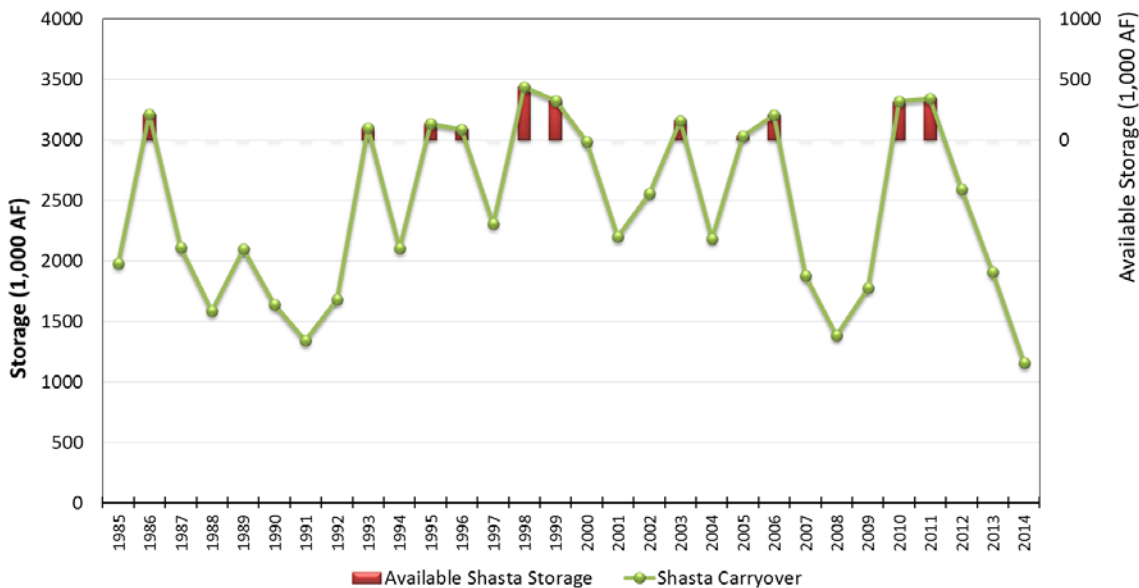


Figure 7-4: Historical Shasta Lake Carryover and Potential Available Supply

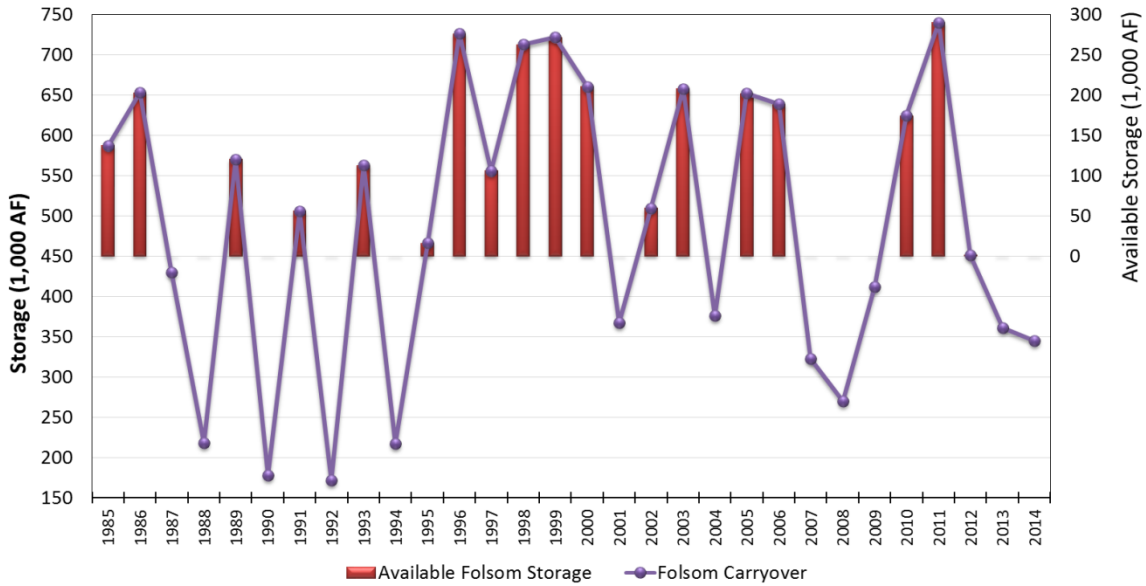


Figure 7-5: Historical Folsom Lake Carryover and Potential Available Supply

Additional historical JPOD use may be estimated by taking the minimum of unused JPOD export capacity and supply available in both Shasta and Folsom lakes. Review of the data shows that there was a potential to increase average annual exports by about 31 taf. This value does not consider south-of-Delta conditions, need for additional supply, or numerous other factors operators must consider.

### 7.2.2 Historical Sharing of Reservoir Release Obligations

Sharing of reservoir release obligation occurs when one of the CVP or SWP reservoir releases are constrained, resulting in one of the projects either falling short or exceeding their obligation of shared system flow requirements. When this occurs, COA debt or credit is established between the projects that must be paid back in the future. In the history of the projects, this has occurred many times due to facility outages, flow constraints for environmental protections, and basic release scheduling. Accumulated COA debt can be short-term between both projects, with small volumes accruing over several months into a debt in excess of 100 taf. The design of COA accounting and ability to incur debt is a basic tool in the COA to allow operators the flexibility to operate more efficiently. The reasons for historical COA debt are difficult to determine from publically available records. However, there are clear examples of COA debt being incurred to protect environmental conditions, such as occurred during the spring and summer of 2015.

During the spring and summer of 2015, there was concern that temperatures in the Sacramento River below Keswick would be too high to protect the endangered winter-run Chinook salmon. Regulators and operators agreed to limit releases from Shasta Lake during this period. Consequently, the CVP could not meet its portion of shared Delta outflow requirements. SWP

operators responded in two ways: (1) by exporting less from the Delta, and (2) increasing releases from Lake Oroville to meet the unmet CVP share of Delta outflow. From late March to mid-June, Lake Oroville releases increased while Shasta Lake releases were capped. The CVP incurred over 100 taf of COA debt that could not be made up from Folsom Lake or Trinity Lake releases or from reduced CVP exports. This is an excellent example of debt operations within the bounds of COA for the purpose of protecting environmental conditions.

Again, this assessment has confirmed that the integration of the SWP and CVP operations, similar to the reoperation component described in this SRS Phase III, is already being used by operators. And like the FBO operations, this integrated operation has historically been used in a more limited way than the component was described in this Phase III SRS.

## Chapter 8. FINDINGS AND RECOMMENDATIONS

### 8.1 Findings from SRS Phase III Evaluations

Key findings derived from System Reoperation Study Phase III are listed below based on an evaluation of reoperation strategies for Shasta Lake, Lake Oroville, and Lake McClure, as well as an integrated reoperation of the Central Valley Project and State Water Project. The reservoir reoperation strategies included the following reoperation components: Forecast-Based Operations, Conjunctive Management of surface and groundwater, and Supplemental Spring Flows. The integrated reoperation of the CVP and SWP included increased sharing of both projects' facilities. Water agencies can apply the information, analytical framework, and tools/models developed for SRS Phase III to guide the formulation and evaluation of various combinations of reoperation strategies for water systems/reservoirs of interest. Water agencies and/or water system owners may also be able to apply for Proposition 1 funding from the Water Storage Investment Program to help implement their system reoperation projects.

1. The system reoperation strategies evaluated in SRS Phase III provided benefits for the three SRS objective categories - water supply reliability, ecosystem protection and restoration, and flood protection. The reservoir reoperation strategies that included FBO, CM, and SSF were effective in achieving concurrent benefits in all three objective categories. These strategies could also be implemented to improve water quality and buffer the effects of climate change.
2. SWP and CVP integration (i.e., operation as a single project) provided water supply reliability and ecosystem restoration benefits. There is a potential of increasing the average water supply reliability by 100 to 150 taf per year.
3. The total benefits associated with the reservoir reoperation strategies evaluated in SRS Phase III were limited. For example, average water supply reliability is improved from 2 taf to 37 taf per year, spring ecosystem flows are increased by a volume of 4 taf to 80 taf per year, and flood hazard is reduced by a negligible amount, 0.23 feet. This is because the reservoirs and their associated projects (i.e., SWP, CVP, and MID) are already significantly optimized to meet existing flood and regulatory requirements, and contractual commitments.
4. Some reoperation measures evaluated in SRS Phase III are already being applied by reservoir operators, in most cases informally and at a smaller scale. For example, forecast-based operations, conjunctive water management, and some SWP and CVP integration (i.e., sharing facilities) have been used by operators historically. The informal use of these measures is less than the conceptual implementation studied in this Phase III report. Because the SRS evaluations assumed that these reoperation measures have not been implemented yet at all, the actual benefits associated with reoperation implementation would be less than SRS Phase III results.

5. The reoperation benefits from SRS Phase III evaluations were resilient or improved with new Delta conveyance and potential climate change effects. For example, average water supply reliability is improved by up to 89 taf per year, and spring ecosystem flows are increased by a volume up to 74 taf per year with new Delta conveyance. With a range of climate change effects, average water supply reliability is improved by 45 to 85 taf per year and spring ecosystem flows are increased by a volume of 57 to 123 taf per year. Flood protection benefits were not evaluated for the new Delta conveyance or climate change uncertain futures.
6. Risk management is an important consideration for operators that was not quantified or characterized by SRS Phase III analyses. While the reoperations strategies attempted to mitigate risk by employing operational safeguards, some residual risk associated with reoperation implementation would remain. Operational safeguards were developed to size the implementation of FBO, CM, and SSF based upon various studies. FBO was sized based upon review of the Folsom Dam Water Control Manual Update; CM was sized based upon guidance from the GCID/NHI study; SSF was sized based upon the SRS Phase II Tradeoff analysis. Examples of risk that may not be fully mitigated by the operational safeguards considered include:
  - Providing additional ecosystem flows may be achievable without adverse effects, assuming historic hydrology. However, supplemental ecosystem flows with future flow patterns may cause unintended and unacceptable adverse effects, such as a diminished cold water pool, reduced stream flows during other periods, and reduced water supply reliability.
  - Implementation of forecast-based operations would inherently increase risk. Specifically, FBO flood benefits are achieved by encroaching into the conservation pool (water storage maintained for beneficial uses), while FBO water supply reliability and ecosystem restoration benefits are achieved by encroaching into the existing flood storage space (based on historical hydrology). More extreme flow conditions could overcome operational safeguards needed for flood protection, as well as water supply and ecosystem management.
  - Pumping additional water from groundwater basins in northern California, which was evaluated in SRS Phase III, does not account for water losses associated with groundwater — surface water interaction. Also, the new SGMA requirements could make this conceptual approach institutionally infeasible as local and regional groundwater interests have expressed concerns about this conceptual approach.

## 8.2 Recommendations for SRS Next Phase Evaluations

1. SRS Next Phase reoperation strategies and evaluations should incorporate the following considerations, as the context for California water management has changed since the SRS was initiated.
  - The 2014 California Water Action Plan identified ten actions addressing the most pressing water issues that California faces while laying the groundwork for a sustainable and resilient future. Action 10 of the CWAP directs agencies to increase operational and regulatory efficiency. The focus of SRS is to identify reoperation concepts that increase the efficiency of water systems.
  - Proposition 1 (2014) provides \$2.7 Billion for investments in public benefits associated with water storage projects and reservoir reoperation projects. The System Reoperation Study has been designed to support both public and non-public benefits. Public benefits evaluated in SRS include ecosystem restoration and flood hazard reduction. Improved water supply reliability is generally considered a non-public benefit according to the bond language (an exception is water supply for an ecosystem purpose such as wildlife refuges).
  - The Sustainable Groundwater Management Act (2014) has formally recognized the need for describing, quantifying, and achieving sustainable groundwater management.
  - The 18 Principles for Water Conveyance in the Delta, Storage Systems, and for the Operation of Both to Achieve the Coequal Goals, adopted by the Delta Stewardship Council, emphasize the need for these integrated improvements.
  - The recent five-year drought underscores the need for water managers to plan for extreme multi-year dry conditions.
  - The effects of Delta conveyance and climate change on water system performance (positive or negative impacts) are of concern among the state's water managers.
2. Evaluate potential for using flood water for managed groundwater recharge on farmland and working landscapes for flood protection, drought preparedness, aquifer remediation, and ecosystem restoration. DWR will work with flood managers, land owners, and Groundwater Sustainability Agencies to determine opportunities to implement managed groundwater recharge projects that use excess flood flows as the source water.
3. Evaluate existing flood operating rules of the reservoirs under changing hydrology. DWR will work with USACE, USBR, and reservoir owners to evaluate the adequacy of existing flood operating rules to address today's challenges in a post-SGMA world and climate-induced extreme events (floods and droughts).
4. Assess feasibility of existing reservoir spillways and outlets to pass floodwater safely with changing hydrology. In coordination with USACE, USBR, and reservoir owners, DWR will support evaluation of potential modifications of flood control structures of the reservoir.
5. Identify system reoperation implementation challenges and opportunities. DWR will work with USBR, USACE, SWRCB, local/regional flood and water managers, and fishery



agencies to determine opportunities and barriers to implementing system reoperation, and follow necessary pathways to remove barriers and pursue opportunities.

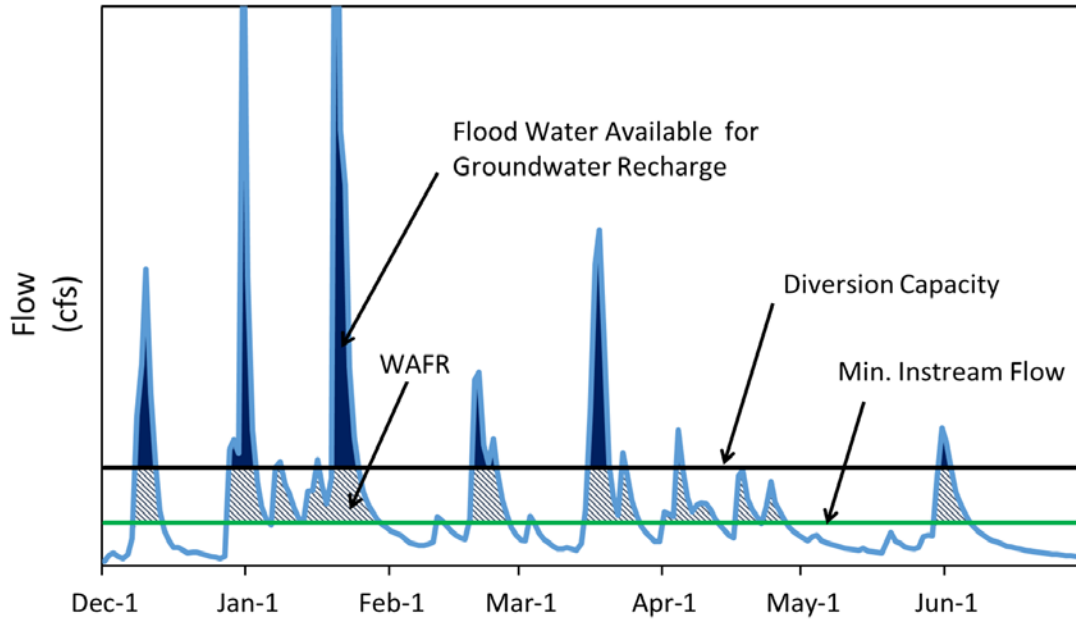


Figure 8-1: Typical Hydrograph

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