CDFW - Sites 60 day Evaluation Meeting No. 4: Meeting Agenda and Action Items

Sites Reservoir Project

Date: *June 18, 2019*

Location: *HDR Office: 2379 Gateway Oaks Drive, Suite 200 Fleming Conference Room*

Time: 10:00 am – 12:00 pm

Purpose: Continue 60 day evaluation of Operational Scenarios.

Invitees:

Rob Thomson, Sites Authority
Kevin Spesert, Sites Authority
Ali Forsythe, Sites Authority
Duane Linander, CDFW
Kristal Davis Fadtke, CDFW
Ian Boyd, CDFW
Ken Kundargi- CDFW
Johnathan Williams, CDFW
Lenny Grimaldo, ICF
Marin Greenwood, ICF
Jim Lecky, ICF
Mike Dietl, Reclamation
Felipe La Luz – CDFW
Chris Fitzer, ESA Associates
Rob Tull, Jacobs
Reed Thayer, Jacobs
Chad Whittington, Jacobs
John Spranza, HDR
Jelica Arsenijevic, HDR

Action Item		Owner	Deadline	Notes
1	USDROM documentation/meta data	Sites-Tull	06/12/19	Outstanding
2	Assist CDFW in locating CalSim assumptions	Sites-Tull	06/12/19	Outstanding
3				
4				
5				
6				
7				
8				

Agenda:

Discussion Topic	Topic Leader	Est Time
1. Introductions/Safety/ Admin	Ken Kundargi Ali Forsythe	5 min
2. Review of Action Items from Previous Meeting	Ali Forsythe	15 min
3. Daily Operations – 2010 to 2018	Rob Tull	90 min

4. Next steps for 60 day schedule	Group discussion	10 min

Meeting Minutes:

Link to Sites data and modeling package for CDFW:
https://jftt.jacobs.com/download.aspx?ID=086395b3-466e-4a71-851b-ecdf7d881205&RID=d339c4e6-dfff-4760-9701-f79c0b20066c

Sites Project

Modeling Background Information

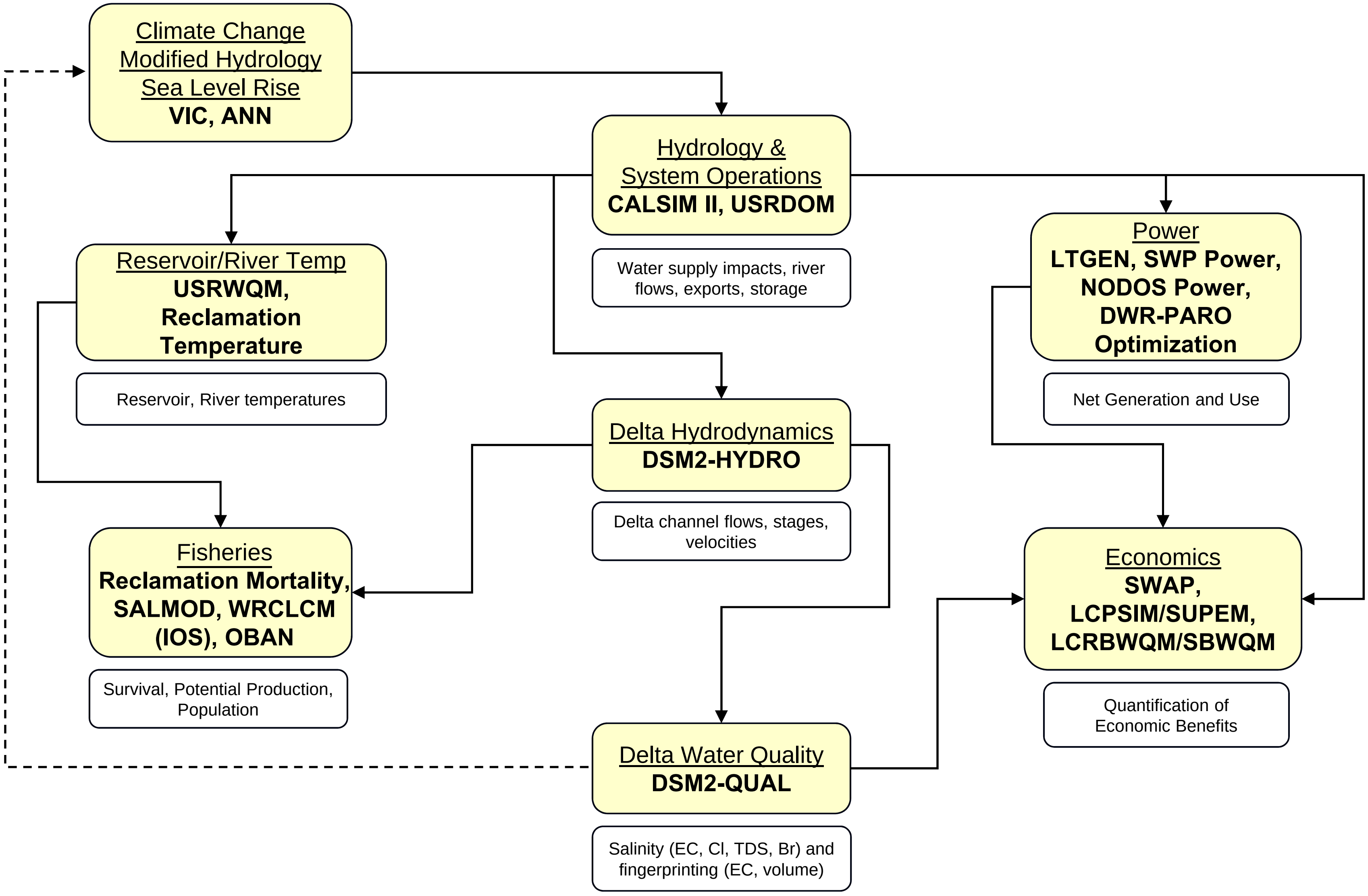
June 12, 2019

In response to your request on Friday, June 7, we are providing background information regarding the modeling performed for the Sites Reservoir Project. All the included information was part of either the Water Storage Investment Program (WSIP) Application or the WSIP Appeal.

Please disregard any results pertaining to the WSIP 2030 and WSIP 2070 climate scenarios. These were special scenarios performed for the WSIP process. The pertinent information in the documents below is from the DCR 2015 modeling.

Contents (All page numbers are overall page numbers from this PDF)

Analytical Framework –
System (feasibility, system-level impacts)



Climate Change
Modified Hydrology
Sea Level Rise
VIC, ANN

Hydrology &
System Operations
CALSIM II, USRDOM

Water supply impacts, river flows, exports, storage

Reservoir/River Temp
USRWQM, Reclamation Temperature

Reservoir, River temperatures

Power
LTGEN, SWP Power, NODOS Power, DWR-PARO Optimization

Net Generation and Use

Delta Hydrodynamics
DSM2-HYDRO

Delta channel flows, stages, velocities

Fisheries
Reclamation Mortality, SALMOD, WRCLCM (IOS), OBAN

Survival, Potential Production, Population

Economics
SWAP, LCPSIM/SUPEM, LCRBWQM/SBWQM

Quantification of Economic Benefits

Delta Water Quality
DSM2-QUAL

Salinity (EC, Cl, TDS, Br) and fingerprinting (EC, volume)

Model Glossary

Climate Change, Modified Hydrology, Sea Level Rise
VIC: Variable Infiltration Capacity (VIC) model (Liang et al., 1994), a large-scale, semi distributed hydrologic model

ANN: Artificial Neural Network used to calculate Delta salinity in CalSim II

Hydrology &System Operations
CalSim II: Monthly model of CVP and SWP operations

USRDOM: Upper Sacramento River Daily Operations Model, A model developed to simulate daily reservoir operations and daily river flows for the Upper Sacramento River.

Reservoir/River Temp
USRWQM: Upper Sacramento River Water Quality Model, a model developed to simulate the temperature regime of the Upper Sacramento River and provide estimates of daily average riverine temperature conditions.
Reclamation Temperature: This model provides monthly average temperature calculations'

Fisheries
Reclamation Mortality: Monthly egg mortality linked to the Reclamation Temperature model
SALMOD: Salmonid population model that incorporates streamflow, water temperature, and habitat type.

WRCLCM (IOS): Winter-run Chinook Life Cycle Model (Interactive Object-oriented Simulation)

OBAN: Oncorhynchus Bayesian Analysis for winter run Chinook

Delta Hydrodynamics
DSM2-HYDRO: Delta Simulation Model II simulates one-dimensional hydrodynamics including flows, velocities, depth, and water surface elevations

Delta Water Quality
DSM2-QUAL: Delta Simulation Model II simulates one-dimensional fate and transport of conservative and non-conservative water quality constituents

Power
LT-GEN: Spreadsheet power generation and consumption model of the CVP developed by USBR

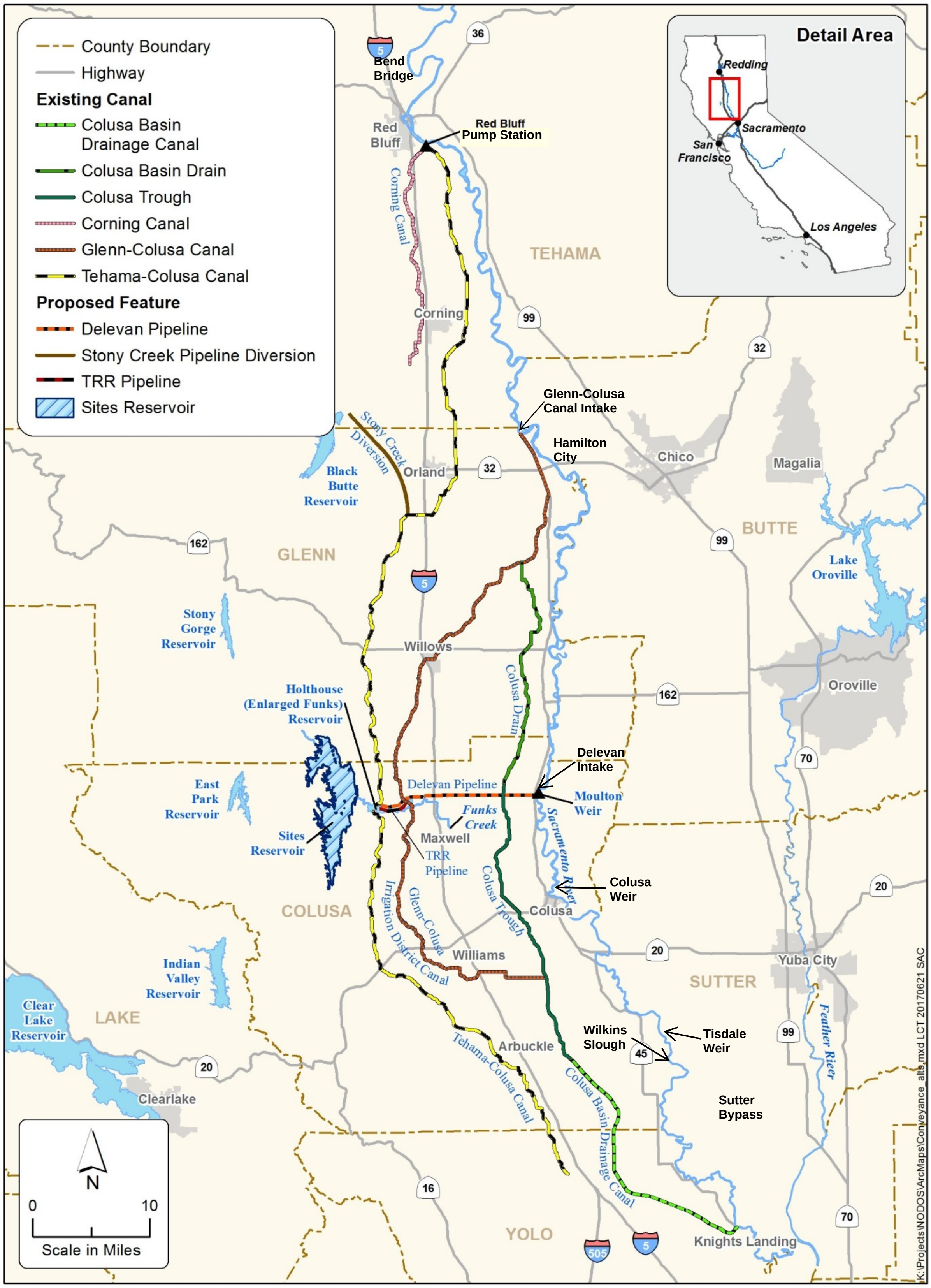
SWP Power: Spreadsheet power generation and consumption model of the SWP

NODOS Power: Spreadsheet power generation and consumption model of the Sites Project

DWR-PARO: DWR Power and Risk Office model

Economics
SWAP: Statewide Agricultural production
LCPSIM/SUPEM: Urban economic model that determines the least-cost solution for supply/demand balance.
LCRBWQM/SBWQM: Urban water quality economic model for the South Bay and Lower Colorado River Basin

Sites Project Facilities Map
DRAFT



Sites Reservoir Project Description and Assumptions of with-Project Conditions for Years 2030 and 2070 plus with and without-Project Current Conditions

August 9, 2017

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Figures

Acronyms and Abbreviations

Authority	Sites Project Authority
CALFED	CALFED Bay-Delta Program
cfs	cubic feet per second
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
DCR	Delivery Capability Report
Delta	Sacramento-San Joaquin River Delta
DSM2	Delta Simulation Model
DWR	California Department of Water Resources
Funks Reservoir	Holthouse Reservoir
GCID	Glenn-Colusa Irrigation District
M&I	municipal and industrial
MAF	million acre-foot (feet)
NODOS	North-of-Delta Offstream Storage
Reclamation	Bureau of Reclamation
SRSC	Sacramento River Settlement Contractor
SVI	Sacramento Valley 40-30-30 water year type index
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
T-C Canal	Tehama-Colusa Canal
TCCA	Tehama-Colusa Canal Authority
TRR	Terminal Regulating Reservoir
USACE	U.S. Army Corps of Engineers
USRDOM	Upper Sacramento River Daily Operations Model
VIC	Variable Infiltration Capacity

Introduction

This document provides descriptions and assumptions of the with-project conditions for the Sites Reservoir Project for years 2030 and 2070 as proposed by the Sites Project Authority (Authority). In addition, this document includes a description of the with- and without-project current conditions.

The with-project conditions include a 1.81-million-acre-foot (MAF) reservoir, which would be located in the Sacramento Valley west of the town of Maxwell, and associated conveyance facilities including use of existing Tehama-Colusa Canal (T-C Canal) and Glenn-Colusa Irrigation District (GCID) Main Canal diversion and conveyance facilities, plus a proposed new diversion and discharge pipeline. The proposed reservoir would be filled by diversion of excess Sacramento River water that originates from unregulated tributaries to the Sacramento River downstream from Keswick Dam. These flows are "excess" to those needed to meet current regulatory requirements or other water demands. Operation of the proposed reservoir would be in cooperation with the operations of existing Central Valley Project (CVP) and State Water Project (SWP) system facilities to facilitate and maximize the potential for a wide range of benefits. Detailed operating agreements would need to be developed that define a framework and procedures for cooperative operations among the Sites Project Authority (Authority), Central Valley Project (CVP), and State Water Project (SWP).

Approach

The with-project assumptions were developed through a series of meetings and coordination with Authority representatives including participating water district managers and county representatives, California Department of Water Resources (DWR), and Bureau of Reclamation (Reclamation). The with-project condition builds on previous work conducted under the CALFED Bay-Delta Program (CALFED) by DWR and Reclamation. Subsequent to CALFED, DWR has been the lead on technical studies in coordination with the Authority as part of the North-of-Delta Offstream Storage (NODOS) Project and associated investigations.

The analyses conducted for the Sites Reservoir Project utilized the model products and assumptions described in section 6004(a)(1) of the code of regulations. This includes the 2030 and 2070 future conditions CALSIM II and DSM2 models provided by the California Water Commission on November 2, 2016. The models provided by the commission were modified to include the facilities and operation of the Sites Project as described below in the Project Description and Assumptions section. There were no modifications to existing CVP and SWP operating criteria.

The with- and without-project Current Conditions analyses were based on the DWR State Water Project Final Delivery Capability Report 2015 (DWR 2015) – base scenario. Similar to above, the DCR 2015 base scenario, provided by DWR, was modified to include the facilities and operation of the Sites Project. The project description and assumptions for the with-project current condition is the same as described for the 2030 and 2070 with-project conditions.

The CALSIM II model is based on a monthly time step and, therefore, does not incorporate all the detailed decision processes that occur in actual daily operations of the CVP and SWP systems. To evaluate naturally occurring storm event flows, supplemental modeling was conducted on a daily time step to assess availability of excess Sacramento River flows.

Table 1 (located at the end of this document) shows the range of potential beneficiary operations under drought and other hydrologic conditions, and priorities assumed for various seasonal operations. It is intended that storage and associated releases could be adaptively managed to support operational actions found to produce the greatest benefits over time.

The analyses included the use of other analytical tools that were updated for future 2030 and 2070 conditions. These tools include:

- USRDOM – Upper Sacramento River Daily Operations Model
- Sacramento River HEC5Q model
- SALMOD
- American River CE-QUAL Model
- CWEST
- SWAP
- LTGEN
- SWP Power
- NODOS Power

The analytical framework, tools, and analyses were formulated for evaluating the benefits and impacts of the Project. The framework provides for iteratively refining operations criteria to minimize both the systemwide and localized impacts on various resources while maximizing the benefits.

The primary model in the framework is CALSIM II with inputs describing the hydrology, facilities, water management, regulatory standards, and operational criteria assumptions. CALSIM II outputs regarding system operation decisions including deliveries, flows and storages are then used by every other model in the analytical framework. CALSIM II operations were informed based on the reporting metrics from various models that simulate river temperatures, anadromous fish survival, Delta water quality, hydropower generation and economics.

Upper Sacramento River Daily Operations Model (USRDOM) uses the CALSIM II outputs regarding the operational controls and reservoir releases to simulate daily reservoir operations and daily river flows for the upper Sacramento River from Shasta Dam to Knights Landing. For evaluating Project operations, CALSIM II and USRDOM were simulated iteratively to determine potential Reservoir diversions based on flow conditions in Sacramento River.

Delta Simulation Model (DSM2) was used to simulate hydrodynamics (flow, velocity and water levels) and water quality (salinity) in the Sacramento-San Joaquin Delta. The Upper Sacramento River HEC5Q model was used to simulate reservoir and river temperatures in the upper Sacramento River, from Shasta Lake to Knights Landing. The Folsom CE-QUAL-W2 model was used to simulate reservoir and river temperatures on the American River. The SALMOD model was used to simulate benefits to anadromous fish in the Sacramento River. The LTGEN, SWP Power, and NODOS Power were used to study the power production and use. The SWAP and CWEST economic modeling tools were used to study the benefits to agricultural water supply and urban water supply. The interrelationships between the models are shown in the analytical framework in Figure 1.

Descriptions of the models used in the analytical framework are included in the following attachments.

- CALSIM II and DSM2 Modeling Assumptions
- HEC5Q Modeling for the Sites Project
- SALMOD Salmon Modeling of the Sacramento River
- Upper Sacramento River Daily Flow and Operations Modeling
- Power Modeling of the Sites Reservoir Project
- Economic Modeling of the Sites Reservoir Project
- Folsom Reservoir CE-QUAL-W2 Temperature Modeling

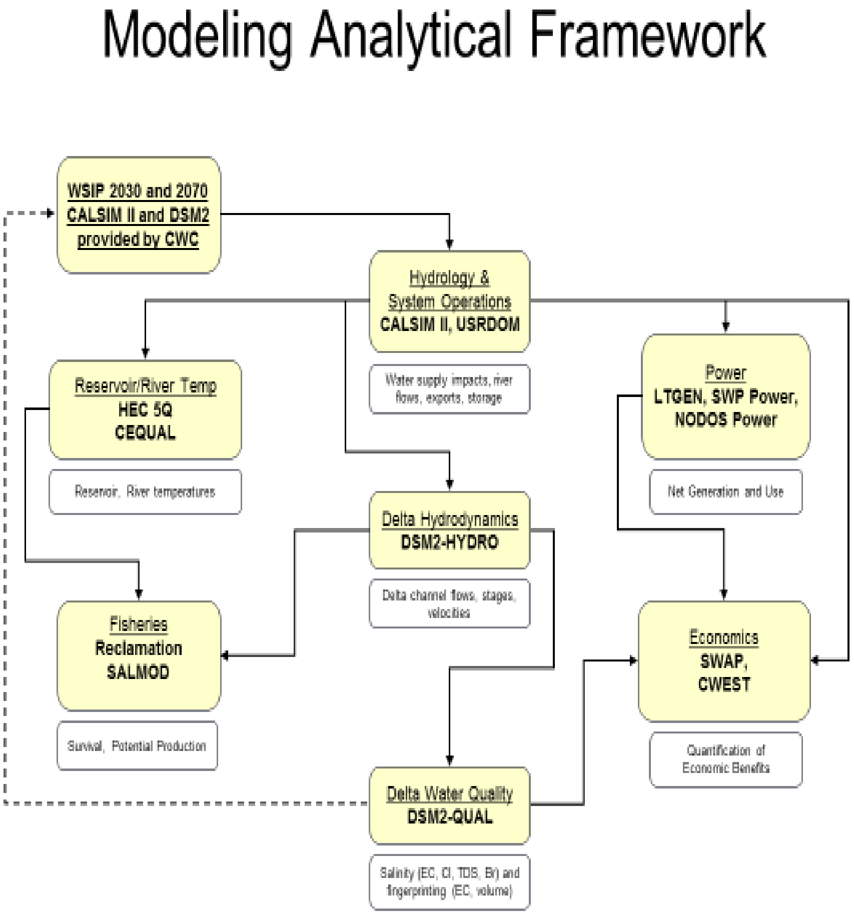


Figure 1. Modeling Analytical Framework

Project Description and Assumptions

Sites Reservoir would be filled by diversion of excess Sacramento River flows that originate from unregulated tributaries to the Sacramento River downstream from Keswick Dam. As described below, diversions are assumed to potentially occur in any month or water year type, but would likely be greatest in the winter months with wetter conditions (depending on storage conditions and annual flows and events). The Sites Reservoir Project could operate in cooperation with CVP and SWP system facilities to facilitate a wide range of benefits. Sites Reservoir would provide water through four primary mechanisms:

- Water stored in Sites Reservoir could be released directly to Colusa Basin users,
- Water could be released to the Sacramento River
- Water could be released through the Colusa-Basin Drain and Knights Landing Ridge Cut
- Water stored in Sites Reservoir could be exchanged for water stored in Shasta Lake or other CVP and SWP system reservoirs.

This last mechanism could be used to significantly increase upstream north-of-Delta storage and operational flexibility to support multiple water supply and ecosystem benefits.

The project employs a strategy to maximize the potential benefits of Sites Reservoir while not adversely affecting the CVP and SWP's ability to meet existing system regulatory requirements including the following:

- Water rights
- Instream flow requirements
- Biological opinions
- Delta water quality requirements
- CVP and SWP requirements
- Central Valley Project Improvement Act (CVPIA)

The following sections describe the proposed Sites Reservoir Project infrastructure, Sacramento River diversion criteria and assumptions, public benefits, and water supply benefits.

Project Infrastructure

The primary facilities include a 1.81-MAF Sites Reservoir that would rely on the existing T-C Canal and GCID Main Canal for diversion and conveyance purposes, as well as a new proposed Delevan Pipeline and intake to divert and convey water to and from the reservoir. Figure 1 shows the location of the proposed reservoir and associated conveyance facilities. A description of existing and proposed new conveyance facilities and their proposed operation follows.

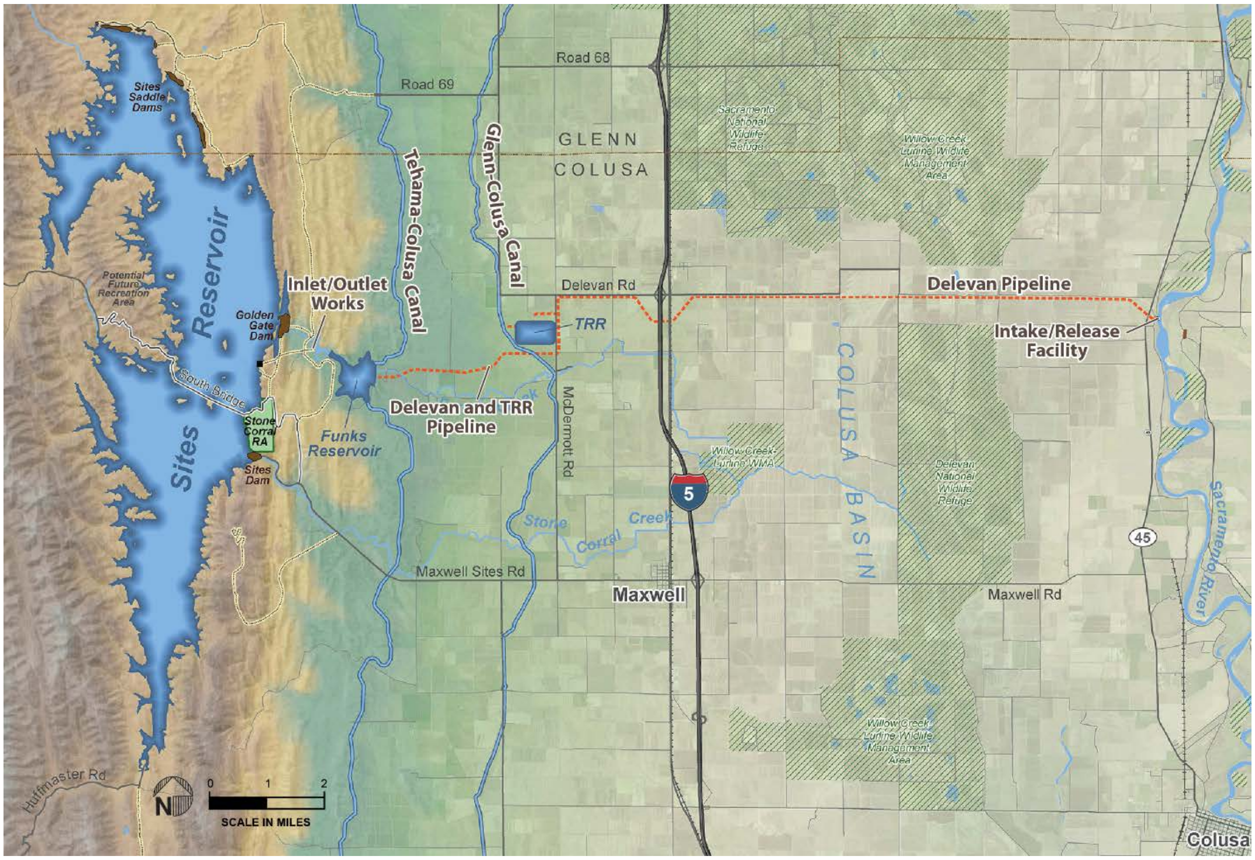


Figure 2. Sites Reservoir and Proposed Facilities

Tehama-Colusa Canal and Red Bluff Pumping Plant Facilities and Capacity

The existing Tehama-Colusa Canal Authority's (TCCA) T-C Canal through the TCCA service area and Red Bluff Pumping Plant located on the Sacramento River near Red Bluff would be used to divert and convey water to the proposed Sites Reservoir. Operating agreements among the Authority, TCCA, and Reclamation would need to be developed to define Sites Reservoir Project operations and cooperation among the parties.

Red Bluff Pumping Plant has an existing pumping capacity of 2,000 cubic feet per second (cfs), which is used to meet current agricultural water demand. The project would include installation of one additional pump (250 cfs) to the existing pump grouping, which would increase the overall pumping capacity to 2,250 cfs to fully use the 2,100-cfs capacity for diversion of water through T-C Canal to Sites Reservoir. The total conveyance capacity of T-C Canal is assumed to be 2,250 cfs at the upstream end of the canal and 2,100 cfs at Holthouse Reservoir. Any unused capacity remaining after meeting existing agricultural demands could be used as necessary to convey water to fill Sites Reservoir. Approximately 50 to 60 cfs of the T-C Canal capacity is assumed to be used for existing winter operations, based on communication with TCCA representatives.

No dedicated period for maintenance was assumed for T-C Canal on the basis of current canal capacity and projected Sites Reservoir diversion amounts. Discussions with TCCA representatives revealed operations and maintenance could be scheduled around proposed Sites Reservoir Project operations.

Glenn-Colusa Irrigation District Main Canal and Hamilton City Pumping Facilities and Capacity

Similar to T-C Canal, GCID Main Canal would be used to convey water pumped from the existing Hamilton City pumping facility to divert and convey Sacramento River water to the proposed Sites Reservoir. Operating agreements between the Authority and GCID would need to be developed to define Sites Reservoir Project operations and cooperation between the parties. The Hamilton City pumping facility has a 3,000 cfs diversion capacity at the Sacramento River intake, and the capacity of GCID Main Canal is 1,800 cfs at TRR. Any unused capacity remaining after existing agricultural operations could be used to convey water to the proposed Sites Reservoir. The following flows are assumed to occupy capacity in the canal during existing winter operations of GCID Main Canal (values in cfs).

October	November	December	January	February	March
513	534	389	235	56	48

A dedicated annual maintenance shutdown period was assumed from January 7 through February 21.

Proposed Delevan Pipeline and Intake Diversion and Release Capacities

The proposed Delevan Pipeline would extend east/west across the GCID service area located west of the existing Maxwell Irrigation District intake facility. The proposed intake and discharge facility would include a fish screen and pump station intake to divert up to 2,000 cfs from the Sacramento River to Sites Reservoir when excess Sacramento River water is available for diversion. The pipeline would also have the ability to convey up to 2,500 cfs by gravity from the Sites Reservoir back to the Sacramento River for downstream uses.

A dedicated annual maintenance shutdown period sometime between April 1 and May 31 is assumed for the pipeline, intake, and fish screen facility in wet, above-normal, and below-normal water year types in accordance with the Sacramento Valley 40-30-30 index. During the maintenance, both diversion and release operations at Delevan would be shut down. No maintenance would be scheduled in dry and critical water year types.

Existing Tehama-Colusa Canal and Glenn-Colusa Irrigation District Main Canal Intertie

The existing T-C Canal and GCID Main Canal intertie provides flexibility in routing flows of up to 285 cfs from the T-C Canal to the GCID Main Canal.

Williams Outlet

The Williams Outlet provides flexibility in routing water of up to 65 cfs from the T-C Canal to the GCID Main Canal.

Holthouse (Funks) Reservoir

The existing Funks Reservoir includes a storage capacity of 2,250 acre-feet and serves as a re-regulating reservoir to stabilize flows in T-C Canal as diverters come on line and off line. The existing Funks Reservoir would be expanded to form Holthouse Reservoir by constructing a new dam (Holthouse Dam) and reservoir to the east of Funks Reservoir, with an enlarged active storage capacity of approximately 6,500 acre-feet and a surface area of approximately 450 acres.

Terminal Regulating Reservoir and Pipeline

TRR would be a 1,200-acre-foot regulating reservoir constructed adjacent to GCID Main Canal, approximately 3 miles northeast of Holthouse Reservoir. TRR would be composed of an earthen embankment dam, concrete emergency overflow weir, outfall standpipe, and an approximate 4,000-foot-long underground 60-inch-diameter overflow outlet pipe to Funks Creek.

Water conveyed down GCID Main Canal would be directed into the proposed TRR. A new pump station (the proposed TRR pumping and generating plant) would then convey the water from TRR via the proposed TRR pipeline to the proposed Holthouse Reservoir. TRR would be required to provide operational storage for the TRR pumping and generating plant to balance normal and emergency flow variations between the upstream GCID Main Canal pump station, the 40 miles of connecting canal, and the TRR pumping and generating plant.

The proposed TRR pipeline would be bidirectional, allowing water to be pumped from TRR to Holthouse (Funks) Reservoir for storage, and allowing water to flow by gravity from Holthouse Reservoir for release to TRR and GCID Main Canal. The pipeline would have a capacity of 1,800 cfs to convey water pumped from TRR to Holthouse Reservoir. The capacity of the pipeline to convey water by gravity flow from Holthouse Reservoir to TRR would be 900 cfs.

Diversions to Sites Reservoir

The proposed Sites Reservoir would be filled through the diversion of excess Sacramento River water that originates from unregulated tributaries to the Sacramento River downstream from Keswick Dam. Less than 1 percent of diversions to Sites Reservoir are assumed to be provided by flood releases or spills that flow through Lake Shasta. Sacramento River water would be diverted at the three locations on the river as described above. Excess flows are defined as river flows in addition to those required to meet the following:

- Senior downstream water rights, existing CVP and SWP and other water rights diversions including SWP Article 21 (interruptible supply), and other more senior excess flow priorities (diversions associated with Freeport Regional Water Project and existing Los Vaqueros Reservoir)
- Existing regulatory requirements including State Water Resources Control Board (SWRCB) D-1641, CVPIA 3406(b)(2), the 2008 U.S. Fish and Wildlife Service biological opinion, and the 2009 National Marine Fisheries Service biological opinion and other instream flow requirements
- Bypass flow conditions needed to maintain and protect anadromous fish survival and Delta water quality

The Authority would need to obtain a water right permit to allow the intended operations. Operations would be consistent with the terms and conditions contained in the water right permit approved by SWRCB. The permit would describe the points and methods of diversion, diversion season, purposes of use, and places of use.

A description of proposed minimum bypass flow requirements and pulse flow criteria to protect existing and future water uses are provided below.

Sites Reservoir Diversion Bypass Flow Protection

Excess Sacramento River flow diversions to Sites Reservoir would only take place when flow monitoring indicates that bypass flows are present in the river due to storm event flows. Several existing and additional proposed bypass flow criteria were assumed at specified locations. These flow criteria are designed to make certain only excess water would be diverted into Sites Reservoir to maintain and protect existing downstream water uses, as follows.

- A bypass flow of 3,250 cfs downstream from Red Bluff Diversion Dam must be present to maintain flows in the upper Sacramento River that are required in SWRCB WR 90-5 to prevent dewatering salmonid redds and maintain water temperatures. Diversions at Red Bluff Pumping Plant for filling Sites Reservoir would only be allowed when flows in the river were above the 3,250-cfs bypass flow criteria.
- Diversions at the Hamilton City intake for GCID Main Canal currently require a bypass flow of 4,000 cfs to prevent fish entrainment. Diversions at Red Bluff Pumping Plant and GCID Main Canal intake for filling Sites Reservoir would only be allowed when flows in the river were above the 4,000-cfs bypass flow requirement downstream from Hamilton City.
- Diversions for filling Sites Reservoir would only be allowed when flows below Wilkins Slough were above 5,000 cfs given the current minimum flow requirements. Wilkins Slough Navigation Control Point minimum flows currently range from 3,250 to 5,000 cfs depending on hydrologic conditions.
- Diversions for filling Sites Reservoir would only be allowed when a Sacramento River flow of 15,000 cfs is present at Freeport in January, 13,000 cfs in December and February through June, and 11,000 cfs in all other months. This flow threshold was designed to protect and maintain existing downstream water uses and water quality in the Delta.

Pulse Flow Protection Diversion Assumptions

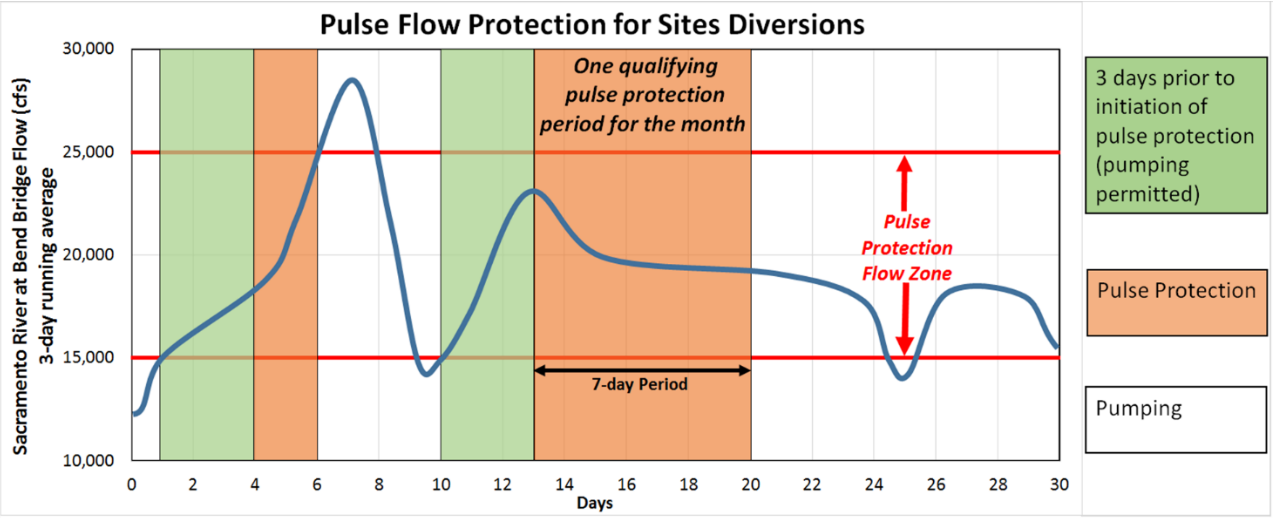
Operations modeling of the proposed Project included restrictions on diversions to limit impacts on out-migrating juvenile fish as a “surrogate” for likely permit conditions. Based on recent literature and the proposed permit conditions for other diversion projects, operations modeling for the proposed Project diversions were assumed to be restricted to minimize impacts to fish passage associated with pulse flow events that stimulate the observed spike in juvenile salmon outmigration. Actual operations are anticipated to be informed by real-time monitoring of fish movement.

The assumed limits on diversions during naturally occurring, storm-induced pulse flow events in the Sacramento River were based on a recent study by del Rosario et al. (2013), which found an abrupt and substantial spike in winter-run Chinook salmon arrivals at Knights Landing in association with the first storm event producing a flow of 400 cubic meters per second (14,126 cfs) at Wilkins Slough. This spike was followed shortly by passage of up to the 50th percentile of cumulative migration. This relationship was apparent for a wide range of water year types based on catch data collected between 1999 and 2007.

Accordingly, an assumed pulse protection period was developed that would extend from October through May to address out-migration of juvenile winter-, spring-, fall- and late-fall-run Chinook salmon, as well as steelhead. Pulse flows during this period would provide flow continuity between the upper and lower Sacramento River to support fish migration. It is recognized that research regarding the benefits of pulse flows is ongoing, and further research and adaptive management would be required to develop and refine a pulse flow protection strategy for fish migration and, as such, this assumption was used for modeling and informational purposes only.

For proposed Sites Reservoir operations, pulse flows are defined by extended peak river flows at Bend Bridge that originate primarily from storm event tributary inflows downstream from Keswick Dam. For the purposes of operations modeling, a naturally occurring pulse event was considered initiated when the 3-day running average flow below Bend Bridge exceeded 15,000 cfs. Such an event would need to continue for at least a 7-day duration to be considered a qualified storm event for the simulation process. Diversions to Sites Reservoir would not be allowed during the 7-day period that flow was greater than 15,000 cfs. The duration of a pulse flow event would be considered terminated under the following conditions: 1) the 3-day running average discharge flow remained greater than 15,000 cfs for 7 days after initiation, 2) the 3-day running average discharge flow dropped below 15,000 cfs before reaching the 7-day duration, or 3) the 3-day running average discharge flow exceeded 25,000 cfs before reaching the 7-day duration.

Given that del Rosario et al. (2013) indicate that the first storm event was associated with a spike in salmon arrivals at Knights Landing, diversions to Sites Reservoir would not be allowed during the first 7-day qualified pulse period, when flows reach 15,000 cfs during the out-migration season. For evaluation of Sites Project Reservoir operations, it was assumed that up to one qualified 7-day pulse event would occur each month during the pulse protection period from October through May, to encourage and support salmonid out-migration and minimize potential diversion impacts. Therefore, for operations modeling, diversions to Sites Reservoir storage would be restricted under the following conditions: 1) if pulse conditions exist at Bend Bridge, and a qualified pulse event has not already occurred within the given month, and 2) if Bend Bridge flows are less than 25,000 cfs during the pulse event. Diversions are allowed when flows exceed 25,000 cfs because flows of this magnitude are considered to provide lesser benefits to fish migration, as shown in Figure 2.



Pulse flow protection period is October through May

Figure 3. Pulse Flow Protection for Sites Diversions

Diversions to Fill Sites Reservoir Storage

Diversions of excess Sacramento River water to Sites Reservoir using existing T-C Canal and GCID Main Canal conveyance facilities could occur at any time during the year, given the flow conditions described above are present in the river. Deliveries for TCCA and GCID service areas have first priority at the existing T-C Canal and GCID intakes, with diversions to Sites Reservoir using the unused capacities of the two canals.

Diversions through the proposed Delevan Pipeline could also occur at any time of the year assuming Sacramento River flow conditions are above the bypass and pulse flow criteria described above. In summer months, preference would generally be given to Sites Reservoir releases to the river, resulting in limited diversions to storage because the pipeline could only convey flows in one direction at a time.

Sites Reservoir Evaporation

In the absence of available evaporation data, Sites Reservoir “net-evaporation” rates were estimated using evaporation and precipitation data from existing nearby reservoirs. Net-evaporation is the difference between evaporation and precipitation. Positive values indicate higher rates of evaporation than precipitation while negative values indicate lower rates of evaporation than precipitation. Evaporation and precipitation data have been collected for three nearby reservoirs along Stony Creek including: (1) East Park Reservoir, (2) Stony Gorge Reservoir, and (3) Black Butte Lake.

The evaporation data was taken from Reclamation’s Stony Creek model (Yaworsky, 2006), which makes monthly estimates based on historical data from DWR, Reclamation, and U.S. Army Corps of Engineers (USACE). These evaporation rates are consistent with the data used as inputs in the DCR 2015, WSIP 2030, and WSIP 2070 CALSIM II models.

The data consists of six historical time series ranging from October 1922 to September 2003 at a monthly time-step. The average annual evaporation rates at East Park Reservoir, Stony Gorge Reservoir, and Black Butte Lake are 6.5 TAF, 4.7 TAF, and 12.2 TAF, respectively. The precipitation data has been provided by the Variable Infiltration Capacity (VIC) model (Liang et al., 1994), a large-scale, semi-distributed hydrologic model originally developed by Xu Liang at the University of Washington.

The net-evaporation rates for East Park Reservoir, Stony Gorge Reservoir, and Black Butte Reservoir were computed by subtracting each reservoir's precipitation rates from its evaporation rates. The monthly net-evaporation of the three reservoirs was averaged and used as the input for Sites Reservoir net-evaporation. Using this method, the average annual net-evaporation for Sites Reservoir equates to 33.3 TAF.

Consistent with all other evaporation inputs in CALSIM II, the Sites Reservoir net-evaporation rates are unchanged under 2030 and 2070 future climate conditions.

Reservoir Operations Assumptions

The primary operational criteria include the following:

- A defined ecosystem enhancement storage account would be established in Sites Reservoir to be managed by the State to provide water for ecosystem and water quality purposes.
- Each of the participating Authority members would be allocated a defined storage account in the Sites Reservoir Project to manage their water, as well as store water from other potential sources of supply.
- It is assumed that a water market of some form would be facilitated by the Authority to promote efficient use and exchange of water in Sites Reservoir storage.
- All storage accounts would receive an equal proportional share of new water diversions into Sites Reservoir storage.
- Any water in storage beyond designated member account volumes would be "at risk" and would be "spilled" if the reservoir fills to capacity.
- A set of operating guidelines and rules would be developed to promote efficient water management for operations of Sites Reservoir and associated facilities.
- All water stored in Sites Reservoir storage accounts are subject to evaporation and other losses.

Public Benefits

The operation of Sites Reservoir Project would allow for the development and administration of an ecosystem enhancement storage account that could be managed by the State to provide water for ecosystem and water quality purposes. Such an account would provide a pool of dedicated storage to manage in cooperation with existing operations to improve coldwater conservation storage, stabilize river flows during critical fisheries periods, increase flows through certain watercourses and/or facilities (such as, Yolo Bypass), improve water quality, and/or enhance habitat restoration.

Sites Reservoir Project would be operated in cooperation with CVP and SWP operations to coordinate releases from Trinity Lake, Shasta Lake, Lake Oroville, and Folsom Lake. Releases from Sites Reservoir would allow reduced releases from other reservoirs while still meeting requirements for minimum instream flow objectives, Sacramento River temperature requirements, and Delta salinity control assigned to CVP and SWP. Through this reduction in releases, storage could be conserved in Trinity Lake, Shasta Lake, Lake Oroville, and Folsom Lake to significantly increase operational flexibility to improve river water temperatures for fish survival, Delta water quality, flood control, and recreation.

The following summarizes the anticipated primary benefits that could be realized through the provision of Sites Reservoir Project water beyond that required to meet Authority member needs. The priorities and amount of water potentially allocated to achieving the benefits listed below will be subject to the participation of the California Water Commission Water Storage Investment Program. Sites Reservoir Project operations would achieve multiple benefits over a wide range of hydrologic conditions.

In drought conditions, Sites Reservoir Project could:

- Increase coldwater pool conservation in Trinity Lake, Shasta Lake, Lake Oroville, and Folsom Lake
- Help regulate Sacramento River summer flows for best use of cold water for control of temperature conditions adverse to anadromous fish

In non-drought hydrologic conditions, Sites Reservoir Project water could:

- Stabilize Sacramento River fall flows for improving spawning and rearing success of anadromous fish
- Provide water to the Yolo Bypass to support salmon migration and summer food production for delta smelt
- Provide water for Incremental Level 4 refuge deliveries per CVPIA
- Provide (via upstream actions) incidental Delta water quality improvements in the summer and fall

More detailed descriptions of potential actions that could be implemented in cooperation with the CVP and SWP operations are provided below.

Shasta Lake Coldwater Pool and Sacramento River Temperature Control

Maximum benefits could be realized assuming Sites Reservoir and Shasta Lake were operated in cooperation to increase Shasta Lake storage and preserve a greater volume of coldwater pool storage. This additional cold water would improve operational flexibility to provide releases to maintain appropriate water temperatures in the Sacramento River during summer months and in drought years.

Through releases from Sites Reservoir to meet TCCA and GCID irrigation diversions and equivalent reductions in CVP Shasta Lake releases, demands on Shasta Lake storage could be reduced and the coldwater pool maintained for a longer time at higher levels than are currently achievable. Shasta Lake release patterns could be shifted in season and between adjacent years to improve coldwater storage and flow management for salmon and other species using the portion of the Sacramento River between Keswick Dam and the Red Bluff Diversion Dam as habitat.

Stabilize Upper Sacramento River Fall Flows

Additional storage in Shasta Lake could be used to stabilize fall flows between Keswick Dam and Red Bluff to avoid abrupt flow reductions due to changes in local tributary inflows as a results of storm events. This would reduce adverse conditions for spawning fall-run Chinook salmon (such as, dewatering of redds and scour damage).

Sacramento River Diversion Reductions at Red Bluff and Hamilton City

The Sites Reservoir Project could allow Shasta Lake to provide increased Sacramento River flows in spring through fall by reducing Sacramento River diversions into T-C Canal and GCID Main Canal during the irrigation season. This would be achieved through exchange with releases from Sites Reservoir to meet CVP T-C Canal and GCID Main Canal contract demands, and could provide multiple benefits to anadromous fish and estuarine-dependent species by providing or augmenting transport flows, increasing habitat availability, increasing productivity, and improving nutrient transport and food availability.

Folsom Lake Coldwater Pool Improvement and Supply Reliability

Sites Reservoir Project operations in cooperation with Folsom Lake could improve the reliability of coldwater carryover storage at Folsom Lake, stabilize flows in the American River, and help maintain suitable water temperatures in the lower American River. Additional summer releases from Sites Reservoir could reduce the need for releases from Folsom Lake, resulting in increased carryover storage. Sites Reservoir releases could also provide additional Delta outflow and reduce short-term emergency flow reliance on Folsom Lake releases to maintain Delta water quality.

Yolo Bypass and Delta Outflow Improvement

Sites Reservoir releases through the Colusa Basin Drain and Knights Landing Ridge Cut into the Yolo Bypass would help increase productivity in in the lower Cache Slough and lower Sacramento River areas to increase desirable food sources for Delta smelt and other key fish species in the late summer and early fall.

Lake Oroville Coldwater Pool Improvement

Sites Reservoir releases could increase the reliability of coldwater pool storage in Lake Oroville to reduce lower Feather River water temperatures for juvenile steelhead and spring-run Chinook salmon over-summer rearing, and fall-run Chinook salmon. Higher and more stables flows in the lower Feather River at critical times could also minimize redd dewatering, juvenile stranding, and isolation of anadromous salmonids.

Water Supply

The Sites Reservoir Project could provide a substantial amount of water to potential Sites Reservoir Project participants including agricultural and municipal and industrial (M&I) users. Sites Reservoir water would be released to meet demands and supplement existing allocations to CVP contractors in the Colusa Basin and released for other water users in the Sacramento Valley.

The South-of-Delta CVP and SWP contractors that receive water from the Sites Reservoir Project have contract provisions for the conveyance of extra water through SWP of CVP facilities above their SWP or CVP allocations. These water users may opt to have their Sites Reservoir Project water conveyed as either “project” water or “non-project” depending on the conveyance agreements they develop with DWR or Reclamation. If the water is conveyed as project water, then it has a more flexible timeframe for its conveyance and the releases of their water from Sites via the Delevan Pipeline. If the water is conveyed as non-project water, then the water would likely be released from Sites Reservoir and conveyed south or west of the Delta during the “water transfer window” in the biological opinions for the operation on the CVP/SWP in the Delta, provided there is capacity to convey this non-project water.

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CALSIM II and DSM2 Modeling Assumptions

CALSIM II and DSM2 Modeling Assumptions

Introduction

This attachment provides a description of the assumptions for the CALSIM II and DSM2 modeling of the Current Conditions, WSIP 2030, and WSIP 2070 without project scenarios.

The with- and without-project Current Conditions analyses were based on the DWR State Water Project Delivery Capability Report 2015 (DCR 2015) – base scenario. The DCR 2015 base scenario was modified to include the facilities and operation of the Sites Project.

The 2030 and 2070 future conditions CALSIM II and DSM2 models provided by the California Water Commission on November 2, 2016 were modified to include the facilities and operation of the Sites Project.

Assumptions for DCR 2015, WSIP 2030, and WSIP 2070 Model Without Project Simulations

This section documents the assumptions used in the CALSIM II and DSM2 model simulations for the baseline model (Without Project) simulations used in the Sites Reservoir Project evaluation. The DCR 2015, WSIP 2030 Without Project, and WSIP 2070 Without Project models are identical except for hydrologic inflows and sea level rise due to climate change.

The Without Project assumptions include implementation of water operations components of the Reasonable and Prudent Alternatives (RPA) specified in the 2008 Fish and Wildlife Service (FWS) and 2009 National Marine Fisheries Service (NMFS) Biological Opinions (BiOps). The specific assumptions and implementation in the CALSIM II and DSM2 models were developed by a multiagency team comprised of fisheries and modeling experts from the DWR, Department of Fish and Game (DFG), Reclamation, USFWS, and NMFS.

The description of CALSIM II assumptions refers to the DCR 2015 scenario. However, these assumptions are applicable to the WSIP 2030 Without Project and WSIP 2070 Without Project scenarios also. A summary of the CALSIM II model assumptions in the DWR State Water Project Delivery Capability Report 2015 – base scenario is provided in Table 1.

CALSIM II Assumptions for Current Conditions (DCR 2015)

<u>Hydrology</u>

Inflows/Supplies

CALSIM II model includes the historical hydrology with projected 2030 modifications for the operations upstream of the rim reservoirs. Reservoir inflows, stream gains, diversion requirements, irrigation efficiencies, return flows and groundwater operation are all components of the hydrology for CALSIM II.

Level of Development

CALSIM II input hydrology is based on an analysis of agricultural and urban land use and population estimates. The assumptions used for Sacramento Valley land use result from aggregation of historical survey and projected data developed for the California Water Plan Update (Bulletin 160-98). Generally, land use projections are based on Year 2020 estimates (hydrology serial number 2020D09E). However, the San Joaquin Valley hydrology reflects draft 2030 land use assumptions developed by Reclamation. Where appropriate Year 2030 projections of demands associated with water rights and SWP and CVP water service contracts have been included. Specifically, projections of full build out are used to describe the American River region demands for water rights and CVP contract supplies and California Aqueduct and the Delta Mendota Canal SWP/CVP contractor demands are set to full contract amounts.

Demands, Water Rights, CVP/SWP Contracts

CALSIM II demand inputs are preprocessed monthly time series for a specified level of development (e.g. 2030) and per hydrologic conditions. Demands are classified as CVP project, SWP project, local project or non-project (e.g. pre-1914 water rights, in-Delta consumptive use etc.). CVP and SWP demands are separated into different classes based on the contract type. A description of various demands and classifications included in CALSIM II is provided in the 2008 OCAP Biological Assessment Appendix D (Reclamation 2008a). Non-project demands within each Depletion Study Area (DSA) are based on the proportion of the acreage served by the projects versus the total acreage, for each land-use type. Non-project demands are satisfied from sources other than project storage and project conveyance facilities and are reduced as a function of water availability in the absence of project operations.

DCR 2015 assumes demands north of the Delta at the future level of development assuming full build-out of facilities and increases associated with water rights and CVP and SWP service contracts. This is primarily an increase in CVP M&I service contracts (253 TAF/Yr) and water rights (184 TAF/Yr) related to urban municipal and industrial (M&I) use, especially in the communities in El Dorado, Placer, and Sacramento counties.

DCR 2015 also assumes full contract amounts for demands associated with SWP contracts, south of the Delta at the future level of development, in all hydrologic conditions.

Facilities

CALSIM II includes representation of all the existing CVP and SWP storage and conveyance facilities. Key storage facilities including Shasta Lake, Trinity Lake, Whiskeytown Lake, Lake Oroville, Folsom Lake, Los Vaqueros Reservoir, San Luis Reservoir and Millerton Lake are represented in CALSIM II. Regulating reservoirs such as Lewiston, Keswick, Thermalito and Nimbus are also included in CALSIM II.

CALSIM II also represents existing conveyance facilities in the Colusa Basin region. Red Bluff Diversion Dam, Tehama-Colusa Canal (TCC) and its intake on the Sacramento River, Corning Canal, Glenn Colusa Canal (GCC) and its intake on the Sacramento River, Stony Creek – TCC intertie, TCC – GCC intertie, and Colusa Basin Drain are some of the key facilities included in the model.

CALSIM II also represents the flood control weirs along the Sacramento River such as Ord Ferry, Moulton Weir, Colusa Weir and Tisdale Weir, which bypass flood flows into Sutter Bypass. USRDOM was used to model the weir spills into the Sutter Bypass for the simulations. In addition, CALSIM II also represents the flood control weirs such as Fremont Weir and Sacramento Weir, which spill flood flows from the Sacramento River into Yolo Bypass.

Freeport Regional Water Project, located along the Sacramento River near Freeport, is assumed to be operational under the DCR 2015. Similarly, 30 mgd capacity, City of Stockton Delta Water Supply Project is assumed to be operational under the DCR 2015. Delta-Mendota Canal–California Aqueduct Intertie is assumed to be operational under the DCR 2015. Contra Costa Water District Alternative Intake Project and Los Vaqueros expanded storage capacity of 160 TAF, are included in the DCR 2015 along with the South Bay Aqueduct rehabilitation, to 430 cfs capacity, from junction with California Aqueduct to Alameda County FC&WSD Zone 7.

Red Bluff Pumping Plant

The permanent TCC Pumping Plant and intake facilities are in place and the Red Bluff Diversion Dam is operated with gates out of the water all year as required in the NMFS BO Action I.3.1 providing unimpeded upstream and downstream fish passage.

Tehama Colusa Canal Capacity

Fish Passage Improvements at Red Bluff Pumping Plant and Fish Screen are included in the DCR 2015 allowing for a pumping capacity of 2,000 cfs into TCC.

Glenn Colusa Canal Capacity

3,000 cfs of total diversion capacity is assumed at the Sacramento River intake near Hamilton City into GCC.

Existing TCC-GCC Intertie

The existing TCC-GCC intertie provides flexibility in routing flows of up to 285 cfs, between TCC and GCC.

Williams Outlet

The Williams Outlet provides flexibility in routing flows of up to 65 cfs, between TCC and GCC.

Funks Reservoir

The existing Funks Reservoir includes a storage capacity of 2,250 acre-foot and is part of the TCC system. Funks Reservoir serves as a re-regulating reservoir to stabilize flows in the TCC downstream of Funks Reservoir as diverters come on line and off line. Funks Reservoir is not modeled explicitly in CALSIM II.

The Delta serves as a natural system of channels to transport river flows and reservoir storage to the CVP and SWP facilities in the south Delta, which export water to the projects' contractors through two pumping plants: SWP's Harvey O. Banks Pumping Plant and CVP's C.W. Jones Pumping Plant. Banks and Jones Pumping Plants supply water to agricultural and urban users throughout parts of the San Joaquin Valley, South Lahontan, Southern California, Central Coast, and South San Francisco Bay Area regions.

The Contra Costa Canal and the North Bay Aqueduct supply water to users in the northeastern San Francisco Bay and Napa Valley areas.

SWP Banks Pumping Plant Capacity

SWP Banks pumping plant has an installed capacity of about 10,668 cfs (two units of 375 cfs, five units of 1,130 cfs, and four units of 1,067 cfs). The SWP water rights for diversions specify a maximum of 10,350 cfs, but the U. S. Army Corps' of Engineers (ACOE) permit for SWP Banks Pumping Plant allows a maximum pumping of 6680 cfs. With additional diversions depending on Vernalis flows the total diversion can go up to 8,500 cfs during December 15th – March 15th. Additional capacity of 500 cfs (pumping limit up to 7,180 cfs) is allowed to reduce impact of NMFS BO Action 4.2.1 on SWP.

CVP C.W. Bill Jones Pumping Plant (Tracy PP) Capacity

The Jones Pumping Plant consists of six pumps including one rated at 800 cfs, two at 850 cfs, and three at 950 cfs. DMC-California Aqueduct Intertie that allows 400 cfs additional DMC capacity is assumed to be in place; therefore, pumping capacity is 4,600 cfs in all months.

CCWD Intakes

The Contra Costa Canal originates at Rock Slough, about four miles southeast of Oakley, and terminates after 47.7 miles at Martinez Reservoir. The canal and associated facilities are part of the CVP, but are operated and maintained by the Contra Costa Water District (CCWD). CCWD also operates a diversion on Old River. CCWD can divert water to the Los Vaqueros Reservoir to store good quality water when available and supply to its customers. In addition to the Rock Slough and Old River diversions, CCWD's Middle River Intake and Pump Station (previously known as the Alternative Intake Project) is included in the DCR 2015. The Alternative Intake Project is a new drinking water intake at Victoria Canal, about 2.5 miles east of Contra Costa Water District's (CCWD) existing intake on the Old River.

Regulatory Standards

Major regulatory standards that govern the operations of the CVP and SWP facilities are briefly described below. Specific assumptions related to key regulatory standards are also outlined below.

D-1641 Operations

The SWRCB Water Quality Control Plan (WQCP) and other applicable water rights decisions, as well as other agreements are important factors in determining the operations of both the Central Valley Project (CVP) and the State Water Project (SWP).

The December 1994 Accord committed the CVP and SWP to a set of Delta habitat protective objectives that were incorporated into the 1995 WQCP and later, were implemented by D-1641. Significant elements in the D-1641 standards include X2 standards, export/inflow (E/I) ratios, Delta water quality standards, real-time Delta Cross Channel operation, and San Joaquin flow standards.

Coordinated Operations Agreement (COA)

The CVP and SWP use a common water supply in the Central Valley of California. The DWR and Reclamation have built water conservation and water delivery facilities in the Central Valley in order to deliver water supplies to project contractors. The water rights of the projects are conditioned by the SWRCB to protect the beneficial uses of water within each respective project and jointly for the protection of beneficial uses in the Sacramento Valley and the Sacramento-San Joaquin Delta Estuary. The agencies coordinate and operate the CVP and SWP to meet the joint water right requirements in the Delta.

The Coordinated Operations Agreement (COA), signed in 1986, defines the project facilities and their water supplies, sets forth procedures for coordination of operations, identifies formulas for sharing joint responsibilities for meeting Delta standards, as the standards existed in SWRCB Decision 1485 (D-1485), 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 Projects, and provides for periodic review of the agreement.

CVPIA (b)(2) Assumptions

The previous 2008 Operations Criteria and Plan (OCAP) Biological Assessment (BA) modeling included a dynamic representation of Central Valley Project Improvement Act (CVPIA) 3406(b)(2) water allocation, management and related actions (B2). The selection of discretionary actions for use of B2 water in each year was based on a May 2003 Department of the Interior policy decision. The use of B2 water is assumed to continue in conjunction with the USFWS and NMFS BO RPA actions. The CALSIM II implementation does not explicitly account for the use of (b)(2) water, but rather assumes pre-determined USFWS BO upstream fish objectives for Clear Creek and Sacramento River below Keswick Dam in addition to USFWS and NMFS BO RPA actions for the American River, Stanislaus River, and Delta export restrictions.

USFWS Delta Smelt BO Actions

The USFWS Delta Smelt BO was released on December 15, 2008, in response to Reclamation’s request for formal consultation with the USFWS on the coordinated operations of the Central Valley Project (CVP) and State Water Project (SWP) in California. To develop CALSIM II modeling assumptions for the RPA documented in this BO, the Department led a series of meetings that involved members of fisheries and project agencies. This group has prepared the assumptions and CALSIM II implementations to represent the RPA in DCR 2015 CALSIM II simulation. The following actions of the USFWS BO RPA have been included in the DCR 2015 CALSIM II simulations:

- Action 1: Adult Delta smelt migration and entrainment (RPA Component 1, Action 1 – First Flush)
- Action 2: Adult Delta smelt migration and entrainment (RPA Component 1, Action 2)
- Action 3: Entrainment protection of larval and juvenile Delta smelt (RPA Component 2)
- Action 4: Estuarine habitat during Fall (RPA Component 3)
- Action 5: Temporary spring head of Old River barrier and the Temporary Barrier Project (RPA Component 2)

NMFS BO Salmon Actions

The NMFS Salmon BO on long-term actions of the CVP and SWP was released on June 4, 2009. To develop CALSIM II modeling assumptions for the RPA documented in this BO, the Department led a series of meetings that involved members of fisheries and project agencies. The following NMFS BO RPA have been included in the DCR 2015 CALSIM II simulations:

- Action I.1.1: Clear Creek spring attraction flows
- Action I.3.1: Operations after May 14, 2012: Operate RBDD with Gates Out
- Action I.4: Wilkins Slough operations
- Action II.1: Lower American River flow management
- Action III.1.3: Stanislaus River flows below Goodwin Dam
- Action IV.1.2: Delta Cross Channel gate operations
- Action IV.2.1: San Joaquin River flow requirements at Vernalis and Delta export restrictions
- Action IV.2.3: Old and Middle River flow management

For Action I.2.1, which calls for a percentage of years that meet certain specified end-of-September and end-of-April storage and temperature criteria resulting from the operation of Lake Shasta, no specific CALSIM II modeling code is implemented to simulate the performance measures identified.

Water Transfers

Lower Yuba River Accord (LYRA)

Lower Yuba River Accord (LYRA) Component 1 water is assumed to be transferred to South of Delta (SOD) State Water Project (SWP) contractors to help mitigate the impact of the NMFS BO on SWP exports during April and May. An additional 500 cfs of capacity is permitted at Banks Pumping Plant from July through September to export this water.

Phase 8 transfers

Phase 8 transfers are not included.

Short-term or Temporary Water Transfers

Short term or temporary transfers such as Sacramento Valley acquisitions conveyed through Banks PP are not included.

Specific Regulatory Assumptions

Upstream Reservoir Operations

Minimum flow below Lewiston Dam

The volume of the Trinity River instream flow requirement below Lewiston Dam ranges from 369 – 815 TAF/year, based on the Trinity EIS Preferred Alternative. The minimum flow volume is determined based on the Trinity River water year classification. The flow schedules from the Trinity Sites Reservoir Project were assumed for each water year type.

Trinity Lake End-of-September Minimum Storage

Based on the Trinity EIS Preferred Alternative, a minimum end-of-September carryover storage objective of 600 TAF at Trinity Reservoir was assumed to help provide coldwater resource protection. This objective may not be fully accomplished in extended drought periods.

Minimum flow below Whiskeytown Dam

Whiskeytown Dam is operated to meet the downstream water rights in the Clear Creek and 1963 Reclamation Proposal to USFWS and National Park Service (NPS). It is also operated to meet the predetermined CVPIA 3406(b)(2) flows, and the flow requirements identified under NMFS BO Action I.1.1.

Shasta Lake End-of-September Minimum Storage

Shasta Lake is operated such that the end-of-September carryover storage is 1900 TAF in non-critically dry years per the NMFS 2004 Winter-run Biological Opinion.

2009 NMFS BO Action 1.2.1 requires certain storage to be met at certain percentile of all years. A post-process of operations is used to determine whether or not these requirements are met.

Minimum flow below Keswick Dam

Keswick Dam is operated to meet the release schedule under SWRCB WR 90-5, which maintains 3,250 cfs in the Sacramento River. It is also operated to meet predetermined CVPIA 3406(b)(2) flows. NMFS BO Action I.2.2 includes actions that call for minimum flows to protect temperatures.

Flow Objective for Navigation at Wilkins Slough

NMFS BO Action 1.4 requires that to conserve cold water pool in Shasta Lake, Wilkins Slough is operated at a flow ranging from 3,500 cfs to 5,000 cfs based on the CVP water supply condition.

Minimum flow below Thermalito Diversion Dam

Thermalito diversion dam is operated to meet a minimum flow requirement of 700 cfs or 800 cfs in the Feather River low flow channel based on the 2006 Oroville Relicensing Settlement Agreement.

Minimum flow below Thermalito Afterbay Outlet

1983 DWR – DFG Agreement requires a minimum flow in the Feather River below Thermalito Afterbay Outlet to be between 750 cfs and 1,700 cfs, depending on the Oroville storage condition and the forecasted Feather River runoff condition.

Flow at Mouth of the Feather River

During the Feather River Service Area (FRSA) diversion season from April through September, a minimum flow of 2,800 cfs is maintained at the mouth of the Feather River depending on Lake Oroville inflow and FRSA allocation.

Minimum flow below Nimbus Dam

Nimbus Dam is operated to meet a minimum flow requirement based on the American River Flow Management under the NMFS BO Action II.1. Minimum release requirements range from 800 to 2,000 cfs based on a sequence of seasonal indices and adjustments.

American River Minimum flow at H Street Bridge

The minimum allowable flows in the Lower American River are defined by SWRCB Decision 893 (D-893) which states that, in the interest of fish conservation, releases should not ordinarily fall below 250 cfs between January 1 and September 15 or below 500 cfs at other times.

Minimum flow near Rio Vista

The minimum flow required on the Sacramento River at Rio Vista under the WQCP, SWRCB D-1641 is included. During September through December months, the flow requirement ranges from 3,000 cfs to 4,500 cfs, depending on the month and D-1641 40-30-30 index water year type.

Delta Outflow Index (Flow and Salinity)

SWRCB D-1641:

All flow based Delta outflow requirements per SWRCB D-1641 are included in the DCR 2015 simulation. Similarly, for the February through June period X2 standard is included.

USFWS BO (December, 2008) Action 4:

USFWS BO Action 4 requires additional Delta outflow to manage X2 in the fall months following the wet and above normal years to maintain average X2 for September and October no greater (more eastward) than 74 kilometers in the fall following wet years and 81 kilometers in the fall following above normal years.

Combined Old and Middle River Flows

USFWS BO restricts south Delta pumping to preserve certain OMR flows in three of its Actions: Action 1 to protect pre-spawning adult Delta smelt from entrainment during the first flush, Action 2 to protect pre-spawning adults from entrainment and from adverse hydrodynamic conditions, and Action 3 to protect larval Delta smelt from entrainment. CALSIM II simulates these actions to a limited extent.

Brief description of USFWS BO Actions 1-3 implementations in CALSIM is as follows: Action 1 is onset based on a turbidity trigger that takes place during or after December. This action requires limit on exports so that the average daily OMR flow is no more negative than -2,000 cfs for a total duration of 14 days, with a 5-day running average no more negative than 2,500 cfs (within 25 percent of the monthly criteria). Action 1 ends after 14 days of duration or when Action 3 is triggered based on a temperature criterion. Action 2 starts immediately after Action 1 and requires range of net daily OMR flows to be no more negative than -1,250 to -5,000 cfs (with a 5-day running average within 25 percent of the monthly criteria). The Action continues until Action 3 is triggered. Action 3 also requires net daily OMR flow to be no more negative than -1,250 to -5,000 cfs based on a 14 day running average (with a simultaneous 5-day running average within 25 percent). Although the range is similar to Action 2, the Action implementation is different. Action 3 continues until June 30 or when water temperature reaches a certain threshold.

NMFS BO Action 4.2.3 requires OMR flow management to protect emigrating juvenile winter-run, yearling spring-run, and Central Valley steelhead within the lower Sacramento and San Joaquin rivers from entrainment into south Delta channels and at the export facilities in the south Delta. This action requires reducing exports from January 1 through June 15 to limit negative OMR flows to -2,500 to -5,000 cfs. CALSIM II assumes OMR flows required in NMFS BO are covered by OMR flow requirements developed for actions 1 through 3 of the USFWS BO.

South Delta Export-San Joaquin River Inflow Ratio

NMFS BO Action 4.2.1 requires exports to be capped at a certain fraction of San Joaquin River flow at Vernalis during April and May while maintaining a health and safety pumping of 1,500 cfs. This export constraint is included.

Exports at the South Delta Intakes

Exports at Jones and Banks Pumping Plant are restricted to their permitted capacities per SWRCB D-1641 requirements. In addition, the south Delta exports are subjected Vernalis flow based export limits during April and May as required Action 4.2.1. Additional 500 cfs pumping is allowed to reduce impact of NMFS BO Action 4.2.1 on SWP during July through September period.

D-1641 1:1 CVP/SWP export limit based on the Vernalis flow from April 15 – May 15, is also included.

Under D-1641 the combined export of the CVP Tracy Pumping Plant and SWP Banks Pumping Plant is limited to a percentage of Delta inflow. The percentages range from 35% to 45% during February depending on the January eight river index and 35% during March through June months. For rest of the months 65% of the Delta inflow is allowed to be exported.

Delta Water Quality

The DCR 2015 simulation includes compliance with the SWRCB D-1641 salinity requirements. However, not all salinity requirements are included as CALSIM II is not capable of predicting salinities in the Delta. Instead, empirically based equations and models are used to relate interior salinity conditions with the flow conditions. DWR’s Artificial Neural Network (ANN) trained for salinity is used to predict and interpret salinity conditions at Emmaton, Jersey Point, Rock Slough and Collinsville stations. Emmaton and Jersey Point standards are for protecting water quality conditions for agricultural use in the western Delta and they are in effect from April 1st to August 15th. The EC requirement at Emmaton varies from 0.45 mmhos/cm to 2.78 mmhos/cm, depending on the water year type. The EC requirement at Jersey Point varies from 0.45 mmhos/cm to 2.20 mmhos/cm, depending on the water year type. Rock Slough standard of 250 mg/L chloride is for protecting water quality conditions for M&I use for water through the Contra Costa Canal. It is a year-round standard. D-1641 also requires a certain number of days in a year with chloride concentration less than 150 mg/L. The number of days required is dependent upon the water year type. A pre-processed fixed number of days is used as input to CALSIM II to comply with 150 mg/L chloride standard at Rock Slough. Collinsville standard is applied during October through May months to protect the water quality conditions for the migrating fish species, and it varies between 12.5 mmhos/cm in May and 19.0 mmhos/cm in October.

Operations Criteria

Delta Cross Channel Gate Operations

SWRCB D-1641 DCC standards provide for closure of the DCC gates for fisheries protection at certain times of the year. From November through January, the DCC may be closed for up to 45 days for fishery protection purposes. From February 1 through May 20, the gates are closed for fishery protection purposes. The gates may also be closed for 14 days for fishery protection purposes during the May 21 through June 15 time period. Reclamation determines the timing and duration of the closures after discussion with USFWS, DFG, and NMFS.

NMFS BO Action 4.1.2 requires gates to be operated as described in the BO based on presence of salmonids and water quality from October 1 through December 14; and gates to be closed from

December 15 to January 31, except short-term operations to maintain water quality. CALSIM II includes NMFS BO DCC gate operations in addition to the D-1641 gate operations. When the daily flows in the Sacramento River at Wilkins Slough exceeds 7,500 cfs (flow assumed to flush salmon into the Delta), DCC is closed for a certain number of days per month.

Allocation Decisions

CALSIM II includes allocation logic for determining deliveries to north-of-Delta and south-of-Delta CVP and SWP contractors. The delivery logic uses runoff forecast information, which incorporates uncertainty in the hydrology and standardized rule curves (i.e. Water Supply Index versus Demand Index Curve). The rule curves relate forecasted water supplies to deliverable "demand," and then use deliverable "demand" to assign subsequent delivery levels to estimate the water available for delivery and carryover storage. Updates of delivery levels occur monthly from January 1 through May 1 for the SWP and March 1 through May 1 for the CVP as runoff forecasts become more certain. The south-of-Delta SWP delivery is determined based on water supply parameters and operational constraints. The CVP system wide delivery and south-of-Delta delivery are determined similarly upon water supply parameters and operational constraints with specific consideration for export constraints.

San Luis Operations

CALSIM II sets targets for San Luis storage each month that are dependent on the current South-of-Delta allocation and upstream reservoir storage. When upstream reservoir storage is high, allocations and San Luis fill targets are increased. During a prolonged drought when upstream storage is low, allocations and fill targets are correspondingly low. The San Luis rule curve is managed to minimize situations in which shortages may occur due to lack of storage or exports.

CALSIM II Assumptions for WSIP 2030

The WSIP 2030 without project CALSIM II model was provided by the CWC. The assumptions and operating criteria are identical to DCR 2015 assumptions except for hydrologic inflows and sea level rise due to climate change.

CALSIM II Assumptions for WSIP 2070

The WSIP 2070 without project CALSIM II model was provided by the CWC. The assumptions and operating criteria are identical to DCR 2015 except for hydrologic inflows and sea level rise due to climate change.

DSM2 Assumptions for Current Conditions

The Current Conditions DSM2 model was developed from the baseline WSIP 2030 study. The boundary conditions and dispersion factors in the CWC model representing 2030 conditions were removed to create the current conditions DSM2 study. Model input data from DWR's Bay Delta Office Modeling Support Branch Delta Modeling Section was incorporated to represent Current Conditions. All other data used in the Current Conditions study is consistent with the CWC 2030 DSM2 model.

River Flows

For the Current Conditions (DCR 2015) DSM2 simulation, the river flows at the DSM2 boundaries are based on the monthly flow time series from DWR CALSIM II DCR 2015 model results.

Tidal Boundary

The tidal boundary condition at Martinez is provided by an adjusted astronomical tide normalized for sea level rise (Ateljevich and Yu, 2007).

Water Quality

Martinez EC

Martinez EC boundary condition is estimated using the G-model based on the net Delta outflow simulated in CALSIM II and the pure astronomical tide (Ateljevich, 2001).

Vernalis EC

For the Current Condition DSM2 simulation, the Vernalis EC boundary condition is based on the monthly San Joaquin EC time series estimated in the DWR DCR 2015 CALSIM II model results.

Morphological Changes

No additional morphological changes were assumed as part of the Current Condition simulation. DSM2 model and grid developed as part of the 2009 recalibration effort (CH2M HILL, 2009) was used as part of the modeling.

DSM2 Assumptions for WSIP 2030 and WSIP 2070

The WSIP Baseline DSM2 without project models for 2030 and 2070 conditions were provided by the CWC.

Table 1
CALSIM II Model Assumptions

CALSIM II Modeling Assumptions from DWR State Water Project Delivery Capability Report 2015

	Existing Condition[1]
Planning Horizon	2015
Period of Simulation	82 years (1922-2003)
HYDROLOGY	
Level of Development (land use)	2030 Level[2]
DEMANDS	
North of Delta (excluding the American River)	
CVP	Land-use based, full build-out of contract amounts[3]
SWP (FRSA)	Land-use based, limited by contract amounts[4, 7]
Non-project	Land-use based, limited by water rights and SWRCB Decisions for Existing Facilities
Antioch Water Works	Pre-1914 water right
Federal refuges	Firm Level 2 water needs[5]
American River Basin	
Water rights	Year 2025, full water rights[6]
CVP	Year 2025, full contracts, including Freeport Regional Water Project[6]
San Joaquin River Basin[8]	
Friant Unit	Limited by contract amounts, based on current allocation policy
Lower basin	Land-use based, based on district level operations and constraints
Stanislaus River basin[9, 17]	Land-use based, based on New Melones Interim Operations Plan, up to full CVP Contractor deliveries (155 TAF/yr) depending on New Melones Index
South of Delta	
CVP	Demand based on contract amounts[3]
Federal refuges	Firm Level 2 water needs[5]
CCWD	195 TAF/yr CVP contract supply and water rights[10]
SWP [4, 11]	Demand based on full Table A amounts (4.13 MAF/yr)
Article 56	Based on 2001-2008 contractor requests
Article 21	MWD demand up to 200 TAF/month (December-March) subject to conveyance capacity, KCWA demand up to 180 TAF/month, and other contractor demands up to 34 TAF/month, subject to conveyance capacity
North Bay Aqueduct	77 TAF/yr demand under SWP contracts, up to 43.7 cfs of excess flow under Fairfield, Vacaville and Benicia Settlement Agreement NOD Allocation Settlement Agreement terms for Napa and Solano [15]

	Existing Condition[1]
FACILITIES	
System-wide	Existing facilities
Sacramento Valley	
Shasta Lake	Existing, 4,552 TAF capacity
Red Bluff Diversion Dam	Diversion dam operated with gates out all year, NMFS BO (Jun 2009) Action I.3.1[17];assume permanent facilities in place
Colusa Basin	Existing conveyance and storage facilities
Lower American River	Hodge criteria for diversion at Fairbairn
Upper American River	PCWA American River pump station
Lower Sacramento River	Freeport Regional Water Project
Fremont Weir	Existing Weir
Delta Export Conveyance	
SWP Banks Pumping Plant (South Delta)	Physical capacity is 10,300 cfs, permitted capacity is 6,680 cfs in all months and up to 8,500 cfs during Dec 15th - Mar 15th depending on Vernalis flow conditions[18]; additional capacity of 500 cfs (up to 7,180 cfs) allowed Jul–Sep for reducing impact of NMFS BO (Jun 2009) Action IV.2.1[17] on SWP[19]
CVP C.W. "Bill" Jones Pumping Plant (formerly Tracy PP)	Permit capacity is 4,600 cfs in all months (allowed for by the Delta-Mendota Canal- California Aqueduct Intertie)
Upper Delta-Mendota Canal Capacity	Exports limited to 4,200 cfs plus diversion upstream from DMC constriction plus 400 cfs Delta-Mendota Canal-California Aqueduct Intertie
Los Vaqueros Reservoir	Enlarged storage capacity (160 TAF), existing pump location, Alternate Intake Project included[13]
San Joaquin River	
Millerton Lake (Friant Dam)	Existing, 520 TAF capacity
Lower San Joaquin River	City of Stockton Delta Water Supply Project, 30 mgd capacity
South of Delta (CVP/SWP project facilities)	
South Bay Aqueduct	SBA rehabilitation, 430 cfs capacity from junction with California Aqueduct to Alameda County FC&WSD Zone 7 point
California Aqueduct East Branch	Existing capacity
REGULATORY STANDARDS	
Trinity River	
Minimum Flow below Lewiston Dam	Trinity EIS Preferred Alternative (369-815 TAF/yr)
Trinity Reservoir end-of-September minimum storage	Trinity EIS Preferred Alternative (600 TAF/yr as able)

	Existing Condition[1]
Clear Creek	
Minimum flow below Whiskeytown Dam	Downstream water rights, 1963 Reclamation proposal to USFWS and NPS, predetermined Central Valley Protection Improvement Act 3406(b)(2) flows[20], and NMFS BO (Jun 2009) Action I.1.1[17]
Upper Sacramento River	
Shasta Lake end-of-September minimum storage	NMFS 2004 Winter-run Biological Opinion (1,900 TAF in non-critical dry years), and NMFS BO (Jun 2009) Action I.2.1[17]
Minimum flow below Keswick Dam	Flows for the SWRCB Water Rights Order 90-5, predetermined Central Valley Protection Improvement Act 3406(b)(2) flows, and NMFS BO (Jun 2009) Action I.2.2[17]
Feather River	
Minimum flow below Thermalito Diversion Dam	2006 Settlement Agreement (700 / 800 cfs)
Minimum flow below Thermalito Afterbay outlet	1983 DWR, DFG agreement (750 – 1,700 cfs)
Yuba River	
Minimum flow below Daguerre Point Dam	D-1644 Operations (Lower Yuba River Accord)[14]
American River	
Minimum flow below Nimbus Dam	American River Flow Management as required by NMFS BO (Jun 2009) Action II.1[17]
Minimum flow at H Street Bridge	SWRCB D-893
Lower Sacramento River	
Minimum flow near Rio Vista	SWRCB D-1641
Mokelumne River	
Minimum flow below Camanche Dam	Federal Energy Regulatory Commission 2916-029[12], 1996 (Joint Settlement Agreement) (100 – 325 cfs)
Minimum flow below Woodbridge Diversion Dam	Federal Energy Regulatory Commission 2916-029, 1996 (Joint Settlement Agreement) (25 – 300 cfs)
Stanislaus River	
Minimum flow below Goodwin Dam	1987 Reclamation, DFG agreement, and flows required for NMFS BO (Jun 2009) Action III.1.2 and III.1.3[17]
Minimum dissolved oxygen	SWRCB D-1422

	Existing Condition1
Merced River	
Minimum flow below Crocker- Huffman Diversion Dam	Davis-Grunsky (180 – 220 cfs, Nov – Mar), and Cowell Agreement
Minimum flow at Shaffer Bridge	Federal Energy Regulatory Commission 2179 (25 – 100 cfs)
Tuolumne River	
Minimum flow at Lagrange Bridge	Federal Energy Regulatory Commission 2299-024, 1995 (Settlement Agreement) (94 – 301 TAF/yr)
Updated Tuolumne River	New Don Pedro operations
San Joaquin River	
San Joaquin River below Friant Dam/Mendota Pool	Full San Joaquin River Restoration flows
Maximum salinity near Vernalis	SWRCB D-1641
Minimum flow near Vernalis	SWRCB D1641. VAMP is turned off since the San Joaquin River Agreement has expired.[16] NMFS BO (Jun 2009) Action IV.2.1 Phase II flows not provided due to lack of agreement for purchasing water
Sacramento-San Joaquin Delta	
Delta Outflow Index (flow and salinity)	SWRCB D-1641 and FWS BO (Dec 2008) Action 4[17]
Delta Cross Channel gate operation	SWRCB D-1641 with additional days closed from Oct 1-Jan 31 based on NMFS BO (Jun 2009) Action IV.1.2[17] (closed during flushing flows from Oct 1-Dec 14 unless adverse water quality conditions)
South Delta exports (Jones PP and Banks PP)	SWRCB D-1641 export limits as required by NMFS BO (June 2009) Action IV.2.1 Phase II[17] (additional 500 cfs allowed for Jul-Sep for reducing impact on SWP)[19]
Combined Flow in Old and Middle River (OMR)	FWS BO (Dec 2008) Actions 1-3 and NMFS BO (Jun 2009) Action IV.2.3[17]
OPERATIONS CRITERIA: RIVER-SPECIFIC	
Upper Sacramento River	
Flow objective for navigation (Wilkins Slough)	NMFS BO (Jun 2009) Action I.4[17]; 3,250 – 5,000 cfs based on CVP water supply condition
American River	
Folsom Dam flood control	Variable 400/670 flood control diagram (without outlet modifications)
Feather River	
Flow at mouth of Feather River (above Verona)	Maintain the DFG/DWR flow target of 2,800 cfs for Apr - Sep dependent on Oroville inflow and FRSA allocation
Stanislaus River	
Flow below Goodwin Dam	Revised Operations Plan and NMFS BO (Jun 2009) Action III.1.2 and III.1.3[17]

	Existing Condition[1]
San Joaquin River	
Salinity at Vernalis	Grasslands Bypass Project (full implementation)
OPERATIONS CRITERIA: SYSTEMWIDE	
CVP Water Allocation	
CVP settlement and exchange	100% (75% in Shasta critical years)
CVP refuges	100% (75% in Shasta critical years)
CVP agriculture	100% - 0% based on supply. South-of-Delta allocations are additionally limited due to D-1641, FWS BO (Dec 2008), and NMFS BO (Jun 2009) export restrictions[17]
CVP municipal & industrial	100% - 50% based on supply. South-of-Delta allocations are additionally limited due to D-1641, FWS BO (Dec 2008), and NMFS BO (Jun 2009) export restrictions[17]
SWP Water Allocation	
North of Delta (FRSA)	Contract-specific NOD Allocation Settlement Agreement terms for Butte and Yuba [15]
South of Delta (including North Bay Aqueduct)	Based on supply; equal prioritization between Ag and M&I based on Monterey Agreement; allocations are limited due to D-1641, FWS BO (Dec 2008), and NMFS BO (Jun 2009) export restrictions[17] NOD Allocation Settlement Agreement terms for Napa and Solano [15]
CVP/SWP Coordinated Operations	
Sharing of responsibility for in-basin use	1986 Coordinated Operations Agreement (FRWP and EBMUD 2/3 of the North Bay Aqueduct diversions are considered as Delta export, 1/3 of the North Bay Aqueduct diversion is considered as in-basin use)
Sharing of surplus flows	1986 Coordinated Operations Agreement
Sharing of restricted export capacity for project-specific priority pumping	Equal sharing of export capacity under SWRCB D-1641, FWS BO (Dec 2008), and NMFS BO (Jun 2009) export restrictions[17]
Water transfers	Acquisitions by SWP contractors are wheeled at priority in Banks Pumping Plant over non-SWP users; LYRA included for SWP contractors[19]
Sharing of export capacity for lesser priority and wheeling-related pumping	Cross Valley Canal wheeling (max of 128 TAF/yr), CALFED ROD defined Joint Point of Diversion (JPOD)
San Luis Reservoir	San Luis Reservoir is allowed to operate to a minimum storage of 100 TAF
CVPIA 3406(b)(2)	
Policy decision	Per May 2003 Department of Interior decision
Allocation	800 TAF/yr, 700 TAF/yr in 40-30-30 dry years, and 600 TAF/yr in 40-30-30 critical years
Actions	Pre-determined non-discretionary FWS BO (Dec 2008) upstream fish flow objectives (Oct-Jan) for Clear Creek and Keswick Dam, non-discretionary NMFS BO

	Existing Condition[1]
	(Jun 2009) actions for the American and Stanislaus Rivers, and NMFS BO (Jun 2009) actions leading to export restrictions[17]
Accounting adjustments	No discretion assumed under FWS BO (Dec 2008) and NMFS BO (Jun 2009)[17], no accounting
WATER MANAGEMENT ACTIONS	
Water Transfer Supplies (long term programs)	
Lower Yuba River Accord[19]	Yuba River acquisitions for reducing impact of NMFS BO export restrictions[17] on SWP
Phase 8	None
Water Transfers (short term or temporary programs)	
Sacramento Valley acquisitions conveyed through Banks PP[21]	Post analysis of available capacity

Notes:

[1] These assumptions have been developed under the direction of the Department of Water Resources and Bureau of Reclamation management team for the BDCP HCP and EIR/EIS. Additional modifications were made by Reclamation for its October 2014 NEPA NAA baselines and by DWR for the 2015 DCR.

[2] The Sacramento Valley hydrology used in the Existing Condition CALSIM II model reflects 2020 land-use assumptions associated with Bulletin 160-98. The San Joaquin Valley hydrology reflects draft 2030 land-use assumptions developed by Reclamation to support Reclamation studies.

[3] CVP contract amounts have been reviewed and updated according to existing and amended contracts, as appropriate. Assumptions regarding CVP agricultural and M&I service contracts and Settlement Contract amounts are documented in the Delivery Specifications attachments to the BDCP CALSIM assumptions document.

[4] SWP contract amounts have been updated as appropriate based on recent Table A transfers/agreements. Assumptions regarding SWP agricultural and M&I contract amounts are documented in the Delivery Specifications attachments to the BDCP CALSIM assumptions document.

[5] Water needs for Federal refuges have been reviewed and updated, as appropriate. Assumptions regarding firm Level 2 refuge water needs are documented in the Delivery Specifications attachments to the BDCP CALSIM assumptions document. Refuge Level 4 (and incremental Level 4) water is not included.

[6] Assumptions regarding American River water rights and CVP contracts are documented in the Delivery Specifications attachments to the BDCP CALSIM assumptions document. The Sacramento Area Water Forum agreement, its dry year diversion reductions, Middle Fork Project operations and “mitigation” water is not included.

[7] Demand for rice straw decomposition water from Thermalito Afterbay was added to the model and updated to reflect historical diversion from Thermalito in the October through January period.

[8] The new CALSIM II representation of the San Joaquin River has been included in this model package (CALSIM II San Joaquin River Model, Reclamation, 2005). Updates to the San Joaquin River have been included since the preliminary model release in August 2005. The model reflects the difficulties of on-going groundwater overdraft problems. The 2030 level of development representation of the San Joaquin River Basin does not make any attempt to offer solutions to groundwater overdraft problems. In addition, a dynamic groundwater simulation is not yet developed for the San

Joaquin River Valley. Groundwater extraction/ recharge and stream-groundwater interaction are static assumptions and may not accurately reflect a response to simulated actions. These limitations should be considered in the analysis of result

[9] The CALSIM II model representation for the Stanislaus River does not necessarily represent Reclamation's current or future operational policies. A suitable plan for supporting flows has not been developed for NMFS BO (Jun 2009) Action III.1.3.

[10] The actual amount diverted is reduced because of supplies from the Los Vaqueros project. The existing Los Vaqueros storage capacity is 100 TAF, and future storage capacity is 160 TAF. Associated water rights for Delta excess flows are included.

[11] Under DCR 2015 and the Future No Action baseline, it is assumed that SWP Contractors can take delivery of all Table A allocations and Article 21 supplies. Article 56 provisions are assumed and allow for SWP Contractors to manage storage and delivery conditions such that full Table A allocations can be delivered. Article 21 deliveries are limited in wet years under the assumption that demand is decreased in these conditions. Article 21 deliveries for the NBA are dependent on excess conditions only, all other Article 21 deliveries also require that San Luis Reservoir be at capacity and that Banks PP and the California Aqueduct have available capacity to divert from the Delta for direct delivery.

[12] Mokelumne River flows reflect EBMUD supplies associated with the Freeport Regional Water Project.

[13] The CCWD Alternate Intake Project, an intake at Victoria Canal, which operates as an alternate Delta diversion for Los Vaqueros Reservoir.

[14] D-1644 and the Lower Yuba River Accord are assumed to be implemented for Existing baselines. The Yuba River is not dynamically modeled in CALSIM II. Yuba River hydrology and availability of water acquisitions under the Lower Yuba River Accord are based on modeling performed and provided by the Lower Yuba River Accord EIS/EIR study team.

[15] This includes draft logic for the updated Allocation Settlement Agreement for four NOD contractors: Butte, Yuba, Napa and Solano.

[16] It is assumed that D-1641 requirements will be in place in 2030, and VAMP is turned off.

[17] In cooperation with Reclamation, National Marine Fisheries Service, Fish and Wildlife Service, and CA Department of Fish and Game, the CA Department of Water Resources has developed assumptions for implementation of the FWS BO (Dec 15th 2008) and NMFS BO (June 4th 2009) in CALSIM II.

[18] Current ACOE permit for Banks PP allows for an average diversion rate of 6,680 cfs in all months. Diversion rate can increase up to 1/3 of the rate of San Joaquin River flow at Vernalis during Dec 15th – Mar 15th up to a maximum diversion of 8,500 cfs, if Vernalis flow exceeds 1,000 cfs.

[19] Acquisitions of Component 1 water under the Lower Yuba River Accord, and use of 500 cfs dedicated capacity at Banks PP during Jul-Sep, are assumed to be used to reduce as much of the impact of the Apr-May Delta export actions on SWP contractors as possible.

[20] Delta actions, under USFWS discretionary use of CVPIA 3406(b)(2) allocations, are no longer dynamically operated and accounted for in the CALSIM II model. The Combined Old and Middle River Flow and Delta Export restrictions under the FWS BO (Dec 15th 2008) and the NMFS BO (June 4th 2009) severely limit any discretion that would have been otherwise assumed in selecting Delta actions under the CVPIA 3406(b)(2) accounting criteria. Therefore, it is anticipated that CVPIA 3406(b)(2) account availability for upstream river flows below Whiskeytown, Keswick and Nimbus Dams would be very limited. It appears the integration of BO RPA actions will likely exceed the 3406(b)(2) allocation in all water year types. For these baseline simulations, upstream flows on the Clear Creek and Sacramento River are pre-determined

based on CVPIA 3406(b)(2) based operations from the Aug 2008 BA Study 7.0 and Study 8.0 for Existing and Future No Action baselines respectively. The procedures for dynamic operation and accounting of CVPIA 3406(b)(2) are not included in the CALSIM II model.

[21] Only acquisitions of Lower Yuba River Accord Component 1 water are included.

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HEC5Q Modeling for the Sites Reservoir Project

Development of WSIP Climate Scenarios for Use in HEC5Q

The section describes the updates to HEC5Q that were necessary for performing temperature benefits analysis to support the Water Storage Investment Program (WSIP) application.

Background

HEC5Q Model Background and Limitations

Over the last 15 years, the US Bureau of Reclamation (Reclamation) has developed applications of the US Army Corps of Engineers HEC5Q model for evaluation of water temperatures on the Sacramento River, American River, and Stanislaus Rivers. Reclamation made substantial revisions to these models for use in their NEPA EIS analysis of the Coordinate Long-Term Operations of the Central Valley Project and State Water Project (LTO EIS) (Reclamation, 2015). The HEC5Q model was designed to work with the model results of the CALSIM II model and was calibrated for historical meteorological conditions. For the LTO EIS analysis, procedures were established to incorporate operational assumptions related to selective withdrawal features at Shasta Lake (temperature control device). HEC5Q is listed in Table 4-14 of the WSIP Technical Reference document as one of the applicable water quality models that can be used to quantify physical changes in water temperatures.

The regulations for the WSIP require that the models used in the evaluation of the Project incorporate changes associated with the WSIP 2030 and 2070 climate conditions. This required establishing Without Project versions of the HEC5Q models that reflected the change in temperatures associated with the WSIP 2030 and 2070 climate conditions. The LTO EIS HEC5Q model for the Sacramento River was modified to adjust for increases in temperature associated with each climate condition. Further, the operational assumptions related to selective withdrawal features at Shasta Lake were adjusted to consider the effects of each climate condition on the management of reservoir release temperatures and the extent to which water temperature objectives could be achieved within the critical reaches downstream of these reservoirs.

The HEC5Q models calculate the change over time in water temperatures in reservoirs and rivers based on estimates of equilibrium water temperature and the rate at which heat exchange in the water will change as it approaches equilibrium. These estimates are based on meteorological and environmental information associate with the geographic location being studied. Based on temperature information included in the WSIP statewide gridded monthly data products (CWC, 2016) model inputs for equilibrium temperatures were adjusted for the WSIP climate scenarios.

In applying the HEC5Q models, water temperature objectives downstream of Shasta Lake are required for the model to select what elevation to withdrawal releases from. The temperature of water varies with depth in a reservoir depending on the degree to which the profile is stratified (due to temperature and density variation). Warmer water is less dense than cooler water and will move to the top of the reservoir. Much of the warming of a reservoir over the spring and early summer months comes from solar radiation through the surface of the lake. To meet temperature objectives downstream of the reservoir, water is selectively withdrawn at an elevation that provides water cool enough to meet the downstream objective. The Shasta Lake schedule is varied each year of simulation based on reservoir storage and inflow conditions and expected changes in water temperature that occur between the reservoirs and the objective locations in the rivers. Based on reiterative analysis, schedules of temperature objectives are modified to reflect the effects of the WSIP climate conditions.

The HEC5Q model provides a projection of how the water temperature trends with changes in storage and flows in the water resources system. The model does not provide a prediction of what future water temperatures will be. This model is intended for use in comparative analysis and demonstration of potential effects in the setting of hydrologic information considering historical variability and the effects of climate change. It should be recognized that the HEC5Q model is a simplified and generalized representation of complex hydrodynamic and thermodynamic processes in the riverine environment. While the HEC5Q model can provide 6-hour to daily timestep information at any location within the model domain, evaluation of the model results should consider the limitations of the information used to calibrate the model and the inputs to the model for the specific conditions being evaluated. Because the CALSIM II model results used are subject to specific location and monthly timestep limitations, care must be used in drawing any conclusion from the HEC5Q model results that is finer in spatial and temporal resolution than the CALSIM II model used. Nevertheless, HEC5Q is the best available tool for this evaluation of system effects related to the Project.

Approach

HEC5Q Changes

Updates were made to the Trinity-Sacramento River Reclamation HEC5Q models used for the Coordinated Long-Term Operations of the Central Valley Project and State Water Project Environmental Impact Study (LTO EIS) to support temperature modeling for the WSIP Application process. The following changes were made to better simulate water temperatures at Current Conditions, and in the 2030 and 2070 climate scenarios developed by the California Water Commission (CWC) for the WSIP Application process: 1) increasing the equilibrium temperatures based on the calculated increase in air temperature for the WSIP 2030 and 2070 climate scenarios, and 2) adjusting the Shasta release temperature schedule assumptions in the Trinity-Sacramento HEC5Q model.

Equilibrium Temperature Adjustment

Changes in climate can have a myriad of potential and unpredictable effects on water temperatures. However, several studies indicate that increasing air temperatures result in increased water temperatures, regardless of climate scenario (Webb and Walsh 2004, Cushing 1997, Isaak et al. 2012). Since air temperatures are predicted to increase under the WSIP 2030 and 2070 climate scenarios, an increase in water temperature is assumed.

With the limited data provided, equilibrium temperatures were increased based on the increased air temperature in the WSIP 2030 and 2070 climate scenarios. This approach was supported with an analysis between observed air temperature data from the Gerber and Nicolaus CIMIS stations and the calculated equilibrium temperatures at those two stations. The equilibrium temperatures were developed as part of the Sacramento River Water Quality Extension effort conducted by Reclamation (Smith et al. 2013). The period of record of the observed air temperature data was 01Jan2001 to 31Dec2011. The observed air temperature was averaged by month and then plotted against the calculated current climate equilibrium temperature as shown in Figures 1 and 2. Two linear regressions were performed on the data, one regression for the fall and winter months (October-March) and one regression for the spring and summer months (April-September). Regressions at Gerber indicate a 1:1 ratio of air temperature to equilibrium temperature during fall and winter months and 1:0.8 ratio of air temperature to equilibrium temperature in spring and summer months. Regressions at Nicolaus indicate a 1:1 ratio, year-round. The calculation of the climate adjusted equilibrium temperature, based on these regressions, is described in the next section.

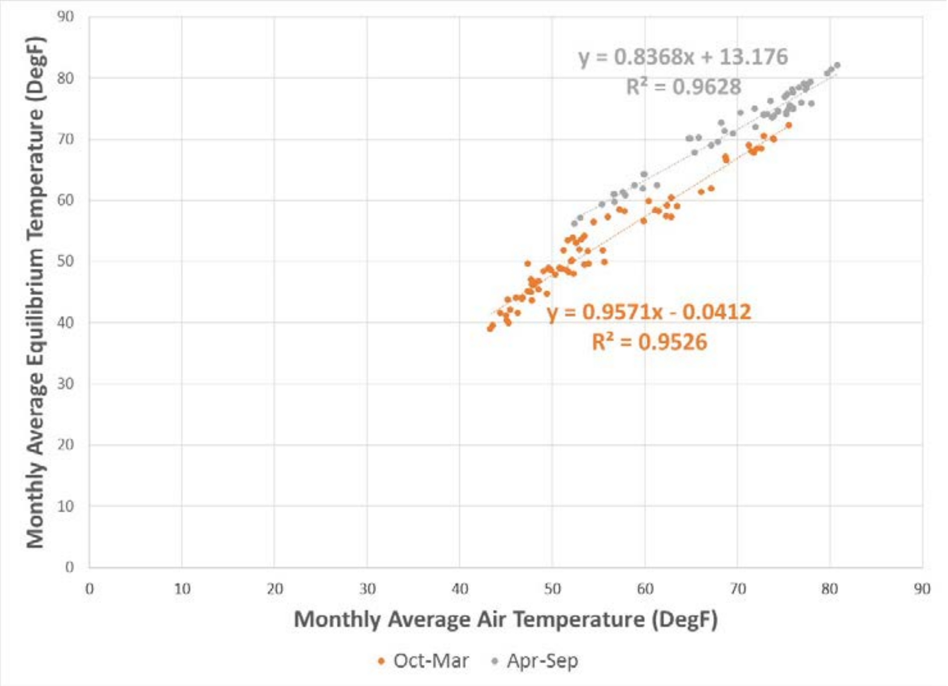

Figure 1: Gerber CIMIS Station Monthly Average Observed Air Temperature vs. Monthly Average Calculated Equilibrium Temperature

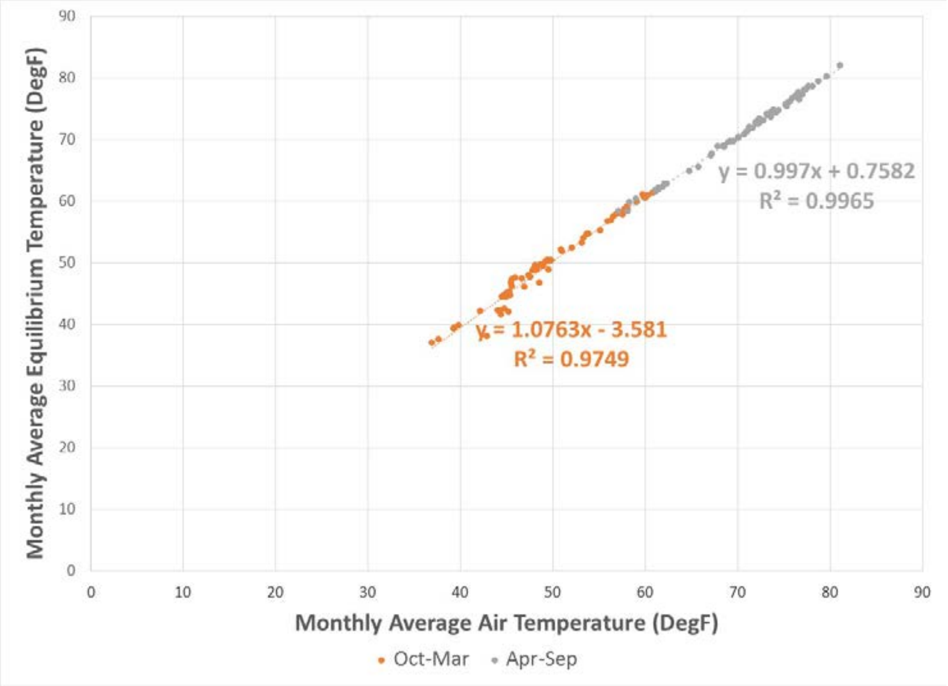

Figure 2: Nicolaus CIMIS Station Monthly Average Observed Air Temperature vs. Monthly Average Calculated Equilibrium Temperature

After performing the regressions to determine the seasonal adjustment factor, the following process was used to calculate the climate scenario adjusted equilibrium temperatures. The WSIP climate scenario data was obtained from the CWC website (Water Commission 2016). The data comes in files that correspond to grid cells with different latitude and longitudes. In order to perform the equilibrium temperature adjustments, the latitude and longitude coordinates of the Gerber and Nicolaus California Irrigation Management Information System (CIMIS) stations the meteorology data is based from were obtained and then matched with the closest WSIP climate scenario grid cell (Table 1). The climate scenario data that corresponded to that grid cell was then retrieved for the two CIMIS stations.

Table 1: CIMIS Station Latitude and Longitude coordinates and the corresponding WSIP grid cell coordinates

Station	**CIMIS**		**WSIP**	
	Latitude	*Longitude*	*Latitude*	*Longitude*
Gerber	40.05	122.16	40.03125	122.15625
Nicolaus	38.87	121.55	38.84375	121.53125

After retrieving the data, the maximum and minimum monthly air temperatures (Tmax & Tmin) in the WSIP climate scenario data were converted to Fahrenheit from Celsius to match the units of the HEC5Q model. For each WSIP climate scenario, the average monthly air temperature (Tavg) was calculated by averaging the maximum and minimum monthly air temperatures (Tmax + Tmin)/2. Then, the monthly average temperature shifts from Current Climate to WSIP 2030 and 2070 were calculated by subtracting the WSIP Current Climate Tavg from the 2030 Tavg and the 2070 Tavg, respectively. Gerber temperature shifts for April to September were multiplied by 0.8 to reflect the equilibrium temperature ratio described earlier. This difference was added to the existing HEC5Q Current Climate Equilibrium Temperature time series (described earlier) to calculate the climate adjusted equilibrium temperature for 2030 and 2070. Figures A1 to A6 in Appendix A show the 2030 and 2070 temperature shifts for each of the Gerber and Nicolaus CIMIS stations.

It should be noted that the WSIP Current Climate and the LTO EIS HEC5Q Current Climate are based on different climate analyses that do not reflect the same set of assumptions. However, for the WSIP climate updates, it was assumed that both represent the same current climate. In addition, the California Department of Water Resources 2015 Delivery Capability Report (DCR 2015) CALSIM II model was used to analyze the benefits of Sites reservoir under current climate conditions. The WaterFix HEC5Q Current Climate inputs are used for DCR 2015. See Figure 3 for a schematic of the climate adjustment process and climate scenarios used. With project and without project refer to without or with Sites Reservoir.

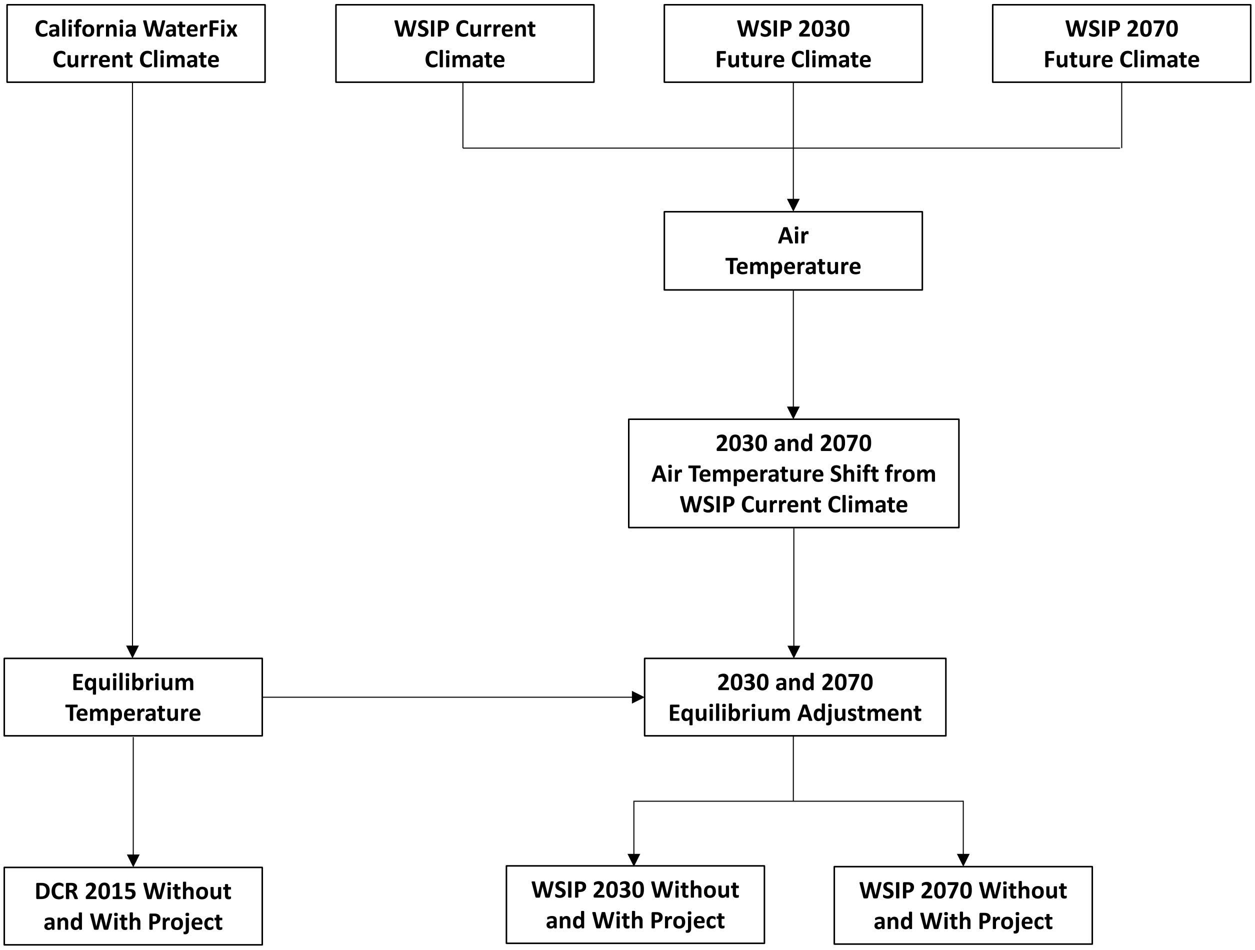

Figure 3: Climate scenarios and climate update process used to update equilibrium temperature for the Sites Reservoir WSIP Application.

Shasta Release Temperature Targeting Adjustments

The HEC5Q model simulates the Shasta Temperature Control Device (Shasta TCD) to manage temperature downstream at the following four temperature compliance locations: Clear Creek at Bonnyview Bridge, Balls Ferry, Jelly's Ferry, and Bend Bridge. The Shasta TCD modeling code requires a temperature release target for Shasta to operate to. These temperature target schedules are developed as a series of annual temperature target schedules in a pre-processing spreadsheet tool for each temperature compliance location. For the Sites WSIP Application, two adjustments were made to the assumptions of the temperature target spreadsheet tool to demonstrate the Sacramento River temperature benefits of the changed operations at Shasta due to the operational flexibility provided by Sites Reservoir. These adjustments are described below.

Storage Tier Adjustments

For the Sites WSIP Application, the maximum of April and May end-of-month storage was used to specify that year's compliance location. This adjustment was made because End-of-May is greater than End-of-April storage in some years. Allowing flexibility between End-of-April and End-of-May storage gives a more complete picture of how much cold water pool is available for the temperature management season than if just End-of-April storage was used as the indicator of available cold water pool.

Second, the storage tiers were adjusted due to the change in inflows and air temperatures in the WSIP 2030 and 2070 climate scenarios. The changes in climate variables requires a greater volume of water to meet temperature compliance at the targeted compliance location (e.g. it will take more storage volume to meet temperature compliance at Balls Ferry throughout the year).

An iterative approach was used to adjust the storage levels for both the WSIP 2030 and 2070 climate scenarios. An initial HEC5Q run was completed that utilizes the Maximum End-of-April or May Shasta Storage levels (see Table 2). After the run was completed, temperature outputs for the four compliance locations were loaded into the spreadsheet along with Shasta storage data from CALSIM II. The average of July and August temperature for each year of the 81 year period of record was calculated for each compliance location. The average between July and August was used because it represents the two months with the highest expected temperatures. The furthest downstream location that had a July-August temperature below 56 degrees was the compliance location that was met for that year. For example, if the July-August temperature is 54.5, 55, 55.8, and 56.2 for Bonnyview, Balls Ferry, Jellys Ferry, and Bend Bridge respectively, then the compliance location that was met was Jellys Ferry, since it is the most downstream location that is below 56 degrees. The compliance location based on the Maximum End-of-April or May Shasta storage was also calculated. The number of years where the compliance location was different between the July-August average temperature and the Maximum End-of-April or May Shasta storage was tabulated. The Maximum End-of-April or May Shasta storage levels were then adjusted until the smallest difference was achieved.

The Shasta temperature target schedules were then recomputed for each year and the HEC5Q model was then rerun. The new temperature results at the compliance locations were loaded into the spreadsheet and the same process of changing the Maximum End-of-April or May Shasta storage levels was performed. The final Maximum End-of-April or May Shasta storage levels were settled upon after the third iteration for the WSIP 2030 and WSIP 2070 climate scenarios, as shown in Table 2 below. The values in the table show the maximum storage necessary for each compliance location.

Table 2: Adjusted End-of-April Shasta Storage Levels

Compliance Location	**Maximum End-of-April or May Shasta Storage**		
	Current Conditions	*2030*	*2070*
Bend Bridge	9999	9999	9999
Jelly’s Ferry	4425	4500	4500
Balls Ferry	4000	4300	4400
Below Clear Creek	3600	3600	4000
None	2000	2000	2000

Temperature Target Adjustments

A temperature schedule was developed for each temperature compliance location. These temperature schedules are Shasta release temperatures that are calculated based on the amount of warming that will occur between Shasta and the four compliance locations. The amount of warming that occurs was calculated using an exceedance based approach. With the change in operations to Shasta with Sites Reservoir in place, these exceedance percentages were adjusted in order to demonstrate the potential amount of temperature benefit Sites Reservoir can provide. The June to October exceedance percentages were lowered, which calculates a higher warming that occurs between Shasta and the compliance locations for which Shasta has to adjust to by lowering its release temperature target. Lowering the release temperature targets means Shasta uses more of the cold water pool that is available. The exceedance percentages were adjusted to save cold water in the cold water pool for August and September. See Table 3 for the June to September exceedance percentages used for the without project scenarios and the adjusted exceedance percentages used to characterize warming in the river for the with-project scenarios in the Sites WSIP Application.

Table 3: June to October exceedance percentages used to characterize warming between Shasta and the temperature compliance locations on the Sacramento River

Compliance Location	**Exceedance Percentages**							
	June		*July*		*August*		*September*	
	W/O Sites	W Sites	W/O Sites	W Sites	W/O Sites	W Sites	W/O Sites	W Sites
Clear Creek	75%	5%	50%	5%	15%	5%	5%	5%
Balls Ferry	75%	10%	50%	10%	15%	5%	5%	5%
Jellys Ferry	75%	15%	50%	15%	15%	5%	5%	5%
Bend Bridge	75%	25%	50%	25%	15%	5%	5%	5%

After setting the exceedance percentages, the HEC5Q model was run three times in order to settle in on the Shasta release temperatures based on these new exceedances. This process was done for the three climate scenarios. See Attachment B for the final Shasta Release temperature schedules for the three climate scenarios.

Results

After making the necessary adjustments to the climate updates described above, the Without-Project CALSIM II models for each of the three climate scenarios provided by the California Water Commission were run through the updated Trinity-Sacramento River HEC5Q models to quantify the river temperatures on the Sacramento River under the Without Project condition. This established the river temperature baselines for the three climate scenarios that river temperature benefits of the With-Project conditions would be quantified from. Attachment D shows river temperature results on the Sacramento River at Jellys Ferry. The results for both the Sacramento River show that river temperatures increase between the Current Conditions climate, the WSIP 2030 climate scenario, and the WSIP 2070 climate scenario. There are two major factors for this change, the shift in equilibrium temperature based on the increased air temperature and the change in operations based on the change in hydrologic conditions between the climate scenarios.

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Final

USRDOM Development, Calibration, and Application

Prepared for

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Acronyms and Abbreviations

ACID	Anderson Cottonwood Irrigation District
ADEIRS	Administrative Draft Environmental Impact Report and Statement
AFRP	Anadromous Fish Restoration Program
CACMP	Common Assumption Common Model Package
CBWQM	Colusa Basin Water Quality Model
CDEC	California Data Exchange Center
cfs	cubic feet per second
COA	Coordinated Operation Agreement
Comp Study	Sacramento and San Joaquin River Basins Comprehensive Study
Corps	U.S. Army Corps of Engineers
CVO	Central Valley Operations Office
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
DEM	digital elevation model
DSOD	Division of Safety of Dams
DWR	California Department of Water Resources
EOP	end-of-period
GCC	Glenn-Colusa Canal
HEC-DSS	Hydrologic Engineering Center's Data Storage System
IBU	In-basin Use
IOS	Interactive Object-oriented Salmonid Simulation
MAF	million acre-feet
NHD	National Hydrography Dataset
NMFS	National Marine Fisheries Service
NODOS	North-of-Delta Off-stream Storage
PG&E	Pacific Gas & Electric
PSC	Project Settlement Contractors

QA/QC	quality control and quality assurance
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Bureau of Reclamation
RHEM	Riparian Habitat Establishment Models
ROD	Record of Decision
Sac-EFT	Sacramento Ecological Flow Tool
SALMOD	Salmon Mortality Model
SRH-lbv	Sedimentation and River Hydraulics and Vegetation 1-Dimensional
SWP	State Water Project
TAF/yr	thousand acre-feet per year
TCC	Tehama-Colusa Canal
USGS	U.S. Geological Survey
USRDOM	Upper Sacramento River Daily Operations Model
USRWQM	Upper Sacramento River Water Quality Model
WDL	Water Data Library
WRCLCM	Winter-Run Chinook Life Cycle Model
WY	water year

SECTION 1

Introduction

1.1 Background

The U.S. Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) are conducting feasibility-level engineering and environmental studies for the Surface Storage Investigations Program. Modeling of hydrologic, regulatory, and operational conditions on a daily timestep is needed to support the evaluation of potential benefits and impacts of the North-of-Delta Off-stream Storage (NODOS) program alternatives. A modeling tool capable of simulating both low flow (water supply) and high flow (flood) operations is necessary. The Upper Sacramento River Daily Operations Model (USRDOM) is designed to model the flows and related operations of the Sacramento River and existing and proposed facilities related to the operation of proposed NODOS alternatives. USRDOM also can assess temperature and flow regime impacts and benefits. The model includes the streams and facilities in the upper portion of Sacramento River from Shasta Reservoir to Knights Landing and the Trinity River section of the Central Valley Project (CVP). Figure 1.1 shows the spatial scope of this model.

1.2 Purpose of USRDOM Development

USRDOM allows the user to establish bounds on availability and operating criteria for diversion of excess flows to NODOS. It simulates realistic daily flow conditions in the Sacramento River based on the operations specified by CALSIM II under projected conditions (future) or historical operations for use in river morphology and fisheries analyses for NODOS. It also can be used to evaluate NODOS performance for ecosystem restoration objectives. Finally, it can be used to demonstrate incremental environmental impacts of various NODOS scenarios.

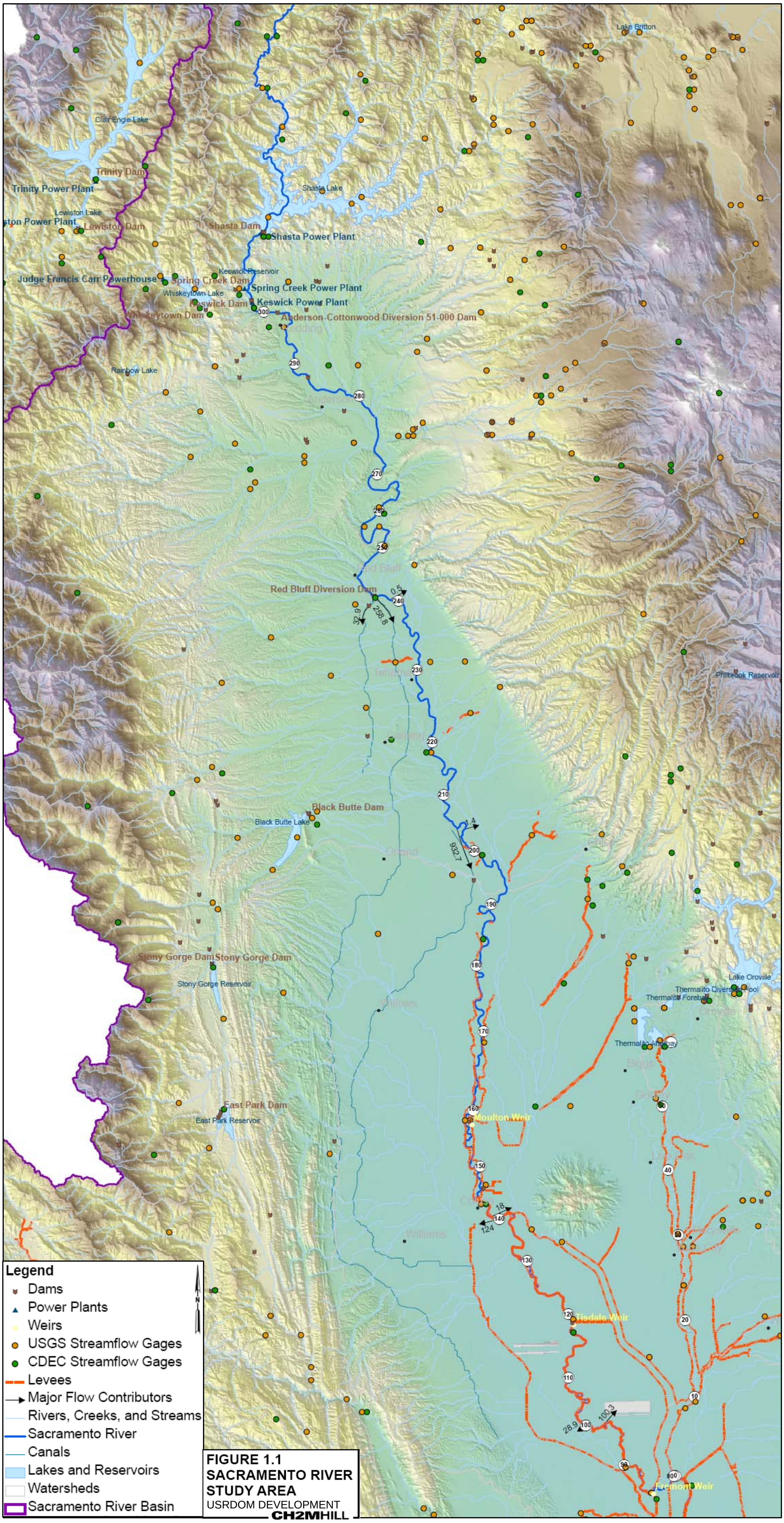
1.3 Scope of USRDOM Development

The scope of USRDOM development includes hydrology development, model setup and testing, model calibration and verification, 82-year full-period simulation capability, development of model linkages, model application and documentation. A brief description of the scope of each task is provided below.

- Hydrology Development—A hydrology dataset including reservoir inflows and tributary flows was developed for the 82-year period from water year (WY) 1922 to WY 2003 using the available historical gage records and operations data for the streams and facilities in the geographical area of interest.

- Model Setup and Testing—This task included selecting software to model the daily operations, identifying the spatial and temporal extents of the model, identifying spatial and temporal resolution, preparing the schematic, preparing the input datasets using the historical hydrology and operations data, and testing the model.

- Model Calibration and Verification—This task included calibrating and verifying the simulation of reservoir operations during flood conditions, assessing the quality of the hydrology dataset, and simulating the flow routing using the observed reservoir operations data and gage records as the reference.
- 82-year Full-period Simulation Capability—This task included enhancing the calibrated USRDOM to simulate full-period operations on a daily timestep for projected level conditions. It also included the developing CAL2DOM to downscale monthly CALSIM II operations to daily USRDOM inputs and developing an example full-period simulation.
- Development of Model Linkages—Flow outputs from USRDOM are used by several water quality, habitat, and biological models. The spatial representation of the Sacramento River in each model varies from USRDOM. Therefore, in this task, USRDOM output locations that are appropriate for each individual model were identified and documented.
- Model Application—As part of this task, USRDOM was extended to include NODOS-related conveyance features. In addition, CAL2DOM was modified to include downscaling of CALSIM II operations related to NODOS and develop an example full-period projected level simulation.



- Dams
- Power Plants
- Weirs
- ● USGS Streamflow Gages
- ● CDEC Streamflow Gages
- Levees
- → Major Flow Contributors
- Rivers, Creeks, and Streams
- Sacramento River
- Canals
- Lakes and Reservoirs
- Watersheds
- Sacramento River Basin

FIGURE 1.1
SACRAMENTO RIVER STUDY AREA
USRDOM DEVELOPMENT
CH2MHILL

SECTION 2

Hydrology Development

2.1 Overview

The development of a daily hydrology dataset for the Upper Sacramento River for the 82-year period (WY 1922 to WY 2003) was the first task performed as part of USRDOM development. Input time series were developed for inflows into the reservoirs and for tributaries along the Sacramento River. Available historical reservoir inflows and tributary flows were compiled for the entire 82-year period and used where available. Various methods were developed and applied to estimate flows during the periods with missing data.

2.2 Historical Data Available

An historical dataset was assembled to aid in developing the hydrology for the upper Sacramento River and in verifying the operations and routing capabilities of USRDOM. The dataset contains daily average Sacramento River flows and its tributary inflows where gaged. Historical reservoir operation data also were collected, including end-of-day storage; total release; and computed daily inflows for Trinity, Lewiston, Whiskeytown, Shasta, and Keswick reservoirs.

Sources for the historical daily data collected included the U.S. Geological Survey (USGS), Reclamation, and DWR's California Data Exchange Center (CDEC) and Water Data Library (WDL). Table 2.1 lists the source of each data record, which generally is the agency maintaining the gage, USGS gage identification number or CDEC short name, location of the measurement, the parameters measured, and the period of available daily data for every record in the historical dataset.

TABLE 2.1
Collected Historical Data

Location	Agency/ID	Parameter	Period Available
Trinity River above Coffee Creek	USGS/11523200	Flow	10/01/1957 - 10/01/2007
Sacramento River at Antler	USGS/11342500	Flow	10/01/1910 - 09/30/1941
McCloud River at Baird	USGS/11369000	Flow	10/01/1910 - 09/30/1943
Pit River near Ydalpom	USGS/11366500	Flow	10/01/1910 - 09/30/1943
Trinity River at Lewiston	USGS/11525500	Flow	10/01/1911 - 09/23/2007
Trinity Reservoir	Reclamation	Storage-EOP	11/01/1962 - 09/12/2007
Trinity Reservoir	Reclamation	Release-Total	11/01/1962 - 09/12/2007
Trinity Lake	CDEC/CLE	Outflow	11/01/1962 - 09/23/2007
Shasta Reservoir	Reclamation	Storage-EOP	12/31/1943 - 12/06/2006
Shasta Reservoir	Reclamation	Inflow	12/31/1943 - 09/12/2007
Shasta Reservoir	Reclamation	Release-Total	12/31/1943 - 09/12/2007
Shasta Dam	CDEC/SHA	Outflow	01/05/1987 - 09/30/2006
Shasta Dam	CDEC/CLE	Storage	01/01/1985 - 09/23/2007

TABLE 2.1
Collected Historical Data

Location	Agency/ID	Parameter	Period Available
Lewiston Reservoir	Reclamation	Storage-EOP	04/01/1964 - 09/30/2005
Lewiston Reservoir	Reclamation	Inflow	04/01/1964 - 09/30/2005
Lewiston Reservoir	Reclamation	Release-to-River	04/01/1964 - 09/30/2005
Lewiston Reservoir	Reclamation	Release-Total	04/01/1964 - 09/30/2005
Sacramento River at Kennett	USGS/11369500	Flow	10/01/1925 - 09/30/1942
Clear Creek at French Gulch	USGS/11371000	Flow	10/01/1950 - 09/30/1993
Judge Francis Carr Powerplant near French Gulch	USGS/11525430	Diversion	04/16/1963 - 09/30/2006
Whiskeytown Reservoir	Reclamation	Storage-EOP	04/01/1964 - 08/30/2007
Whiskeytown Reservoir	Reclamation	Release-to-SCT	04/01/1964 - 08/30/2007
Whiskeytown Reservoir	Reclamation	Inflow	04/01/1964 - 08/30/2007
Whiskeytown Reservoir	Reclamation	Release-Total	04/01/1964 - 08/30/2007
Whiskeytown Dam	CDEC/WHI	Diversion	4/01/2000 - 09/23/2007
Whiskeytown Dam	CDEC/WHI	Outflow	04/01/2000 - 09/23/2007
Spring Creek at Keswick	USGS/11371600	Diversion	01/01/1964 - 09/30/2006
Keswick Reservoir	Reclamation	Storage-EOP	10/01/1974 - 08/30/2007
Keswick Reservoir	Reclamation	Inflow	10/01/1974 - 08/30/2007
Keswick Reservoir	Reclamation	Release-Total	10/01/1974 - 08/30/2007
Keswick Reservoir	CDEC/KES	Outflow	10/02/1993 - 09/23/2007
Sacramento River at Keswick	USGS/11370500	Flow	10/01/1938 - 09/23/2007
ACID Canal at Sharon Ave Redding	USGS/11370700	Flow	04/01/1991 - 09/23/2007
Clear Creek near Igo	USGS/11372000	Flow	10/01/1940 - 09/23/2007
Churn Creek below Newtown Creek near Redding	USGS/11372060	Flow	10/01/1965 - 10/05/1972
Churn Creek near Redding	USGS/11372050	Flow	10/01/1960 - 09/30/1966
Cow Creek near Millville	USGS/11374000	Flow	10/01/1949 - 09/23/2007
Bear Creek near Millville	USGS/11374100	Flow	10/01/1959 - 09/30/1967
Cottonwood Creek near Cottonwood	USGS/11376000	Flow	10/01/1940 - 09/23/2007
Battle Creek near Cottonwood	USGS/11376500	Flow	10/01/1940 - 09/30/1961
Battle Creek near Coleman Fish Hatchery near Cottonwood	USGS/11376550	Flow	10/01/1961 - 09/23/2007
Paynes Creek near Red Bluff	USGS/11377500	Flow	10/01/1949 - 10/31/1966
Antelope Creek near Red Bluff	USGS/11379000	Flow	10/01/1940 - 09/30/1982
Red Bank Creek near Red Bluff	USGS/11378800	Flow	10/01/1959 - 09/30/1982
Red Bank Creek near Rawson Road Bridge near Red Bluff	USGS/11378860	Flow	10/01/1964 - 09/30/1967
Sacramento River above Bend Bridge near Red Bluff	USGS/11377100	Flow	10/01/1891 - 09/23/2007
Sacramento River at Bend Bridge near Red Bluff	USGS/11377200	Flow	10/01/1967 - 09/30/1970
Sacramento River near Red Bluff	USGS/11378000	Flow	10/01/1902 - 09/30/1968

TABLE 2.1
Collected Historical Data

Location	Agency/ID	Parameter	Period Available
Deer Creek near Vina	USGS/11383500	Flow	10/01/1911 - 09/24/2007
Elder Creek near Paskenta	USGS/11379500	Flow	10/01/1948 - 09/23/2007
Mill Creek near Los Mollinos	USGS/11381500	Flow	10/01/1928 - 09/23/2007
Thomes Creek at Paskenta	USGS/11382000	Flow	10/01/1920 - 09/30/1996
Thomes Creek at Rawson Road Bridge near Richfield	USGS/11382090	Flow	10/01/1977 - 11/04/1980
Big Chico Creek near Chico	USGS/11384000	Flow	10/01/1930 - 09/30/1986
Stony Creek near Hamilton City	USGS/11388500	Flow	01/01/1941 - 09/30/1973
Black Butte	CDEC/BLB	Outflow	10/01/1993 - 09/23/2007
Sacramento River at Vina Bridge near Vina	USGS/11383730	Flow	04/13/1945 - 09/30/1978
Sacramento River at Vina Bridge Near Corning	WDL/A02700	Flow	10/01/1975 - 09/30/2004
Sacramento River near Hamilton City	USGS/11383800	Flow	04/21/1945 - 10/2/1980
Sacramento River at Hamilton City	WDL/A02630	Flow	10/01/1975 - 09/30/2005
Sacramento River at Ord Ferry	WDL/A02570	Flow	10/01/1975 - 09/30/2004
Sacramento River at Butte City	USGS/1138900	Flow	10/01/1938 - 06/30/1995
Sacramento River at Butte City	WDL/A02500	Flow	10/01/1997 - 09/30/2006
Sacramento River opposite Moulton Weir	USGS/11389390	Flow	10/01/1972 - 05/02/1973
Moulton Weir Spill to Butte Basin	USGS/11389350	Flow-Spill	01/01/1943 - 09/30/1977
Moulton Weir Spill to Butte Basin near Colusa	WDL/A02986	Flow-Spill	10/01/1997 - 09/30/2004
Colusa Weir Spill to Butte Basin near Colusa	USGS/11389470	Flow-Spill	01/01/1943 - 09/30/1980
Colusa Weir Spill to Butte Basin near Colusa	WDL/A02981	Flow-Spill	10/01/1997 - 09/30/2004
Sacramento River at Colusa	USGS/11389500	Flow	04/11/1921 - 09/23/2007
Tisdale Weir near Grimes	USGS/11390480	Flow-Spill	01/01/1943 - 09/30/1980
Tisdale Weir near Grimes	WDL/A02960	Flow-Spill	10/01/1977 - 09/30/2004
Sacramento River below Wilkins Slough near Grimes	USGS/11390500	Flow	10/01/1938 - 09/23/2007
Sacramento River at Knights Landing	USGS/11391000	Flow	10/01/1940 - 04/29/1981
Colusa Basin Drain at Knights Landing	WDL/A02945	Flow	10/01/1975 - 09/30/2004

2.3 Reservoir Inflows

The mean daily inflows to Trinity and Shasta reservoirs and local flow components of the inflows to Lewiston and Whiskeytown reservoirs were estimated for the 82-year period as part of the hydrology development process. These four inflows were computed using

Reclamation operations data when available. Reclamation computed the reservoir inflow data based on the releases and other operational information. The Reclamation data were smoothed by doing a 3-day running average to eliminate mass balance errors found in the observed data from the Reclamation. Further, the inflow data were corrected for any negative values and adjusted to maintain minimum daily flows by scaling down the flows on days with higher flows to maintain the same overall monthly volume. For the periods with missing data, other historical gage data were used to synthesize the inflows. A brief description of the process and the gages that were used to synthesize the missing data is provided below. Table 2.2 summarizes this information.

TABLE 2.2
Historical Data Used for Compiling the Reservoir Inflows

Reservoir Inflow	Historical Data Source		Period the Adjacent Historical Data Source Was Used	Reservoir Inflow Synthesis Process and Parameters
	Gage Location	**Agency/ID**		
Trinity	Trinity River at Lewiston	USGS/11525500	10/1/1921 - 9/30/1960	Corrected for Lewiston local flow
	Trinity River above Coffee Creek	USGS/11523200	10/1/1960 - 9/30/1962	Scaled using the ratio of average Trinity inflow (Trinity release corrected for 50 cubic feet per second [cfs] evaporation) and average Trinity River at Coffee Creek flow for the same periods (4/1/1964 to 9/30/2003)
	Trinity Reservoir	Reclamation CVO	10/1/1962 - 9/30/2003	3-day running average and a minimum inflow of 150 cfs
Lewiston	Trinity River at Lewiston	USGS/11525500	10/1/1921 - 9/30/1960	Scaled using the ratio of average Lewiston local inflow to average Trinity River flow at Lewiston. The average Lewiston local flow was estimated by performing mass-balance based on the average observed releases at Trinity and Lewiston reservoirs for 4/1/1964 to 9/30/2003 period.
	Synthesized Trinity Reservoir inflow based on the Trinity River above Coffee Creek gage	USGS/11523200	10/1/1960 - 9/30/1962	Scaled using the ratio of average Lewiston local inflow to average Trinity River inflow. The average Lewiston local flow was estimated by performing mass-balance based on the average observed releases at Trinity and Lewiston reservoirs for 4/1/1964 to 9/30/2003 period.
	Trinity Reservoir	Reclamation CVO	10/1/1962 - 9/30/2003	

TABLE 2.2
Historical Data Used for Compiling the Reservoir Inflows

Reservoir Inflow	Historical Data Source		Period the Adjacent Historical Data Source Was Used	Reservoir Inflow Synthesis Process and Parameters
	Gage Location	Agency/ID		
Whiskeytown	Thomes Creek at Paskenta	USGS/11382000	10/1/1921 - 9/30/1940	Using Method 4 as described in Section 2.5, with reference baseflow of 50 cfs to compute Clear creek at French Gulch flow
	Clear Creek near Igo	USGS/11372000	10/1/1940 - 9/30/1950	Scaled using a ratio of average flow of Clear Creek at French Gulch to that of Clear Creek at Igo after a 50 cfs baseflow was removed from Igo flow to compute Clear Creek at French Gulch flow
	Clear Creek at French Gulch	USGS/11371000	10/1/1950 - 3/31/1964	Scaled using ratio of average Whiskeytown inflow to that of average flow at Clear Ck at French Gulch after a 50 cfs baseflow was removed from Whiskeytown inflow
	Whiskeytown Reservoir	Reclamation CVO	4/1/1964 - 9/30/2003	3-day running average and a minimum inflow of 50 cfs
Shasta	Sacramento River at Antler	USGS/11342500	10/1/1921 - 9/30/1925	Used to compute Sacramento River flow at Kennett by scaling it to the volume at Kennett
	McCloud River at Baird	USGS/11369000	10/1/1921 - 9/30/1925	Used to compute Sacramento River flow at Kennett by scaling it to the volume at Kennett
	Pit River near Ydalpom	USGS/11366500	10/1/1921 - 9/30/1925	Used to compute Sacramento River flow at Kennett by scaling it to the volume at Kennett
	Sacramento River at Kennett	USGS/11369500	10/1/1925 - 9/30/1938	Used to compute Sacramento River flow at Keswick by scaling it to the flow at Keswick using simple linear regression
	Sacramento River at Keswick	USGS/11370500	10/1/1938 - 12/30/1943	NA
	Shasta Reservoir	Reclamation CVO	12/31/1943 - 9/30/2003	3-day running average and a minimum inflow of 2000 cfs

Notes:

CVO = Central Valley Operations Office
NA = not applicable

Trinity Reservoir inflow for the missing period was estimated using historical records from the USGS gage on Trinity River at Lewiston. The flow at this gage was corrected for a local inflow component of Lewiston Reservoir because the gage was located downstream. The Trinity Reservoir inflow was assumed to equal this corrected flow for the period when Reclamation operations data were unavailable. For the period between 10/1/1960 and 9/30/1962, which was part of the period of construction of the Trinity and Lewiston reservoirs, the synthesized inflow from this USGS gage was found to be far lower than the rest of the period. Therefore, for these two water years, the flow data from the USGS gage on Trinity River above Coffee Creek were used to synthesize Trinity Reservoir inflows. Lewiston Reservoir local inflow for the 82-year period was computed as a fraction of Trinity River inflow. Based on the source of the observed data, different ratios of flow volumes were used to estimate Lewiston local flow as reported in Table 2.2.

Whiskeytown Reservoir local inflow for the missing period was estimated using three historical records. These data were taken from the USGS gages on Clear Creek at French Gulch, Clear Creek at Igo, and Thomes Creek at Paskenta. The inflow was estimated in two steps. The first step involved synthesizing Clear Creek at French Gulch flow since it was unavailable for the entire period, using the Clear Creek at Igo and Thomes Creek flows. The second step included synthesizing Whiskeytown local inflow using the synthesized and measured Clear Creek at French Gulch flow.

Shasta Reservoir inflow for the missing period was synthesized based on the historical data from the gage on the Sacramento River at Keswick. Because this record is not complete, data from the gage on the Sacramento River at Kennett were used to synthesize the missing Sacramento River at Keswick flow record. Because the gage at Kennett was missing some data, the combined measured flows of the Sacramento River at Antler, McCloud River at Baird, and Pit River at Ydalpom were used to synthesize the Sacramento River at Kennett flow. The periods during which each of the gages was used to synthesize Shasta inflow are summarized in Table 2.2. During the period (10/1/1938 to 12/30/1943) when Shasta Dam was under construction, the observed flow from Sacramento River at Keswick gage was used as the inflow into Shasta Reservoir.

2.4 Sacramento River Tributary Inflows

The Sacramento River Basin extending from Shasta Reservoir to Knights Landing comprises several tributaries throughout the watershed. The basin area can be divided into sub-watersheds that contribute to their respective streams and ultimately drain into the Sacramento River. These watersheds resulted from the well-defined topography in the upper regions of the area. The inflow contribution of these watersheds to the Sacramento River is observed in the form of runoff through their respective streams. Runoff through the tributary streams depends on the orientation and extent of the stream. Seasonal runoff patterns can be observed for the streams that depend purely on the precipitation for flow. Continuous flow patterns throughout the year are observed for the streams that extend high into the mountains, for which snowmelt is the source of runoff.

The Sacramento River Basin also includes other contributing areas, usually flatlands, that do not have well-defined structures to form a stream. These areas also drain into the river, but usually in the form of overland flow or groundwater inflow. The flow patterns of these areas are strongly correlated to rainfall patterns and result in flashy hydrographs.

To accurately estimate the total inflow to the Sacramento River, all streams in the basin that contribute to the river were identified. Figure 2.1 shows all 37 streams, along with their

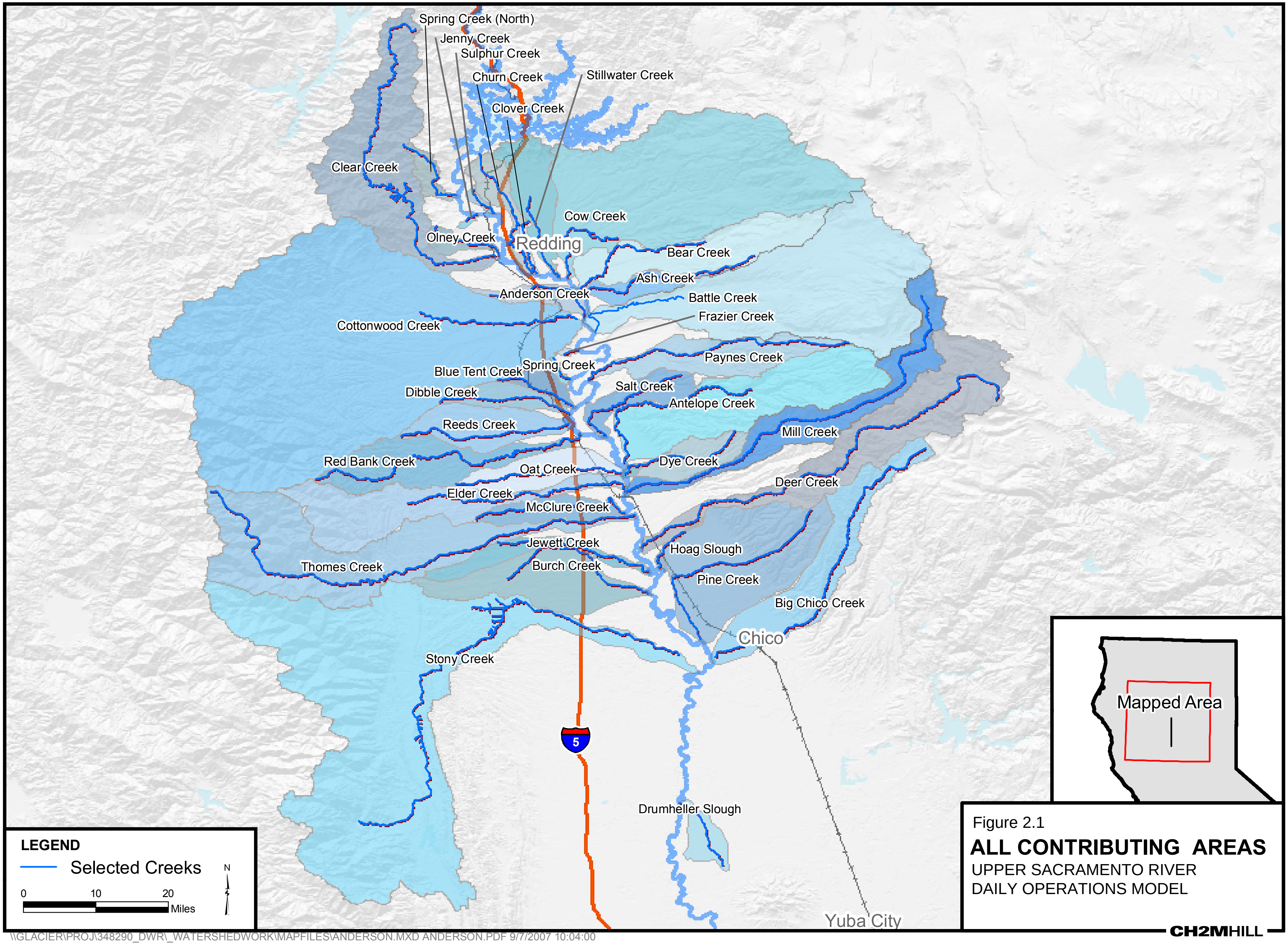


Figure 2.1

ALL CONTRIBUTING AREAS

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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contributing watersheds, that flow into the river. The grey spaces in between the watersheds are the areas that do not fall in any of the sub-watersheds but contribute directly to the river (Figure 2.1).

All streams that contribute to the river were categorized based on gage availability. The streamflow information for the gaged tributaries is known, but streamflows for ungaged tributaries were estimated using synthesis methods.

2.4.1 Contributing Area Estimation

To estimate the contributing watershed areas of all the identified tributaries of the Sacramento River, a high-resolution National Hydrography Dataset (NHD) was obtained from USGS. NHD is a comprehensive set of digital spatial data that contains information about surface water features. Surface water features are combined to form 'reaches,' which provide the framework for linking water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream and downstream order. NHD data were obtained in a combined format that covered the study area in one dataset.

2.4.1.1 Stream Tracing

For each of the identified creeks, ArcGIS ArcInfo version 9.2 software was used to trace upstream from the confluence of the creek and the Sacramento River. Using the NHD network, an attempt was made to identify all contributing streams to the main stem. Results of the tracing were visually inspected. In most cases, the NHD data yielded satisfactory results. In some cases, the stream network was not correct and tracing was performed manually. Using a 30-meter digital elevation model (DEM) raster dataset, a hill-shaded relief image was created to allow visual identification of slope direction, ridge lines, and other topography to improve estimates of stream connectivity. Finally, subsets of NHD were created consisting of all streams contributing to each of the creeks under consideration.

2.4.1.2 Watershed Delineation

CalWater version 2.2.1 was used to identify watershed boundaries. CalWater is the State of California's working definition of watershed boundaries.[1] CalWater 2.2.1 most accurately delineates true watersheds in mountainous terrain, but does not provide accurate information in the valley areas closest to the Sacramento River. In some cases, watershed boundaries within CalWater are based on administrative boundaries rather than physical geography.

For areas surrounding the NHD subsets where inaccuracies were found and additional watershed delineation was needed to calculate the contributing areas. The contributing areas were manually delineated using a combination of the NHD and CalWater data sets and the DEM hill-shaded images.

2.4.1.3 Contributing Area Calculations

Contributing areas were calculated by visually inspecting each upstream tracing and, where appropriate, using CalWater watershed boundaries to define the surface area associated with each of the contributing streams. In cases where watershed definitions were not

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[1] More information about CalWater can be found at: http://gis.ca.gov/casil/hydrologic/watersheds/calwater/.

accurate, the contributing areas were manually delineated. The manual process required a visual examination of topography, slope direction, stream locations, and watershed boundaries to derive surface area contribution. In some cases (because of agricultural diversion structures such as canals), creating an accurate estimate was difficult. However, using a combination of the three data sets mentioned above provided sufficient accuracy for the delineation and area calculations for the purposes of this study.

2.4.2 Gaged Tributaries

Historical streamflow data for the gaged tributaries shown in Figure 2.1 were obtained from USGS. From the analysis described above, the contributing watershed areas of the streams up to the mouth of the stream and the gage locations were estimated. These estimated areas were verified using drainage area data from USGS. The watersheds have distinct shapes and orientations that result in varied inflow magnitudes and varied timing of flow to the Sacramento River. Inflows from the tributaries on each side of the river correlate well with other tributaries on the same side. Minimum correlation was observed between the tributaries on opposite banks of the river. When considering the correlations on same side of the bank, tributaries with watershed areas similar in shape and size were found to be well correlated. For example, Deer Creek and Mill Creek are similar in shape and have inflows approximately equal to the ratio of their watershed areas.

In most cases, watersheds at lower elevations show good correlation with similar creeks because the source of runoff is mostly rainfall. For example Cottonwood Creek is very well correlated with Elder Creek and Red Bank Creek. Table 2.3 lists the gaged tributaries and their contributing watershed areas up to the confluence with the Sacramento River.

TABLE 2.3
Gaged Tributaries and Contributing Watershed Areas

Tributary	Bank (Left = Eastside, Right = Westside)	Contributing Watershed Area up to the gage (mi^2)	Total Contributing Watershed Area (mi^2)
Clear Creek	Right	228	244
Churn Creek	Left	11.9	36
Cow Creek	Left	425	428
Bear Creek	Left	75.7	122
Cottonwood Creek	Right	927	944
Battle Creek	Left	357	372
Paynes Creek	Left	92.8	92
Red Bank Creek	Right	109	111
Antelope Creek	Left	123	197
Elder Creek	Right	136	150
Mill Creek	Left	133	142
Thomes Creek	Right	284	292
Deer Creek	Left	210	227
Big Chico Creek	Left	72.4	150
Stony Creek	Right	773	795

Note:
mi^2 = square miles

This section provides a brief description of each gaged tributary in terms of hydrographic characteristics, location (origin and confluence), and information about the reference tributary used to develop the time series for the 82-year period. A more detailed description of some locations can be found in the reference document (CH2M HILL, 1998). The attributes of the gaged streams in terms of flow magnitudes, period of data available, and confluence with river are shown in Table 2.4. Table 2.5 summarizes the reference tributaries used to develop missing data in the 82-year flow record for the gaged tributaries. The 82-year daily flow time series were not developed for Churn Creek, Clear Creek, Bear Creek, and Stony Creek.

TABLE 2.4
Attributes of Gaged Tributaries

Tributary Name	River Mile at Confluence with River	Agency/ID	Data Availability Period	Mean Flow for the Gaged Period (cfs)	Annual Volume Avg (TAF/yr)
Clear Creek	289	USGS/11372000	10/01/1940 - 09/12/2007	261.70	189.60
Churn Creek	284	USGS/11372060	10/01/1965 - 10/05/1972	23.75	17.20
Cow Creek	280	USGS/11374000	10/01/1949 - 09/12/2007	687.30	497.90
Bear Creek	277.5	USGS/11374100	10/01/1959 - 09/30/1967	81.57	59.10
Cottonwood Creek	273	USGS/11376000	10/1/1940 - 09/12/2007	886.90	642.50
Battle Creek	271.5	USGS/11376500	10/01/1940 - 09/30/1961	448.20	324.70
Paynes Creek	253	USGS/11377500	10/01/1949 - 10/31/1966	70.30	50.90
Red Bank Creek	243	USGS/11378800	10/01/1959 - 09/30/1982	48.60	35.20
Antelope Creek	235	USGS/11379000	10/01/1940 - 09/30/1982	150.70	109.20
Elder Creek	230	USGS/11379500	10/01/1948 - 09/12/2007	104.00	75.40
Mill Creek	230	USGS/11381500	10/01/1928 - 09/12/2007	304.90	220.90
Thomes Creek	226	USGS/11382000	10/01/1920 - 09/30/1996	289.70	209.90
Deer Creek	220	USGS/11383500	10/01/1911 - 09/12/2007	320.50	232.20
Big Chico Creek	193	USGS/11384000	10/01/1930 - 09/30/1986	149.50	108.30
Stony Creek	190	USGS/11388500	01/01/1941 - 09/30/1973	437.24	316.80

Note:

TAF/yr = thousand acre-feet per year

TABLE 2.5
Historical Data Used for Developing Tributary Inflow Hydrology

Tributary	Data Source		Period the Corresponding Data Were Used in the Combined Time Series
	Location	Agency/ID	
Cow Creek	Big Chico Creek	USGS/11384000	10/01/1921 - 09/30/1949
	Cow Creek	USGS/11374000	10/01/1949 - 09/30/2003
Cottonwood Creek	Elder Creek	USGS/11379500	10/01/1921 - 09/30/1940
	Thomes Creek	USGS/11382000	10/01/1921 - 09/30/1940
	Red Bank Creek	USGS/11378800	10/01/1921 - 09/30/1940
	Cottonwood Creek	USGS/11376000	10/01/1940 - 09/30/2003
Battle Creek	Mill Creek	USGS/11381500	10/01/1921 - 09/30/1940
	Battle Creek	USGS/11376500	10/01/1940 - 09/30/1961
	Battle Creek	USGS/11376550	10/01/1961 - 09/30/2003
Paynes Creek	Big Chico Creek	USGS/11384000	10/01/1921 - 09/30/1949
	Paynes Creek	USGS/11377500	10/01/1949 - 10/31/1966
	Big Chico Creek	USGS/11384000	11/01/1966 - 09/30/2003
Red Bank Creek	Elder Creek	USGS/11379500	10/01/1921 - 09/30/1959
	Red Bank Creek	USGS/11378800	10/01/1959 - 09/30/1982
	Elder Creek	USGS/11379500	10/01/1982 - 09/30/2003
Antelope Creek	Mill Creek	USGS/11381500	10/01/1921 - 09/30/1940
	Antelope Creek	USGS/11379000	10/01/1940 - 09/30/1982
	Mill Creek	USGS/11381500	10/01/1982 - 09/30/2003
Elder Creek	Thomes Creek	USGS/11382000	10/01/1921 - 09/30/1948
	Elder Creek	USGS/11379500	10/01/1948 - 09/30/2003
Mill Creek	Deer Creek	USGS/11383500	10/01/1911 - 09/30/1928
	Mill Creek	USGS/11381500	10/01/1928 - 09/30/2003
Thomes Creek	Thomes Creek	USGS/11382000	10/01/1921 - 09/30/1996
	Elder Creek	USGS/11379500	10/01/1996 - 09/30/2003
Deer Creek	Deer Creek	USGS/11383500	10/01/1921 - 09/30/2003
Big Chico Creek	Deer Creek	USGS/11383500	10/01/1911 - 09/30/1930
	Big Chico Creek	USGS/11384000	10/01/1930 - 09/30/1986
	Deer Creek	USGS/11383500	10/01/1986 - 09/30/2003

2.4.2.1 Clear Creek

Clear Creek originates in the Trinity Mountains west of Shasta Reservoir at an elevation of about 6,200 feet and flows east for about 50 miles to the Sacramento River near the town of Anderson, California, at river mile 289 (Figure 2.2). Total contributing area of the watershed up to the mouth of the stream is about 244 square miles. Runoff is usually observed year-long because of snowmelt from the Trinity Mountains. Clear Creek has been heavily affected by regulation in Whiskeytown Reservoir, which was completed in 1963. The contributing area of the watershed below the reservoir down to the mouth of the stream is only 44 square miles, while the region above the reservoir is 200 square miles. The USGS gage at Igo has the longest period of record for the Clear Creek streamflow, covering October 1940 to present. The drainage area of the watershed above this gage is 228 square miles.

2.4.2.2 Churn Creek

Churn Creek originates just below the ridge line of the mountains surrounding Shasta Reservoir. It flows north to south, parallel to the Sacramento River from Lake Shasta to the point of confluence below Redding (Figure 2.3). Churn Creek is partly influenced by snowmelt. The USGS gage located closest to the confluence is at Redding and has records from 1965 to 1972.

2.4.2.3 Cow Creek

Cow Creek flows southeast from the Cascade Range, entering the Sacramento River approximately 4 miles east of Anderson, California. It drains 428 square miles, with many tributaries. The main stream system is approximately 66 miles long, flowing from an elevation of about 6,500 feet near Huckleberry Mountain to about 350 feet at the confluence with the Sacramento River. Although there is no significant water storage Dam on Cow Creek, there are numerous small agricultural diversions in the watershed. Figure 2.4 shows the Cow Creek watershed with measurement gages and contributing areas.

USGS gage Cow Creek at Millville (11374000) is the closest gage to the confluence of the river. Records are available from October 1949 to present. To have a complete data set for WY 1922 to WY 2003, Cow Creek data prior to October 1949 were synthesized using Big Chico Creek flow patterns and flow magnitudes as references. The contributing areas of watersheds and flow averages are used to compute different synthetic parameters such as Reference Area Multiplier, Reference Base Flow Multiplier, Runoff Factor, and Reference-based Runoff Multiplier. A detailed description of the synthesis methods is provided later in this report. Cow Creek is mostly dependent on spring runoff and has no baseflow. Big Chico Creek is dependent on snowmelt and has a consistent baseflow. Therefore, for computing the runoff factor, the baseflow of Big Chico Creek was removed.

2.4.2.4 Cottonwood Creek

Cottonwood Creek originates on the western side of the Sacramento Valley, draining the eastern side of the Trinity and North Yola Bolly mountains of the interior Coast Range into the Sacramento River at a point near the town of Cottonwood, about midway between Redding and Red Bluff (Figure 2.5). The 944-square-mile watershed has numerous tributaries, flowing from an elevation of 7,863 feet to about 350 feet at the confluence of the Sacramento River. There are no major regulating reservoirs in the Cottonwood Creek watershed. Cottonwood Creek is mainly influenced by heavy winter precipitation runoff.

Cottonwood Creek flow is measured by a gage near Cottonwood (USGS 11376000). The gage is located below all local development and has flow records for WY 1941 through WY 2007. Data from this gage are used as tributary inflow for the available period. For WY 1921 to WY 1940, the data were estimated using the combined historical and synthesized records of Elder, Thomes, and Red Bank creeks. The reference creeks were chosen because the combined watershed areas of the three creeks are similar in shape to the watershed area of Cottonwood Creek.

2.4.2.5 Battle Creek

Battle Creek originates on the eastern slopes of Lassen Peak at an elevation of 10,457 feet. Draining about 372 square miles, Battle Creek travels west, entering the Sacramento River near the town of Cottonwood at an elevation of 350 feet. The stream is 41 miles long and has north and south forks that meet about 16 miles above the Sacramento River. Battle Creek is regulated by McCumber Reservoir, located on the north fork, and by several hydroelectric facilities owned by Pacific Gas & Electric (PG&E).

Battle Creek flow is measured by USGS gages 11376500 and 11376550, which are close to each other (Figure 2.6). The historical data combined from two gages are available from October 1940 to September 2007. Data from WY 1921 to WY 1940 were estimated from the combined historical and synthesized data of Mill Creek.

2.4.2.6 Paynes Creek

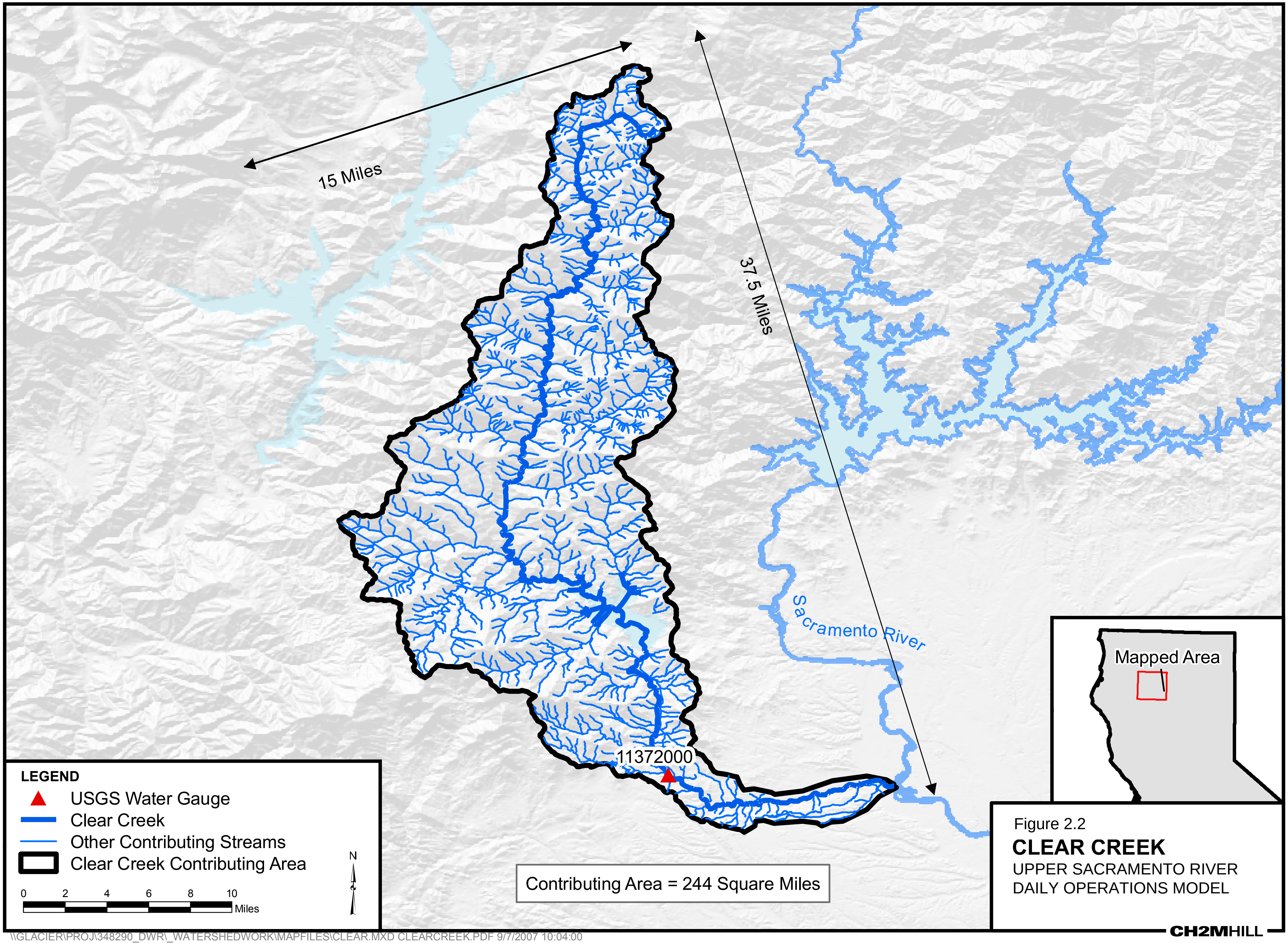
Paynes Creek originates in the mountains of Lassen National Forest and flows west to the Sacramento River to join the river above Red Bluff. Paynes Creek drains about 92 square miles, forming a narrow leaf-shaped watershed (Figure 2.7). Because of its narrow shape, runoff times are usually short during precipitation events. USGS gage (11377500) on Paynes Creek near Red Bluff measures the daily mean flow. The historical streamflow data are available for WY 1949 to WY 1966. Data prior to 1949 and after 1966 for Paynes Creek were estimated using the combined records of Big Chico Creek.

2.4.2.7 Red Bank Creek

Red Bank Creek originates on Ball Mountain west of the Sacramento River and is formed by numerous tributaries from the mountains joining in the main stream. Red Bank Creek flows east to the Sacramento River, meeting just upstream of the Red Bluff Diversion Dam (Figure 2.8). USGS gage (11378800) measures the daily mean flow of the creek. The period of record available for this gage is WY 1959 to WY 1982. Missing period inflow data for the creek were estimated using the combined flow records of Elder Creek.

2.4.2.8 Antelope Creek

The headwaters of the Antelope Creek watershed are located on Turner Mountain in the Cascade Range. Antelope Creek drains about 197 square miles flowing southwest from an elevation of about 6,890 feet through the Lassen National Forest to an elevation of about 230 feet at the Sacramento River confluence, about 9 miles south of Red Bluff, California.



Contributing Area = 244 Square Miles

Figure 2.2

CLEAR CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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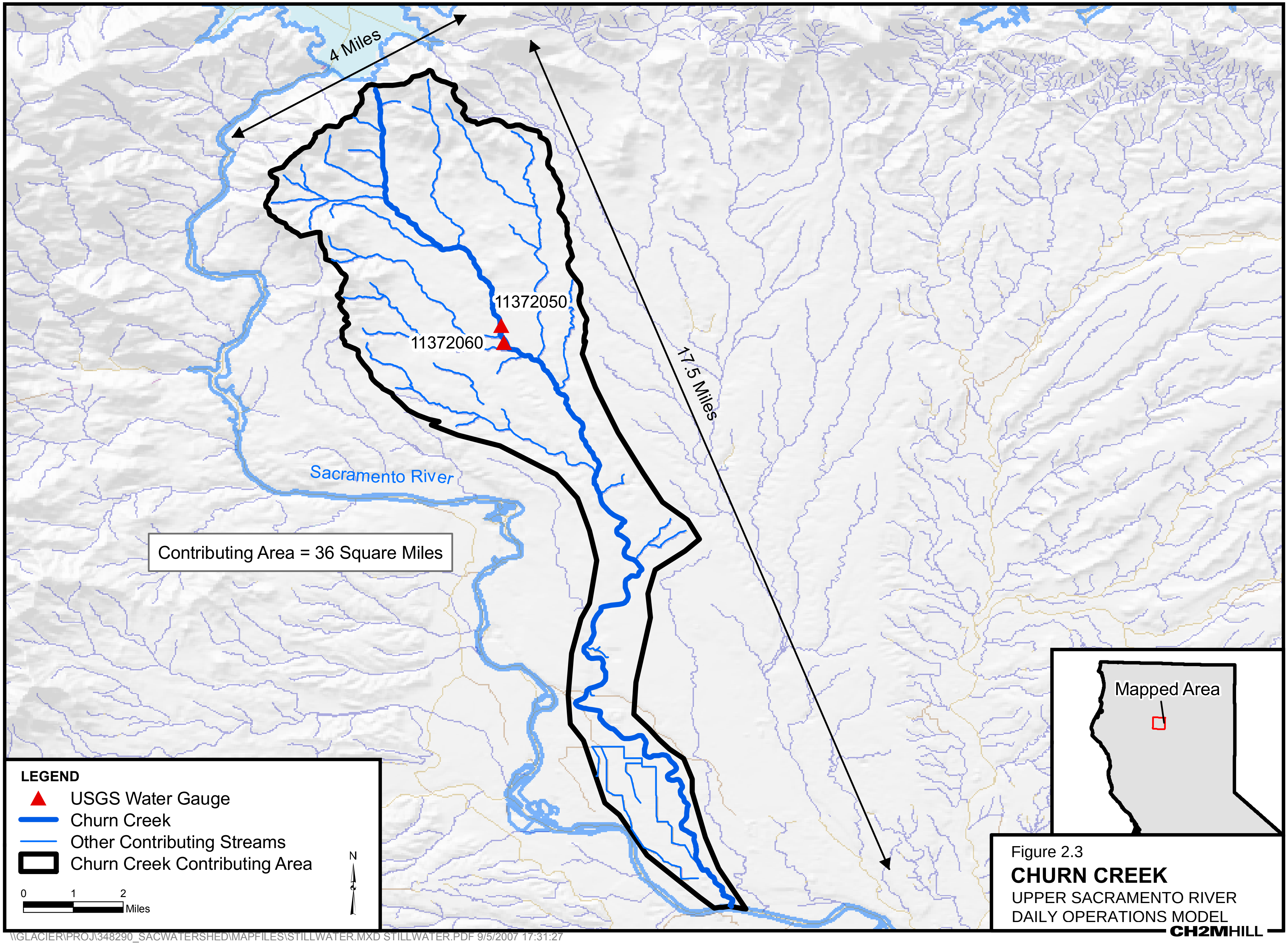

Figure 2.3

CHURN CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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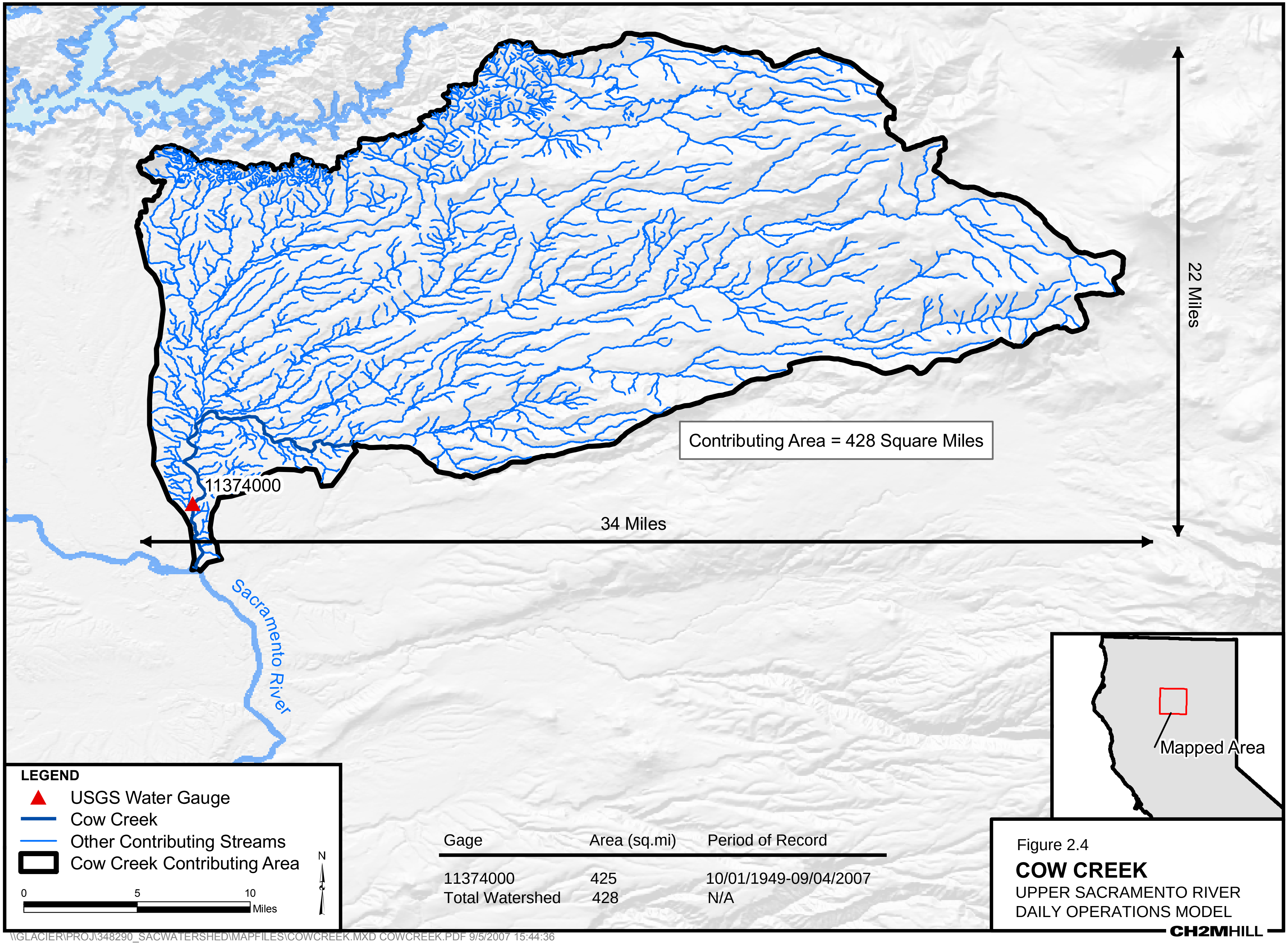

Gage	Area (sq.mi)	Period of Record
11374000	425	10/01/1949-09/04/2007
Total Watershed	428	N/A

Figure 2.4

COW CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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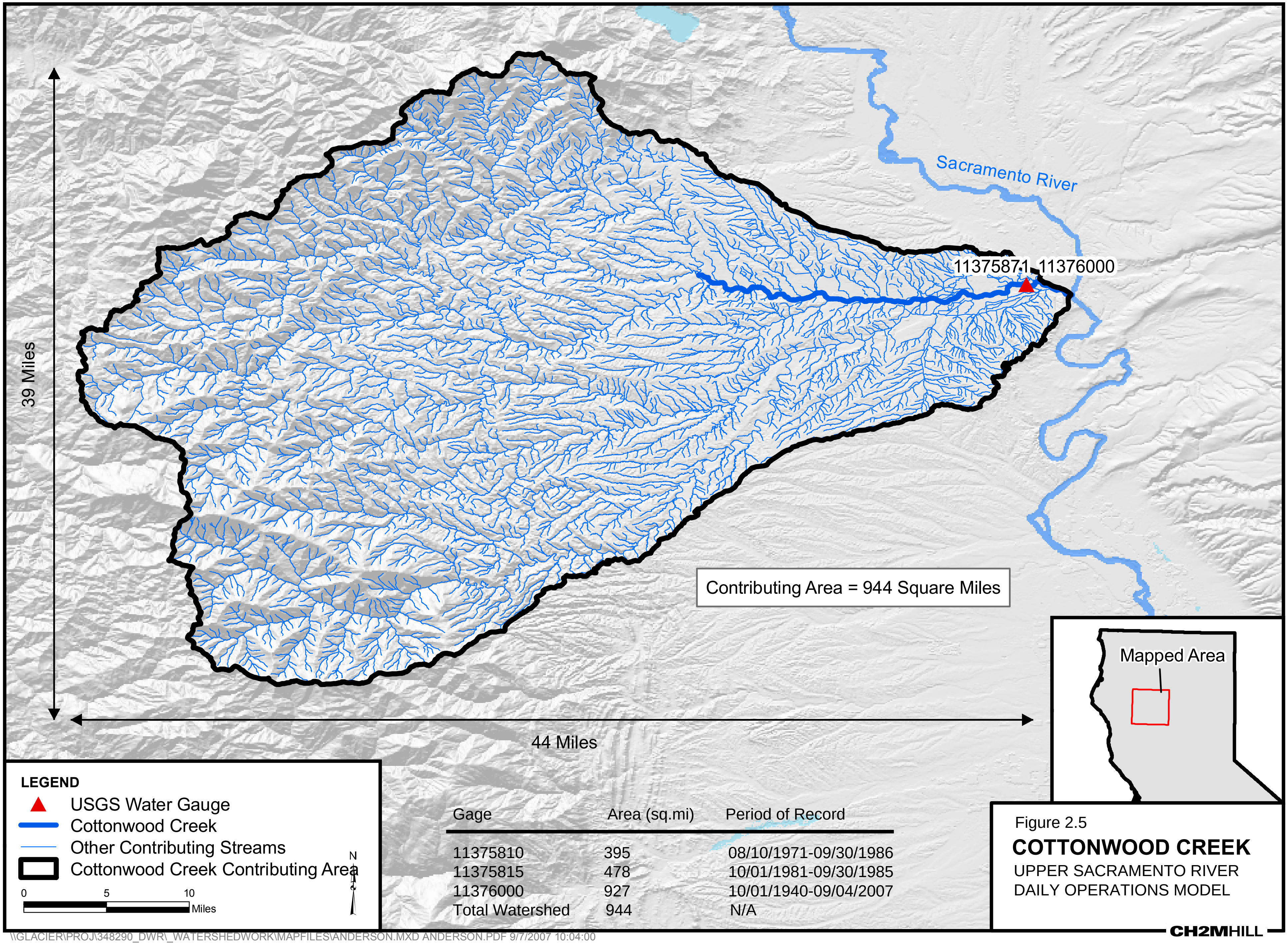

Gage	Area (sq.mi)	Period of Record
11375810	395	08/10/1971-09/30/1986
11375815	478	10/01/1981-09/30/1985
11376000	927	10/01/1940-09/04/2007
Total Watershed	944	N/A

Figure 2.5

COTTONWOOD CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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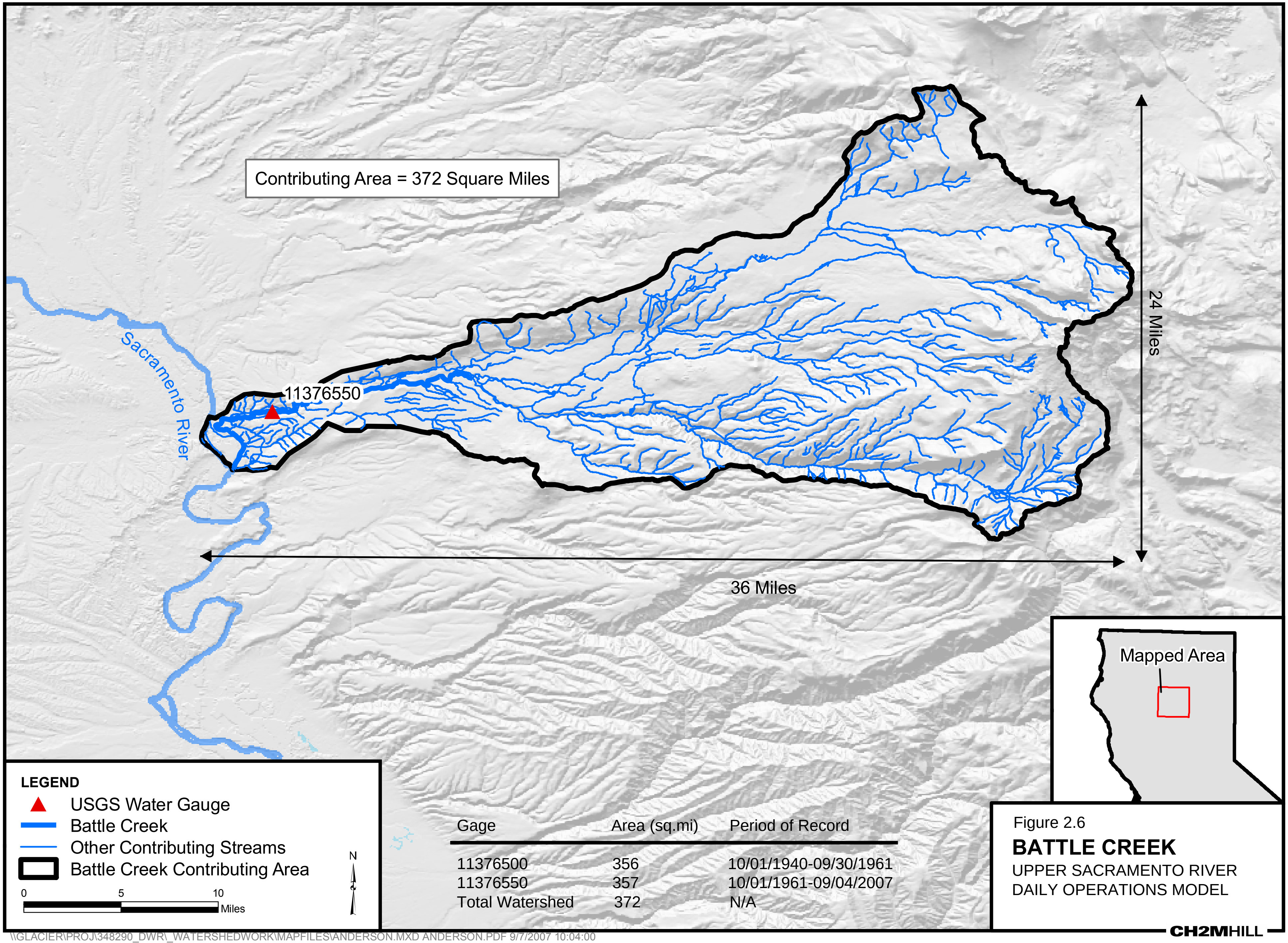

Gage	Area (sq.mi)	Period of Record
11376500	356	10/01/1940-09/30/1961
11376550	357	10/01/1961-09/04/2007
Total Watershed	372	N/A

Figure 2.6

BATTLE CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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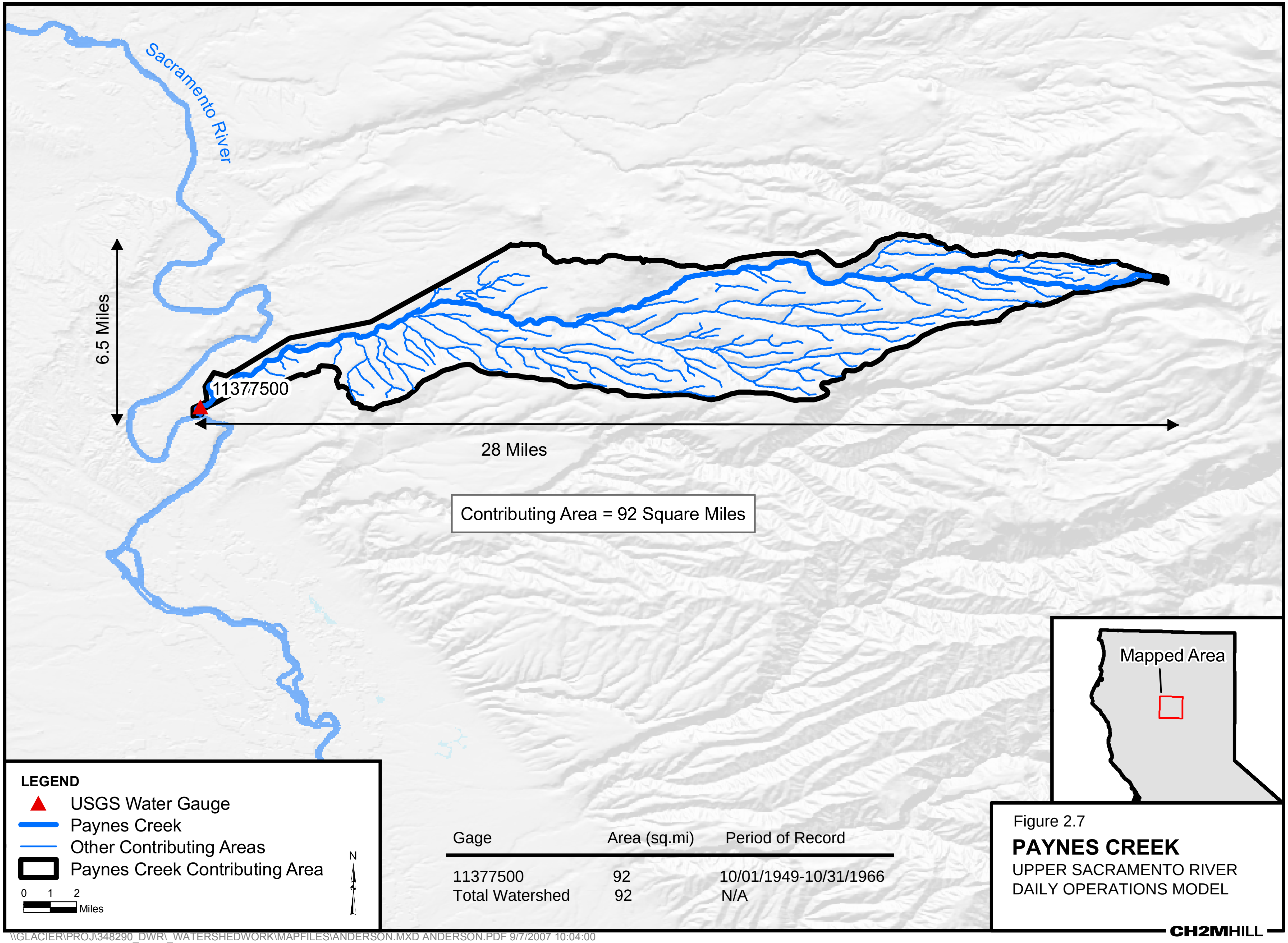

Gage	Area (sq.mi)	Period of Record
11377500	92	10/01/1949-10/31/1966
Total Watershed	92	N/A

Figure 2.7

PAYNES CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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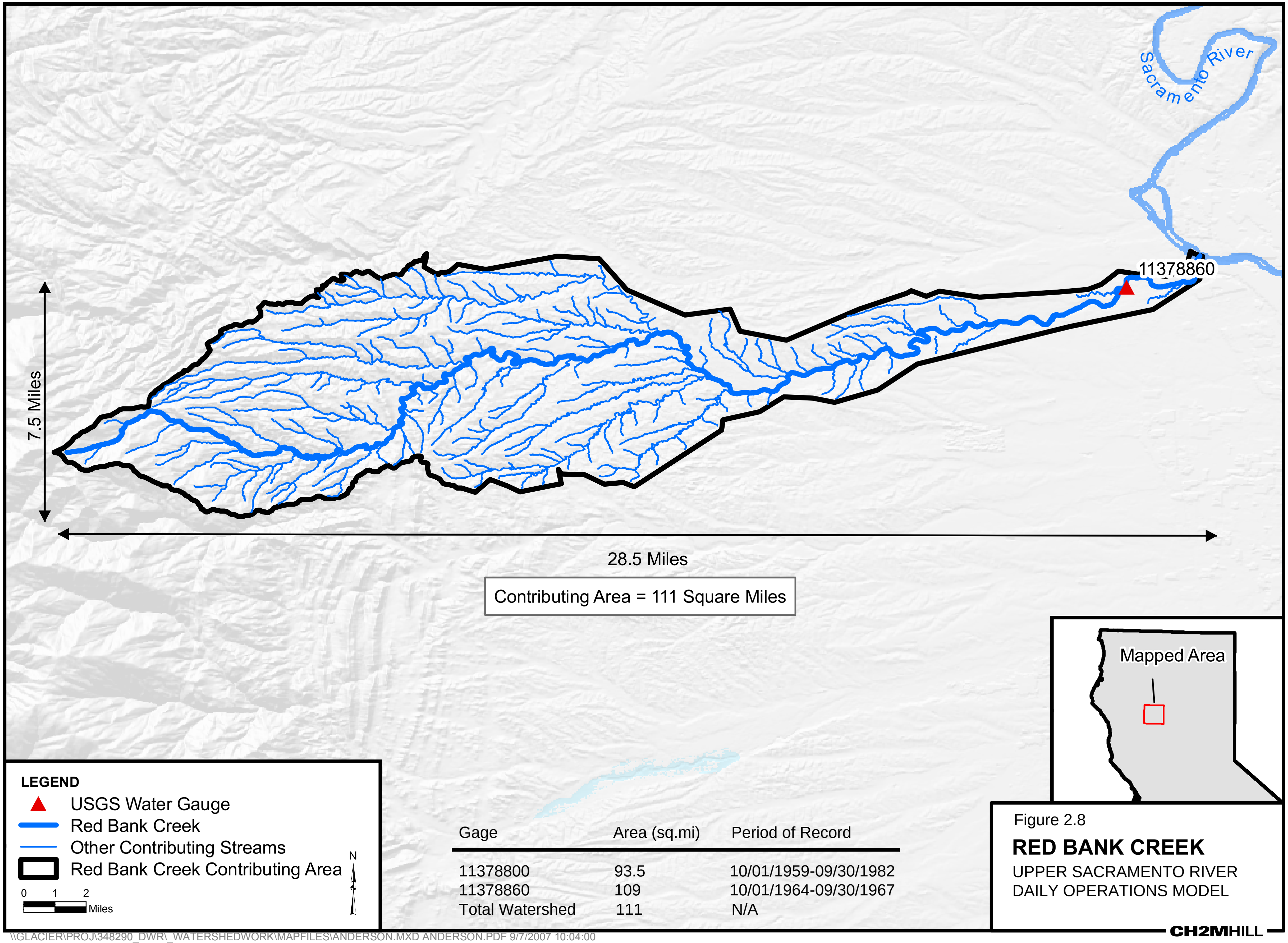

Gage	Area (sq.mi)	Period of Record
11378800	93.5	10/01/1959-09/30/1982
11378860	109	10/01/1964-09/30/1967
Total Watershed	111	N/A

Figure 2.8

RED BANK CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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Antelope Creek daily flow is measured by USGS gage (11379000) located near Red Bluff (Figure 2.9). This gage has historical data from WY 1940 to WY 1982. Inflow data before 1940 and after 1982 for the creek were estimated using the combined inflow data from Mill Creek.

2.4.2.9 Elder Creek

Elder Creek originates west of the Sacramento River and flows east to join the river near Tehama City. Tributaries from Ball Mountain combine and flow as a single stream through Tehama County toward the Sacramento River. The total watershed area draining to the creek is about 150 square miles. Figure 2.10 shows the Elder Creek watershed and USGS gages located on the creek. The gage with the longest record is USGS 11379500, which is about halfway to the river and drains approximately 92.5 square miles. The historical streamflow data for this gage are available from WY 1948 to WY 2007. Inflow data before 1948 were estimated using historical data from Thomes Creek.

2.4.2.10 Mill Creek

Mill Creek originates high on the western side of Lassen Peak at an elevation of 10,457 feet. It flows west, draining about 142 square miles and entering the Sacramento River near the town of Los Molinos, just south of Red Bluff at an elevation of 230 feet (Figure 2.11).

Mill Creek flow is measured by USGS 11381500 for WY 1928 to WY 2007. Data prior to WY 1928 were estimated using the historical gage records from Deer Creek.

2.4.2.11 Thomes Creek

Thomes Creek originates in the Mendocino National Forest at Ball Mountain. Numerous tributaries in the mountains combine and flow as Thomes Creek east to the Sacramento River. The main source of runoff is snowmelt from Ball Mountain. Its total watershed area is about 292 square miles (Figure 2.12). Two USGS gages measure the streamflow. USGS gage 11382000 has the longest record, from WY 1920 to WY 1996, and is located halfway to the river. Data after WY 1996 were estimated using historical records from Elder Creek.

2.4.2.12 Deer Creek

Deer Creek originates high on the northern slope of Butt Mountain and drains about 227 square miles, entering the Sacramento River at Woodson Bridge State Recreation Area. Deer Creek flow is measured by USGS 11383500, which has a complete record from WY 1911 to WY 2007 (Figure 2.13).

2.4.2.13 Big Chico Creek

Big Chico Creek originates on Colby Mountain in the Cascade Range at an elevation of 6,000 feet. It drains a 150-square-mile watershed into the Sacramento River 5 miles west of Chico (Figure 2.14). Flow in Big Chico Creek is measured by USGS 11384000, which has records from WY 1930 to WY 1986. Data prior to 1930 and after 1986 were estimated using historical records from Deer Creek.

2.4.2.14 Bear Creek

Bear Creek originates on the eastern side of the Sacramento Valley and drains 122 square miles of watershed. Bear Creek flow is measured by USGS 11374100 near Millville (Figure 2.15). This gage has flow records for WY 1959 through WY 1967.

2.4.2.15 Stony Creek

Stony Creek originates on the west side of the Sacramento Valley. The total contributing area of the watershed up to the mouth of the stream is about 795 square miles east to the Sacramento River near Ord, California, at river mile 190 (Figure 2.16). Stony Creek flows are affected by regulation in the Black Butte Reservoir. USGS 11388500 near Hamilton City has the longest period of record (from January 1941 to September 1973) for Stony Creek streamflow. The drainage area of the watershed above this gage is 773 square miles.

2.4.3 Ungaged Tributaries and Areas

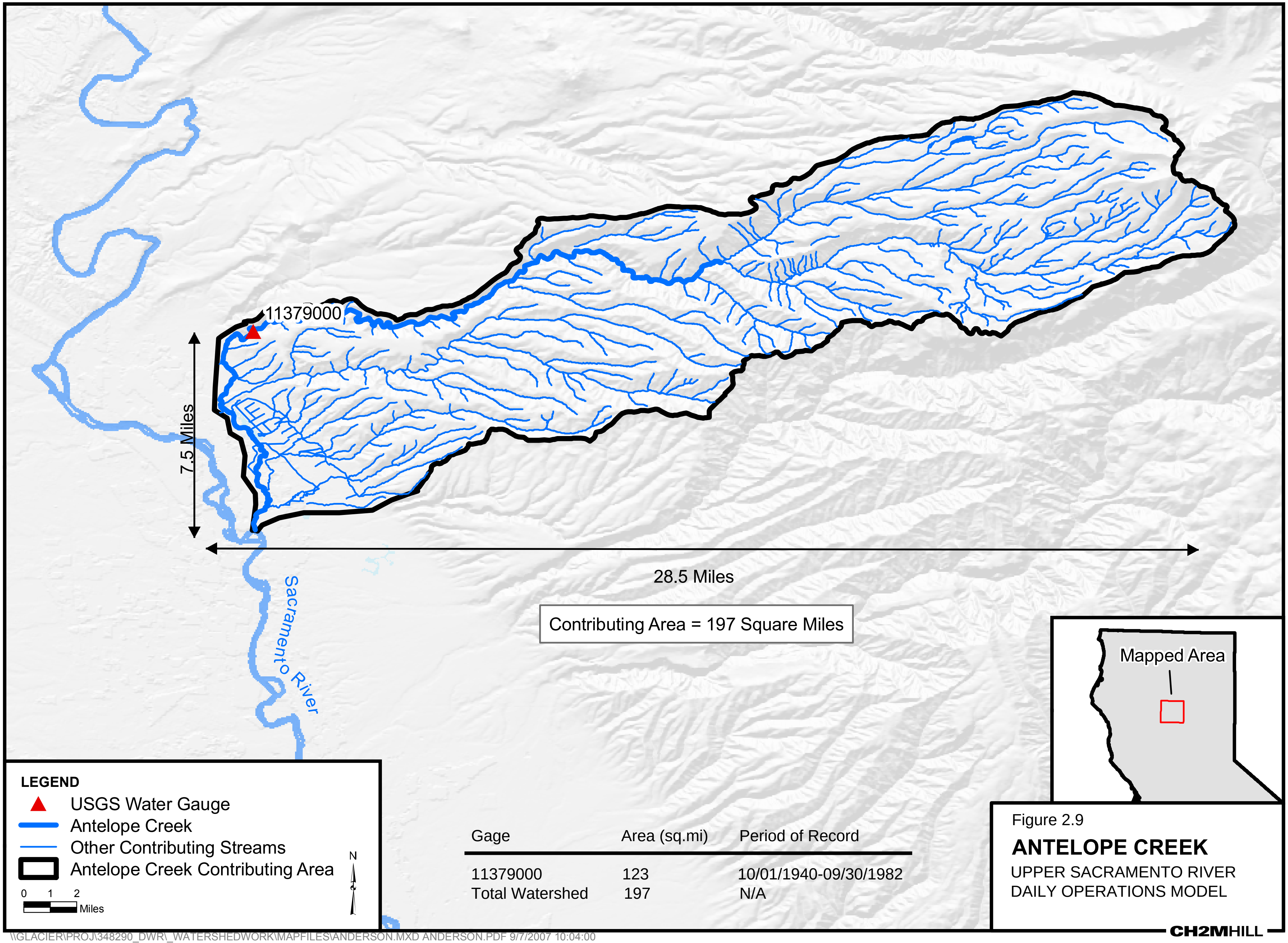
In addition to the flows from the above described gaged tributaries, the Sacramento River receives flows from the ungaged tributaries and the valley floor areas. These flows are generally intermittent and strongly dependent on the rainfall. In developing the hydrology, flows were not estimated for these individual ungaged areas. Instead the flow contributions from these areas were lumped into “closure terms” for modeling purposes as described Section 3.3. Since some of the gages on the tributaries described in Section 2.4.2 were not necessarily located at the mouth of each stream, the additional contributing areas from the gage location to the mouth of the stream were also lumped with the other ungaged areas.

2.5 Data Synthesis Methods

Historical data prior to the 1940s were unavailable for most of the tributaries and the main rivers flowing into the reservoirs. Therefore, several methods for synthesizing tributary flows and reservoir inflows were developed for filling the missing flow data in the 82-year period hydrology.

In general, the data synthesis for any tributary was based on one or more reference streams. Initial selection of a reference stream was based on the correlation between the historical flows in the tributary with missing data and the reference stream. Factors such as contributing watershed areas, average runoff volumes, and baseflows of the two streams were also considered. Tributaries were found to be well correlated with streams on the same side of the Sacramento River, which may be because of the similar hydrologic characteristics in the respective watersheds.

The missing data for the tributaries and reservoir inflows were estimated based on streamflow in a reference tributary using one of the synthesis methods described below. The selection of the method was based on the quality of the synthesized tributary flow in comparison to the observed flow for the same tributary. Histograms were plotted for the gaged tributary flow and the combined (synthesized and historical) tributary flow to prevent the synthesized flow from altering the natural variability in the tributary flows. For each method, a reference stream was identified based on the available gage data and how well it correlated with the tributary being synthesized.



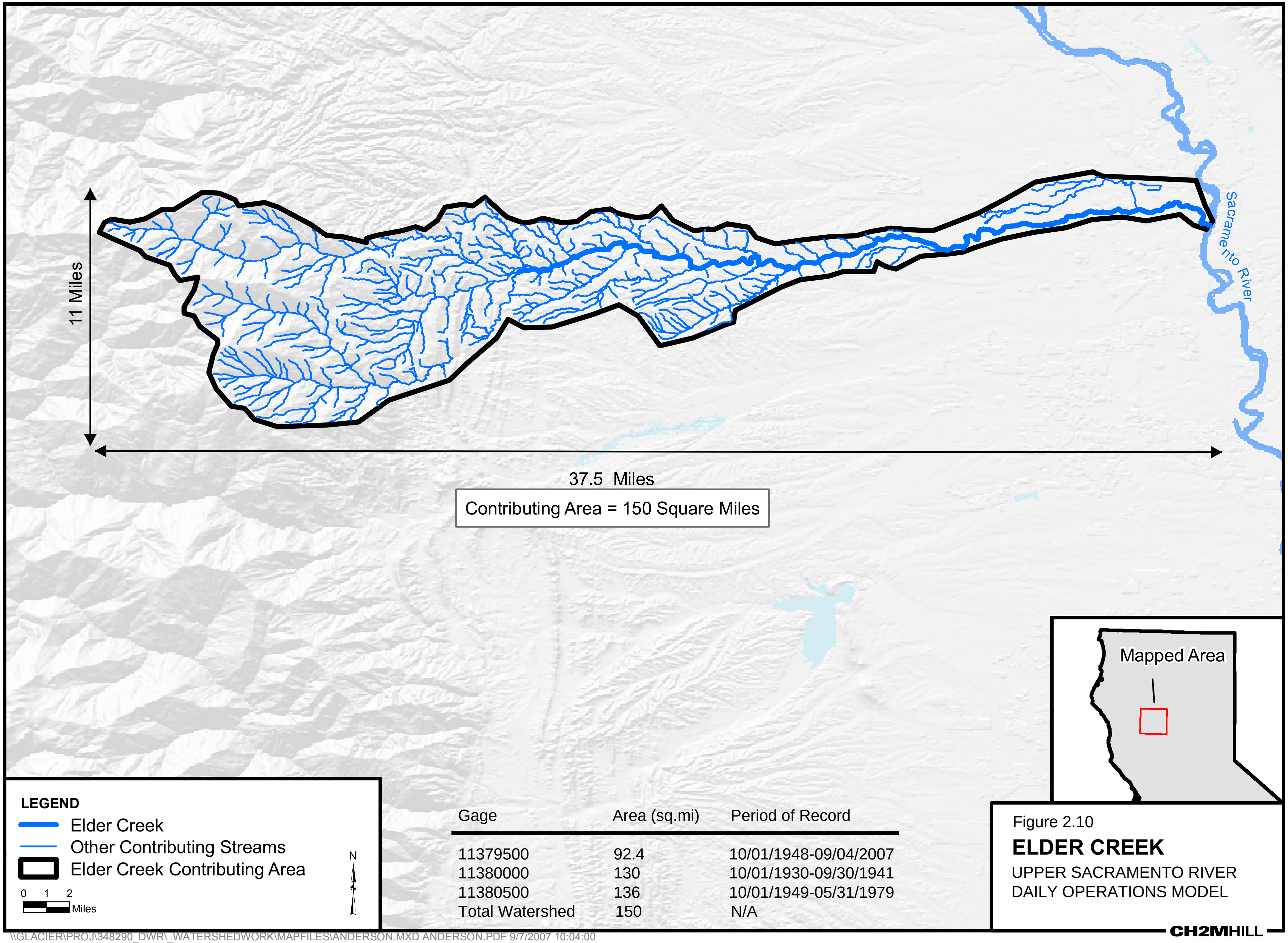
Gage	Area (sq.mi)	Period of Record
11379000	123	10/01/1940-09/30/1982
Total Watershed	197	N/A

Figure 2.9

ANTELOPE CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

CH2MHILL



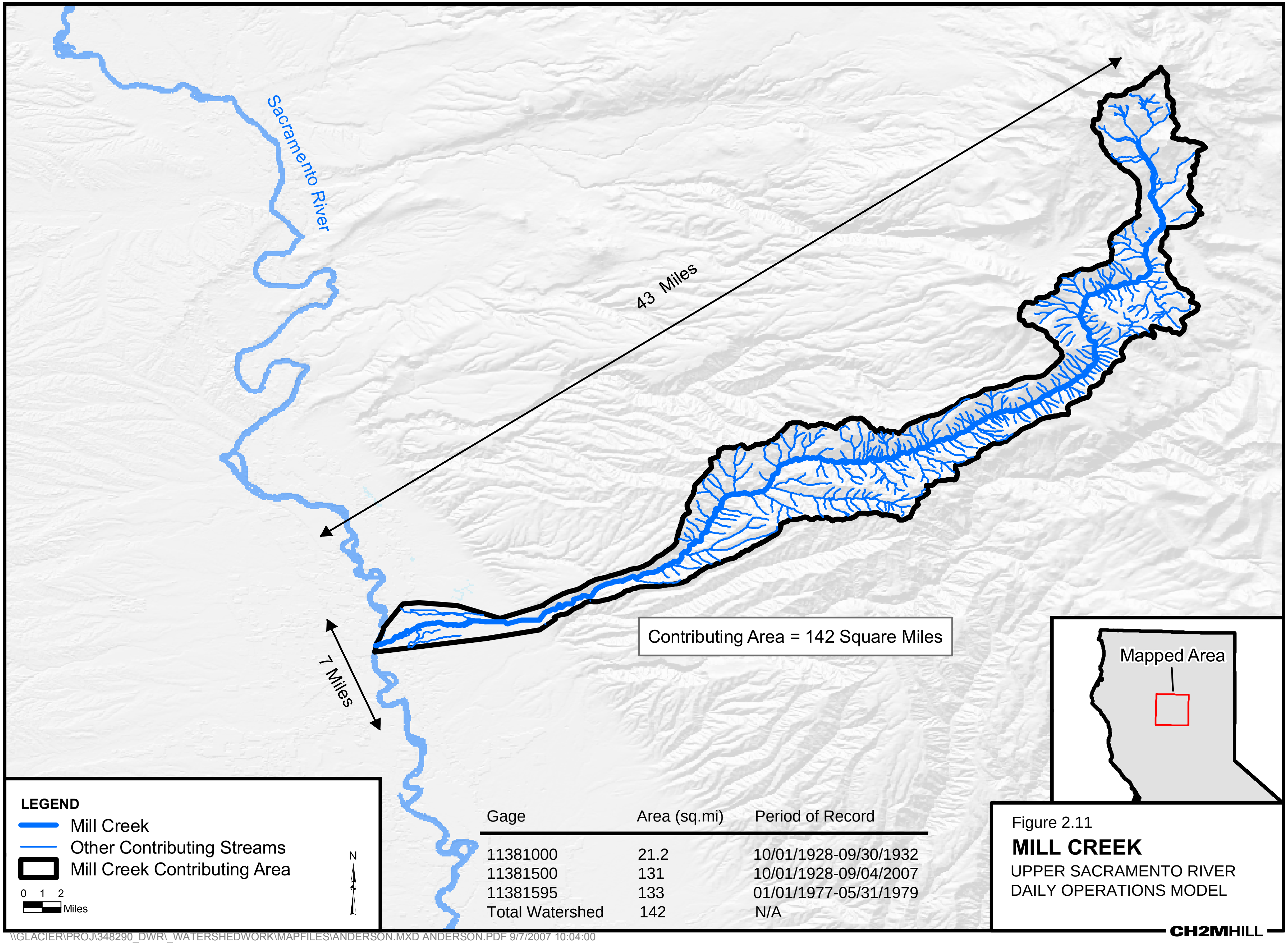
Gage	Area (sq.mi)	Period of Record
11379500	92.4	10/01/1948-09/04/2007
11380000	130	10/01/1930-09/30/1941
11380500	136	10/01/1949-05/31/1979
Total Watershed	150	N/A

Figure 2.10

ELDER CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

\\GLACIER\PROJ\348290_DWR_WATERSHEDWORK\MAPFILES\ANDERSON.MXD ANDERSON.PDF 9/7/2007 10:04:00



Gage	Area (sq.mi)	Period of Record
11381000	21.2	10/01/1928-09/30/1932
11381500	131	10/01/1928-09/04/2007
11381595	133	01/01/1977-05/31/1979
Total Watershed	142	N/A

Figure 2.11

MILL CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

CH2MHILL

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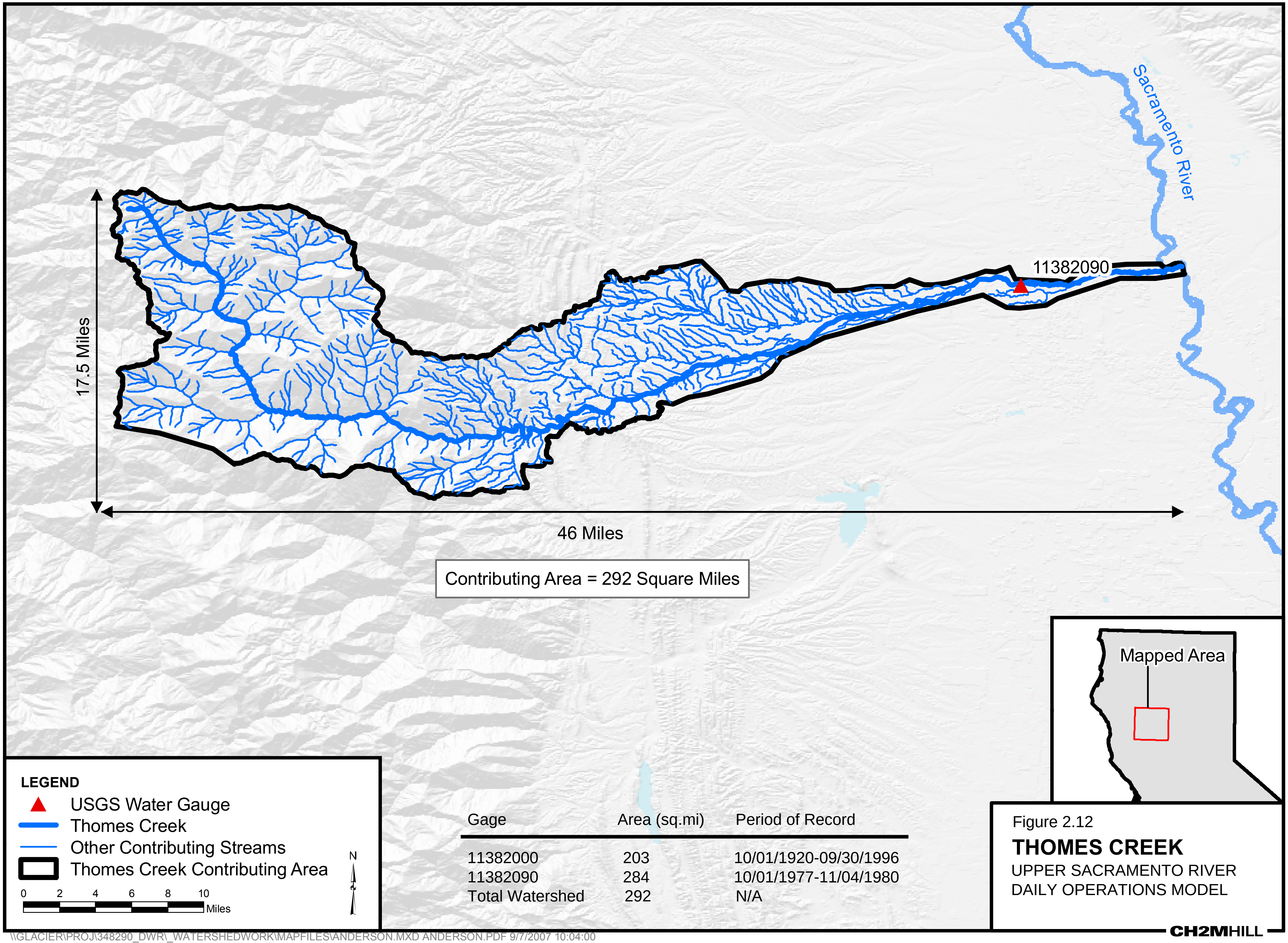
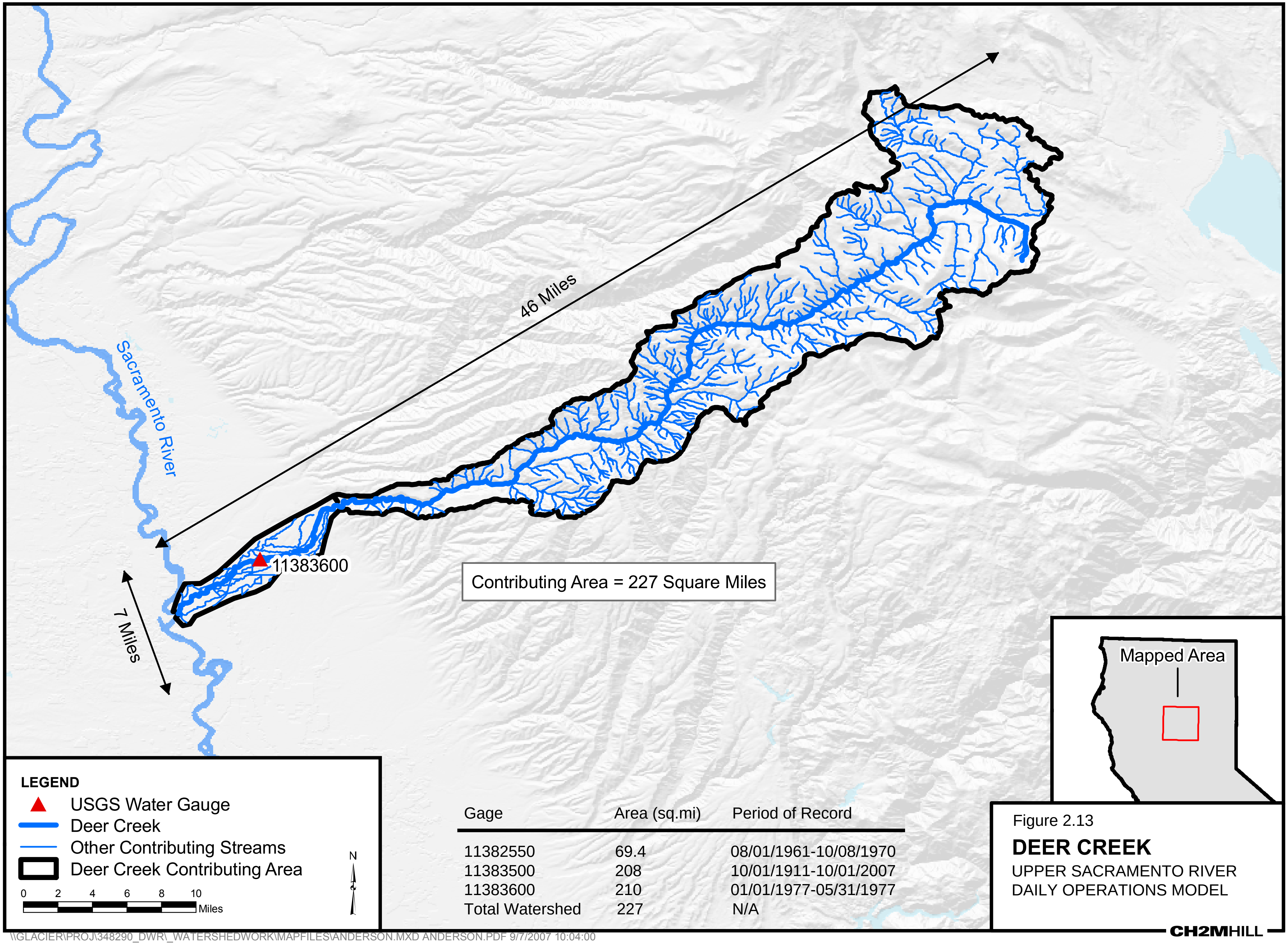


Gage	Area (sq.mi)	Period of Record
11382000	203	10/01/1920-09/30/1996
11382090	284	10/01/1977-11/04/1980
Total Watershed	292	N/A

Figure 2.12

THOMES CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

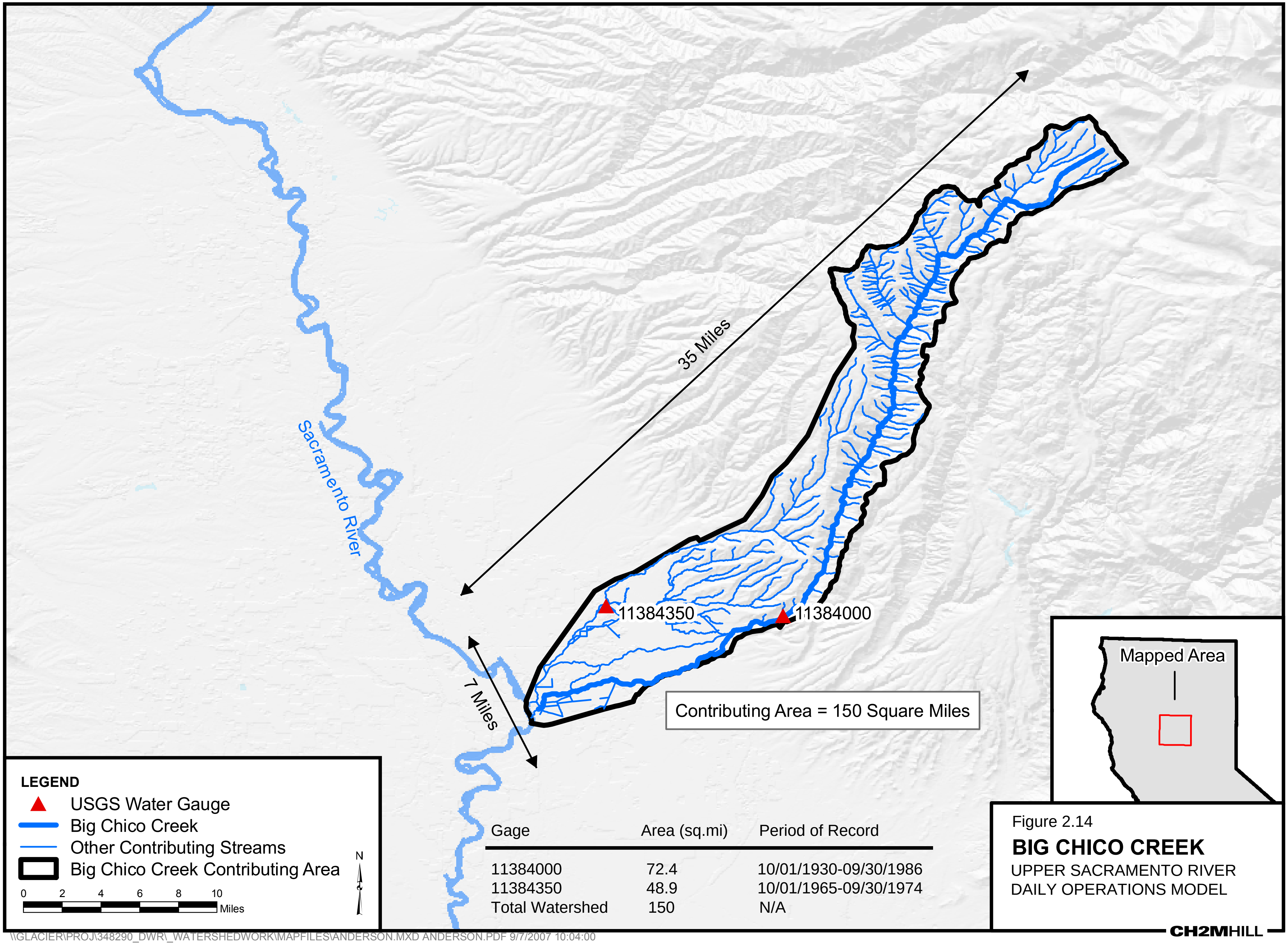


Gage	Area (sq.mi)	Period of Record
11382550	69.4	08/01/1961-10/08/1970
11383500	208	10/01/1911-10/01/2007
11383600	210	01/01/1977-05/31/1977
Total Watershed	227	N/A

Figure 2.13

DEER CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL



Gage	Area (sq.mi)	Period of Record
11384000	72.4	10/01/1930-09/30/1986
11384350	48.9	10/01/1965-09/30/1974
Total Watershed	150	N/A

Figure 2.14

BIG CHICO CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

CH2MHILL

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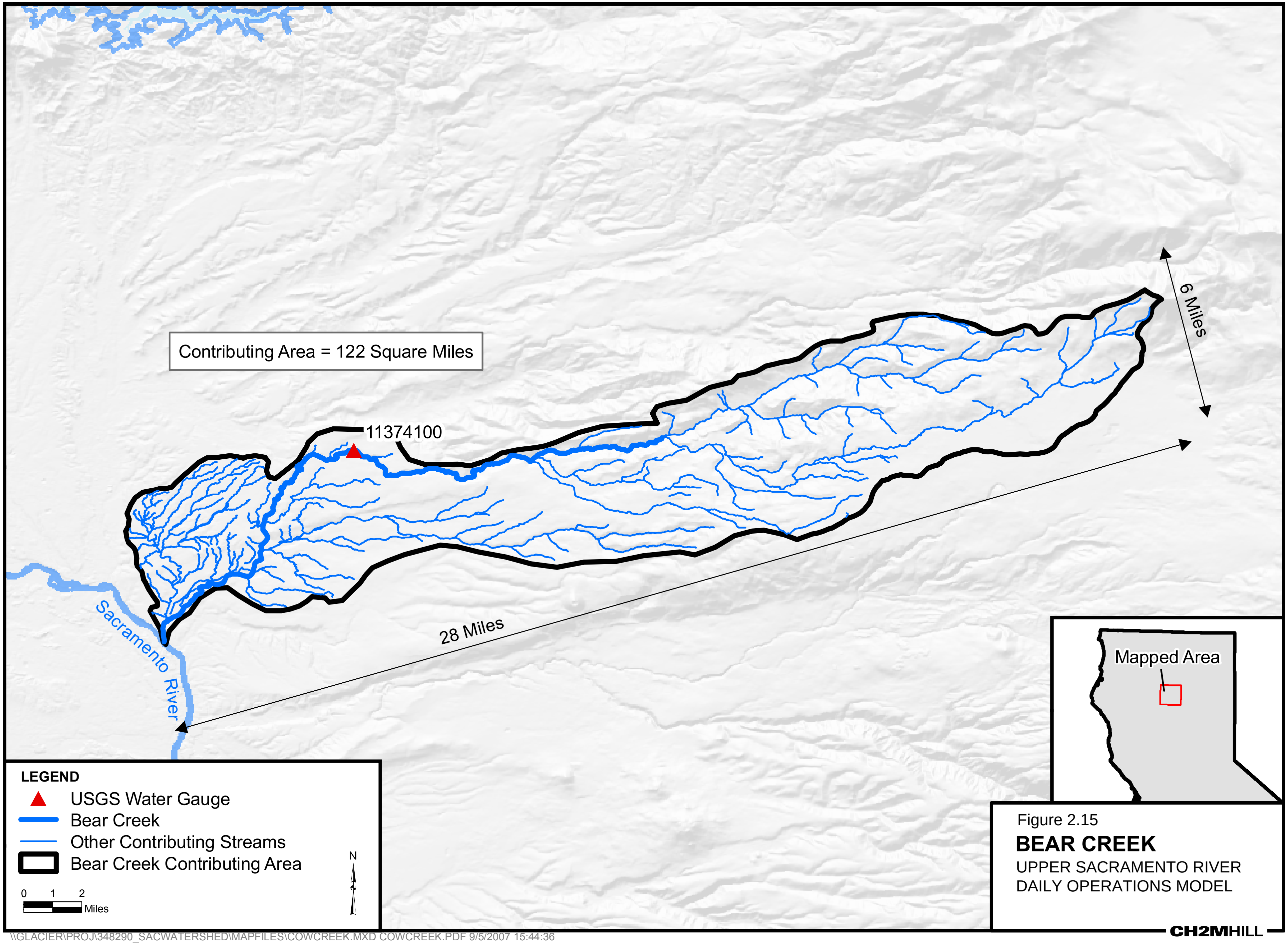


Figure 2.15

BEAR CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

CH2MHILL

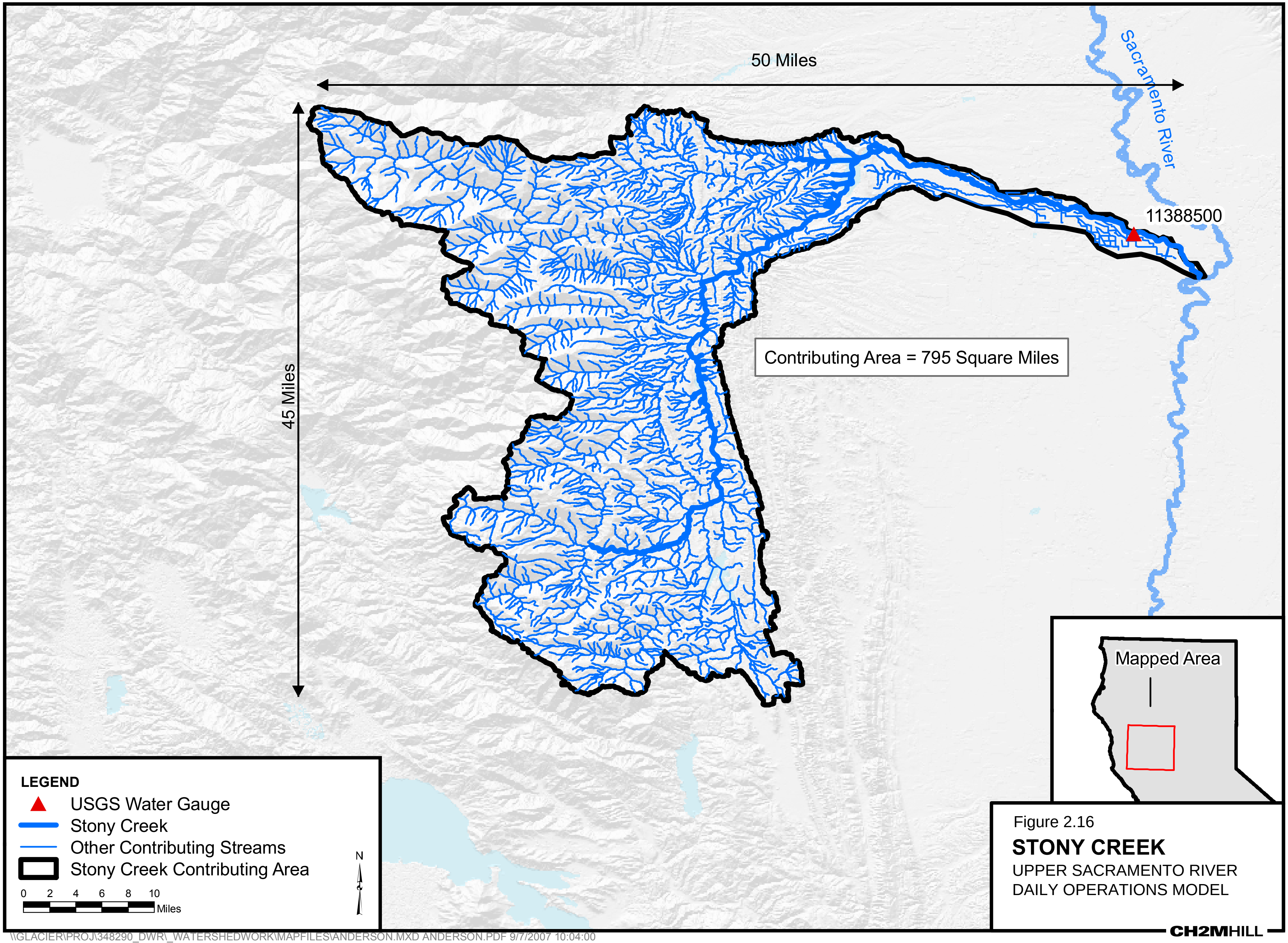


Figure 2.16

STONY CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

Method 1: Basin Area Multiplier Method

This method estimates the synthesized tributary flow during the periods with missing gage data by scaling the flow from a reference tributary using a factor computed based on the contributing watershed areas for the two streams. A non-dimensional multiplier called 'Basin Area Multiplier,' reflecting the variability in the contributing watershed areas of the synthesized tributary and the reference stream, was computed by taking the ratio of the contributing area of the tributary to the contributing area of the reference stream. Finally, the flow from the reference stream was scaled using the multiplier to estimate the flow in the synthesized tributary.

$$Q_{synTrib} = K_{area} * Q_{refTrib}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}$$

$Q_{synTrib}$ = Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib}$ = Reference Tributary flow in cubic feet per second (cfs)

K_{area} = Basin Area Multiplier

$A_{synTrib}$ = Contributing Area of Synthesized Tributary in square miles (mi^2)

$A_{refTrib}$ = Contributing Area of Reference Tributary in square miles (mi^2)

Method 2: Basin Area and Runoff Multiplier Method

This method synthesizes the missing flow in a tributary by scaling the flow from the reference stream using two multipliers related to the contributing areas and average runoff. The Basin Area Multiplier, representing the variability in the contributing areas, was computed using Method 1. Another non-dimensional multiplier, "Reference-based Runoff Multiplier," representing the variability of the runoff characteristics between the two watersheds, was computed by taking the ratio of average annual runoff volumes per square mile for the synthesized tributary and the reference stream. Finally, the reference tributary flow was scaled using the two multipliers to estimate the synthesized tributary flow.

$$Q_{synTrib} = K_{area} * K_{runoff} * Q_{refTrib}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}, \quad K_{runoff} = \frac{q_{synTrib}}{q_{refTrib}}$$

$$q_{synTrib} = \frac{V_{synTrib}}{A_{synTrib}}, \quad q_{refTrib} = \frac{V_{refTrib}}{A_{refTrib}}$$

$Q_{synTrib}$ = Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib}$ = Reference Tributary flow in cubic feet per second (cfs)

K_{area} = Basin Area Multiplier

K_{runoff} = Runoff Multiplier

$A_{synTrib}$ = Contributing area of synthesized tributary in square miles (mi^2)

$A_{refTrib}$ = Contributing area of reference tributary in square miles (mi^2)

$q_{synTrib}$ = Runoff factor for synthesized tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$q_{refTrib}$ = Runoff factor for reference tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$V_{synTrib}$ = Average annual runoff volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refTrib}$ = Average annual runoff volume for reference tributary in thousand acre-feet per year (TAF/YR)

Method 3: Basin Area and Runoff Multiplier with Separate Baseflow Method

This method is similar to Method 2, except it separates the flow values that are exceeded during most periods, or the "baseflow" in the reference stream and the synthesized tributary. It is appropriate use this method when baseflows exist in both the reference and synthesized tributaries. In addition to the multipliers defined in Methods 1 and 2, a new scaling factor called the "Reference-based Baseflow Multiplier" was computed as a ratio of the synthesized tributary baseflow to reference stream baseflow. This multiplier was used to scale flows less than or equal to the baseflow in the reference stream to estimate the baseflow in the synthesized tributary.

Because a separate scaling factor was estimated for estimating the baseflow in the synthesized tributary, while computing the Reference-based Runoff Multiplier (Method 2), the respective baseflows were deducted from the average annual runoff volume computation for the synthesized tributary and the reference stream. The final synthesized tributary flow under this method was the sum of the scaled baseflow from reference tributary using the baseflow multiplier and the scaled reference tributary flow in excess of its baseflow, using the Basin Area Multiplier and the Reference-based Runoff Multiplier.

$$Q_{synTrib} = K_{base} * Min\{Q_{refTrib}, Q_{refBase}\} + K_{area} * K_{runoff} * Max\{0, (Q_{refTrib} - Q_{refBase})\}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}, \quad K_{runoff} = \frac{q_{synTrib}}{q_{refTrib}}, \quad K_{base} = \frac{\left(Q_{synBase} / Q_{refBase}\right)}{K_{area}}$$

$$q_{synTrib} = \frac{\left(V_{synTrib} - V_{synBase}\right)}{A_{synTrib}}, \quad q_{refTrib} = \frac{\left(V_{refTrib} - V_{refBase}\right)}{A_{refTrib}}$$

$Q_{synTrib}$ = Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib}$ = Reference Tributary flow in cubic feet per second (cfs)

$Q_{synBase}$ = Base-flow for synthesized tributary in cubic feet per second (cfs)

$Q_{refBase}$ = Base-flow for reference tributary in cubic feet per second (cfs)

K_{area} = Basin Area Multiplier

K_{runoff} = Runoff Multiplier

K_{base} = Reference based base-flow multiplier

$A_{synTrib}$ = Contributing area of synthesized tributary in square miles (mi^2)

$A_{refTrib}$ = Contributing area of reference tributary in square miles (mi^2)

$q_{synTrib}$ = Runoff factor for synthesized tributary in thousand acre-feet per year per square mile ($TAF/YR/mi^2$)

$q_{refTrib}$ = Runoff factor for reference tributary in thousand acre-feet per year per square mile ($TAF/YR/mi^2$)

$V_{synTrib}$ = Average annual runoff volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refTrib}$ = Average annual runoff volume for reference tributary in thousand acre-feet per year (TAF/YR)

$V_{synBase}$ = Average annual base-flow volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refBase}$ = Average annual base-flow volume for reference tributary in thousand acre-feet per year (TAF/YR)

Method 4: Basin Area and Runoff Multiplier with Baseflow Removal Method

Method 4 is a variation of Method 3 in which the synthesized tributary baseflow ($V_{synBase}$) is zero, while the reference baseflow is not. This method helps improve the correlation between the tributary flows and the reference streamflows by separating the baseflow from the reference stream.

Method 5: Basin Area and Runoff Multiplier with Baseflow Addition Method

Method 5 is similar to Method 2 and was appropriate when a baseflow component was observed in the synthesized tributary while not in the reference streamflow. Under this method, prior to calculating the Runoff Multiplier (Method 2), the volume corresponding to the estimated baseflow is subtracted from the total volume for the synthesized tributary. Finally, the synthesized tributary flow under this method was computed as the sum of the estimated baseflow and the reference streamflow scaled with the Basin Area Multiplier and the Reference-based Runoff Multiplier.

$$Q_{synTrib} = Q_{synBase} + K_{area} * K_{runoff} * Q_{refTrib}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}, \quad K_{runoff} = \frac{q_{synTrib}}{q_{refTrib}}$$

$$q_{synTrib} = \frac{\left(V_{synTrib} - V_{synBase}\right)}{A_{synTrib}}, \quad q_{refTrib} = \frac{V_{refTrib}}{A_{refTrib}}$$

$Q_{synTrib} =$ Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib} =$ Reference Tributary flow in cubic feet per second (cfs)

$Q_{synBase} =$ Base-flow for synthesized tributary in cubic feet per second (cfs)

$K_{area} =$ Basin Area Multiplier

$K_{runoff} =$ Runoff Multiplier

$A_{synTrib} =$ Contributing area of synthesized tributary in square miles (mi^2)

$A_{refTrib} =$ Contributing area of reference tributary in square miles (mi^2)

$q_{synTrib} =$ Runoff factor for synthesized tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$q_{refTrib} =$ Runoff factor for reference tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$V_{synTrib} =$ Average annual runoff volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refTrib} =$ Average annual runoff volume for reference tributary in thousand acre-feet per year (TAF/YR)

$V_{synBase}$ = Average annual base-flow volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

Table 2.6 lists the synthesized tributaries and summarizes the synthesis method used and parameters for each tributary. The process of synthesizing missing tributary flows retained seasonable variability in addition to preserving daily variability for a tributary. The latter was verified using frequency histograms. For retaining the observed seasonal variability in each synthesized tributary, the fraction of average annual volume within each month were computed for both the period with available gaged data and the period with the synthesized data for that tributary. Based on these fractional volumes from the observed and synthesized data, monthly ratios were computed. These monthly ratios were adjusted iteratively until the fraction of average annual volume within each month was the same for both the observed and synthesized periods. For the tributaries that required baseflow adjustment (Cow Creek, Battle Creek, and Cottonwood Creek) the baseflow volume was removed from the average annual volume before computing the monthly fractions of the annual volume.

TABLE 2.6
Synthesized Tributaries, Period and Method of Synthesis, and Parameters Used

				Synthesis Parameters								
				Contributing Area (mi^2)			Runoff Factor (TAF/yr)/mi^2			Baseflow (cfs)		
Tributary	Period of Synthesis	Reference Stream (Gaged or Combined)	Method of Synthesis	Tributary	Reference Stream	Basin Area Multiplier	Tributary	Reference Stream	Reference-based Runoff Multiplier	Tributary	Reference Stream	Reference-based Baseflow Multiplier
Cow Creek	10/01/1921 - 09/30/1949	Big Chico Creek (Combined)	Method 4	425.0	72.4	5.8702	1.17	1.13	1.0338	0	30	0
Cottonwood Creek	10/01/1921 - 09/30/1940 10/01/1982 - 09/30/2003	Sum of Elder, Thomes and Red Bank Creeks (Combined)	Method 5	927.0	388.9	2.3836	0.65	0.85	0.7570	60	NA	NA
Battle Creek	10/01/1921 - 09/30/1940	Mill Creek (Combined)	Method 3	357.0	131.0	2.7252	0.53	1.21	0.4412	225	95	2.3684
Paynes Creek	10/01/1921 - 09/30/1949 11/01/1966 - 09/30/2003	Big Chico Creek (Combined)	Method 2	92.8	72.4	1.2818	0.55	1.48	0.3716	NA	NA	NA
Red Bank Creek	10/01/1921 - 09/30/1959 10/01/1982 - 09/30/2003	Elder Creek (Combined)	Method 2	93.5	92.4	1.0119	0.38	0.78	0.4857	NA	NA	NA
Antelope Creek	10/01/1921 - 09/30/1940 10/01/1982 - 09/30/2003	Mill Creek (Combined)	Method 2	123.0	131.0	0.9389	0.89	1.77	0.5027	NA	NA	NA
Mill Creek	10/01/1921 - 09/30/1928	Deer Creek (Gaged)	Method 2	131.0	208.0	0.6298	1.69	1.14	1.4817	NA	NA	NA
Elder Creek	10/01/1921 - 09/30/1948	Thomes Creek (Gaged)	Method 2	92.4	203.0	0.4552	0.79	1.13	0.6949	NA	NA	NA
Thomes Creek	10/01/1996 - 09/30/2003	Elder Creek (Gaged)	Method 1	203.0	92.4	2.1970	NA	NA	NA	NA	NA	NA
Big Chico Creek	10/01/1921 - 09/30/1930 10/01/1986 - 09/30/2003	Deer Creek (Gaged)	Method 1	72.4	208	0.3481	NA	NA	NA	NA	NA	NA

Note:

NA = not applicable

SECTION 3

Model Development

3.1 Overview

The capabilities of USRDOM include simulating the physical and operational processes of the hydrologic features in the Sacramento River system on a daily time scale. The processes include reservoir operations and hydrologic stream routing in the main stem Sacramento River and its tributaries and diversions. The model accounts for the inflows, diversions, accretions, and depletions occurring in the river and is constrained by daily assumptions based on the regulatory and operational details consistent with the Common Assumptions Common Model Package CALSIM II model (CACMP CALSIM II). The solution is constrained by the delivery flow targets and the downstream flow targets from CACMP CALSIM II. USRDOM was developed using the U.S. Army Corps of Engineers' (Corps') HEC-5 software, the same software used by the Upper Sacramento River Water Quality Model (USRWQM), which is part of the CACMP. Using the same software for USRDOM development allowed for easy linkage between the two models.

3.2 Model Schematic

The spatial domain of USRDOM includes the Upper Sacramento River from Shasta Reservoir to Knights Landing, including the facilities and tributaries in the region. It also includes the Trinity River section of the CVP and the Sutter Bypass region. The spatial resolution of USRDOM relies on many factors, including location of reservoirs and diversion control structures and confluence points with major tributaries. Spatial resolution also is influenced by the information needs for other models, such as the NODOS Winter Run Life Cycle Model. A few control points were included to maintain consistency with USRWQM. A complete list of the control points used in the model, along with a description of the control point locations and their river mile on the Sacramento River, are provided in Table 3.1. Figure 3.1 shows the model schematic for USRDOM. An information table with detailed reach by reach descriptions of USRDOM schematic is included in Appendix A with the schematic. This table helps in understanding how the model schematic and some of the modeling parameters were developed.

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
340	Trinity Reservoir	Trinity River	340-TRINITYRES
330	Trinity River above Lewiston Reservoir	Trinity River	330-ABVLEWISTN
320	Lewiston Reservoir	Trinity River	320-LEWISTNRES
300	Dummy reservoir[a] for Trinity River downstream of Lewiston Reservoir	Trinity River	300-BLWLEWISTN

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
244	(Clear Creek Tunnel Flow + Trinity River Spills) at Lewiston Reservoir	Trinity River	244-TRINMINREL
242	Clear Creek Powerplant	Trinity River	242-CLEARCKTUN
240	Whiskeytown Dam	Clear Creek	240-WHSKYTWNDAM
214	(Spring Creek Tunnel Flow + Clear Creek Spills) at Whiskeytown Reservoir	Clear Creek	214-WHISKMINREL
2112	Spring Creek Powerplant	Clear Creek	212-SPRINGCRTUN
230	Dummy reservoir[a] for Clear Creek downstream of Whiskeytown Reservoir	Clear Creek	230-CLRCKBLWWSK
220	Shasta Dam/Reservoir	310.6	220-SHASTADAM
210	Sacramento River Above Keswick Reservoir	302.0	210-ABVKESWICK
200	Keswick Reservoir	302.0	200-KESWICKDAM
197	Sacramento River at ACID Diversion	298.5	197-ACID-DIV
195	Sacramento River at Clear Creek Confluence	289.0	195-CLEARCKINF
192	Sacramento River at Churn and Clover Creek Confluence	284.0	192-CHURCLOVINF
191	Sacramento River at Stillwater Creek Confluence	281.0	191-STILLWATINF
1901	Dummy reservoir[a] representing Cow Creek	Cow Creek	1901-COWCK
190	Sacramento River at Cow Creek Confluence	280.0	190-COWCKINF
188	Sacramento River at Bear and Ash Creek Confluence	277.5	188-BEAR-ASHINF
1861	Dummy reservoir[a] representing Cottonwood Creek	Cottonwood Creek	1861-COTTONWDCK
186	Sacramento River at Cottonwood Creek Confluence	273.0	186-COTTONWDINF
1851	Dummy reservoir[a] representing Battle Creek	Battle Creek	1851-BATTLECK
185	Sacramento River at Battle Creek Confluence	271.5	185-BATTLECKINF
1801	Dummy reservoir[a] representing Paynes Creek	Paynes Creek	1801-PAYNESCK
182	Sacramento River at Bend Bridge	260.0	182-BENDBR-GAGE
180	Sacramento River at Paynes Creek Confluence	253.0	180-PAYNESCKINF
1751	Dummy reservoir[a] representing Red Bank Creek	Red Bank Creek	1751-RDBANKCK

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
175	Sacramento River at Red Bluff Diversion Dam	243.0	175-RDBLFDIVDAM
1701	Dummy reservoir[a] representing Antelope Creek	Antelope Creek	1701-ANTELOPECK
170	Sacramento River at Antelope Creek Confluence	235.0	170-ANTELOPEINF
1652	Dummy reservoir[a] representing Mill Creek	Mill Creek	1652-MILLCK
1651	Dummy reservoir[a] representing Elder Creek	Elder Creek	1651-ELDERCK
165	Sacramento River at Mill Creek Confluence	230.0	165-MILLCKINF
1621	Dummy reservoir[a] representing Thomes Creek	Thomes Creek	1621-THOMESCK
162	Sacramento River at Thomes Creek Confluence	226.0	162-THOMESCKINF
1601	Dummy reservoir[a] representing Deer Creek	Deer Creek	1601-DEERCK
160	Sacramento River at Deer Creek Confluence	220.0	160-DEERCKINF
155	Sacramento River Below Woodson Bridge	214.0	155-BLW-WOODSON
150	Sacramento River at Glenn-Colusa Diversion	206.0	150-GCC-DIV
1451	Dummy reservoir[a] representing Big Chico Creek	Big Chico Creek	1451-BIGCHICOCK
145	Sacramento River at Big Chico Creek Confluence	193.0	145-BIGCHICOINF
1136	Black Butte Reservoir	Stony Creek	1136-BLKBUTTEDM
1134	Stony Creek at Tehama-Colusa Canal	Stony Creek	1134-STONYCR-TC
142	Sacramento River at Stony Creek Confluence	190.0	142-STONYCKINF
140	Sacramento River at Ord Ferry Overflow	189.0	140-ORDFERRY
135	Sacramento River at Butte City	169.0	135-BUTTE-CITY
132	Sacramento River above Moulton Weir	160.0	132-ABVMOULTONW
130	Sacramento River at Moulton Weir	159.0	130-MOULTONWEIR
129	Sacramento River at NODOS Diversion	159.0	129-NODOS-DIV
127	Sacramento River at above Colusa Weir	147.0	127-ABVCOLUSAWR
125	Sacramento River at Colusa Weir	146.0	125-COLUSA-WEIR
120	Sacramento River at Butte Slough Confluence	138.0	120-BUTTE-SL
117	Sacramento River above Tisdale Weir	121.0	117-ABV-TISDALE
115	Sacramento River at Tisdale Weir	119.0	115-TISDALEWEIR

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
110	Sacramento River at D129A and D128 Diversions	100.0	110-LOW-SAC-DIV
105	Sacramento River at Knights Landing	84.0	105-KNIGHTSLNDG
1184	Dummy reservoir[a] to route Ord Ferry Overflow to Butte Basin	Sutter Bypass	1184-ORD-ROUTE
1158	Dummy reservoir[a] to route Moulton Weir Diversion through sub-Butte Basin	Sutter Bypass	1158-MWEIR-ROUTE
1146	Dummy reservoir[a] to route Colusa Weir Diversion through sub-Butte Basin	Sutter Bypass	1146-CWEIR-ROUTE
1119	Dummy reservoir[a] to route Tisdale Weir Diversion through sub-Butte Basin	Sutter Bypass	1119-TWEIR-ROUTE
2119	Tisdale Weir spills flowing into Sutter Bypass	Sutter Bypass	2119-TWEIR-END
2184	Ord Ferry spills flowing into Butte Basin	Sutter Bypass	2184-ORD-END
2158	Moulton Weir spills flowing into Butte Basin	Sutter Bypass	2158-MWEIR-END
2146	Colusa Weir spills flowing into Butte Basin	Sutter Bypass	2146-CWEIR-END
2222	Dummy reservoir[a] for Butte Basin Total Flow	Sutter Bypass	2222-B-BASIN
2000	Sutter Bypass at Meridian	Sutter Bypass	2000-MERIDIAN
1500	Sutter Bypass at junction with Tisdale Weir	Sutter Bypass	1500-SUTRBYPASS
1400	Dummy node[b] representing end of Sutter Bypass	Sutter Bypass	1400-SB-OUTLET

[a] HEC-5 requires the most upstream location on each tributary to be a reservoir. If no reservoir exists, a dummy reservoir with no storage is used.

[b] A dummy node is a HEC-5 control point sometimes used to represent a given location more than once in the model or to represent an end point to route all the streams in the model schematic.

3.3 Modeling of Tributary Inflows and Diversions

A critical element of upper Sacramento River flood operations is the local runoff entering the Sacramento River between Keswick Reservoir (control point 210) and Bend Bridge (control point 182). The unregulated creeks (major creek systems are Cottonwood Creek, Cow Creek, and Battle Creek) in this reach of the Sacramento River can be sensitive to large rainfall events and can produce large rates of runoff into the Sacramento River in short time periods. During large rainfall or flooding events, the local runoff between Keswick Reservoir and Bend Bridge can exceed 100,000 cfs. The tributaries that contribute significant flow to the main stem and have flow gage data or that are necessary as part of NODOS reporting metrics were included in USRDOM. Table 3.2 lists tributaries that were explicitly modeled in USRDOM. It also includes the control point numbers where each tributary inflow meets the main stem, the contributing area for each inflow, and the HEC-5 identification of the dummy reservoir where each inflow is included in USRDOM.

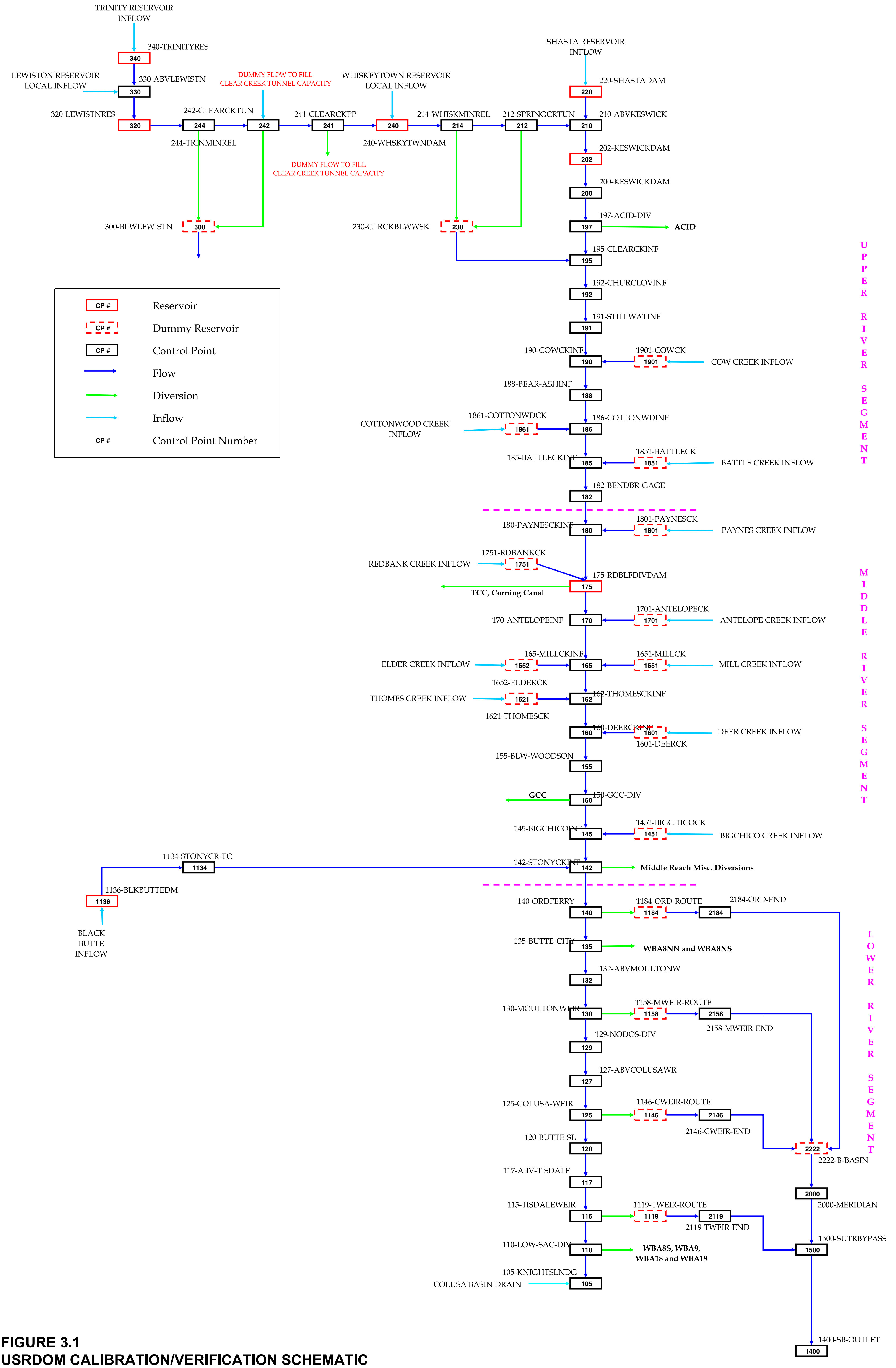


FIGURE 3.1
USRDOM CALIBRATION/VERIFICATION SCHEMATIC

TABLE 3.2
Tributaries Explicitly Modeled in USRDOM

Tributary	Control Point Number at Confluence with Sacramento River	Contributing Area (mi^2)	Dummy Reservoir for Tributary Inflow
Cow Creek	190	425	1901-COWCKINF
Cottonwood Creek	186	927	1861-COTTONWDCK
Battle Creek	185	357	1851-BATTLECK
Paynes Creek	180	92.8	1801-PAYNESCK
Red Bank Creek	175	109	1751-RDBANKCK
Antelope Creek	170	123	1701-ANTELOPECK
Mill Creek	165	133	1652-MILLCK
Elder Creek	165	136	1651-ELDERCK
Thomes Creek	162	284	1621-THOMESCK
Deer Creek	160	210	1601-DEERCK
Big Chico Creek	145	72.4	1451-BIGCHICOCK

The major diversions along the Sacramento River that were modeled in USRDOM include Anderson Cottonwood Irrigation District (ACID), Tehama-Colusa Canal (TCC), Glenn-Colusa Canal (GCC), and the flood bypass overflows downstream of Hamilton City. Other diversions in the Colusa Basin area and the lower river diversions were aggregated into a few locations and were modeled as diverted from the nearest control point. The diversion data for calibration and verification of USRDOM was derived from the CACMP V8 CALSIM II Existing Condition Simulation when the historical data were unavailable. Monthly CALSIM II data were downscaled using the CALSIM25Q utility. CALSIM25Q is used for disaggregating monthly CALSIM II output to daily time step for using as input to the USRWQM model (RMA, 2003). The diversions modeled explicitly in USRDOM are listed in Table 3.3, along with the corresponding definition in CALSIM II, the control point number at which the diversion is simulated, and the HEC-5 identifier for the Hydrologic Engineering Center’s Data Storage System (HEC-DSS) time series.

Other Sacramento River diversions, accretions, depletions, and inflows from tributaries not explicitly included in the model were accounted for as part of two closure terms. One covers the upper Sacramento River from Keswick to Bend Bridge, and the other covers its middle stretch from Bend Bridge to Ord Ferry. Details on the closure terms are provided in Sections 4 and 5.

TABLE 3.3
Diversions Explicitly Modeled in USRDOM

Diversions	Corresponding Values in CALSIM II	Control Point Number at the Location of Diversion	Name for Diversion's Time Series
Anderson Cottonwood Irrigation District and other depletions	D104_PSC	197	**QD197**
Tehama-Colusa Canal and Corning Canal	D112	175	**QD175**
Glenn-Colusa Canal	D114	150	**QD150**
Miscellaneous above Ord	D113A+D113B+GS61	142	**QD142**
West Bank (D122A and D122B)	D122A+D122B	135	**QD135**
Lower River (D128 and D129A)	D128+D129A	110	**QD110**

Table 3.4 lists tributaries not explicitly modeled in USRDOM at each control point. It also includes respective areas of contribution for each tributary and any ungaged areas; the control point number where the inflows are accounted for; and a fraction called the 'C1 ratio,' which corresponds to the contributing watershed area at each control point, runoff from which was not explicitly modeled in USRDOM. To compute this fraction, the total contributing watershed areas for the inflows that were not accounted for in USRDOM were estimated for the upper (Keswick to Bend Bridge) and the middle (Bend Bridge to Ord Ferry) segments of the Sacramento River. The C1 ratio for each control point is estimated as the ratio of the lumped ungaged contributing area located along the River reach up to the upstream control point to the total ungaged watershed area for the segment in which the control point is present. The total ungaged watershed area in the upper segment of the Sacramento River is 515.2 sq. mi. and in the middle segment of the Sacramento River is 1556.9 sq. mi. C1 ratio is used to distribute the closure flows along the River for each segment. Closure flow computation and implementation is described in Sections 4 and 5.

TABLE 3.4
Contribution Areas for Ungaged Tributaries and Areas along Sacramento River

Ungaged Tributary or Area	Contributing Area (mi^2)	Control Point Number at Confluence with Sacramento River	C1 Ratio
Clear Creek below Whiskeytown	44	230	0.0854
Spring Creek (N)	17	195	0.1799
Jenny Creek	1.7		
Olney Creek	14		
Sulphur Creek	4		
Other Ungaged Areas	56		
Churn Creek	36	192	0.0992
Clover Creek	6		

TABLE 3.4
Contribution Areas for Ungaged Tributaries and Areas along Sacramento River

Ungaged Tributary or Area	Contributing Area (mi^2)	Control Point Number at Confluence with Sacramento River	C1 Ratio
Other	9.1		
Stillwater Creek	67	191	0.1374
Other Ungaged Areas	3.8		
Cow Creek (ungaged)	3	190	0.0113
Other Ungaged Areas	2.8		
Bear Creek	122	188	0.2995
Ash Creek	31		
Other Ungaged Areas	1.3		
Cottonwood Creek (ungaged)	17	186	0.1403
Anderson Creek	26		
Other Ungaged Areas	29.3		
Battle Creek (ungaged)	15	185	0.0353
Other Ungaged Areas	3.2		
Frazier Creek	1.6	182	0.0116
Other Ungaged Areas	4.4		
Paynes Creek (ungaged)	0	180	0.0392
Spring Creek	3.3		
Other Ungaged Areas	57.7		
Red Bank Creek (ungaged)	17.5	175	0.0652
Reeds Creek	18		
Blue Tent Creek	18		
Dibble Creek	33		
Other Ungaged Areas	15		
Antelope Creek (ungaged)	74	170	0.0897
Salt Creek	43		
Other Ungaged Areas	22.6		
Mill Creek (ungaged)	11	165	0.0938
Dye Creek	47		
Oat Creek	63		
Elder Creek (ungaged)	14		
Other Ungaged Areas	11		
Thomes Creek (ungaged)	89	162	0.0903
McClure Creek	42		
Other Ungaged Areas	9.6		

TABLE 3.4
Contribution Areas for Ungaged Tributaries and Areas along Sacramento River

Ungaged Tributary or Area	Contributing Area (mi^2)	Control Point Number at Confluence with Sacramento River	C1 Ratio
Deer Creek (ungaged)	19	160	0.0844
Other Ungaged Areas	112.4		
Jewett Creek	42	155	0.0342
Hoag Slough	7.4		
Other Ungaged Areas	3.9		
Burch Creek	377	150	0.2495
Other Ungaged Areas	11.4		
Pine Creek	215	145	0.1965
Big Chico Creek (ungaged)	77.6		
Other Ungaged Areas	13.3		
Stony Creek below Black Butte	35	142	0.0573
Other Ungaged Areas	54.2		

3.4 Stream Routing

Accurate stream routing is an essential component of proper simulation of reservoir operations. For example, the travel time required for changes in releases at Keswick Reservoir to affect Bend Bridge flows is approximately 8 to 10 hours. If this travel time were not modeled accurately, then in a likely event where the channel capacity is projected to exceed at Bend Bridge, the releases from Keswick Reservoir would not be ramped down in time to protect Bend Bridge location from flooding.

3.4.1 Description of Routing Methods

Stream routing in USRDOM was simulated using coefficient methods. These methods compute outflow from a routing reach as a linear function. Equation (1) is the basic routing equation. For the direct input of coefficients, the series of ‘C’ values are input and their sum should equal 1 to maintain continuity.

$$O_n = C_1 I_n + C_2 I_{n-1} + C_3 I_{n-2} + \ldots\ldots\ldots\ldots \quad (1)$$

where:

O_n = ordinate of outflow hydrograph at time ‘n’

I_n, I_{n-1}, etc. = ordinates of inflow hydrograph at times n, n-1, etc.

C_1, C_2, etc. = routing coefficients, as coefficients of inflow

Two coefficient methods were used in USRDOM: the Attenuation of Hydrographs method and the Muskingum Routing method. The Attenuation of Hydrographs method was used for the stream routing in the main stem Sacramento River. This method requires user-specified ‘C’ values. Muskingum Routing was used in the Sutter Bypass reaches. The ‘C’ values for this method are computed based on the travel time in hours (K) and the dimensionless routing parameter between 0 and 0.5 (X) specified for each reach. In addition to specifying K and X values in Muskingum Routing, the number of sub-reaches within a routing reach is required. To avoid computing negative coefficients, the K value must be greater than or equal to [t/(2*(1-X)] and less than or equal to [t/(2*X)], where ‘t’ is the timestep used in the model.

3.4.2 Development of Routing Coefficients

The routing coefficients for the main stem Sacramento River were developed based on the travel times and routing coefficients used in the USRWQM. When the USRDOM schematic was developed, control points consistent with USRWQM in terms of location were included. Table 3.5 shows the routing coefficient computation process for USRDOM using the information from USRWQM for the Clear Creek confluence to Cow Creek confluence reach of the Sacramento River.

The information in columns 3 through 8 corresponds with USRWQM. According to the information from USRWQM, the Clear Creek to Cow Creek reach was 9 miles long and the travel time was 2.05 hours. The routing coefficient C_1 was 0.91 and C_2 was 0.09. Columns 9 to 14 correspond with USRDOM. According to this information, Clear Creek to Cow Creek reach now has three sub-reaches, Clear Creek to Churn and Clover creeks, Churn and Clover creeks to Stillwater Creek, and Stillwater Creek to Cow Creek. The lengths of the sub-reaches were 5 miles, 3 miles, and 1 mile, respectively. These lengths add up to 9 miles, which is the same value in USRWQM. In column 12, the travel time within each sub-reach was estimated based on the ratio of sub-reach length to the total reach length from USRWQM. Thus, for Clear Creek to Churn and Clover creeks, the travel time was five/ninths of 2.05 hours, or 1.14 hours. Column 14 has the routing coefficient C_2 values for each sub-reach in USRDOM. These values were estimated based on the ratio of travel time for individual sub-reaches to the total travel time for the reach in USRWQM. Thus, for the first sub-reach in USRDOM, C_2 was (1.14/2.05) times 0.09 (value of C_2 for the reach in USRWQM). Finally, C_1 values were estimated simply by subtracting C_2 values from 1. The routing coefficients in Columns 6 and 7 are verified by computing a cumulative value of routing coefficients for Clear Creek to Cow Creek, which are shown in columns 15 and 16. The equivalent C_1 and C_2 values are the same as the routing coefficients for Clear Creek to Cow Creek reach in USRWQM, or 0.91 and 0.09, respectively. Travel times and routing coefficients were estimated for other sub-reaches in similar fashion. Table 3.6 lists the routing coefficients used in USRDOM for all routed reaches in the main stem Sacramento River.

TABLE 3.5
An Example of Routing Coefficients Estimation for the Main Stem Sacramento River

		USRWQM						USRDOM							
Location Name & Description (1)	River Mile (2)	Control Point (3)	Length of d/s Reach (4)	Routed To CP (5)	Routing Coefficient		Travel Time [hr] (8)	CP (9)	Length of d/s Reach (10)	Routed To CP (11)	Travel Time [hr] (12)	Routing Coefficient		Equiv C_1 (15)	Equiv C_2 (16)
					C_1 (6)	C_2 (7)						C_1 (13)	C_2 (14)		
Sacramento River at Clear Creek Confluence	289.0	180	9.0	178	0.91	0.09	2.05	195	5.0	192	1.14	0.9500	0.0500		
Sacramento River at Churn and Clover Creek Confluence	**284.0**							**192**	**3.0**	**191**	**0.68**	**0.9701**	**0.0299**	**0.92**	**0.08**
Sacramento River at Stillwater Creek Confluence	**281.0**							**191**	**1.0**	**190**	**0.23**	**0.9899**	**0.0101**	**0.9100**	**0.0900**
Sacramento River at Cow Creek Confluence	280.0	178						190							

Notes:

Rows in bold represent new control points added in the USRDOM model within the same reach in USRWQM.

d/s = downstream

TABLE 3.6
Routing Coefficients Used in USRDOM for the Reaches in the Main Stem Sacramento River

Upstream Control Point	Downstream Control Point	Travel Time (hrs)	Routing Coefficients	
			C1	C2
200	197	0.80	0.9650	0.0350
197	195	2.16	0.9050	0.0950
195	192	1.14	0.9500	0.0500
192	191	0.68	0.9700	0.0300
191	190	0.23	0.9900	0.0100
190	188	0.50	0.9821	0.0179
188	186	0.90	0.9679	0.0321
186	185	0.30	0.9885	0.0115
185	182	2.30	0.9115	0.0885
182	180	1.24	0.9382	0.0618
180	175	1.76	0.9118	0.0882
175	170	2.21	0.9172	0.0828
170	165	1.38	0.9483	0.0517
165	162	1.10	0.9586	0.0414
162	160	1.66	0.9379	0.0621
160	155	1.66	0.9379	0.0621
155	150	2.00	0.9000	0.1000
150	145	3.25	0.8781	0.1219
145	142	0.75	0.9719	0.0281
1136	1134	Not Available	0.7500	0.2500
1134	1132	Not Available	0.6500	0.3500
142	140	0.29	0.9881	0.0119
140	135	5.71	0.7619	0.2381
135	132	2.70	0.8650	0.1350
132	130	0.30	0.9850	0.0150
130	129	0.00	1.0000	0.0000
129	127	4.62	0.8154	0.1846
127	125	0.38	0.9846	0.0154
125	120	2.96	0.8815	0.1185
120	117	6.30	0.7481	0.2519
117	115	0.74	0.9704	0.0296
115	110	6.51	0.7286	0.2714
110	106	5.49	0.7714	0.2286

The routing coefficients for the reaches in the Sutter Bypass region were obtained from the Sacramento and San Joaquin River Basins Comprehensive Study (Comp Study) (California Reclamation Board and Corps, 2002). Because the Comp Study is an hourly timestep model and USRDOM is a daily timestep model, the number of sub-reaches and K values specified for a few routed reaches were modified in USRDOM to avoid negative routing coefficients by checking the criteria described in the Section 3.4.1. Comp Study included higher number of sub-reaches and smaller K values. When using this information in USRDOM, the number of sub-reaches was reduced and K values were increased such that the negative routing coefficients were avoided. Table 3.7 lists the X and K values used in USRDOM for all routed reaches in Sutter Bypass region.

TABLE 3.7
Routing Parameters Used in USRDOM for Reaches in the Sutter Bypass Region

Upstream Control Point	Downstream Control Point	Routing Parameters	
		X	K (hr)
1184	2184	0.10	20
1158	2158	0.10	20
1146	2146	0.10	16
1119	2119	0.20	16
2000	1500	0.20	20

As noted earlier, the routing coefficients used in USRDOM for the main stem Sacramento River were developed based on USRWQM model data. To verify the accuracy of these routing coefficients, it was necessary to double check with other sources. This process is described in Section 4.

3.5 Modeling **of Flood Bypass Weirs**

Flood bypass weirs downstream of Hamilton City, Ord Ferry, Moulton Weir, Colusa Weir, and Tisdale Weir were modeled in USRDOM. Table 3.8 shows the control point numbers where these bypass diversions are located. The operation of the weirs in USRDOM was based on the Comp Study. Diversion flows through Ord Ferry, Moulton, Colusa, and Tisdale weirs along the Sacramento River were defined as a relationship between the flows in the river and flows over the weirs.

TABLE 3.8
USRDOM Control Points and Flood Bypass Weir Locations

Control Point at Confluence with River	Weir
140	Ord Ferry to Sutter Bypass
130	Moulton Weir
125	Colusa Weir
115	Tisdale Weir

The relationships used in the Comp Study were verified using the historical flow data through the river and through diversions. Historical data were obtained at three locations on Sacramento River (near Colusa, Tisdale, and Moulton weirs). The gage locations were chosen in such a way that flow through the weir and flow in the river immediately downstream of the weir were captured.

Figures 3.2 through 3.5 show the comparison of the diversion relationships used in the Comp Study and the historical data. Mean daily flow over a weir was plotted on the x-axis and the river flow upstream of a weir is plotted on the y-axis. The relationships between the flows for different years were plotted as separate series to check the patterns during the high flood and low flood events. The corresponding flow relationship used by the Comp Study for each weir is also plotted, along with the historical flow values.

Figure 3.2 shows the relationship between flow through Moulton Weir and flow in the Sacramento River just upstream of Moulton Weir. The black line on the graph indicates the relationship used by the Comp Study, and scatterpoints represent historical flow values from USGS and WDL gages. The blue scatterpoints are the flow values for high flood events from 1980 to 2000.

Figure 3.3 and Figure 3.4 show the flow relationship curves for Colusa and Tisdale weirs, respectively. By observing the curves for the weirs using historical data and comparing them with the values used by the Comp Study, it is evident that the relationships used in the Comp Study agree with historical observations.

Figure 3.5 shows the relationship used for Ord Ferry in the Comp Study. Because the historical flow data were not available for the Sutter Bypass, this relationship was not verified.

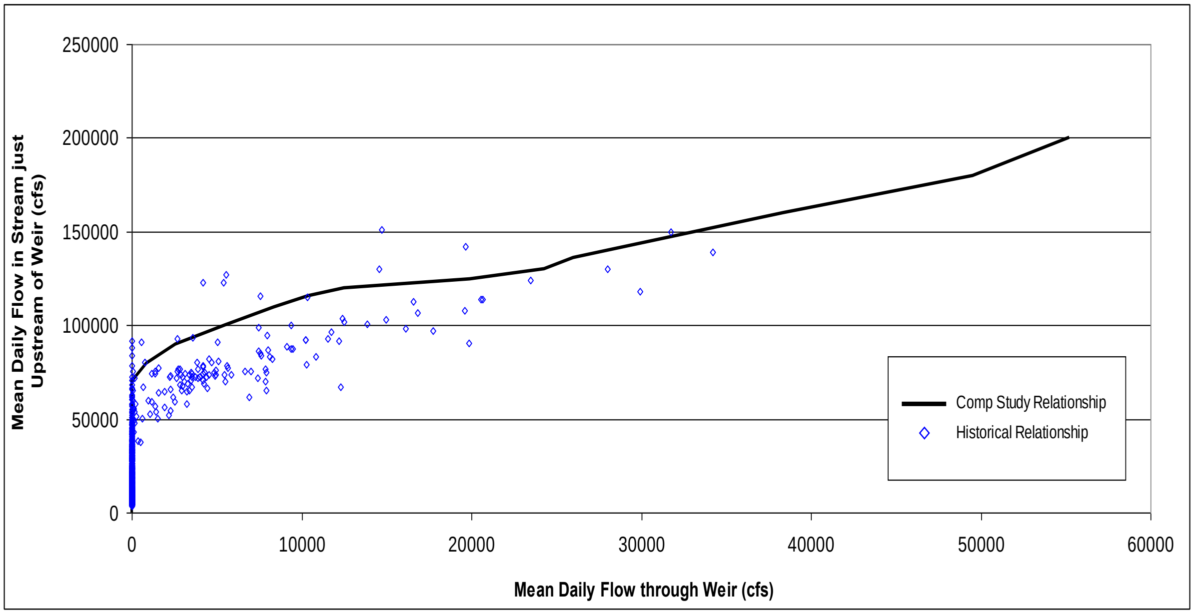


FIGURE 3.2
Flow Relationship Curve for Moulton Weir

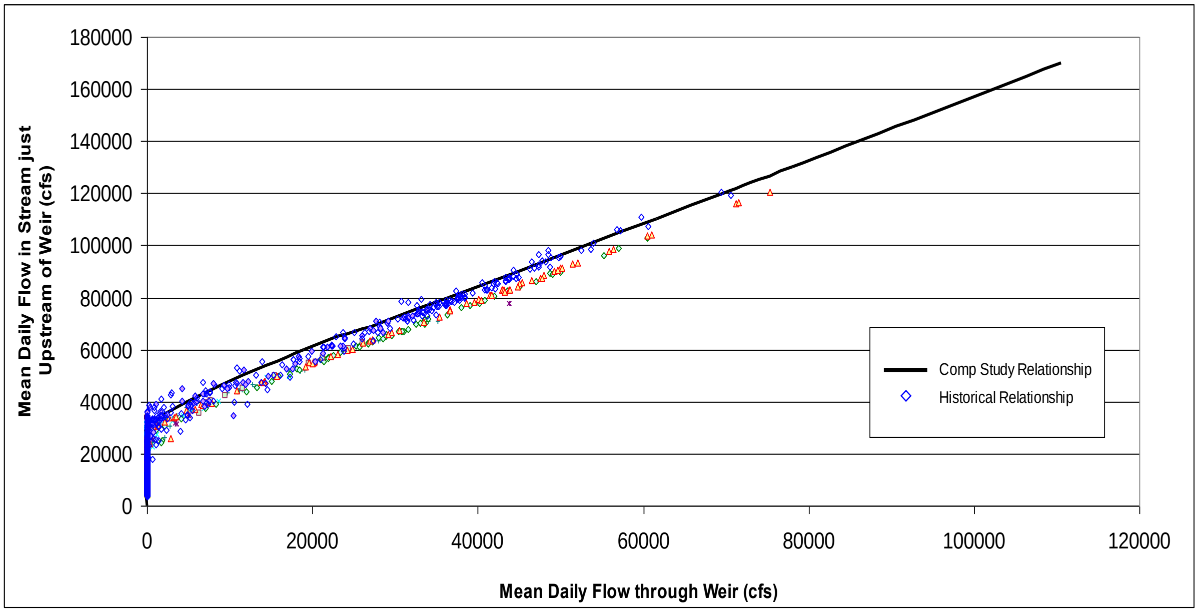


FIGURE 3.3
Flow Relationship Curve for Colusa Weir

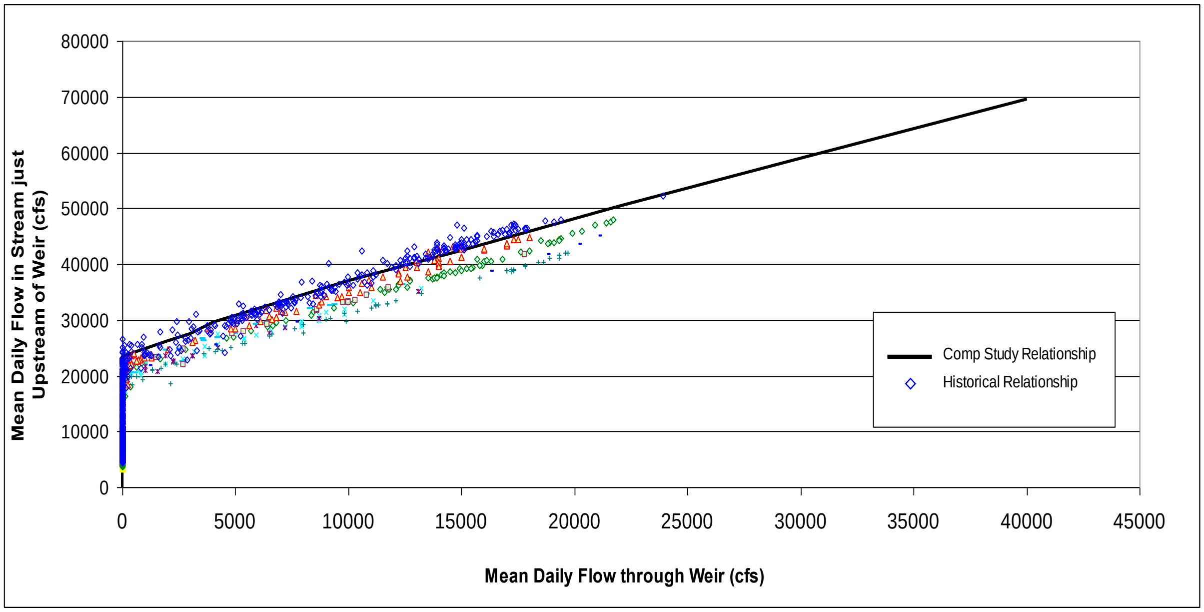


FIGURE 3.4
Flow Relationship Curve for Tisdale Weir

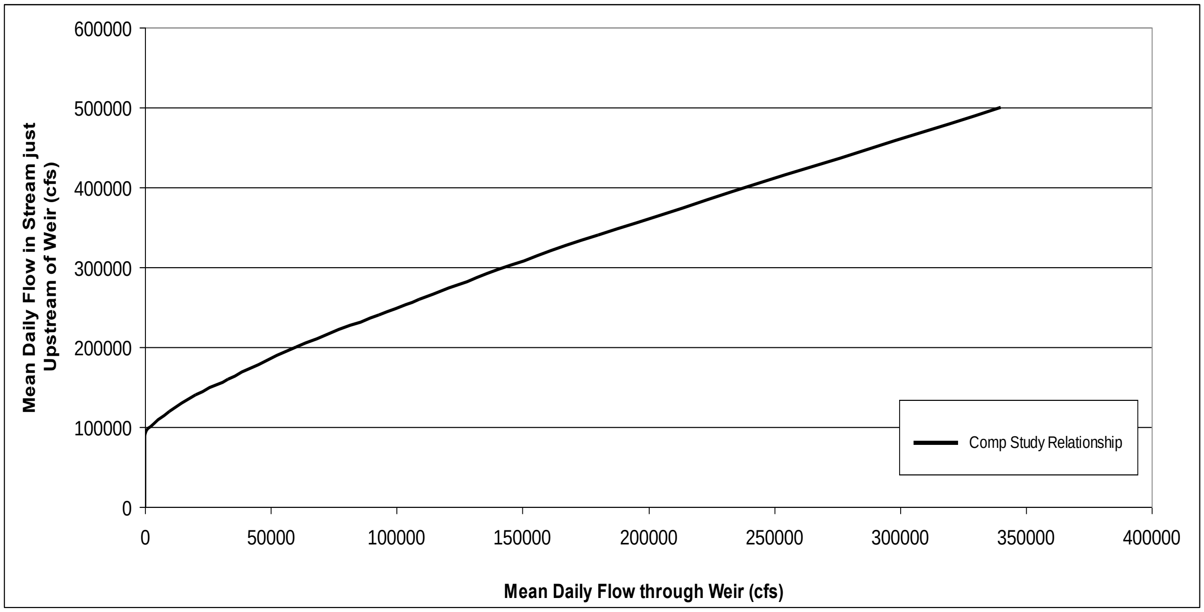


FIGURE 3.5
Flow Relationship Curve for Ord Ferry Spills

3.6 Modeling of Reservoir Operations

USRDOM includes the five CVP reservoirs at the upstream end of Sacramento River: Trinity Reservoir, Lewiston Reservoir, Whiskeytown Reservoir, Shasta Reservoir, and Keswick Reservoir. It also includes the Black Butte Reservoir on Stony Creek. This section provides a brief description of the operation criteria used and how each reservoir operation was simulated in USRDOM.

3.6.1 Trinity and Lewiston Operations

Trinity Dam is on the Trinity River and regulates the flow from a drainage area of approximately 720 square miles. The dam was completed in 1962, forming Trinity Reservoir, which has a maximum storage capacity of approximately 2.4 million acre-feet (MAF). The mean annual inflow to Trinity Reservoir from the Trinity River is about 1.2 MAF. Historically, an average of about two-thirds of the annual inflow has been diverted to the Sacramento River Basin. Trinity Reservoir stores water for release to the Trinity River and for diversion to the Sacramento River via Lewiston Reservoir, Carr Tunnel, Whiskeytown Reservoir, and Spring Creek Tunnel where it mixes in Keswick Reservoir with Sacramento River water released from Shasta Dam and water released from Spring Creek Debris Dam.

Flood control is not an authorized purpose of the Trinity River Division, but flood control benefits are provided by implementing the California Division of Safety of Dams (DSOD) requirement that storage does not exceed 2.1 MAF from November through March. Therefore, the top of the conservation level was modeled as at 2.1 MAF from November through March in USRDOM.

Trinity Dam operates to the capacity constraints and minimum release requirements at Lewiston Reservoir and Judge Francis Carr Powerplant. The minimum release requirements for Trinity River below Lewiston are based on the fish and wildlife requirements on Trinity River as specified in the Record of Decision (ROD) (USFWS and Hoopa Valley Tribe, 1999). The minimum required releases from Lewiston Reservoir to the Trinity River in USRDOM were specified based on historical Trinity River releases from Lewiston while calibrating the model. In USRDOM, the necessary downstream control points were added to the RO record for Trinity Reservoir in the model code. A daily varying minimum release requirement was also included for Trinity Reservoir using MR record in the model code. This minimum flow was computed as sum of the minimum flow requirement for Trinity River below Lewiston and the minimum flow requirement to Clear Creek Tunnel.

Trinity imports are constrained based on whether the Sacramento River is spilling at Tisdale Weir and whether Whiskeytown is nearing spill condition or spilling. Trinity releases for import are reduced so that the flood risk on the Sacramento River and Clear Creek downstream of Whiskeytown is not increased. The channel capacity of Clear Creek Tunnel and the Trinity minimum release is reduced to 300 cfs when Tisdale Weir is spilling.

The storage-capacity curves and other facility data for the Trinity Reservoir were derived from USRWQM.

Lewiston Reservoir is on the Trinity River, 7 miles downstream from Trinity Dam. Lewiston Reservoir functions as a regulating reservoir to control flow fluctuations downstream for the Trinity Powerplant and as a forebay for the Carr Powerplant. Lewiston Reservoir was set as a flow-through reservoir in USRDOM so that all constraints for minimum releases and Clear Creek Tunnel capacity are relayed to Trinity Reservoir. The buffer and conservation levels (Levels 2 and 3) for the Lewiston Reservoir were bound to 14,000 acre-feet to reflect the average operating condition. Lewiston Reservoir facility data were taken from USRWQM. In USRDOM, all Lewiston Reservoir releases are reflected at control point 320; therefore, downstream channel capacity for Lewiston Reservoir includes Clear Creek Tunnel capacity.

Total river release is limited to 6,000 cubic feet per second (cfs) below Lewiston Reservoir under DSOD requirements because of local high water concerns and local bridge flow capacities. Because only 3,200 cfs of flow can be conveyed through the Clear Creek Tunnel, USRDOM allows no more than 6,000 cfs below Lewiston when the total inflow to Lewiston is less than or equal to 9,200 cfs. This is true until the total inflow to Lewiston Reservoir, including local flow and Trinity Reservoir releases, exceeds 9,200 cfs, at which time the excess flows are spilled downstream into the river.

3.6.2 Whiskeytown Operations

As part of the CVP since 1964, a portion of the flow from the Trinity River Basin has been exported to the Sacramento River Basin through Whiskeytown Reservoir on Clear Creek. From Whiskeytown Reservoir, water is released through the Spring Creek Power Conduit to the Spring Creek Powerplant and into Keswick Reservoir. All the water diverted from the Trinity River and a portion of Clear Creek flows, are conveyed through the Spring Creek Tunnel into Keswick Reservoir. From 1964 to 1992, an average annual quantity of 1,269,000 acre-feet of water was diverted from Whiskeytown Reservoir to Keswick Reservoir. This annual quantity is approximately 17 percent of the flow measured in the Sacramento River at Keswick.

Whiskeytown is normally operated to regulate inflows for power generation and recreation, support upper Sacramento River temperature objectives, and provide for releases to Clear Creek consistent with Central Valley Project Improvement Act (CVPIA) Anadromous Fish Restoration Program (AFRP) objectives. Whiskeytown Reservoir is drawn down approximately 35,000 acre-feet per year of storage space during November through April to regulate flows for power generation. Heavy rainfall events occasionally result in spillway discharges to Clear Creek.

To reflect this operating criteria in USRDOM, Whiskeytown Reservoir operates under the constraints from Spring Creek Tunnel capacity (4,200 cfs) and a minimum required release downstream into Clear Creek. The buffer level was reduced to 27,542 acre-feet and the conservation level was varied between 206,000 acre-feet (November through April) and 238,500 acre-feet to reflect the average operating conditions. The minimum required release for Clear Creek below Whiskeytown was computed based on historical operations data so that a flow between 50 cfs and 250 cfs was ensured. In addition to the minimum required releases, Whiskeytown releases greater than 4,200 cfs are routed down Clear Creek.

3.6.3 Shasta and Keswick Operations

Shasta Dam is located on the Sacramento River just below the confluence of the Sacramento, McCloud, and Pit rivers. The dam regulates the flow from a drainage area of approximately 6,649 square miles. Shasta Dam was completed in 1945, forming Shasta Reservoir, with a maximum storage capacity of 4,552,000 acre-feet. Water in Shasta Reservoir is released through or around the Shasta Powerplant to the Sacramento River, where it is re-regulated downstream by Keswick Reservoir.

Flood control objectives for Shasta Reservoir require releases to be restricted so that the flow at the tail water of Keswick Reservoir does not exceed 79,000 cfs and a stage of 39.2 feet is not exceeded in the Sacramento River at the Bend Bridge gaging station, which corresponds to a flow of approximately 100,000 cfs. Therefore, in USRDOM, Shasta Reservoir operates to the channel capacity constraints at Keswick Reservoir and Bend Bridge (control point 182). To ensure the 79,000 cfs criterion was met, QS and CC records from the Comp Study were used in the model code to specify channel capacity as a function of inflow for Shasta Reservoir.

According to the regulating criteria developed by the Corps for Shasta flood control operations, maximum flood space reservation is 1.3 MAF, with variable storage space requirements based on an inflow parameter. For USRDOM, this inflow parameter was estimated based on the Shasta daily inflows. Daily top of the conservation storage pool was estimated based on the flood control diagram in the Shasta flood control manual (Corps, 1977). Daily conservation level (Level 3) values were specified in USRDOM using the ST record in the model code to regulate the flood control space in Shasta Reservoir on a daily basis.

Flood control criteria for Keswick releases specify that releases should not be increased more than 15,000 cfs or decreased more than 4,000 cfs in a 2-hour period. In USRDOM, this was implemented using the R2 records for Shasta Reservoir.

Another operational criterion is to meet the navigation flow requirement of 5,000 cfs to Wilkins Slough (gaging station on the Sacramento River) under all but the most critical water supply conditions to facilitate pumping. Moreover, the 1993 National Marine

Fisheries Service (NMFS) winter-run Biological Opinion requires a minimum release of 3,250 cfs for normal years from September 1 through the end of February. In USRDOM, Shasta Reservoir was operated to meet a daily varying minimum required flow forced using the MR record. This daily minimum requirement was computed based on the historical Shasta releases so that a minimum flow of 3,250 cfs is released between November and April 15, and 15,000 cfs is released the rest of the year.

Storage, capacity, area, and elevation curves are a combination of the data from USRWQM and the Comp Study. For Shasta storage less than 3.7 MAF, the data from USRWQM were used. For storage greater than 3.7 MAF, the Comp Study data were used. Table 3.9 lists the control points that constrain the operation of each reservoir.

TABLE 3.9
Reservoirs and Corresponding Control Points on the RO Card

Reservoir/Control Point	Operating Control Point Numbers	Channel Capacity (cfs)
Trinity/340	340	9,200
	330	9,200
	320	9,200
	244	9,200
Whiskeytown/240	240	53,600
	214	53,600
	212	3,600
Shasta/220	220	15,000 to 79,000
	210	79,000
	202	15,000 to 79,000
	186	100,000
	180	100,000
	142	260,000
	132	160,000
	127	135,000
	117	66,000
	110	30,000
Black Butte/1136	1134	5,000

Keswick Reservoir was formed by the completion of Keswick Dam in 1950. It has a capacity of approximately 23,800 acre-feet and serves as an afterbay for releases from Shasta Dam and for discharges from the Spring Creek Powerplant. In USRDOM, Keswick is operated as a flow-through reservoir. To reflect the historical operations, the buffer and conservation levels are set to vary seasonally so that 22,250 acre-feet of storage is available from July 15 through October 31 and 21,250 acre-feet for the rest of the year. The facility data were obtained from USRWQM. The CL and CC records from the Comp Study were used to provide variable channel capacity with Shasta storage level, which ensures that Shasta operates to the maximum flow constraint of 79,000 cfs at Keswick.

3.6.4 Red Bluff Diversion Dam Operations

The Red Bluff Diversion Dam (RBDD), located on the Sacramento River approximately 2 miles southeast of Red Bluff, is a gated structure with fish ladders at each abutment. Construction of the RBDD was completed in 1964. When the gates are lowered, the impounded water rises about 13 feet, creating Lake Red Bluff and allowing gravity diversions through a set of drum screens into a stilling basin serving the Tehama-Colusa and Corning canals. The gates are lowered June 5 to impound water for diversion and raised September 25 to allow river flow through. In USRDOM, RBDD was operated as a flow-through reservoir. The buffer and conservation levels were varied seasonally to reflect the gate closure dates.

3.6.5 Black Butte Operations

Black Butte operations specified in USRWQM were used in USRDOM.

SECTION 4

Model Calibration

4.1 Overview

The calibration and verification process used a three-phase approach to evaluate the performance of the individual components of USRDOM and the full model. The process also allowed for identifying and understanding any inherent biases in the results.

The three calibration and verification phases used to evaluate the performance of USRDOM are:

1. Calibration/Verification of Hydrologic Inputs and Stream Routing
2. Calibration/Verification of Reservoir Operations
3. Calibration/Verification of Full Model

The following sections provide details for each phase.

4.2 Calibration/Verification of Hydrologic Inputs and Stream Routing (1964–2003)

4.2.1 Approach

In this first step, the goal was to calibrate and verify the hydrologic inputs and river processes, such as stream routing in the upper Sacramento River from Keswick to Knights Landing in the USRDOM. USRDOM was used to simulate the flow conditions in the upper Sacramento River over a 40-year period from WY 1964 to WY 2003. Observed tributary inflows and Keswick releases were used as the boundary conditions for this simulation. This 40-year USRDOM run allowed for hindcasting of the River flows at different locations where flow observations were unavailable, historically. It provides a synthesis of river flows at all control points in USRDOM downstream of Keswick based on the historical inflows and operations.

The 40-year hindcast run was developed to verify the ability of USRDOM to simulate flow routing, tributary inflows, weir overflows, diversions, and other closure flows in the model. To isolate and assess the uncertainty in the modeled flows with respect to these parameters, the effects of reservoir operations and import mechanisms were not included in the hindcast simulation by specifying the Keswick Reservoir outflow to be equal to the observed data (USGS 11370500). Clear Creek inflows into the Sacramento River were also forced to be equal to the historical data (Reclamation – Whiskeytown Reservoir Release). In addition, the tributary inflows and diversions were set equal to historical data as described in Section 3.3. Two closure flow time series were developed to account for accretions and depletions that were not explicitly modeled in USRDOM for the upper and the middle segments of the Sacramento River. The development of these two closure flow terms is described in the following sections.

4.2.2 Closure Terms

The USRDOM hydrology was developed based on historical flow data. However, not all the tributaries were gaged for the entire simulation period, which were synthesized as described in Section 2. A closure term represents the uncertainty between the synthesized and observed flow data, which results from incomplete flow data, and assumptions involved in estimating the missing data. In addition, the closure term also represents the flows that were not explicitly modeled in USRDOM such as ungaged stream flows, valley-floor runoff, groundwater interactions and minor diversions. Closure terms were developed for the calibration process to bring closure between the observed flow at a location in the river and the model inflows and diversions upstream of that location.

The closure term was computed by estimating the differences between the observed flows at a location and all known inflows and diversions modeled in USRDOM upstream of that location. For ease of computation, the upper Sacramento River was divided into three river segments, an upper segment extending from Keswick to Bend Bridge, a middle segment from downstream of Bend Bridge to Ord Ferry, and a lower segment downstream of Ord Ferry to Knights Landing. Closure terms were computed separately for the upper and middle segments but not for the lower segment because of incomplete data records available downstream of Ord Ferry. However, the USRDOM hindcast simulation still resulted in a satisfactory performance for the lower segment. This may be attributed to the fact that most of the River in this segment has been constrained by levees and hence the accretions and depletions, apart from those represented in the model explicitly, are minor.

Additional diversion and groundwater interaction data from CALSIM II hydrology were used for closure term computation for the upper and middle segments, when observed data was unavailable. Ungaged tributary inflow data were estimated using known inflows from the hydrology development and outflows for each river segment represented by a gage measurement. The computed closure terms were patterned to fit the observed river flows and are distributed based on the fraction of ungaged area at each control point in USRDOM. Detailed computation information for the upper and middle segment closure terms is provided below.

4.2.2.1 Upper Segment

As mentioned before, the closure term was computed by estimating the differences between the observed flows at a location and all known inflows and diversions modeled in USRDOM upstream of that location. Upper segment flow closure computation included following flow information for the river stretch from Keswick to Bend Bridge:

1. Main-stem river flows
2. Gaged tributary flows
3. Stream diversions
4. Miscellaneous flows
5. Ungaged tributary flows

Main-stem river flows for the upper segment closure term computation include Sacramento River flow at Keswick, Clear Creek flow below Whiskeytown, and Sacramento River flow at Bend Bridge. All these flows were obtained from historical gage and operational records. Gaged tributary flows used in this closure term computation include flows from Cow Creek, Cottonwood Creek, and Battle Creek. The daily flows for these tributaries were developed using the observed data as part of the hydrology development for USRDOM as described Section 2.

Stream diversions included in the computation of upper segment closure term were those to ACID, City of Redding, and miscellaneous CVP Settlement Contractors; various municipal and industrial diversions; agricultural use diversions; and non-project diversions. Flow delivery information for these components was obtained from the CACMP CALSIM II V8B Existing Condition Simulation. Since the observed data for these diversions were sparse, monthly data from CALSIM II were translated to daily diversion flows.

In CALSIM II, USRWQM, and USRDOM, the ACID diversion is explicitly modeled as a point diversion. However, in CALSIM II and USRWQM, in addition to the flows conveyed through the ACID canal, the modeled ACID diversion includes miscellaneous diversions along the Sacramento River between the Keswick and Clear Creek confluences. In USRDOM, these two sets of diversions are separated and only the diversion flows that are actually conveyed through ACID canal are simulated explicitly as a point diversion. The rest is distributed as part of the upper segment closure term. The ACID diversion in USRDOM is assumed equal to the D104_PSC flow from the CACMP CALSIM II V8B Existing Condition Simulation up to the ACID canal capacity of 315 cfs. The daily values are assumed to equal the monthly values from CALSIM II.

Miscellaneous flows include groundwater interactions, additional accretions, and return flows within the upper river segment, for which observed data was unavailable. Any data available for these types of flows were obtained from the CACMP CALSIM II V8B Existing Condition Run. Monthly timestep values are converted to daily format and separated as inflows and outflows.

Ungaged tributary flows represent the flows from ungaged streams or diversions that were not modeled explicitly. In USRDOM, these flows are modeled as distributed inflows as part of the closure term. The difference between the daily known outflows and inflows in the segment is used to compute the ungaged tributary flow. The negative differences are zeroed out, and the positive differences were adjusted to get the right pattern, while maintaining the total volume of the difference between the known outflows and known inflows for each water year.

Table 4.1 shows the categorization and source of the flow information used to compute the closure term for the upper segment of the Sacramento River.

4.2.2.2 Middle Segment

Similar to the upper segment closure computation, the middle segment closure is computed using the flow information from the above-mentioned types of flows for the river stretch downstream of Bend Bridge to Ord Ferry.

Main-stem river flows for this segment include observed data for the Sacramento River at Bend Bridge and synthesized data for Sacramento River below Stony Creek. Gaged

TABLE 4.1
Flow Information Used to Compute the Historical Upper Segment River Flow Closure Terms

Flow Data	Inflows	Outflows
Main-Stem River Flows	Sac River at Keswick (Combined Impaired [USGS 11370500] and Unimpaired [Shasta Inflow*] flow) Clear Creek below Whiskeytown (Combined Impaired [Whiskeytown Release*] and Unimpaired [Whiskeytown Inflow*] flow)	Sacramento River at Bend Bridge (USGS 11377100).
Gaged Tributary Flows	Cow Creek (Combined Observed/Synthesized Data) Cottonwood Creek (Combined Observed/Synthesized Data) Battle Creek (Combined Observed/Synthesized Data)	
Stream Diversions		ACID, City of Redding, Miscellaneous Settlement Contractors (CALSIM II D104_PSC) Municipal and Industrial Use (CALSIM II D104_PMI) Agricultural Use (CALSIM II D104_PAG)
Miscellaneous Flows	Negative Groundwater/Streamflow Interaction (CALSIM II GS60) Accretions Adjustments (CALSIM II D109) Return Flow (CALSIM II R109)	Positive Groundwater/Streamflow Interaction (CALSIM II GS60)
Ungaged Tributary Flows	Inflow computed based on the difference between the known inflows and outflows	

*Observed data obtained from Reclamation operations records

tributary flows for this segment include Paynes Creek, Antelope Creek, Mill Creek, Deer Creek, Red Bank Creek, Big Chico Creek, Elder Creek, and Thomes Creek. The daily flows for these tributaries were developed using the observed data as part of the hydrology development for USRDOM as described in Section 2.

Stream diversions include diversions to Sacramento River miscellaneous users; Thomes, Mill, Deer, and Antelope creek users; Corning, Tehama-Colusa, and Glenn-Colusa canal users; and Stony Creek users. Delivery flow information for these components was obtained from the CACMP CALSIM II V8B Existing Condition Simulation. Monthly data from CALSIM II were translated to daily diversion flows.

Miscellaneous flows in the segment include groundwater interactions and return flows. This information was obtained from the CACMP CALSIM II V8B Existing Condition Simulation. Monthly timestep values were converted to daily format and separated as inflow and outflows. All the ungaged tributary flows in the segment are computed based on the difference between known outflows and known inflows in the reach, similar to the upper segment closure term.

Table 4.2 shows the categorization and source of the flow information used to compute the closure term for the middle segment of Sacramento River.

4.2.3 Hydrologic Routing

The model development section of this document describes the methodology and development of routing coefficients for USRDOM. Two coefficient methods were used in USRDOM: the Attenuation of Hydrographs method and the Muskingum Routing method. Attenuation of Hydrographs method was used for the stream routing in the main stem Sacramento River. This method requires user specified 'C' values. Muskingum Routing was used in the Sutter Bypass reaches. The 'C' values for this method are computed based on the travel time in hours (K) and the dimensionless routing parameter between 0 and 0.5 (X) specified for each reach.

For the main-stem Sacramento River, the routing coefficients and the travel times are obtained from the USRWQM calibration document (RMA, 2003). USRDOM routing coefficients were obtained by modifying the USRWQM routing coefficients to account for the differences in the reach lengths in the two models as described in Section 3.4. To validate routing coefficients, USRDOM based travel times are compared with the travel times computed in the Comp Study. They are also compared with another independent source (Jones, 1999) to check the validity of the travel times.

Table 4.3 shows the comparison of USRDOM-based travel times with travel times computed from the Comp Study and Jones.

USRDOM travel times agreed well with the Comp Study and Jones' travel times from Keswick to Moulton Weir. The travel times deviate slightly downstream of Moulton Weir to Knights Landing. Total difference in the travel time at Knights Landing is less than 20 hours, which would result in a day offset in the modeled results compared to the Comp Study. However, USRDOM travel time values are closer to those estimated by Jones.

4.2.4 Verification Metrics

To quantify the quality of USRDOM hydrologic inputs and performance of stream routing, the following metrics were defined using the results from the USRDOM hindcast simulation.

1. Cumulative probability exceedance plots showing the scatter of daily modeled flows at each rank of daily historical observed flows in high (October–March) and low (April-September) flow seasons
2. Average daily residuals (simulated minus historical observed flows) for each of the following flow ranges for high and low flow seasons
    - 0 to 15,000 cfs
    - 15,000 to 45,000 cfs
    - 45,000 cfs
    - Full range

TABLE 4.2
Flow Information Used to Compute the Historical Component of Middle Segment River Flow Closure Terms

Flow Data	Inflows	Outflows
Main-Stem River Flows	Sacramento River at Bend Bridge (USGS 11377100)	Sacramento River below Stony Creek (Combined Observed/Synthesized Data)
Gaged Tributary Flows	Paynes Creek (Combined Observed/Synthesized Data) Antelope Creek (Combined Observed/Synthesized Data) Mill Creek (Combined Observed/Synthesized Data) Deer Creek (Combined Observed/Synthesized Data) Big Chico Creek (Combined Observed/Synthesized Data) Red Bank Creek (Combined Observed/Synthesized Data) Elder Creek (Combined Observed/Synthesized Data) Thomes Creek (Combined Observed/Synthesized Data)	
Stream Diversions		Sacramento River, Thomes, Elder, Deer, Mill and Antelope Misc. Users (CALSIM II D11301+D105+D11305) Corning Canal Historical Diversion (DWR Monthly Historical) Tehama-Colusa Historical Diversion (DWR Monthly Historical) Glenn-Colusa Historical Diversion (DWR Monthly Historical) Stony Creek Historical Diversion (DWR Monthly Historical)
Miscellaneous Flows	Negative Groundwater/Streamflow Interaction (CALSIM II GS61) Return Flow (CALSIM II R113+R114A+R114B+R114C)	Positive Groundwater/Streamflow Interaction (CALSIM II GS61)
Ungaged Tributary Flows	Inflow computed based on the difference between the known inflows and outflows	

TABLE 4.3
Comparison of USRDOM-based Travel Times

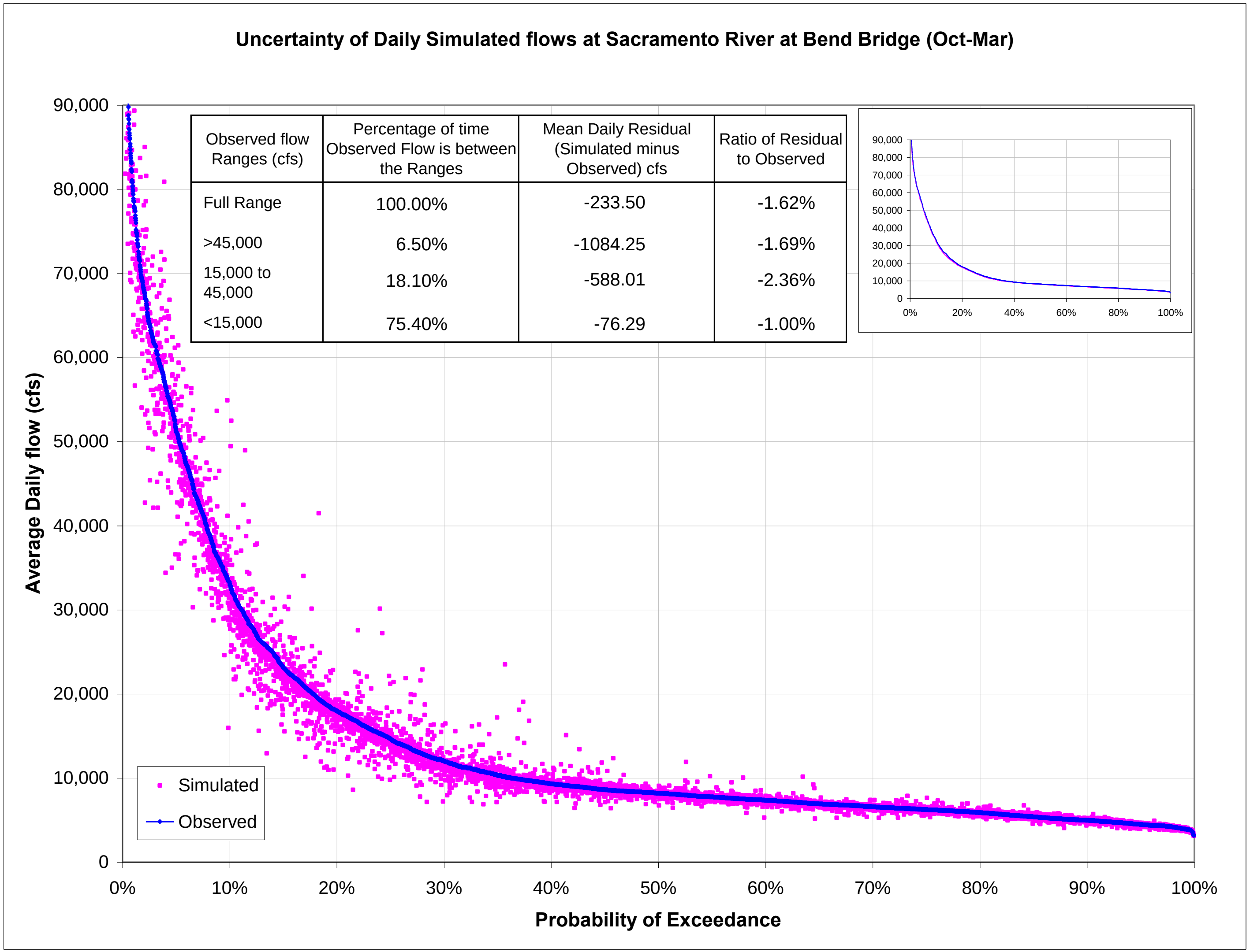
	Travel Time (Hours)		
Location	**USRWQM/USRDOM**	**Comp Study**	**Jones, 1999**
Keswick Reservoir	0	0	0
Cow Creek	5	5.2	-
Bend Bridge	9	10.2	12
Red Bluff Diversion Dam	12	-	-
Woodson Bridge	20	19.8	22
GCID intake	22	-	-
Stony Creek	26	26.5	-
Butte City	32	26.5	-
Moulton Weir	35	34.5	38
Colusa Weir	40	34.5	39
Tisdale Weir	50	42.5	47
Wilkins Slough	-	-	65
Knights Landing	62	42.5	-

Cumulative probability exceedance plots show the uncertainty in daily simulated flows with respect to the observed daily flows for the full range of flows for high flow and low flow seasons. Separate seasonal data sets (October–March and April–September) of observed and simulated mean daily flows were used to compare the uncertainty in simulated flows. The mean daily paired data sets were then sorted by observed data to obtain the cumulative probability of exceedance of daily flows.

4.2.5 Comparison of Model Results with Observed Data

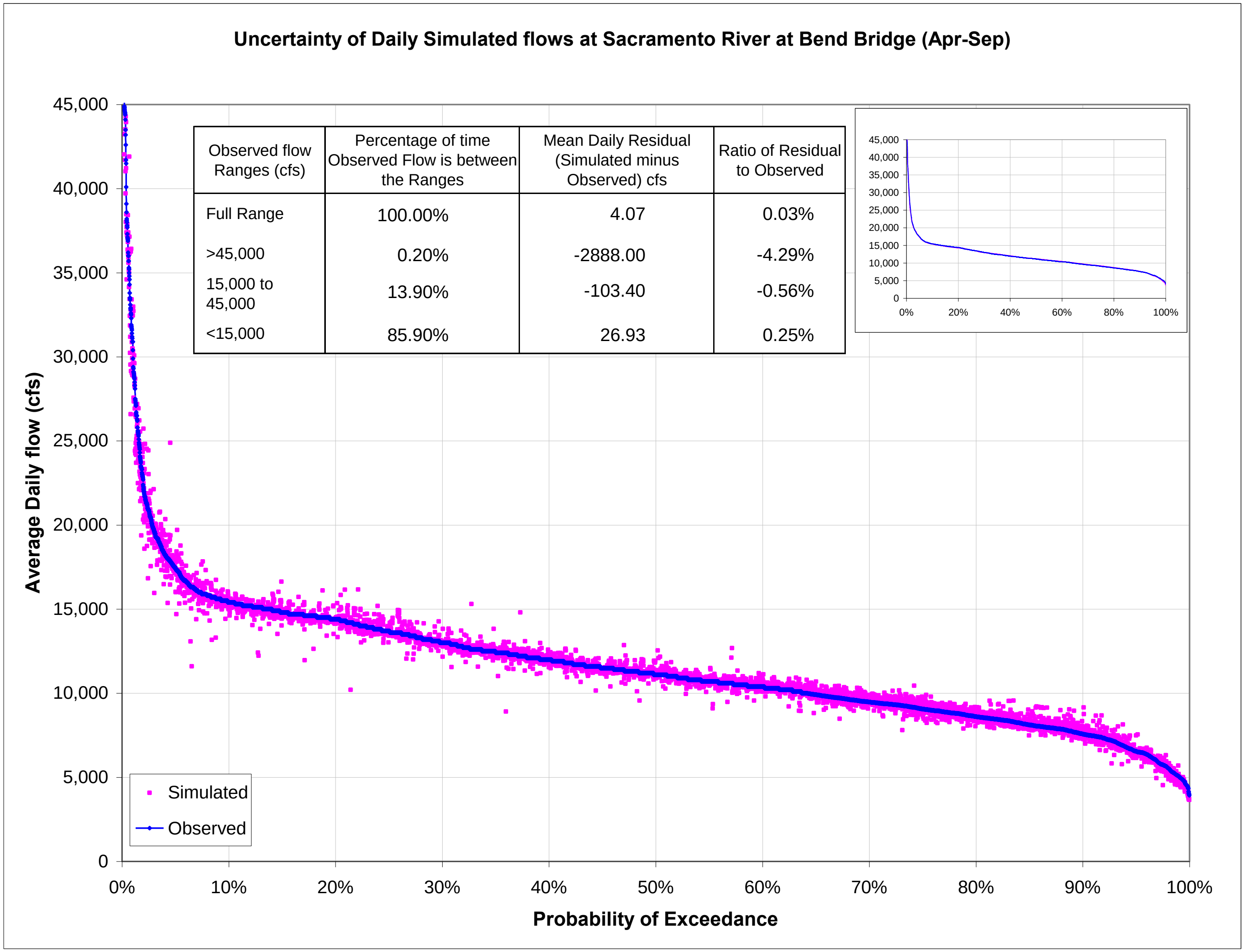
Cumulative probability exceedance plots for the full range of flows for the high flow and low flow seasons and average daily residual tables for different flow ranges are presented for the Sacramento River at Bend Bridge. Exceedance plots for other locations are presented in Appendix A.

Figure 4.1 is a cumulative probability of exceedance plot showing the uncertainty of daily simulated Sacramento River flows at Bend Bridge for the high flow season, October through March. Probability of exceedance (percent) is shown on the x-axis and the daily flows (cfs) are shown on the y-axis. The solid blue line represents the observed flow and the magenta scatter points represent the simulated flow on the same day. If the model is able to emulate the observed flows exactly both in terms of the timing and magnitude, the magenta scatter points should fall on top of the blue curve. Therefore, the uncertainty in the simulated flows for a given observed flow value can be measured based on the vertical scatter of simulated flow around it. Figure 4.2 shows a similar plot for Sacramento River at Bend Bridge for the low flow season (April–September). In both Figures 4.1 and 4.2 a probability of exceedance


Uncertainty of Daily Simulated flows at Sacramento River at Bend Bridge (Oct-Mar)

Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	-233.50	-1.62%
>45,000	6.50%	-1084.25	-1.69%
15,000 to 45,000	18.10%	-588.01	-2.36%
<15,000	75.40%	-76.29	-1.00%

FIGURE 4.1
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (October – March)



Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	4.07	0.03%
>45,000	0.20%	-2888.00	-4.29%
15,000 to 45,000	13.90%	-103.40	-0.56%
<15,000	85.90%	26.93	0.25%

FIGURE 4.2
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (April – September)

plot is shown as inset where the observed and simulated data are sorted independently. These plots show that the probability of exceedance for observed and simulated flows show good agreement indicating that the variability in the observed flow magnitudes over the calibration period is accurately represented in the USRDOM results.

The average daily residuals for the high flow and low flow seasons are summarized in Tables 4.4 and 4.5, respectively. (They are also shown as insets in Figures 4.1 and 4.2). Mean daily residuals (average of simulated minus observed daily flows) and relative difference in the simulated flows with respect to the observed mean are computed for the flow ranges defined in Section 4.2.4. Column 1 describes the flow range for which the residuals have been computed. Column 2 shows the percentage of time for which the observed flow is within the ranges described in column 1. The sum of the percentages for different flow ranges should equal 100 percent. Columns 3 and 4 show the mean daily residual in cfs and the relative difference between simulated and observed flows, respectively. The summary tables help to clarify the uncertainty in simulated daily flows for different flow ranges, which is helpful in assessing the performance of the model for purposes such as temperature modeling, diversion analysis, and flood control.

TABLE 4.4
Average Daily Residuals between Simulated and Observed Daily Flows along the Sacramento River for Oct – Mar Using Results from USRDOM Hindcast Model

Locations	Observed Flow Ranges (cfs)	% of Time Observed Flow within Range	Mean Daily Residual (Simulated minus Observed) (cfs)	Ratio of Residual to Observed (%)
Sacramento River at Bend Bridge	Full Range	100.0	-233.5	-1.6
	>45,000	6.5	-1084.3	-1.7
	15,000 to 45,000	18.1	-588.0	-2.4
	<15,000	75.4	-76.3	-1.0
Sacramento River at Hamilton city	Full Range	100.0	-591.5	-3.5
	>45,000	8.8	-4010.7	-5.7
	15,000 to 45,000	20.4	-1331.9	-5.3
	<15,000	70.8	46.9	0.6
Sacramento River at Colusa	Full Range	100.0	-333.1	-2.3
	>45,000	0.9	-604.1	-1.3
	15,000 to 45,000	30.4	-804.4	-2.8
	<15,000	68.7	-122.5	-1.6
Sacramento River at Knights Landing	Full Range	100.0	-693.0	-4.9
	>45,000	0.0	-	-
	15,000 to 45,000	35.6	-852.9	-3.7
	<15,000	64.4	-605.5	-6.6

TABLE 4.5
Average Daily Residuals between Simulated and Observed Daily Flows along the Sacramento River for Apr – Sep Using Results from USRDOM Hindcast Model

Locations	Observed Flow Ranges (cfs)	% of Time Observed Flow within Range	Mean Daily Residual (Simulated minus Observed) (cfs)	Ratio of Residual to Observed (%)
Sacramento River at Bend Bridge	Full Range	100.0	4.1	0.0
	>45,000	0.2	-2888.0	-4.3
	15,000 to 45,000	13.9	-103.4	-0.6
	<15,000	85.9	26.9	0.3
Sacramento River at Hamilton city	Full Range	100.0	380.6	3.7
	>45,000	0.3	-3795.2	-5.6
	15,000 to 45,000	9.3	-177.8	-0.8
	<15,000	90.4	451.6	5.1
Sacramento River at Colusa	Full Range	100.0	266.8	2.7
	>45,000	0.0	-	-
	15,000 to 45,000	9.2	-984.7	-4.4
	<15,000	90.8	391.3	4.5
Sacramento River at Knights Landing	Full Range	100.0	-207.3	-2.2
	>45,000	0.0	-	-
	15,000 to 45,000	8.8	-1239.1	-6.4
	<15,000	91.2	-111.8	-1.3

Figure 4.1 shows that the uncertainty in the simulated flows at Bend Bridge is higher at times when the observed flow is greater than 15,000 cfs, with better agreement between the simulated and observed flows below 15,000 cfs. The summary table shows that observed flows are less than 15,000 cfs 75.4 percent of the time, and the average daily residual in that range is -76.29 cfs, which is approximately 1 percent of the mean observed flows in that range. This flow statistic supports the conclusion that USRDOM simulates the river flows accurately when the river flows are below 15,000 cfs for the high flow season.

For flows of 15,000 to 45,000 cfs, the mean simulated flow is 2.4 percent lower than the observed flows. However, the observed flows are in this range only 18 percent of the time. Similarly, for flows greater than 45,000 cfs, the mean daily residual is about 1.7 percent of the mean observed flows in this range, but observed flows fall in this range only 6.5 percent of the time. For the full range of flows, the mean simulated flow is 1.6 percent lower than the observed flows. Therefore, USRDOM is capable of accurately simulating the full range of flows during the high flow season when the reservoirs are under the flood operations.

Figure 4.2 shows the cumulative probability of exceedance plot for daily simulated flows at the Sacramento River at Bend Bridge for the low flow season (April through September). The daily residuals of different flow ranges show agreement between the simulated and observed flows. This implies that USRDOM performs better in simulating the full range of flows for the low flow season likely because the reservoirs mainly release to meet specific downstream demands and the influence of local tributary flows is insignificant.

The cumulative probability of exceedance plots shown as insets in Figures 4.1 and 4.2 represent the frequency of daily observed and simulated flows sorted independently. Both datasets appear nearly identical, which means the model is capable of simulating all the flow ranges accurately in terms of magnitude.

The higher discrepancy seen between the simulated and observed data when the river flow is higher than 15,000 cfs may be a combination of various factors. One factor may be the uncertainty associated with the assumed ungaged flows in USRDOM, in terms of magnitude, timing, and inflow location. Another factor may be the constant monthly demands used in the hindcast simulation for the major diversions and the lumped diversions in certain reaches. Finally, the hydrology development process used for USRDOM does not capture valley-floor dynamics associated with flood routing. In other words, the representation of storm driven, intermittent high runoff events that occur on the valley floor have not been fully resolved in the hydrology development process.

4.3 Calibration/Verification of Reservoir Operations (1996-2003)

4.3.1 Approach

USRDOM includes Trinity, Lewiston, Whiskeytown, Shasta, Keswick, and Black Butte reservoirs. The model is equipped with operating rules to simulate the daily operations at each of the reservoirs as close to the observed conditions as possible. The quality of the simulated daily operations in comparison to the observed data was evaluated. The focus of the calibration/verification was mainly on the three CVP reservoirs: Trinity, Shasta, and Whiskeytown.

The performance of USRDOM in simulating daily reservoir operations was assessed by running eight separate simulations for WY 1996 through WY 2003. In each simulation, the initial storage of Trinity, Whiskeytown, and Shasta reservoirs is set equal to the observed data at the start of the run. Simulation of daily reservoir operations was verified by comparing the end-of-day simulated reservoir storage and releases for each separate run with the observed data during the period when the reservoirs were not operating under downstream control.

4.3.2 Definition of Control Periods

Reservoir storage and release operations in the Trinity River system and Sacramento River system are influenced primarily by the upstream flood control operations during the high flow season and by the downstream control for the low flow season. During the downstream control periods, the releases from the reservoirs are made to meet the demands for the diversions and other minimum requirements along the Sacramento River. Therefore, during this period, each reservoir operates based on a specified downstream release requirement.

The beginning of the downstream control periods was identified by locating the timestep where the observed reservoir releases just meet the minimum release requirements for the reservoir following the last major flood of the season. The period prior to this timestep was assumed as the period of upstream control. Performance of the reservoir operations of

USRDOM were evaluated by comparing the simulated storages and reservoir releases with the observed operations during the upstream control period.

4.3.3 Changes to Reservoir Operating Criteria

Reservoir operating criteria for the Trinity, Whiskeytown, and Shasta reservoirs were refined to achieve better agreement with the observed data. Some of the operating rules were evaluated and implemented in the model as part of the calibration/verification process. Minimum required releases for Shasta and Trinity reservoirs were updated to account for the isolated X2 related releases that rarely occurred historically during the upstream control periods. Evaporation was included at Shasta, Trinity, Whiskeytown, and Black Butte reservoirs using the monthly evaporation rates from the CACMP V9 CALSIM II Existing Condition Run. The sensitivity of the simulated operations to the specified release ramping rates was tested for Trinity and Shasta reservoirs.

Trinity River releases in USRDOM are determined based on the Trinity River flow schedules and Clear Creek Tunnel flows. Observed data for Clear Creek Tunnel flows show that Trinity River imports to the Sacramento River are reduced to 300 cfs when flood conditions begin to occur in the Sacramento River. To simulate this condition, when the Tisdale Weir (control point 115) is spilling, the Trinity import to the Sacramento River is reduced to 300 cfs. Further, to reduce the flooding risk of Clear Creek below Whiskeytown, the Trinity import to the Sacramento River is also reduced when Whiskeytown (control point 240) is near spilling.

In order to modify Trinity imports dynamically in USRDOM, Clear Creek Tunnel (control point 242) channel capacity needs to change between full capacity (3,200 cfs) and the limited capacity (300 cfs). However, in HEC-5 channel capacity cannot be modified based on the flows at downstream control points. Therefore, to implement the above Trinity import logic few deliberate changes were implemented in USRDOM. The first change was to add a dummy inflow to the Clear Creek Tunnel control point (242) in the USRDOM, which is diverted out of the system at the next downstream control point (241). This dummy flow allows in artificially changing the available channel capacity for the Trinity imports.

The second change was to run USRDOM in two iterations. The first USRDOM iteration is simulated without limiting the Trinity imports. The dummy inflow at control point 242 is set to zero throughout the simulation, keeping full channel capacity available for the Trinity imports. The results from the first iteration are used to determine the days when Tisdale Weir spills and Whiskeytown is ready to spill or spills. On the identified days, the Trinity import utility changes the dummy flow value to 2,900 cfs, which fills the channel capacity of Clear Creek Tunnel (3,200 cfs) and thereby reducing the available tunnel capacity for the Trinity imports to 300 cfs. This dummy flow is diverted just upstream of Whiskeytown Reservoir. The utility also reduces Trinity releases for imports. Using the modified dummy flow and the Trinity release requirements, the second and final iteration of USRDOM is simulated to produce the final results. Testing has verified that this Trinity import logic reasonably limits the Trinity flows to Sacramento River.

4.3.4 Verification Metrics

To quantify the performance of USRDOM in simulating the reservoir operations, the following metrics were defined.

1. Annual time series plots showing simulated and observed storage with a delineation of conservation and flood storage capacity, and modeled and historical observed flow releases with a delineation of releases associated with identified downstream requirements
2. Tables showing modeled, observed, and residual (modeled minus observed) and annual average ending storage conditions associated with the date at which the reservoir begins to operate each year for downstream requirements exclusively

4.3.5 Comparison of Model Results with Observed Data

Annual time series plots comparing the simulated and observed storage and reservoir releases are presented for Trinity, Whiskeytown, and Shasta reservoirs.

The storage residuals at the end of the upstream control period for Trinity and Shasta reservoirs are presented in Tables 4.6 and 4.7.

Figures 4.3 and 4.4 show the time series comparison plot between observed and simulated storage and reservoir releases for Shasta Reservoir for WY 1998 and WY 2003, respectively. Plots for other water years are provided in Appendix A.

The beginning of the period for which the operations are based on the downstream control in the observed data is shown by a vertical solid black line. The period before this line is the upstream control period during which the performance of USRDOM reservoir operations is being assessed. In some years, brief cases of downstream control occur before the date indicated by the solid black line. The numerical difference in observed and simulated storage at the end of the upstream control period is computed for each water year. This information is provided for Trinity and Shasta reservoirs in Tables 4.6 and 4.7, respectively.

The simulated Shasta storage closely follows the observed storage in the upstream control period. Because the initial storage for the simulation is reset to the observed storage, the simulated storage at the beginning of the water year matches the observed data. The difference in the storage is seen when a high flow event occurs in the observed data. During this period, the storage in the reservoir encroaches into the flood storage pool (above the top of conservation storage pool level) to accommodate the increased inflows to the reservoir. As the event recedes, USRDOM releases more water compared to the observed data, until the simulated reservoir storage level equals the top of the conservation storage pool. The observed storage during this period, however, shows encroachment for a longer period, resulting in a difference between the simulated and observed releases. The difference in the storage is carried until the end of the upstream operations control period. The cause of this difference in operation is that the model is not informed about the forecast information that the operators may have had and, therefore, the release decisions in the model and the field are different.

The storage residuals at the end of upstream control period for Shasta Reservoir for all the water years are provided in Table 4.7. The percentage difference in simulated storages for

TABLE 4.6
Comparison of Simulated and Observed Storage at Beginning of Downstream Control for Trinity Reservoir

Simulated Water Year	Date at the Beginning of Downstream Control	Trinity Reservoir Storage (TAF)				Remarks
		Simulated	Observed	Difference (Simulated minus Observed)	Ratio of Difference to Observed	
1996	04/04/1996	2,106	2,185	-79	-3.6%	Observed storage did not follow the flood diagram and encroached on the flood storage pool by releasing lower flows, but simulated releases were higher and the storage followed the flood diagram.
1997	04/04/1997	2,101	2,114	-13	-0.6%	Observed releases were lower compared to the simulated, resulting in higher storage.
1998	07/12/1998	2,448	2,447	0	0.0%	Higher observed releases than simulated in February 1998 caused the storage difference, which continued until few days prior to 07/12/1998.
1999	03/31/1999	2,100	2,096	4	0.2%	Observed releases were higher from 11/16/1998 until 03/31/1999, and observed storage did not follow the flood diagram. Simulated storage followed the flood diagram.
2000	05/31/2000	2,424	2,384	40	1.7%	Higher observed releases at the end of April 1999 caused the storage difference between observed and simulated storages and continued until 05/31/2000.
2001		-	-	-	-	There were no flood events during this year.
2002		-	-	-	-	There were no flood events during this year.
2003	06/10/2003	2,373	2,407	-35	-1.4%	Observed releases were lower from December 2002, resulting in higher observed storage than the simulated storage.
Average:				-14	-0.6%	

TABLE 4.7
Comparison of Simulated and Observed Storage at the Beginning of Downstream Control for Shasta Reservoir

Simulated Water Year	Date at the Beginning of Downstream Control	Shasta Reservoir Storage (TAF)				Remarks
		Simulated	Observed	Difference (Simulated minus Observed)	Ratio of Difference to Observed	
1996	04/01/1996	3,738	3,904	-166	-4.3%	Because of an event on 02/06/1996, storage encroached into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas observed storage did not.
1997	02/16/1997	3,442	3,438	4	0.1%	Even though the difference is very small, events from 12/06/1996 led to the encroachment into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas observed storage receded slowly.
1998	04/13/1998	3,873	3,734	139	3.7%	Because of events in January and February, storage encroached into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas the observed storage continued to drop below the flood diagram.
1999	03/30/1999	3,937	3,842	95	2.5%	Observed releases were lower than simulated, resulting in higher storage; however, simulated storage followed the flood diagram, causing higher releases.
2000	03/25/2000	3,590	3,659	-68	-1.9%	Because of events in January and February, storage encroached into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas observed storage receded from the flood pool slowly.
2001	01/17/2002	-	-	-	-	There were no flood events during this year.
2002	05/10/2003	3,446	3,431	15	0.4%	Observed releases on 01/05/2002 were higher than simulated, resulting in lower observed storage.
2003	04/01/1996	4,534	4,459	75	1.7%	Observed releases on 05/04/2003 were higher than simulated, resulting in lower observed storage.
Average:				14	0.3%	

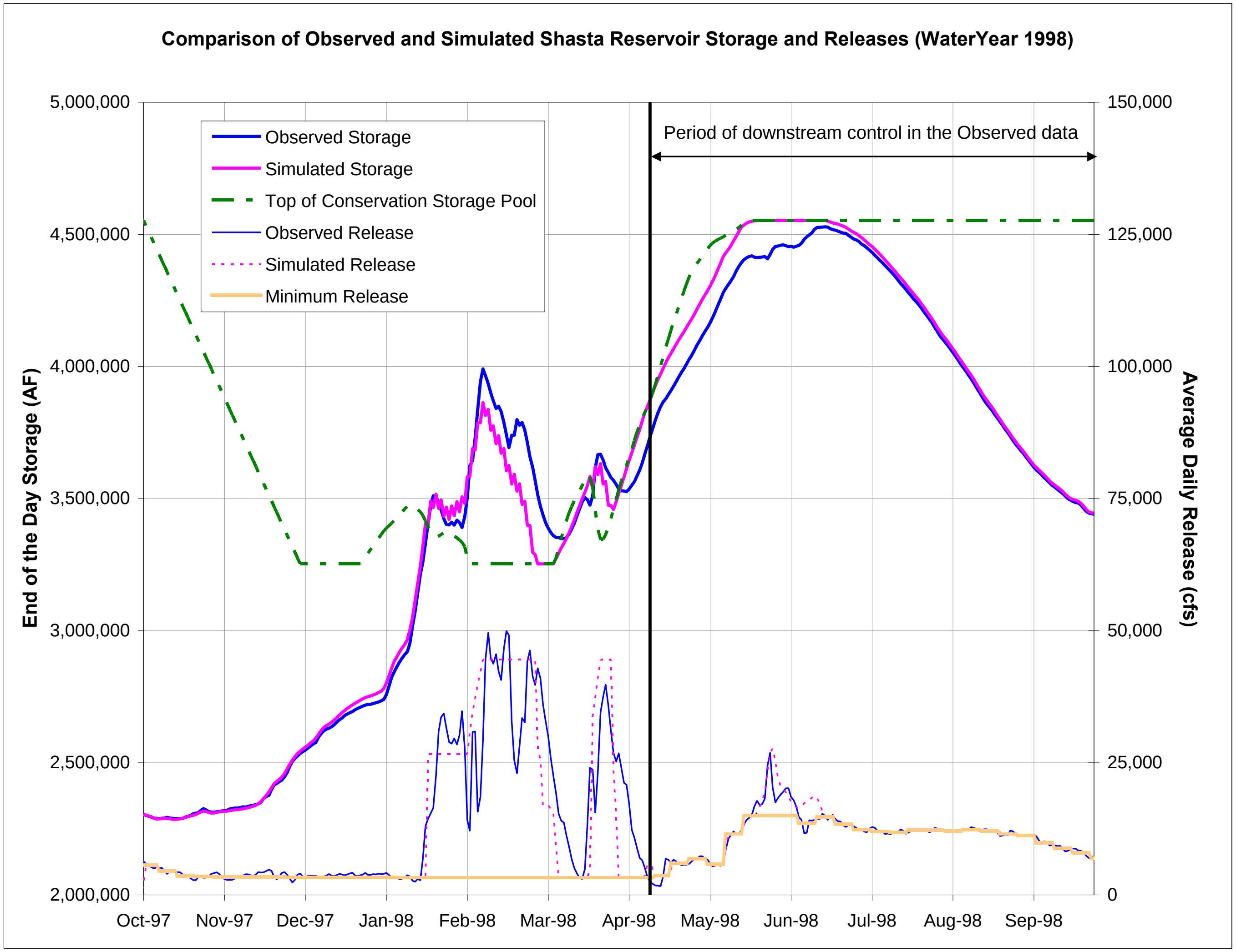


FIGURE 4.3

Comparison of Observed and Simulated Shasta Reservoir Storage and Releases (WY 1998)

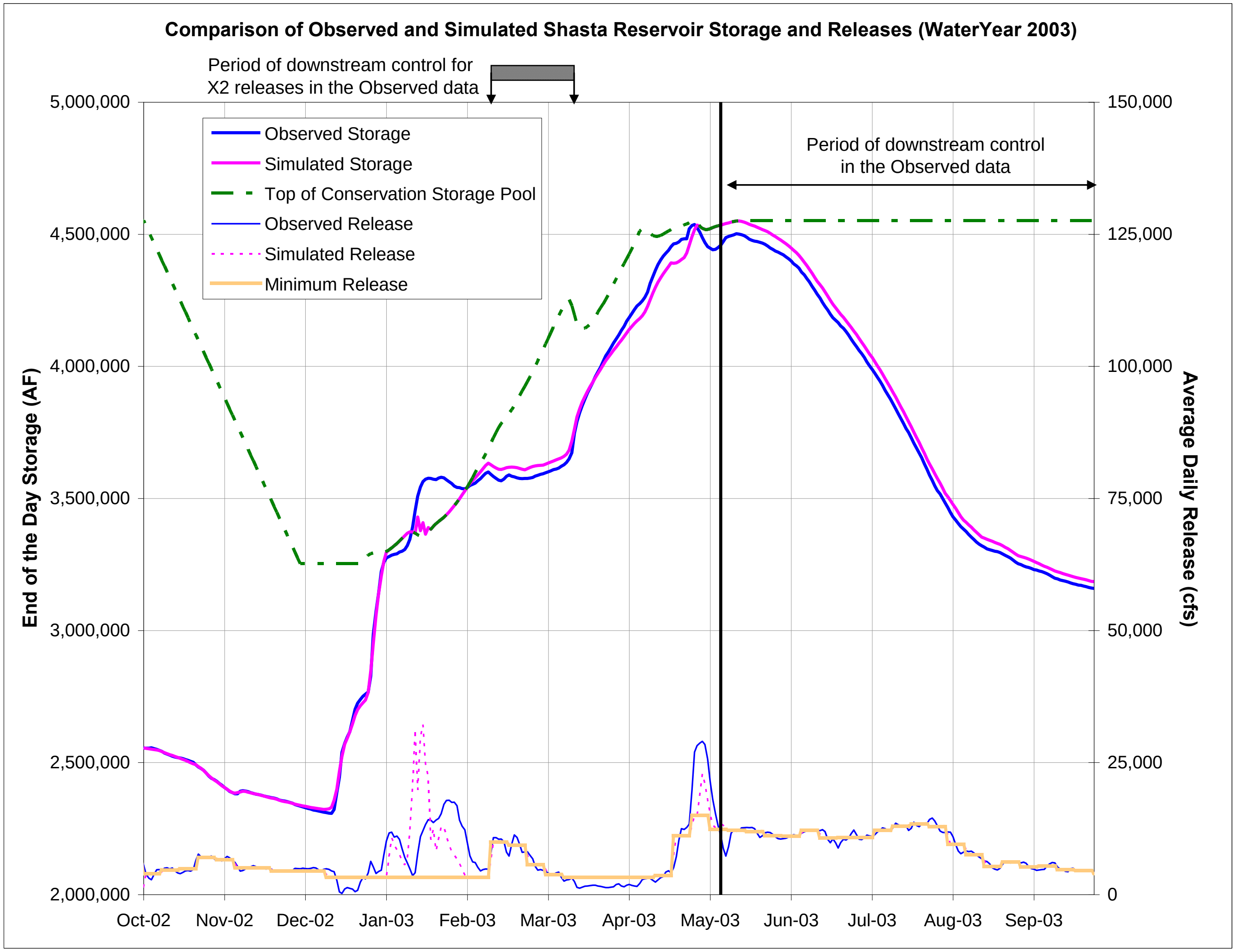


FIGURE 4.4

Comparison of Observed and Simulated Shasta Reservoir Storage and Releases (WY 2003) the water years is very small and is mostly because of the differences in the encroachment of storage into the flood pool. The results in the table demonstrate that USRDOM simulates Shasta Reservoir operations accurately. Similarly, based on the residuals shown in Table 4.6, USRDOM mimics the observed Trinity operations accurately. For the water years where the residuals were not reported, the year did not have any flood operations.

4.4 Full Verification of USRDOM Simulation (1996–2003)

4.4.1 Approach

This section discusses the process of full verification of USRDOM, including the full extent of the schematic, with the reservoir operations simulated according to the rules described previously and the flow routed from Keswick to Knights Landing. An 8-year simulation with the historical hydrologic inputs for WY 1996 to WY 2003 was used for the full verification of USRDOM. The goal of full verification was to assess the performance of USRDOM in simulating the daily flows in the river and identify uncertainty in the simulated flows when compared to the observed data.

The version of USRDOM used for the full verification contains the same reservoir operations criteria and river flow operations as the reservoir operations verification simulation and hindcast simulation. The model was simulated for WY 1996 to WY 2003 with initial conditions equal to the observed data at the end of September 30, 1995.

4.4.2 Verification Metrics

To evaluate the performance of full verification simulation, the following metrics were defined and reported for several key locations.

- High flow season (October through March) and low flow season (April through September) cumulative probability exceedance plots showing the scatter of daily modeled flows at each rank of daily historical observed flows
- High flow season (October through March), low flow season (April through September), and annual total average of daily residuals (simulated minus historical observed flows) for each of the following flow ranges:
    - 0 to 15,000 cfs
    - 15,000 to 45,000 cfs
    - > 45,000 cfs
- Time series plots showing the simulated and observed daily flows
- Time series plots showing the simulated and observed end-of-the-day storage

4.4.3 Comparison of Model Results with Observed Data

The following locations were selected for the USRDOM full verification simulation:

- River flow verification locations
    - Clear Creek Tunnel
    - Clear Creek below Whiskeytown Dam
    - Spring Creek Tunnel

  - Sacramento River below Keswick Reservoir
  - Sacramento River at Bend Bridge
  - Sacramento River at Hamilton City
  - Sacramento River at Colusa
  - Sacramento River at Knights Landing

- Reservoir storage verification locations
  - Trinity Reservoir
  - Whiskeytown Reservoir
  - Shasta Reservoir

This section presents the storage results for three reservoirs and the flow results for the Bend Bridge location. All other verification results are presented in Appendix A.

Figure 4.5 shows the cumulative probability of exceedance plot showing the uncertainty of daily simulated flows at Sacramento River at Bend Bridge for October through March. Figure 4.6 shows a similar plot for Sacramento River at Bend Bridge for April through September.

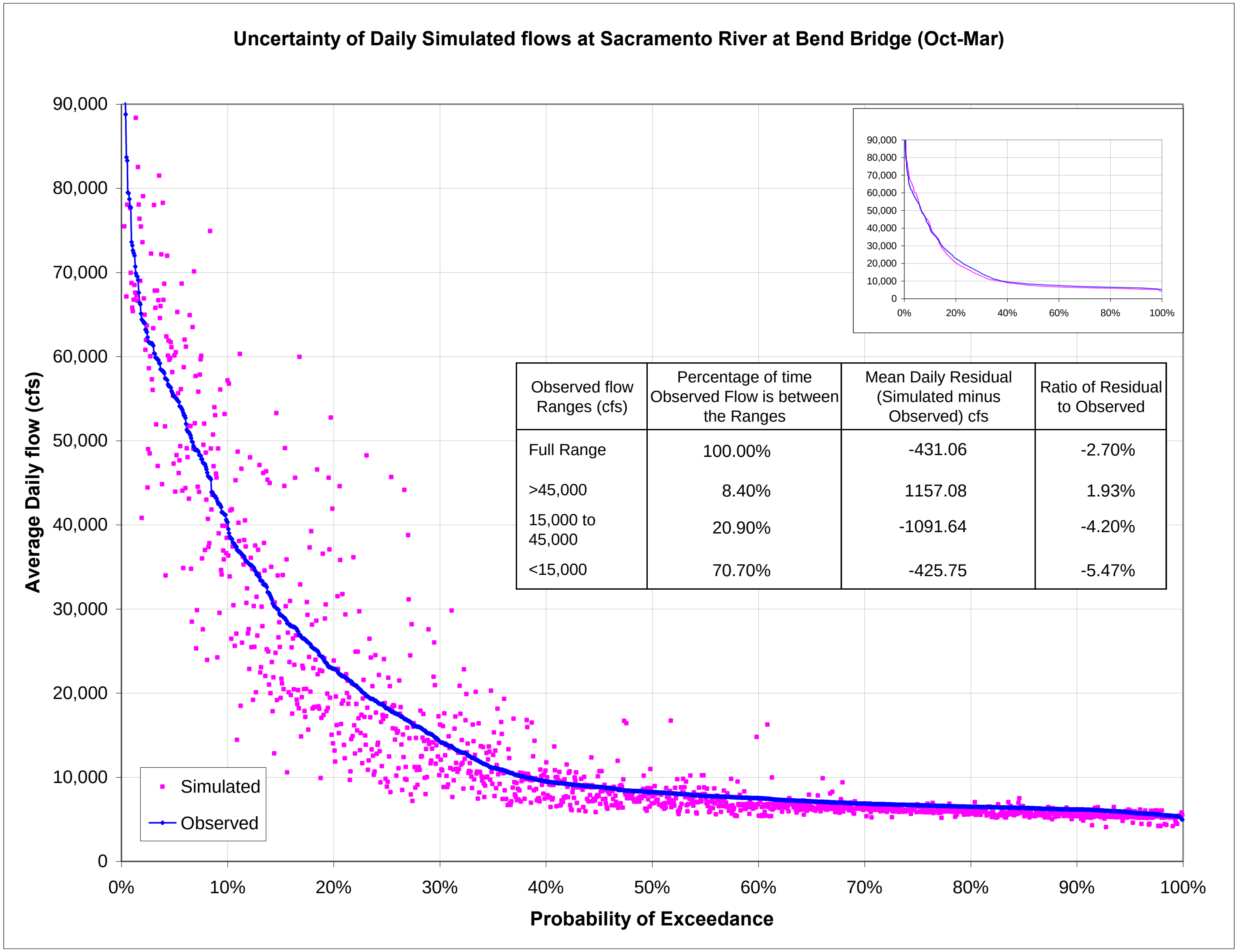
A summary table of the average daily residuals is provided as an inset in Figure 4.5. Mean daily residuals (average of simulated minus observed daily flows) and ratios of average daily residual to the observed mean are computed for the flow ranges defined in the verification metrics section.

Figure 4.5 shows that, during the high flow season, the uncertainty in the simulated flows at Bend Bridge is significant when the observed flows are greater than 15,000 cfs. There is comparatively less uncertainty in the simulated flows when the daily observed flows are below 15,000 cfs. Observed flows are less than 15,000 cfs about 70 percent of the time, and the average daily residual is -425.75 cfs. The same parameter for the hydrology verification simulation is only -76.3 cfs. This implies that additional -349.5 cfs of average daily residual is introduced at Bend Bridge because of simulated reservoir operations.

From the daily residuals for the flow ranges 15,000 to 45,000 cfs; above 45,000 cfs; and full range of flows, the relative error in the mean flows is -4.2 percent, 1.9 percent, and -2.7 percent, respectively. Therefore, the USRDOM model performs reasonably well for the high flow ranges during the high flow season, when most diversion and flood control operations occur. Mean daily residuals for the full range of flows show that the modeled flows are 2.7 percent less than the observed flows, meaning that USRDOM is capable of simulating the flows accurately for the full range of flows for the high flow season.

The cumulative probability of exceedance plot provided as an inset in Figure 4.5 represents the frequency of daily observed and simulated flows. Both curves are similar, which means the model is capable of simulating all the flow ranges accurately in terms of magnitude.

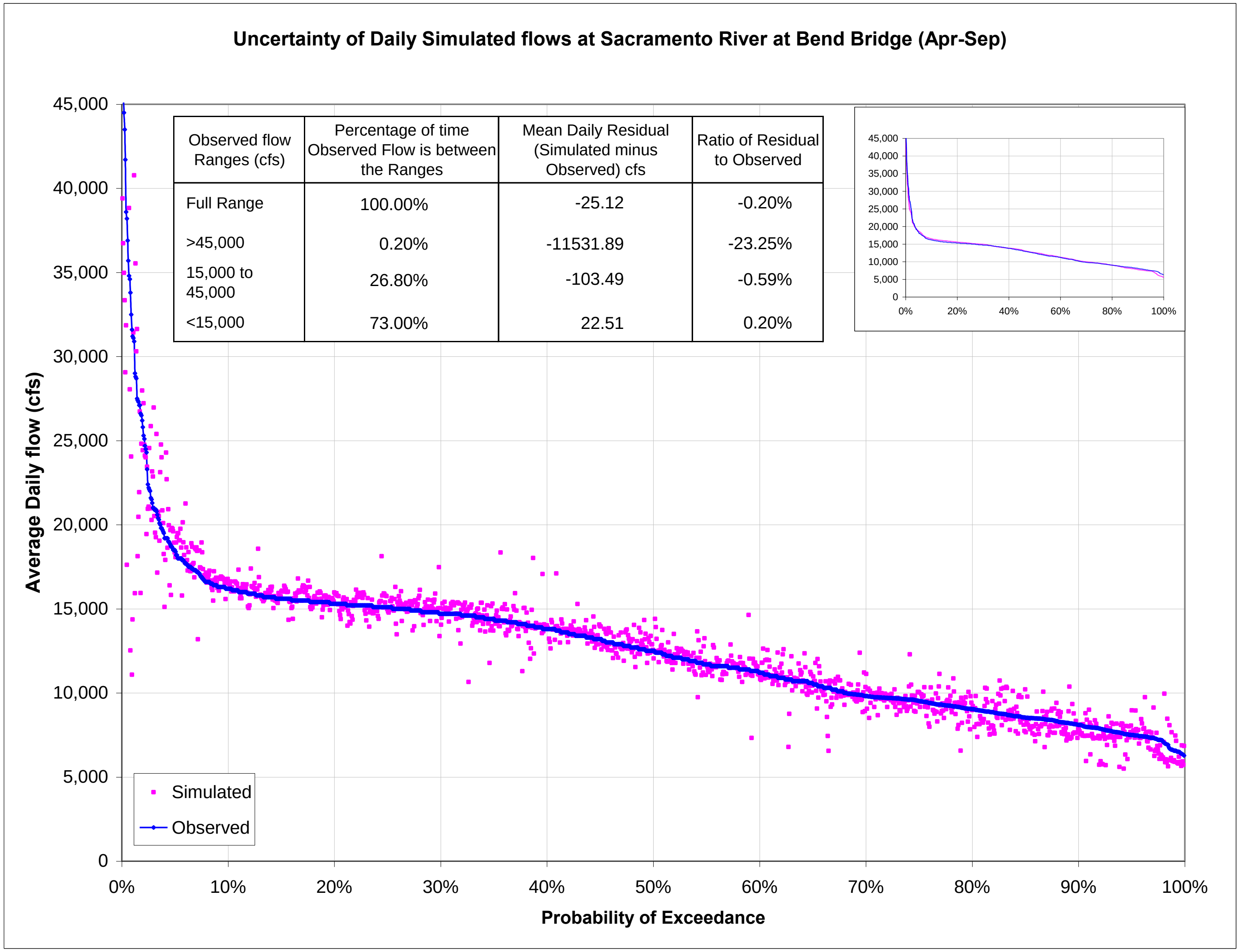
Similarly, Figure 4.6 shows the cumulative probability of exceedance plot of the uncertainty in the daily simulated flows at Sacramento River at Bend Bridge for April to September. The daily residuals of different flow ranges show a better agreement between the simulated and observed flows for the low flow season. This implies that USRDOM performs better in simulating flows for the low flow season because the reservoir operations' induced



Uncertainty of Daily Simulated flows at Sacramento River at Bend Bridge (Oct-Mar)

Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	-431.06	-2.70%
>45,000	8.40%	1157.08	1.93%
15,000 to 45,000	20.90%	-1091.64	-4.20%
<15,000	70.70%	-425.75	-5.47%

FIGURE 4.5
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (October–March)



Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	-25.12	-0.20%
>45,000	0.20%	-11531.89	-23.25%
15,000 to 45,000	26.80%	-103.49	-0.59%
<15,000	73.00%	22.51	0.20%

FIGURE 4.6
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (April–September)

uncertainty is significantly lower in this season. Reservoirs only release to meet specified minimum in-stream flow requirements and other downstream demands.

The full verification simulation's reservoir operations can also be assessed by comparing the simulated and observed reservoir storage and outflows. Figures 4.7 through 4.12 show the time series plots of simulated and observed storages and the outflow for Trinity Reservoir, Whiskeytown Reservoir, and Shasta Reservoir, respectively.

The figures show that the storage is simulated accurately to follow the timing and magnitude of the observed data. Overall, the simulated storage in all three reservoirs agrees with the observed data for the entire simulation period. One exception is that during WY 2001 to WY 2003, simulated Trinity storage is higher than the observed data. The Trinity Reservoir release during this period is significantly lower than the observed data. This occurs because the process used to develop the minimum release requirement in the model does not capture all of the operational decisions that led to observed releases during this period.

The uncertainty induced in the river flows because of reservoir operations can be quantified by comparing the average daily residuals at key locations in the system between full verification simulation and hindcast simulation. To facilitate the comparison of the statistics, system diagrams have been developed that indicate the average daily residuals and ratios of these residuals to the observed means at each location. The results of full verification simulation and hindcast simulation are presented in the system diagrams (Figures 4.13, 4.14, and 4.15). Because the full verification simulation is for WY 1996 to WY 2003, the mean daily residuals for the hindcast were also computed only for this period.

Figure 4.13 shows the system diagram with a comparison of mean daily residuals at key locations in the Upper Sacramento River for the full verification simulation and the hindcast simulation for October to March. Figures 4.14 and 4.15 present the summary of mean daily residual in flows for April to September and the full period averages, respectively.

Figure 4.13 shows that, during the high flow season, the ratios of daily residuals to the observed data for Trinity, Clear Creek Tunnel, and Whiskeytown, are 0.46 percent, 2.0 percent, and 1.46 percent, respectively. These ratios indicate that the uncertainty in the simulated flows for the Trinity system is not more than 2.0 percent, which implies that the full verification of USRDOM simulates Trinity import flows reasonably well. The uncertainty in the simulated flows at Spring Creek Tunnel and Clear Creek below Whiskeytown are -8.52 percent and 84.93 percent, respectively. This indicates that there is a mismatch in simulating the imports to the Sacramento River from Clear Creek below Whiskeytown Dam and through Spring Creek Tunnel. Because the flows through Clear Creek are small compared to the Sacramento River, this does not have a significant impact on the results in the Sacramento River.

By observing the uncertainties in the main-stem Sacramento River, we can conclude that Shasta Reservoir outflows are simulated well in USRDOM and have only 0.34 percent uncertainty. The uncertainty goes up to -4.16 percent at Keswick but drops back to -2.7 percent at Bend Bridge, reflecting the small differences in Clear Creek and Spring Creek Tunnel simulated flows. Comparison of uncertainties between full verification and hindcast

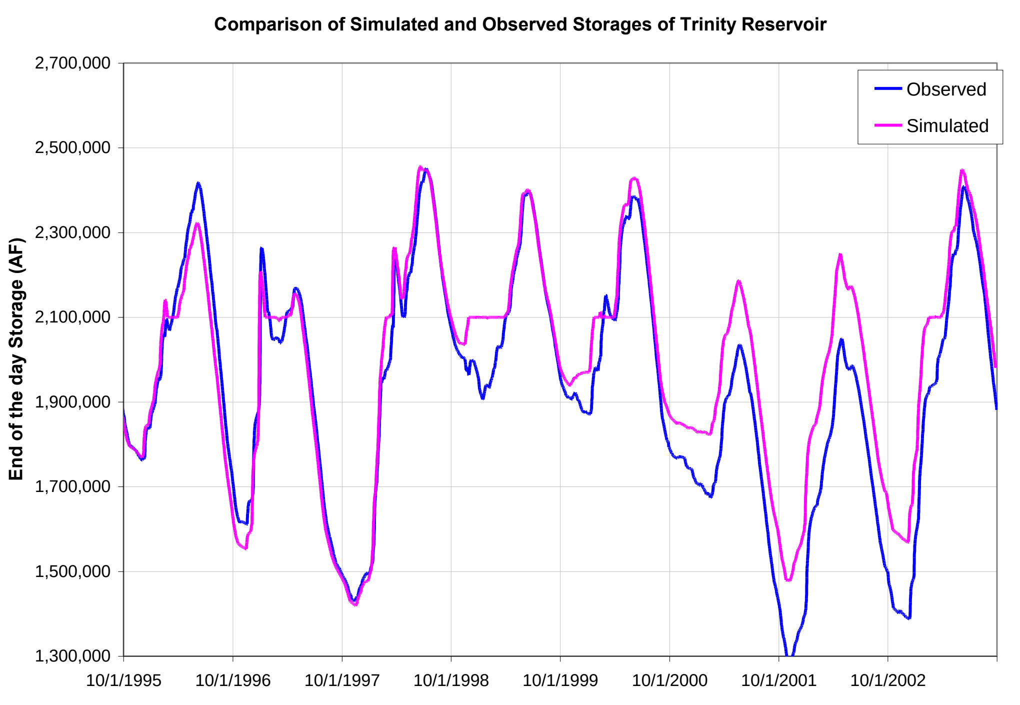


FIGURE 4.7
Comparison of Observed and Simulated Storages at Trinity Reservoir

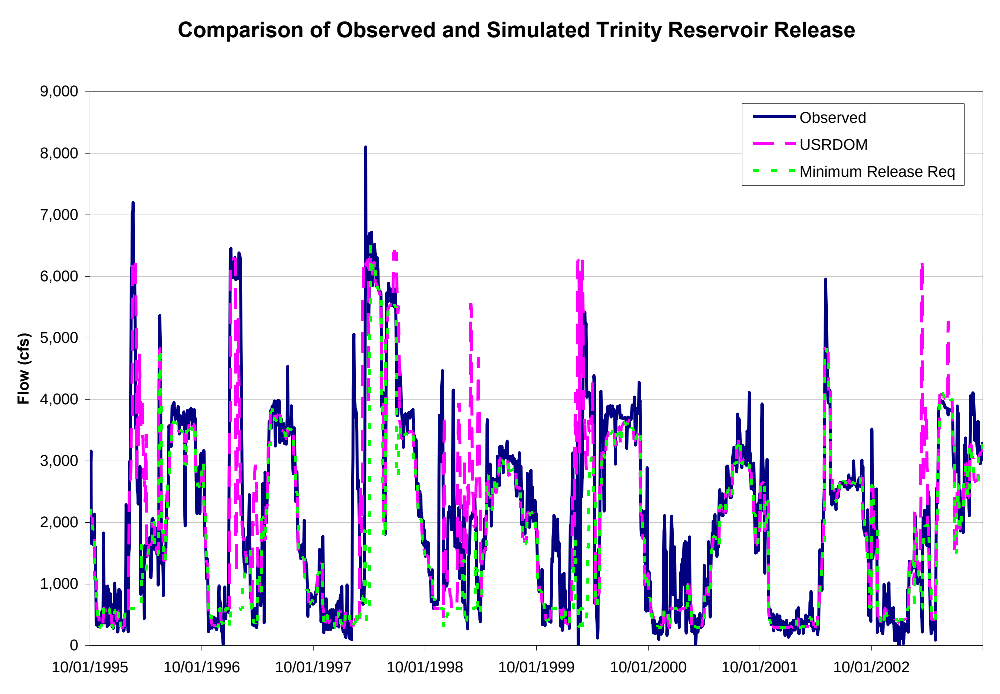


FIGURE 4.8
Comparison of Observed and Simulated Trinity Reservoir Outflow

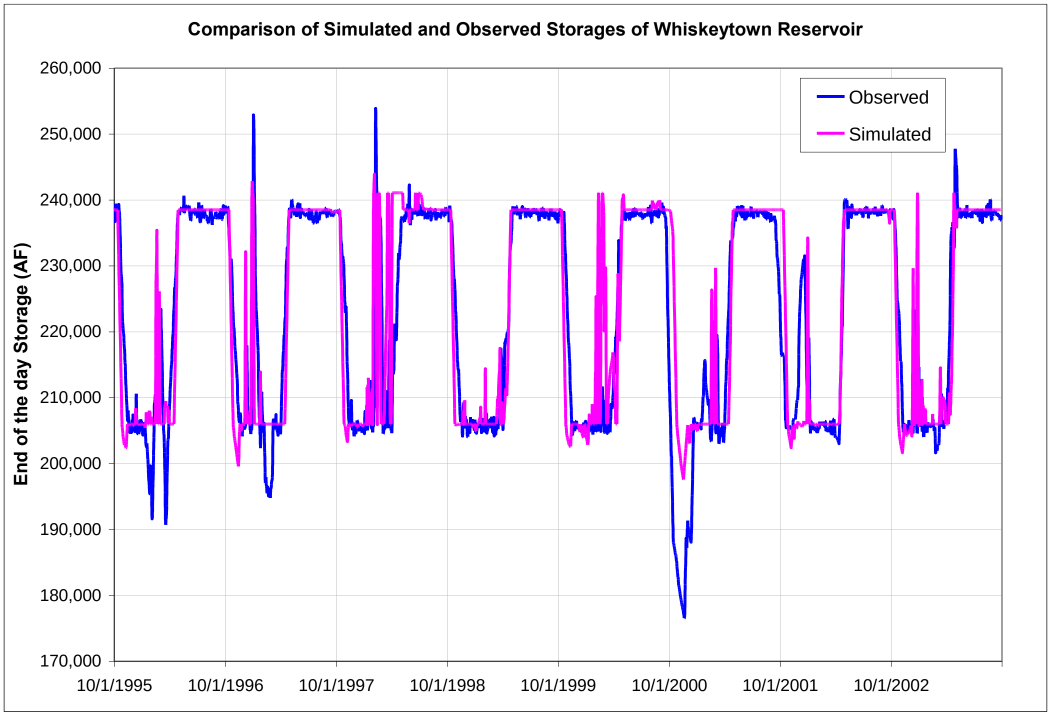


FIGURE 4.9
Comparison of Observed and Simulated Storage at Whiskeytown Reservoir

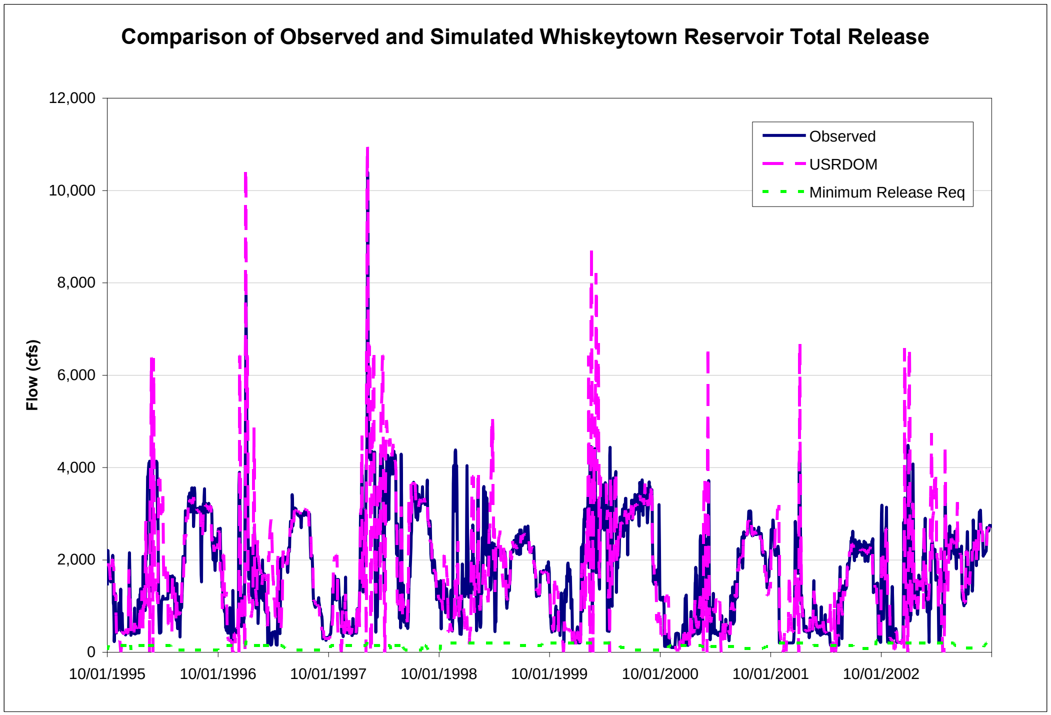


FIGURE 4.10
Comparison of Observed and Simulated Whiskeytown Reservoir Outflow

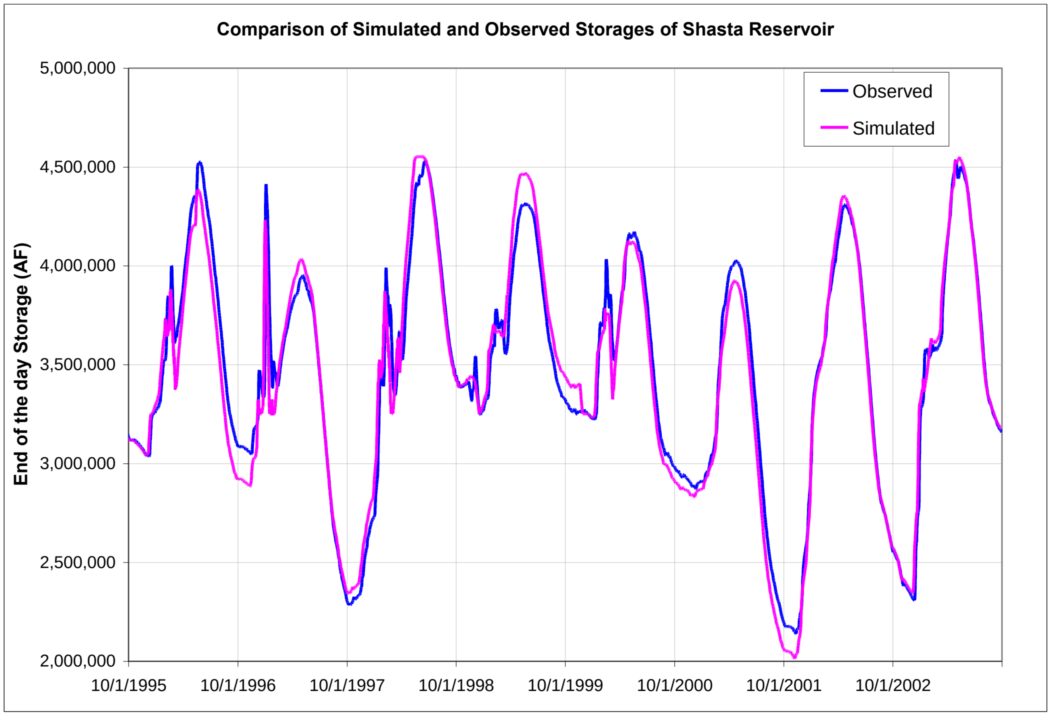


FIGURE 4.11
Comparison of Observed and Simulated Storage at Shasta Reservoir

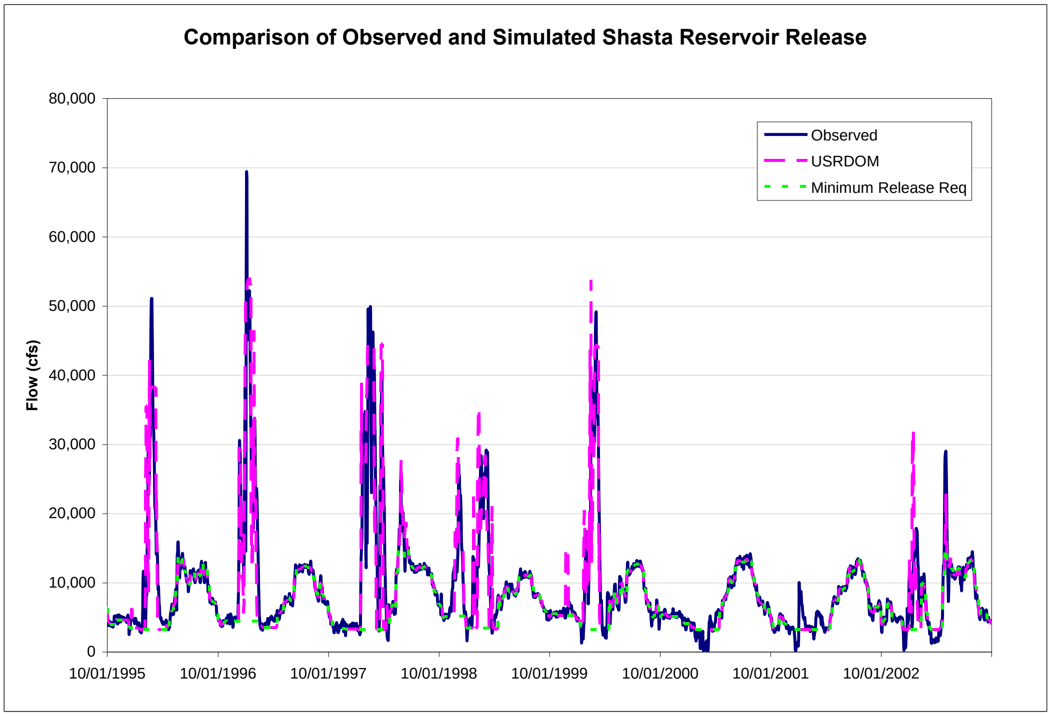
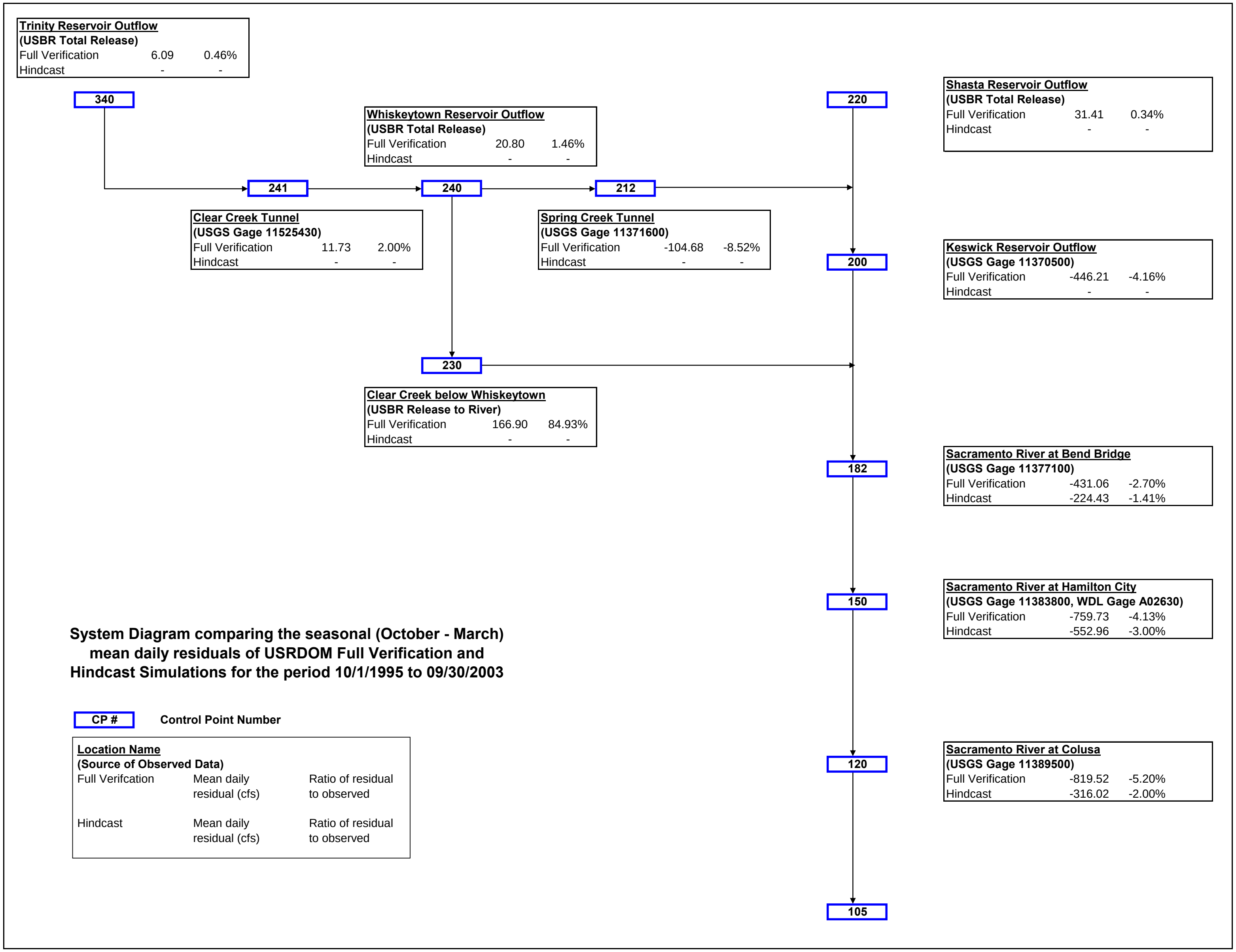


FIGURE 4.12
Comparison of Observed and Simulated Shasta Reservoir Outflow



System Diagram comparing the seasonal (October - March) mean daily residuals of USRDOM Full Verification and Hindcast Simulations for the period 10/1/1995 to 09/30/2003

Trinity Reservoir Outflow
(USBR Total Release)

Full Verification	6.09	0.46%
Hindcast	-	-

Whiskeytown Reservoir Outflow
(USBR Total Release)

Full Verification	20.80	1.46%
Hindcast	-	-

Shasta Reservoir Outflow
(USBR Total Release)

Full Verification	31.41	0.34%
Hindcast	-	-

Clear Creek Tunnel
(USGS Gage 11525430)

Full Verification	11.73	2.00%
Hindcast	-	-

Spring Creek Tunnel
(USGS Gage 11371600)

Full Verification	-104.68	-8.52%
Hindcast	-	-

Keswick Reservoir Outflow
(USGS Gage 11370500)

Full Verification	-446.21	-4.16%
Hindcast	-	-

Clear Creek below Whiskeytown
(USBR Release to River)

Full Verification	166.90	84.93%
Hindcast	-	-

Sacramento River at Bend Bridge
(USGS Gage 11377100)

Full Verification	-431.06	-2.70%
Hindcast	-224.43	-1.41%

Sacramento River at Hamilton City
(USGS Gage 11383800, WDL Gage A02630)

Full Verification	-759.73	-4.13%
Hindcast	-552.96	-3.00%

Sacramento River at Colusa
(USGS Gage 11389500)

Full Verification	-819.52	-5.20%
Hindcast	-316.02	-2.00%

CP # **Control Point Number**

Location Name
(Source of Observed Data)

Full Verifcation	Mean daily residual (cfs)	Ratio of residual to observed
Hindcast	Mean daily residual (cfs)	Ratio of residual to observed

FIGURE 4.13
Comparison of Mean Daily Residuals between Reservoir Operations Verification Run and Hindcast Simulation Run (October–March)

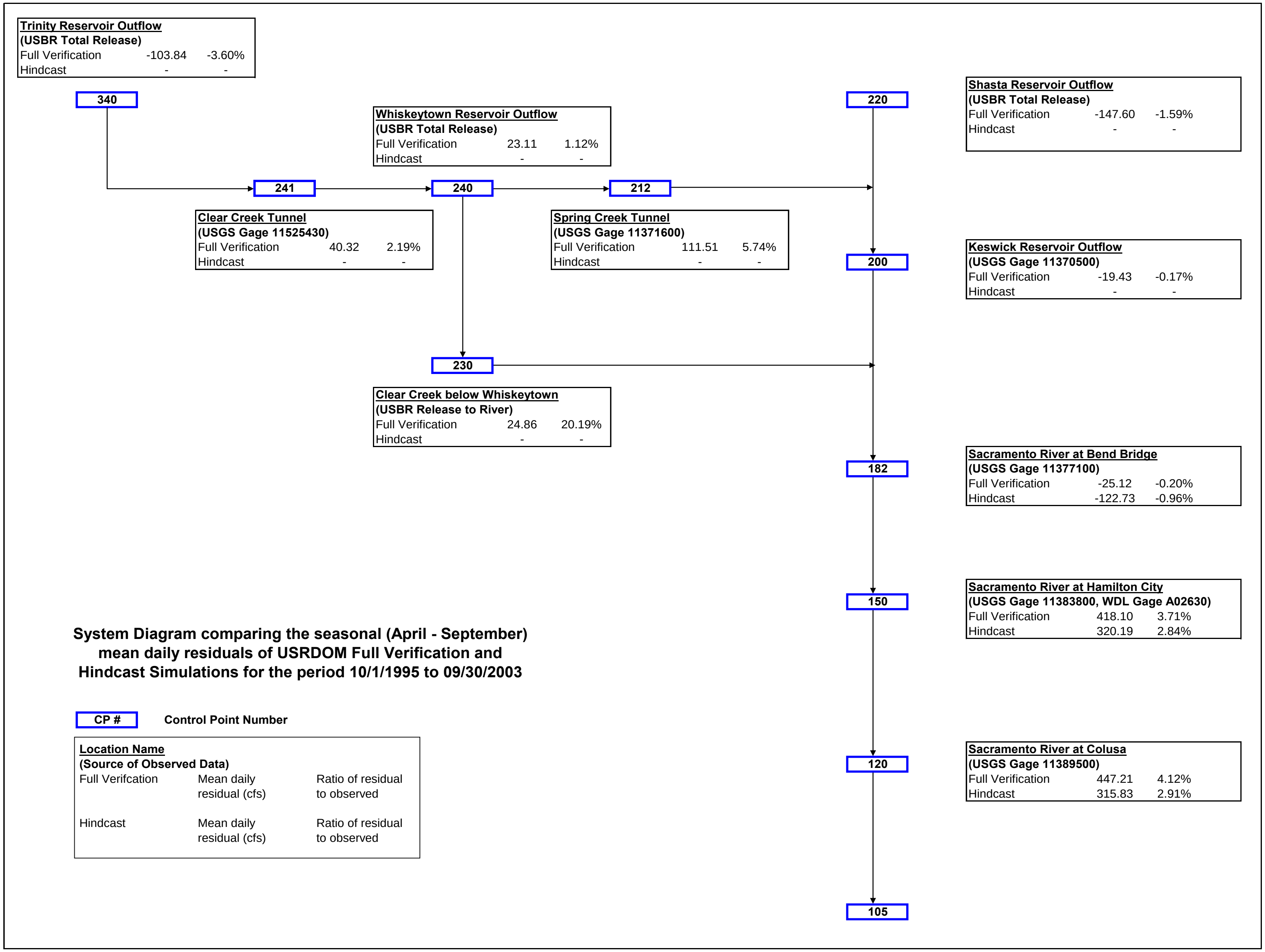


FIGURE 4.14

Comparison of Mean Daily Residuals between Reservoir Operations Verification Run and Hindcast Simulation Run (April–September)

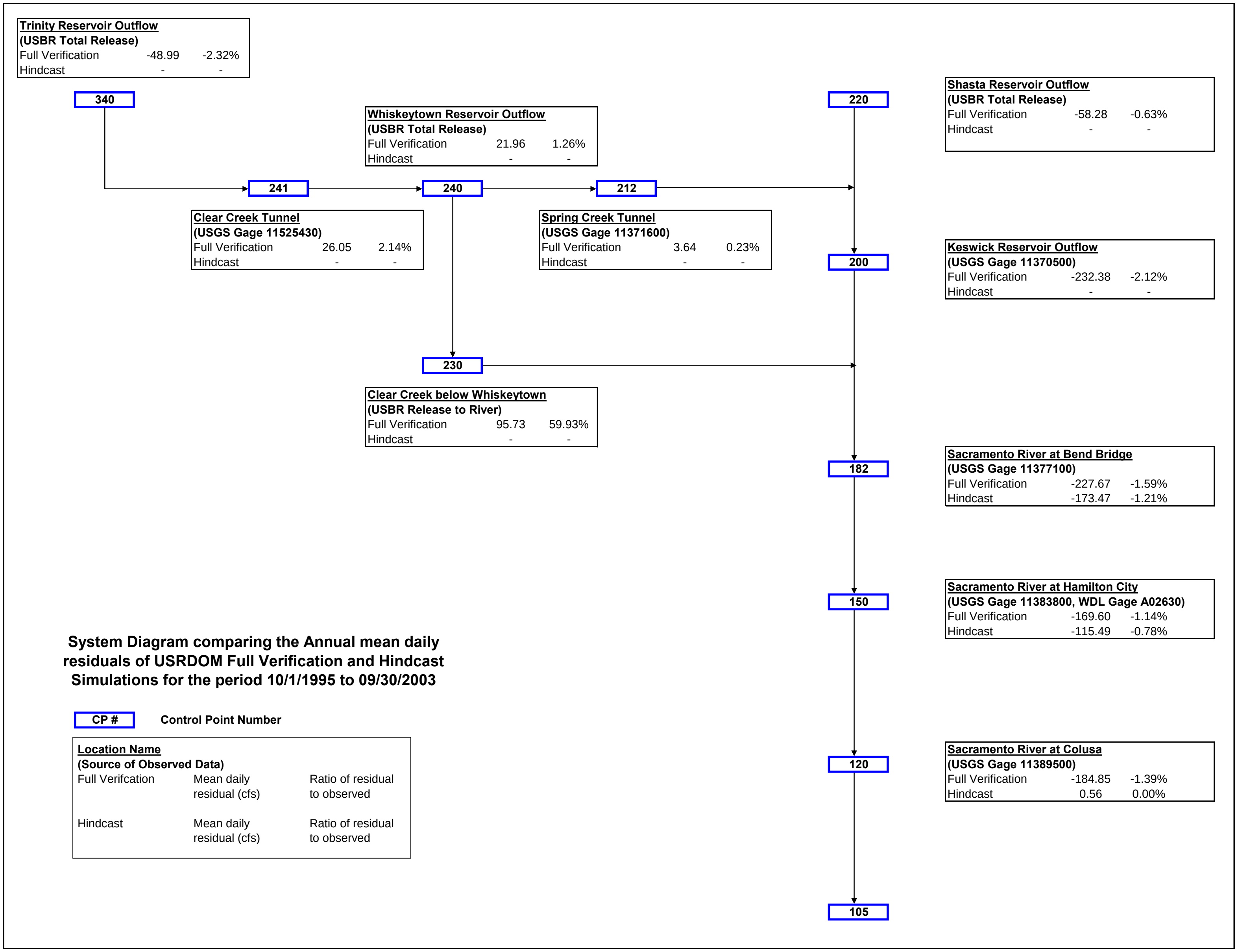


FIGURE 4.15

Comparison of Mean Daily Residuals between Reservoir Operations Verification Run and Hindcast Simulation Run (Annual) simulation at Bend Bridge shows that there is 1.3 percent higher uncertainty in the river flows caused by the reservoir operations.

The uncertainties increase downstream along the Sacramento River because of the increase in the complexity of river processes downstream of Bend Bridge. The effect of diversions, stream routing, valley floor routing, bypass weirs, and local accretions accumulates and is shown as the net uncertainty at the Sacramento River at Colusa.

From the system diagram of April to September (Figure 4.14), we can conclude similar results in terms of propagation of uncertainties in the system. The only difference is the magnitude of the uncertainties is less compared to the high flow season. This implies that the model performs better in the low flow season in terms of reservoir operations and hydrology and river processes.

Figure 4.15 shows the performance of the full verification simulation of USRDOM for the full 8-year period. The uncertainties for the annual average scale are relatively better than the high flow season. Overall, the Trinity and Whiskeytown operations are simulated very well in USRDOM, except for the Clear Creek flows below Whiskeytown with a high daily mean residual. Because the flows from Clear Creek are small compared to the Sacramento River, the model is appropriate for analyses of the Sacramento River. However, it should not be used for analyses that solely focus on Clear Creek.

4.5 Development of Full-period Simulation Capability (1922–2003)

For use in planning analyses, USRDOM must be capable of simulating full 82-year daily flow conditions in the upper Sacramento River using the results from CALSIM II simulations. The inputs and the model used in the full verification simulation are the starting point for this full-period model.

4.5.1 Extension of Hydrology (1922–1963)

The calibration/verification process was focused on WY 1964 to WY 2003. The daily hydrology dataset developed for use in the calibration/verification process was extended to the full 82-year period, anticipating the need for it in the projected full-period simulations. The methods described in Section 2 were implemented in estimating the reservoir inflows, tributary flows, and ungaged local flows.

Available gage records were sparse in the pre-1964 water years for the tributary flows and reservoir inflows (pre-1940). Therefore, missing daily flow data for these years were estimated using the methods described in Section 2.

4.5.2 Standard Assumptions and Inputs (Future Conditions)

As part of preparing USRDOM for the full-period projected condition simulations, some of the assumptions used in the full verification simulations were modified to better reflect the future level conditions, including:

- The channel capacity of the Trinity River downstream of Lewiston Reservoir was increased from 6,000 cfs to 11,000 cfs based on the proposed modifications to the bridge capacities and channel widening.

- The Trinity River minimum release requirement that provides the daily release schedule was changed to the projected conditions based on the Trinity River Flow Evaluation Final Report (USFWS and Hoopa Valley Tribe, 1999) recommendation. In the verification simulation, this requirement was estimated based on the observed releases from Lewiston Reservoir.
- All other projected model inputs, such as minimum reservoir release requirements, minimum in-stream flow requirements, downstream diversions, and other demands, were estimated based on the results of the CALSIM II simulations.

4.5.3 Model Schematic Changes

The USRDOM schematic used in the full verification simulation was modified slightly to ensure better conformity between CALSIM II and USRDOM. In the projected conditions schematic, the Stony Creek reach downstream of Black Butte Reservoir was modified to include CALSIM II WBA6 diversions and Stony-TCC intertie flow. Routing remained consistent with the verification simulation in this reach of Stony Creek.

In the main stem Sacramento River, the proposed Delevan pipeline diversion and inflow were added to the schematic just upstream of Moulton Weir. Unlike the full verification simulation, a closure flow was included in the lower river segment from Ord Ferry to Knights Landing. Finally, miscellaneous diversions in the lower river segment were relocated for better agreement between CALSIM II and USRDOM.

Figure 4.16 provides a model schematic for the USRDOM full-period projected condition simulations. The schematic also includes the detailed conveyance features of the proposed NODOS project in the Colusa Basin region. This portion of the model is described in Section 6. The schematic used for the projected conditions simulation and an information table describing the schematic are included in Appendix B.

4.5.4 USRDOM Toolset

The Common Assumptions framework and the models included in it will be used to analyze the feasibility of the proposed NODOS project. It is anticipated that USRDOM would be part of the framework. The USRDOM toolset was developed so that it is ready to be integrated into the Common Assumptions framework. The toolset includes utilities and batch processes to set up and run USRDOM, and to create linkage datasets from the USRDOM output for other models along with the documentation and model protocols.

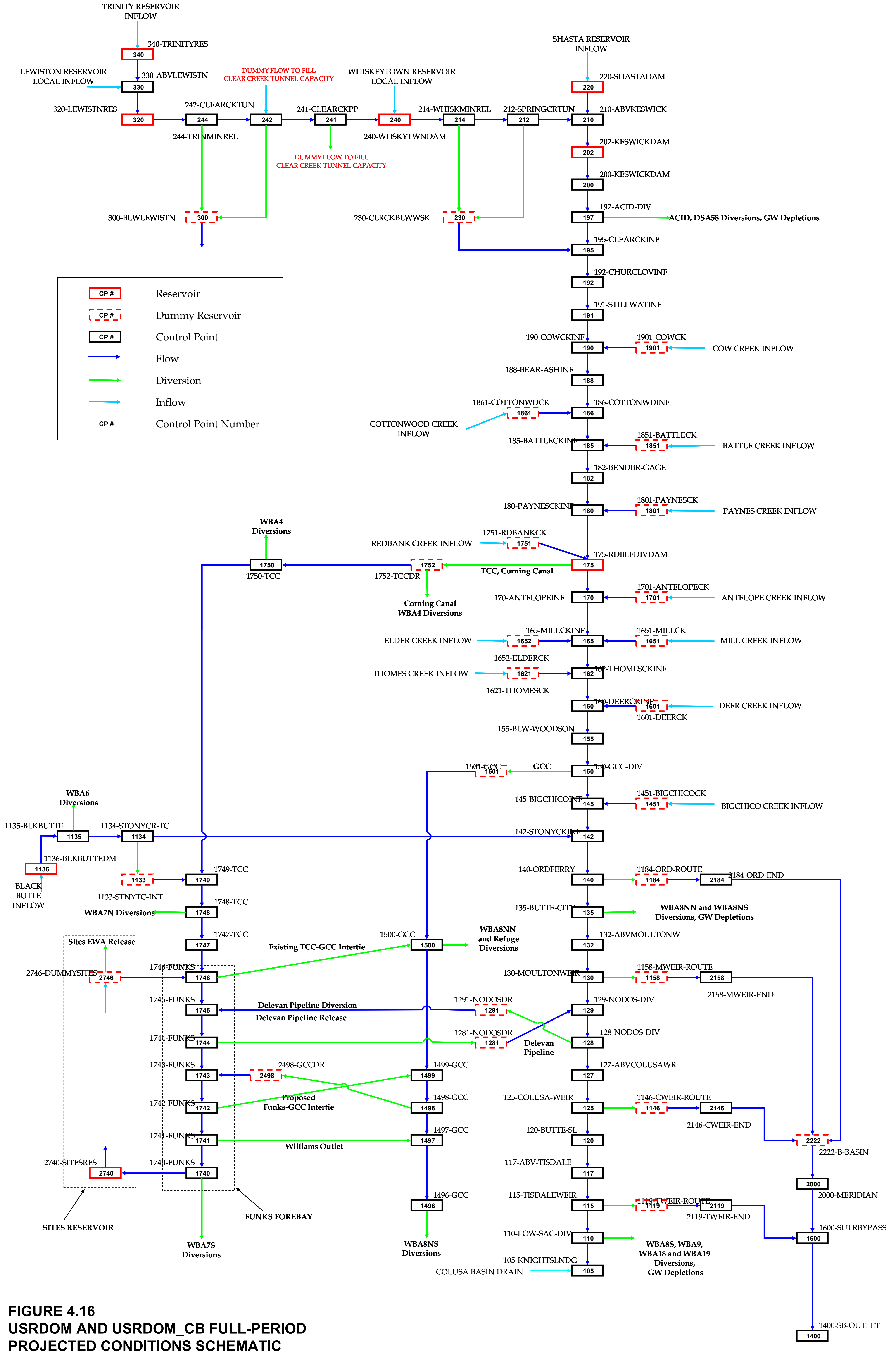


FIGURE 4.16
USRDOM AND USRDOM_CB FULL-PERIOD PROJECTED CONDITIONS SCHEMATIC

SECTION 5

Model Application

5.1 Overview

The main objective of USRDOM development is to simulate daily operations in the Upper Sacramento River to evaluate and compare proposed alternatives in the NODOS feasibility study analysis. This section describes the development of USRDOM to simulate daily flow conditions in Sacramento River for the full 82-year period based on the inputs derived from CASLIM II results. The framework and the utilities developed as part of this application are also described in this section.

5.1.1 Integrated Analysis Framework

The USRDOM model for projected condition simulations includes several pieces. Figure 5.1 shows the process diagram for USRDOM, which identifies the input data sources and the utilities that are part of the USRDOM toolset. Several new utilities and batch files have been created to run USRDOM as part of the Common Assumptions framework.

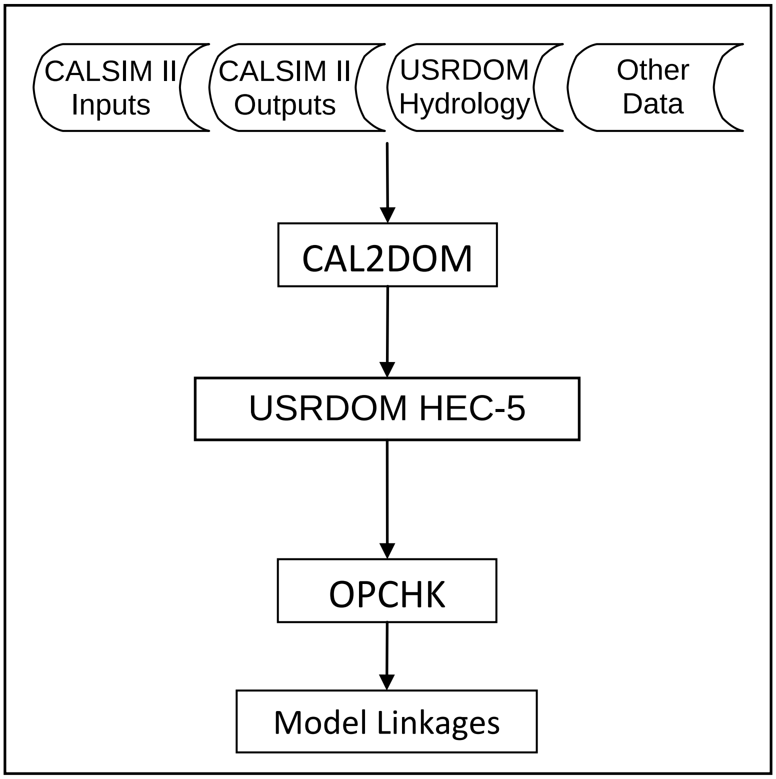


FIGURE 5.1
USRDOM Process

The inputs for USRDOM are derived from the database of daily hydrology time series described in Section 2 and other operational inputs developed as part of the full verification simulation such as the reservoir operation parameters and flow routing data described in Section 3. The projected level inputs for USRDOM such as the reservoir evaporation rates, initial storage conditions, minimum requirements, reservoir releases and storages, deliveries are derived from CALSIM II input and output databases. A full list of CALSIM II variables used and the method used to convert them to USRDOM inputs is provided in the following sections.

A new utility called 'CAL2DOM' was developed to perform quality assurance and prepare the time series inputs for USRDOM from these individual data sources. The processed inputs from CAL2DOM are fed to the HEC-5 model, the core engine of USRDOM. The results from HEC-5 are fed to another new utility called 'OPCHK,' which generates summary results for quick quality assurance check. Utilities that generate input datasets for several habitat and water quality models based on the results from USRDOM are also included in the USRDOM toolset.

5.2 USRDOM and CALSIM II

CALSIM II simulates CVP and State Water Project (SWP) operations on a monthly timestep from WY 1922 through WY 2003. The 82-year hydrology for CALSIM II was developed using historical rainfall and runoff data and has been adjusted for changes in water and land use that have occurred or may occur in the future. The model simulates the operation of the water resources infrastructure in the Sacramento and San Joaquin river basins on a month-to-month basis during this 82-year period. In the model, the reservoirs and pumping facilities of the SWP and CVP are operated to meet the flow and water quality requirements for these systems. The model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over 82 years from 1922 to 2003, representing a fixed level of development (Reclamation, 2008).

As part of the NODOS feasibility study, CALSIM II is the model of choice for the lead agencies to simulate reservoir operations and river flow conditions. Therefore, for the USRDOM projected conditions simulation, the inputs are taken from CALSIM II for a consistent analysis. Because USRDOM requires inputs on a daily timestep, the monthly inputs and outputs of the CALSIM II model must be downscaled to a daily timestep. Because spatial resolution between USRDOM and CALSIM II is inconsistent, the CAL2DOM utility translates data between the two models, including the disaggregation and consolidation of flow data.

A well-maintained catalog and dataflow record are necessary to track the data and the number of variables that need to be translated between the two models. Appendix D includes a spreadsheet called "*DSS_Catalog_and_DZYMAN_CFGs.xls*" that documents the data catalog and dataflow between various models as part of USRDOM and a few snapshots from it. In the "*Reports*" worksheet of this spreadsheet, by selecting the destination, the data from all the sources to the selected model or utility is shown organized by various categories. For example, to find all the data from CALSIM II that is used as inputs in USRDOM, the user can select the destination as CAL2DOM and the spreadsheet lists all the CALSIM II inputs and outputs. The "*Data Flowpaths*" worksheet shows the sources of data for each model or utility and is helpful for understanding the USRDOM data flow and framework. This spreadsheet is also used to generate configuration files using the DZYMAN utility, which is described in the next section.

5.2.1 DZYMAN

DZYMAN is a generic FORTRAN program that provides fast, automated batch processing of large amounts of HEC-DSS time series data. It requires free-format instruction files, with simple keywords to initiate a computation. It contains a wide variety of commonly used algebraic, time conversion, and smoothing functions to perform data translations and computations on DSS data. It automatically converts the units of the inputs based on the outputs requested. It requires instruction files that are easy to maintain or modify, even with minimal programming skills. DZYMAN standardizes the computation approaches and assures quality control during data processing.

DZYMAN requires a configuration (**.cfg*) file and an instruction file (**.dzy*). The configuration file includes a list of handles or variables with various DSS pathnames assigned to them. This file should include all the DSS data records that are needed in the computation process. The instruction file includes the computation steps using simple keywords representing the DZYMAN functions (e.g., ADD, MAX, ISEQUAL etc.) and the handles (listed in the configuration file) on which the computation has to occur. Appendix E contains an instruction key with the keywords representing the functions in DZYMAN. A brief description of each function is included along with the source code for the utility.

DZYMAN is used to create the intermediate USRDOM utilities such as CAL2DOM, OPCHK, Trinity Import Logic utility (WIDGET) and other utilities that translate USRDOM output as inputs to other fisheries and habitat models. CAL2DOM, OPCHK, WIDGET are applications of DZYMAN. Each utility or a DZYMAN application would have unique configuration (*.cfg) and instruction (*.dzy) files. "*DSS_Catalog_and_DZYMAN_CFGs.xls*" spreadsheet in Appendix D helps in generating the configuration files for the above utilities. Another spreadsheet called "*CAL2DOM_OPCHK_DZYMAN_Instructions.xls*" is used to generate the instruction files for the utilities and is included in the Appendix B. To create a new DZYMAN application, a DSS file with time series data, a configuration file with the list of DSS pathnames with handle names and an instructions file with the computation steps are needed.

5.2.2 CAL2DOM

The CAL2DOM utility translates monthly CALSIM II operations data to a daily time step. It uses the inputs and outputs from CALSIM II, USRDOM hydrology, and other datasets and computes inflows, diversions, and evaporation rates for USRDOM. CAL2DOM performs consistency checks between USRDOM and CALSIM II inputs and outputs. CAL2DOM also identifies operation controls for storage release requirements and computes the minimum release requirements for the reservoirs included in USRDOM. Table 5.1 shows the consolidated list of USRDOM inputs CAL2DOM computes based on the CALSIM II inputs and outputs. Appendix B includes the CAL2DOM instruction file with detailed computations for each of the inputs.

TABLE 5.1
USRDOM Inputs Based on CALSIM II data Using CAL2DOM

Input Type	USRDOM Inputs	USRDOM Nickname

TABLE 5.1
USRDOM Inputs Based on CALSIM II data Using CAL2DOM

Input Type	USRDOM Inputs	USRDOM Nickname
Minimum Reservoir Releases	Trinity Reservoir	MR340
	Whiskeytown Reservoir	QD214
	Shasta Reservoir	MR220
Minimum In-stream Flows	Trinity River flow downstream of Lewiston	QD244
	Sacramento River downstream of Red Bluff Diversion Dam	MR175
	Sacramento River downstream of GCC diversion	MR150
	Sacramento River downstream of Wilkins Slough	MR110
	Sacramento River downstream of Knights Landing	MR105
Diversions	ACID and other lumped upper segment diversions	QD197
	Tehama-Colusa Canal and Corning Canal	QD175
	Lumped middle segment miscellaneous diversions	QD155
	Stony Creek WBA6 Diversions	QD1135
	Stony Creek - TCC Intertie Flow	QD1134
	Glenn-Colusa Canal	QD150
	Lumped WBA8NN and WBA8NS Diversions (Lower Segment)	QD135
	New Delevan Pipeline Diversion to NODOS	QD128
	Lumped WBA8S, WBA9, WBA18, and WBA19 Diversions (Lower Segment)	QD110
Closure terms	Upper segment closure term	IN182
	Middle segment closure term	IN142
	Lower segment closure term	IN132
Evaporation Rate	Trinity Reservoir	EV340
	Whiskeytown Reservoir	EV240
	Shasta Reservoir	EV220
	Black Butte Reservoir	EV1136
Reservoir Outflow	Black Butte Reservoir	QA1136
Reservoir Inflow	Black Butte Reservoir	IN1136

5.2.3 CAL2DOM Methodology

This section provides an overview of the computation methodology in CAL2DOM to develop the daily inputs for the full period USRDOM projected conditions simulation. Different approaches were developed and tested in the process leading to an approach that resulted in USRDOM operations that were fully consistent with CALSIM II results. A brief description of all the approaches that resulted in the final CAL2DOM methodology is provided in this section.

The first approach, Option A, was a simplified approach in which the Shasta Reservoir minimum release requirement in USRDOM was set equal to CALSIM II monthly Shasta releases, if one of the following trigger conditions was true:

1. If the simulation month is June through October
2. If In-Basin Use (IBU) conditions under the Coordinated Operations Agreement (COA) sharing exists
3. Delta Controls—If the Shasta release in CALSIM II is determined based on any of the Delta outflow, export, or salinity control requirements
4. Sacramento River Controls—If the Shasta release in CALSIM II is determined based on the minimum required in-stream flow in Sacramento River at Keswick, Red Bluff Diversion Dam, Wilkins Slough, or Knights Landing

The Option A approach ensures that the end-of-month storage in Shasta Reservoir simulated in USRDOM is equivalent to CALSIM II data. However, under this approach, there may be insufficient flow in the river to fully meet the deliveries and minimum required flow needs along the Sacramento River simulated by CALSIM II. This situation may arise because the daily diversion needs may be higher than the monthly average Shasta releases determined by CALSIM II, which does not account for daily variability in the unregulated tributary inflows along the Sacramento River.

Option B is similar to Option A, except that Sacramento River Controls (trigger 4) are calculated based on daily flow conditions and shortages in every reach, including downstream boundary conditions at Knights Landing. In determining the shortages the daily reach flow is computed based on the unregulated inflows and the CALSIM II demands translated to daily time step. If one of the triggers 1 through 4 exist, then the required Shasta release in USRDOM is set equal to the monthly CALSIM II Shasta release, unless a flow shortage is anticipated in the Sacramento River at Keswick, Red Bluff Diversion Dam, Wilkins Slough, or Knights Landing control locations. In the event of a flow shortage, Shasta release is set to meet the flow required at that control location.

Under the Option B approach, even though the demands and minimum required flows are consistent with CALSIM II, there is a considerable drawdown in Shasta storage in USRDOM. In other words, though this approach addresses the daily flow controls it did not have the benefit of CALSIM II adjusting operations in response to daily varying flow balances (at a monthly level). Therefore, to make the models consistent with each other it was concluded that CALSIM II needed to be informed about daily variability of flows.

The final approach is an improvement to Option B. In the final approach, unregulated flows that are below the monthly average are summed up for the whole month and averaged to come up with a monthly adjustment. Preprocessed time series of the necessary additional flows are added to the CALSIM minimum instream flow requirement as a time series. This allows CALSIM II to dynamically adjust its operations to account for this variability. With this change the CAL2DOM controls to determine Trinity operations based on Sacramento River conditions and Knights Landing control in Option B were no longer necessary and were removed from the shortage computation. The Knights Landing control provided Delta requirements in Option B that are now provided at Keswick in the final approach.

5.2.3.1 Consistency Checks

The hydrology data used in CALSIM II and USRDOM are consistent. CAL2DOM performs checks between CALSIM II inputs and the USRDOM inputs to ensure consistency. The inputs to both models are compared on monthly time step at various locations along the River. Table 5.2 summarizes the list of inflows for which CAL2DOM compares the CALSIM II values to monthly USRDOM inputs. CAL2DOM also compares certain variables computed using the CALSIM II translations with the variables from the USRDOM full verification simulation. These variables are listed in Table 5.3. Daily USRDOM inputs are converted to monthly scale from which the CALSIM II values are then subtracted. The results are stored in a temporary DSS file (TEMP.DSS) using the handle name in the Result column as Part B. Finally, basic statistics are computed and are written to the console.

TABLE 5.2
Data Checks between CALSIM II Inputs and USRDOM Inputs in CAL2DOM

Description	QA/QC (Result)	USRDOM	CALSIM II
Trinity Reservoir Inflow	IN340_CHK	IN340	I1
Lewiston Reservoir Inflow	IN330_CHK	IN330	I100
Lewiston Reservoir Outflow Release	QD244_CHK	QD244	C100_MIF
Whiskeytown Reservoir Inflow	IN240_CHK	IN240	I3
Shasta Reservoir Inflow	IN220_CHK	IN220	I4
Cow Creek Inflow	IN1901_CHK	IN1901	I10801
Cottonwood Creek Inflow	IN1861_CHK	IN1861	I10802
Battle Creek Inflow	IN1851_CHK	IN1851	I10803
Paynes Creek Inflow	IN1801_CHK	IN1801	I11001
Red Bank Creek Inflow	IN1751_CHK	IN1751	I112
Elder Creek Inflow	IN1652_CHK	IN1652	I11303
Thomes Creek Inflow	IN1621_CHK	IN1621	I11304
Antelope Creek Inflow	IN1701_CHK	IN1701	I11307
Mill Creek Inflow	IN1651_CHK	IN1651	I11308
Deer Creek Inflow	IN1601_CHK	IN1601	I11309
Big Chico Creek Inflow	IN1451_CHK	IN1451	I11501

TABLE 5.3
Additional Data Checks between Translated USRDOM Inputs (from CALSIM II) and Verification Inputs in CAL2DOM

Description	QA/QC (Result)	USRDOM	USRDOM Full Verification
ACID, DSA58 Diversions and GW Depletions	QD197_CHK	QD197	QD197_VER
Upper Reach Historical Ungaged Tributary Inflows	IN182_CHK	IN182	IN182_UG_VER
Middle Reach Historical Ungaged Tributary Inflows	IN142_CHK	IN142	IN142_UG_VER

5.2.3.2 CALSIM II Operational Controls

CAL2DOM identifies the operational controls for the storage release requirements for Trinity and Shasta Reservoirs in CALSIM II for each month. It uses these controls to determine the minimum in-stream flow requirements and minimum reservoir release requirements in USRDOM. Table 5.4 shows the list of operational controls computed in CAL2DOM. CALSIM II operational (simulated) and control variables (requirements) are listed in separate columns.

TABLE 5.4
CALSIM II Operational Controls in CAL2DOM

Description	CAL2DOM Ops Controls (Result)	CALSIM II		Method used to determine the control
		Control	Operation	
Trinity River Minimum Flow	C100_CTRL	C100_MIF	C100	C100_CTRL is 1 if C100 = C100_MIF, otherwise is 0
Clear Creek Minimum Flow	C3_CTRL	C3_MIF	C3	C3_CTRL is 1 if C3 = C3_MIF, otherwise is 0
Sacramento River at Keswick Reservoir Minimum Flow	C5_CTRL	C5_MIF	C5	C5_CTRL is 1 if C5 = C5_MIF, otherwise is 0
Red Bluff Diversion Dam Bypass Flow	C112_CTRL	C112_MIF, C112_MIFADJ	C112	C112_CTRL is 1 if C112 = C112_MIF + C112_MIFADJ, otherwise is 0
Glenn-Colusa Canal Diversion Bypass Flow	C114_CTRL	C114_MIF, C114_MIFADJ	C114	C114_CTRL is 1 if C114 = C114_MIF + C114_MIFADJ, otherwise is 0
Sacramento River at Wilkins Slough (NCP) Flow Objective	C129_CTRL	C129_MIF, C129_MIFADJ	C129	C129_CTRL is 1 if C129 = C129_MIF + C129_MIFADJ, otherwise is 0
Sacramento River at Rio Vista Minimum Flow	C405_CTRL	C405_MIF	C405	C405_CTRL is 1 if C405 = C405_MIF, otherwise is 0

TABLE 5.4
CALSIM II Operational Controls in CAL2DOM

Description	CAL2DOM Ops Controls (Result)	CALSIM II Control	CALSIM II Operation	Method used to determine the control
Delta Inflow needed for Delta Export for ANN compliance	C400_CTRL	C400_MIF	C400_ANN	C400_CTRL is 1 if C400 = C400_MIF, otherwise is 0
Delta Outflow needed to comply with Jersey Point salinity standards	JP_CTRL	JP_MRDO	C407, D407	JP_CTRL is 1 if JP_MRDO >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Emmaton salinity standards	EM_CTRL	EM_MRDO	C407, D407	EM_CTRL is 1 if EM_MRDO >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Rock Slough salinity standards	RS_CTRL_1	RS_MRDO_1	C407, D407	RS_CTRL_1 is 1 if RS_MRDO_1 >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Rock Slough salinity standards	RS_CTRL_2	RS_MRDO_2	C407, D407	RS_CTRL_2 is 1 if RS_MRDO_2 >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Rock Slough salinity standards	RS_CTRL_3	RS_MRDO_3	C407, D407	RS_CTRL_3 is 1 if RS_MRDO_3 >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Collinsville salinity standards	CO_CTRL	CO_MRDO	C407, D407	CO_CTRL is 1 if CO_MRDO >= C407 + D407, otherwise is 0
Sacramento and San Joaquin River Delta Outflow	C407_CTRL	0	C407	C407_CTRL is 1 if C407 = 0., otherwise is 0
Delta Inflow needed to maintain Delta Export/Inflow Ratio	EI_CTRL	EIExpCtrl	D418, D419	EI_CTRL is 1 if EIExpCtrl <= D418 + D419, otherwise is 0
Status of COA Sharing (UWFE or IBU conditions)	IBU_TRUE	0	UWFE_TRUE	IBU_TRUE is 1 if UWFE_TRUE = 0., otherwise is 0
Shasta Reservoir is in Flood Control	S4_FLD_CTRL	S4LEVEL5	S4, S44	S4_FLD_CTRL is 1 if S4LEVEL5 <= S4 + S44, otherwise is 0
Cumulative Sacramento River Control	SACR_CTRL	C5_CTRL, C112_CTRL, C114_CTRL, C129_CTRL	N/A	Take the maximum of all CTRL values

TABLE 5.4
CALSIM II Operational Controls in CAL2DOM

Description	CAL2DOM Ops Controls (Result)	CALSIM II		Method used to determine the control
		Control	Operation	
Cumulative Sacramento/San Joaquin Delta Control	DELTA_CTRL	C400_CTRL, JP_CTRL, EM_CTRL, RS_CTRL_1, RS_CTRL_2, RS_CTRL_3, CO_CTRL, C407_CTRL, EI_CTRL	N/A	Take the maximum of all CTRL values
Set Trinity Reservoir Release Trigger	TRIN_TRUE	1, S4_FLD_CTRL, JUNOCT_TRUE, SACR_CTRL	N/A	Maintain Trinity Reservoir releases if Shasta Reservoir is NOT in flood control (S4_FLD_CTRL is subtracted from the value of 1) or if it is June through October or if Sacramento River controls are in effect
Set Shasta Reservoir Release Trigger (Option A)	SHASTA_TRUE	JUNOCT_TRUE, IBU_TRUE, DELTA_CTRL, SACR_CTRL	N/A	Maintain Shasta Reservoir releases if it is June through October, IBU conditions exist, and Sacramento/San Joaquin Delta controls or Sacramento River controls are in effect
Set Shasta Reservoir Release Trigger (Option B)	SHASTA_TRUE	JUNOCT_TRUE, IBU_TRUE, DELTA_CTRL	N/A	Maintain Shasta Reservoir releases if it is June through October, IBU conditions exist, or Sacramento/San Joaquin Delta controls are in effect (Sacramento River controls are implemented as flow checks)

Notes:

ANN = artificial neural network
N/A = not applicable
NCP = navigation control point
UWFE = unstored water for export

5.2.3.3 Minimum In-stream Flows

Table 5.5 includes the CALSIM II variables and the methodology used in CAL2DOM to compute various minimum in-stream flow requirements used in USRDOM. Minimum in-stream requirements in USRDOM are specified at four Sacramento River locations: Red Bluff Diversion Dam, GCC diversion, Wilkins Slough, and Knights Landing. The minimum in-stream flow requirement for Trinity River is specified as a diversion at the Lewiston Reservoir.

TABLE 5.5
Computation of Minimum In-stream Flow Requirements in CAL2DOM

USRDOM Inputs	USRDOM Nickname	CALSIM II Variables	CAL2DOM Translation
Trinity River flow downstream of Lewiston	QD244	N/A	Estimated based on the Trinity River Flow Evaluation Final Report (USFWS and Hoopa Valley Tribe, 1999) recommendation
Sacramento River downstream of Red Bluff Diversion Dam	MR175	C112_MIF	Converted to daily, ramped 2 days going up and saved the result as average weekly values
Sacramento River downstream of GCC diversion	MR150	C114_MIF	Converted to daily, ramped 3 days going up and saved the result as average weekly values
Sacramento River downstream of Wilkins Slough	MR110	C129_MIF	Converted to daily, ramped 6 days going up and saved the result as average weekly values
Sacramento River downstream of Knights Landing	MR105	C134	If Shasta Reservoir release trigger, SHASTA_TRUE (described in Table 5.4), is 1, then C134 value is used. Checked to make sure at least 3,000 cfs of flow exists, ramped 6 days going up and saved the result as average weekly values.

Note:

N/A = not applicable

5.2.3.4 Diversions

Table 5.6 lists the diversions explicitly modeled in USRDOM, along with the CALSIM II variables and the methodology used by CAL2DOM to compute them. In addition to the diversions modeled in the full verification simulation, Stony Creek – TCC Intertie flow and the new Delevan pipeline diversion to NODOS are included in the projected conditions version of USRDOM.

TABLE 5.6
Diversions in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
ACID Diversion	QD197	D104_PSC	Limited to a maximum of 315 cfs (used the remainder, D104_PSC_REM for estimating upper segment closure term, IN182). Converted to daily and smoothed over 9-day period without conserving the monthly volume and saved as average weekly values
Red Bluff Diversion Dam Diversion (Tehama-Colusa and Corning Canals)	QD175	D112	Converted monthly to daily and smoothed over 21 days while conserving monthly volume and saved as average weekly values
Middle Reach Miscellaneous Diversions	QD155	D11301, D11305, D113B	Converting the sum of the three monthly CALSIM II diversions to daily, smoothed over 21 days while conserving monthly volume and saved as average weekly values

TABLE 5.6
Diversions in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
Hamilton City Diversion (Glenn-Colusa Canal)	QD150	L143, D413A, D143A_WTS, D143A_EWA, D143B, D14401, D145A, D145B, D145A_WTS, D145A_EWA, C17502, C17502A, C17502B	Estimated based on the deliveries and inflows along the Glenn – Colusa canal. Losses and diversions along the GCC are added and the inflows from TCC are subtracted to estimate daily Hamilton City diversion. Converted monthly to daily and smoothed over 21 days while conserving monthly volume and saved as average weekly values for all except for C17502, C17502A and D14401 for which converted monthly to daily values and smoothed over 9 days without conserving monthly volume
Stony Creek WBA6 Diversions	QD1135	D42, L17301, D17301, L173, L142	Converting the sum of the three monthly CALSIM II diversions and two loss terms (L173 and L142 are losses lower down on Stony Creek) to daily, smoothed over 21 days while conserving monthly volume and saved a as average weekly values
Stony Creek - TCC Intertie Flow	QD1134	C173B_STCR	Converting monthly to daily values and smoothed over 9 days without conserving monthly volume
WBA8NN and WBA8NS Diversions	QD135	D122A, D122B, D122A_WTS, D122B_WTS, D122_EWA	Converted the sum of five monthly CALSIM II diversions to daily, smoothed over 21 days while conserving monthly volume and saved as average weekly values (negative diversions are removed)
New Delevan Pipeline Diversion to NODOS	QD128	D124A	Converting monthly to daily values and smoothed over 9 days without conserving monthly volume and saved as average weekly values – ensured the diversion did not exist on the same day as a release from NODOS to the River
WBA8S, WBA9, WBA18, and WBA19 Diversions	QD110	D128, D128_WTS, D128_EWA, D129A	Converted the sum of four monthly CALSIM II diversions to daily, smoothed over 21 days while conserving monthly volume and saved as average weekly values

5.2.3.5 Closure Terms

CAL2DOM computes closure terms for the three river segments in USRDOM. The closure terms for the projected conditions simulation are mainly comprised of ungaged tributary flows, accretions or gains, and depletions within the river segment. The general methodology in estimating these closure terms involved:

1. Removing the volume of ungaged tributary flows estimated in the hydrology development for use in the full verification simulation from the volume of total distributed accretions and depletions within each river segment
2. Separating the remaining volume into gains (positive flows) and depletions (negative flows)
3. Converting the monthly gains to daily and smoothing over a 21-day period while conserving monthly volume

4. Converting the monthly depletions to daily, smoothing over a 21-day period while conserving monthly volume and computing average weekly values
5. Subtracting the smoothed depletions from the smoothed gains and adding the daily ungaged tributary flows estimated in the hydrology development for use in the full verification simulation.

This process preserves the variability and the daily pattern of the ungaged flows used in the full verification simulation, thereby reducing any inconsistency that may result between CALSIM II and USRDOM from the ungaged tributary flows.

To address some outliers within middle and lower segment negative gains, net negative gains over both segments were computed and a portion of the lower segment negative gains were shifted to the middle segment while computing the closure terms for these two segments. Because the lower river segment did not include a closure adjustment in the verification simulation step 1 was not included while computing the closure adjustment for the projected conditions USRDOM simulation. Table 5.7 includes the variables used and the methods used in computing the three closure terms.

TABLE 5.7
Closure Terms in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Methodology used to determine Closure Adjustments
Upper Reach Distributed Accretions and Closure Adjustment	IN182	IN182_UG_VER (monthly), IN182_UG_VER (daily)	I109, R109, GS60, D104_PSC, D104_PAG, D104_PMI, demand_D109	IN182 is distributed over upstream USRDOM nodes from 195 to 182; I109 is separately patterned based on the IN182_UG_VER pattern (by subtracting monthly and adding daily back in); adjustments smoothed over 21 days; conserving monthly volume (GS60, D104_PAG, D104_PMI, demand_D109 and remainder of D104_PSC: D104_PSC_REM are subtracted)
Middle Reach Distributed Accretions and Closure Adjustment	IN142	IN142_UG_VER (monthly), IN142_UG_VER (daily)	I118, R113, R114A, R114B, R114C, GS61, demand_D118, demand_D123 Shift	IN142 is distributed over USRDOM nodes 180 through 142; I118 is separately patterned based on the IN142_UG_VER pattern (by subtracting monthly and adding daily back in); adjustments smoothed over 21 days; conserving monthly volume (GS61 and demand_D118 are subtracted; demand_D123 shift is also subtracted - this is an adjustment for negative gain outliers in the lower segment)

TABLE 5.7
Closure Terms in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Methodology used to determine Closure Adjustments
Lower Reach Distributed Accretions and Closure Adjustment	IN132		GS63, demand_D123 Adjusted, I123	IN132 is located at 132, however may be distributed over upstream nodes from 140 to 105; I123 is separately smoothed to daily; smooth operations are over 21 days; conserving monthly volume (GS63 and demand_D123 are subtracted and demand_D123 is adjusted for negative gain outliers in the lower segment)

5.2.3.6 Reservoir Inflow, Outflow, and Evaporation Rates

Black Butte Reservoir inflow and outflow are specified in USRDOM. CAL2DOM computes these time series based on CALSIM II outputs. The inflows to Trinity, Shasta and Whiskeytown are synthesized for the 82-year simulation period in the hydrology development process and are forced as time series inputs in USRDOM. Table 5.8 shows the CALSIM II variables used and the translation method to obtain daily USRDOM inputs. Similarly, CAL2DOM converts monthly evaporation rates from CALSIM II for Trinity, Shasta, Whiskeytown, and Black Butte reservoirs to daily values.

TABLE 5.8
Reservoir Outflow in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
Black Butte Reservoir Outflow Release	QA1136	C42, D42	Converting monthly to daily, smoothed over 21 days while conserving monthly volume, and saved the result as average weekly values
Stony Creek Flow (above Black Butte)	IN1136	C41, I42	Converting monthly to daily, smoothed over 21 days while conserving monthly volume, and saved the result as average weekly values
Trinity Reservoir Evaporation	EV340	S1EVAP	Converts monthly evaporation rates to daily values
Whiskeytown Reservoir Evaporation	EV240	S3EVAP	
Shasta Reservoir Evaporation	EV220	S4EVAP	
Black Butte Reservoir Evaporation	EV1136	S42EVAP	

5.2.3.7 Minimum Reservoir Release Requirements

CAL2DOM estimates the minimum reservoir release requirements for Trinity, Shasta, and Whiskeytown reservoirs in USRDOM based on the identified CALSIM II operational controls. Table 5.9 shows the methodology and the variables used to compute the minimum release requirements for the three reservoirs under the final CAL2DOM approach.

As described earlier, the Shasta Reservoir minimum release requirement is set equal to the CALSIM II monthly release if the month is June through October, IBU conditions exist, and Sacramento/San Joaquin Delta controls are in effect. Additional release requirement is estimated by computing the maximum flow shortage at the Sacramento River control points (Keswick, Red Bluff Diversion Dam and Wilkins Slough). The assumed Clear Creek Tunnel flow is added to the flow shortage and the initial Shasta Reservoir outflow release is estimated (used to calculate shortages). Finally, the total flow is limited to 15,000 cfs, which is the capacity of the Keswick Powerplant, and the assumed Clear Creek Tunnel flow is removed.

The Trinity Reservoir minimum release is determined based on the minimum in-stream flow required in Trinity River below Lewiston and the required Clear Creek Tunnel flows. Clear Creek Tunnel flow (3,200 cfs, in general) is restricted based on whether Sacramento

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Clear Creek Tunnel Flow (Initial)	D100_INIT		D100, D100_IMPORT	Use CALSIM II D100 value if TRIN_TRUE = 1; smoothed to daily over 9 days, and saved the result as average weekly values
Trinity Reservoir Outflow Release	MR340	D100_INIT, IN330, QD244		IN330 subtracted from D100_INIT; the result is converted to daily, converted to average weekly value, and added the daily QD244 values
Whiskeytown Reservoir	QD214		C3_MIF	Converted to daily, ramped 2 days going up, and saved the result as average weekly values
Shasta Reservoir Outflow Release (Initial)	MR220_INIT		C4	Initial Shasta Reservoir outflow release was set to C4 value, if SHASTA_TRUE = 1; performed 21-day smoothing while conserving monthly volume, and saved the result as average weekly values
Keswick Reservoir Minimum Release	MR210		C5_MIF	Check to make sure at least the bypass flow is 3,250 cfs, then ramped 2 days going up and saved the result as average weekly values

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Estimated Flows at Keswick Reservoir Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT210_INIT	MR220_INIT, IN240, QD214	D100_INIT	Estimate of flow used to check compliance with Keswick Minimum Requirement (MR210) (QD214 is subtracted)
Estimated Additional Flow Needed to Satisfy Keswick Reservoir Compliance Point	MR210_SHORT	MR210, OUT210_INIT		Estimate of additional flow needed to comply with Keswick Minimum Requirement (MR210) (OUT210_INIT is subtracted; negatives are ignored)
Estimated Flows at Bend Bridge Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT182_INIT	OUT210_INIT, QD197, QD214, IN1901, IN1861, IN1851, IN182		Estimate of flow used to check potential flow needs at Bend Bridge (QD197 is subtracted)
Estimated Flows at Red Bluff Diversion Dam Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT175_INIT	OUT182_INIT, IN1801, IN1751, 0.1044 * IN142, QD175		Estimate of flow used to check compliance with Red Bluff Diversion Dam Bypass Flow (MR175) (includes 10.4% of IN142) (QD175 is subtracted)
Estimated Additional Flow Needed to Satisfy Red Bluff Diversion Dam Compliance Point	MR175_SHORT	MR175, OUT175_INIT,		Estimate of additional flow needed to comply with Red Bluff Diversion Dam Minimum Requirement (MR175) (OUT175_INIT is subtracted; negatives are ignored); 2-day FMA is used to mimic a 12-hour travel time
Estimated Flows at Hamilton City Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT150_INIT	OUT175_INIT, IN1652, IN1621, IN1701, IN1651, IN1601, QD155, 0.6419 * IN142, QD150		Estimate of flow used to check compliance with GCC Diversion Bypass Flow (MR150) (includes 64.2% of IN142) (QD155 and QD150 are subtracted)

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Estimated Additional Flow Needed to Satisfy Hamilton City Compliance Point	MR150_SHORT	MR150, OUT150_INIT		Estimate of additional flow needed to comply with Hamilton City Minimum Requirement (MR150) (OUT150_INIT is subtracted; negatives are ignored); 3-day FMA is used to mimic a 24-hour travel time
New Delevan Pipeline Release from NODOS (without Colusa Basin)	IN129		C17603	Converted to daily and smoothed over a 9-day period without conserving monthly volume and saved as average weekly values – ensured the release did not exist on the same day as a diversion from the River to the NODOS
Estimated Flows at Wilkins Slough Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT110_INIT	OUT150_INIT, IN1451, QA1136, QD1135, QD1134, 0.2537 * IN142, QD135, IN132, IN129, QD128, QD110		Estimate of flow used to check compliance with Wilkins Slough NCP Flow Objective (MR110) (includes 25.4% of IN142 and IN132 as well as NODOS New Delevan Pipeline IN129 and QD128) (includes Stony Creek components) (QD1135, QD1134, QD135, QD128 and QD110 are subtracted)
Estimated Additional Flow Needed to Satisfy Wilkins Slough Compliance Point	MR110_SHORT	MR110, OUT110_INIT		Estimate of additional flow needed to comply with Wilkins Slough Minimum Requirement (MR110) (OUT110_INIT is subtracted; negatives are ignored); 6-day FMA is used to mimic a 60-hour travel time
Colusa Basin Drain Flow and Colusa Basin Closure Adjustment	IN105		C184A, R134, demand_D134	Converted to daily and smoothed over a 21-day period conserving monthly volume and saved as average weekly values
Estimated Flows at Knights Landing Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT105_INIT	OUT110_INIT, IN105		Estimate of flow used to set Knights Landing boundary condition flow

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Estimated Additional Flow Needed to Satisfy Knights Landing Compliance Point	MR105_SHORT	MR105, OUT105_INIT		Estimate of additional flow needed to comply with Delta/IBU Requirements at Knights Landing (MR105) (OUT105_INIT is subtracted; negatives are ignored); 6-day FMA is used to mimic a 60-hour travel time
Shasta Reservoir Outflow Release (Option B Final)	MR220	MR210_SHORT, MR175_SHORT, MR150_SHORT, MR110_SHORT, D100_INIT, MR220_INIT		Final Shasta Reservoir outflow release determined by taking the maximum of each flow shortage to determine additional flow needed, added the assumed Clear Creek Tunnel flow and the initial Shasta Reservoir outflow release (used to calculate shortages), limited the total to 15,000 cfs (the capacity of the Keswick Powerplant), and removed the assumed Clear Creek Tunnel flow

River is in flood conditions (Tisdale weir spill greater than 500 cfs) and/or if high flow conditions exist in Whiskeytown Reservoir (inflow greater than 5,200 cfs).

The Whiskeytown Reservoir minimum release is determined based on the minimum in-stream flow required in Clear Creek below Whiskeytown. In the event of spilling at Whiskeytown Reservoir, any flows in excess of 4,200 cfs are routed into Clear Creek below Whiskeytown in addition to minimum in-stream flow requirement. Spring Creek Tunnel can divert up to 4,200 cfs.

5.2.4 Quality Assurance

A utility called ‘OPCHK’ (Operations Check) was developed as the quality assurance tool for USRDOM. OPCHK was configured using DZYMAN to generate data to perform quality assurance/quality control (QA/QC). It generates basic statistics for input, output, and model comparisons.

OPCHK checks for insufficient flows in diversions and at minimum requirement locations by comparing USRDOM outputs to the inputs. It checks for consistency between USRDOM outputs and CALSIM II outputs at key locations. OPCHK generates monthly equivalent flows of the USRDOM daily flows for post-analysis. Appendix B includes the list of variables that OPCHK computes and the DZYMAN instruction file for OPCHK.

5.3 Linkages with Other Models

Linkages between USRDOM and other habitat and water quality models have been identified and documented. Utilities were developed using DZYMAN to generate linkage datasets automatically for each implemented model linkage using the results from USRDOM. These models include USRWQM, Salmon Mortality Model (SALMOD), the Winter Run Chinook Life Cycle Model (WRCLCM), Sedimentation and River Hydraulics and Vegetation 1-Dimensional (SRH-1DV) model, Riparian Habitat Establishment Models (RHEM), Sacramento Ecological Flow Tool (Sac-EFT), and Colusa Basin Water Quality Model (CBWQM). Figure 5.2 shows the process diagram with the models involved in the simulating physical processes in Sacramento River. It shows the two different methods to determine daily operations, either by using CALSIM25Q and USRWQM or CAL2DOM and USRDOM. CALSIM25Q downscales monthly CALSIM II data and passes it to USRWQM. USRWQM in turn mimics CALSIM II operations on a daily scale and generates daily flows and temperatures for other models (red lines). CAL2DOM translates CALSIM II operations to guide USRDOM in simulating daily flows in the Sacramento River. These daily flows can be used by other models, including USRWQM, as shown in the figure by blue lines.

Figure 5.3 shows a detailed dataflow diagram with USRDOM being the central model, receiving information from various sources and providing daily flows to various models. CALSIM25Q is not shown in this figure because it is no longer needed. The flows for USRWQM are provided by USRDOM through a new utility called 'USRWQMLink,' which translates the USRDOM flow output to USRWQM. The items in green boxes are the utilities developed to enable the linkages between USRDOM and other models.

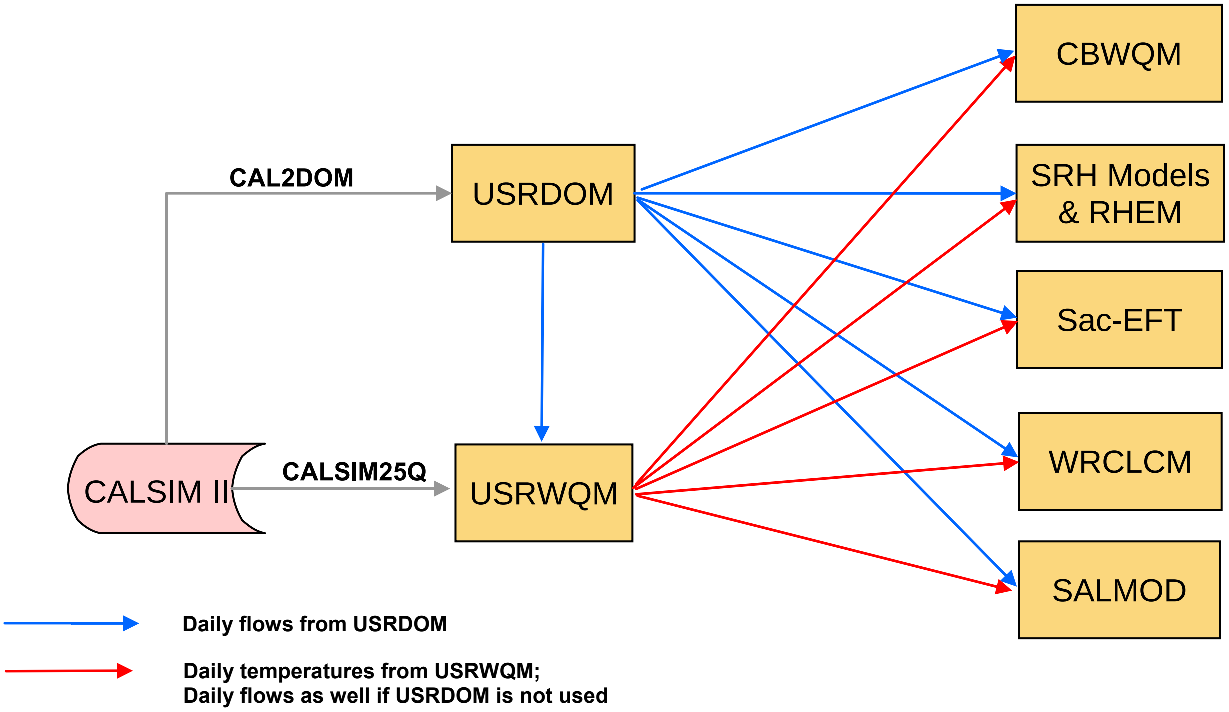


FIGURE 5.2

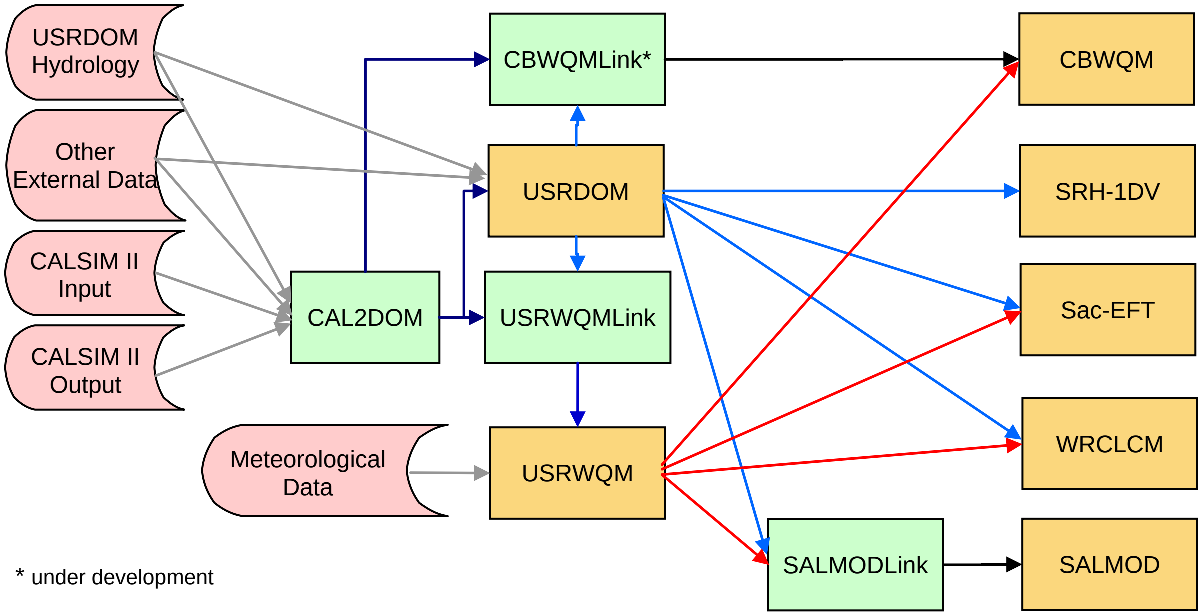


FIGURE 5.3
USRDOM Linkages and Utilities

5.3.1 USRWQM

USRWQM is Reclamation's temperature model for the Upper Sacramento River. A linkage has been developed between USRDOM and USRWQM so that the flow operations in USRWQM mimic USRDOM. A linkage document describing the translations between the two models has been developed. A new utility called 'USRWQMLink' has been developed using DZYMAN and incorporating the translations defined in the linkage document. Appendix C includes the linkage document and the DZYMAN instruction file for USRWQMLink.

5.3.2 SALMOD

SALMOD is a salmonid population model that simulates partial life cycle of four runs of Chinook salmon in the Upper Sacramento River. It depends on daily flow and temperature data. A linkage document was developed to identify the USRDOM flow outputs needed for SALMOD. The document also includes the temperature outputs from USRWQM needed for SALMOD. A new utility called 'SALMODLink' was developed to provide flow and temperature data needed for SALMOD. SALMODLink uses DZYMAN, which incorporates USRDOM and USRWQM translations identified in the linkage document. Appendix C contains the linkage document and the DZYMAN instructions file for SALMODLink.

5.3.3 SRH Models and RHEM

SRH models include SRH-SIAM, SRH-Meander, SRH-2D, and SRH-1DV. RHEM provides inputs to the SRH-1DV model. A linkage document describing various flow outputs from USRDOM was developed for standardizing the data transfer from USRDOM to SRH models. The linkage document is included in Appendix C. Because no data manipulation was involved, no utility was created.

5.3.4 WRCLCM

WRCLCM is the Interactive Object-oriented Salmonid Simulation (IOS) winter-run Chinook life cycle model. It requires flow and temperature data. The daily flow outputs needed from USRDOM and the daily temperature outputs from USRWQM for the WRCLCM were identified and documented. The linkage document detailing the flow and temperature data used by WRCLCM is included in Appendix C. Because no data manipulation was involved, no utility was created.

5.3.5 CBWQM

CBWQM simulates daily flows and temperatures in the Colusa Basin region, including the proposed NODOS conveyance and storage features. It requires inputs from USRDOM and USRWQM for flows and temperatures, respectively. A document identifying the linkage between USRDOM and CBWQM is being developed.

5.3.6 Sac-EFT

Sac-EFT evaluates the ecological value of a proposed operations alternative from a multiple species point of view. It requires flow and temperature data from USRDOM and USRWQM. A linkage document detailing the dataflow between USRDOM and Sac-EFT is being developed.

5.4 Example Full-period Simulation

An example full-period USRDOM simulation was developed using the results from the CACMP V9B1 Future 1 CALSIM II simulation. The full functionality of the USRDOM toolset in the Common Assumptions framework was tested, including the OPCHK, USRWQMLink, and SALMODLink utilities. Figures 5.4 and 5.5 show the sample results from the simulation. Figure 5.4 compares the simulated end-of-the-day Shasta storage from USRDOM with the monthly CALSIM II end-of-month storage over a 10-year period. USRDOM result matches fairly closely to CALSIM II end-of-month storage. USRDOM shows encroachments into the flood space, which are absent in the monthly CALSIM II result. Figure 5.5 shows a comparison of Bend Bridge flow time series from daily USRDOM simulation and the monthly CALSIM II simulation. USRDOM matches the general trend observed in the monthly CALISM II flows, however exhibits daily variability. The daily variability in USRDOM result at times is more than double the monthly averages.

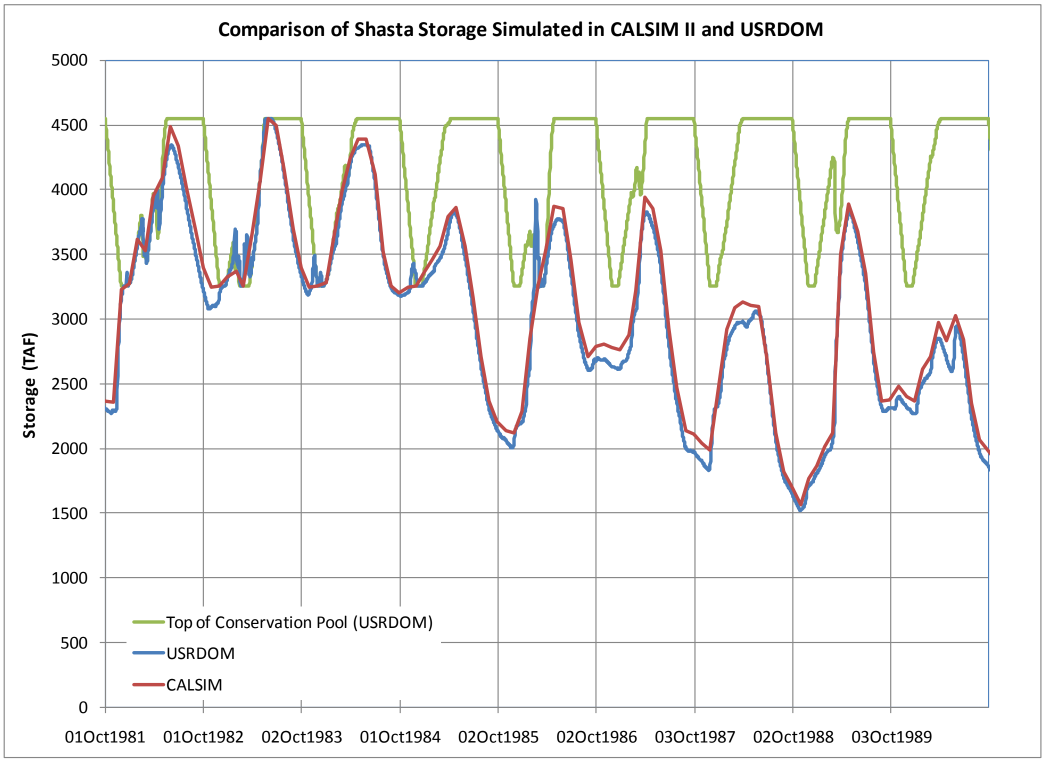


FIGURE 5.4

Comparison of Shasta Storage in CALSIM II and USRDOM Simulations

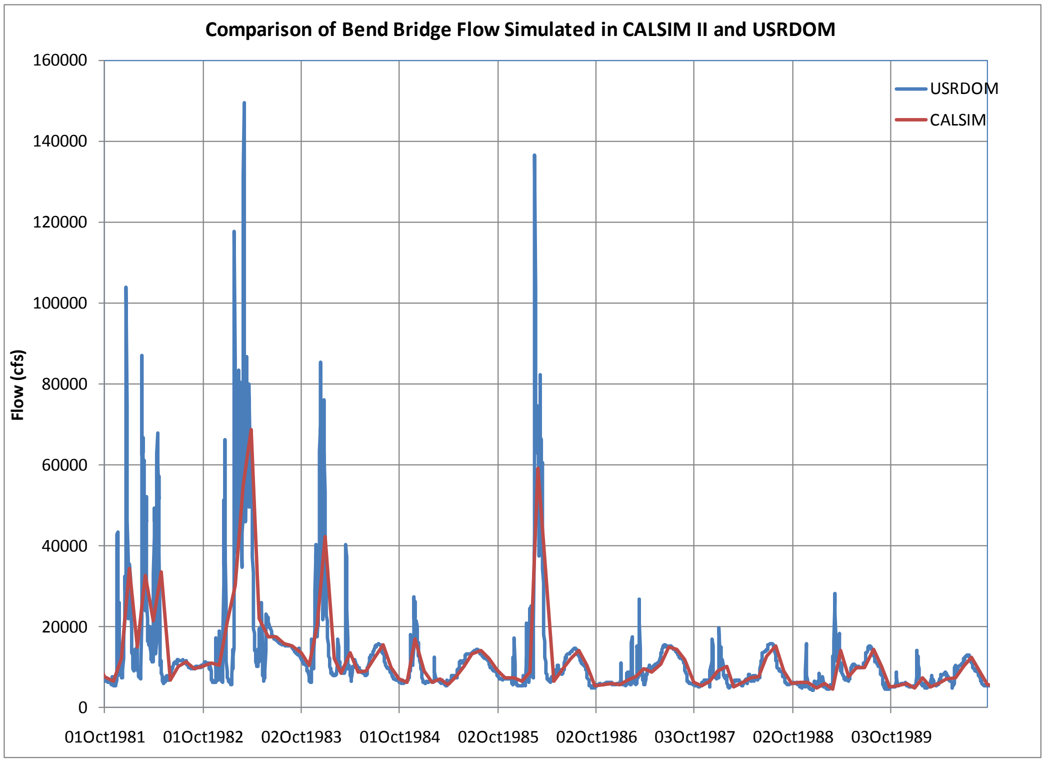


FIGURE 5.5
Comparison of Bend Bridge Flow in CALSIM II and USRDOM Simulations

5.5 Contrasting USRDOM and CALSIM25Q

USRDOM was developed to provide an alternative to the CALSIM25Q/USRWQM toolset (RMA, 2003) to simulate daily operations in the upper Sacramento River. Significant improvements have been achieved in the quality of the simulated daily flows using USRDOM. Table 5.10 provides a list of the key differences in the two approaches.

TABLE 5.10
Comparison of USRDOM and CALSIM25Q/USRWQM

USRDOM	CALSIM25Q/USRWQM (RMA, 2003)
Daily inflows based on historical flows	**Monthly inflows from CALSIM II patterned on daily historical flows**
Preserved the daily variability in the river flows because the ungaged flows from calibration/verification are used	Flows were smoothed; therefore, significant daily variability is lost in the river flows
Capable of simulating Shasta and Trinity reservoirs based on operating rules outside downstream control periods	Shasta and Trinity reservoir operations are fixed to match CALSIM II results smoothed to a daily timestep
Monthly CALSIM II diversions are smoothed to a weekly timestep	Monthly CALSIM II diversions are kept constant all month
Major CALSIM II diversion volumes within months are maintained	N/A
Option available to modify reservoir releases to ensure diversion volume available in the river; otherwise, diversion may be shorted on daily basis	Major CALSIM II diversion volumes are fixed and accounted for in the Shasta releases

5.6 Summary

USRDOM was developed to simulate daily reservoir operations and river flow conditions. It was successfully calibrated and verified for all ranges of flows in the Sacramento River. Trinity and Shasta reservoir operations in USRDOM have been adequately verified using the observed data.

USRDOM was modified to incorporate 82-year (full-period) simulation capabilities using CALSIM II data. Full-period hydrology was developed for projected level simulations. CAL2DOM, a CALSIM II to USRDOM translation utility, was developed and tested. An example full-period USRDOM simulation based on the CACMP v9B1 Future 1 scenario was developed, and extensive quality assurance and testing were performed.

USRDOM provides a good representation of daily operations on the Sacramento River that is an improvement over previously available models.

SECTION 6

USRDOM NODOS Sub-model

6.1 Overview

One of the key objectives of USRDOM is to support the feasibility study analyses for the proposed NODOS surface storage project. Therefore, USRDOM was enhanced to include the storage and conveyance features of NODOS in the Colusa Basin region. A sub-model specific to NODOS and Colusa Basin (USRDOM_CB) was created to simulate the projected diversions from the Sacramento River to NODOS and releases from NODOS back to the river on a daily timestep. A new pipeline connecting NODOS with the Sacramento River at river mile 159 (Delevan pipeline) provides an additional facility for this operation of NODOS. The existing TCC and GCC diversions would be re-operated to allow use of these facilities for operation of NODOS.

6.2 Model Schematic

The spatial domain of USRDOM was extended to include NODOS features such as TCC and GCC reaches; interconnections between Stony Creek and TCC; existing and proposed interconnections between the TCC and GCC, Sites Reservoir, and Funks Forebay; and new Delevan pipeline components. Figure 4.16 shows the extended USRDOM schematic with NODOS features. The channel reaches, connections, and capacity information were derived based on the NODOS implementation in the CALSIM II model used for the NODOS Administrative Draft Environmental Impact Report and Statement (ADEIRS)Analysis.

Implementing complex interconnections between Funks Forebay, TCC, and GCC was challenging because of the inherent limitations of HEC-5. Several NODOS conveyance features are proposed to be bi-directional, such as the proposed Delevan pipeline and the Funks Forebay-GCC intertie. Similarly, the exchange of flow between Funks Forebay and Sites Reservoir is bi-directional. Because, at any given node, HEC-5 allows only one channel connection with a downstream node and only one diversion, Funks Forebay was required to be simulated as seven control points to allow for all the interconnections. Several dummy reservoirs were needed to properly simulate the interconnections between Sacramento River, Funks Forebay, TCC, and GCC. Moreover, because HEC-5 does not allow the flow to be bi-directional in a channel and does not allow more than one channel between two nodes, Sites Reservoir was modeled as two reservoirs. The first reservoir receives water from the Funks Forebay and the second reservoir releases water to Funks Forebay. Table 6.1 shows the list of the new control points in the NODOS Sub-Model, along with the descriptions of the locations, HEC-5 IDs, and the assumed channel capacities. Channel routing was not implemented in USRDOM_CB.

TABLE 6.1
USRDOM NODOS Sub-model Schematic Information

Control Point #	Description of Control Point Location	Control Point ID in HEC-5	Channel Capacity (cfs)

1752	Dummy reservoir to route Tehama-Colusa Canal diversion from Sacramento River	1752-TCCDR	2,530
1750	Tehama-Colusa Canal downstream of Corning Canal	1750-TCC	2,400
1749	Tehama-Colusa Canal	1749-TCC	2,200
1748	Tehama-Colusa Canal	1748-TCC	2,100
1747	Tehama-Colusa Canal	1747-TCC	2,100
1746	Funks Forebay control points	1746-FUNKS	99,999
1745	Funks Forebay control points	1745-FUNKS	99,999
1744	Funks Forebay control points	1744-FUNKS	99,999
1743	Funks Forebay control points	1743-FUNKS	99,999
1742	Funks Forebay control points	1742-FUNKS	99,999
1741	Funks Forebay control points	1741-FUNKS	99,999
1740	Funks Forebay control points	1740-FUNKS	99,999
2740	Sites Reservoir	2740-SITES	999,999
2746	Dummy Sites Reservoir	2746-SITES	999,999
1501	Dummy reservoir to route Glenn-Colusa Canal diversion from Sacramento River	1501-GCCDR	3,000
1500	Glenn-Colusa Canal	1500-GCC	1,800
1499	Glenn-Colusa Canal	1499-GCC	1,200
1498	Glenn-Colusa Canal	1498-GCC	1,200
1497	Glenn-Colusa Canal	1497-GCC	1,200
1496	Glenn-Colusa Canal	1496-GCC	1,200
2498	Dummy reservoir to route diversion from Glenn-Colusa Canal to Funks Forebay	2498-GCCDR	999,999
1291	Dummy reservoir to route Delevan pipeline inflow from Sacramento River to Funks Forebay	1291-NODOSDR	99,999
1281	Dummy reservoir to route Delevan pipeline delivery from Funks Forebay to Sacramento River	1281-NODOSDR	99,999
1133	Dummy reservoir to route Stony Creek - TCC intertie flows	1133-STNYTC-INT	99,999

6.3 Model Input Dataset

All the model inputs related to USRDOM_CB are derived from the monthly CALSIM II operations, including inflows, evaporation, reservoir outflows, and diversions. The inflows coming into USRDOM_CB include the TCC, GCC, and Delevan pipeline diversions from the Sacramento River and Stony Creek–TCC intertie flows. Table 6.2 lists the inflows, including the control point where the flow comes in, the source of the flow, and the HEC-5 name for the inflow. Table 6.3 shows the diversions modeled in USRDOM_CB, including the corresponding CALSIM II variables, the control point where the flow is diverted, and the HEC-5 name for the diversion.

TABLE 6.2
Inflows in NODOS Sub-model

Inflow	Control Point Number at the Inflow Location	Source of Flow	HEC-5 Name for Inflow Time Series
TCC Diversion	1752	Sacramento River	QD175
GCC Diversion	1501	Sacramento River	QD150
Delevan Pipeline Diversion	1291	Sacramento River	QD128
Stony Creek–TCC Intertie	1133	Stony Creek	QD1134

TABLE 6.3
Diversions in NODOS Sub-model

Diversions	Corresponding Values in CALSIM II	Control Point Number at the Diversion Location	HEC-5 Name for Diversion Time Series
Corning Canal and WBA4 Diversions	D171	1752	QD1752
WBA4 Diversions	L172, D172	1750	QD1750
WBA7N Diversions	D174	1748	QD1748
Existing TCC-GCC Intertie Flow to GCC	C17502A	1746	QD1746
Delevan Pipeline Release to Sacramento River	C17603	1744	QD1744
Proposed Funks-GCC Intertie to GCC	C17502	1742	QD1742
Williams Outlet from Funks to GCC	C17502B	1741	QD1741
WBA7S Diversions	D178	1740	QD1740
EWA Release	D33	2746	QD2746
WBA8NN and Refuge Diversions	L143, D143A, D143A_WTS, D143A_EWA, D143B	1500	QD1500
Proposed Funks-GCC Intertie to Funks	D14401	1498	QD1498
WBA8NS Diversions	D145A, D145A_WTS, D145A_EWA, D145B	1496	QD1496
Sites Reservoir Evaporation Rate	S30EVAP	2740	EV2740

6.4 Modeling of Reservoir Operations

Sites Reservoir and Funks Forebay are two storage features proposed as part of NODOS. As explained earlier, because of limitations in HEC-5, Sites Reservoir is modeled as two reservoirs, one to receive water from Funks Forebay and the other to release water to Funks Forebay. Although Funks Forebay has some available storage, it is proposed as a regulating reservoir. Therefore, Funks Forebay was not modeled as a reservoir in HEC-5. Instead, it was modeled as an extension of TCC and represented by seven control points to allow for all the interactions that occur with Sites Reservoir, GCC, and the Sacramento River.

To represent flow availability in Funks Forebay for diversions to GCC and Sacramento River, inflows into Funks Forebay are accounted for at the three upstream control points representing Funks Forebay. Diversions are taken from the five downstream control points. Inflow from Sites Reservoir to Funks Forebay is located at the most upstream control point 1746. The existing TCC-GCC intertie is represented as a diversion from control point 1746 to control point 1500. The Delevan pipeline diversion from the Sacramento River comes into control point 1745 just downstream of the Sites inflow. The flow from GCC to Funks Forebay through the proposed intertie comes in next at control point 1744. The diversion from Funks Forebay to GCC through the proposed intertie occurs at control point 1742. The diversion from Funks Forebay to GCC through the Williams Outlet occurs at control point 1741. Finally, the flow pumped into Sites Reservoir is diverted from the most downstream control point, 1740, from which the WBA7 diversions are also taken.

Storage changes because of evaporation and outflow from the Sites Reservoir are simulated at the first reservoir (control point 2740), where the inflow from Funks Forebay (control point 1740) enters. Information related to reservoir levels, storage, outlet capacities, area, and elevation relationships for the Sites Reservoir were obtained from CALSIM II model for each NODOS Alternative. The outflow for the Sites Reservoir is fixed, (HEC-5 is forced to release a specified outflow from the reservoir at each timestep). Based on the operations assumed in CALSIM II, a constant outflow of 6,800 cfs was assumed for the entire simulation time period. This outflow is routed to the second Sites Reservoir represented by a dummy reservoir in HEC-5 without any associated storage. After water for the Environmental Water Account is diverted from this dummy reservoir, the remaining flow is routed back to the most upstream Funks Forebay control point (1746).

6.5 USRDOM and NODOS Sub-model (USRDOM_CB)

Because USRDOM with the NODOS Sub-model exceeded the maximum number of control points allowed by HEC-5 (80), it was not possible to simulate the NODOS Sub-model in the standard two steps process used in the USRDOM Full Verification Simulation and the Projected Condition Simulation. Therefore, a three-step process was used to simulate the NODOS Sub-model (Figure 6.1). The first two steps simulate the standard USRDOM schematic without the Colusa Basin region. However, all diversions and inflows common to both models (TCC, GCC, Delevan diversions, Delevan inflow, and Stony-TCC intertie flow) are accounted for in the standard USRDOM simulation. The simulated Sacramento River flow downstream of the Paynes Creek confluence from the second step is assumed as the upstream boundary for USRDOM_CB. Therefore, the domain of the USRDOM_CB includes the Sacramento River downstream of the Paynes Creek confluence and the Colusa Basin region with the NODOS features. This approach is reliable as long as the inflows and diversions common to USRDOM and USRDOM_CB are simulated in both models.

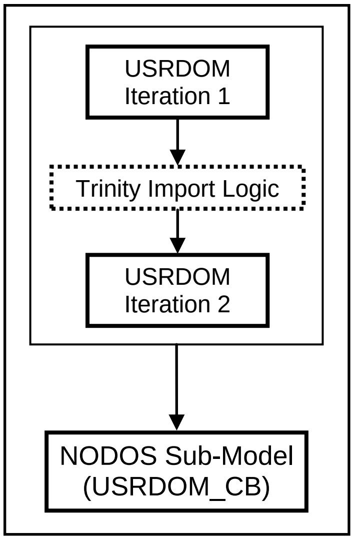


FIGURE 6.1
Strategy for Simulating USRDOM_CB

6.6 Modifications to CAL2DOM

The operations in USRDOM_CB depend on monthly CALSIM II operations. Therefore, the monthly CALSIM II operations are translated to a daily timestep for use in USRDOM_CB. CAL2DOM was modified to include translation of Colusa Basin and NODOS-related operations from CALSIM II to a daily timestep. Because the operations are fixed in the NODOS Sub-model, the translation of the monthly CALSIM II data is straightforward. The most common approach involved converting the monthly data to daily, smoothing over a 21-day period while conserving monthly volume, and saving the daily time series using average weekly values. For four diversions (the existing TCC-GCC intertie flow, the releases to the Sacramento River through the new Delevan pipeline, and the release and filling of NODOS through the proposed Funks-GCC intertie), 9-day smoothing is performed without conserving the monthly volume because of issues with channel capacity constraints.

Table 6.4 lists the NODOS-related operations that are translated by CAL2DOM, along with the CALSIM II variables used and the methodology used for the translation. The GCC diversion from the Sacramento River is estimated on a daily basis to get an accurate estimate instead of simply translating the monthly GCC diversion from CALSIM II. This estimate is required because of the frequency of channel capacity constraints occurring in the GCC. The DZYMAN configuration and instruction files for the Colusa Basin version of CAL2DOM are included in Appendix B. In addition to the above changes some other changes have been made to CAL2DOM to ascertain consistency between the CALSIM II and USRDOM results. Specifically, the CAL2DOM shortage computations used in determining the Shasta release requirement in the USRDOM_CB model are modified. CAL2DOM computations to estimate minimum reservoir release requirements are described in section 5.2.3.7 and Table 5.9. Estimates of the additional flow needed to satisfy the flow required at Red Bluff Diver Dam, Hamilton City and Wilkins Slough compliance points (MR175_SHORT, MR150_SHORT and MR110_SHORT) are limited to the corresponding minimum instream flows specified in CALSIM II to address the daily variability due to the unregulated flows (C112_MIFADJ, C114_MIFADJ and C129_MIFADJ).

TABLE 6.4
Computation of USRDOM_CB Specific Operations in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
Corning Canal and WBA4 Diversions	QD1752	D171	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA4 Diversions	QD1750	L172, D172	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA7N Diversions	QD1748	D174	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Existing TCC-GCC Intertie Flow	QD1747	C17502A	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
New Delevan Pipeline Release from NODOS	QD1744	C17603	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
Proposed TCC-GCC Intertie Flow - Release from NODOS	QD1742	C17502	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
Williams Outlet Flow	QD1741	C17502B	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA7S Diversions	QD1740	D178	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA8NN and Refuge Diversions	QD1500	L143, D143A, D143A_WTS, D143A_EWA, D143B	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Proposed TCC-GCC Intertie Flow - For Filling NODOS	QD1498	D14401	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
WBA8NS and Refuge Diversions	QD1496	D145A, D145A_WTS, D145A_EWA, D145B	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Sites Reservoir Evaporation	EV2740	S30EVAP	Converted monthly evaporation rates to daily values
Sites Reservoir EWA Outflow Release	QD2746	D33	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Hamilton City Diversion (Glenn-Colusa Canal)	QD150	QD1500, QD1747, QD1498, QD1742, QD1496, QD1741	Flow needed from Sacramento River for the GCC (QD1747, QD1742 and QD1741 are subtracted)

6.7 Quality Assurance and Linkages with Other Models

The utilities developed to perform QA/QC and create linkage datasets for other models using the output from USRDOM were modified to retrieve the necessary data directly from USRDOM_CB. Specifically, alternate versions of OPCHK and USRWQMLink were created to use USRDOM_CB results directly. This allows scenario testing with NODOS while maintaining linkages with other models. New instructions were added to OPCHK to create a Colusa Basin version for checking USRDOM outputs against inputs and for checking USRDOM/USRDOM_CB outputs at key locations against CALSIM II outputs. The DZYMAN configuration and instruction files for the Colusa Basin version of OPCHK and USRWQMLink are included in Appendix B.

6.8 Example Full-period Simulation

An example full-period USRDOM_CB simulation was developed using the results from the CACMP V9B1 NODOS 1 CALSIM II simulation. The full functionality of the USRDOM toolset including USRDOM_CB was tested within the Common Assumptions framework, including the OPCHK, USRWQMLink, and SALMODLink utilities.

Figures 6.2 and 6.3 show the sample results from the example full-period simulation. Figure 6.2 compares the simulated Knights Landing flow from USRDOM and USRDOM_CB models to show that there is no difference in the Sacramento River operations from the inclusion of the Colusa Basin region in the USRDOM_CB model. In other words, the three-step model does not result in any differences in the Sacramento River operations from the two-step model. This is expected since the Delevan Pipeline diversion and inflow values are simulated in the two-step model as well. Figure 6.3 compares the simulated CALSIM II end-of-month storage in Sites Reservoir with end-of-the-day storage from USRDOM_CB over a 10-year period. Figure 6.3 indicates that Sites Reservoir storage is nearly identical in both the models. The slight differences in Sites Reservoir storage between the two models result from channel capacity constraints in USRDOM_CB.

6.9 NODOS Sub-model Implementation Summary

The spatial domain of USRDOM was extended to include NODOS and Colusa Basin storage and conveyance features. The operations of NODOS in USRDOM_CB are fixed to CALSIM II and the CAL2DOM utility was modified to translate CALSIM II NODOS operations to provide inputs to the USRDOM_CB model. A three-step approach was developed to run a full-period daily USRDOM and USRDOM_CB simulations using inputs from NODOS CALSIM II scenarios. The utilities to generate QA/QC metrics (OPCHK) and USRWQM linkage dataset (USRWQMLink) were updated to incorporate Colusa Basin results. An example full-period USRDOM_CB simulation based on CACMP v9B1 NODOS1 scenario was developed and extensive quality assurance and testing was performed. Using the results from USRDOM_CB, example model linkage datasets were also developed. Finally, USRDOM has been developed so that the model can be modified to analyze diversion conditions for NODOS dynamically or through iteration with an external processor (DZYMAN based). The tool is ready to be used to study potential benefits and impacts of the proposed NODOS alternatives.

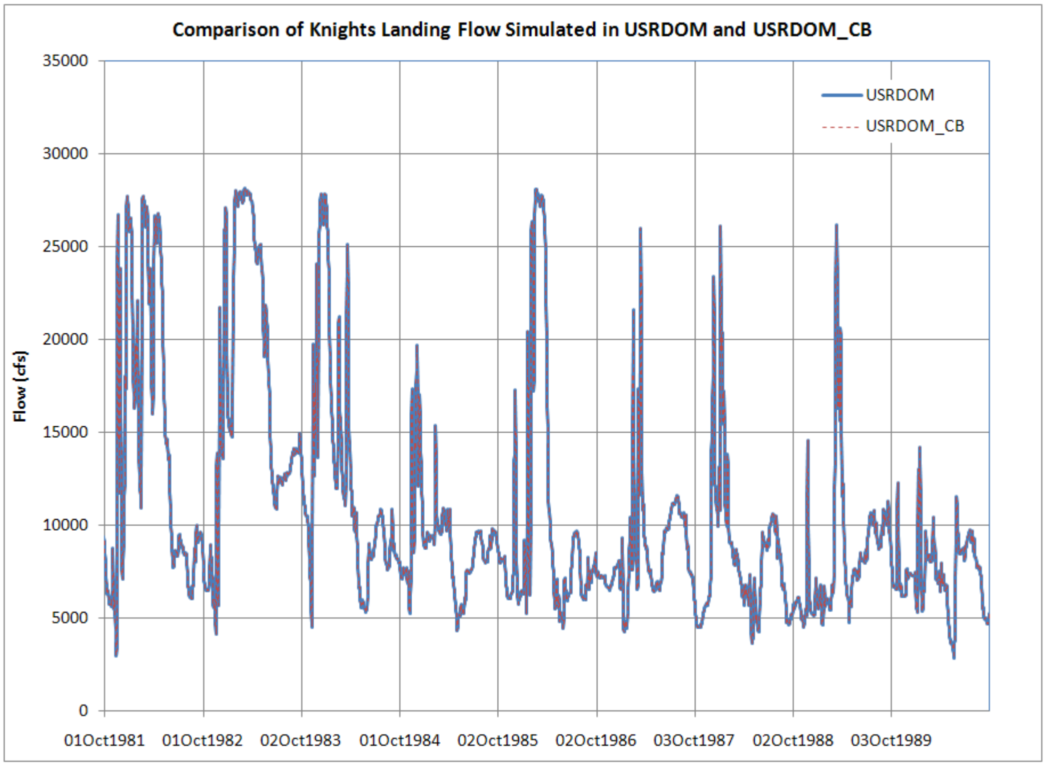


FIGURE 6.2
USRDOM and USRDOM_CB Simulated Knights Landing Flow

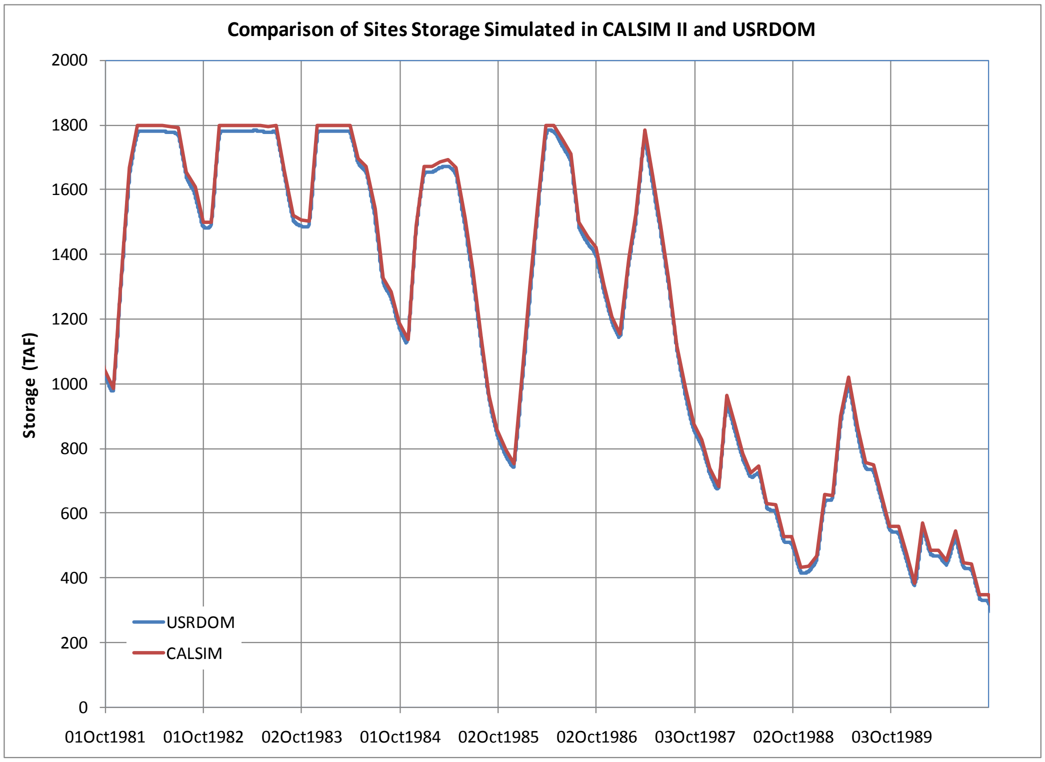


FIGURE 6.3
USRDOM_CB and CALSIM II Simulated Sites Reservoir Storage

6.10 Application of USRDOM to NODOS ADEIRS Alternatives

USRDOM is used in several ways as part of modeling of the operations of NODOS ADEIRS Alternatives. First,it was used to test and finalize the CALSIM II operations for the NODOS Alternatives. Then the daily storage and flow results from USRDOM were used for various temperature, biological and flow regime models used in the evaluation of NODOS Alternatives. This section describes how USRDOM has been applied in the evaluation of the NODOS Alternatives.

6.10.1 Description of the Alternatives

The assumptions for the Existing Conditions and No Action Alternative are summarized in an October 1, 2010 memorandum, "Assumptions for Existing and Future No Action Alternative Conditions CALSIM II and DSM2 Models" (see file: *Confirmation_of_Baselines_Assumptions_070510_compiled_100110.pdf*). The assumptions for the NODOS Alternatives are summarized in a January 5, 2011 document, "Definition of Proposed Alternatives for Evaluation in the North-of-the-Delta Offstream Storage Administrative Draft Environmental Impact Report and Statement" (see file: *Definition of Proposed Alternatives for Evaluation in NODOS ADEIR 2011-01-05 SS_JW.pdf*).

Three Alternatives have been identified by the lead agencies for the NODOS ADEIRS. Alternatives A, B, and C differ in the storage or conveyance capacities. The three proposed alternatives are as follows:

- Alternative A (ALT A) has a 1.2 MAF storage capacity with existing Tehama-Colusa Canal (2,100 cfs) and Glenn-Colusa Irrigation District Canal (1,800 cfs) and a new Delevan pipeline with a diversion capacity of 2,000 cfs and release capacity of 1,500 cfs.
- Alternative B (ALT B) has a 1.8 MAF storage capacity with existing Tehama-Colusa Canal (2,100 cfs) and Glenn-Colusa Irrigation District Canal (1,800 cfs) and a new release only Delevan pipeline (release capacity of 1,500 cfs). There are no fish screen intake and pumping plant associated with the new Delevan pipeline.
- Alternative C (ALT C) is similar to Alternative B, except the new Delevan pipeline has a fish screen intake and pumping plant with a diversion capacity of 2,000 cfs and a release capacity of 1,500 cfs..

Several ecosystem enhancement actions (EEA) are proposed to show the ability of NODOS Alternatives to support the ecological goals of the system. Some of the key EEA actions identified include improving coldwater pool storage in Shasta Lake and increasing the availability of coldwater to provide suitable habitat conditions for different life stages of Chinook Salmon, stabilize flows in the Sacramento River during fall months to minimize dewatering of fall-run Chinook salmon redds and reduce diversions at RBDD and Hamilton City by meeting local demands with water from the Sites Reservoir.

6.10.2 NODOS Intake Operations Assumptions

The operational assumptions for the three NODOS intakes, namely existing TCC Intake, GCC Intake and the proposed Delevan Pipeline Intake are described in this section. In general, Red Bluff, Hamilton City and the proposed Delevan Pipeline diversions to Sites Reservoir storage are permitted in any month of the year. However, each intake has specific conveyance and maintenance restrictions, bypass flow restrictions and diversion restrictions associated with pulse flow protection that were assumed in the modeling.

6.10.2.1 Conveyance Capacities and Maintenance Periods

The lead agencies in coordination with the TCCA and GCID authorities laid out the following assumptions for the three NODOS intakes. This section summarizes the key assumptions used in the model for the conveyance capacities and the maintenance periods for the each intake, except where noted.

- <u>Red Bluff Diversions (for filling of NODOS)</u>
    - Tehama Colusa Canal Capacity:
        - At Red Bluff: 2,250 cfs minus diversions for non-Sites Reservoir operations
        - At Funks Forebay: 2,100 cfs minus flows for non-Sites Reservoir operations
        - Approximately 50 to 60 cfs of capacity is assumed to be used for other winter time operations of the canal. (This capacity is reserved for winter time operations in CALSIM II, however this water is not routed.)
    - No dedicated period for maintenance assuming:
        - Every other year one month is available between December 1st to February 15th, and
        - Every fifth year two or more months are available between December 1st to February 15th
        - These outages are not modeled as dedicated outages in CALSIM II, instead these are the outcomes of the winter operations in the Colusa Basin conveyance system
- <u>Hamilton City Diversions (for filling of NODOS)</u>
    - Glenn Colusa Canal Capacity:
        - At Hamilton City: 3,000 cfs minus diversions for non-Sites Reservoir operations
        - At Terminal Regulating Reservoir (TRR) intertie to Funks Fore-bay: 1,800 cfs minus flows for non-Sites Reservoir operations
        - The capacities listed in Table 6.5 are assumed to be used for other winter time operations of the canal

TABLE 6.5
Assumed Glenn Colusa Canal Conveyance Capacities for other Winter Time Operations of the Canal

Oct	Nov	Dec	Jan	Feb	Mar
513 cfs	534 cfs	389 cfs	235 cfs	56 cfs	48 cfs

-
    - Dedicated maintenance period is required from January 7th through February 21st every year
- <u>New Delevan Pipeline Diversions/Releases</u>

- Dedicated maintenance period is required from April 1st to May 31st under Alternatives A and C (intake, screen and sediment related maintenance)
- No diversions or releases allowed during maintenance period

6.10.2.2 Bypass Flow Requirements

Diversions to storage are restricted until the specified bypass flow requirements achieved at each of the three intakes. These requirements must be met for the diversions to storage to occur.

- Downstream of Red Bluff Diversion Dam, a bypass flow requirement was assumed based on the existing State Water Resources Control Board minimum flow requirement. A 3-day moving average flow was used for assessing this bypass flow requirement. Following flow was used as the required bypass flow downstream of Hamilton City:
  - 3,250 cfs (3 day average)
- Downstream of Hamilton City, a bypass flow requirement was assumed based on the existing operational requirement for the GCC intake. A 3-day moving average flow was used for assessing this bypass flow requirement. Following flow was used as the required bypass flow downstream of Hamilton City:
  - 4,000 cfs (3 day average)
- At Wilkins Slough location, a bypass flow requirement was assumed for the protection of the navigational control point requirement. This is mainly to protect the water levels for the long-time water users diverting along the Sacramento River in this reach. A 3-day moving average flow was used for assessing this bypass flow requirement. Following flow was used as the required bypass flow at Wilkin Slough:
  - 5,000 cfs (3 day average)
- At Freeport/Hood location, bypass flow requirement was assumed for the protection of the Delta from water quality impact. Approximate flows needed to maintain the X2 at or west of Chipps Island were assumed for the bypass flows. It was assumed that a moving average criterion of 15 day or greater would be sufficient since water quality depends on the antecedent conditions and is insensitive to instantaneous flow variations. Monthly average was assumed as approximate to the 15 day or greater moving average. Following flows were used as the required bypass flows at Freeport:
  - 15,000 cfs in January
  - 13,000 cfs in December or February through June
  - Otherwise 11,000 cfs

6.10.2.3 Pulse Flow Protection

NODOS winter diversion operating criteria was identified considering the importance of limiting the potential impact of winter diversions on fisheries resources. This sub-section summarizes the diversion restriction criteria used in the modeling of NODOS Alternatives to protect pulse flow conditions associated with outmigration of juvenile winter-, spring-, fall- and late fall-run Chinook salmon.

Pulse flows are defined by peaks in the impaired hydrograph, rather than scheduled operational events. The peak flows originate primarily from tributaries that come into the river downstream of Keswick Dam. Pulse flows provide key biological cues for the fish species and enhance the turbidity effects. The period for pulse protection was assumed to extend from October through May to address outmigration of juvenile winter-, spring-, fall- and late fall-run Chinook salmon, as well as a portion of the steelhead juvenile outmigration period. Diversions were restricted for up to one qualified pulse event recognized in each month of the October through May period, and is recognized for the month in which it ends.

Bend Bridge flow was used to identify pulse signals as part of the modeling. If the 3-day trailing average of Bend Bridge flows exceeds 15,000 cfs, a pulse event is assumed to be initiated if the previous day was not already in a pulse event. A pulse event is terminated seven days after initiation, constituting a qualified pulse event, or if the three-day trailing average drops below 15,000 cfs during the seven days following initiation, without constituting a qualified pulse event.

Diversions to NODOS storage are restricted if pulse conditions exist at Bend Bridge, if a qualified pulse event has not already occurred within the given month, and if Bend Bridge daily flows are less than 25,000 cfs. Diversions are otherwise unrestricted and are therefore limited only by the available capacity. Figure 6.4 provides an example where the pulse protection periods were identified based on the assumptions described above.

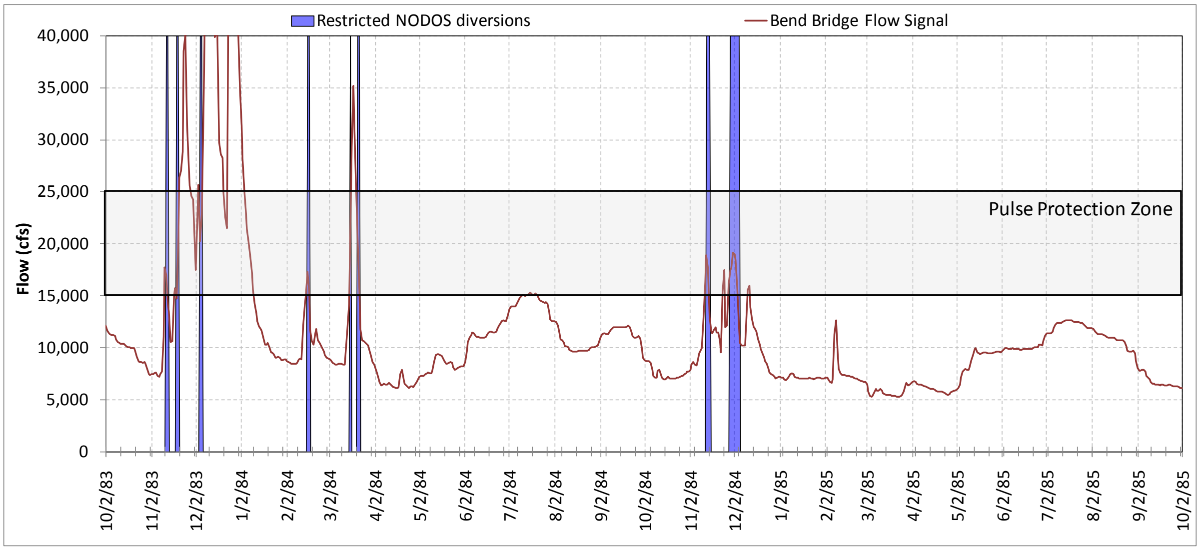


FIGURE 6.4
Example of Pulse Protection Assumed in the NODOS Alternatives Modeling

6.10.3 NODOS Operations Modeling Process

CALSIM II was the core model used to simulate the NODOS operations. However, the assumptions related to the intake operations as described above require daily flow data in determining the diversions allowed at the intakes, in turn affecting the system-wide operations. Since CALSIM II is a monthly timestep model, USRDOM results were used to enforce the intake operations on a sub-monthly scale. Due to the complexity in the intake operational rules, a spreadsheet tool was developed to implement the operational constraints using the daily results from the USRDOM. Further, the models were iterated to ensure all the intake operations assumptions were simulated accurately. Figure 6.5 shows the schematic of the modeling process used to simulate NODOS operations.

In the first iteration, CALSIM II and USRDOM models are simulated for a NODOS Alternative to determine the days requiring the pulse protection. A draft CALSIM II simulation was run with all the physical, regulatory and operational assumptions for the NODOS Alternative. The results from this "draft" CALSIM II simulation were used to run the USRDOM model. The USRDOM setup included NODOS assumptions consistent with the draft CALSIM II. Since this USRDOM run is used to estimate daily flows in the river to determine the days requiring pulse protection, the diversions at the TCC, GCC and proposed Delevan intakes are restricted to meet the agricultural demands and other local uses in Colusa Basin region. The CAL2DOM logic was altered to estimate the diversions at the three intake locations without including the diversions for filling Sites Reservoir in this USRDOM run (called as, draft USRDOM No Fills Run). The results from the draft USRDOM No Fills run are used in a spreadsheet tool to determine the number of days under pulse protection in each month, over the 82-year period.

In the second iteration, the draft CALSIM II from the first iteration is re-run with the pulse protection data, to simulate the final monthly operations for the NODOS Alternative. The goal of this iteration is to determine the daily diversion amounts at the TCC, GCC and proposed Delevan pipeline intakes. Since the complexity involved in simulating capacity and maintenance constraints, bypass flow requirements and pulse protection restrictions simultaneously, the existing CAL2DOM logic to determine the daily diversions at the three intakes is insufficient. Therefore, the results from the final CALSIM II simulation are used to run another USRDOM simulation without including the diversions needed to fill the Sites Reservoir at the three intake locations (called as, final USRDOM No Fills Run). The purpose of this final USRDOM No Fills run is to determine the daily flows in the Sacramento River at key control points. This data is used in a spreadsheet tool to determine the daily diversions required to fill Sites Reservoir at the three intakes while complying with all the operational rules.

The daily diversions for the Sites fills at the three intakes are determined in three steps in the spreadsheet tool. In the first step the available diversion capacity is determined based on the capacity and maintenance constraints described above. In addition, based on the daily USRDOM flow the available flow to meet the monthly average diversion for fill (from CALSIM II) is determined at each intake, while meeting the bypass flow requirements. If there are no pulse flow restrictions for a given day, then the diversion at each intake is estimated as the minimum of available capacity and the available flow for diversion.

If the total diversion volumes at each intake from the first step for each month are less than the amount determined in CALSIM II, additional diversions needed to make up the difference are estimated in the second step. In this step, the additional diversions are made up at any of the three intakes depending on the available diversion capacity and the available flow for the diversion. First TCC intake is checked, then the GCC intake and finally the proposed Delevan pipeline intake for any available diversion capacity for each month.

Based on the diversions from the second step, the months with volumes continue to be short of the CALSIM II values are flagged in the third and final step. These shortages are carried forward to the next months in which the diversion capacity and the flow for the diversion are available. This carrying forward of the shortages is only allowed in November though May months, which generally is the Sites Reservoir filling period. The availability of the flow for the diversion is estimated as the Wilkins Slough flow in excess of the minimum flow requirement at Knights Landing (estimated in CAL2DOM).

In this process, a few reasonable simplifying assumptions were made for modeling purposes, mainly because CALSIM II determines the diversions at the three intakes on a monthly timestep without knowing the daily constraints due to the intake operations assumptions and the daily variability in the unregulated flows. It is assumed that in reality based on the available real-time monitoring, there is enough flexibility in TCC, GCC and proposed Delevan pipeline operations and in the interoperability among the three conveyance systems such that the diversions to fill Sites Reservoir can be made up –

1. through diversions at any of the three intake locations while meeting all the intake operations assumptions at each intake, and
2. through diversions in any of the months during the fill season of November through May if usable diversion capacity and divertible flow is available.

In the third iteration final USRDOM run is simulated using the final CALSIM II results and the daily diversions for fills from the final step of the spreadsheet tool. CAL2DOM is modified to combine the diversions for the fills and the diversions for meeting local Colusa Basin demands to determine the total daily diversions at each of the three intakes. The flow and storage results from the final USRDOM simulation are used to run the USRWQM for Sacramento River temperatures and other models to study the biological and flow regime effects of the NODOS Alternatives.

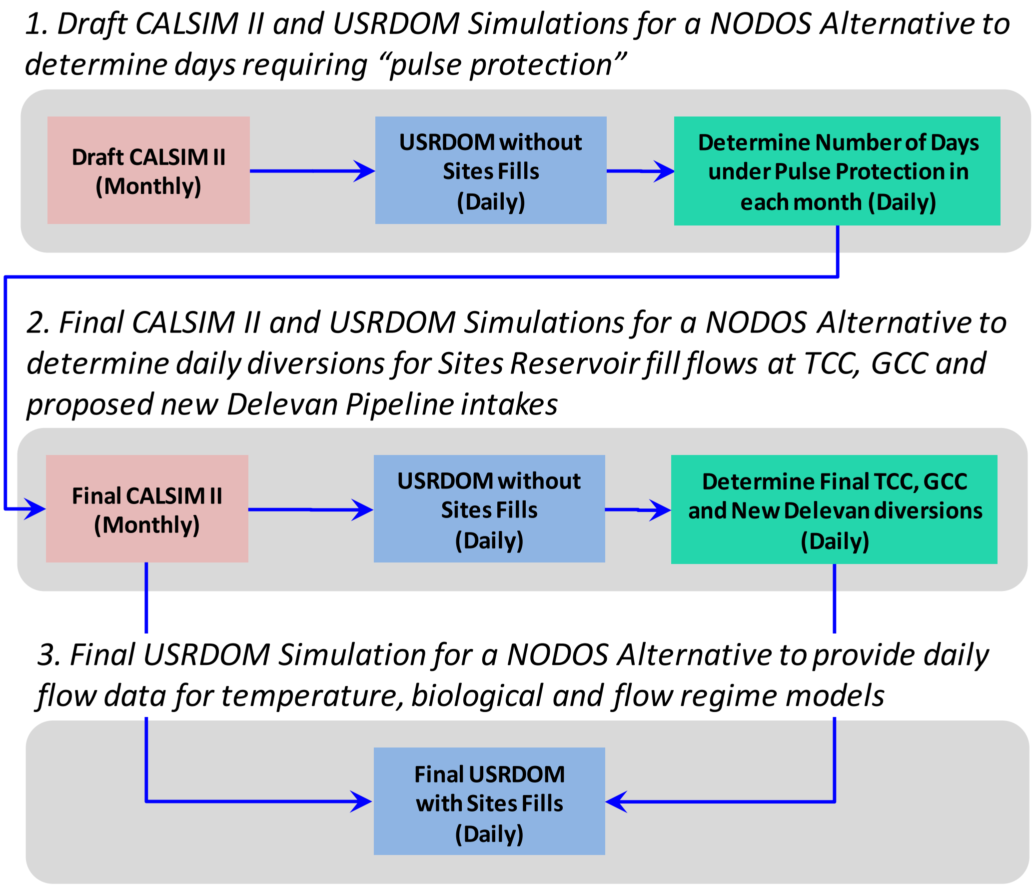


FIGURE 6.5
Operations Modeling Process used for the NODOS Alternatives Evaluation

6.10.4 Results and Discussion

This section presents a few key results from the USRDOM simulations for NODOS Alternatives A, B, and C, No Action Alternative and Existing Condition. The results presented in here are based on the daily results from the USRDOM simulations. Plots showing probability of exceedance of the 82 year daily results are presented for several flow and storage results.

Figure 6.6 shows a time series comparison of the Sites Reservoir storage for NODOS Alternatives A, B and C. Additional conveyance to fill the Sites Reservoir in the form of the proposed Delevan pipeline causes higher storage in ALT C than ALT B even though both simulations initialized from same storage. ALT A follows similar pattern as the other ALTs B and C, it is limited by storage capacity of about 1.2 MAF. Interestingly, in a critically dry year such as 1926, both ALT A and C resulted in similar storage conditions, even though ALT C includes additional storage capacity. Another interesting observation is that all the Alternatives show rapid decline in storage (almost 1 MAF drop in less than a year) going in to a dry year. Further, ALT C by the virtue of starting at a higher storage condition, last longer in to a dry period. Figure 6.7 shows the probability of exceedance of the daily Sites

Reservoir storage for NODOS Alternatives A, B and C. In the driest 20% of the years ALT B shows the lowest storage levels of all the three Alternatives.

Probability of exceedance of daily diversions at the Tehama Colusa Canal Intake near Red Bluff is shown for the NODOS Alternatives A, B and C, No Action Alternative and Existing Condition simulations in Figures 6.8 and 6.9. Three NODOS Alternatives show higher diversions at the Tehama Colusa Canal Intake. The flows in excess of the diversions shown for No Action Alternative and Existing Condition are for filling the Sites Reservoir. This occurs mainly in November through May months as shown in Figure 6.9. Note that all the NODOS Alternatives include an additional 250 cfs pump at Tehama Colusa Canal Intake near Red Bluff. In May through September months, the TCC diversions are less than the No Action Alternative as Sites Reservoir releases for the local demands in the Colusa Basin during this period reducing the diversions at the Sacramento River. The winter diversions at TCC intake are higher in ALT B compared to ALT C as in ALT B diversions for filling Sites Reservoir can only occur at TCC and GCC intakes. Diversions can occur at the proposed Delevan Pipeline intake in ALT C and ALT A. Since the Sites Reservoir storage is lower in ALT A, it has the lowest winter diversions at TCC intake. ALT B summer diversions at TCC intake are closer to the No Action Alternative unlike the diversions in ALT A and ALT C as some of the summer diversions are shifted to Delevan intake in the latter cases. Therefore, ALT B does not show similar levels of reduction in the diversions at the Sacramento River as ALT A and ALT C.

Probability of exceedance of daily diversions at the Glenn Colusa Canal Intake near Hamilton City is shown for the NODOS Alternatives A, B and C, No Action Alternative and Existing Condition simulations in Figures 6.10 and 6.11. The GCC intake diversions in the NODOS Alternatives exhibit similar patterns as the TCC diversions. During the winter months, the diversions at GCC intake are higher in the NODOS Alternative compared to the No Action Alternative and the Existing Condition run, so as to fill the Sites Reservoir. Again, Alt B has the highest diversions of the three alternatives due to the reduced diversion capacity. Because of the scheduled maintenance in January and February (3 weeks in each month), the diversions for fill remain lower at GCC intake in all the alternatives. During June and July, the diversions at Hamilton City are reduced in the NODOS Alternatives for two reasons. First, Sites Reservoir releases for meeting the local demands in the summer months and second, the diversions at Hamilton City are shifted to proposed Delevan pipeline intake during June and July to reduce impacts to the Green Sturgeon habitat in the vicinity of Hamilton City. The second reason does not apply to ALT B and therefore, does not show same level of reduction in diversions at Sacramento River as ALT A and C in the summer months. Note that all the alternatives assumed 3000 cfs capacity for the Hamilton City Intake. Flows exceeding 3000 cfs are caused by the smoothing function used by the USRDOM and are an artifact of the modeling process.

Figure 6.12 shows the probability of exceedance of daily diversion at proposed Delevan Pipeline Intake for NODOS Alternatives A and C. The intake does not exist in the ALT B. ALT C shows slightly higher diversions compared to ALT A. The diversions at the Delevan intake mainly occur in November through March months for filling the Sites Reservoir in all years and also in April and May only during Dry and Critical years. Except for Dry and Critical years, the Delevan Intake and Pipeline is shut down for maintenance. For Alternative A and C this means the Pipeline is also shut down for releases to the river in these months. In June and July the diversions continue to occur at the Delevan Pipeline to deliver water to meet the Colusa Basin demands as the diversions at TCC and GCC are reduced and shifted to Delevan to protect the habitat for Green Sturgeon. These diversions are delivered directly to the local needs and do not contribute to the Sites storage. Note that NODOS Alternatives A and C include the Delevan Intake with a capacity to divert up to 2000 cfs Flows exceeding 2000 cfs are caused by the smoothing function used by USRDOM and are an artifact of the modeling process.

Figure 6.13 shows the probability of exceedance of daily flow from Funks Reservoir to Sacramento River through the proposed Delevan Pipeline for NODOS Alternatives A, B and C. The three Alternatives include 1500 cfs release capacity through the Delevan Pipeline. Majority of releases occur during the summer and fall months when the downstream demands on the Sacramento River are higher. In April and May months, ALT A and ALT C show releases only during Dry and Critical years. ALT B, however, continue to make releases during April and May as the pipeline is not shut down for the maintenance. ALT B also shows higher releases in June and July, as in ALT A and ALT C, the Pipeline is used to divert water shifted from TCC and GCC to meet the Colusa Basin demands. In a few winter months (February and March), releases are made through Delevan Pipeline to enhance the occurrence of X2 at or west of Chipps Island.

Figure 6.14 shows the probability of exceedance of daily flow (fills) from Funks Reservoir to Sites Reservoir for NODOS Alternatives A, B and C. ALT B shows lower fill flows into Sites Reservoir compared to ALT A and C, however, occur for more days. This is due to the reduce diversion capacity in ALT B. ALT A and C, on the other hand, can divert more flows and for shorter periods to fill the Sites Reservoir. Figure 6.15 shows the probability of exceedance of daily flow (releases) from Sites Reservoir to Funks Reservoir for NODOS Alternatives A, B and C. Releases from Sites Reservoir are used for meeting local demands in the Colusa Basin and for the downstream needs along the Sacramento River. The patterns are similar to the Delevan Pipeline releases described above. ALT C can sustain the releases for longer periods because of the higher carry over storage.

Figure 6.16 shows the probability of exceedance of daily fill flows from Tehama Colusa Canal to Sites Reservoir through Funks Reservoir for NODOS Alternatives A, B and C. Figure 6.17 shows the probability of exceedance of daily fill flows from Glenn Colusa Canal to Sites Reservoir through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C. As described above, the diversions for filling Sites Reservoir are higher in ALT B compared to ALT A and ALT C. The diversions for fills generally occur during November through May months in all alternatives. All scenarios assume 2100 cfs for the TC Canal capacity constraint just upstream of Funks Reservoir. Flows exceeding 2100 cfs in TCC are generally caused by the smoothing function used by USRDOM and are an artifact of the modeling process. For GCC, all scenarios assume 1800 cfs as the Canal capacity constraint just upstream of the TRR. However, this is at times reduced in consideration of ongoing GCC winter operations that are not explicitly included in the CALSIM II or USRDOM models. Also, as noted earlier the GCC is shut down for maintenance for three weeks each in January and February months, thus reducing the fill flows.

Figure 6.18shows the probability of exceedance of daily flow (release) from Funks Reservoir to Glenn Colusa Canal through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C. This release occurs to supply irrigation flows in the lower Colusa

Basin by doing so, the GCC diversion from the Sacramento River is reduced. ALT B shows the lowest releases to meet the local demands in the Colusa Basin of the three alternatives. These releases mainly occur during April through November months.

Figure 6.19 shows the probability of exceedance of daily flow from Tehama Colusa Canal to Glenn Colusa Canal through the existing intertie for NODOS Alternatives A, B and C. Figure 6.20 shows the probability of exceedance of combined daily flow in TCC downstream of Funks Reservoir and flow through Williams Outlet for NODOS Alternatives A, B and C. Both the plots show that all the alternatives have similar flows at these three locations. Again, these flows serve the local demands in the Colusa Basin region and mainly exist during April through November months. These flows can be releases from Sites Reservoir as well as diversions at the Sacramento River.

Figure 6.21and 6.22 show the daily Shasta Reservoir storage for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition simulations. All the NODOS Alternatives show higher storage conditions than the No Action Alternative and Existing Condition run as Sites Reservoir is able to meet some of the downstream demands in the former cases that were solely served by Shasta Reservoir in the latter. Also, Shasta storage drawdown is proportional to the Sites storage drawdown in the NODOS Alternatives, during the drier years. The higher storage conditions in Shasta Reservoir under the NODOS Alternatives enable increased coldwater pool volumes and increased flexibility to use the additional storage for improved temperature control and other habitat improvement needs on the Sacramento River.

Figures 6.23 to 6.26 show the daily spills into the Sutter Bypass for NODOS Alternative A, B and C, No Action Alternative and Existing Condition simulations at Ord Ferry, Moulton Weir, Colusa Weir and Tisdale Weirs along the Sacramento River. Spills at Ord Ferry and Moulton Weir under the NODOS Alternatives are similar to the No Action Alternative and Existing Condition run, however, slightly lower at Colusa and Tisdale weirs, due to the increased diversions along the Sacramento River.

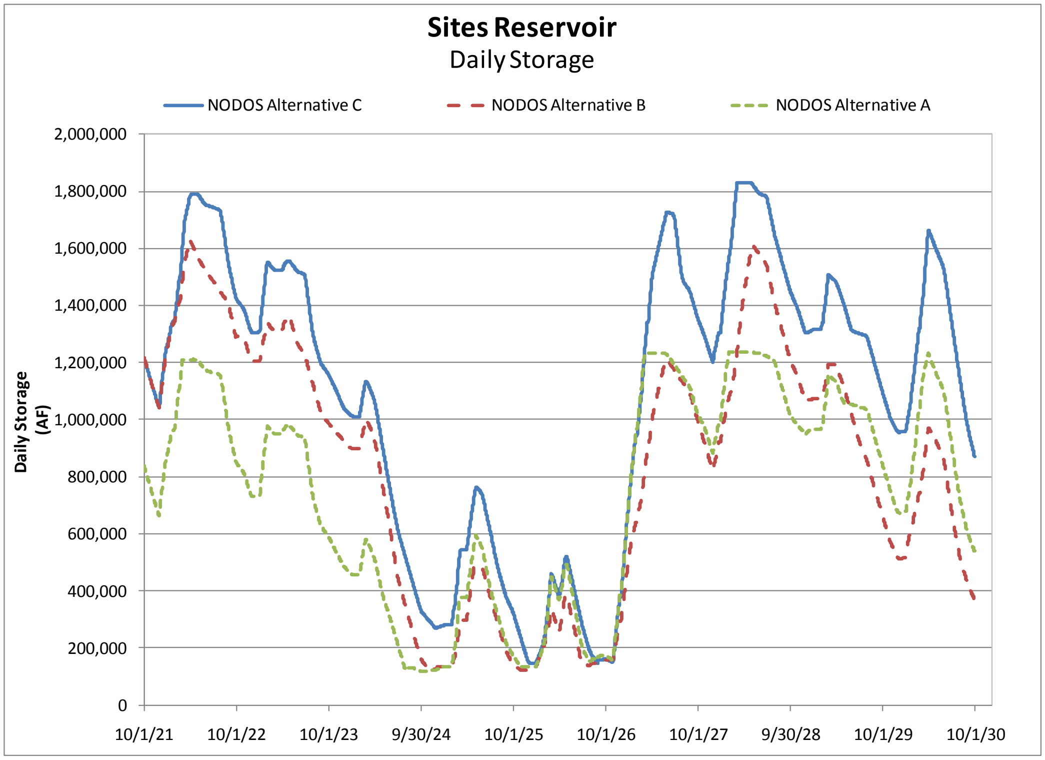


FIGURE 6.6
Daily Sites Reservoir Storage for NODOS Alternatives A, B and C

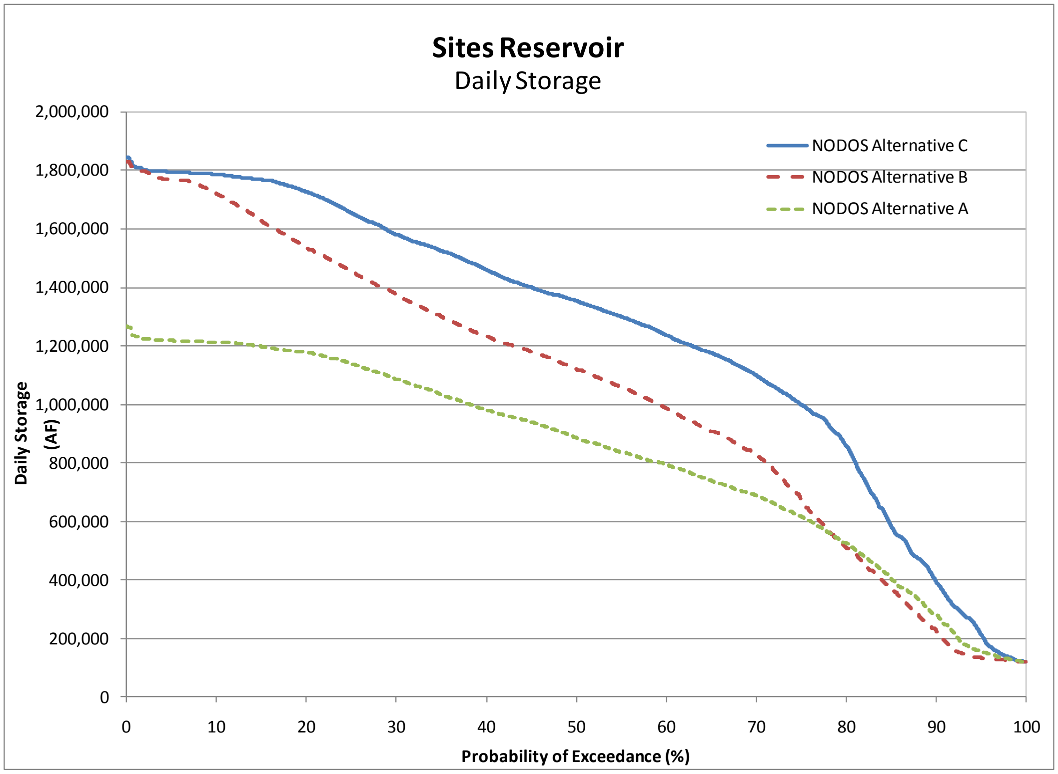


FIGURE 6.7
Probability of Exceedance of Daily Sites Reservoir Storage for NODOS Alternatives A, B and C

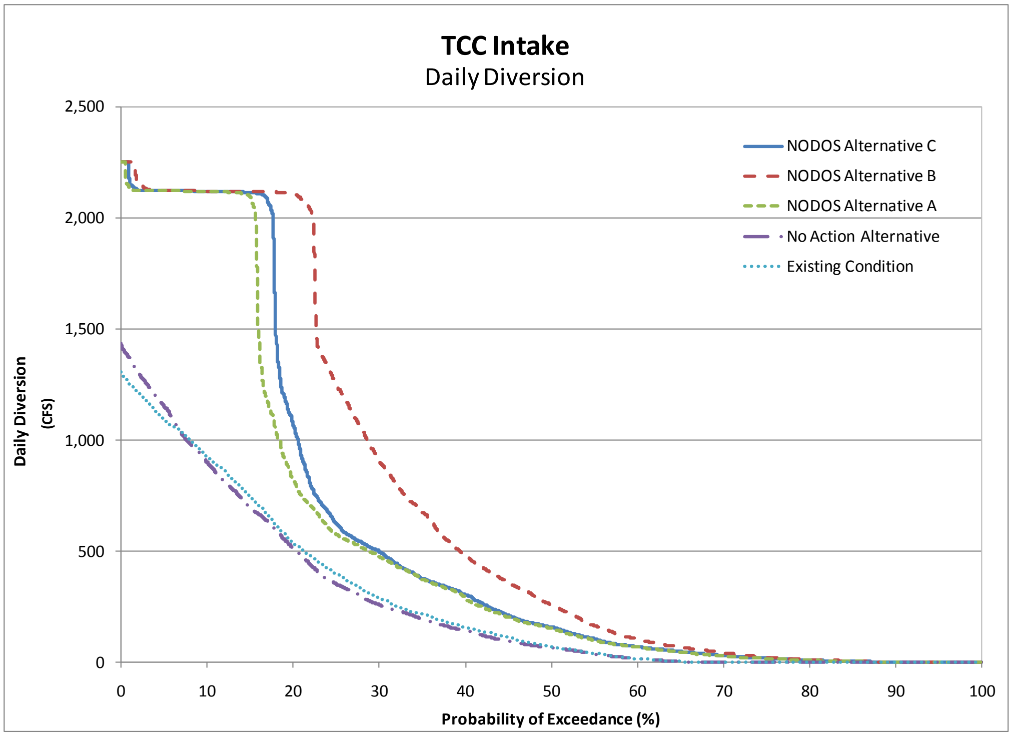


FIGURE 6.8

Probability of Exceedance of Daily Diversion at Tehama Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

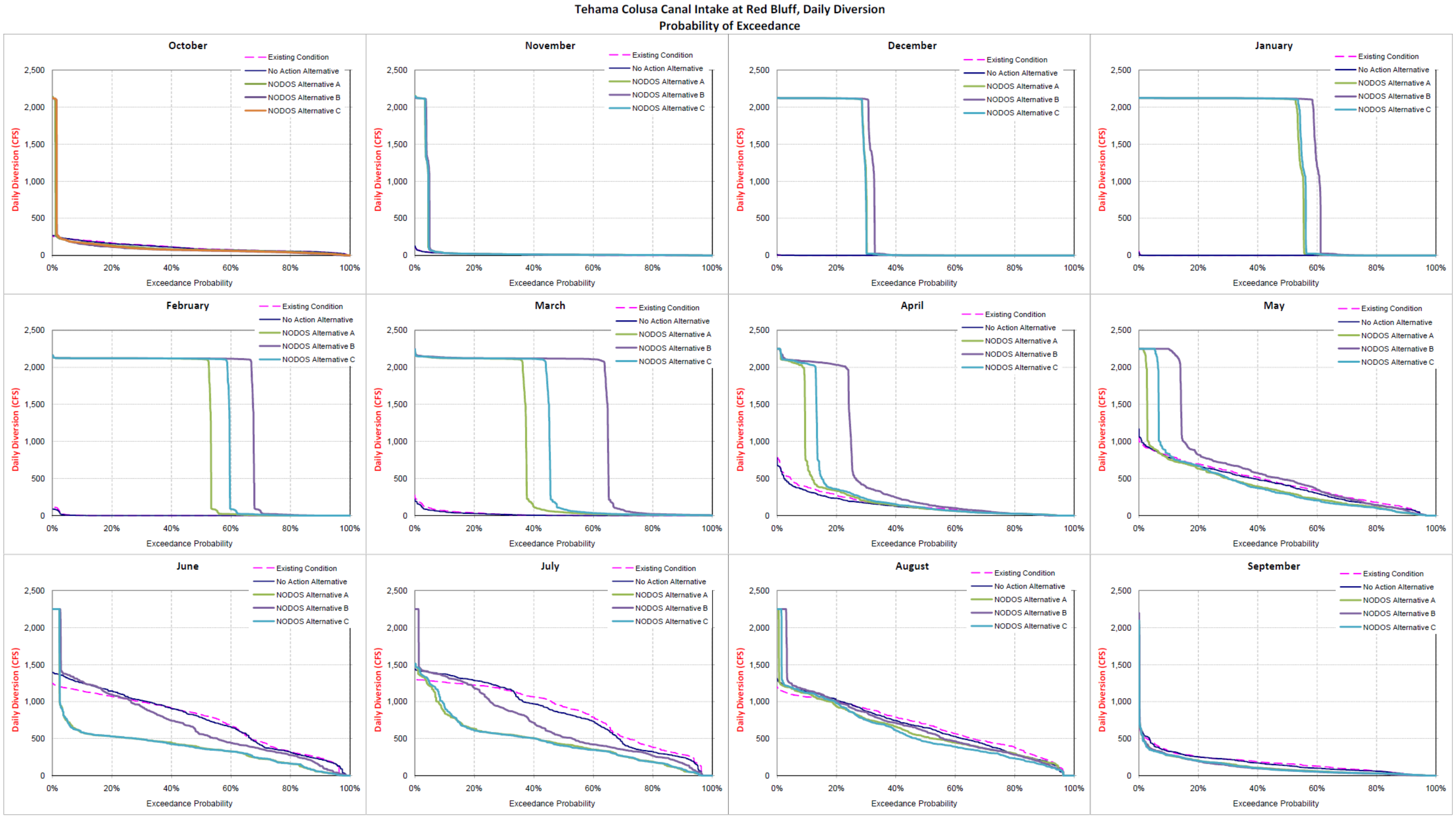


FIGURE 6.9

Probability of Exceedance of Daily Diversion at Tehama Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations by Month

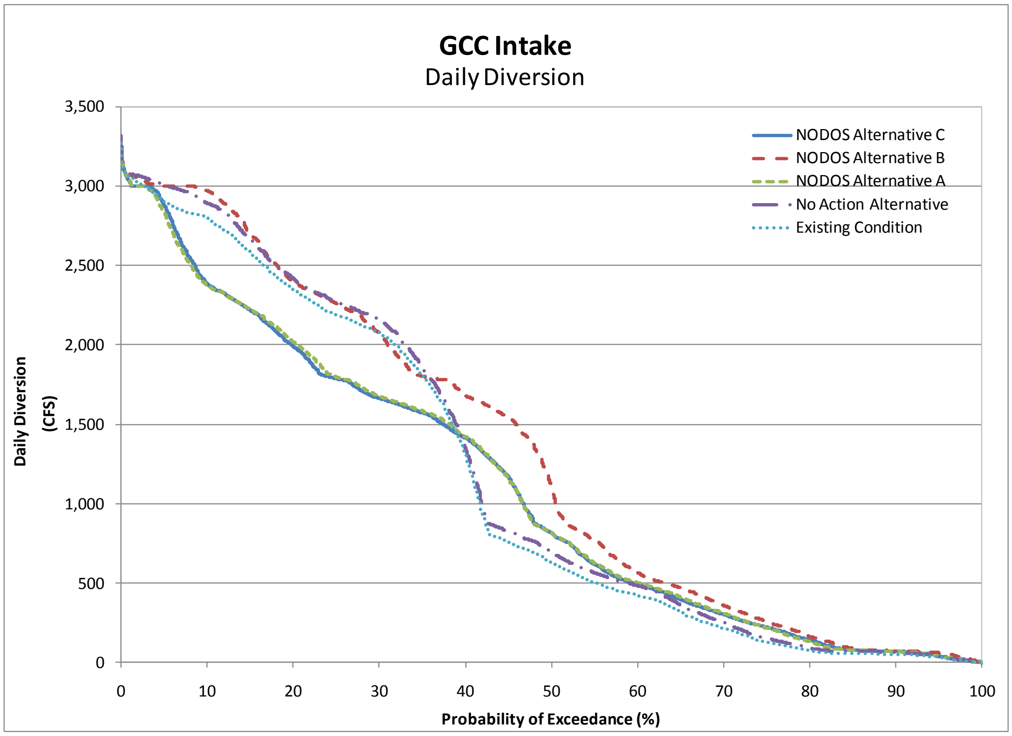


FIGURE 6.10

Probability of Exceedance of Daily Diversion at Glenn Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

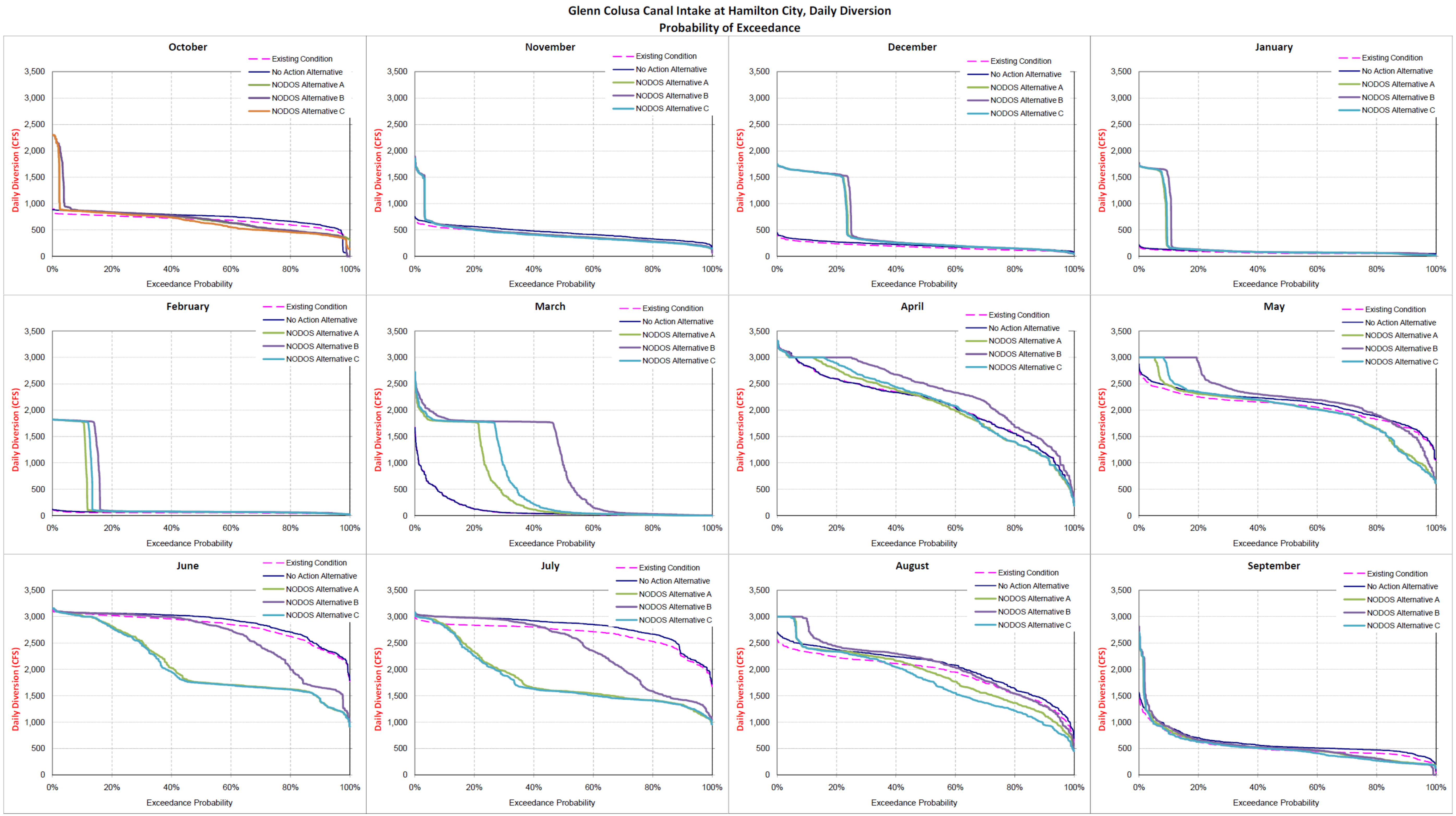


FIGURE 6.11

Probability of Exceedance of Daily Diversion at Glenn Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations by Month

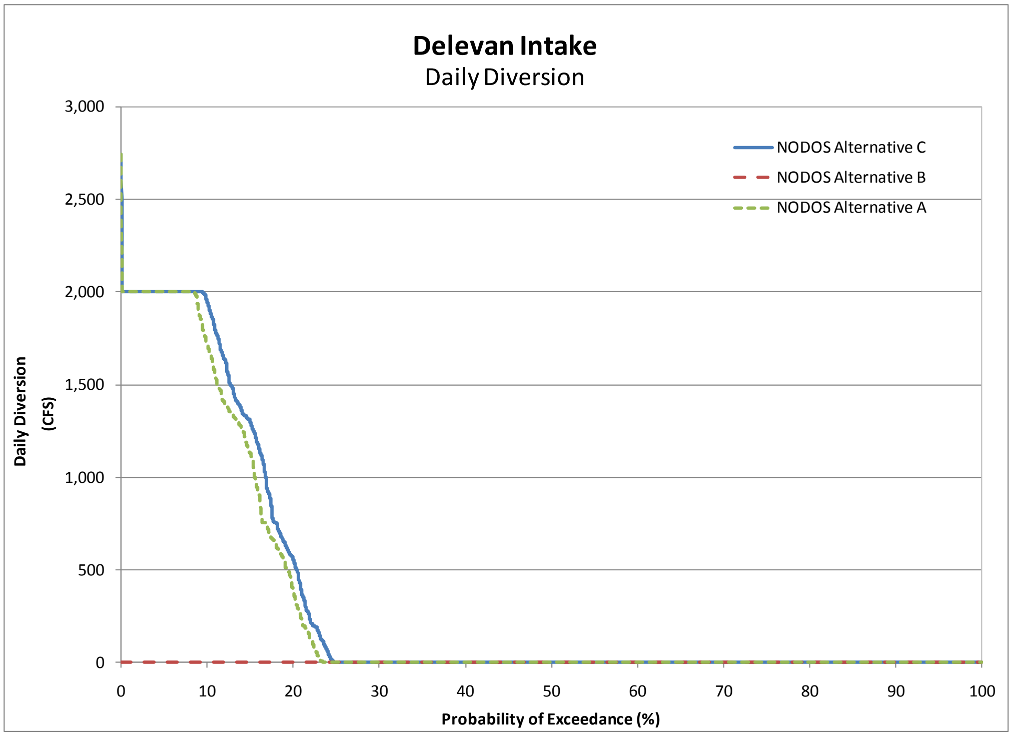


FIGURE 6.12

Probability of Exceedance of Daily Diversion at Proposed Delevan Pipeline Intake for NODOS Alternatives A and C

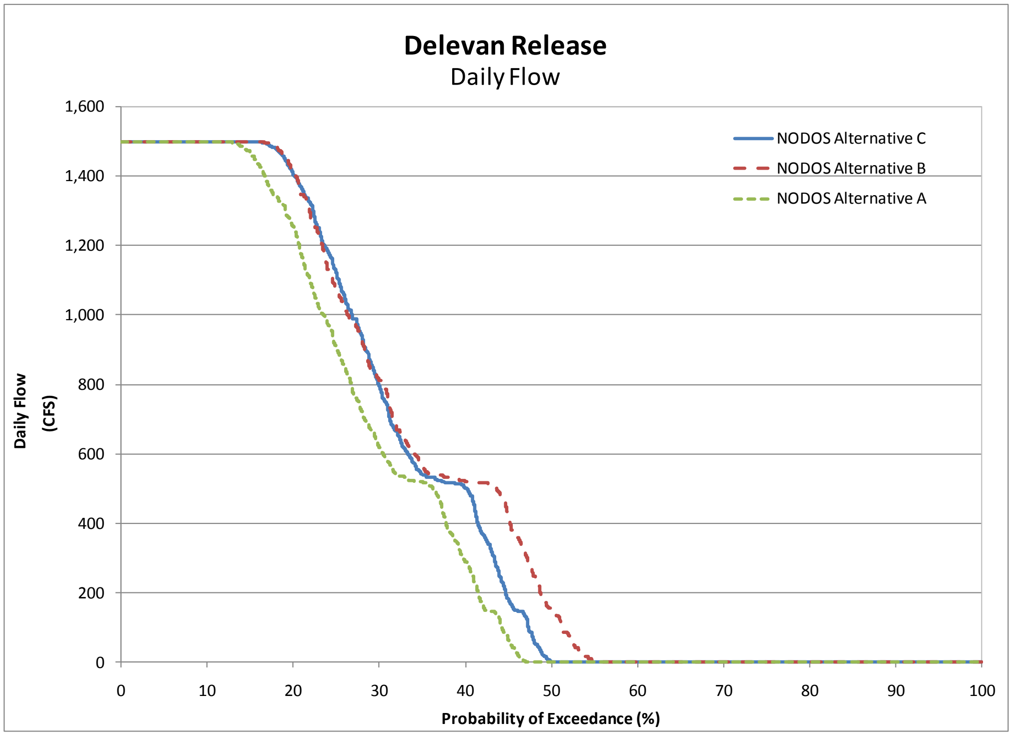


FIGURE 6.13

Probability of Exceedance of Daily Flow from Funks Reservoir to Sacramento River through Proposed Delevan Pipeline for NODOS Alternatives A, B and C

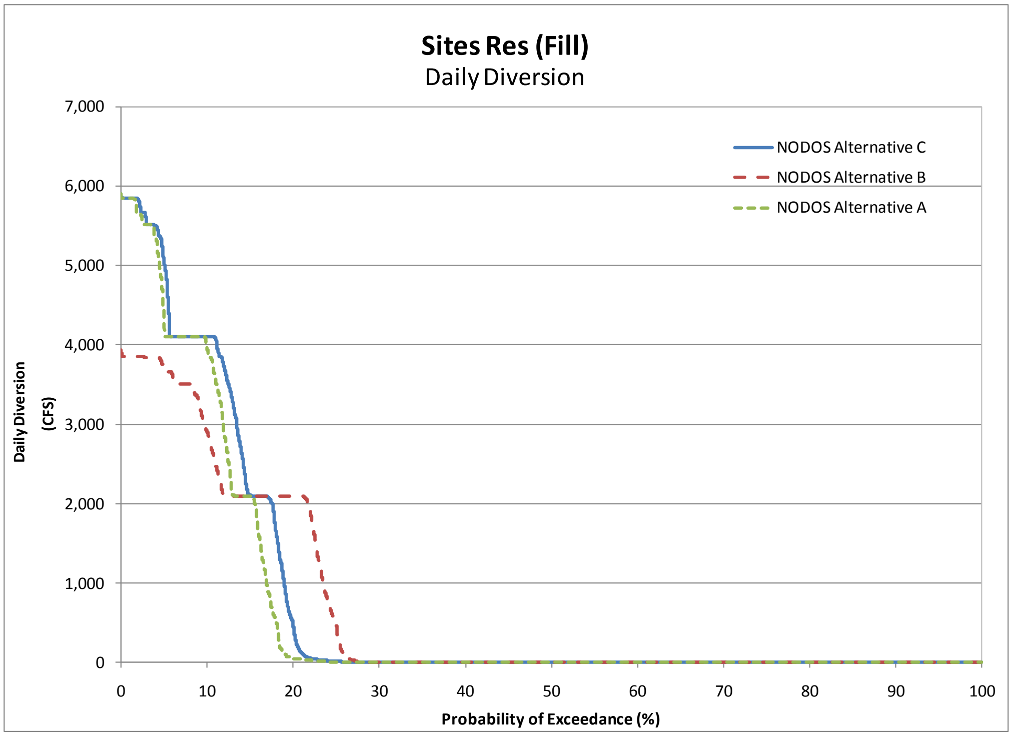


FIGURE 6.14

Probability of Exceedance of Daily Flow from Funks Reservoir to Sites Reservoir for NODOS Alternatives A, B and C

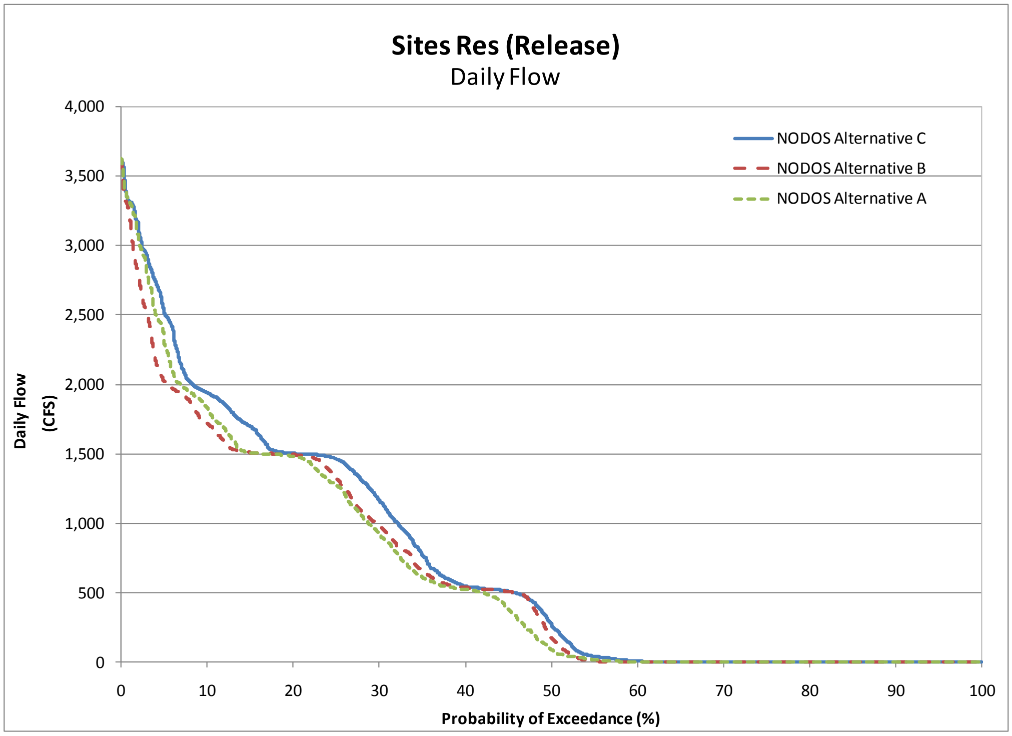


FIGURE 6.15

Probability of Exceedance of Daily Flow from Sites Reservoir to Funks Reservoir for NODOS Alternatives A, B and C

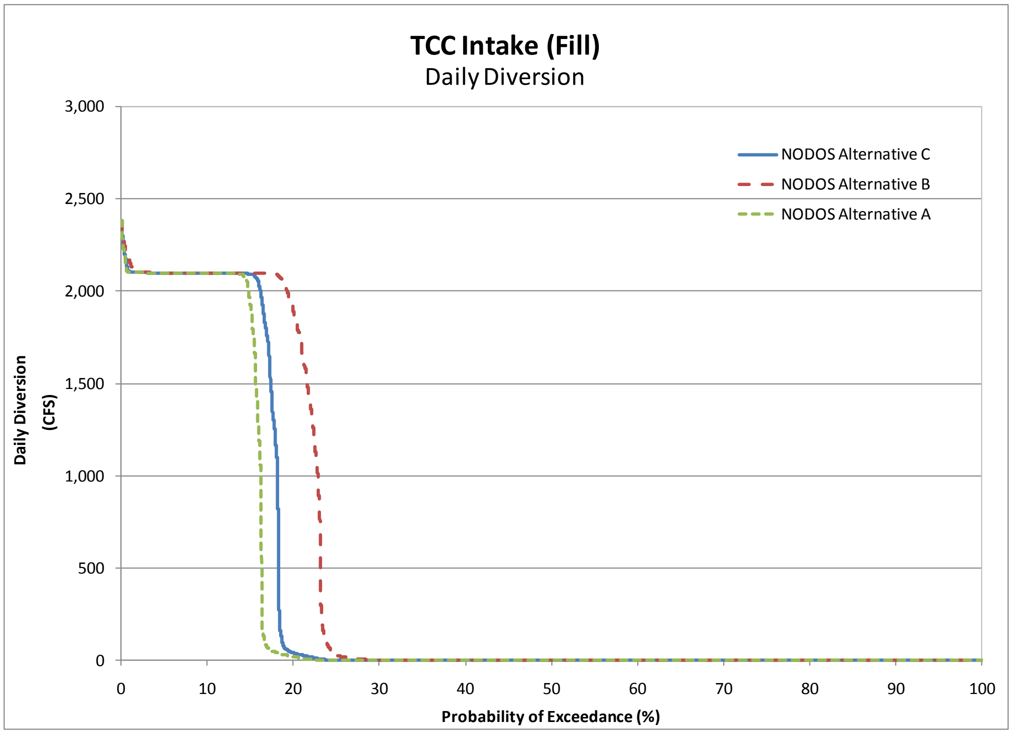


FIGURE 6.16
Probability of Exceedance of Daily Flow from Tehama Colusa Canal to Sites Reservoir through Funks Reservoir for NODOS Alternatives A, B and C

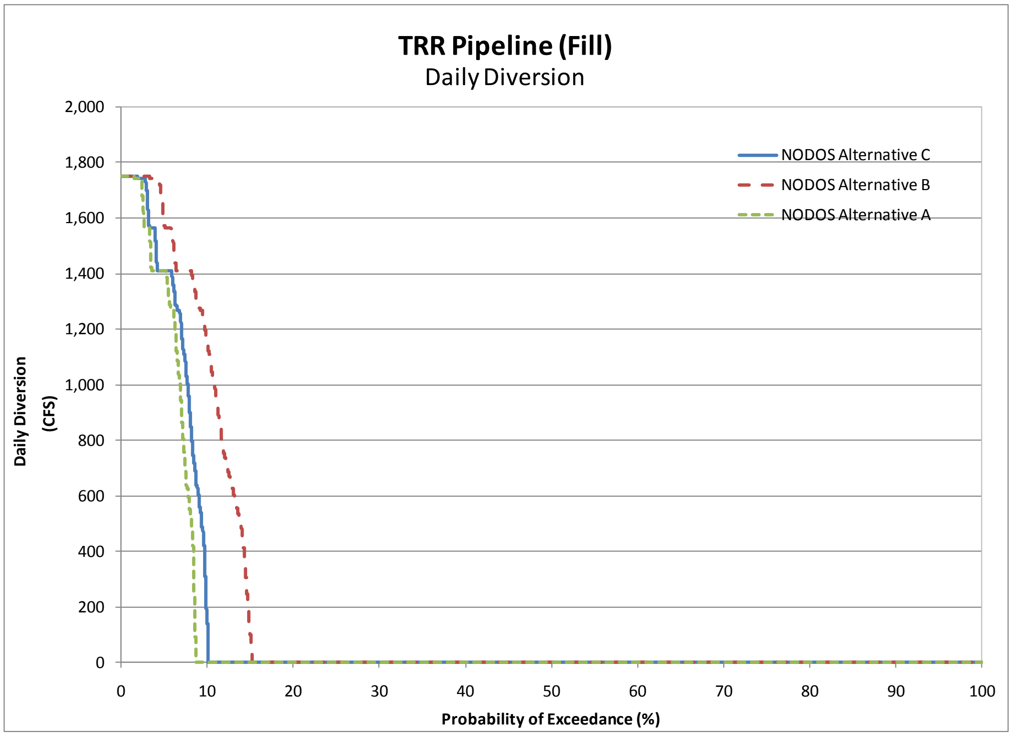


FIGURE 6.17
Probability of Exceedance of Daily Flow from Glenn Colusa Canal to Sites Reservoir through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C

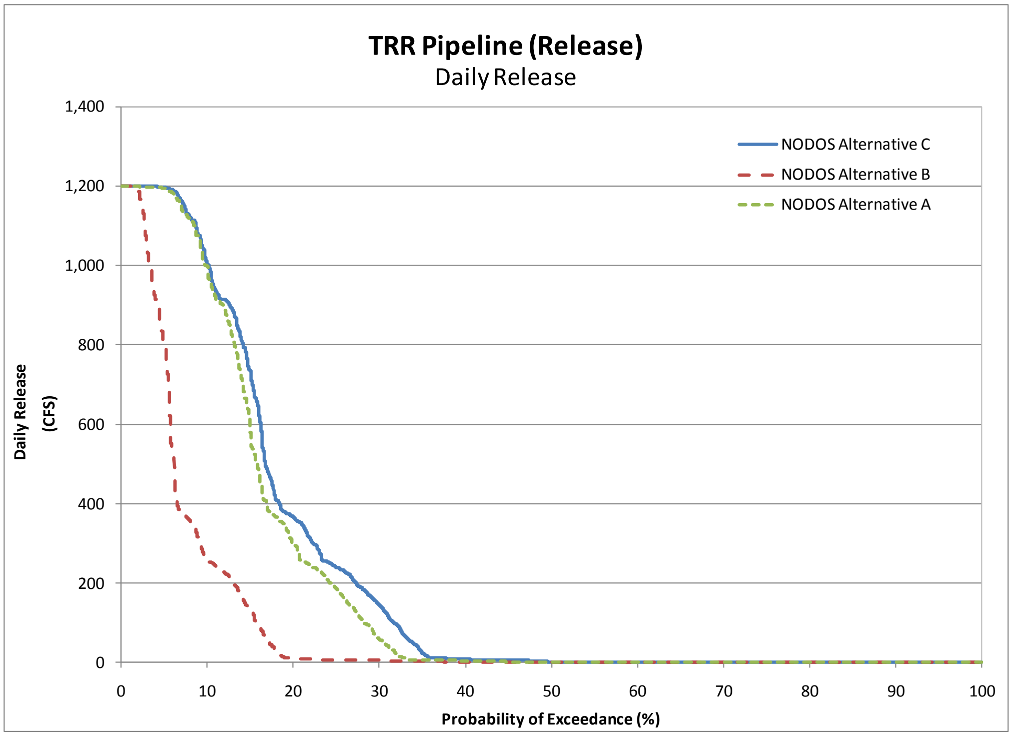


FIGURE 6.18

Probability of Exceedance of Daily Flow from Funks Reservoir to Glenn Colusa Canal through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C

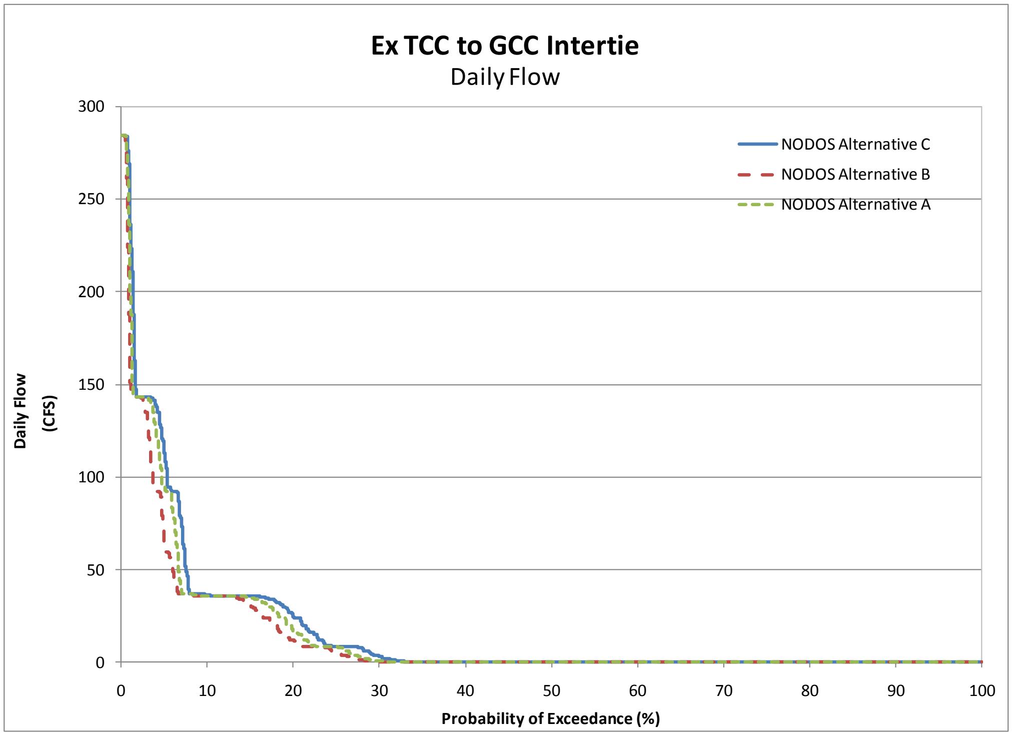


FIGURE 6.19

Probability of Exceedance of Daily Flow from Tehama Colusa Canal to Glenn Colusa Canal through Existing Intertie for NODOS Alternatives A, B and C

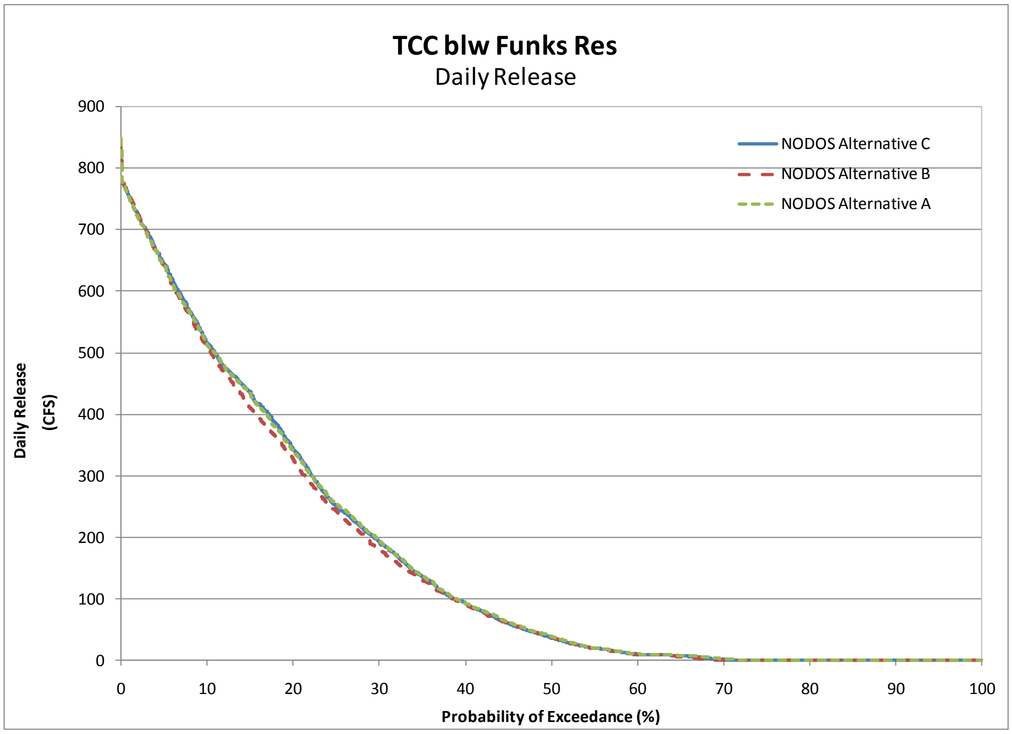


FIGURE 6.20

Probability of Exceedance of Daily Flow in TCC below Funks Reservoir and flow through Williams Outlet for NODOS Alternatives A, B and C

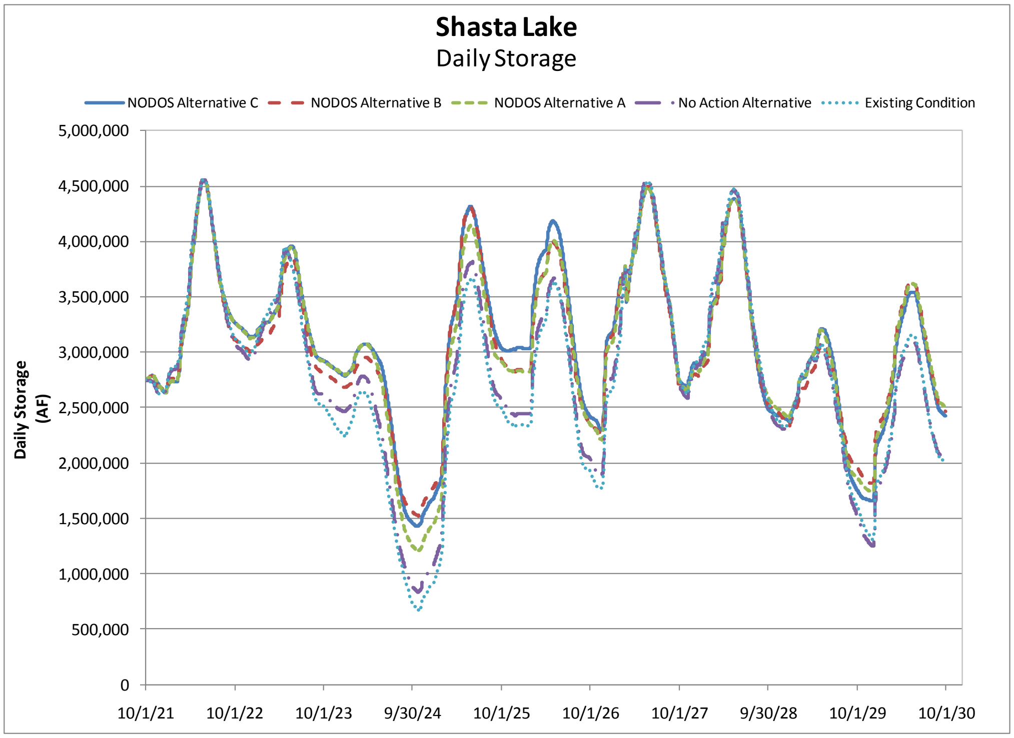


FIGURE 6.21

Daily Shasta Reservoir Storage for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

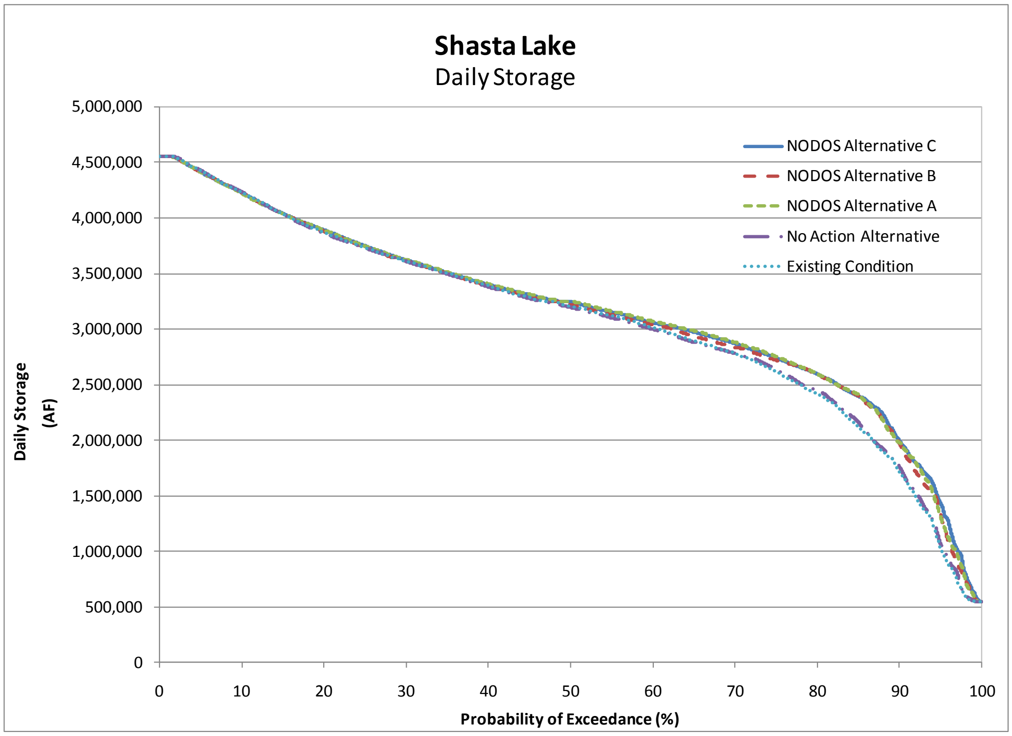


FIGURE 6.22

Probability of Exceedance of Daily Shasta Reservoir Storage for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

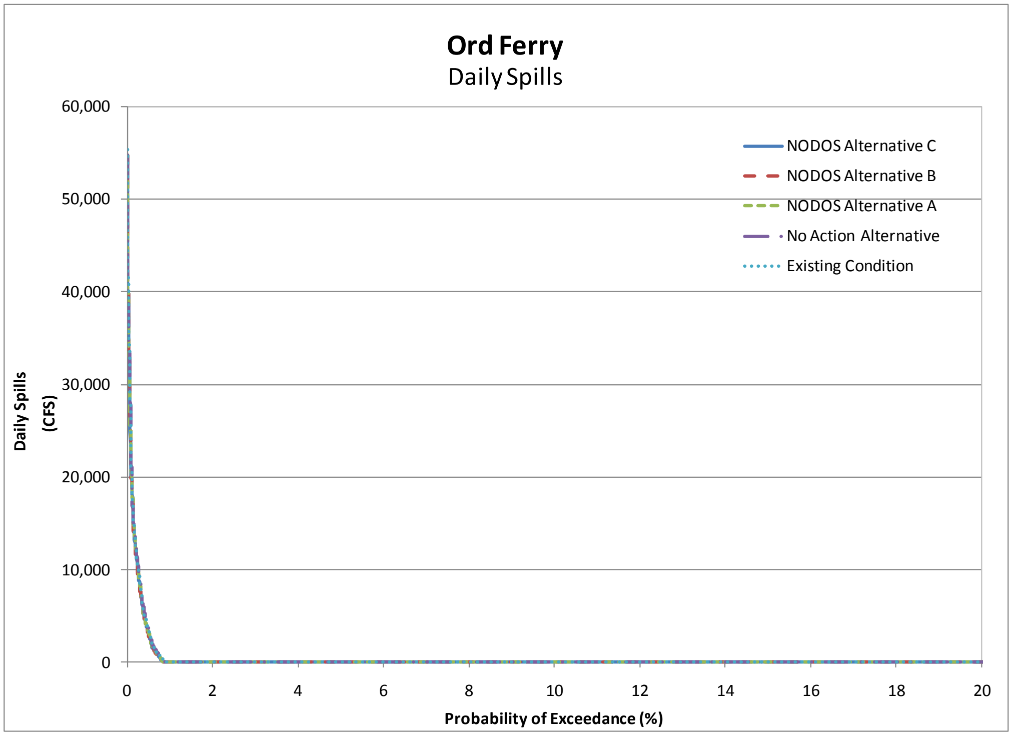


FIGURE 6.23

Probability of Exceedance of Daily Ord Ferry Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

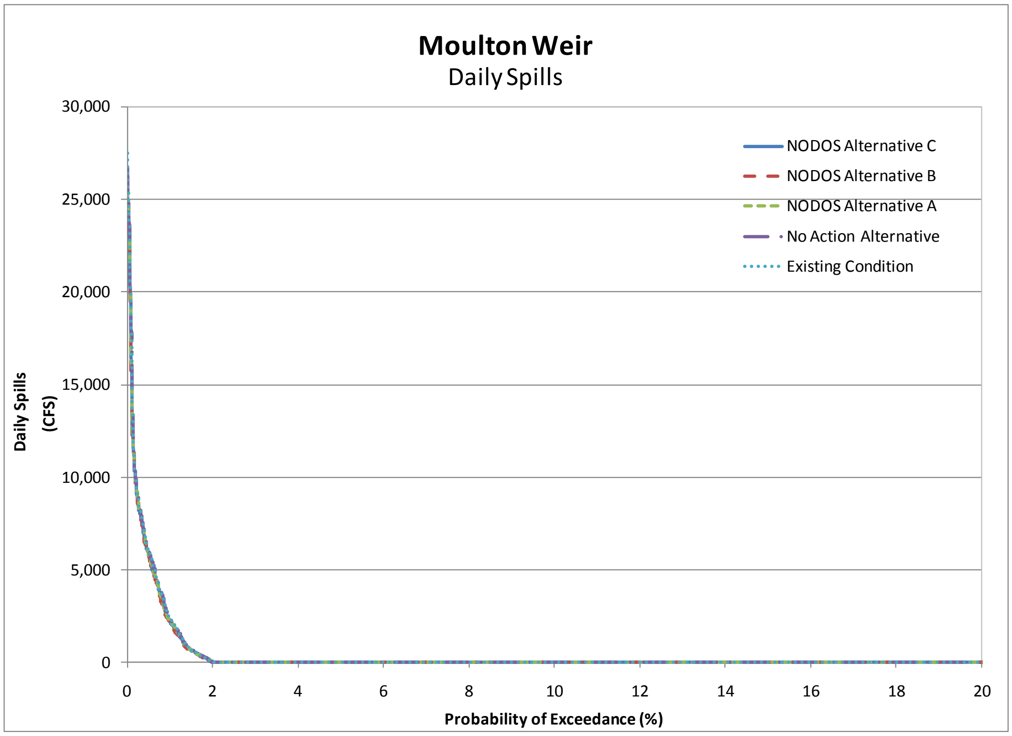


FIGURE 6.24

Probability of Exceedance of Daily Moulton Weir Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

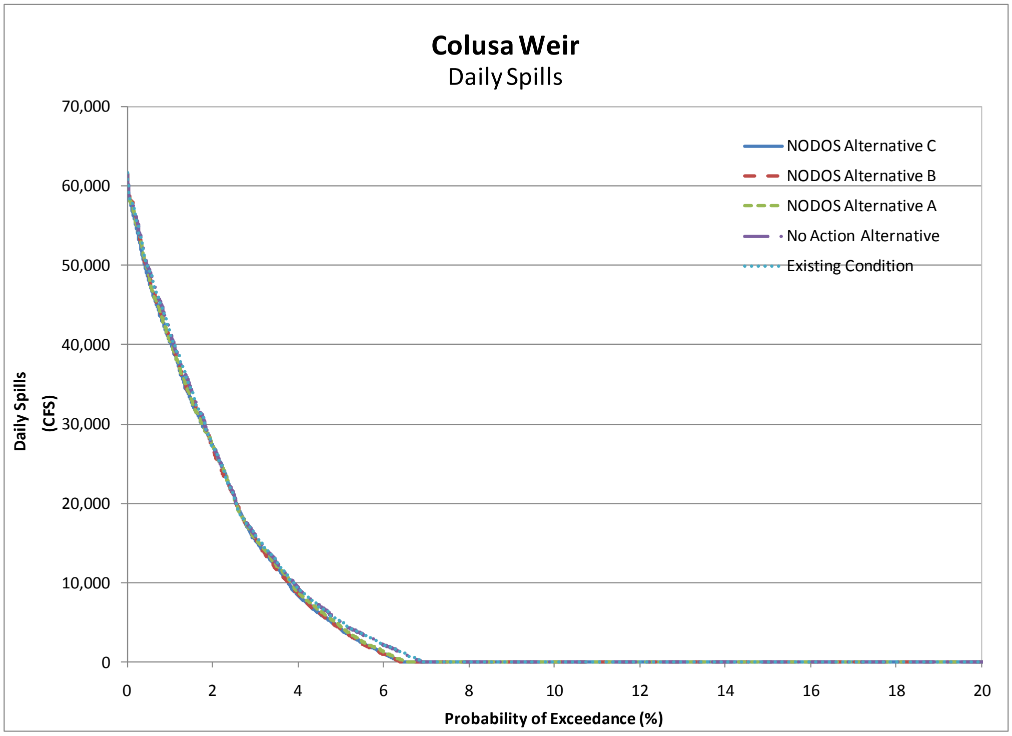


FIGURE 6.25

Probability of Exceedance of Daily Colusa Weir Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

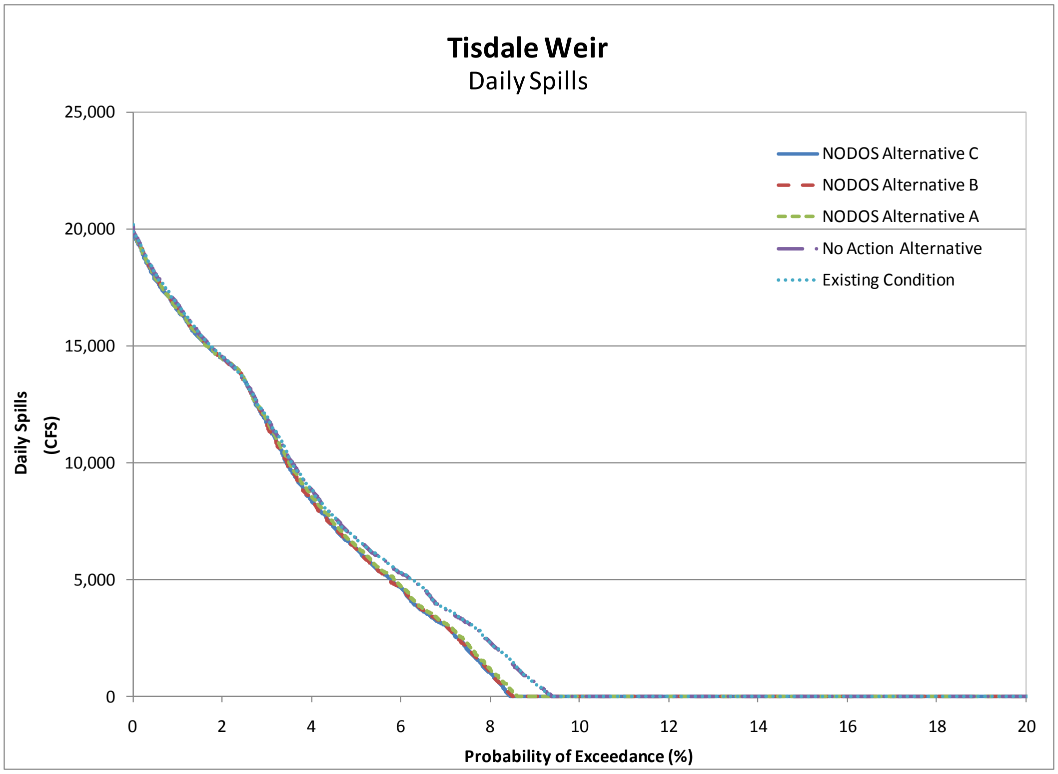


FIGURE 6.26
Probability of Exceedance of Daily Tisdale Weir Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

6.10.5 Summary

USRDOM simulates daily flow and storage conditions. It utilizes results from CALSIM II to evaluate the impacts of changing diversion, in-basin use and Delta operations under projected conditions within current or future regulatory and operational regimes. It couples the downstream monthly operational decisions in CALSIM II to a simulation of the associated sub-monthly operational response at Lake Shasta depending on the inflows. It is particularly useful in verifying the CALSIM II simulated river conditions and the availability of excess flows to fill the proposed Sites Reservoir under the capacity and operational constraints of the three intakes at Red Bluff, Hamilton City and Delevan locations. Therefore, USRDOM was successfully used to evaluate the NODOS ADEIRS Alternatives. USRDOM was used to simulate daily flows to inform CALSIM II (monthly) about the potential restrictions on the diversions due to pulse flow conditions. It was also used to evaluate storage conditions in Lake Shasta and Sites Reservoir, flow conditions on a daily-weekly time scale along the Sacramento River from Keswick Dam to Knights Landing and in the Colusa Basin conveyance. The results from USRDOM are used in temperature, biological and flow regime models to evaluate NODOS Alternatives. It was also used to identify sources of flows on a sub-monthly time-step to study likely water quality impacts.

6.10.6 Limitations

In using the USRDOM results for the Alternatives evaluation following limitations should be noted:

The USRDOM calibration for Clear Creek flows below Whiskeytown Dam is significantly weaker than for other flows in the Trinity and Sacramento River systems. It is recommended that the CALSIM II model alone be used as the basis for impact assessment on Clear Creek flows.

In the downscaling of CALSIM II boundary condition flows for use in the USRDOM model simulations, diversions at Red Bluff, Hamilton City and the New Delevan Pipeline (proposed NODOS alternatives) are smoothed from monthly to daily timestep. In this smoothing operation, in order to conserve volume and have a gradual change in diversion flows (as opposed to sharp changes at monthly or other time scale boundaries), there are some days in which diversions are represented in the model at flow rates that exceed the sustainable rate of the physical capacity of these facilities. It is recommended that any assessment of flows or other parameters linked to the peak flow rate of these diversions use monthly average values rather than daily or other sub-monthly average values.

The CALSIM II model is used to establish system operational conditions and the USRDOM model is used to interpret these on a daily time-step; all residuals and inconsistencies between the CALSIM II and USRDOM models accumulate in storage facilities modeled, including Sites Reservoir; the Sites Reservoir storage in the USRDOM model sometimes exceeds physical capacity slightly due to this inconsistency between the models.

SECTION 7

References

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CH2M HILL. 1998. *Hydrologic and Water Rights Analyses for Selected Sacramento Valley Spring Run Salmon Streams (Section 3406 (b)(3) Water CVPIA)*. November.

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Supplemental Information

Attachment A
Anadromous Fish (Sacramento River)

This attachment provides additional details and analysis in response to the reviewers comments within the CWC February 1, 2018 letter regarding physical and monetized benefits for anadromous fish.

A.1 Supplemental Modeling to Address Downstream Impacts

A.1.1 Comment from PBR Review

The California Department of Fish and Wildlife (CDFW) found the monetized ecosystem benefits for the Sites Reservoir Project for anadromous fish were insufficiently supported by the information in the application to establish this benefit and recommended removal of the monetized ecosystem benefit from the calculation of the PBR.

CDFW's criticism of the anadromous fish benefit addressed two areas: the use of SALMOD to assess benefits to the various runs of Chinook salmon (addressed in Section A.1), and failure to address impacts on fish resulting from reduced river flows downstream of the proposed project diversions (addressed in Section A.2).

Following the comments identified above the Sites project conducted additional analyses (including a CDFW recommended winter run Chinook salmon life-cycle model, OBAN), clarified our previously submitted analysis of Chinook salmon recruitment (SALMOD) and enhanced our analysis of out-migration mortality. The details of each of these activities are included in the Section A.1.1 These analyses further demonstrate that the Sites Reservoir Project provides benefits to the anadromous fish in the Sacramento River. The results provided in the attachment show improvements (up to 6%) in habitat conditions and associated production for the four runs of Sacramento River Chinook salmon on an average, and substantial improvements (2% to 67%) in critically dry years. Winter-Run lifecycle modeling indicates that Sites Reservoir project provides substantial improvements (2% to 11%) in total escapement. Application of the flow-survival relationship, when applied to the CalSim II 2015, 2030 and 2070 climate scenario results, during the principle diversion period (December – March) reduced the overall survival from 0–4%. This range would be expected to be reduced (by approximately ½) with the implementation of the pulse protection mitigation proposed by the Sites Project. The analyses presented in the attachment indicate sustained benefits to the anadromous fish with the operation of the Sites Project despite potential effects due to the reduced river flows downstream of the Sites Reservoir diversions.

A.1.2 SALMOD

SALMOD was used to demonstrate the potential for Sites Reservoir in improving conditions for Sacramento River Chinook salmon (egg through pre-smolt life stage) in the reach between Keswick and Red Bluff and benefit the populations through increased production of juveniles. SALMOD is the only tool available that can be used for studying water temperature and flow effects on all four runs of Chinook salmon.

CDFW's concern with SALMOD is that it is not a lifecycle model and using it to estimate "net improvement to salmon" is risky for the following reasons:

- Using SALMOD to calculate the number of fish that will benefit over the life of the project does not accurately represent salmon population dynamics, nor does it account for annually changing population levels. Without careful consideration of inputs this model may underestimate impacts and overestimate benefits;

- Inputs and assumptions need to be clearly documented and explained. Without understanding of inputs and assumptions there is reduced confidence in the outputs;
- Some starting population inputs to SALMOD were much higher than recent data indicate; and
- Impacts on fish resulting from reduced river flows downstream of the proposed project diversion points were not analyzed or disclosed in the quantification of benefits.

In the Sites WSIP Application, SALMOD results were primarily used to identify another project that would provide equivalent anadromous fish benefits in the Keswick to Red Bluff reach, and to estimate potential economic benefit based on the alternative cost analysis. WSIP Technical Reference (TR) (CWC, 2016) refers to SALMOD as a tool that can be used for quantifying riverine effects of the proposed project and assessing ecosystem improvements on the four runs of the Sacramento River Chinook salmon (WSIP TR Table 4-12). SALMOD was used appropriately in the Sites Reservoir WSIP application to project potential benefits to salmon in the Keswick to Red Bluff reach of the Sacramento River. Nevertheless, we acknowledge the CDFW's comments and have provided additional information, conducted additional SALMOD modeling and lifecycle modeling to address those comments.

A.1.2.1 SALMOD Inputs and Starting Populations

The inputs and assumptions such as the ratio of adult spawners, mortality rates etc. used in the SALMOD for evaluating Sites Project, were default values described in the Appendix P of the 2008 Reclamation OCAP BA. This reference was noted in the WSIP TR page 4-107. Given that CDFW expressed concern with the starting population values used in SALMOD for the application, SALMOD was rerun using recent historic returning adults and redd distribution assumptions. To reflect the assumptions based on the recent historic conditions, the version of the SALMOD model used in the California WaterFix Biological Assessment (CWF BA) (USBR and DWR, 2016) was used to simulate effects on Chinook salmon under the With Sites and Without Sites scenarios. CWF BA Appendix 5D Attachment 2 describes inputs and assumptions used in the SALMOD model. The temporal and spatial spawning distributions were based on the 2003-2014 redd survey data, provided by NMFS. The total starting populations assumed (shown below in Table A.1-1) in SALMOD were the geometric mean of the returning adults upstream of Red Bluff on the mainstem Sacramento River from the GrandTab data, for 2003 – 2014 period.

Table A.1-1: Total Number of Returning Adults Assumed in SALMOD for the Four Chinook Salmon Runs

	Winter-Run	Spring-Run	Fall-Run	Late Fall-Run
Number of Returning Adults	4,108	500[1]	23,356	5,545

As noted in the Appendix A.1.B (attached), the assumptions related to Winter Run spawning periods were also updated in SALMOD to reflect the recent historic observations.

A.1.2.2 SALMOD Results

The CWF BA version of SALMOD was run for 80 years of hydrology (1923 – 2002) for the With Sites and Without Sites scenarios, for the four Sacramento River Chinook runs. Sacramento

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[1] Used 500 returning adults for spring-run in SALMOD, per agreement with NMFS biologist as the number of spawning spring-run are very low in the mainstem Sacramento River.

River flow and temperature results from the HEC5Q models presented in the Sites Project WSIP application were used as inputs for running SALMOD. Table A.1-2 summarizes the long-term average annual production results from SALMOD for the four Sacramento River Chinook runs under 2015, 2030 and 2070 climate conditions. The results indicate improvements in annual production for all four runs upstream of Red Bluff with the Sites Reservoir project, under all climate conditions. Results indicate that Winter-Run Chinook salmon would see the largest relative improvement (3.3% – 6%) under all climate conditions. For all four Chinook salmon runs, the largest relative improvements are observed under 2070 climate conditions, for the With Sites scenarios. Appendix A.1.B of this memo includes the annual production SALMOD results for the 80-year simulation period for each run, for the Without Sites and With Sites scenarios under the three climate conditions.

Table A.1-2: Annual Production Results from SALMOD for the Four Sacramento River Chinook Salmon Runs

Runs	2015		2030		2070	
	Without Sites	Sites Increment	Without Sites	Sites Increment	Without Sites	Sites Increment
Winter	1,912,017	63,594 (3.3%)	1,996,967	68,269 (3.4%)	1,818,783	109,752 (6.0%)
Spring	429,539	8,767 (2.0%)	437,648	4,147 (0.9%)	357,458	17,520 (4.9%)
Fall	17,977,800	172,775 (1.0%)	17,896,789	226,190 (1.3%)	15,507,733	623,264 (4.0%)
Late-Fall	2,877,697	32,864 (1.1%)	2,892,264	20,442 (0.7%)	2,744,016	95,108 (3.5%)
All Runs	23,197,052	277,999 (1.2%)	23,223,668	319,047 (1.4%)	20,427,989	845,644 (4.1%)

As shown in Table A.1-3, the incremental improvements in the annual production SALMOD results are greatest for the Critical years. Under 2070 conditions, Sites Reservoir indicates greater than 60% improvement in production for Winter-Run and Spring-Run Chinook, upstream of Red Bluff. This finding validates the operational philosophy of the Sites Reservoir to provide maximum cold water habitat benefits in the driest periods.

Table A.1-3: Incremental Changes in Dry and Critical Years' Average Annual Production Results from SALMOD with the Sites Reservoir (Water year types are based on D-1641 40-30-30 Sacramento River Index)

Runs	Sites Increment in Dry Years			Sites Increment in Critical Years		
	2015	2030	2070	2015	2030	2070
Winter	2.3%	2.6%	6.1%	23.3%	14.8%	66.7%
Spring	1.3%	0.3%	6.3%	20.2%	6.0%	64.8%
Fall	1.6%	0.6%	7.0%	3.9%	3.1%	11.3%
Late-Fall	2.3%	1.2%	1.6%	4.4%	1.6%	21.2%

A.1.2.3 Flow Survival Effects of Sites Reservoir Diversions

CDFW noted that flow-survival effects downstream of the Sites Reservoir diversions have not been assessed in the Sites Project WSIP application, and recommended consideration of flow-survival relationships. Iglesias et al. (2017) flow-survival relationship was used to compute the monthly survival values for 1922 – 2003 period, downstream of the proposed Delevan diversion for the With Sites and the Without Sites scenarios at 2015, 2030 and 2070. A detailed description of various flow-survival relationships available for lower Sacramento River and the rationale for using Iglesias et al. (2017) along with computation of monthly survival estimates for the With and Without Sites scenarios are presented in Section A.2. Annual survival values were computed based on the average of monthly survival values for primary migration months for each run. Appendix A.1.A of this memo includes the annual survival values for the 82-year simulation period for each run. Table A.1-4 shows the relative change in long-term average annual survival downstream of the Sites Reservoir for the four runs. On average, annual survival is reduced by up to 1.4% for Winter-Run, 1.3% for Spring-Run and 1.1% for Fall-Run.

Table A.1-4: Relative Change in Lower River Average Annual Survival with Sites Project based on Iglesias et al. (2017)

Runs	Sites Increment		
	2015	2030	2070
Winter	-1.3%	-1.3%	-1.4%
Spring	-1.1%	-1.2%	-1.3%
Fall	-1.1%	-1.1%	-1.1%
Late-Fall	0.2%	0.1%	0.0%

For each run of Chinook salmon, the annual production results from SALMOD for the three With Sites scenarios were adjusted by the relative change in lower river annual survival computed for each year to recognize the potential effect of the reduced flows downstream of the proposed Delevan diversion. This adjustment assumes that the all fish “produced” above Red Bluff would be subject to any potential effects of reduced flows in the lower river due to Sites Reservoir diversions. Table A.1-5 shows the long-term average SALMOD annual production results for Without Sites and With Sites scenarios. Values for the With Sites scenarios reflect the relative change in lower river survival. All the runs continued to see improvements with the Sites Reservoir, with few exceptions. Spring-Run at 2030 shows 0.3% reduction and Fall-Run at 2015 shows 0.1% reduction. When all runs are considered together, on an average there is a 0.2% to 2.9% improvement in production above Red Bluff with the Sites Reservoir, even after adjusting for potential flow-survival effects downstream of the Sites diversions. Appendix A.1.B of this memo includes the annual production SALMOD results for the 80-year simulation period for each run, adjusted for the reduced flows downstream of the Sites Reservoir diversions.

Incremental changes in adjusted production for Dry and Critical years are summarized in Table A.1-6. For Dry years, incremental changes for Spring-Run and Fall-Run show a small reduction, when SALMOD production results were adjusted for flow-survival effects. However, results indicate large improvement in the production upstream of Red Bluff for all four Chinook runs with Sites Reservoir in Critical years.

Table A.1-5: Annual Production Results from SALMOD Adjusted for Reduced Flows Downstream of Sites Reservoir Diversions

Runs	2015		2030		2070	
	Without Sites	Sites Increment with Flow-Survival Adjustment	Without Sites	Sites Increment with Flow-Survival Adjustment	Without Sites	Sites Increment with Flow-Survival Adjustment
Winter	1912017	37990 (2.0%)	1996967	40459 (2.0%)	1818783	79484 (4.4%)
Spring	429539	3748 (0.9%)	437648	-1302 (-0.3%)	357458	12055 (3.4%)
Fall	17977800	-22827 (-0.1%)	17896789	22595 (0.1%)	15507733	424598 (2.7%)
Late-Fall	2877697	22348 (0.8%)	2892264	9195 (0.3%)	2744016	78820 (2.9%)
All Runs	23197052	41259 (0.2%)	23223668	70947 (0.3%)	20427989	594956 (2.9%)

Table A.1-6: Incremental Changes in Dry and Critical Years' Average Annual Production Results from SALMOD with the Sites Reservoir including Adjustment for Reduced Flows Downstream of Sites Reservoir Diversions (Water year types are based on D-1641 40-30-30 Sacramento River Index)

Runs	Sites Increment with Flow-Survival Adjustment in Dry Years			Sites Increment with Flow-Survival Adjustment in Critical Years		
	2015	2030	2070	2015	2030	2070
Winter	0.7%	0.9%	4.0%	22.2%	13.7%	65.7%
Spring	0.0%	-1.0%	4.4%	19.4%	5.2%	64.3%
Fall	0.4%	-1.5%	5.9%	2.6%	1.6%	9.4%
Late-Fall	2.0%	0.9%	1.0%	4.3%	1.5%	20.9%

A.1.3 OBAN Winter-Run Chinook Salmon Lifecycle Modeling

In addition to the SALMOD model, the Oncorhynchus Bayesian Analysis (OBAN) model was used to evaluate the potential for improvement and deterioration of winter-run population dynamics under the Sites Project.Detailed description of the OBAN 2015 model is provided in the Section 5.D.3.2.5 of the CWF BA Appendix 5D (USBR and DWR, 2016). The OBAN 2015 model was simulated for a With Sites scenario versus a Without Sites scenario to evaluate the relative differences in several population metrics (escapement, probability of extinction, etc.). For each of the three climate conditions, paired OBAN model runs were simulated.

In addition, to account for the potential flow-survival effects downstream of the Sites Reservoir diversions, three more paired OBAN model runs were simulated. For these three paired runs, survival downstream of the Red Bluff Diversion Dam was adjusted for the With Sites scenarios to reflect the flow-survival effects. The monthly survival values computed for flows downstream of the proposed Delevan diversion (based on Iglesias et al., 2017) were used to adjust the survival in the With Project scenarios. The relative changes in monthly survival values were weighted based on the proportions of the Winter-Run that undergo smoltification in each month in the NMFS WRLCM (NMFS, 2017) to compute the annual change in survival. The assumed proportions were: 0.269 for January, 0.366 for February, 0.348 for March and 0.017 for April. The annual change in survival was then used to adjust the survival in the With Sites scenarios for appropriate brood year.

Table A.1-7 shows the long-term average escapement values for Winter-Run Chinook salmon for Without Sites and the two variations of the With Sites scenarios. The results show substantial improvements in the escapement under the With Sites scenarios (2.5% to 10.6%). Even when the flow-survival adjustments were considered, the escapement under the With Sites scenarios show substantial improvement (2 to 10%). Detailed escapement results are presented in Appendix A.1.C.

Table A.1-7: Long-term Average Escapement for Winter-Run Chinook Salmon (1971-2002)

	2015	2030	2070
Without Sites Scenario	3997	2813	2258
Increment under With Sites Scenario	283 (7.1%)	70 (2.5%)	240 (10.6%)
Increment under With Sites Scenario with Flow-Survival Adjustment	264 (6.6%)	58 (2.1%)	228 (10.1%)

A.1.4 Conclusions

Additional analyses were performed to substantiate the anadromous fish ecosystem benefits identified for the Sites Project in its WSIP application, in response to CDFW comments. An updated version of the SALMOD model with inputs based on the recent historic fish population was used to simulate salmonid population dynamics for the With Sites and Without Sites scenarios. SALMOD results showed up to 6% improvement in average production between Keswick and Red Bluff for the four runs of Sacramento River Chinook salmon. In Critical years, average production increased by 2% to 67% in the With Sites scenarios for all Chinook runs. SALMOD production results were adjusted to recognize potential flow-survival effects in the Sacramento River downstream of the Sites diversions in the With Sites scenarios. Even with this adjustment SALMOD results indicate improvements in production of the Chinook salmon on the Sacramento River.

In addition, the OBAN lifecycle model was run to simulate Sacramento River Winter-Run Chinook salmon population dynamics for the With Sites and Without Sites scenarios. The With Sites scenarios were also simulated considering an adjustment to survival downstream of Red Bluff Diversion Dam, recognizing potential effects related to reduced Sacramento River flows downstream of the Sites diversions. The OBAN results indicated 2% - 10% improvements in Winter-Run escapement under the With Sites scenarios.

The information included in here adequately substantiates the anadromous fish ecosystem benefits claimed in the Sites Project WSIP application.

A.1.5 References

CWC. 2016. Water Storage Investment Program Technical Reference.

Iglesias, I. S., M. J. Henderson, C. J. Michel, A. J. Ammann, and D. D. Huff. 2017. Chinook salmon smolt mortality zones and the influence of environmental factors on out-migration success in the Sacramento River Basin. Prepared for U.S. Fish and Wildlife Service, Pacific Southwest Region, Central Valley Project Improvement Act, Sacramento, CA. Agreement Number F15PG00146. April. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

USBR and DWR. 2016. Biological Assessment for the California WaterFix.

NMFS. 2017. California WaterFix Biological Opinion.

Appendix A.1.A – Flow-Survival Effects

To address CDFW concerns regarding potential effects related to lower flows in the Sacramento River downstream of the intakes, Iglesias et al. (2017) flow-survival relationship was used to compute the monthly survival values. CalSim II monthly Sacramento River flow outputs downstream of the proposed Delevan diversion were used to compute the survival values for 1922 – 2003 simulation period, for the six With Sites and the Without Sites scenarios at 2015, 2030 and 2070. A detailed description of various flow-survival relationships available for lower Sacramento River and the rationale for using Iglesias et al. (2017) along with computation of monthly survival estimates for the With and Without Sites scenarios are presented in Attachment A.2. For each run, monthly survival values were used to compute annual survival values based on the average[2] of survival values in primary migration months[3]. The resulting annual survival values for each run under the six scenarios are included below in Tables A.1.A-1 through A.1.A-4.

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[2] Assumes equal likelihood of fish moving in each primary migration month.

[3] Based on the 2017 NMFS California WaterFix BiOp Appendix B Tables B-1 and B-2, November through April and November through May were assumed as primary migration months for Sacramento River Winter-Run and Spring-Run, respectively. Based on historic (1994-2016) Sac trawl data and the Red Bluff Diversion Dam 2002-2014 compendium report, December through June and August through January were assumed as primary migration months for Sacramento River Fall-Run and LateFall-Run Chinook salmon, respectively.

Table A.1.A-1: Annual survival estimates based on Iglesias et al. 2017 for Winter-Run Chinook salmon using the monthly Sacramento River flow downstream of proposed Delevan diversion.

Winter Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1922	0.72	0.70	0.73	0.71	0.74	0.72
1923	0.71	0.70	0.71	0.70	0.71	0.70
1924	0.66	0.66	0.67	0.66	0.67	0.67
1925	0.74	0.73	0.76	0.74	0.75	0.74
1926	0.72	0.70	0.72	0.71	0.73	0.72
1927	0.83	0.80	0.85	0.83	0.83	0.80
1928	0.78	0.77	0.78	0.76	0.79	0.77
1929	0.68	0.68	0.68	0.68	0.68	0.68
1930	0.72	0.70	0.72	0.69	0.74	0.71
1931	0.67	0.67	0.67	0.67	0.67	0.68
1932	0.69	0.68	0.70	0.68	0.71	0.69
1933	0.67	0.67	0.68	0.68	0.69	0.69
1934	0.69	0.68	0.70	0.68	0.70	0.68
1935	0.75	0.73	0.77	0.76	0.76	0.75
1936	0.74	0.72	0.76	0.75	0.77	0.76
1937	0.71	0.69	0.72	0.70	0.73	0.72
1938	0.91	0.90	0.92	0.91	0.91	0.89
1939	0.67	0.67	0.68	0.69	0.68	0.67
1940	0.83	0.83	0.83	0.82	0.84	0.83
1941	0.93	0.92	0.92	0.92	0.93	0.92
1942	0.86	0.86	0.84	0.84	0.85	0.84
1943	0.82	0.81	0.79	0.78	0.80	0.79
1944	0.70	0.69	0.70	0.69	0.70	0.69
1945	0.72	0.71	0.73	0.72	0.73	0.72
1946	0.78	0.77	0.79	0.78	0.79	0.77
1947	0.69	0.68	0.69	0.68	0.69	0.68
1948	0.70	0.69	0.72	0.71	0.70	0.69
1949	0.71	0.70	0.73	0.71	0.74	0.72
1950	0.71	0.69	0.71	0.69	0.72	0.70
1951	0.83	0.80	0.84	0.80	0.84	0.81
1952	0.90	0.88	0.87	0.87	0.87	0.86
1953	0.79	0.78	0.79	0.79	0.80	0.78
1954	0.83	0.82	0.82	0.82	0.81	0.80
1955	0.71	0.70	0.71	0.70	0.71	0.69
1956	0.86	0.85	0.86	0.86	0.85	0.85
1957	0.73	0.72	0.72	0.71	0.72	0.71
1958	0.91	0.90	0.90	0.90	0.90	0.89
1959	0.75	0.75	0.73	0.73	0.76	0.75
1960	0.72	0.70	0.72	0.71	0.73	0.72
1961	0.75	0.74	0.77	0.75	0.76	0.75
1962	0.76	0.74	0.76	0.74	0.77	0.75

Winter Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1963	0.81	0.78	0.81	0.78	0.80	0.78
1964	0.69	0.69	0.70	0.69	0.69	0.68
1965	0.84	0.82	0.83	0.82	0.83	0.81
1966	0.75	0.74	0.76	0.74	0.75	0.73
1967	0.84	0.83	0.85	0.83	0.87	0.84
1968	0.77	0.76	0.77	0.76	0.78	0.77
1969	0.86	0.85	0.85	0.85	0.86	0.85
1970	0.84	0.83	0.84	0.83	0.83	0.83
1971	0.82	0.82	0.83	0.82	0.83	0.82
1972	0.72	0.72	0.72	0.71	0.71	0.70
1973	0.85	0.84	0.86	0.85	0.85	0.85
1974	0.95	0.95	0.95	0.95	0.94	0.93
1975	0.79	0.79	0.80	0.79	0.81	0.80
1976	0.69	0.68	0.69	0.68	0.68	0.68
1977	0.68	0.67	0.67	0.67	0.66	0.67
1978	0.86	0.85	0.87	0.86	0.87	0.85
1979	0.73	0.71	0.73	0.72	0.73	0.71
1980	0.82	0.82	0.83	0.82	0.82	0.82
1981	0.74	0.72	0.75	0.73	0.75	0.74
1982	0.94	0.93	0.98	0.98	0.98	0.97
1983	0.95	0.94	0.95	0.94	0.94	0.93
1984	0.82	0.83	0.83	0.82	0.82	0.81
1985	0.71	0.71	0.71	0.70	0.71	0.69
1986	0.80	0.79	0.80	0.79	0.80	0.79
1987	0.71	0.70	0.72	0.71	0.72	0.70
1988	0.70	0.70	0.71	0.72	0.72	0.73
1989	0.71	0.70	0.71	0.70	0.72	0.71
1990	0.68	0.67	0.68	0.66	0.68	0.67
1991	0.69	0.68	0.68	0.68	0.68	0.68
1992	0.71	0.69	0.71	0.70	0.72	0.71
1993	0.82	0.79	0.83	0.81	0.83	0.80
1994	0.71	0.70	0.71	0.70	0.71	0.71
1995	0.84	0.83	0.86	0.85	0.86	0.85
1996	0.82	0.81	0.83	0.82	0.85	0.83
1997	0.82	0.81	0.82	0.81	0.82	0.81
1998	0.88	0.88	0.88	0.87	0.88	0.87
1999	0.83	0.83	0.84	0.83	0.83	0.82
2000	0.80	0.80	0.81	0.80	0.80	0.80
2001	0.72	0.71	0.72	0.70	0.72	0.70
2002	0.76	0.75	0.78	0.77	0.79	0.77
2003	0.81	0.78	0.83	0.81	0.83	0.81
Average	0.77	0.76	0.78	0.77	0.78	0.77
Relative Change	--	-1.3%	--	-1.3%	--	-1.4%

Table A.1.A-2: Annual survival estimates based on Iglesias et al. 2017 for Spring-Run Chinook salmon using the monthly Sacramento River flow downstream of proposed Delevan diversion.

Spring Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1922	0.71	0.70	0.73	0.71	0.73	0.71
1923	0.71	0.70	0.71	0.70	0.71	0.69
1924	0.66	0.66	0.66	0.66	0.67	0.67
1925	0.73	0.73	0.74	0.73	0.74	0.73
1926	0.71	0.70	0.72	0.71	0.73	0.72
1927	0.81	0.78	0.82	0.81	0.81	0.78
1928	0.76	0.76	0.77	0.75	0.78	0.76
1929	0.68	0.67	0.68	0.68	0.68	0.68
1930	0.71	0.69	0.71	0.69	0.73	0.70
1931	0.66	0.67	0.67	0.67	0.67	0.68
1932	0.69	0.67	0.69	0.68	0.70	0.68
1933	0.67	0.67	0.68	0.67	0.68	0.68
1934	0.69	0.68	0.70	0.68	0.70	0.68
1935	0.74	0.72	0.76	0.75	0.75	0.74
1936	0.73	0.71	0.75	0.73	0.76	0.75
1937	0.70	0.69	0.71	0.70	0.72	0.71
1938	0.89	0.89	0.89	0.88	0.88	0.87
1939	0.67	0.67	0.69	0.69	0.68	0.68
1940	0.81	0.81	0.81	0.80	0.82	0.81
1941	0.91	0.91	0.90	0.89	0.90	0.89
1942	0.85	0.84	0.82	0.82	0.82	0.82
1943	0.80	0.80	0.77	0.77	0.78	0.77
1944	0.70	0.68	0.69	0.69	0.70	0.68
1945	0.72	0.71	0.72	0.71	0.72	0.71
1946	0.77	0.76	0.78	0.76	0.77	0.75
1947	0.68	0.68	0.69	0.68	0.69	0.68
1948	0.72	0.70	0.73	0.72	0.71	0.69
1949	0.71	0.70	0.72	0.71	0.73	0.72
1950	0.70	0.69	0.71	0.69	0.71	0.70
1951	0.81	0.78	0.82	0.78	0.82	0.78
1952	0.88	0.86	0.85	0.84	0.84	0.84
1953	0.78	0.78	0.78	0.77	0.78	0.77
1954	0.81	0.81	0.80	0.80	0.80	0.79
1955	0.71	0.70	0.70	0.69	0.70	0.69
1956	0.85	0.84	0.83	0.83	0.83	0.83
1957	0.73	0.72	0.71	0.70	0.71	0.70
1958	0.89	0.88	0.87	0.87	0.86	0.86
1959	0.74	0.73	0.72	0.72	0.75	0.74
1960	0.71	0.70	0.71	0.71	0.72	0.71
1961	0.74	0.73	0.75	0.74	0.75	0.74
1962	0.75	0.73	0.75	0.73	0.75	0.74

Spring Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1963	0.79	0.76	0.79	0.76	0.79	0.77
1964	0.69	0.69	0.69	0.68	0.69	0.68
1965	0.81	0.80	0.81	0.80	0.81	0.80
1966	0.74	0.73	0.75	0.73	0.74	0.73
1967	0.84	0.83	0.83	0.82	0.85	0.82
1968	0.75	0.75	0.76	0.75	0.76	0.76
1969	0.84	0.84	0.83	0.83	0.83	0.83
1970	0.82	0.81	0.82	0.81	0.81	0.81
1971	0.81	0.80	0.81	0.80	0.81	0.80
1972	0.72	0.71	0.71	0.70	0.71	0.70
1973	0.82	0.82	0.83	0.83	0.82	0.82
1974	0.91	0.91	0.91	0.91	0.91	0.90
1975	0.79	0.78	0.78	0.78	0.79	0.78
1976	0.68	0.68	0.68	0.68	0.68	0.68
1977	0.67	0.67	0.66	0.67	0.66	0.67
1978	0.84	0.83	0.85	0.83	0.84	0.83
1979	0.72	0.70	0.72	0.71	0.72	0.70
1980	0.80	0.80	0.80	0.80	0.80	0.80
1981	0.73	0.72	0.74	0.72	0.74	0.73
1982	0.90	0.90	0.94	0.93	0.93	0.93
1983	0.93	0.92	0.92	0.92	0.91	0.91
1984	0.80	0.81	0.81	0.80	0.80	0.79
1985	0.71	0.70	0.71	0.70	0.70	0.69
1986	0.78	0.78	0.78	0.78	0.78	0.77
1987	0.71	0.70	0.71	0.70	0.72	0.70
1988	0.70	0.70	0.70	0.71	0.72	0.72
1989	0.71	0.70	0.71	0.70	0.72	0.71
1990	0.68	0.67	0.68	0.66	0.68	0.67
1991	0.68	0.67	0.68	0.67	0.68	0.68
1992	0.70	0.69	0.70	0.70	0.71	0.71
1993	0.80	0.78	0.81	0.80	0.81	0.79
1994	0.70	0.69	0.70	0.69	0.70	0.70
1995	0.85	0.83	0.86	0.85	0.85	0.84
1996	0.81	0.80	0.82	0.81	0.83	0.82
1997	0.80	0.79	0.79	0.80	0.79	0.79
1998	0.89	0.88	0.87	0.87	0.86	0.86
1999	0.82	0.81	0.82	0.81	0.80	0.80
2000	0.79	0.78	0.79	0.78	0.78	0.78
2001	0.71	0.71	0.71	0.70	0.71	0.70
2002	0.75	0.74	0.77	0.75	0.77	0.76
2003	0.82	0.80	0.83	0.82	0.83	0.81
Average	0.76	0.75	0.76	0.75	0.76	0.75
Relative Change	--	-1.1%	--	-1.2%	--	-1.3%

Table A.1.A-3: Annual survival estimates based on Iglesias et al. 2017 for Fall-Run Chinook salmon using the monthly Sacramento River flow downstream of proposed Delevan diversion.

Fall Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1922	0.72	0.70	0.72	0.71	0.72	0.71
1923	0.70	0.69	0.70	0.70	0.70	0.69
1924	0.66	0.66	0.67	0.67	0.67	0.67
1925	0.74	0.73	0.75	0.74	0.74	0.74
1926	0.71	0.70	0.73	0.72	0.74	0.73
1927	0.80	0.78	0.82	0.80	0.81	0.79
1928	0.76	0.75	0.76	0.75	0.78	0.76
1929	0.67	0.67	0.68	0.68	0.69	0.69
1930	0.71	0.69	0.72	0.69	0.73	0.71
1931	0.67	0.67	0.67	0.68	0.67	0.68
1932	0.69	0.68	0.70	0.68	0.70	0.69
1933	0.68	0.67	0.68	0.68	0.69	0.69
1934	0.69	0.69	0.71	0.69	0.71	0.69
1935	0.74	0.72	0.76	0.75	0.75	0.74
1936	0.73	0.72	0.75	0.74	0.76	0.76
1937	0.71	0.69	0.72	0.71	0.72	0.71
1938	0.88	0.87	0.86	0.85	0.85	0.84
1939	0.67	0.67	0.68	0.68	0.68	0.68
1940	0.81	0.81	0.82	0.81	0.83	0.82
1941	0.91	0.91	0.90	0.89	0.90	0.89
1942	0.84	0.84	0.82	0.81	0.82	0.81
1943	0.79	0.79	0.77	0.77	0.77	0.77
1944	0.69	0.68	0.69	0.68	0.69	0.68
1945	0.71	0.70	0.72	0.70	0.72	0.71
1946	0.76	0.75	0.78	0.76	0.78	0.76
1947	0.69	0.69	0.70	0.68	0.70	0.69
1948	0.72	0.70	0.74	0.72	0.71	0.69
1949	0.71	0.70	0.72	0.71	0.74	0.73
1950	0.70	0.69	0.71	0.69	0.71	0.70
1951	0.79	0.76	0.81	0.78	0.81	0.79
1952	0.87	0.86	0.84	0.84	0.84	0.83
1953	0.78	0.78	0.77	0.76	0.77	0.77
1954	0.80	0.79	0.79	0.79	0.80	0.79
1955	0.69	0.69	0.70	0.68	0.69	0.68
1956	0.85	0.84	0.83	0.83	0.83	0.82
1957	0.72	0.70	0.71	0.70	0.71	0.70
1958	0.88	0.87	0.87	0.86	0.86	0.86
1959	0.73	0.73	0.72	0.72	0.75	0.74
1960	0.71	0.70	0.72	0.72	0.73	0.72
1961	0.74	0.73	0.76	0.74	0.76	0.74
1962	0.75	0.73	0.75	0.73	0.76	0.74

Fall Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1963	0.79	0.77	0.79	0.77	0.80	0.78
1964	0.68	0.68	0.68	0.67	0.68	0.67
1965	0.81	0.79	0.80	0.79	0.81	0.80
1966	0.73	0.72	0.74	0.73	0.74	0.72
1967	0.84	0.83	0.83	0.81	0.85	0.82
1968	0.75	0.75	0.75	0.75	0.76	0.76
1969	0.84	0.84	0.83	0.82	0.83	0.82
1970	0.81	0.81	0.81	0.81	0.81	0.82
1971	0.80	0.79	0.80	0.79	0.80	0.79
1972	0.71	0.70	0.70	0.70	0.70	0.70
1973	0.82	0.81	0.83	0.82	0.83	0.82
1974	0.87	0.87	0.87	0.87	0.88	0.88
1975	0.78	0.77	0.77	0.77	0.78	0.78
1976	0.68	0.68	0.68	0.68	0.68	0.68
1977	0.68	0.67	0.67	0.67	0.67	0.67
1978	0.85	0.83	0.85	0.84	0.85	0.84
1979	0.71	0.70	0.72	0.71	0.72	0.71
1980	0.80	0.80	0.80	0.79	0.80	0.79
1981	0.73	0.72	0.73	0.72	0.74	0.73
1982	0.88	0.87	0.89	0.89	0.90	0.89
1983	0.94	0.93	0.91	0.91	0.90	0.91
1984	0.77	0.77	0.78	0.78	0.78	0.78
1985	0.70	0.69	0.69	0.69	0.69	0.68
1986	0.78	0.78	0.78	0.78	0.78	0.78
1987	0.71	0.70	0.71	0.70	0.72	0.70
1988	0.71	0.71	0.71	0.72	0.73	0.73
1989	0.71	0.70	0.71	0.71	0.72	0.71
1990	0.68	0.67	0.68	0.67	0.69	0.68
1991	0.68	0.68	0.69	0.68	0.68	0.68
1992	0.71	0.71	0.71	0.71	0.72	0.72
1993	0.81	0.79	0.83	0.80	0.82	0.79
1994	0.69	0.69	0.70	0.69	0.70	0.69
1995	0.86	0.84	0.87	0.86	0.86	0.85
1996	0.80	0.80	0.82	0.81	0.83	0.82
1997	0.79	0.78	0.79	0.79	0.79	0.78
1998	0.92	0.91	0.88	0.88	0.87	0.87
1999	0.81	0.80	0.80	0.80	0.80	0.80
2000	0.78	0.77	0.78	0.78	0.78	0.78
2001	0.71	0.71	0.70	0.69	0.71	0.69
2002	0.75	0.74	0.77	0.75	0.77	0.76
2003	0.82	0.80	0.84	0.82	0.84	0.82
Average	0.76	0.75	0.76	0.75	0.76	0.75
Relative Change	--	-1.1%	--	-1.1%	--	-1.1%

Table A.1.A-4: Annual survival estimates based on Iglesias et al. 2017 for Late-Fall-Run Chinook salmon using the monthly Sacramento River flow downstream of proposed Delevan diversion.

Late-Fall Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1922	0.72	0.71	0.71	0.70	0.71	0.70
1923	0.66	0.67	0.66	0.67	0.66	0.67
1924	0.67	0.67	0.67	0.67	0.67	0.67
1925	0.67	0.67	0.68	0.68	0.68	0.68
1926	0.72	0.70	0.74	0.73	0.73	0.71
1927	0.72	0.71	0.72	0.72	0.71	0.69
1928	0.69	0.69	0.68	0.68	0.67	0.68
1929	0.68	0.68	0.68	0.68	0.71	0.69
1930	0.66	0.67	0.66	0.67	0.66	0.67
1931	0.68	0.67	0.69	0.68	0.69	0.68
1932	0.66	0.66	0.66	0.67	0.66	0.67
1933	0.68	0.67	0.67	0.67	0.68	0.67
1934	0.68	0.68	0.69	0.69	0.70	0.69
1935	0.68	0.67	0.69	0.69	0.70	0.70
1936	0.66	0.66	0.66	0.67	0.68	0.68
1937	0.76	0.76	0.78	0.78	0.77	0.77
1938	0.69	0.69	0.70	0.70	0.69	0.69
1939	0.69	0.70	0.69	0.69	0.70	0.70
1940	0.76	0.76	0.77	0.77	0.79	0.78
1941	0.80	0.80	0.79	0.78	0.80	0.80
1942	0.75	0.75	0.74	0.74	0.76	0.76
1943	0.70	0.70	0.70	0.70	0.70	0.71
1944	0.68	0.68	0.68	0.69	0.68	0.68
1945	0.76	0.77	0.78	0.78	0.77	0.77
1946	0.67	0.68	0.69	0.69	0.66	0.68
1947	0.67	0.69	0.67	0.69	0.68	0.68
1948	0.67	0.68	0.68	0.69	0.68	0.68
1949	0.68	0.69	0.68	0.68	0.68	0.68
1950	0.77	0.76	0.79	0.76	0.77	0.76
1951	0.77	0.77	0.79	0.79	0.79	0.78
1952	0.79	0.78	0.79	0.79	0.79	0.79
1953	0.73	0.73	0.73	0.72	0.73	0.73
1954	0.73	0.72	0.73	0.72	0.73	0.72
1955	0.77	0.80	0.78	0.79	0.77	0.78
1956	0.71	0.72	0.70	0.71	0.70	0.71
1957	0.77	0.76	0.75	0.75	0.74	0.75
1958	0.72	0.72	0.71	0.70	0.71	0.71
1959	0.68	0.69	0.67	0.68	0.67	0.68
1960	0.69	0.70	0.69	0.71	0.69	0.70
1961	0.70	0.70	0.70	0.70	0.70	0.69
1962	0.72	0.71	0.74	0.73	0.72	0.70

Late-Fall Run	DCR2015	DCR2015_WP	WSIP2030	WSIP2030_WP	WSIP2070	WSIP2070_WP
1963	0.71	0.71	0.72	0.72	0.72	0.72
1964	0.78	0.79	0.78	0.79	0.78	0.79
1965	0.73	0.72	0.73	0.73	0.73	0.73
1966	0.76	0.76	0.75	0.75	0.76	0.75
1967	0.72	0.72	0.72	0.72	0.73	0.72
1968	0.75	0.76	0.76	0.77	0.76	0.77
1969	0.79	0.78	0.78	0.78	0.78	0.77
1970	0.80	0.79	0.81	0.80	0.81	0.80
1971	0.71	0.71	0.73	0.72	0.73	0.72
1972	0.76	0.77	0.75	0.76	0.75	0.76
1973	0.84	0.85	0.84	0.84	0.82	0.82
1974	0.72	0.72	0.71	0.71	0.71	0.71
1975	0.70	0.71	0.68	0.68	0.68	0.69
1976	0.67	0.68	0.66	0.68	0.66	0.68
1977	0.73	0.73	0.74	0.73	0.74	0.73
1978	0.70	0.69	0.70	0.69	0.70	0.69
1979	0.74	0.76	0.74	0.75	0.74	0.74
1980	0.70	0.70	0.71	0.71	0.71	0.71
1981	0.79	0.80	0.83	0.84	0.83	0.84
1982	0.81	0.80	0.81	0.80	0.80	0.80
1983	0.83	0.84	0.81	0.81	0.80	0.80
1984	0.73	0.72	0.73	0.72	0.72	0.72
1985	0.69	0.69	0.69	0.69	0.68	0.68
1986	0.68	0.68	0.69	0.69	0.69	0.69
1987	0.70	0.70	0.70	0.71	0.71	0.71
1988	0.67	0.68	0.67	0.68	0.69	0.68
1989	0.68	0.67	0.67	0.68	0.67	0.68
1990	0.66	0.67	0.65	0.66	0.66	0.67
1991	0.66	0.67	0.66	0.67	0.66	0.67
1992	0.74	0.73	0.73	0.73	0.72	0.73
1993	0.71	0.70	0.71	0.71	0.71	0.71
1994	0.73	0.74	0.73	0.74	0.72	0.74
1995	0.74	0.74	0.75	0.75	0.77	0.75
1996	0.81	0.81	0.81	0.81	0.82	0.81
1997	0.77	0.77	0.78	0.77	0.77	0.77
1998	0.76	0.76	0.75	0.75	0.74	0.74
1999	0.72	0.71	0.72	0.72	0.72	0.71
2000	0.70	0.70	0.70	0.71	0.71	0.70
2001	0.75	0.75	0.76	0.77	0.77	0.78
2002	0.77	0.77	0.77	0.79	0.77	0.79
2003	0.69	0.70	0.71	0.71	0.72	0.72
Average	0.72	0.72	0.72	0.72	0.72	0.72
Relative Change	--	0.2%	--	0.1%	--	0.0%

Appendix A.1.B – SALMOD Results

The version of the SALMOD model used in the August 2016 California WaterFix Biological Assessment (CWF BA) was used for simulating Chinook salmon population dynamics for the six With Sites and Without Sites scenarios. The model was described in detail in the Appendix 5D Attachment 2 of the CWF BA, and it can be accessed using one of the following weblinks.

http://cms.capitoltechsolutions.com/ClientData/CaliforniaWaterFix/uploads/App_5.D_Methods_Att2_SALMOD.pdf

or

https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/exhibit104/docs/App_5.D_Methods_Att2_SALMOD_RevisedDraftBA.pdf

SALMOD simulates the dynamics of freshwater salmonid populations. The model tracks a population of spatially distinct cohorts that originate as eggs and grow from one life stage to another as a function of local water temperature. SALMOD has been constructed, in part, as a way to integrate habitat limitations to a population through time and space, both microhabitat and macrohabitat that are dependent on streamflow.

Sacramento River application of the SALMOD model includes 279 computational units from Keswick Dam to the Red Bluff inundation pool (approximately 85 km [53 miles] in length). SALMOD is a weekly timestep model, and the simulation period is 80 biological years (1923 to 2002). Each biological year is independent and is initialized with same number of fish at the beginning of every year. SALMOD has a fixed timing template for the model's treatment of each run's biological year. The weekly timestep was identified corresponding to the start of the biological year for each of the four runs of Chinook salmon are identified below in Table A.1.B-1.

The biological processes simulated in the Sacramento River application of SALMOD include spawning, egg development and juvenile growth, mortality, and movement. Each biological year SALMOD is initiated with same number of the spawners. The number of spawners (Table A.1.B-2) and spatial distribution (Table A.1.B-3) of spawners are based on 2003 – 2014 historic observations.

The model is provided with the proportion of adults ready to spawn each week of the designated period (Figure A.1.B-1). These proportions will hold unless other factors preclude spawning, such as temperatures being too high (they wait) or not enough spawning habitat even with superimposition (the adults shed their eggs and die). Assumptions for the temporal distribution of Winter-Run spawners were updated based on average 2003–2014 redd survey data. The timing and durations of some of the key SALMOD processes were updated for Winter-Run based on the updated temporal distribution. The processes for which the durations were modified are listed below:

- Carry: week 1 to week 29
- Spawn: week 13 to week 29
- Invivo Mortality: week 1 to week 29
- Habitat Movement for fry, presmolts and immature smolts: week 27 to week 52

Tables A.1.B-4 through A.1.B-7 show the annual SALMOD production results for the four Sacramento River Chinook salmon runs, corresponding to six Without Sites and With Sites scenarios. The tables also include the annual SALMOD production results adjusted for potential effects on survival due to reduced flows in the Sacramento River downstream of the proposed Delevan diversion as discussed in Appendix A.1.A, for the three With Project scenarios.

Table A.1.B-1: Correspondence between SALMOD Weekly Timestep and start of the Biological Year for each of the Four Runs of Chinook Salmon

Simulation week	Fall Run	Late-Fall Run	Winter Run	Spring Run
1	2-Sep	3-Dec	4-Feb	6-May

Table A.1.B-2: Total Number of Returning Adults Assumed in SALMOD for the Four Chinook Salmon Runs

	Winter-Run	Spring-Run	Fall-Run	Late Fall-Run
Number of Returning Adults	4,108	500[4]	23,356	5,545

Table A.1.B-3: Assumed Distribution of Spawners in Eight Spawning Segments of the Study Area

Spawning Segment Number	Description	Cumulative Distance from Keswick (meters)	Spawning Distribution (%)			
			Fall	Late-Fall	Winter	Spring
1	Keswick to A.C.I.D.	5,791	19.50%	71.30%	45.10%	12.83%
2	A.C.I.D to Highway 44 Bridge	9,025	6.60%	5.20%	42.10%	33.97%
3	Highway 44 Br. to Airport Road Bridge	28,810	14.70%	3.90%	12.20%	29.76%
4	Airport Road Br. to Balls Ferry Bridge	41,411	19.40%	8.90%	0.30%	11.12%
5	Balls Ferry Bridge to Battle Creek.	49,207	12.50%	5.90%	0.10%	7.41%
6	Battle Creek to Jellys Ferry Bridge	56,538	15.20%	3.10%	0.10%	1.50%
7	Jellys Ferry Bridge to Bend Bridge	71,413	8.00%	1.20%	0.10%	2.61%
8	Bend Bridge to Red Bluff inundation zone	84,828	4.20%	0.60%	0.00%	0.80%
	Totals		100.0%	100.0%	100.0%	100.0%

Note:
It was assumed that there were no redds in the Red Bluff inundation zone

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[4] Used 500 returning adults for spring-run in SALMOD, per agreement with NMFS biologists as the number of spawning spring-run are very low in the mainstem Sacramento River.

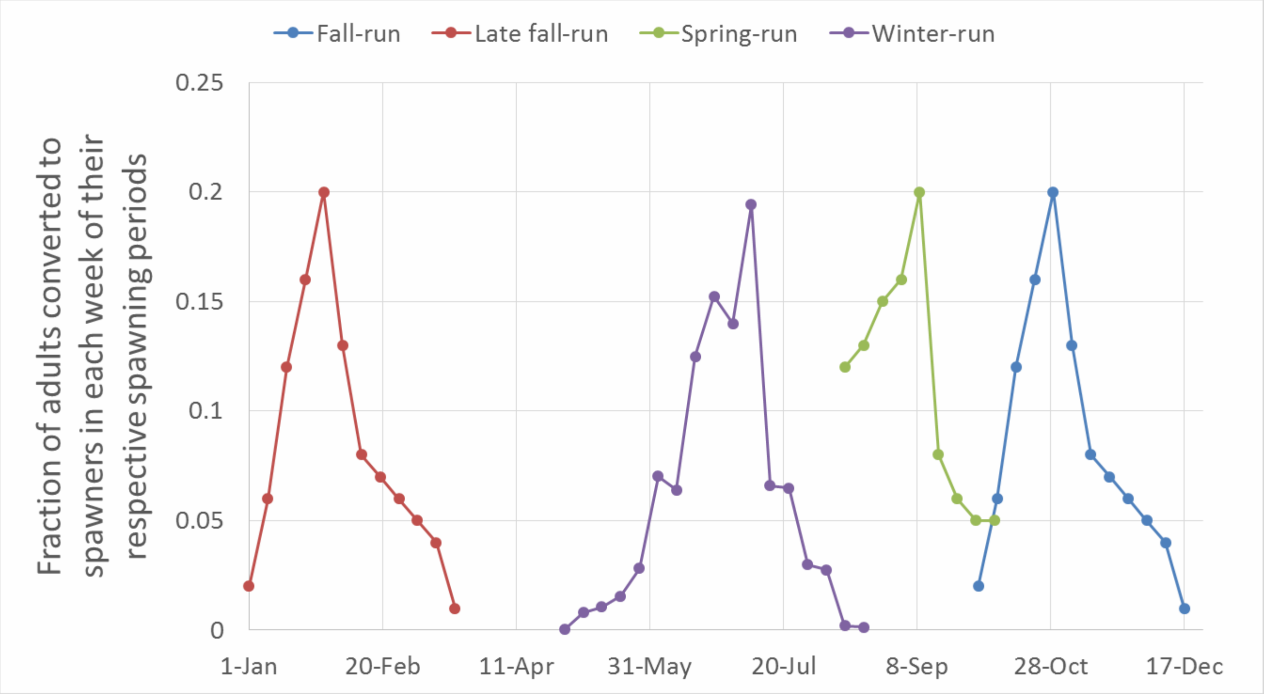

Figure A.1.B-1. Fraction of Adults Converted to Spawners in each Week of their Respective Spawning Periods

Table A.1.B-4: SALMOD Annual Winter-Run Production Results

	SALMOD Winter-Run Production (# of fish)						Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1923	2314487	2283003	2246969	2254780	2289643	2238126	2218643	2199566	2184620
1924	2064832	2134537	2083887	2129297	2033726	2157124	2110958	2088149	2111714
1925	2177188	2104428	2175662	2158982	635801	1194738	2096974	2154842	1194738
1926	2067741	2054133	1946483	1978677	2068499	1930019	2027993	1944855	1917223
1927	2115471	1986027	2059903	2051474	2131318	2236083	1944760	2021979	2208166
1928	1948428	1863692	2017931	2058094	2040014	1847115	1793070	2009314	1771287
1929	2184711	2085836	2130302	2066555	2128219	2111828	2063379	2024958	2062063
1930	2016393	2043722	2117468	2150620	1389357	2121812	2028320	2150556	2119549
1931	1993296	2069038	2014035	2029146	2025446	2113339	2004473	1937248	2026253
1932	1164977	2124586	2159623	2151354	179012	934499	2124586	2139808	934499
1933	2125179	2149443	2041599	2136700	2127489	2155700	2097235	2078651	2094702
1934	979375	2050885	2091649	2135820	998149	1960189	2042852	2122391	1958451
1935	553368	1008035	2146711	2170923	516343	1723957	994103	2110664	1673316
1936	2031010	1976066	2080930	2114567	1989830	2006577	1913795	2074613	1968112
1937	1937406	1967192	1967460	1987732	2042928	1979540	1923839	1952967	1966342
1938	1942594	2000429	2064361	2099258	2032454	2131751	1942164	2055994	2091400
1939	1927286	1914629	2035989	2071074	2026487	2038539	1901552	2053466	2007629
1940	2051525	2087243	2143738	2157402	2016401	1977873	2087243	2157402	1970719
1941	1828006	1923371	2074950	2082467	1912158	1873925	1914305	2058998	1849880
1942	2031930	2041252	2083803	2096955	2086127	2096414	2035421	2081402	2073920
1943	1970404	1930261	2093882	2103521	2119692	2135810	1921216	2098889	2114388
1944	1975899	2032197	2192538	2210453	2266519	2262685	2017871	2193546	2240212
1945	1996716	2024636	2074984	2185231	2064609	2213397	1989981	2158574	2169403
1946	1918674	2049813	2050640	2151808	2020201	2073365	2017566	2105766	2029698
1947	1923883	1923581	2041492	2048903	1731373	1903992	1895822	2002396	1846764
1948	1961573	2012172	2102986	2115549	2153216	2090271	2001298	2069644	2064484
1949	1998923	2002202	2123243	2179695	2011719	2129072	1964039	2157900	2090572
1950	1890564	1985117	2016251	2097506	1969988	2137118	1953773	2057373	2093348
1951	1901847	2008935	1949251	2105010	1905943	2080001	1963922	2045012	2040242
1952	1888714	1838214	2072916	2086485	2043596	2049969	1766127	1990332	1962304
1953	2067420	2072789	2063086	2146758	1941856	2046545	2040552	2131453	2022003
1954	1928358	1944056	2079094	2066680	2069195	2011345	1933408	2052712	1981598
1955	1941701	1991889	2016917	2000261	2066724	2020801	1983384	1995150	1987347
1956	1886828	2052743	1981787	2113792	2023663	2091948	2028347	2064799	2039652
1957	1869601	1848685	1916164	2068064	1903034	2042455	1837731	2068064	2042455
1958	2129745	2133474	2089361	2109824	2087926	2092353	2108386	2073810	2055815
1959	2075864	2031804	2091578	2170610	2100422	2138420	2002354	2153727	2129372
1960	1759175	1957950	1879541	2088156	1683596	2027691	1946939	2073172	1993963
1961	2020469	2027736	2068944	2096806	2000318	2099486	1995865	2080588	2071124
1962	2042293	1993681	2101991	2009514	2091503	2100605	1971035	1977945	2053745
1963	1844703	1904520	1777288	1869457	1722397	1924894	1857707	1822337	1877563
1964	2026153	1933213	2232671	2270565	2306008	2310768	1859734	2189789	2242426
1965	1897325	2040214	2085332	2102505	2040674	2122947	2038507	2073907	2090818

SALMOD Winter-Run Production (# of fish)							Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1966	1932380	2001737	2068248	2097039	2018920	2098982	1961448	2060720	2063719
1967	2067741	2071349	2062713	2149992	2021795	2032217	2035850	2094729	1982476
1968	2104271	2031844	2161608	2087110	2087094	2043149	1999348	2037695	1977178
1969	1917418	1921921	2122594	2063450	1937008	2002255	1912749	2045312	1977921
1970	1913628	1913124	1988984	2011108	1932000	1933746	1903020	2007948	1921787
1971	2070517	2052571	2031777	2115824	2073946	2103586	2038003	2099669	2103586
1972	2107042	2055116	2123999	2142274	2149647	2115560	2036955	2118675	2086800
1973	2009794	2005691	1959449	2110661	1926773	2050936	1988250	2087717	2022575
1974	1635476	1680825	1754369	1789068	1838233	1811263	1669585	1780041	1805213
1975	2026286	2025472	2040498	2110159	2050362	2132970	2024663	2109851	2121492
1976	2151451	2160361	2113587	2128731	2236620	2211679	2144243	2104961	2185111
1977	1853267	2086507	1889662	2212873	1952504	2161126	2075715	2190372	2154670
1978	120991	680146	23025	223589	374	134	675148	223589	134
1979	1959163	1879800	1910372	1890086	2075111	2069209	1855166	1861892	2035395
1980	1949871	2034476	2009190	2108303	1962929	2131693	1980529	2073571	2072198
1981	1731713	1902050	1805150	1856957	1872598	1909576	1893723	1838890	1899148
1982	1909404	1962636	2000292	1992697	2055668	2065217	1926098	1955234	2022347
1983	2091072	1890563	1918671	1876519	2038932	1973581	1880512	1872242	1963706
1984	2083644	2057556	2088654	2069262	2037278	1976535	2037041	2058784	1956321
1985	1976795	1949967	2163513	2150039	2132615	2182983	1949967	2139436	2154625
1986	2062750	2140782	2139622	2139337	1974341	2131865	2116744	2119936	2094432
1987	1764236	1804092	1937397	1964137	2041086	1989159	1794228	1952588	1974034
1988	2091906	2059383	2057191	2126665	1886288	2088056	2021564	2095584	2033087
1989	1974991	2025231	2022408	2160187	239971	771310	2015176	2160187	771310
1990	1968034	1988621	1998361	2084175	912461	1813243	1963036	2058080	1795850
1991	2100314	2181958	2156953	2148706	37588	136930	2140787	2102458	136081
1992	1978428	2110146	1138401	1986963	17751	119997	2083994	1967728	119997
1993	380465	858671	336966	1669831	4972	22302	844105	1646432	22011
1994	2147378	2139910	2154763	2225151	2183476	2105655	2063461	2188102	2045655
1995	2029074	2086192	2040416	2137225	1950969	2057638	2059245	2109625	2042749
1996	2171820	2147370	2160085	2158114	2176652	2181278	2109432	2140640	2162802
1997	2115621	2147392	2183007	2164693	2178127	2173463	2134482	2147957	2129943
1998	2034398	2058776	2090512	2134481	2067490	2154562	2039602	2132752	2136318
1999	2175590	2163668	2142653	2142521	2194265	2174920	2147486	2120768	2154335
2000	2041253	2027537	2019136	2053690	2101873	2134325	2026608	2044981	2113222
2001	2085363	2065715	2158661	2132592	2178424	2143704	2045829	2110152	2124021
2002	1855749	2072235	1999086	2125624	1962925	2142879	2045476	2080100	2075209
Average:	1912017	1975610	1996967	2065236	1818783	1928535	1950006	2037426	1898267
Relative Change:	--	3.3%	--	3.4%	--	6.0%	2.0%	2.0%	4.4%

Table A.1.B-5: SALMOD Annual Spring-Run Production Results

SALMOD Spring-Run Production (# of fish)							Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1923	479396	482110	480683	480873	480037	474346	470560	470467	464116
1924	465762	476342	464904	481775	448900	469497	471777	473661	460868
1925	460516	459913	425613	438521	0	51	458712	438521	51
1926	472325	467543	473717	474717	475872	474991	462274	467494	471922
1927	462345	456221	465189	470525	409347	417130	449080	462598	412908
1928	463965	464313	472404	471372	479967	481093	446620	461292	464033
1929	473118	470941	477305	480090	466535	471728	466533	471429	462131
1930	460944	455664	458289	447924	9	161547	453139	446996	161429
1931	467422	464554	469942	469384	446150	463104	452031	450945	446492
1932	10442	422648	355598	449738	0	0	422648	448296	0
1933	418518	454053	445001	457768	406442	444649	444583	446921	433587
1934	6	67808	448847	445450	0	21362	67581	443025	21362
1935	722	194	448579	429868	0	1760	192	419768	1718
1936	462466	454298	473414	474600	464348	469296	441255	464642	461627
1937	468535	458453	481239	482613	483610	484038	449729	475231	481900
1938	449299	450473	464089	470361	455815	470125	439112	461248	462107
1939	470782	475609	478202	481952	479061	480064	472647	478621	475360
1940	458424	468367	440933	420068	79363	66224	468367	420068	65942
1941	460872	456261	466896	465855	5949	5734	454352	461158	5668
1942	463861	460843	460404	459627	467311	471894	459620	456516	467377
1943	458916	459879	469624	470957	478920	477576	457908	469914	472553
1944	469913	469645	480942	476552	482009	486148	466379	473228	481692
1945	452111	460588	452986	451770	367533	445909	453811	446965	438540
1946	439741	434310	460660	457856	453221	450195	428437	448665	441367
1947	456013	450617	471564	470467	463850	477585	444977	461028	464894
1948	456630	468060	459956	465616	422049	450047	466653	456162	446098
1949	459909	461785	476562	478412	454131	476035	450692	472118	462928
1950	457409	452327	474199	472917	471912	477045	446834	465021	470223
1951	450613	451712	456355	467605	425219	447453	443042	455374	440283
1952	446596	439969	454623	455058	465793	469575	424832	436429	451593
1953	463085	464989	471501	472018	471484	470743	458519	468794	465319
1954	460173	460241	472303	471221	477496	475383	457925	468318	468976
1955	461994	462985	466991	467546	474629	482034	461770	466383	475289
1956	435840	449478	428100	442282	416904	439085	444860	433294	429379
1957	467187	468418	479292	478003	479711	481548	465877	477832	480879
1958	460140	459881	472222	470497	462341	471163	454779	463550	463712
1959	482973	478208	483674	482182	471552	483545	471934	478602	481379
1960	463484	478167	459964	472315	380665	386790	475831	468914	382041
1961	462234	461687	464195	466211	432908	463590	455429	463093	457907
1962	461732	458882	471877	470160	461404	471604	454128	463689	463215
1963	461364	459283	472873	476368	455892	480638	449505	465895	469894
1964	465492	465723	478143	479737	412283	445695	450298	464729	434347
1965	449388	454015	454713	446016	381987	360731	453686	440727	355627

SALMOD Spring-Run Production (# of fish)							Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1966	446647	442310	461562	462947	470663	474659	434517	455714	468064
1967	456582	451609	466637	466955	462204	453788	444852	456435	443587
1968	468740	469148	469829	471222	476372	470335	462587	461394	456654
1969	453294	453932	467078	468213	459642	471397	452044	464571	466312
1970	464614	466367	468368	469624	470464	470606	463963	468647	467485
1971	458579	459536	463805	466514	289486	432069	456651	463345	432069
1972	458814	459677	470543	472314	478281	477711	455386	467615	471829
1973	457809	456715	450801	463973	418701	449117	453297	459824	444855
1974	440064	436623	455244	456472	459489	461634	434038	454249	460070
1975	461760	464084	474030	477722	476240	480487	463854	477454	478299
1976	470010	468868	479843	483338	481390	487686	465675	478446	482234
1977	431327	473445	366042	441420	293691	382541	471358	438411	381779
1978	18	74	2	5	0	0	74	5	0
1979	469726	464764	472390	470536	476538	479956	457233	463925	473034
1980	448329	458031	442236	453414	396795	445501	447592	446838	434532
1981	459353	454290	466830	466313	470449	474463	452555	462231	472057
1982	448386	448841	461486	460949	447752	463451	441638	453398	454617
1983	455415	458122	465095	459675	470449	471154	457368	458586	468783
1984	470466	471365	467027	469005	457070	456465	467260	466830	453353
1985	463017	464469	475505	476028	426687	424208	464469	473891	419269
1986	472361	469194	473315	473509	333856	347044	464642	469730	341833
1987	472571	471475	479137	482771	66522	443522	469211	480197	440392
1988	468208	450456	446578	436045	29001	157923	443626	430284	154575
1989	446967	448544	66603	75763	0	0	446523	75763	0
1990	468433	454734	432162	436907	63	26439	451345	432929	26229
1991	449473	447539	379987	341082	0	0	440290	334756	0
1992	386911	435400	0	26615	0	0	430800	26394	0
1993	296	9	0	2602	0	0	9	2584	0
1994	475773	478241	472559	478910	469630	472154	465685	469201	460161
1995	407180	460489	392568	445312	144213	154330	455495	440304	153335
1996	480310	482535	479357	481282	475910	477507	472781	476426	471733
1997	472356	470858	464873	464570	399029	397568	468285	461303	390410
1998	456657	460263	450581	457047	341614	249792	456488	457047	247886
1999	461392	457774	479309	479281	468110	463776	454852	475070	459975
2000	474622	473648	480088	480909	469876	470851	473328	478961	466541
2001	483734	482279	472767	485852	413764	395238	478129	481270	391937
2002	390263	461281	413015	423632	290051	316108	456129	415994	308414
Average:	429539	438306	437648	441795	357458	374978	433287	436346	369513
Relative Change:	--	2.0%	--	0.9%	--	4.9%	0.9%	-0.3%	3.4%

Table A.1.B-6: SALMOD Annual Fall-Run Production Results

	SALMOD Fall-Run Production (# of fish)						Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1923	20086562	19798699	19890459	20064678	19605956	19395566	19321264	19614048	18962763
1924	19709791	19981781	19074442	19368154	18395805	18950295	19825763	19203543	18626514
1925	19325531	19544465	18566601	18962397	6025823	8956594	19544465	18962397	8956594
1926	19073136	19321618	19051462	18879311	19005736	19158569	19105362	18616494	19062002
1927	18756925	18492205	18279285	18472136	16892125	16896125	18275083	18212924	16769296
1928	19025254	19101460	19042022	19409579	19510107	19462759	18530252	18936741	18947916
1929	19971300	19920273	19888078	20076949	19879374	19799709	19773687	19725450	19446924
1930	19501726	19345026	19309192	19205840	5285930	11147413	19306615	19145575	11118216
1931	20164326	20351817	19783323	20027105	19273293	19528454	19821933	19225206	18889235
1932	15126850	19138803	18044424	19346217	3204783	6197088	19138803	19346217	6197088
1933	19369415	19811004	19375486	19680420	17917360	18951195	19464870	19306826	18584453
1934	8693459	14967442	18923358	18842640	4574342	9888234	14935528	18775793	9888234
1935	8512138	11080867	18857731	18718341	3210153	10079666	11012719	18391069	9881605
1936	18977399	18847759	19141480	19045591	18903769	18701121	18296123	18749169	18443229
1937	19449548	19443841	19370085	19780205	19134289	18986067	19098702	19524772	18901743
1938	17700594	17870225	17519827	17519863	15602634	15785552	17491566	17267324	15526712
1939	19495574	19571245	19500402	19085465	19678628	19869148	19394389	18951347	19715310
1940	18666136	18537084	18550845	18497182	8833804	9576413	18537084	18494425	9553900
1941	18375586	18510829	18748271	18567431	10232684	10102192	18414342	18439866	10034250
1942	18549319	18545114	18667360	18744697	18226761	18614435	18545114	18614023	18412375
1943	18847709	18813285	19110180	19161264	19672925	19537837	18787054	19111983	19338797
1944	19664176	19760501	19666183	19512465	19078469	19345441	19614823	19360181	19212359
1945	18938515	19357974	19115842	19408097	17549596	19281283	19157573	19232961	19010985
1946	17342112	16993661	16857087	16664947	17280433	16909512	16762765	16291791	16615049
1947	18915101	18969389	19445059	19355977	19276328	19570337	18612623	18965399	19198375
1948	19377149	19633903	19383052	19690808	19094858	19628296	19591623	19299423	19398980
1949	18612345	18674635	19227494	19313558	18991186	19160536	18135901	18960578	18566808
1950	18952362	18822602	19229334	19453449	19064768	19021922	18596044	19203798	18820707
1951	18370098	18583114	18925855	18963359	18519927	18664506	18195372	18518909	18413907
1952	17940898	18132482	18456262	18383821	19060523	18938619	17476627	17838978	18316227
1953	18926986	18872930	19145048	19039987	19244948	19162132	18707589	18941487	18956577
1954	18509307	18627307	18826633	18764505	19156809	18848557	18561084	18639520	18656307
1955	20252058	20173146	20212543	20317555	20048815	20295845	20144950	20286036	20113565
1956	16529623	16617038	16324289	17003714	13844756	13921904	16471465	16671517	13669910
1957	18753261	19044468	19648078	19557883	19173626	19492705	18822428	19510800	19439208
1958	17596621	11344372	13202352	13348280	13564109	13589187	11169515	13135073	13364511
1959	19020226	19118360	18831935	19124584	18981191	19161675	18869405	19045833	19090225
1960	19589586	19853893	18915820	19312142	17786633	17057483	19796647	19184718	16923322
1961	18646628	18638504	19281142	19181681	18767616	19184615	18408194	19097707	19022318
1962	18767755	18519466	18772407	19081061	18774058	18831101	18336856	18729073	18450080
1963	18509664	18561392	18885301	18973487	18900536	18988531	18055015	18451900	18543717
1964	19890994	19903296	19896874	19988663	18913914	19303915	19314702	19453343	18872464
1965	18071726	18092699	18778262	18801480	18184791	17450881	18048602	18619744	17254179

SALMOD Fall-Run Production (# of fish)							Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1966	18761077	18755651	19134958	19143709	19252879	19241985	18405209	18859697	19009833
1967	18445681	18372471	18338423	18492040	19054144	18785206	18136588	18088825	18431715
1968	19009244	18995433	19018961	18950810	19078381	18982447	18766804	18530401	18433186
1969	18214039	18094280	18647707	18553062	18483163	18713580	18079299	18485494	18630056
1970	9391611	9436175	10466504	10626727	9273226	9525142	9365047	10570769	9414381
1971	18472341	18629096	18850266	18719569	16693739	18521347	18535164	18596053	18521347
1972	18736203	18919716	18945916	19156049	19039436	19235614	18753566	18963026	18965151
1973	18874514	18644944	18807209	18808154	18524420	18952191	18466645	18644225	18751877
1974	15906232	15550583	15184986	15341052	10323413	10221492	15459449	15291158	10197815
1975	18612310	18642280	18655694	18858026	19093252	19119199	18641554	18858026	19119199
1976	19101242	19157973	19279062	19415969	19372710	19411079	18996129	19257917	19252601
1977	20111986	20287547	18578667	19143270	15646731	17021085	20196979	19065217	17003108
1978	3168324	7183348	3035069	3044620	2931474	2969569	7116453	3044620	2969569
1979	19639286	19502010	19589107	19613078	19198881	19358045	19184888	19335830	19116177
1980	18607145	18665721	18770051	18829324	17898038	18940501	18313153	18610701	18665882
1981	19371148	18938693	18985102	19262110	19177835	19267342	18818082	19046020	19128588
1982	17252384	17342814	17304565	17103902	17326477	17194660	17136135	16845878	16875947
1983	16182576	16213953	15298260	15377970	15287522	15346638	16163085	15312723	15236358
1984	17636368	18018581	17664184	17724000	16801871	16811885	17783448	17724000	16811885
1985	19531585	19617016	19939553	20093213	19642591	19391006	19617016	20093213	19391006
1986	15903311	15315461	17839422	17379924	15625143	15422375	15273630	17346959	15167244
1987	18924036	18905092	18860291	18863164	12207387	17954996	18815802	18742073	17859240
1988	19436369	19062465	19216946	18967472	8629524	12849994	18841129	18670693	12527917
1989	19486220	19335017	13404169	13931192	4017485	6053383	19312456	13931192	6047562
1990	20027720	20259449	19775330	19925736	7094288	11808690	20165070	19741194	11727481
1991	19643941	20132991	18564426	18086100	3416935	3434581	19872748	17765083	3407264
1992	17956618	18711590	4953728	10480425	3337948	3443401	18484095	10377078	3443401
1993	8388453	7602295	4215654	9248905	3342703	3305700	7528775	9232050	3267293
1994	19649855	19949029	19146175	19350347	18893346	18947341	19329383	18869023	18413327
1995	16762558	17129112	15131040	15327838	11517803	11404808	16949581	15185841	11356234
1996	19042527	19098846	18769786	18882925	18659566	18814185	18739068	18673164	18605936
1997	18394855	18095611	18157967	18162425	13251232	13099520	18063478	18061930	12943430
1998	15382686	15572655	14327374	14722783	11020971	9308053	15433067	14722783	9259043
1999	18845904	18772448	18957725	18989976	18766107	18661266	18650665	18857236	18524335
2000	19046262	19009733	18866618	18772532	18296357	18369741	19005779	18720872	18236317
2001	19006276	19183843	18923575	18975927	18389837	18195975	19070336	18843650	18086952
2002	18745624	19652047	18417521	18817081	15727619	17002294	19457563	18532175	16620828
Average:	17977800	18150574	17896789	18122980	15507733	16130997	17954973	17919384	15932330
Relative Change:	--	1.0%	--	1.3%	--	4.0%	-0.1%	0.1%	2.7%

Table A.1.B-7: SALMOD Annual Late Fall-Run Production Results

SALMOD Late Fall-Run Production (# of fish)							Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1923	3073157	3050230	3017818	3037185	3099307	3224674	3022390	2974968	3186244
1924	3183279	3210797	3292501	3135813	2716045	3013364	3210797	3135813	3013364
1925	3114145	3047218	2931277	2940475	2980658	3004686	3047218	2938629	2997629
1926	3149214	3083609	2864959	3035928	3113599	3152170	3080532	3035928	3144455
1927	2872796	2758348	2598467	2609767	2764194	2762927	2702131	2576415	2707786
1928	2809142	3005116	2872905	3029858	2995808	3049302	2971287	2999348	2981930
1929	3245434	3128135	3236143	3190186	2929783	3188456	3128135	3190186	3188456
1930	3073196	3153159	3161688	3271451	3142514	3148868	3153159	3247800	3043899
1931	2861334	3173484	3219777	3183609	1714162	2971195	3173484	3183609	2971195
1932	2813619	2788521	3129486	3008940	3051953	3029833	2738676	2946011	2975798
1933	2836583	3005251	3197008	3200821	2875323	3093236	3005251	3200821	3093236
1934	2554125	2988171	3062776	2945217	2223237	2894413	2948655	2907159	2814526
1935	2806272	2903343	2919719	2862763	2799370	2957953	2902651	2862763	2923657
1936	2990825	2873059	3018679	2938980	2970006	3090566	2827309	2922790	3090566
1937	3207814	3276742	3277344	3150269	3239968	3275570	3276742	3150269	3275570
1938	2611451	2609766	2522031	2554876	2428118	2348077	2609766	2554876	2348077
1939	2926147	3039797	2989960	3031214	3119773	3028275	3039797	3031214	3028275
1940	2717643	2785653	2903885	2766457	2677814	2667351	2785653	2766457	2667351
1941	2795901	2793780	2638127	2775039	2641343	2726178	2793780	2773165	2682260
1942	2848388	2858722	2779803	2794424	2779626	2852358	2849783	2786477	2835169
1943	2734129	2725439	3068476	3156448	3000915	3129840	2699902	3136586	3109200
1944	3156848	3189024	3175569	3215339	3214078	3293369	3189024	3215339	3293369
1945	3048293	3026515	2893066	3140805	3247520	3284462	3026515	3140805	3284462
1946	2880987	2907824	2800803	2729511	2919010	3019404	2907824	2729511	2989873
1947	2824131	3206305	3041020	3079663	3147020	3115756	3206305	3079663	3115756
1948	2959044	3024426	2920440	2963682	3241393	3200823	3024426	2963682	3200823
1949	2921900	3008804	3071712	3161443	3085300	3169255	3008804	3161443	3169255
1950	3112850	3031183	3182020	3257803	3109265	3154692	3031183	3257803	3154692
1951	2749698	2822428	2766697	2974235	2943835	2928042	2808334	2860981	2888066
1952	2800131	2895437	2971408	2895812	2958258	2911037	2871240	2873863	2882183
1953	2756384	3037546	2897524	2815641	3144684	3145010	3010125	2806496	3129797
1954	2925615	2985325	2897618	2988518	2934274	2919225	2970758	2985044	2912858
1955	2863057	3077169	3222011	3143073	2957916	3079300	3043477	3086448	3019520
1956	2834660	2759943	2735566	2645677	2614945	2615806	2759943	2645677	2615806
1957	2980094	3066042	3246882	3111222	3191822	3200444	3066042	3111222	3200444
1958	2502227	1916590	2020600	2019439	1719543	1708650	1894476	2015733	1708650
1959	3013178	3148367	3216087	3091443	3035181	3145622	3124871	3074157	3145622
1960	2972817	3147343	3106560	3205569	3163516	3224376	3147343	3205569	3224376
1961	2871336	2947517	3041477	3114783	3101637	3066662	2947517	3114783	3066662
1962	2688528	2741368	2937737	3016452	3060412	2982601	2741368	3016452	2968713
1963	2996411	2906845	3142240	3193386	3060846	3135983	2894376	3156933	3065110
1964	2961144	2907301	3123635	3128371	3120833	3039112	2904927	3106953	3039112
1965	2835805	2829893	2792765	2802349	2706216	2819221	2829893	2802349	2819221

SALMOD Late Fall-Run Production (# of fish)							Adjusted SALMOD Production for Sites diversions flow-survival effects		
Year	DCR2015 Without Project	DCR2015 With Project	WSIP2030 Without Project	WSIP2030 With Project	WSIP2070 Without Project	WSIP2070 With Project	DCR2015 With Project	WSIP2030 With Project	WSIP2070 With Project
1966	2809698	2749630	2864729	2897099	3030490	3054044	2728530	2881426	3029187
1967	2861371	2799685	2983341	2943087	2979427	3127063	2799685	2943087	3098758
1968	2947993	3046396	2970708	3162054	3052027	3037134	3019877	3142240	3009814
1969	3043140	2934015	2975968	2877115	2856367	2837863	2934015	2877115	2837863
1970	2716101	2744446	2824472	2723064	2921907	2773307	2727685	2709973	2750372
1971	2953590	2981104	2806288	2697814	2839084	2781926	2960819	2672782	2742349
1972	2900801	2863234	3073872	2806445	2990534	3146803	2845886	2770915	3099597
1973	2678545	2756511	2720452	2965858	2908564	2892151	2756511	2965858	2892151
1974	2707488	2577427	2634276	2641176	2719823	2633651	2577427	2641176	2633651
1975	2920895	2831870	2873276	2896970	2922189	3031595	2813465	2896970	3031595
1976	3083118	3235144	3112569	3206079	3064394	3145810	3235144	3206079	3145810
1977	2029769	2733980	1765895	1951703	658509	559019	2733980	1951703	559019
1978	2830840	2798327	2824974	2580337	2703512	2765335	2798327	2559664	2746354
1979	3102771	3160817	3088903	3087047	2957982	3022223	3121517	3051235	2974475
1980	2877200	2840180	2759861	2803506	2803093	2878103	2840180	2803506	2878103
1981	2994287	3027935	2869598	2831257	2833360	3017242	3027935	2825995	3017242
1982	2764825	2903949	3101077	2962709	3103194	3090887	2903949	2962709	3090887
1983	2300307	2198546	1988899	2045081	1652056	1651358	2184786	2025640	1646614
1984	2613053	2682454	2926778	2833286	2897831	2871098	2682454	2802723	2859650
1985	3050588	2999427	3065969	3102162	3040570	3191373	2966785	3080603	3181821
1986	2695309	2546550	2714713	2646652	2632618	2654616	2546550	2646652	2654616
1987	2805908	2926579	3179925	3127140	3129527	3097307	2926579	3127140	3069346
1988	3187173	3059548	2964428	2891780	2308101	2707823	3058407	2891780	2707823
1989	3144676	3201477	3004515	3241713	2706674	3023194	3201477	3241713	2997496
1990	3110277	2918578	3097920	3075987	1268056	2042023	2894348	3075987	2042023
1991	3148355	3094192	2846273	3026289	686693	1536796	3094192	3026289	1536796
1992	2754092	2851461	2606821	3059598	775584	1109234	2851461	3059598	1109234
1993	2742336	2807727	2808981	2847477	2701671	2802803	2770368	2842507	2802803
1994	3004923	3154595	3070356	3175996	3067799	3178194	3153364	3175996	3173540
1995	2231812	2251195	1117171	1144526	1201032	1188122	2251195	1144526	1188122
1996	3048098	3005624	2987435	3013483	2941390	3019514	2977239	3007244	2943046
1997	2982516	2839256	2935434	3003904	3026886	3039705	2816302	3002863	3012707
1998	2415662	2371608	2265714	2344351	1482583	1474303	2352772	2327288	1466628
1999	3085569	3121663	2778571	2890084	2785669	2783082	3119375	2872621	2766034
2000	2806927	2886873	2913001	3013703	2878492	2975322	2867177	2984935	2957627
2001	2939316	3107587	3219645	3292503	3170345	3274313	3094202	3292503	3253217
2002	3046704	2993773	2732021	2893447	2882251	2947478	2993773	2893447	2947478
Average:	2877697	2910561	2892264	2912705	2744016	2839124	2900045	2901458	2822836
Relative Change:	--	1.1%	--	0.7%	--	3.5%	0.8%	0.3%	2.9%

Appendix A.1.C – OBAN Results

The Oncorhynchus Bayesian Analysis (OBAN) model was used to evaluate the potential for improvement and deterioration of winter-run population dynamics under the Sites Project. The OBAN 2015 model was used in this analysis. Detailed description of the OBAN 2015 model is provided in the Section 5.D.3.2.5 of the CWF BA Appendix 5D (USBR and DWR, 2016). The OBAN 2015 model was simulated for a With Sites scenario versus a Without Sites scenario to evaluate the relative differences in several population metrics (escapement, probability of extinction, etc.). For each of the three climate conditions, paired OBAN model runs were simulated.

In addition, to account for the potential flow-survival effects downstream of the Sites Reservoir diversions, three more paired OBAN model runs were simulated. For these three paired runs, survival downstream of the Red Bluff Diversion Dam was adjusted for the With Sites scenarios to reflect the flow-survival effects. The monthly survival values computed for flows downstream of the proposed Delevan diversion (based on Iglesias et al., 2017) as discussed in Appendix A of this memo, were used to adjust the survival in the With Project scenarios. The relative changes in monthly survival values were weighted based on the proportions of the Winter-Run that undergo smoltification in each month in the NMFS WRLCM (NMFS, 2017) to compute the annual change in survival. The assumed proportions were: 0.269 for January, 0.366 for February, 0.348 for March and 0.017 for April. The annual change in survival was then used to adjust the survival in the With Sites scenarios for appropriate brood years.

Figure C-1 shows the distribution of the annual OBAN median escapement results for Winter-Run Chinook salmon for Without Sites and the two variations of the With Sites scenarios, under the three climate conditions. Figure C-2 shows the timeseries comparison of the annual Winter-Run escapement results for Without Sites and the two With Sites scenarios, under 2015 conditions. Figure C3 shows the timeseries of relative differences in escapement for the With Sites scenario compared to the Without Sites scenario, at 25% and 95% confidence intervals. Figure C4 shows the relative differences in escapement for the adjusted With Sites scenario compared to the Without Sites scenario. Similarly, Figures C5 – C7 present escapement results for 2030 conditions, and Figures C8 – C10 present escapement results for 2070 conditions. All the OBAN results presented in here suggest there is a strong potential for the Winter-Run Chinook salmon escapement to improve with the Sites Reservoir.

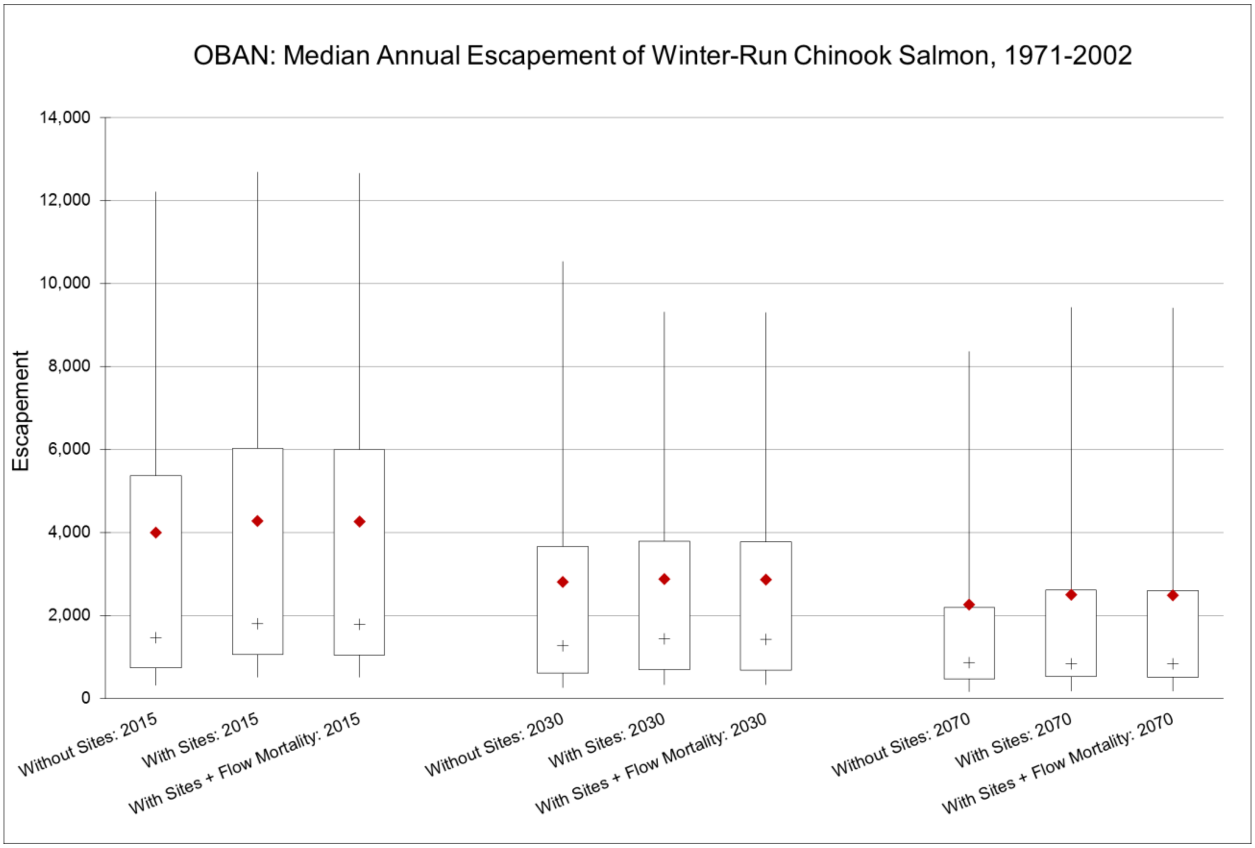

Figure A.1.C-1: Distribution of median annual escapement of Winter-Run Chinook salmon from OBAN (Distribution of median annual escapement of Winter-Run Chinook salmon from OBAN; Lines indicate 5th and 95th percentiles, box indicates 25th and 75th percentiles, + shows median value and diamond shows the mean value)

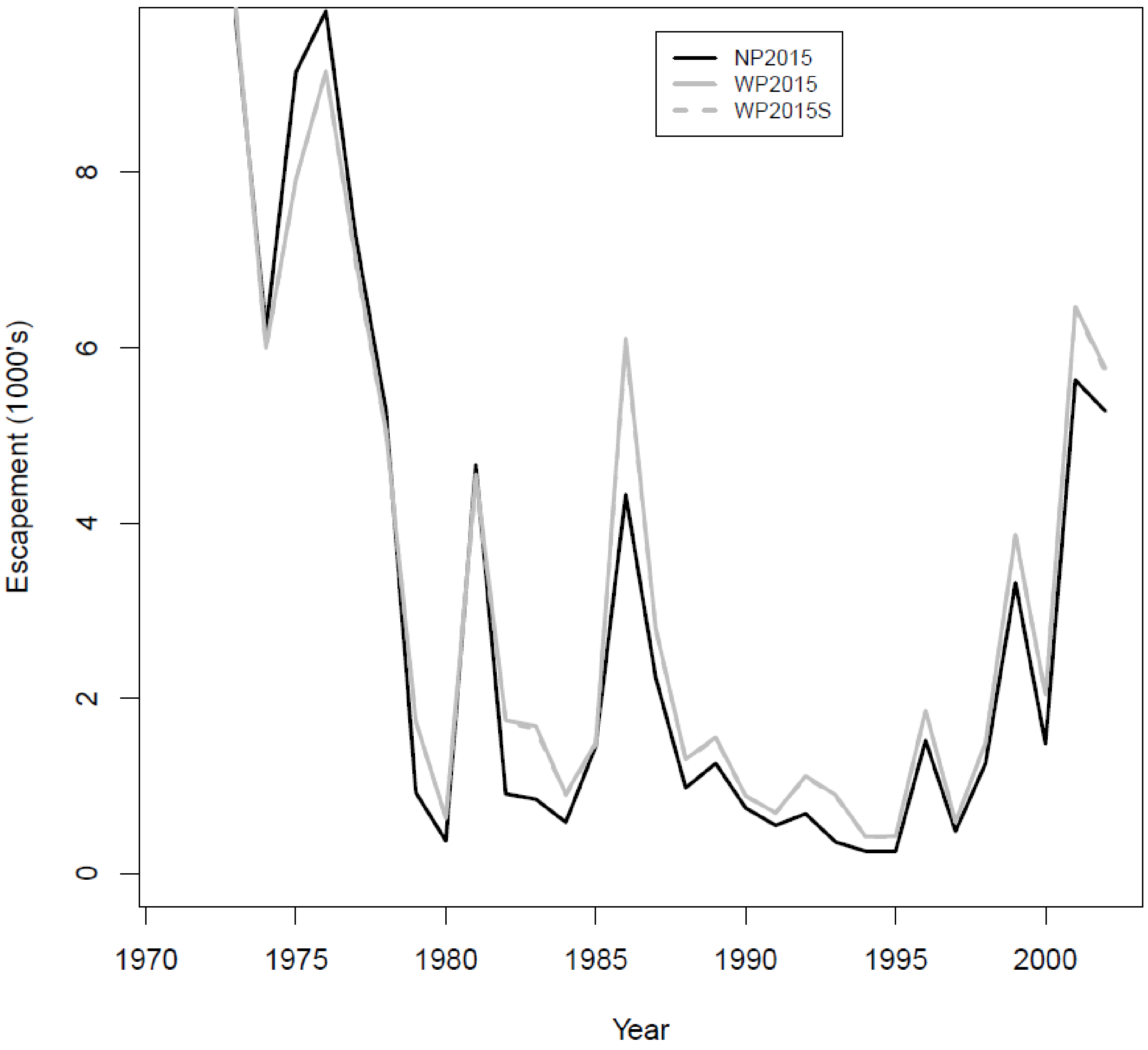

Figure A.1.C-2: Median annual escapement of Winter-Run Chinook salmon from OBAN for Without Sites, and the two With Sites scenarios, under 2015 conditions.

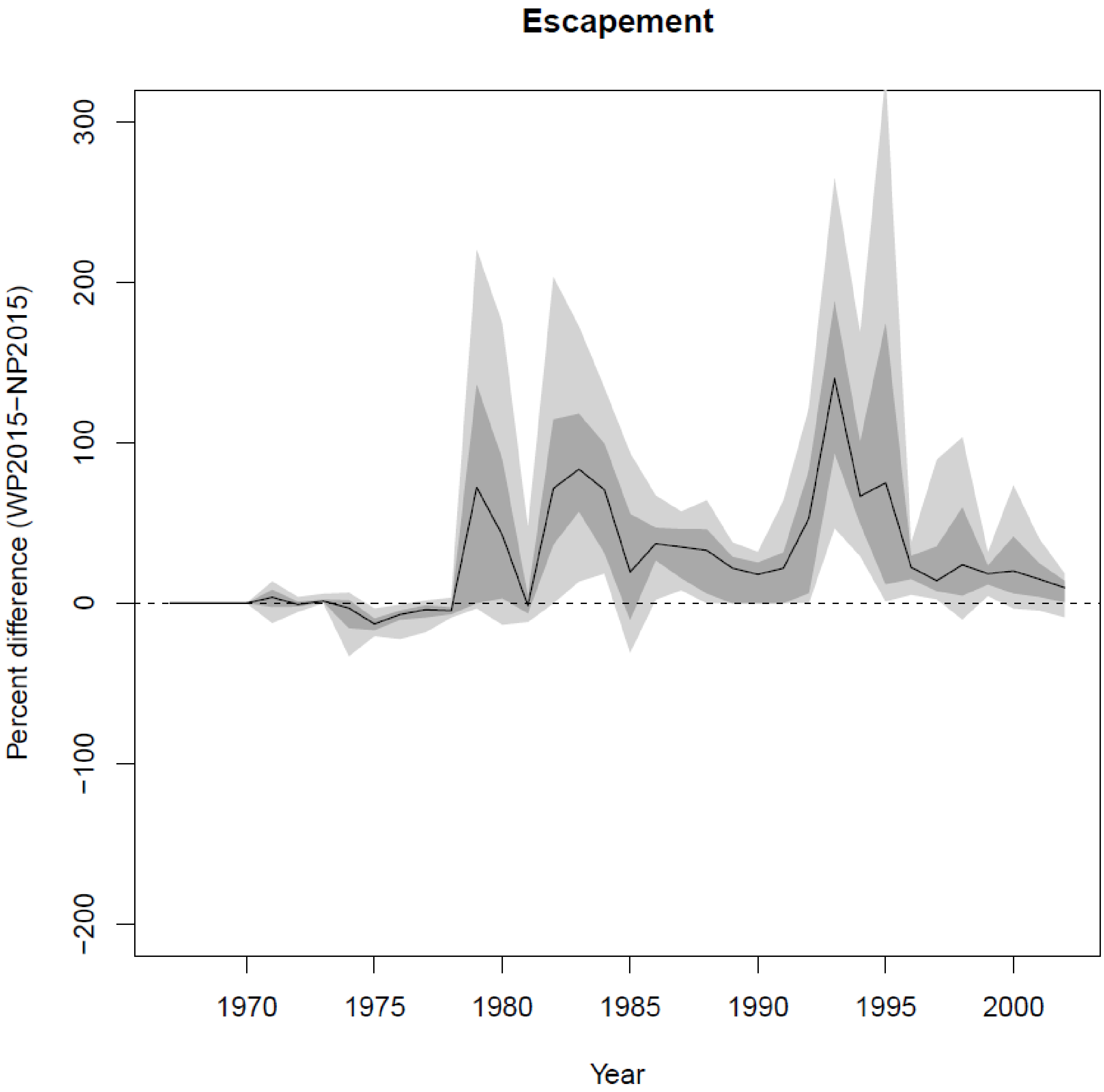

Figure A.1.C-3: Relative differences in median annual escapement of Winter-Run Chinook salmon from OBAN for the With Sites scenario compared to the Without Sites scenario, under 2015 conditions.

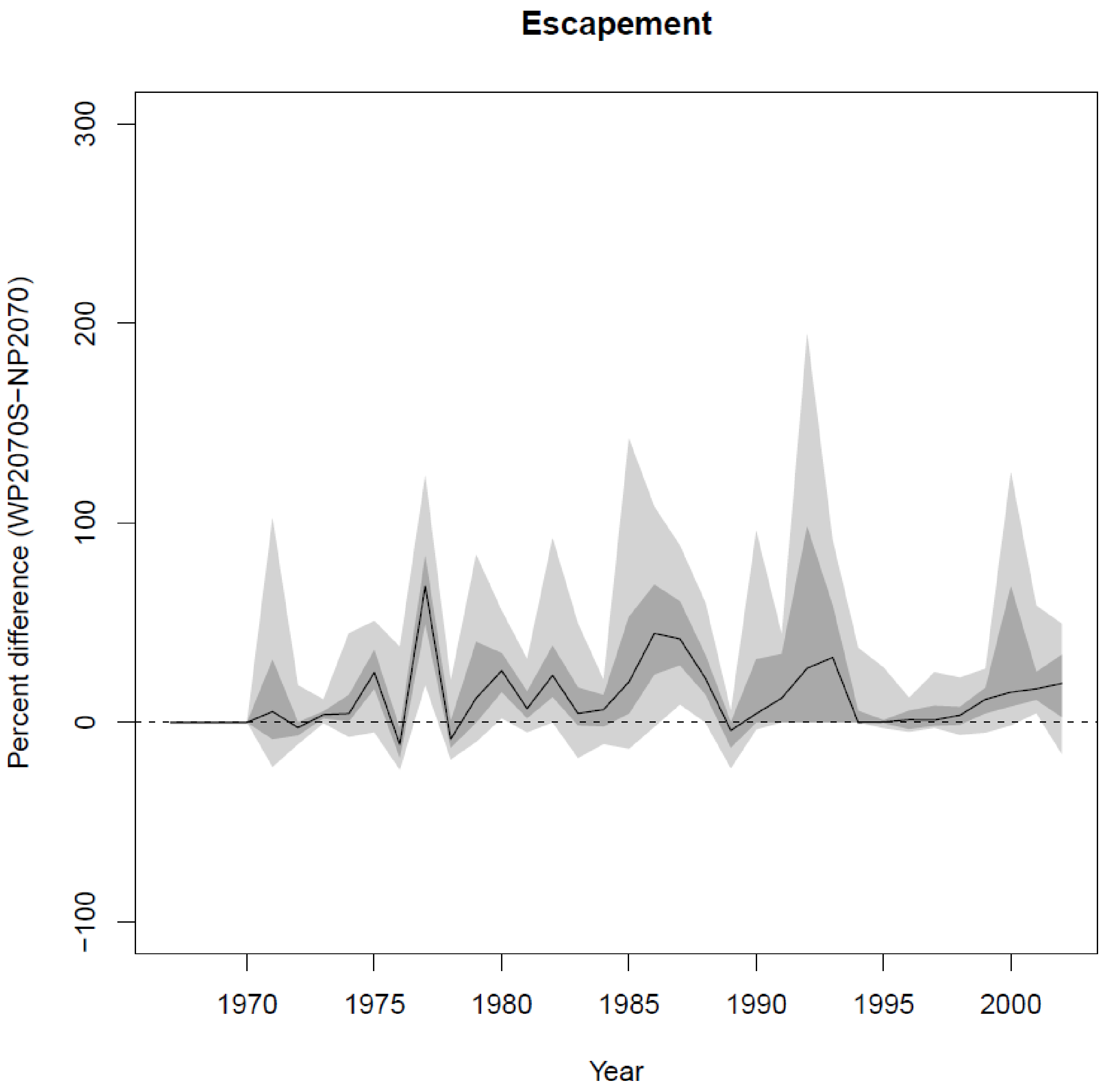

Figure A.1.C-4: Relative differences in median annual escapement of Winter-Run Chinook salmon from OBAN for the With Sites scenario including lower river survival adjustment compared to the Without Sites scenario, under 2015 conditions.

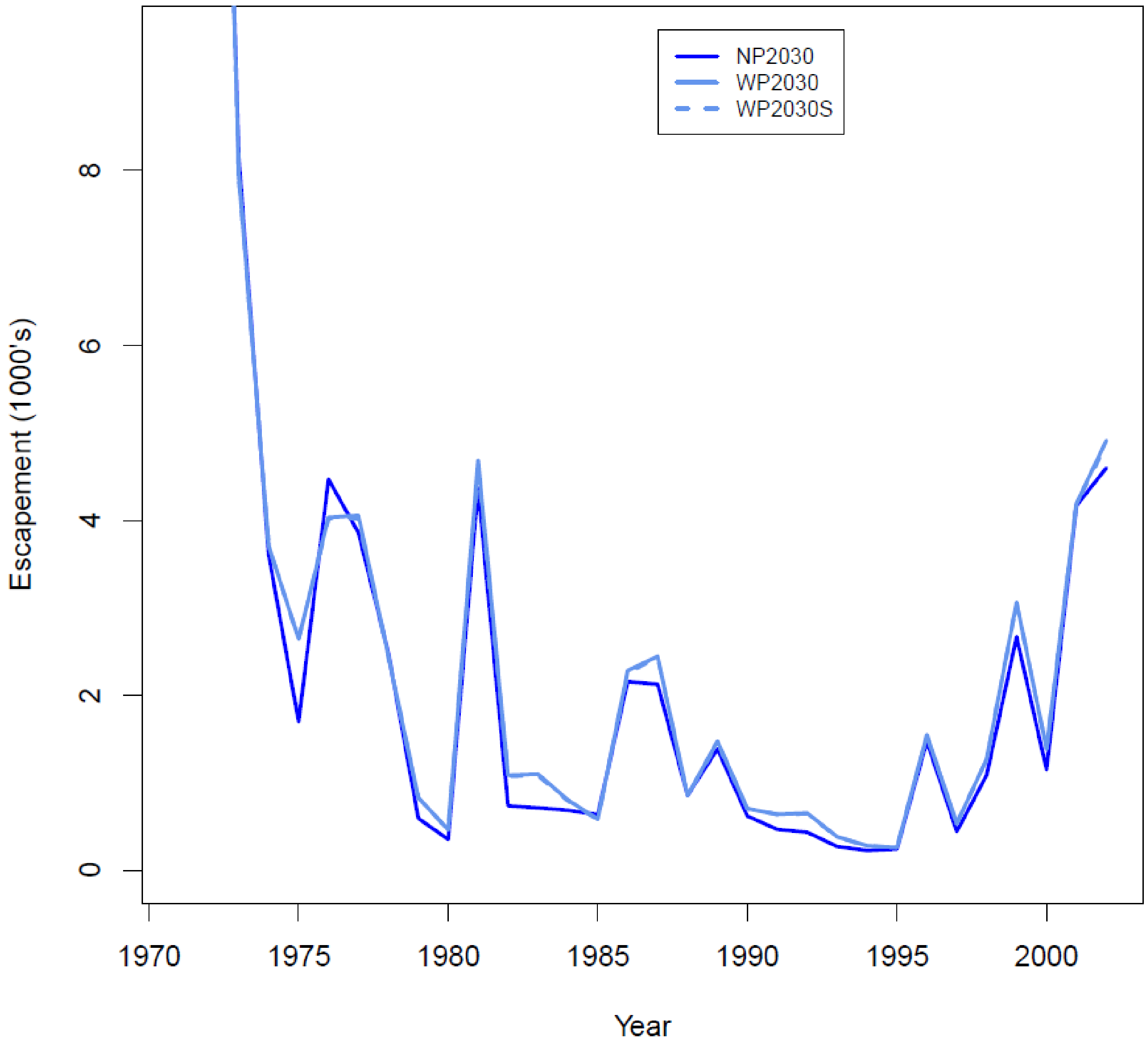

Figure A.1.C-5: Median annual escapement of Winter-Run Chinook salmon from OBAN for Without Sites, and the two With Sites scenarios, under 2030 conditions.

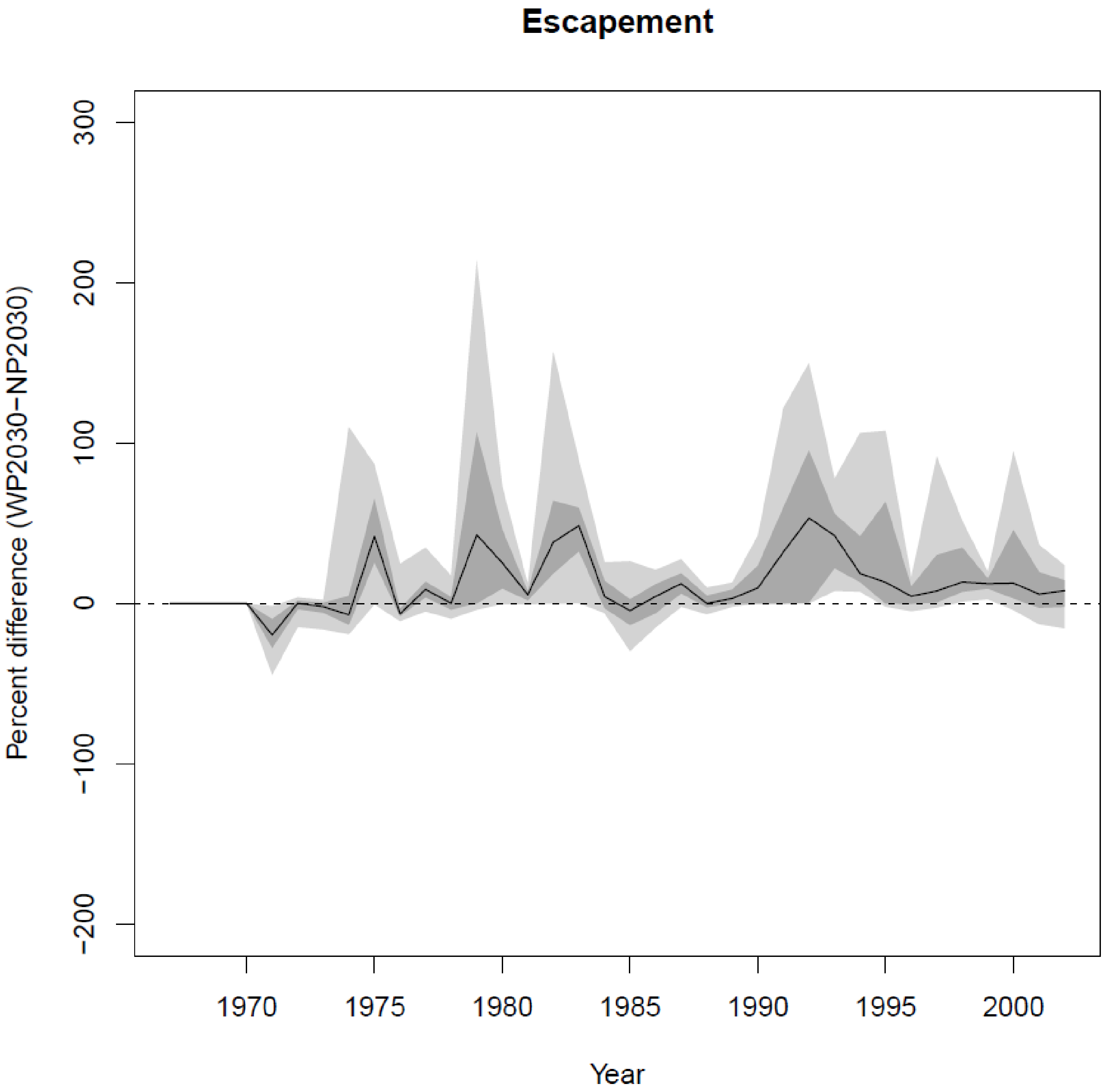

Figure A.1.C-6: Relative differences in median annual escapement of Winter-Run Chinook salmon from OBAN for the With Sites scenario compared to the Without Sites scenario, under 2030 conditions.

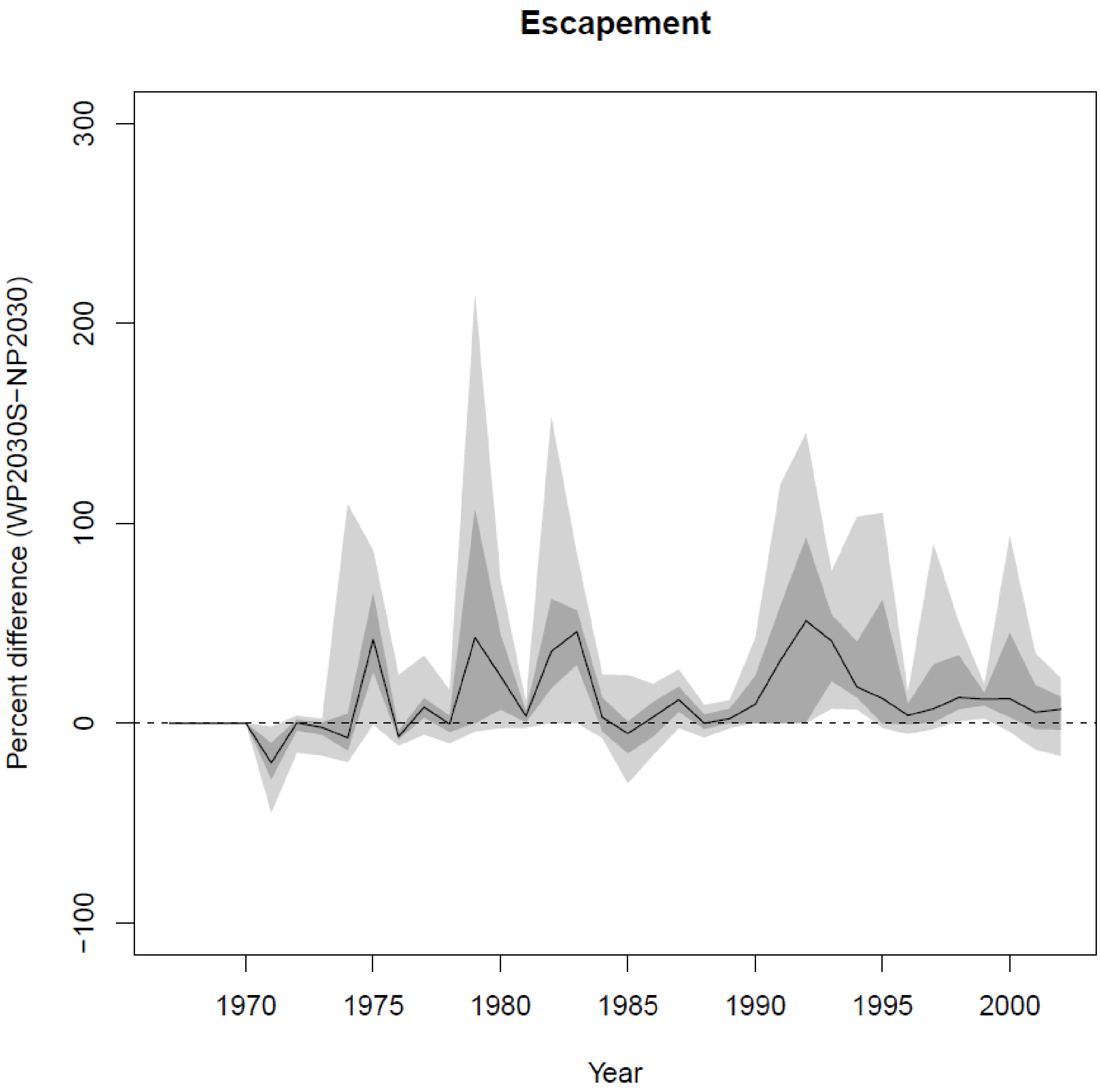

Figure A.1.C-7: Relative differences in median annual escapement of Winter-Run Chinook salmon from OBAN for the With Sites scenario including lower river survival adjustment compared to the Without Sites scenario, under 2030 conditions.

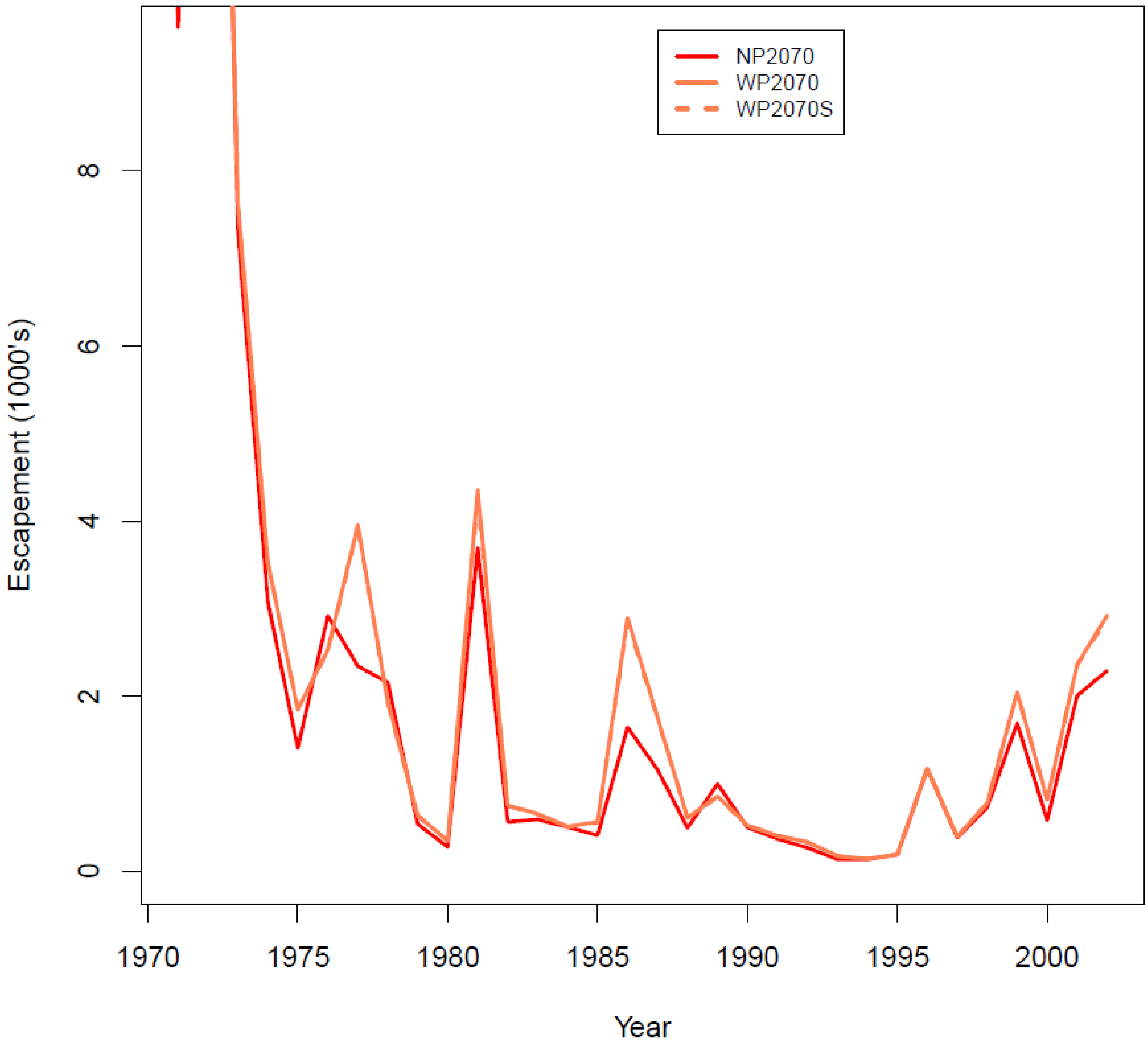

Figure A.1.C-8: Median annual escapement of Winter-Run Chinook salmon from OBAN for Without Sites, and the two With Sites scenarios, under 2070 conditions.

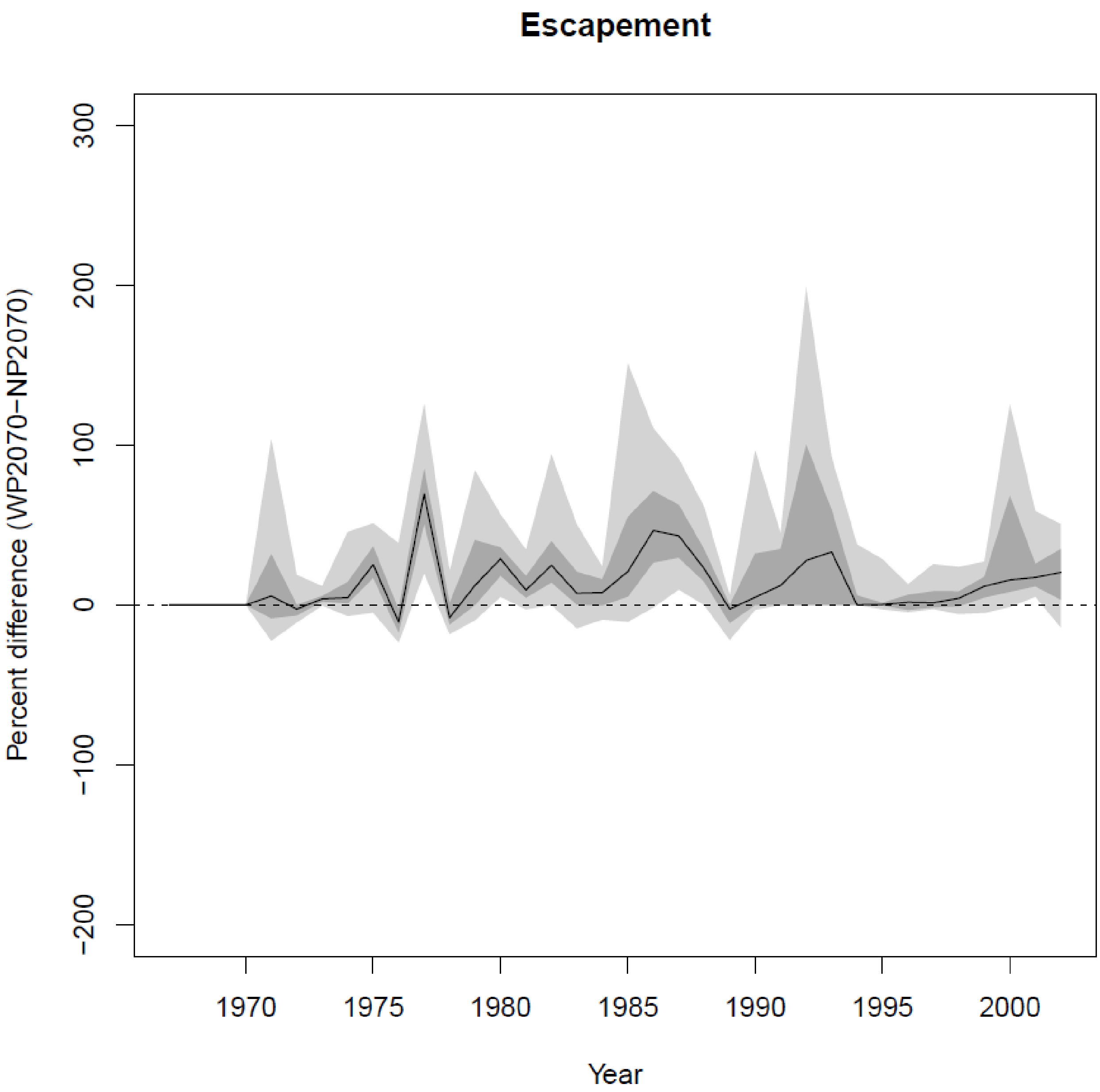

Figure A.1.C-9: Relative differences in median annual escapement of Winter-Run Chinook salmon from OBAN for the With Sites scenario compared to the Without Sites scenario, under 2070 conditions.

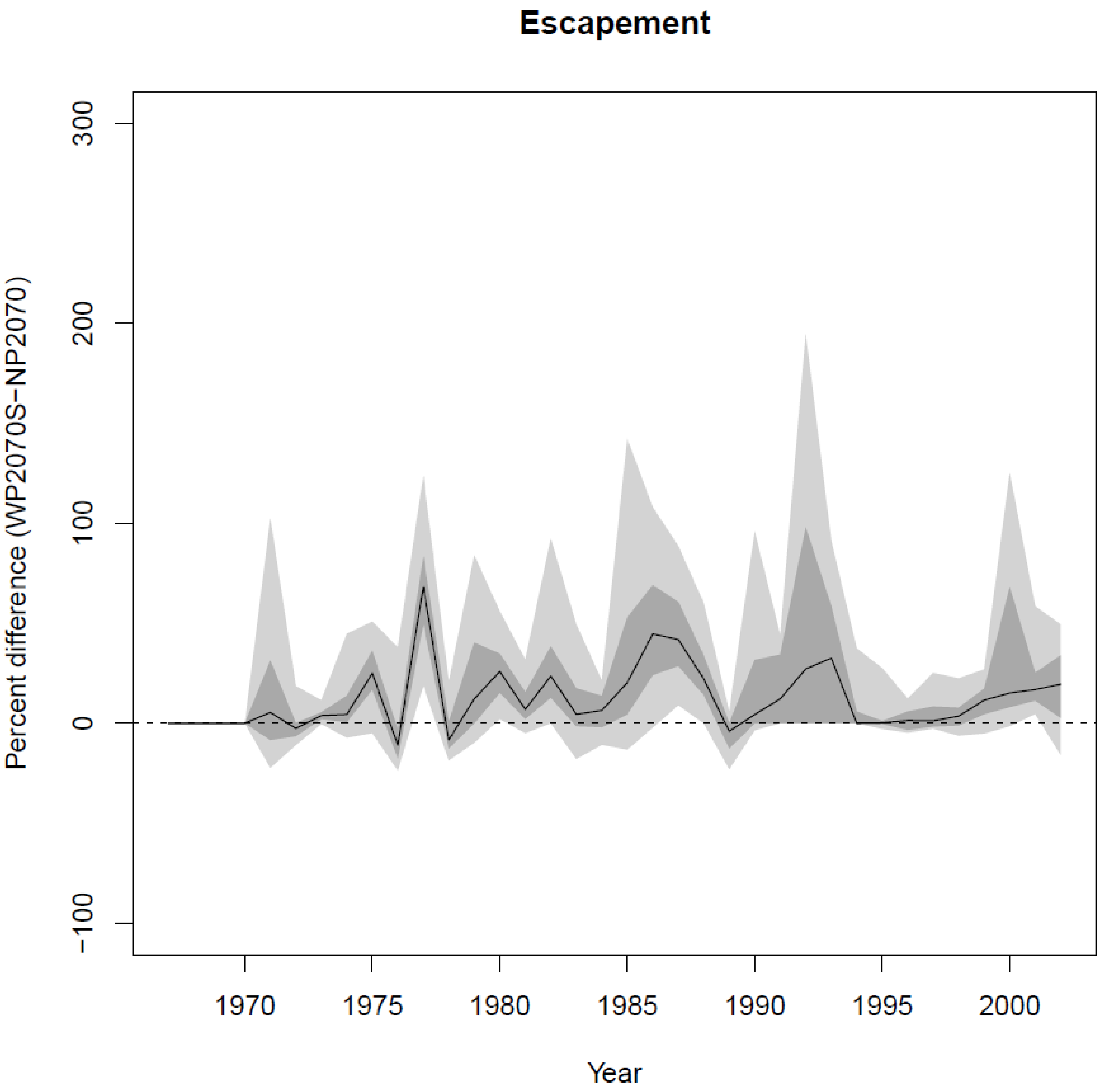

Figure A.1.C-10: Relative differences in median annual escapement of Winter-Run Chinook salmon from OBAN for the With Sites scenario including lower river survival adjustment compared to the Without Sites scenario, under 2070 conditions.

A.2 Potential Flow-Survival Effects on Anadromous Fish from Sites Reservoir Project

A.2.1 Summary

- In their Monetized Ecosystem Benefits review for the Sites Reservoir Project, CDFW noted that flow-survival effects downstream of the Sites Project had not been assessed and recommended consideration of flow-survival relationships, including the preliminary analysis of Michel (2016).
- The review of available flow-survival relationships suggest that the relationship from the preliminary Iglesias et al. (2017) is more appropriate for consideration because it is a based on a completed report (as opposed to the preliminary analysis of Michel [2016]) and is based on assessment of a tagging study (as opposed to statistical fitting to abundance indices, as in the case of the NMFS WRCLM).
- The flow-survival relationship from Iglesias et al. (2017) was applied to the 1922-2003 CalSim modeling of 2015, 2030, and 2070 Without and With Project Monthly mean flows in the Sacramento River below the Delevan intake.
  - Mean predicted survival under the With Project scenarios ranged from similar to Without Project conditions outside of the main Sites Project diversion period (i.e., December-March), to 0-4% less than Without Project during the diversion period.
  - The predictions of survival as a function of CalSim-modeled flow implicitly assume that fish movement is constant through each month, whereas in reality fish move in pulses coincident with flow pulses—differences between Without and With Project scenarios would be less than predicted based on mean monthly flows, depending on what percentage of fish move during the Sites project pulse protection period during which flows, e.g., with 50% of fish moving during flow pulses (as is typically observed for winter-run Chinook salmon), the predicted negative impacts would be halved.

A.2.2 Background

The Sites Reservoir Project Monetized Ecosystem Benefits review by the CDFW noted that “Population trends of native anadromous and pelagic fish are steadily declining under existing regulatory conditions and the additional extraction of water at the proposed bypass rates would exacerbate the problem. Diversions occurring at these bypass rates would result in reduced survival of salmonids as documented in several studies. Impacts on fish resulting from reduced river flows downstream of the proposed project diversion points were not analyzed or disclosed in the quantification of benefits as required by California Code of Regulations, title 23, section 6004, subdivision (a).” (DFW 2018a, p.2). In order to address this comment, during a follow-up Public Benefit Ratio Review meeting with California Water Commission staff at which DFW was also present, the Sites Project Authority asked which specific studies documenting reduced survival were being referred to by DFW (2018a). DFW responded that the studies were those referenced in the DFW (2018b) review of the Draft Environmental Impact Report/Environmental Impact Statement (DEIR/S) for the Sites project. Of the references provided by DFW’s (2018b) review of the DEIR/S (DFW 2018b: p.9), only one reference (Michel 2016) provides quantitative analysis that may be applicable to the potential flow-survival effects of the Sites project in the lower Sacramento River. This attachment reviews the applicability of this relationship in relation to other available relationships, and estimates flow-survival effects for the Sites project as a function of CalSim-modeled flows.

It should be noted that while there are no alternative data to inform management decisions regarding this relationship, the existing studies have limitations that reduce their direct application to existing or proposed operations. These include:

- Many of the studies reviewed below are based on ‘mark and recapture’ studies that use data from hatchery-raised, late-fall run smolt and pre-smolt chinook as a surrogate for wild winter run juvenile for the estimation of downstream mortality. Other researchers (Goodman, D. 2004 and Williams, John G,. 2004) have noted that hatchery raised fish are subject to approximately 50% greater mortality due to predation than wild raised fish. Therefore, the mark and recapture results may overestimate outmigration mortality.
- The use of larger, late-fall run smolt life stage (include the use of deeper and higher velocity portions of the Sacramento River) may not accurately emulate the smaller, winter and spring run juvenile life stage that generally use shallower and slower moving portions of the river that are more likely to contain woody cover and not support larger predatory fish (e.g. striped bass).

A.2.3 Review of Available Flow-Survival Relationships for Lower Sacramento River

Specific to survival in the lower Sacramento River (i.e., below Red Bluff Diversion Dam, upstream of the Delta), in addition to the flow-survival relationship of Michel (2016) that was cited by DFW (2018b), we are also aware of the flow-survival relationships of Iglesias et al. (2017) and the NMFS Winter-Run Lifecycle Model (Hendrix et al. 2017). Other relevant flow-related studies include those of del Rosario et al. (2013), Michel et al. (2013), and Michel et al. (2015). Here we briefly review each of these studies.

A.2.3.1 del Rosario et al. (2013)

This study examined patterns of juvenile migration into and through the Delta in terms of geographic distribution, timing, numbers, and residence time. It analyzed the role of flow, turbidity, temperature, and adult escapement on the downstream movement (migration) of winter-run-sized Chinook salmon. A significant relationship was found between winter-run Chinook salmon passing Knights Landing (river kilometer [rkm] 144 or 51 rkm upstream of the Delta) and high flows (equal to or greater than 400 cubic meters per second [m3s-1] or 14,126 cfs) at Wilkins Slough associated with the onset of winter storms. Although peak migrations varied between October and April, the first 5% of the annual catch usually arrived within a day of the pulse flow and the median (50%) catch occurred several days to a week later in 7 of the 9 years studied, demonstrating that winter-run Chinook salmon tend to migrate en masse following the first large storm event. This flow threshold, in response to the first large rain event of the season, was correlated with the timing of migration, regardless of when during the season the first large rain event occurred.

This study analyzed other variables but found no significant relationships between total seasonal catch of winter-run at Knights Landing (number of fish/day/season) and mean flow during the emigration season ($p = 0.93$), mean turbidity ($p = 0.40$), mean water temperature ($p = 0.27$), and adult escapement ($p = 0.31$). Although flow increase was found to be a consistent precursor to the onset of migration, the authors cautioned that several factors change simultaneously with flow, including turbidity, velocity, olfactory cues, and food supply. The specific cues responsible for downstream movement of winter-run remain unclear.

A.2.3.2 Michel et al. (2013)

This study investigated migration rates of juvenile late fall–run Chinook salmon from 2007 through 2009 using acoustically tagged yearlings from Coleman National Fish Hatchery. It estimated smolt outmigration rates, investigated reach-specific movements, and tested the influence of environmental factors on outmigration success. While reported migration rates through the entire system were similar to rates published for yearling Chinook salmon smolt emigrations in other West Coast rivers (14.3 kilometers [km]·day-1 (± 1.3 S.E.) to 23.5 km day-1 (± 3.6 S.E.)), differences were found in reach-specific movement rates. The authors modeled the potential influence of multiple environmental variables, chosen a priori, based on salmon migration literature and data availability for the watershed. Variables included water temperature (°C), river flow (m3·s-1), water turbidity (nephelometric turbidity units [ntu]), channel water velocity (meters per second [m·s-1]), a ratio of river surface width (meters) to maximum river depth (meters) (WDR), and a ratio of daily river flow to mean river flow over the migration season of the year in question (FMFR). The study also found that WDR provided the strongest, albeit negative, contribution to migration rates (i.e., the wider and shallower the river, the slower the migration rate). The next best supported smolt travel time model was the river flow model, with a positive relationship between flow rate and movement rate. Turbidity and FMFR also correlated with smolt movement rates. The temperature model was the only environmental model that was not found to be better supported than the null model, likely because smolts were released all at once, during two releases each season, and therefore experienced a narrow range of temperatures. Also, Shasta Dam releases tend to moderate temperatures in the upper reaches of the river.

One interesting postulation of this study is that the influence of flow on movement of smolts may be temporal rather than spatial. This was the motivation for creating the model including FMFR as a linear predictor. This relationship was found to be positive, thus supporting the hypothesis and the observed increased watershed-wide smolt movements during particularly strong storm events. The authors concluded that the relationship between flow and movement rate may be strong above a certain flow threshold and a more complex model should be explored to capture the occurrence of those flow levels. This is consistent with migration events reported in del Rosario et al. (2013) for winter-run Chinook salmon.

A.2.3.3 Michel et al. (2015)

This study investigated environmental factors affecting outmigration survival of acoustically tagged hatchery-origin late fall–run Chinook salmon in the Sacramento River in wet and dry years from 2007 through 2011 (expanding on the analysis by Michel et al. 2013 by including 2 more years of data). Overall survival of late fall-run Chinook salmon through the entire migration corridor (rkm 518–2) per year ranged from 2.8% to 15.7%, with the highest flow and survival occurring in 2011 and much lower flow and survival from 2007 to 2010. Survival rates on a reach-by-reach basis were quite variable (Figure A.2-1). During the first 4 years of the study, the upper river reaches (reaches 1 to 8; rkm 518 to 325) had some of the lowest survival per 10 kilometers, and the lower reaches of the river (reaches 9 through 12; rkm 325 to 169) had the highest. The Delta (reach 13) was comparable to the upper river, and the San Francisco and Suisun Bays (reaches 14 to 17; rkm 169–2) had the lowest survival rates. High flows during 2011 resulted in poor detection probabilities at most receiver locations, which precluded estimating reach-specific survival rates for that year. However, the receivers at the downstream end of the major divisions could be used. The authors reported higher survival rates in the river above Knights Landing in 2011 compared to the four previous years, which were all drier than the wet 2011 (water year type for 2007 and 2009 was dry, 2008 was critically dry, and 2010 was below normal) . The authors also reported generally comparable survival rates among all 5 years in the Delta and bays.

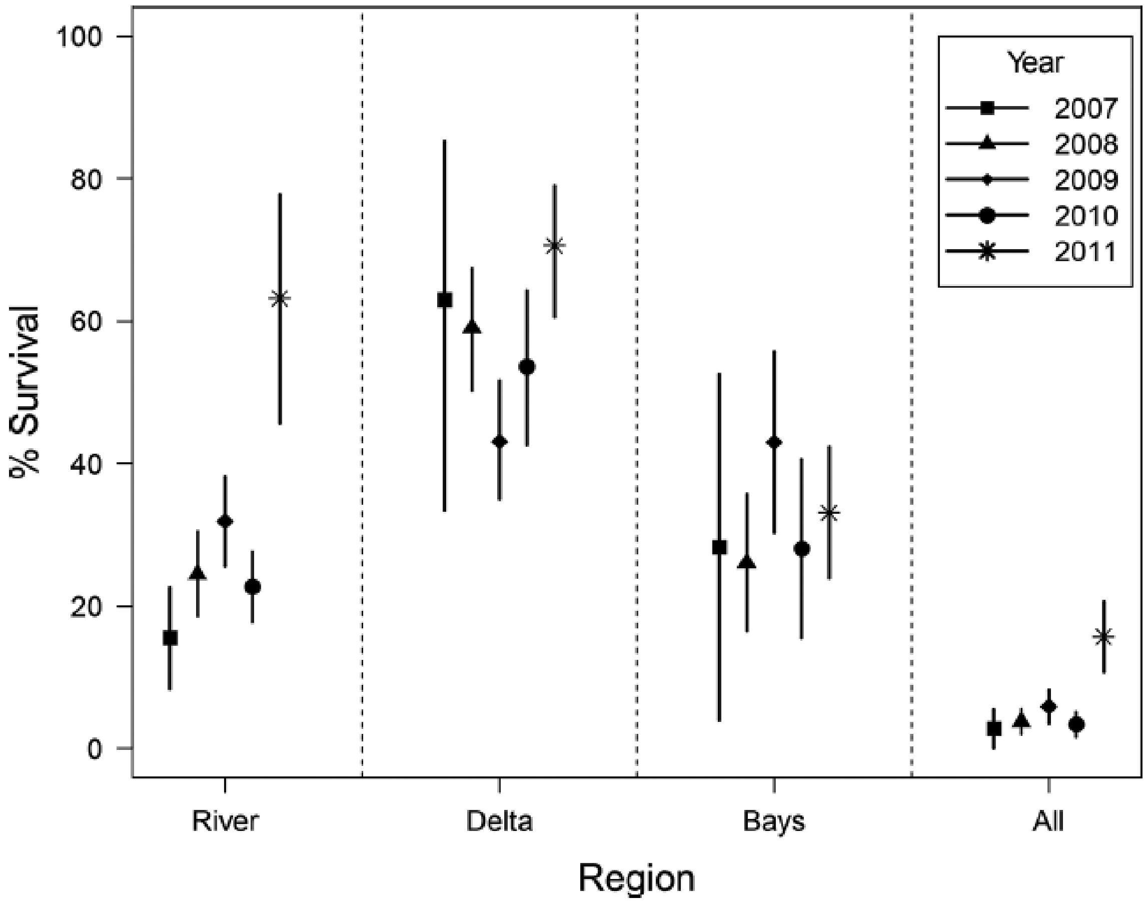

Figure A.2-1: Percent survival of tagged juvenile late fall-run Chinook Salmon per major region for all 5 study years. Regions include river, delta, bays, and the percent survival for the entire watershed (All). Error bars represent 95% confidence intervals. Source: Michel et al. (2015).

A.2.3.4 Michel (2016)

This preliminary analysis re-evaluated the acoustically tagged, hatchery-origin late fall–run Chinook salmon 2007 to 2011 data from Michel et al. (2015), and was the only reference cited by DFW (2018b) that has a flow-survival relationship—albeit only in graphical form—of potential use to the Sites project effects analysis. Michel (2016) investigated a number of flow-survival relationships based on different flow terms, with the untransformed flow term being reasonably well supported by the data (i.e., Akaike Information Criterion adjusted for small sample sizes [AICc] within 2 units of the best relationship, which include flow and squared flow). As noted by DFW (2018b), this relationship suggests a relatively rapid decline in survival below ~13,000 cfs.

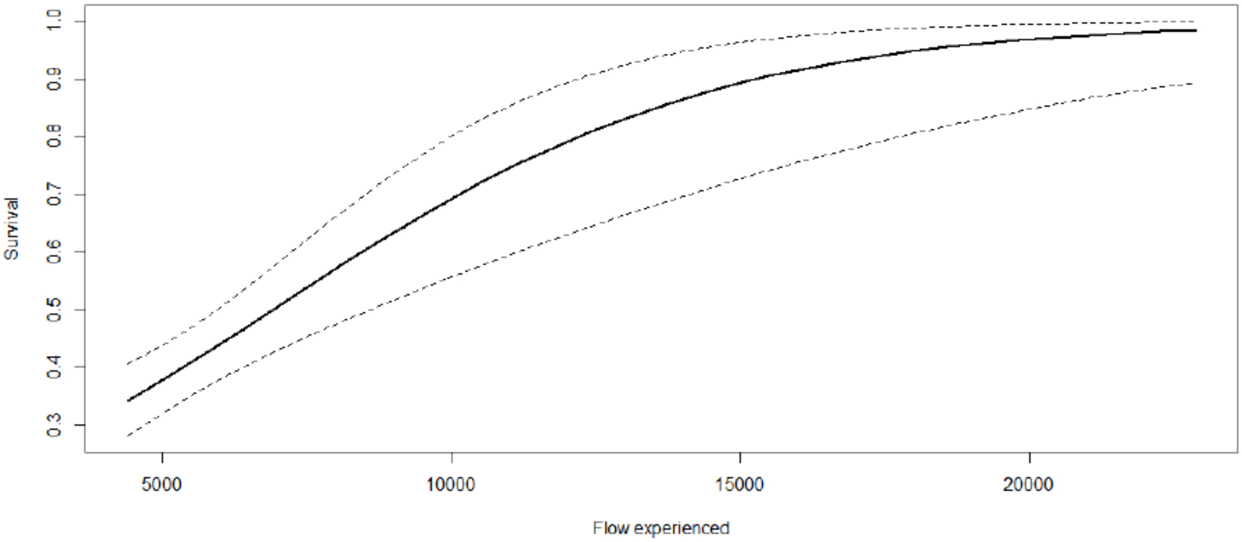

Figure A.2-2: Simulated relationship between flow (cfs) and survival in the river section for the Region + river_flow survival model. Dotted lines are 95% confidence intervals. Source: Michel (2016).

A.2.3.5 Iglesias et al. (2017)

Similar to Michel (2016), this study re-evaluated the acoustically tagged, hatchery-origin late fall–run Chinook salmon 2007 to 2011 data from Michel et al. (2015) and found that flow was the strongest environmental correlate with survival, and had a positive, fairly linear relationship (Figure A.2-3). It is notable how different the flow-survival curve is, when compared to the Michel (2016) discussed in the previous section, particularly given that as we understand it, these curves were derived from essentially the same dataset. Further comparison of the curves is provided below in Comparison of Michel (2016), Iglesias et al. (2017), and NMFS Winter-Run Chinook Salmon Lifecycle Model Flow-Survival Relationships.

As previously discussed in the summary of the Michel et al. (2015) study, 2007 to 2011 comprised four relatively low-flow years (2007 to 2010) and one very high flow year (2011). Using the number of acoustic-tagged fish detected by day during each year of these studies (Michel pers. comm.), the Sites Project examined relative difference in flows between years by weighting the mean daily flow at three CDEC stations (Butte City, Ord Ferry, and Colusa) in each year of the study by the number of fish detected on each day. This showed that the mean flow in 2011 (approximately 18,200 cfs) was considerably greater than in the other years (2007: approximately 7,400 cfs; 2008: approximately 8,000 cfs; 2009: approximately 5,000 cfs; 2010: approximately 6,200 cfs). This suggests that the flow-survival relationship shown in Figure A.2-3 may be driven by the difference between a single very high flow value and four low flow values, with relatively little information on intermediate flows (between approximately 8,000 and 18,200 cfs); see also Figure A.2-1 above.

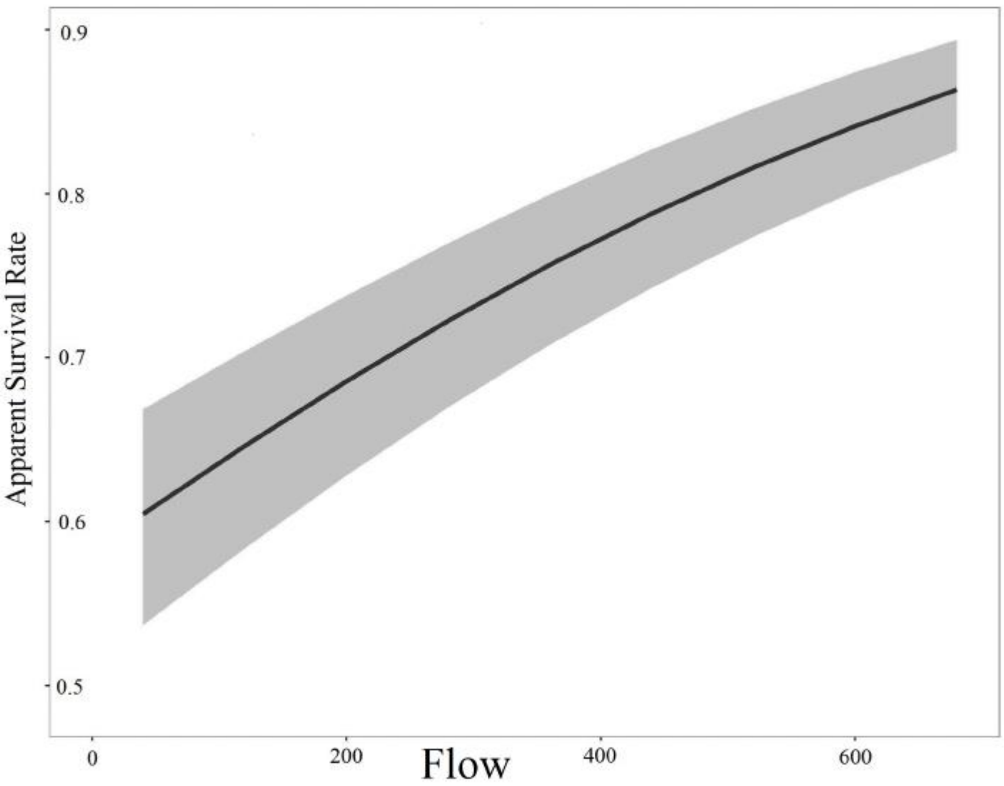

Figure A.2-3: Simulated survival as a function of flow (cubic meters per second) in the Sacramento River. As flow increases, apparent survival increases. Dark line indicates survival estimate, and grey area represents 95% confidence intervals (from Figure 5 in Iglesias et al. [2017])

Examining available release-specific survival results for four releases in 2008 and 2009 also leads to concern about the generality of flow-survival relationships. Fish detection-weighted mean flows in December 2007 (approximately 6,700 cfs) were considerably less than those in January 2008 (approximately 9,600 cfs), yet survival from the upper Sacramento River to the lower river and Delta was not significantly different between the releases (Figure A.2-4a). In contrast, flows in December 2008 (approximately 5,200 cfs) were quite similar to flows in January 2009 (approximately 4,900 cfs), yet survival in December was significantly greater (Figure A.2-4b).

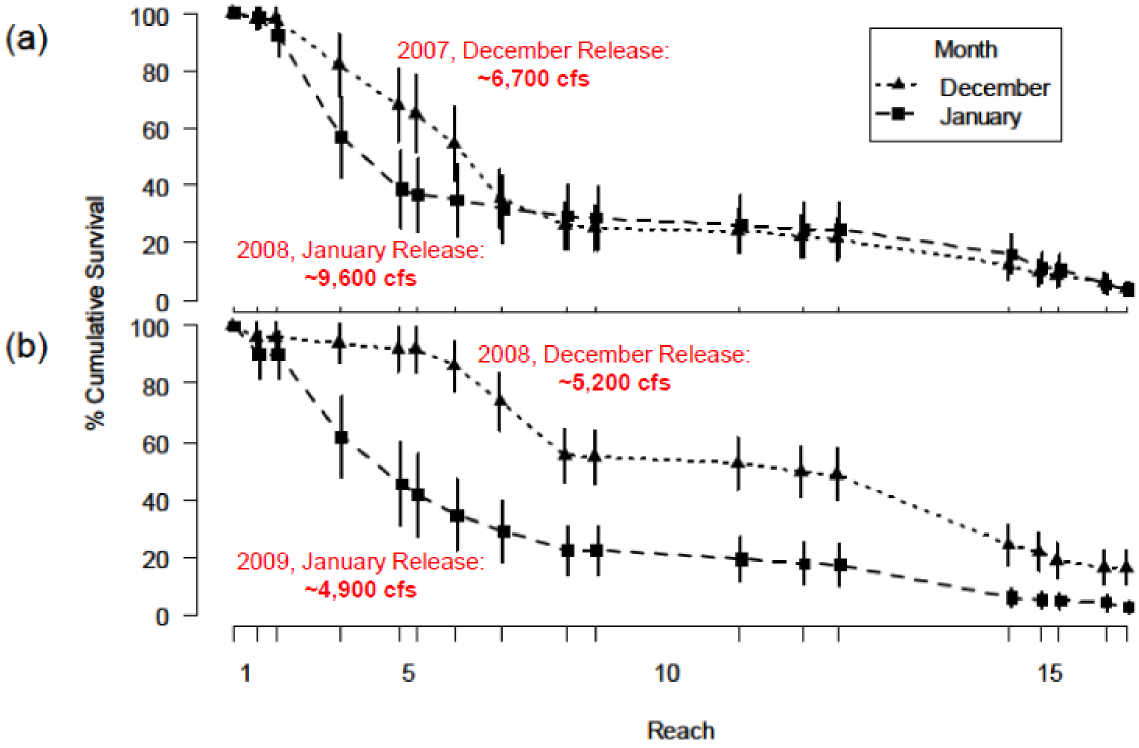

Figure A.2-4. Cumulative survival of outmigrating acoustic tagged, hatchery-origin late fall–run Chinook salmon smolts by month of release in (a) December 2007 and January 2008, (b) December 2008 and January 2009. Reach 1 represents the upper-most reach, and reach 17 represents the lowest reach, in the San Francisco Bay Estuary. Error bars represent 95% confidence intervals. Adapted from Figure 5 of Michel (2010).

Also, the temporal and spatial variability in the distribution of low-survival reaches in the upper and middle reaches of the Sacramento River suggest there are likely to be a number of factors (perhaps habitat-related) that interact with flow to produce reach-specific survival rates (Figure A.2-5).

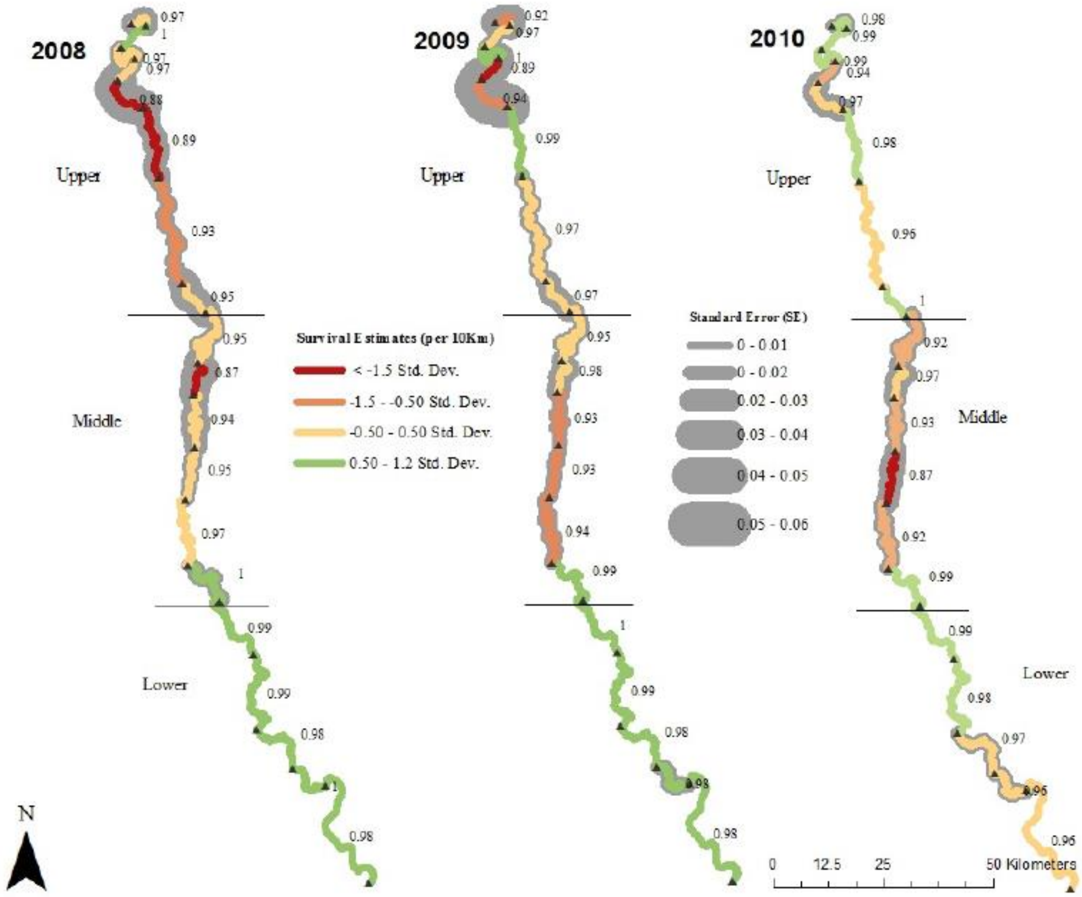

Figure A.2-5. Reach-specific survival estimates (per 10 kilometers) for each study years colored to represent per reach survival risk.

Standard error is represented as the grey buffer surrounding each reach. The values adjacent to each reach represent the survival estimate for a given reach (per 10 kilometers) from our full survival model. Note that the spatial distribution of mortality zones (those areas with lower estimated survival compared to mean survival for that year) varied between reaches and years, with mortality zones occurring in the upper and middle reaches of the river. In 2010, the reach with the greatest amount of mortality (near Butte) was greater than 2 standard deviations from the mean survival of that year. Reproduced from Figure 4 in Iglesias et al. (2017).

A.2.3.6 National Marine Fisheries Service Winter-Run Chinook Salmon Lifecycle Model

The National Marine Fisheries Service (NMFS) Winter-Run Chinook Salmon Lifecycle Model (WRLCM) includes a flow-survival relationship for winter-run Chinook salmon smolts migrating downstream from rearing in the upper and lower mainstem Sacramento River to the Delta (Hendrix et al. 2017). The relationship is based on mean flow at Bend Bridge, is applied on a monthly basis, and is apparently derived from statistical fitting to indices of abundance rather than specific survival studies such as that of Iglesias et al. (2017). A comparison of this relationship to those of Michel (2016) and Iglesias et al. (2017) is provided in the next section.

A.2.4 Comparison of Michel (2016), Iglesias et al. (2017), and NMFS Winter-Run Chinook Salmon Lifecycle Model Flow-Survival Relationships

Of the above flow-survival relationships, the Sites Project considered those of Michel (2016), Iglesias et al. (2017), and the NMFS WRLCM to potentially be applicable for assessing the flow-survival effect from the Sites project. Only the WRLCM had published coefficients available, so the Iglesias et al. (2017) and Michel (2016: this Figure A.2-5) curves were digitized[5] in order to compare the form of the different relationships. This shows that the Michel (2016) has the steepest decline in survival once flows reach ~13,000 cfs (as previously noted), whereas there is a much shallower, almost linear slope in the relationship of Iglesias et al. (2107); the WRLCM curve is intermediate (Figure A.2-6).

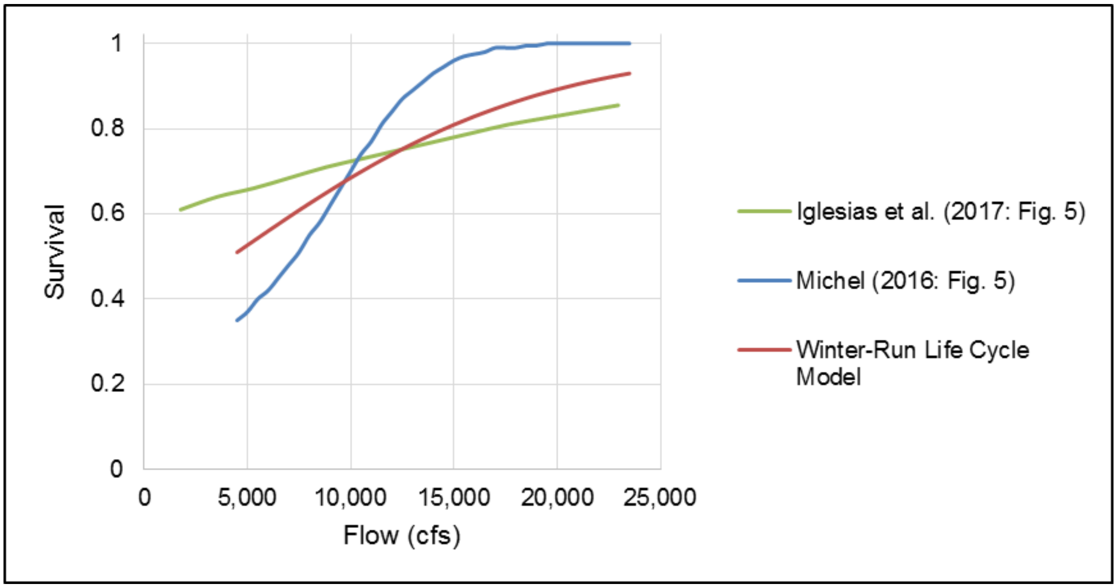

Figure A.2-6. Comparison of the Iglesias et al. (2017), Michel (2016), and NMFS Winter-Run Chinook Salmon Lifecycle Model and flow-survival relationships.

Ultimately, the Sites Project considered the Iglesias et al. (2017) relationship to be most appropriate for assessing the potential effects of the Sites project flow-survival effects for the following reasons:

- It is provided in a completed report, as opposed to a preliminary analysis (which is the case for Michel [2016]);
- It is based specifically on observations of tagged fish, as opposed to statistical fitting to abundance indices (which is the case for the WRLCM).
- Although the Sites Project apply the Iglesias et al. (2017) flow-survival relationship to Sites project modeling, we repeat our concern regarding the derivation of the relationship expressed above in the section discussing Iglesias et al. (2017), i.e., that the relationship may be driven by several relatively low-flow years and one high-flow year. We acknowledge the importance of flow-survival relationships, but are cautious with respect to the specifics

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[5] The digitization consisted of overlaying a grid on top of each curve in order to read off predicted survival for a given flow. This was used to derive look-up tables of survival to the nearest 0.005 at 500-cfs (Michel 2016) or 50-cumec (Iglesias et al. 2017) increments, which form the basis for the plot in Figure A.2-6.

of this particular relationship, particularly at intermediate flows that seem less well represented in the dataset.

A.2.5 Application of Flow-Survival Relationship to Sites Project Modeling Data[6]

The Iglesias et al. (2017) Chinook salmon flow-survival relationship was applied to the 1922-2003 CalSim modeling of 2015, 2030, and 2070 Without and With Project Monthly mean flows in the Sacramento River below the Delevan intake. This location was chosen because it is downstream of all of the Sites project intakes and therefore represents the greatest potential flow-survival effect. The analysis was undertaken for all months of the year, although the main period of juvenile salmonid downstream migration is winter-spring (November-December). To facilitate estimation of survival across the full range of modeled flows, a linear regression between flow and survival was undertaken to estimate the flow at which survival was 1. This value was 34,393.3 cfs, and all flows above this value were also assumed to have survival = 1. Survival predictions were summarized as mean by water year type[7] and month for each modeled scenario. Survival predictions considered only the mean flow-survival relationship, without consideration of the uncertainty around the relationship (e.g., 95% confidence intervals in Figure A.2-3).

Mean predicted survival under the With Project scenarios ranged from similar to or greater than Without Project conditions outside of the main Sites Project diversion period to 0-4% less than Without Project survival during the main December-March diversion period (Table 1). The differences between Without and With Project scenarios tended to be least in wet years, particularly for 2015 and 2030 conditions. With Project long-term-average predicted survival ranged from 1-2% less than Without Project in December-March to 1-3% greater than Without Project in July-September (Table A.2-1).

The predictions of survival as a function of flow reflect the CalSim-modeled mean flows and implicitly assume that fish movement is constant through each month (i.e., each day has an equal weighting of fish movement). However, in reality, fish movement is often in pulses, e.g., del Rosario et al. (2013) found that 50% of juvenile winter-run-sized Chinook salmon usually emigrate within 3-7 days of flow increases at Wilkins Slough. Movement of fish in pulses coinciding with the proposed pulse protection cessation of Sites project diversions would lessen the potential negative impacts shown in Table A.2-1, e.g., with 50% of fish moving downstream within the pulse protection period, the impact would be halved.

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[6] All calculations are provided in the Excel workbook <DRAFT_Illustrate_survival_difference_based_on_Iglesias_et_al_2017.xlsx>

[7] Months were assigned to water-year type based on the February-January water year used in CalSim; February-June was assigned to the previous water year type in order to keep the same cohort of fish within the same water year (for subsequent comparison to SALMOD).

Table A.2-1: Comparison of Survival Estimates Based on Application of Iglesias et al. (2017) Flow-Survival Relationship

Water Year Type	Month	2015			2030			2070		
		Without Project	With Project	Difference (%)	Without Project	With Project	Difference (%)	Without Project	With Project	Difference (%)
Wet	Jul	0.70	0.71	0.01 (1%)	0.72	0.72	0.01 (1%)	0.72	0.73	0.01 (2%)
	Aug	0.69	0.69	-0.01 (-1%)	0.68	0.68	0.00 (0%)	0.68	0.68	0.01 (1%)
	Sep	0.76	0.77	0.00 (1%)	0.76	0.76	0.00 (1%)	0.77	0.77	0.00 (0%)
	Oct	0.69	0.69	0.00 (0%)	0.69	0.69	0.00 (0%)	0.69	0.69	0.01 (1%)
	Nov	0.75	0.75	0.00 (1%)	0.74	0.74	0.00 (0%)	0.73	0.73	-0.01 (-1%)
	Dec	0.76	0.75	-0.01 (-1%)	0.78	0.76	-0.02 (-2%)	0.78	0.76	-0.02 (-3%)
	Jan	0.81	0.80	-0.01 (-1%)	0.83	0.82	-0.01 (-2%)	0.85	0.83	-0.01 (-2%)
	Feb	0.84	0.83	-0.01 (-1%)	0.85	0.84	-0.01 (-1%)	0.86	0.85	-0.01 (-2%)
	Mar	0.82	0.81	-0.01 (-1%)	0.82	0.82	-0.01 (-1%)	0.82	0.81	-0.01 (-1%)
	Apr	0.71	0.71	0.00 (0%)	0.71	0.71	0.00 (0%)	0.71	0.71	0.00 (0%)
	May	0.71	0.71	0.00 (0%)	0.69	0.69	0.00 (0%)	0.68	0.68	0.00 (0%)
	Jun	0.71	0.71	0.01 (1%)	0.70	0.71	0.01 (1%)	0.71	0.72	0.01 (1%)
Above Normal	Jul	0.71	0.73	0.01 (2%)	0.72	0.75	0.03 (4%)	0.73	0.77	0.04 (6%)
	Aug	0.68	0.69	0.00 (0%)	0.69	0.69	0.00 (1%)	0.68	0.69	0.01 (2%)
	Sep	0.71	0.72	0.01 (1%)	0.72	0.72	0.01 (1%)	0.72	0.72	0.00 (0%)
	Oct	0.68	0.68	0.01 (1%)	0.68	0.68	0.01 (1%)	0.68	0.69	0.00 (1%)
	Nov	0.75	0.75	0.00 (0%)	0.74	0.74	0.00 (0%)	0.74	0.74	0.00 (0%)
	Dec	0.76	0.75	-0.02 (-2%)	0.75	0.73	-0.01 (-2%)	0.74	0.73	-0.01 (-1%)
	Jan	0.81	0.79	-0.01 (-2%)	0.77	0.76	-0.01 (-2%)	0.76	0.74	-0.02 (-3%)
	Feb	0.82	0.79	-0.02 (-3%)	0.79	0.77	-0.02 (-3%)	0.79	0.76	-0.03 (-3%)
	Mar	0.80	0.79	-0.01 (-1%)	0.79	0.77	-0.02 (-2%)	0.80	0.78	-0.02 (-3%)
	Apr	0.76	0.76	0.00 (0%)	0.72	0.73	0.00 (0%)	0.70	0.70	0.00 (0%)
	May	0.70	0.70	0.00 (0%)	0.67	0.67	0.00 (0%)	0.68	0.68	0.00 (0%)
	Jun	0.69	0.70	0.01 (1%)	0.69	0.70	0.01 (1%)	0.70	0.71	0.01 (2%)
Below Normal	Jul	0.70	0.72	0.02 (4%)	0.73	0.75	0.02 (3%)	0.73	0.76	0.03 (4%)
	Aug	0.68	0.69	0.02 (2%)	0.69	0.69	0.01 (1%)	0.68	0.69	0.01 (2%)
	Sep	0.66	0.68	0.02 (2%)	0.67	0.69	0.02 (3%)	0.65	0.68	0.03 (4%)
	Oct	0.67	0.69	0.02 (2%)	0.66	0.68	0.02 (2%)	0.66	0.67	0.01 (2%)
	Nov	0.70	0.71	0.01 (1%)	0.69	0.70	0.01 (1%)	0.70	0.71	0.00 (1%)
	Dec	0.78	0.78	-0.01 (-1%)	0.76	0.77	0.00 (1%)	0.79	0.79	0.00 (0%)
	Jan	0.81	0.79	-0.02 (-2%)	0.82	0.80	-0.02 (-3%)	0.86	0.85	-0.02 (-2%)
	Feb	0.86	0.84	-0.02 (-3%)	0.86	0.84	-0.02 (-2%)	0.90	0.87	-0.02 (-3%)
	Mar	0.80	0.76	-0.03 (-4%)	0.82	0.80	-0.02 (-3%)	0.84	0.81	-0.03 (-4%)
	Apr	0.74	0.74	0.00 (0%)	0.73	0.72	0.00 (0%)	0.74	0.74	-0.01 (-1%)
	May	0.70	0.70	0.00 (0%)	0.69	0.69	0.00 (0%)	0.69	0.70	0.00 (0%)
	Jun	0.69	0.70	0.01 (1%)	0.69	0.70	0.01 (1%)	0.70	0.71	0.01 (1%)

Water Year Type	Month	2015			2030			2070		
		Without Project	With Project	Difference (%)	Without Project	With Project	Difference (%)	Without Project	With Project	Difference (%)
Dry	Jul	0.71	0.73	0.02 (3%)	0.71	0.73	0.02 (2%)	0.71	0.73	0.02 (2%)
	Aug	0.68	0.70	0.02 (3%)	0.68	0.70	0.03 (4%)	0.68	0.70	0.01 (2%)
	Sep	0.66	0.68	0.02 (3%)	0.66	0.68	0.02 (3%)	0.65	0.68	0.03 (4%)
	Oct	0.66	0.67	0.01 (1%)	0.68	0.68	0.00 (1%)	0.67	0.67	0.00 (1%)
	Nov	0.68	0.69	0.01 (1%)	0.71	0.71	0.00 (1%)	0.68	0.69	0.00 (1%)
	Dec	0.77	0.76	0.00 (0%)	0.80	0.79	-0.01 (-1%)	0.77	0.77	0.00 (-1%)
	Jan	0.80	0.78	-0.02 (-2%)	0.81	0.79	-0.02 (-2%)	0.80	0.78	-0.02 (-3%)
	Feb	0.83	0.81	-0.02 (-2%)	0.85	0.83	-0.02 (-2%)	0.84	0.82	-0.02 (-2%)
	Mar	0.77	0.74	-0.03 (-3%)	0.77	0.75	-0.02 (-3%)	0.77	0.76	-0.01 (-2%)
	Apr	0.73	0.72	-0.01 (-1%)	0.75	0.75	-0.01 (-1%)	0.73	0.73	-0.01 (-1%)
	May	0.70	0.69	0.00 (0%)	0.68	0.68	0.00 (0%)	0.68	0.67	0.00 (0%)
	Jun	0.69	0.69	0.01 (1%)	0.69	0.70	0.01 (1%)	0.70	0.71	0.01 (1%)
Critically Dry	Jul	0.70	0.71	0.01 (2%)	0.72	0.72	0.00 (0%)	0.70	0.71	0.01 (2%)
	Aug	0.68	0.70	0.02 (3%)	0.68	0.70	0.02 (3%)	0.69	0.69	0.00 (1%)
	Sep	0.65	0.67	0.02 (2%)	0.66	0.67	0.01 (2%)	0.66	0.67	0.01 (2%)
	Oct	0.65	0.66	0.00 (0%)	0.65	0.65	0.01 (1%)	0.66	0.65	0.00 (-1%)
	Nov	0.66	0.66	0.00 (0%)	0.66	0.66	0.00 (1%)	0.65	0.66	0.01 (1%)
	Dec	0.70	0.69	-0.01 (-1%)	0.70	0.69	-0.02 (-3%)	0.71	0.69	-0.02 (-3%)
	Jan	0.78	0.76	-0.02 (-3%)	0.78	0.77	-0.01 (-2%)	0.79	0.77	-0.02 (-2%)
	Feb	0.79	0.78	-0.02 (-2%)	0.81	0.79	-0.01 (-2%)	0.81	0.80	-0.01 (-1%)
	Mar	0.79	0.77	-0.03 (-4%)	0.80	0.77	-0.03 (-3%)	0.80	0.78	-0.02 (-3%)
	Apr	0.73	0.71	-0.01 (-2%)	0.74	0.73	-0.01 (-1%)	0.72	0.71	-0.01 (-1%)
	May	0.69	0.69	0.00 (0%)	0.70	0.69	0.00 (-1%)	0.69	0.69	0.00 (0%)
	Jun	0.69	0.69	0.00 (0%)	0.70	0.71	0.01 (1%)	0.70	0.71	0.01 (1%)
Long-Term Average	Jul	0.71	0.72	0.01 (2%)	0.72	0.73	0.01 (2%)	0.72	0.74	0.02 (3%)
	Aug	0.68	0.69	0.01 (1%)	0.68	0.69	0.01 (2%)	0.68	0.69	0.01 (2%)
	Sep	0.70	0.71	0.01 (2%)	0.70	0.71	0.01 (2%)	0.70	0.71	0.01 (2%)
	Oct	0.67	0.68	0.01 (1%)	0.67	0.68	0.01 (1%)	0.67	0.68	0.00 (1%)
	Nov	0.71	0.72	0.00 (1%)	0.71	0.71	0.00 (0%)	0.70	0.71	0.00 (0%)
	Dec	0.76	0.75	-0.01 (-1%)	0.76	0.75	-0.01 (-1%)	0.76	0.75	-0.01 (-2%)
	Jan	0.80	0.79	-0.02 (-2%)	0.81	0.79	-0.02 (-2%)	0.82	0.80	-0.02 (-2%)
	Feb	0.83	0.81	-0.02 (-2%)	0.84	0.82	-0.02 (-2%)	0.84	0.83	-0.02 (-2%)
	Mar	0.80	0.78	-0.02 (-2%)	0.80	0.79	-0.02 (-2%)	0.81	0.79	-0.02 (-2%)
	Apr	0.73	0.73	-0.01 (-1%)	0.73	0.72	0.00 (0%)	0.72	0.72	0.00 (0%)
	May	0.70	0.70	0.00 (0%)	0.69	0.68	0.00 (0%)	0.68	0.68	0.00 (0%)
	Jun	0.69	0.70	0.01 (1%)	0.70	0.71	0.01 (1%)	0.70	0.71	0.01 (1%)

A.2.6 References

A.2.6.1 Written References

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Sites Project Authority and U.S. Bureau of Reclamation. 2017. Draft Environmental Impact Report/Environmental Impact Statement and Draft Feasibility report for Sites Reservoir Project, Sites, California. August. State Clearinghouse #2001112009.

A.2.6.2 Personal Communications

Michel, Cyril J. Assistant Project Scientist, Salmon Ecology Team, NOAA Fisheries, Santa Cruz, CA. September 28, 2017—Email to Marin Greenwood, Aquatic Ecologist, ICF, Sacramento, CA, containing a csv file with late fall-run Chinook salmon acoustic tag detections per day from 2007 to 2011.

A.3 Yolo Bypass Flows

A.3.1 Modeling Considerations

A.3.1.1 Comment from PBR Review

On page 4 of 5 of the Water Operations Review for Public Benefits Ratio:

The applicant claims that the project will be operated to release two pulse flows of at least 400 cfs each over a 2- to 3-week period between August and October in all years into Yolo Bypass near Knights Landing Ridge Cut to increase desirable food sources for Delta Smelt and other key fish species in the lower Cache Slough and lower Sacramento River areas. Review of the CalSim II model results shows increase in Yolo Bypass monthly flows exceeding 400 cfs approximately 40 percent of the time during August through October over the 82-year simulation period.

The applicant's CalSim II model results indicate that long-term August through October cumulative average Yolo Bypass flows increase by 39 TAF under both 2030 and 2070 conditions. The Yolo Bypass flows during dry and critical water years were updated to reflect the SWRCB D-1641 Sacramento Valley 40-30-30 index water year definition. Compared to the values reported by the applicant, dry and critical water year August through October cumulative average Yolo Bypass flows change by +3 TAF and +8 TAF, respectively, under 2030 conditions and by +3 TAF and +7 TAF, respectively, under 2070 conditions.

While the Yolo Bypass flows increase during August through October, the flows decrease during November through July. Review of the applicant's CalSim II model results indicates that long-term average annual Yolo Bypass flow into the Delta decreases by 84 TAF per year under 2030 conditions, and by 116 TAF per year under 2070 conditions.

On page 2 of 2 of the Sites Reservoir Project Monetized Ecosystem Benefits review by the CDFW:

Ecosystem benefits resulting from the Yolo Bypass pulse flows are consistent with the Delta Smelt Resiliency Strategy. However, long-term average annual Yolo Bypass flow into the Delta is decreased with the Project. The Water Operations Review states. "While the Yolo Bypass flows increase during August through October, the flows decrease during November through July. Review of the applicant's CalSim II model results indicates that long-term average annual Yolo Bypass flow into the Delta decreases by 84 TAF per year under 2030 conditions, and by 116 TAF per year under 2070 conditions [under the with-project scenario]." Impacts from decreased Yolo Bypass flows into the Delta were not analyzed or disclosed in the quantification of a net improvement as required by section 6004 (a). Therefore, the Department recommends removing this monetized ecosystem benefit from the public benefit ratio.

A.3.1.2 Response

An analysis of flows, weir spills, and habitat inundation area was performed for the Yolo Bypass. Daily total Yolo Bypass flow results used in the current analysis were estimated using the monthly CalSim II outputs of spills over the Fremont and Sacramento Weirs and west-side stream flows disaggregated into daily flows using the historical flow patterns.

Daily flows in the Yolo Bypass were calculated based on a monthly-to-daily flow mapping technique applied in the model for a better estimate of the spills at the Fremont Weir and the Sacramento Weir. Historical daily patterns, based on yearly hydrology, were used to convert CalSim II monthly timeseries to a daily timeseries. Daily patterns were developed using the observed DAYFLOW period of 1956-2008. In all cases, the monthly volumes are preserved between the daily and monthly flows. It is important to note that this daily mapping approach does not represent the flows resulting from operational responses on a daily time step. It is simply a technique to incorporate representative daily variability into the flows resulting from monthly operational decisions in CalSim II.

Fremont Weir Spill Flow and Duration

The analysis examined the frequency and duration of spills over the Fremont Weir as well as the total flows in the Yolo Bypass that would provide rearing habitat for salmonids and splittail. The number of years in the 82-year simulation period where there was at least one Fremont Weir spill of varying amounts (0, 2,000, 4,000, 6,000, 8,000, and 10,000 cfs) with a duration of 0-10 days, 11-20 days, 21-30 days, 31 to 45 days, and greater than 45 days were calculated from the daily results. Similarly, the number of years with at least one event where total Yolo flow exceeded these flows for frequency and duration was examined for the entire 82-year simulation period. This analysis was limited to October through April, when juvenile salmonids and spawning splittail are anticipated to be present in the Yolo Bypass. The results of this analysis are in Table A.3-1, Table A.3-2, and Table A.3-3.

The daily spill and total Yolo flow results were analyzed for flows above specified thresholds. If the gap between two events was less than seven days, then it was treated as one continuous event. The duration of these events was then calculated, and categorized by length. This analysis allows for the assessment of the effects of the Sites Project on the duration and magnitude of flows in the Yolo Bypass in comparison to the Without Project scenario. The results of this analysis are in Table A.3-4, Table A.3-5, and Table A.3-6.

Table A.3-1: Count of years that exceed flow magnitude and duration thresholds between 1921-2003: Fremont Weir Spill - DCR 2015 and DCR 2015 With Project

Number of years that contain events with consecutive days of spills (max 7 day gap to count as new event)	> 0 days			>10 days			> 20 days			> 30 days			> 45 days		
	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference
> 0 cfs	51	46	-5 (-9.8%)	39	37	-2 (-5.1%)	26	25	-1 (-3.8%)	21	20	-1 (-4.8%)	14	14	0 (0.0%)
> 1,000 cfs	50	44	-6 (-12.0%)	37	35	-2 (-5.4%)	26	25	-1 (-3.8%)	21	20	-1 (-4.8%)	13	13	0 (0.0%)
> 2,000 cfs	50	44	-6 (-12.0%)	35	32	-3 (-8.6%)	26	25	-1 (-3.8%)	21	20	-1 (-4.8%)	12	13	1 (8.3%)
> 3,000 cfs	49	42	-7 (-14.3%)	35	32	-3 (-8.6%)	26	25	-1 (-3.8%)	20	19	-1 (-5.0%)	12	11	-1 (-8.3%)
> 4,000 cfs	47	41	-6 (-12.8%)	33	31	-2 (-6.1%)	25	25	0 (0.0%)	19	18	-1 (-5.3%)	10	9	-1 (-10.0%)
> 6,000 cfs	46	41	-5 (-10.9%)	32	30	-2 (-6.3%)	24	24	0 (0.0%)	17	17	0 (0.0%)	9	8	-1 (-11.1%)
> 8,000 cfs	44	40	-4 (-9.1%)	31	28	-3 (-9.7%)	24	22	-2 (-8.3%)	17	16	-1 (-5.9%)	9	8	-1 (-11.1%)
> 10,000 cfs	42	40	-2 (-4.8%)	29	27	-2 (-6.9%)	21	21	0 (0.0%)	15	14	-1 (-6.7%)	9	8	-1 (-11.1%)

Table A.3-2: Count of years that exceed flow magnitude and duration thresholds between 1921-2003: Fremont Weir Spill - WSIP 2030 and WSIP 2030 With Project

Number of years that contain events with consecutive days of spills (max 7 day gap to count as new event)	> 0 days			>10 days			> 20 days			> 30 days			> 45 days		
	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference
> 0 cfs	53	52	-1 (-1.9%)	41	39	-2 (-4.9%)	32	30	-2 (-6.3%)	26	24	-2 (-7.7%)	21	19	-2 (-9.5%)
> 1,000 cfs	53	50	-3 (-5.7%)	41	39	-2 (-4.9%)	31	30	-1 (-3.2%)	25	24	-1 (-4.0%)	19	18	-1 (-5.3%)
> 2,000 cfs	52	49	-3 (-5.8%)	40	39	-1 (-2.5%)	31	30	-1 (-3.2%)	25	23	-2 (-8.0%)	17	16	-1 (-5.9%)
> 3,000 cfs	52	49	-3 (-5.8%)	40	39	-1 (-2.5%)	30	30	0 (0.0%)	24	23	-1 (-4.2%)	17	15	-2 (-11.8%)
> 4,000 cfs	52	49	-3 (-5.8%)	38	38	0 (0.0%)	30	29	-1 (-3.3%)	22	21	-1 (-4.5%)	14	14	0 (0.0%)
> 6,000 cfs	52	46	-6 (-11.5%)	37	37	0 (0.0%)	28	28	0 (0.0%)	22	20	-2 (-9.1%)	14	14	0 (0.0%)
> 8,000 cfs	50	46	-4 (-8.0%)	37	36	-1 (-2.7%)	28	27	-1 (-3.6%)	21	20	-1 (-4.8%)	11	11	0 (0.0%)
> 10,000 cfs	48	45	-3 (-6.3%)	36	34	-2 (-5.6%)	28	24	-4 (-14.3%)	20	20	0 (0.0%)	11	11	0 (0.0%)

Table A.3-3: Count of years that exceed flow magnitude and duration thresholds between 1921-2003: Fremont Weir Spill - WSIP 2070 and WSIP 2070 With Project

Number of years that contain events with consecutive days of spills (max 7 day gap to count as new event)	> 0 days			>10 days			> 20 days			> 30 days			> 45 days		
	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference
> 0 cfs	57	52	-5 (-8.8%)	44	43	-1 (-2.3%)	33	33	0 (0.0%)	27	27	0 (0.0%)	23	22	-1 (-4.3%)
> 1,000 cfs	57	51	-6 (-10.5%)	43	43	0 (0.0%)	33	33	0 (0.0%)	27	27	0 (0.0%)	23	21	-2 (-8.7%)
> 2,000 cfs	54	51	-3 (-5.6%)	43	43	0 (0.0%)	33	33	0 (0.0%)	27	27	0 (0.0%)	21	19	-2 (-9.5%)
> 3,000 cfs	54	50	-4 (-7.4%)	43	42	-1 (-2.3%)	33	33	0 (0.0%)	27	27	0 (0.0%)	20	19	-1 (-5.0%)
> 4,000 cfs	52	50	-2 (-3.8%)	42	39	-3 (-7.1%)	33	33	0 (0.0%)	27	27	0 (0.0%)	20	19	-1 (-5.0%)
> 6,000 cfs	52	48	-4 (-7.7%)	41	39	-2 (-4.9%)	33	32	-1 (-3.0%)	25	24	-1 (-4.0%)	17	17	0 (0.0%)
> 8,000 cfs	51	48	-3 (-5.9%)	39	37	-2 (-5.1%)	32	30	-2 (-6.3%)	23	24	1 (4.3%)	16	16	0 (0.0%)
> 10,000 cfs	50	48	-2 (-4.0%)	38	37	-1 (-2.6%)	30	29	-1 (-3.3%)	23	22	-1 (-4.3%)	14	13	-1 (-7.1%)

Table A.3-4: Count of years that exceed flow magnitude and duration thresholds between 1921-2003: Yolo Bypass Flow - DCR 2015 and DCR 2015 With Project

Number of years that contain events with consecutive days of flow (max 7 day gap to count as new event)	> 0 days			>10 days			> 20 days			> 30 days			> 45 days		
	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference	DCR 2015	DCR 2015 with Project	Difference
> 0 cfs	82	82	0 (0.0%)	82	82	0 (0.0%)	82	82	0 (0.0%)	82	82	0 (0.0%)	81	82	1 (1.2%)
> 1,000 cfs	74	71	-3 (-4.1%)	63	60	-3 (-4.8%)	55	52	-3 (-5.5%)	46	45	-1 (-2.2%)	42	41	-1 (-2.4%)
> 2,000 cfs	67	65	-2 (-3.0%)	57	51	-6 (-10.5%)	42	43	1 (2.4%)	38	39	1 (2.6%)	30	30	0 (0.0%)
> 3,000 cfs	64	58	-6 (-9.4%)	53	49	-4 (-7.5%)	37	36	-1 (-2.7%)	32	31	-1 (-3.1%)	25	24	-1 (-4.0%)
> 4,000 cfs	62	55	-7 (-11.3%)	46	44	-2 (-4.3%)	34	32	-2 (-5.9%)	29	26	-3 (-10.3%)	22	19	-3 (-13.6%)
> 6,000 cfs	58	49	-9 (-15.5%)	41	39	-2 (-4.9%)	30	29	-1 (-3.3%)	25	25	0 (0.0%)	14	14	0 (0.0%)
> 8,000 cfs	55	48	-7 (-12.7%)	36	35	-1 (-2.8%)	27	27	0 (0.0%)	21	21	0 (0.0%)	14	14	0 (0.0%)
> 10,000 cfs	51	48	-3 (-5.9%)	33	32	-1 (-3.0%)	26	26	0 (0.0%)	19	18	-1 (-5.3%)	13	11	-2 (-15.4%)

Table A.3-5: Count of years that exceed flow magnitude and duration thresholds between 1921-2003: Yolo Bypass Flow - WSIP 2030 and WSIP 2030 With Project

Number of years that contain events with consecutive days of flow (max 7 day gap to count as new event)	> 0 days			>10 days			> 20 days			> 30 days			> 45 days		
	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference	WSIP 2030	WSIP 2030 with Project	Difference
> 0 cfs	82	82	0 (0.0%)	82	82	0 (0.0%)	82	82	0 (0.0%)	82	82	0 (0.0%)	81	82	1 (1.2%)
> 1,000 cfs	73	71	-2 (-2.7%)	62	62	0 (0.0%)	55	54	-1 (-1.8%)	46	45	-1 (-2.2%)	42	42	0 (0.0%)
> 2,000 cfs	69	66	-3 (-4.3%)	58	56	-2 (-3.4%)	46	43	-3 (-6.5%)	37	38	1 (2.7%)	32	32	0 (0.0%)
> 3,000 cfs	66	61	-5 (-7.6%)	53	51	-2 (-3.8%)	40	38	-2 (-5.0%)	32	32	0 (0.0%)	26	27	1 (3.8%)
> 4,000 cfs	64	57	-7 (-10.9%)	50	46	-4 (-8.0%)	36	36	0 (0.0%)	30	28	-2 (-6.7%)	25	24	-1 (-4.0%)
> 6,000 cfs	60	53	-7 (-11.7%)	44	43	-1 (-2.3%)	33	32	-1 (-3.0%)	27	27	0 (0.0%)	21	21	0 (0.0%)
> 8,000 cfs	57	51	-6 (-10.5%)	39	39	0 (0.0%)	28	28	0 (0.0%)	24	24	0 (0.0%)	18	17	-1 (-5.6%)
> 10,000 cfs	54	50	-4 (-7.4%)	37	37	0 (0.0%)	28	28	0 (0.0%)	23	23	0 (0.0%)	16	16	0 (0.0%)

Table A.3-6: Count of years that exceed flow magnitude and duration thresholds between 1921-2003: Yolo Bypass Flow - WSIP 2070 and WSIP 2070 With Project

Number of years that contain events with consecutive days of flow (max 7 day gap to count as new event)	> 0 days			>10 days			> 20 days			> 30 days			> 45 days		
	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference	WSIP 2070	WSIP 2070 with Project	Difference
> 0 cfs	82	82	0 (0.0%)	82	82	0 (0.0%)	82	82	0 (0.0%)	82	82	0 (0.0%)	81	82	1 (1.2%)
> 1,000 cfs	73	70	-3 (-4.1%)	61	61	0 (0.0%)	53	53	0 (0.0%)	46	45	-1 (-2.2%)	42	42	0 (0.0%)
> 2,000 cfs	69	67	-2 (-2.9%)	58	57	-1 (-1.7%)	47	44	-3 (-6.4%)	38	37	-1 (-2.6%)	32	31	-1 (-3.1%)
> 3,000 cfs	67	62	-5 (-7.5%)	54	53	-1 (-1.9%)	41	38	-3 (-7.3%)	32	32	0 (0.0%)	27	26	-1 (-3.7%)
> 4,000 cfs	65	58	-7 (-10.8%)	54	49	-5 (-9.3%)	36	36	0 (0.0%)	30	30	0 (0.0%)	26	24	-2 (-7.7%)
> 6,000 cfs	61	55	-6 (-9.8%)	46	46	0 (0.0%)	34	34	0 (0.0%)	29	29	0 (0.0%)	24	21	-3 (-12.5%)
> 8,000 cfs	59	54	-5 (-8.5%)	44	41	-3 (-6.8%)	33	32	-1 (-3.0%)	27	25	-2 (-7.4%)	21	20	-1 (-4.8%)
> 10,000 cfs	56	52	-4 (-7.1%)	42	38	-4 (-9.5%)	32	32	0 (0.0%)	25	24	-1 (-4.0%)	18	18	0 (0.0%)

Habitat Inundation Area

An additional analysis was performed to quantify the inundated habitat area in the Yolo Bypass and the duration of inundation.

A flow-inundated habitat relationship was developed for the Yolo Bypass (DWR 2016). The curve is used to determine the inundated acres of habitat in the Yolo Bypass for a given flow at the Woodland gage and is presented in Table A.3-7. The Woodland Gage is near Interstate 5, upstream of the Sacramento Weir.

Table A.3-7: Inundation Area-Woodland Flow relationship for the Yolo Bypass.

Yolo Bypass at Woodland Flow (cfs)	Inundation Area (acres)
2,667	20,052
3,898	22,255
44,300	44,086
60,784	46,616
151,806	54,302
204,560	56,485

Using the daily flow data discussed above, the flow at Woodland was calculated by adding the calculated daily Fremont Weir Spill and west-side stream flows. Then, using the curve in Table A.3-7, the inundated habitat area was calculated for each day through interpolation. The minimum flow in Table A.3-7 is 2,667 cfs. Any flow below that is assumed to inundate no habitat as the flow is contained within the Tule Canal. The maximum flow is 204,560 cfs. Any flow above 204,560 cfs is assumed to inundate 56,485 acres of habitat.

Using the daily habitat area calculations, the duration and magnitude of inundation area was quantified. The length of each period where a given inundated area was exceeded was calculated. Then, for each calendar month, the number of periods not exceeding 10 days and the number exceeding 10 days over the period between water years 1922 and 2003 were counted. Periods of inundation greater than 10 days are considered more beneficial for facilitating the processes that create food for salmonids in the Yolo Bypass. The results for current, WSIP 2030, and WSIP 2070 climate conditions are in Tables A.3-8, A.3-9, and A.3-10.

Table A.3-8: Yolo Bypass Habitat Inundation Duration Frequency, Current Climate, Based on Estimated Daily Flows at Woodland

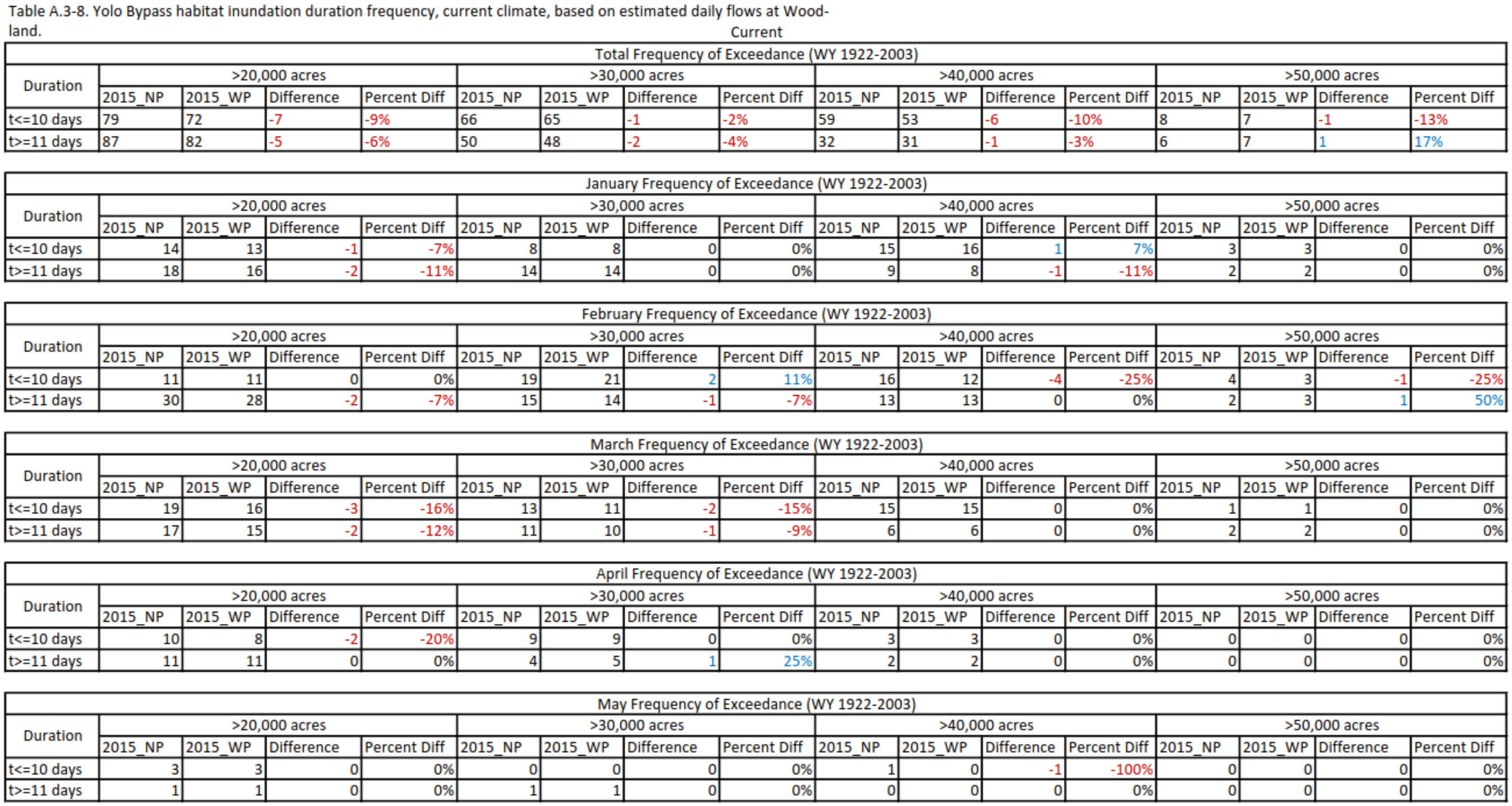

Table A.3-8. Yolo Bypass habitat inundation duration frequency, current climate, based on estimated daily flows at Woodland.

Current

Total Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	79	72	-7	-9%	66	65	-1	-2%	59	53	-6	-10%	8	7	-1	-13%
t>=11 days	87	82	-5	-6%	50	48	-2	-4%	32	31	-1	-3%	6	7	1	17%

January Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	14	13	-1	-7%	8	8	0	0%	15	16	1	7%	3	3	0	0%
t>=11 days	18	16	-2	-11%	14	14	0	0%	9	8	-1	-11%	2	2	0	0%

February Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	11	11	0	0%	19	21	2	11%	16	12	-4	-25%	4	3	-1	-25%
t>=11 days	30	28	-2	-7%	15	14	-1	-7%	13	13	0	0%	2	3	1	50%

March Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	19	16	-3	-16%	13	11	-2	-15%	15	15	0	0%	1	1	0	0%
t>=11 days	17	15	-2	-12%	11	10	-1	-9%	6	6	0	0%	2	2	0	0%

April Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	10	8	-2	-20%	9	9	0	0%	3	3	0	0%	0	0	0	0%
t>=11 days	11	11	0	0%	4	5	1	25%	2	2	0	0%	0	0	0	0%

May Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	3	3	0	0%	0	0	0	0%	1	0	-1	-100%	0	0	0	0%
t>=11 days	1	1	0	0%	1	1	0	0%	0	0	0	0%	0	0	0	0%

June Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	2	2	0	0%	1	1	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

July Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

August Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

September Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

October Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	1	1	0	0%	1	1	0	0%	0	1	1	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

November Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	2	5	3	150%	1	2	1	100%	2	1	-1	-50%	0	0	0	0%
t>=11 days	2	3	1	50%	1	0	-1	-100%	0	0	0	0%	0	0	0	0%

December Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff	2015_NP	2015_WP	Difference	Percent Diff
t<=10 days	17	13	-4	-24%	14	12	-2	-14%	7	5	-2	-29%	0	0	0	0%
t>=11 days	8	8	0	0%	4	4	0	0%	2	2	0	0%	0	0	0	0%

Table A.3-9: Yolo Bypass Habitat Inundation Duration Frequency, WSIP 2030 Climate, Based on Estimated Daily Flows at Woodland

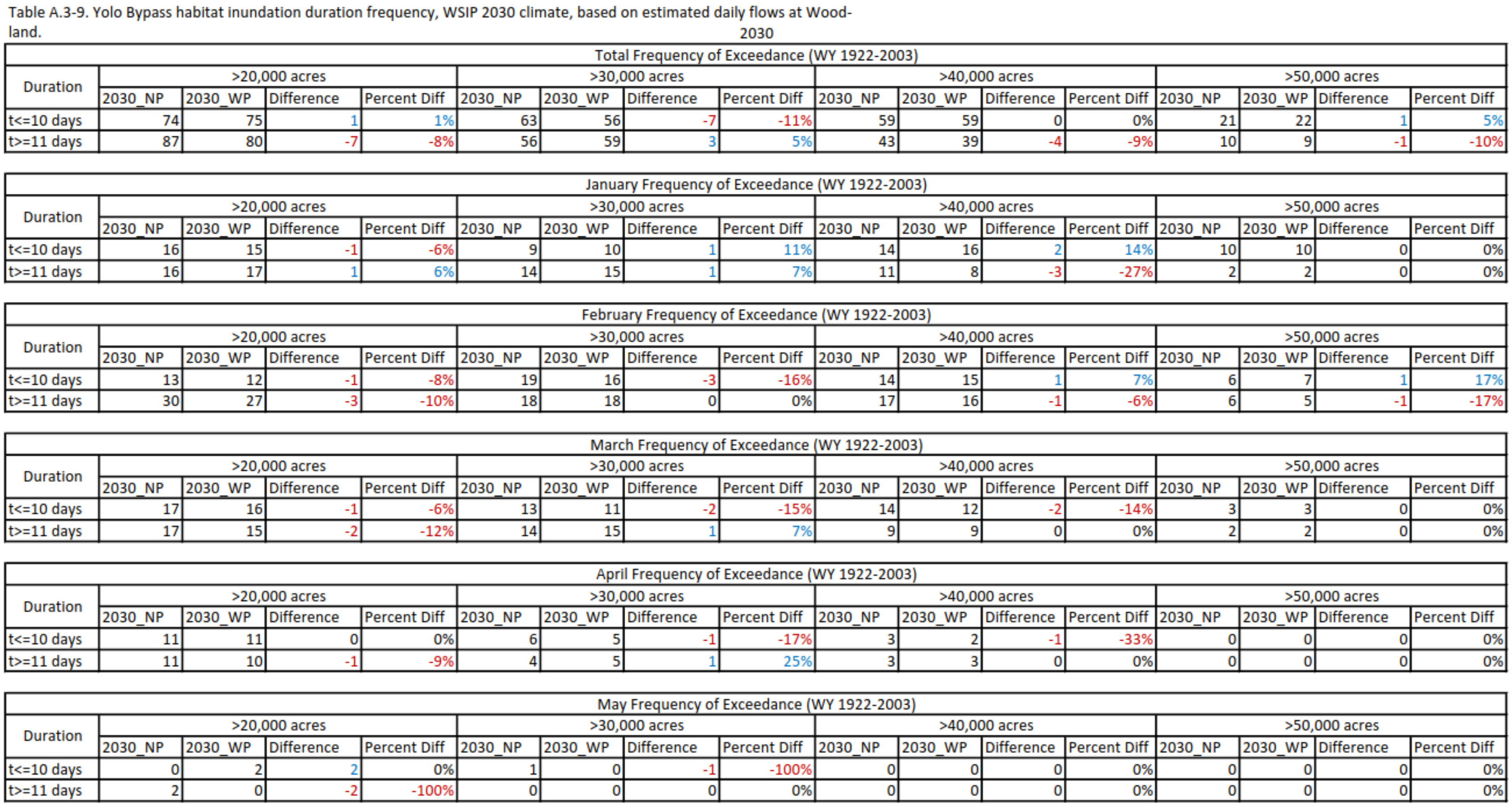

Table A.3-9. Yolo Bypass habitat inundation duration frequency, WSIP 2030 climate, based on estimated daily flows at Woodland.

2030

Total Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	74	75	1	1%	63	56	-7	-11%	59	59	0	0%	21	22	1	5%
t>=11 days	87	80	-7	-8%	56	59	3	5%	43	39	-4	-9%	10	9	-1	-10%

January Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	16	15	-1	-6%	9	10	1	11%	14	16	2	14%	10	10	0	0%
t>=11 days	16	17	1	6%	14	15	1	7%	11	8	-3	-27%	2	2	0	0%

February Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	13	12	-1	-8%	19	16	-3	-16%	14	15	1	7%	6	7	1	17%
t>=11 days	30	27	-3	-10%	18	18	0	0%	17	16	-1	-6%	6	5	-1	-17%

March Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	17	16	-1	-6%	13	11	-2	-15%	14	12	-2	-14%	3	3	0	0%
t>=11 days	17	15	-2	-12%	14	15	1	7%	9	9	0	0%	2	2	0	0%

April Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	11	11	0	0%	6	5	-1	-17%	3	2	-1	-33%	0	0	0	0%
t>=11 days	11	10	-1	-9%	4	5	1	25%	3	3	0	0%	0	0	0	0%

May Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	0	2	2	0%	1	0	-1	-100%	0	0	0	0%	0	0	0	0%
t>=11 days	2	0	-2	-100%	0	0	0	0%	0	0	0	0%	0	0	0	0%

June Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

July Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

August Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

September Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

October Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	1	2	1	100%	1	1	0	0%	1	1	0	0%	1	1	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

November Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	2	2	0	0%	1	1	0	0%	3	3	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	1	1	0%	0	0	0	0%	0	0	0	0%

December Frequency of Exceedance (WY 1922-2003)																
Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff	2030_NP	2030_WP	Difference	Percent Diff
t<=10 days	14	15	1	7%	13	12	-1	-8%	10	10	0	0%	1	1	0	0%
t>=11 days	11	11	0	0%	6	5	-1	-17%	3	3	0	0%	0	0	0	0%

Table A.3-10: Yolo Bypass Habitat Inundation Duration Frequency, WSIP 2070 Climate, Based on Estimated Daily Flows at Woodland

Table A.3-10. Yolo Bypass habitat inundation duration frequency, WSIP 2070 climate, based on estimated daily flows at Woodland.

2070

Total Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	70	62	-8	-11%	63	54	-9	-14%	54	57	3	6%	22	21	-1	-5%
t>=11 days	86	82	-4	-5%	61	58	-3	-5%	47	43	-4	-9%	14	14	0	0%

January Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	13	13	0	0%	9	8	-1	-11%	10	14	4	40%	9	9	0	0%
t>=11 days	18	19	1	6%	18	17	-1	-6%	16	13	-3	-19%	5	5	0	0%

February Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	13	10	-3	-23%	22	16	-6	-27%	15	17	2	13%	7	7	0	0%
t>=11 days	29	27	-2	-7%	19	19	0	0%	17	16	-1	-6%	7	7	0	0%

March Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	17	16	-1	-6%	11	12	1	9%	15	12	-3	-20%	4	3	-1	-25%
t>=11 days	17	17	0	0%	15	13	-2	-13%	10	10	0	0%	2	2	0	0%

April Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	10	7	-3	-30%	6	5	-1	-17%	3	2	-1	-33%	0	0	0	0%
t>=11 days	10	8	-2	-20%	4	4	0	0%	3	3	0	0%	0	0	0	0%

May Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	0	1	1	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	1	0	-1	-100%	0	0	0	0%	0	0	0	0%	0	0	0	0%

June Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

July Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

August Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

September Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

October Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	1	2	1	100%	1	1	0	0%	1	1	0	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

November Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	4	3	-1	-25%	1	0	-1	-100%	0	1	1	0%	0	0	0	0%
t>=11 days	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%

December Frequency of Exceedance (WY 1922-2003)

Duration	>20,000 acres				>30,000 acres				>40,000 acres				>50,000 acres			
	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff	2070_NP	2070_WP	Difference	Percent Diff
t<=10 days	12	10	-2	-17%	13	12	-1	-8%	10	10	0	0%	2	2	0	0%
t>=11 days	11	11	0	0%	5	5	0	0%	1	1	0	0%	0	0	0	0%

A.3.1.3 References

California Department of Water Resources (DWR). 2016. Draft Basin-Wide Feasibility Studies: Sacramento River Basin. November. https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-Planning-and-Studies/Basin-wide-Feasibility-Studies/Files/Basin-Wide-Feasibility-Studies-Sacramento-River.pdf?la=en&hash=D460E4CFCE5510429D40EF19E103F84E34347474

Sommer, T.R., et. Al. 2001a. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Can. J. Fish. Aquat. Sci., 58: 325–333.

Sommer, T.R., et. Al. 2001b. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries, 26: 6-16.

A.3.2 Biological Considerations

- In their Monetized Ecosystem Benefits review for the Sites Reservoir Project, the CDFW noted that impacts from decreased Yolo Bypass flows were not provided.
- ICF used Sites Project modeling to assess the mean Yolo Bypass flooding duration (number of days with Fremont Weir flow >3,500 cfs, based on literature) for With and With Project Scenarios during the important January-June juvenile Chinook salmon rearing and migration period.
- Mean Yolo Bypass flooding duration ranged from 0 to 2 days less per year under With Project scenarios compared to With Project scenarios, which appears unlikely to be significant at a population level, based on available literature of biological responses.

A.3.2.1 Background

The Sites Reservoir Project Monetized Ecosystem Benefits review by the CDFW noted that "Impacts from decreased Yolo Bypass flows into the Delta were not analyzed or disclosed in the quantification of net benefits." (DFW 2018, p.2). During a follow-up Public Benefit Ratio Review meeting with California Water Commission staff at which DFW was also present, DFW clarified that the concern is related to flow into Yolo Bypass as opposed to flow from Yolo Bypass into the Delta. This memorandum reviews potential effects on juvenile Chinook salmon, the main focal species using the Yolo Bypass during the period which could be affected by Sites Project diversions.

A.3.2.2 Methods

Takata et al (2017) examined various juvenile Chinook salmon biological responses to Yolo Bypass flooding, which they defined as the number of days with daily mean flows at the downstream end of Yolo Bypass >4,000 cfs; this is the flow at which floodplain inundation occurs. The data we had available from Sites Project modeling were daily mean flows at Fremont Weir. Flows into the Yolo Bypass Toe Drain >100 cumecs (~3,500 cfs) begin to inundate the floodplain (Sommer et al. 2001), so we assumed that the number of days with mean Fremont Weir flow >3,500 cfs was a reasonable proxy for number of days with flow >4,000 cfs at the downstream end of the bypass. Takata et al.'s (2017) study focused on the January-June period, so we counted the annual number of days of flooding (Fremont Weir spill > 3,500 cfs) from January to June over the 1921-2003 CalSim simulation period, and compared the With and Without Project scenarios for each of the 2015, 2030, and 2070 climate scenarios.

We also explored the effect of the diversion on the mean number of hectares inundated on days with yolo bypass flooding from January through June and the effect of those reductions on the capacity of the bypass for rearing juvenile salmon. We assumed, based on Katz et al. (2017) and Sommer et al. (2005) a capacity of 5,000 fish/hectare and calculate the population potential for the inundated areas. We then used fry equivalent estimates passing Red Bluff Diversion Dam for 2002 -2012 from Poytress et al. (2014) to estimate numbers of emigrating juvenile salmon in the river and applied the maximum estimated proportional entry into Yolo Bypass if Fremont Weir were notched from Roberts et al. (2013) to estimate likely numbers of fish entering the bypass compared to the capacity of the Bypass to evaluated whether the reduction in mean number of hectares inundated would limit the capacity of the bypass for rearing juvenile salmon.

A.3.2.3 Results[8] and Discussion

The mean number of days with Yolo Bypass flooding (Fremont Weir flow >3,500 cfs) during January-June ranged from 0 in critically dry years with 2015 climate to 54-55 days in wet years with 2070 climate (Table 1). The differences in mean duration of flooding between Without and With Project scenarios were small, 1-2 days (Table A.3-11), and the frequency of flood duration over the 82-year simulation was not greatly different between Without and With Project scenarios (Figures A.3-1 through A.3-3).

Takata et al. (2017) found that growth and floodplain residence of coded-wire-tagged juvenile Chinook salmon and catch per unit effort of wild juvenile Chinook salmon, are significantly positively related to the annual duration of Yolo Bypass flooding (Figures A.3-4 and A.3-5). However, given the variability in the observed biological relationships indicated by the spread in the data, and no significant difference in survival to capture in ocean fisheries between coded-wire-tagged juvenile Chinook salmon released in the Yolo Bypass and those released at the same time in the Sacramento River (Takata et al. 2017), the small differences in floodplain inundation shown in the modeling of the Sites Project appear unlikely to be biologically significant at a population level.

The exploration of capacity for rearing juveniles in the bypass suggests the effect of the reduction in flow into the bypass is unlikely to reduce the availability of habitat for rearing juvenile salmon. The area inundated on days with Yolo Bypass flooding, January-June is displayed in Table A.3-12. The capacity of these areas assuming of 5000 fish per hectare (Katz et al. (2017) and Sommer et al. (2005)) exceeds the estimated number of juveniles likely to enter the bypass by orders of magnitude (Figure A.3-6). Even though there is a reduction in inundated area is not likely to limit population growth.

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[8] All calculations are provided in the Excel workbook <DRAFT_Yolo_inundation_days_02152018.xlsx>

Table A.3-11: Mean Annual Number of Days of Yolo Bypass Flooding (Fremont Weir Flow >3,500 cfs, January-June) Simulated for the Sites Reservoir Project.

Water Year Type	2015			2030			2070		
	Without Project	With Project	Difference (%)	Without Project	With Project	Difference (%)	Without Project	With Project	Difference (%)
Wet	47	45	-2 (-4%)	52	51	-1 (-2%)	55	54	-1 (-2%)
Above Normal	20	18	-2 (-10%)	28	26	-2 (-7%)	32	32	-1 (-2%)
Below Normal	3	2	0 (-17%)	6	5	-1 (-16%)	6	5	-1 (-15%)
Dry	2	1	-1 (-41%)	2	1	-1 (-33%)	3	3	0 (-12%)
Critically Dry	0	0	0 (0%)	0	0	0 (0%)	0	0	0 (0%)

Table A.3-12: Mean hectares inundated on days with Yolo Bypass flooding, January-June Mean hectares inundated on days with Yolo Bypass flooding, January-June

Year Type	2015			2030			2070		
	Without Project	With Project	Difference	Without Project	With Project	Difference	Without Project	With Project	Difference
Wet	14,597	14,568	-29	15,234	15,178	-56	15,791	15,820	29
Above Normal	12,442	11,287	-1,155	13,600	13,302	-298	15,034	14,943	-90
Below Normal	8,188	6,673	-1,515	9,324	7,825	-1,500	10,350	9,067	-1,283
Dry	6,527	5,665	-862	7,051	5,494	-1,557	7,427	6,485	-942
Critically Dry	3,203	2,223	-980	3,202	3,010	-192	3,234	3,042	-192 (-6%)

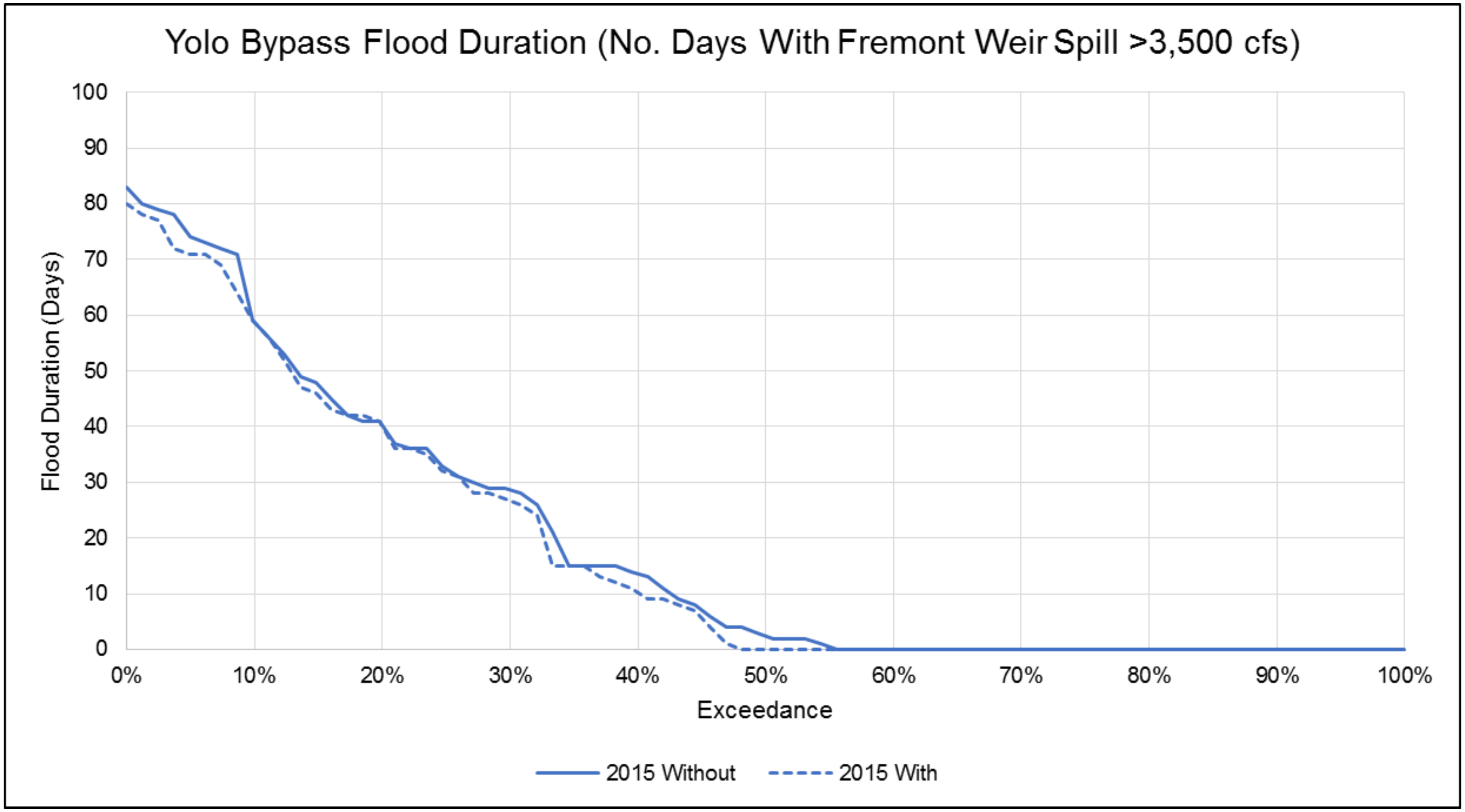


Figure A.3-1: Exceedance Plot of Mean Annual Number of Days of Yolo Bypass Flooding (Fremont Weir Flow >3,500 cfs, January-June) Simulated for the Sites Reservoir Project: 2015 Climate.

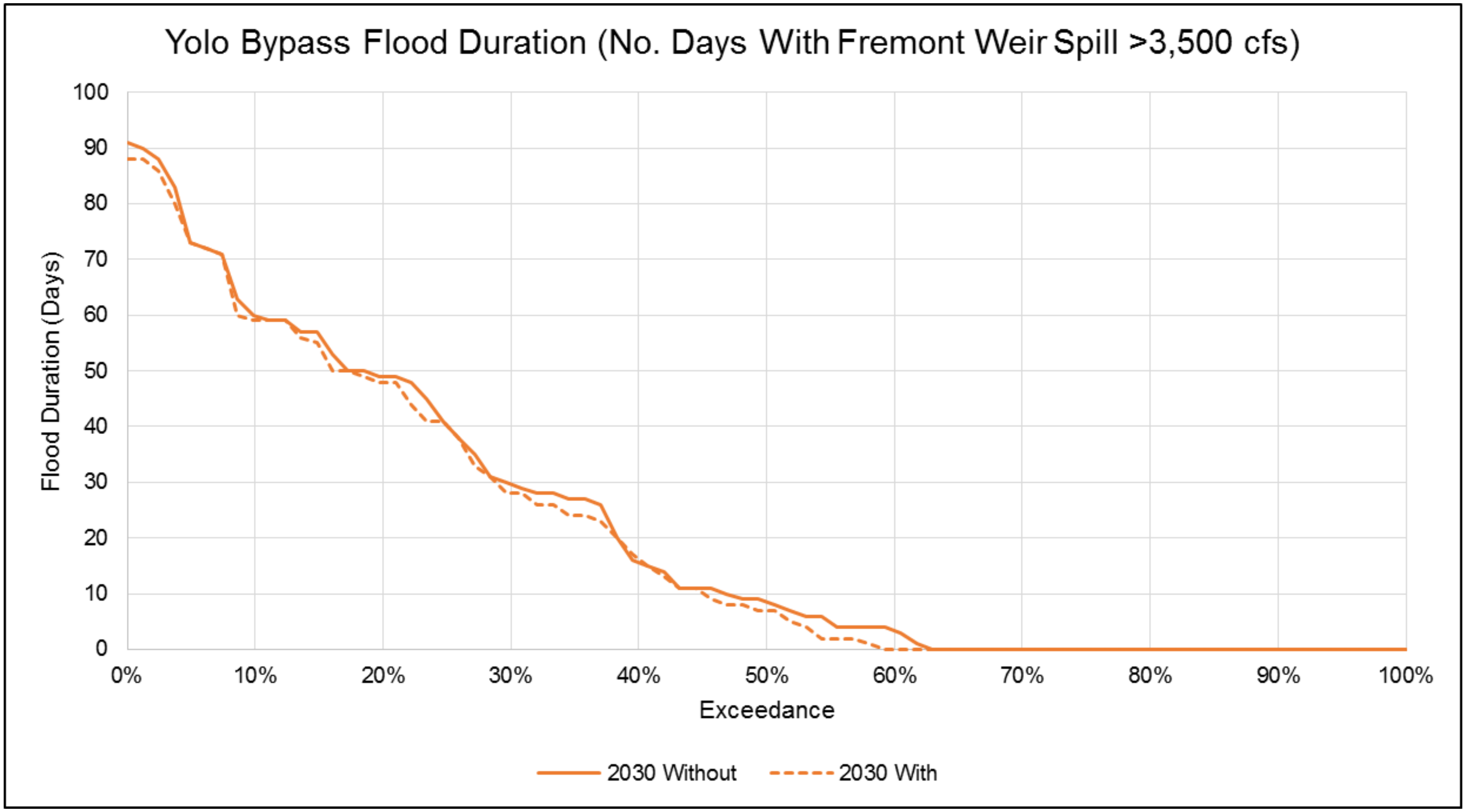


Figure A.3-2: Exceedance Plot of Mean Annual Number of Days of Yolo Bypass Flooding (Fremont Weir Flow >3,500 cfs, January-June) Simulated for the Sites Reservoir Project: 2030 Climate.

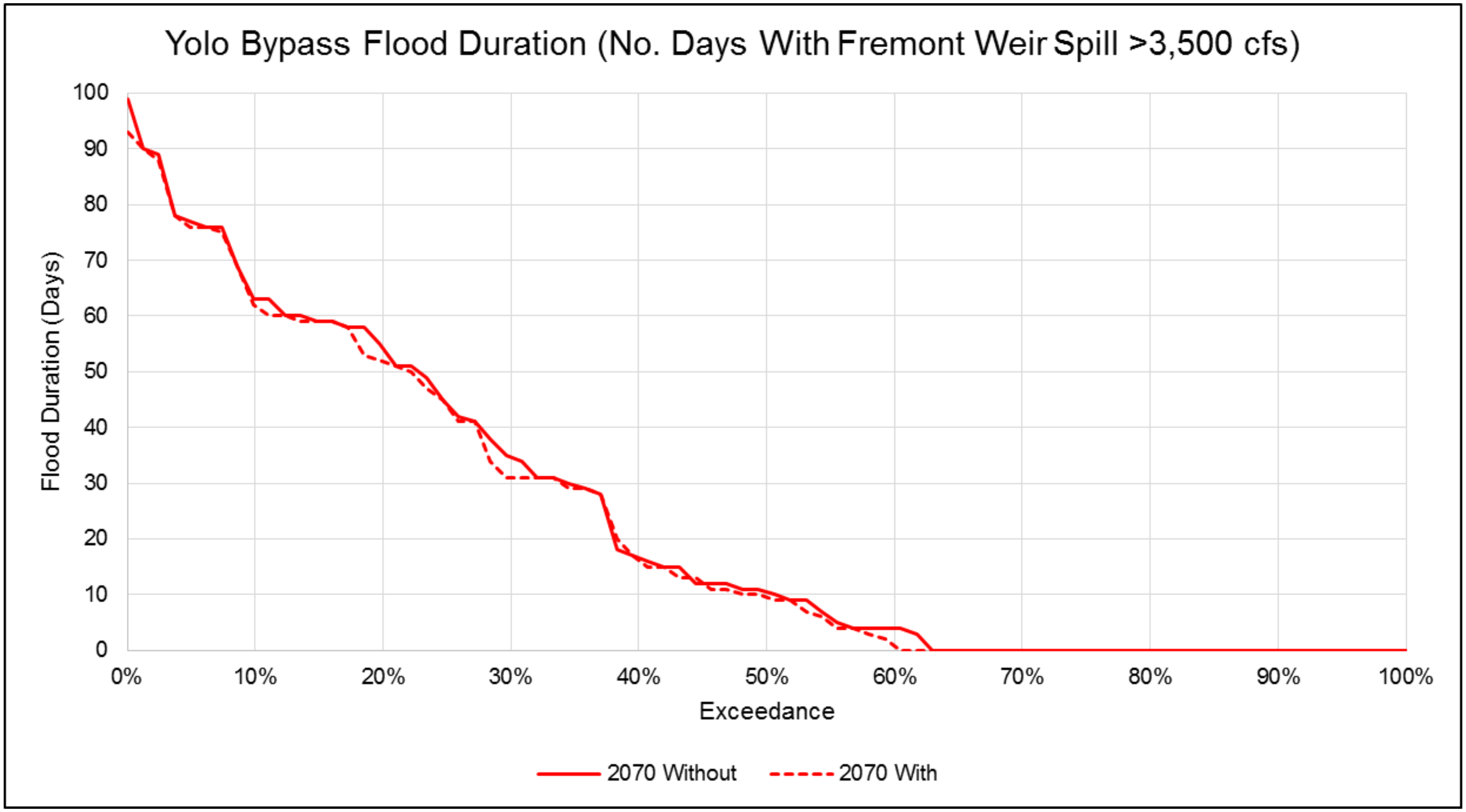
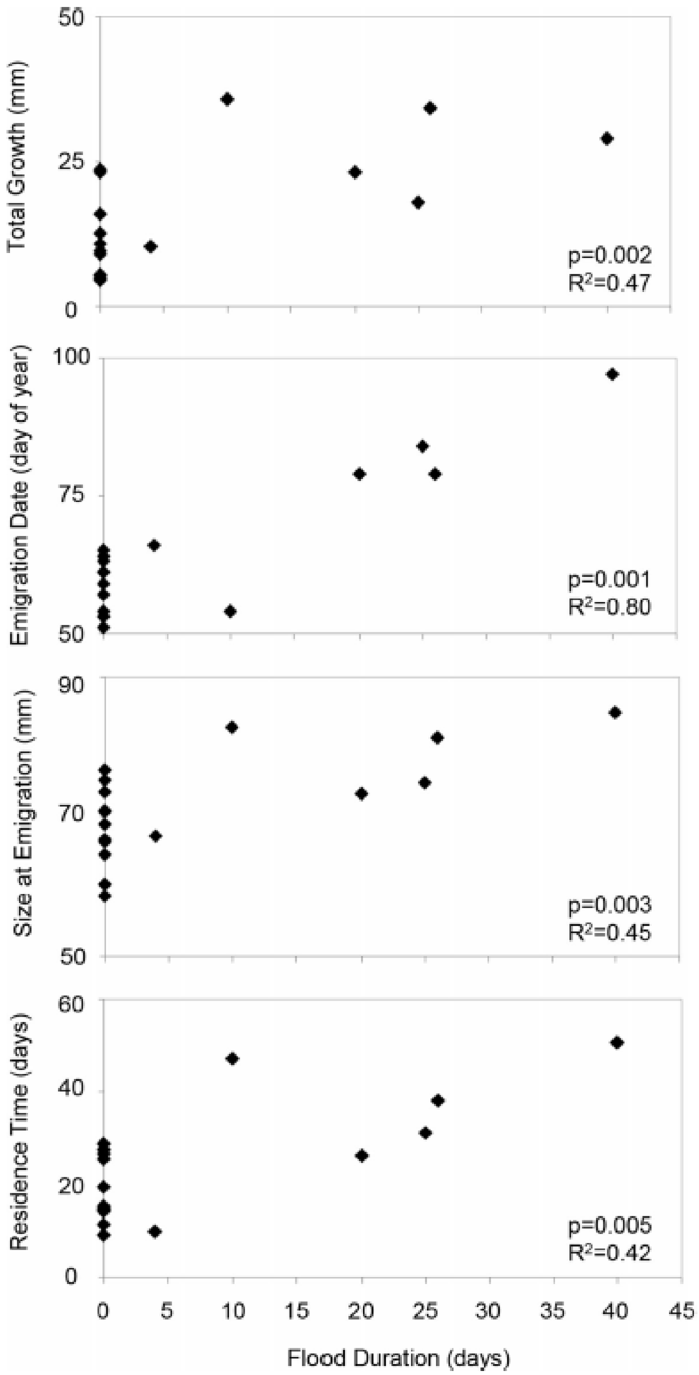
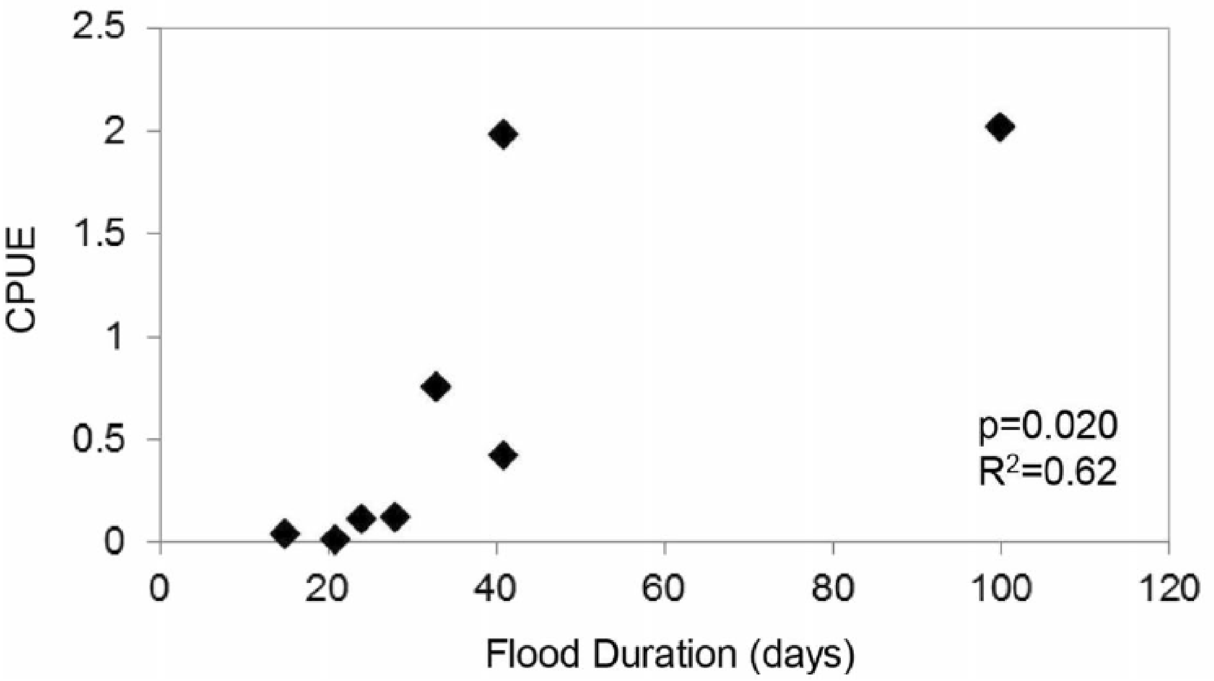


Figure A.3-3: Exceedance Plot of Mean Annual Number of Days of Yolo Bypass Flooding (Fremont Weir Flow >3,500 cfs, January-June) Simulated for the Sites Reservoir Project: 2070 Climate.



Source: Takata et al. (their Figure 3).

Figure A.3-4: Total Growth, Emigration Date, Size at Emigration, and Residence Time of Coded-Wire-Tagged Juvenile Chinook Salmon Released into the Yolo Bypass.



Source: Takata et al. (their figure 4c).

Figure A.3-5: Rotary Screw Trap Catch Per Unit Effort (CPUE) of Wild Juvenile Chinook Salmon in the Yolo Bypass.

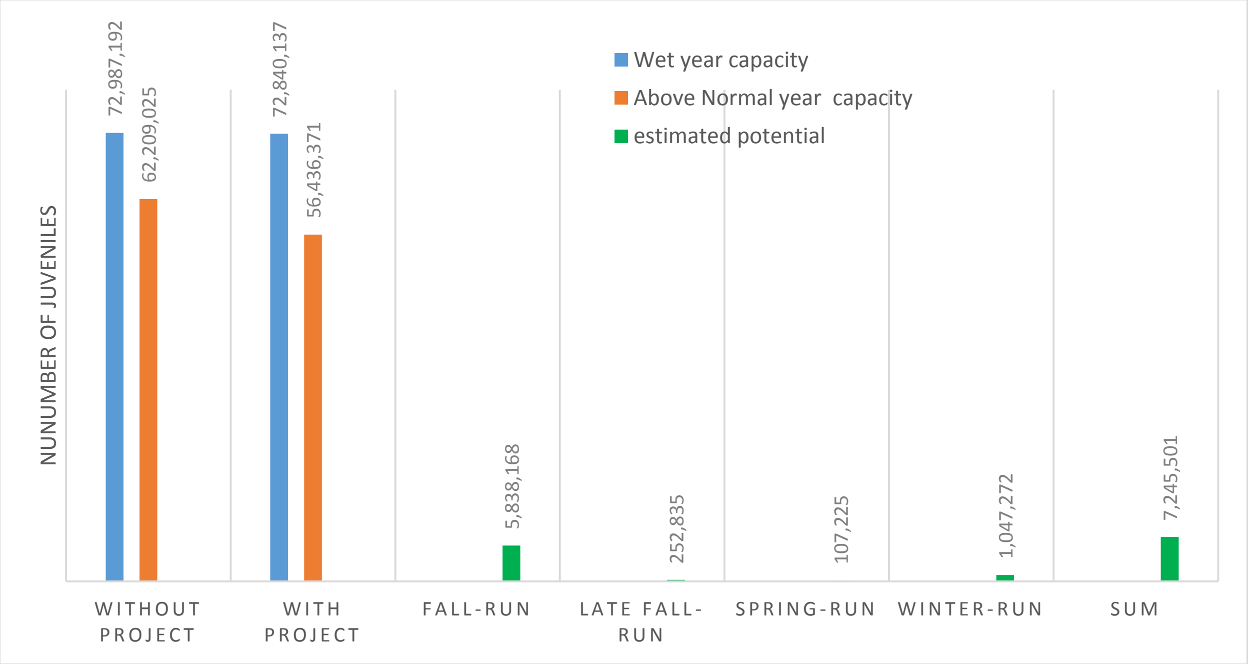


Figure A.3-6: Comparison of Yolo Bypass capacity with mean estimated potential abundance of juveniles entering the bypass under current conditions

A.3.2.4 References

California Department of Fish and Wildlife (DFW). 2018. Sites Reservoir Project Monetized Ecosystem Benefits. Technical review attached to cover letter from Charlton Bonham, Director, DFW, to Joseph Yun, Executive Officer, California Water Commission. January 29.

Katz, J. V. E., C. Jeffres, J. L. Conrad, T. R. Sommer, J. Martinez, S. Brumbaugh, N. Corline, and P. B. Moyle. 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. PLoS ONE 12(6):e0177409.

Poytress, W. R., J. J. Gruber, F. D. Carrillo, and S. D. Voss. 2014. Compendium Report of Red Bluff Diversion Dam Rotary Screw Trap Juvenile Anadromous Fish Production Indices for Years 2002–2012. Prepared for California Department of Fish and Wildlife Ecosystem Restoration Program and the U.S. Bureau of Reclamation. July. U.S. Fish and Wildlife Service, Red Bluff, CA.

Roberts, J., J. Israel, and K. Acierto. 2013. An Empirical Approach to Estimate Juvenile Salmon Entrainment over Fremont Weir. Fisheries Branch Adminstrative Report 2013-01. California Department of Fish and Wildlife, Sacramento.

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Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26(8):6-16.

Takata, L., T. R. Sommer, J. Louise Conrad, and B. M. Schreier. 2017. Rearing and migration of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in a large river floodplain. Environmental Biology of Fishes 100(9):1105-1120.

Attachment C
Oroville (Feather River) and Folsom (American River) Coldwater

This attachment provides additional details and analysis in response to the reviewers comments within the CWC February 1, 2018 letter regarding the physical and monetized ecosystem benefits associated with the Oroville coldwater pool.

C.1 Feather River Temperature Modeling

C.1.1 Comment from PBR Review

On page 3 and 4 of the Water Operations Review for Public Benefits Ratio:

- The applicant claims that the project would "increase cold-water pool storage in Shasta Lake, Lake Oroville, and Folsom Lake and improve temperature in the Sacramento and American Rivers during certain months at specific compliance points.
- The applicant defines the coldwater pool as an increase in the end of May storage at Lake Oroville for all storage levels. Review of the applicant's CalSim II model results confirms the applicant's stated long-term average increase in the May storage at Lake Oroville by 26 TAF under 2030 conditions and 31 TAF under 2070 conditions. However, the applicant does not provide a temperature model to assess the temperature improvements in the lower Feather River resulting from coldwater pool storage at Lake Oroville.

C.1.2 Response to Comment: RecTemp Model

This technical memorandum describes updates made to the Reclamation Temperature Model (RecTemp) for performing the Feather River temperature benefits analysis for the Sites Project Water Storage Investment Program (WSIP) application.

C.1.2.1 Background

Updates were made to the Reclamation Temperature (RecTemp) model that was developed for the California WaterFix Biological Assessment (WaterFix BA) to support temperature modeling of the Feather River for the WSIP Application process. The air temperature, equilibrium temperature, and warming coefficient inputs were changed for locations on the Feather River to be consistent with the 2030 and 2070 climate scenarios developed by the California Water Commission (CWC) for the WSIP program. 1995 Near-Term (NT) data was used for the Current Conditions scenario. The climate data provided by the CWC comes in files that correspond to grid cells with different latitude and longitudes. To perform the equilibrium temperature adjustments, the latitude and longitude coordinates of Marysville and Oroville were obtained and then matched with the closest WSIP climate scenario grid cell (Table C.1-1). The climate scenario data that corresponded to that grid cell was then retrieved for these two locations.

Table C.1-1: WSIP Grid Cell Coordinates

Station	Latitude	Longitude
Marysville	39.1875	-121.5625
Oroville	39.5625	-121.4375

C.1.2.2 Adjustment of RecTemp Inputs

Air Temperature Adjustment

Air temperature data was exported from the WSIP climate grid for Marysville and Oroville for the 1995 (historical), WSIP 2030, and WSIP 2070 climate scenarios. The dataset provided monthly maximum air temperature T_{max} and minimum air temperature T_{min}. The average air temperature was calculated with the following equation:

$$T_{avg} = \frac{T_{max} + T_{\min}}{2}$$

The difference between T_{avg} for WSIP 2030 and historical and WSIP 2070 and historical was taken for each month.

The air temperature timeseries for Lake Oroville was updated by adding the differences between T_{avg} for WSIP 2030 and historical scenarios to the NT air temperature time series to create the WSIP 2030 air temperature time series. The same was done for WSIP 2070 using the differences between WSIP 2070 and historical scenarios.

Tributary Inflow Temperature Adjustment

There are multiple locations where tributary inflows are applied to the RecTemp model based off inflows from CalSim II. Each tributary inflow has a temperature value that is specified for each month of the year and then applied to every year of the simulation (e.g. the March tributary inflow temperature to Oroville is the same in every March of the simulation). These tributary inflows were updated for the WSIP 2030 and WSIP 2070 climate scenarios by taking the monthly average of the air temperature shifts calculated above and adding this average monthly shift to the tributary inflow temperature values for each tributary in the NT climate condition.

Equilibrium Temperature Adjustment

Changes in climate can have a myriad of potential and unpredictable effects on water temperatures. However, several studies indicate that increasing air temperatures result in increased water temperatures, regardless of climate scenario (Webb and Walsh 2004, Cushing 1997, Isaak et al. 2012). Since air temperatures are predicted to increase under the WSIP 2030 and 2070 climate scenarios, an increase in water temperature is assumed.

Equilibrium temperatures were increased based on the incremental air temperature increases in the WSIP 2030 and 2070 climate scenarios detailed in Section 2.1 of this memo. This approach was supported by a comparison between air temperature data and the calculated equilibrium temperatures at Oroville and Marysville under NT climate conditions. Marysville air temperature data was retrieved from the Western Regional Climate Center.

The observed air temperature was plotted against the calculated current climate equilibrium temperature as shown in Figures C.1-1 and C.1-2. Two linear regressions were performed on the data, one regression for the fall and winter months (October-March) and one regression for the spring and summer months (April-September). Regressions at both Oroville and Marysville indicate a 1:1 ratio of air temperature to equilibrium temperature during fall and winter months and 1:0.75 ratio of air temperature to equilibrium temperature in spring and summer months. The calculation of the climate adjusted equilibrium temperature, based on these regressions, is described in the next section.

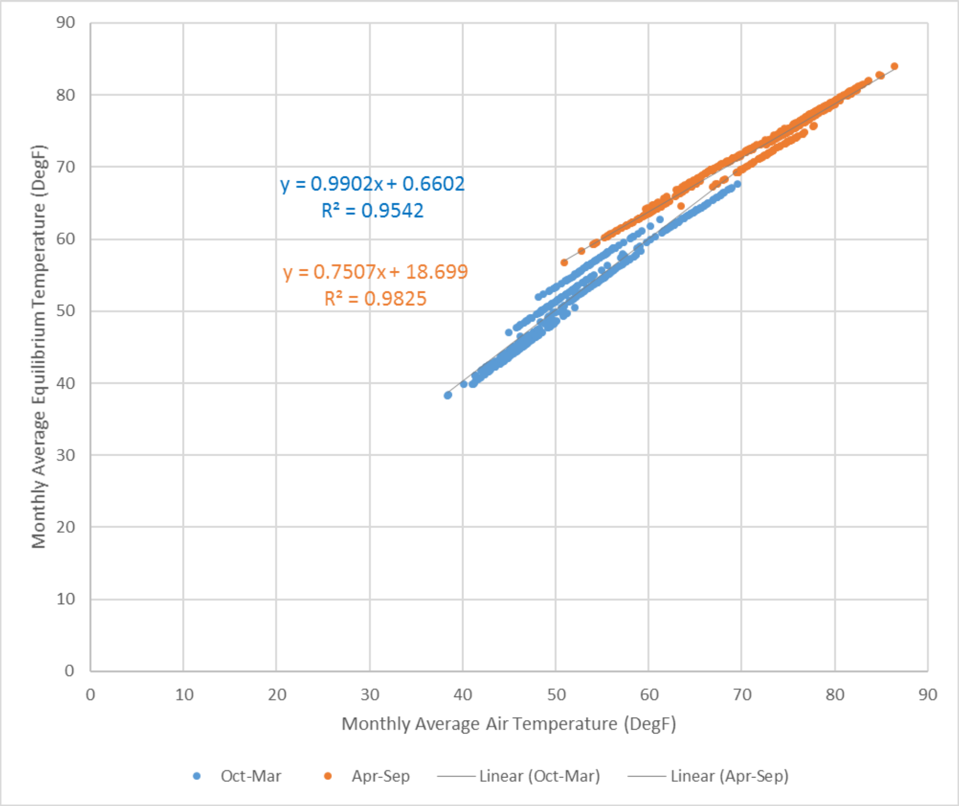

Figure C.1-1: Oroville Monthly Average Observed Air Temperature vs. Monthly Average Calculated Equilibrium Temperature

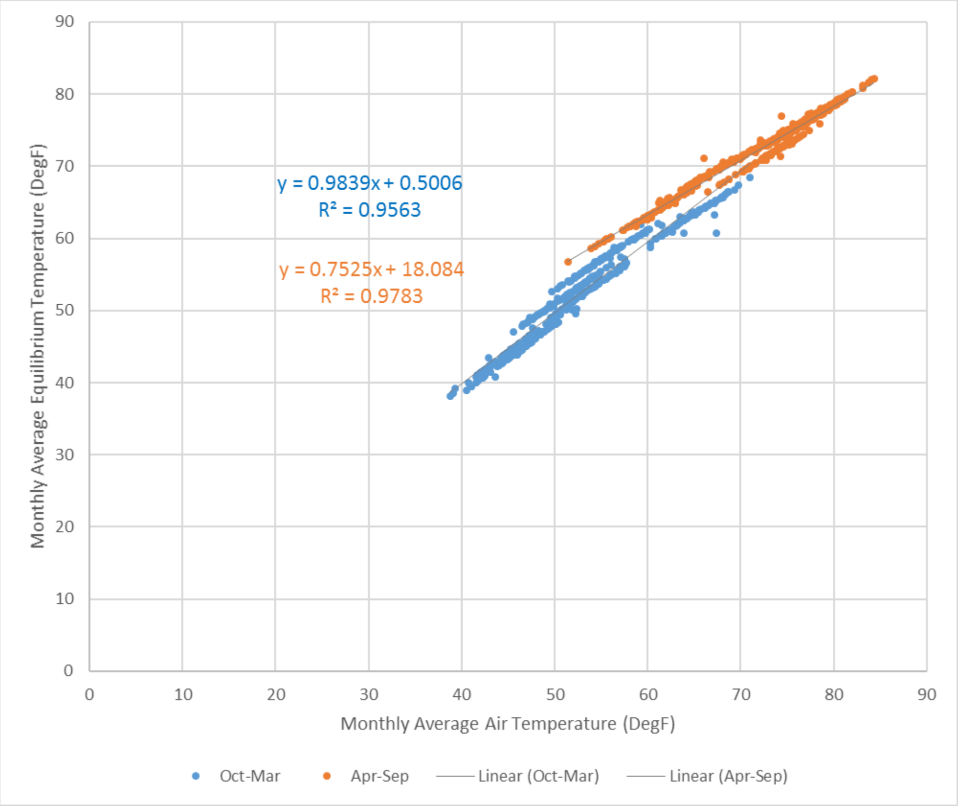

Figure C.1-2: Marysville Monthly Average Observed Air Temperature vs. Monthly Average Calculated Equilibrium Temperature

The air temperature shifts calculated above were multiplied by the seasonal adjustment to calculate the equilibrium temperature ratio. This difference was added to the existing RecTemp Current Climate Equilibrium Temperature file to calculate the climate adjusted equilibrium temperature for WSIP 2030 and WSIP 2070 climate scenarios.

Warming Coefficient

The warming coefficient, K, from NT, was used for the WSIP 2030 and WSIP 2070 climate conditions.

C.1.2.3 Adjustment of Temperature Targets

The RecTemp model modeling logic simulates the Temperature Control Device at Oroville Dam. The model has a specified temperature target that it tries to meet each month. These monthly targets are applied to each year of the simulation and are the same for each year. As part of the modeling of the With Project scenarios, the temperature targets were adjusted to respond to the increase in Oroville Storage from Sites project operations. The increased storage would allow for Oroville to operate to lower temperatures than the Without Project scenarios. Table C.1-2 shows the monthly temperature targets for the Without Project and With Project scenarios for DCR 2015, WSIP 2030, and WSIP 2070. The months where the temperature targets are changed are bolded. These temperature targets were determined after multiple iterations to achieve the best temperature reduction in the Feather River in some months while not increasing temperature in other months. Changes between With and Without Project schedules are in recognition of cold water pool improvements.

Table C.1-2: Oroville Temperature Targets

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DCR 2015 WO PROJ	47	46	47	49	53	55	59	58	53	52	52	49
DCR 2015 W PROJ	47	46	47	49	53	55	59	58	53	**51**	**51**	49
WSIP 2030 WO PROJ	47	46	47	49	53	55	59	58	53	52	52	49
WSIP 2030 W PROJ	**46.5**	46	47	49	53	55	59	58	53	51.2	51	**48.3**
WSIP 2070 WO PROJ	47	46	47	49	53	55	59	58	53	52	52	49
WSIP 2070 W PROJ	47	46	47	49	53	55	59	58	53	51	51	**48.5**

C.1.3 Response to Comment: Temperature Benefits

This memo summarizes temperature results for the Feather River to show the temperature benefits due to the Sites project for current (DCR 2015), WSIP 2030, and WSIP 2070. In wet and above normal water years temperature management is generally not an issue on the Feather River. The most important water year types for decreasing Feather River temperatures for salmonids are in critical years with low Oroville Lake storage and a limited cold water pool. The information provided below substantiates the reductions in water temperatures in critical years that provide important benefits for salmonids. The results also demonstrate greater water temperature benefits under projected WSIP 2070 conditions when warmer air temperatures and less snow pack will make water temperature management more challenging.

C.1.3.1 2015

Under 2015 climate conditions, the change between the with project condition and the without project condition in Feather River May to November long-term average temperature in the low flow channel, above Thermalito Afterbay, below Thermalito Afterbay, and at Gridley is -0.2°F, -0.2°F, 0°F, and 0°F respectively (Table C.1-3). This seasonal period has been designated as important for Spring-Run and Fall-Run Chinook Salmon. These results show a net improvement from the project based on the long-term average, especially in the Low Flow Channel and Above Thermalito where the Fall-run Chinook Salmon spawn.

However, these results do not reflect the larger reductions in Feather River temperature in critical years, when the benefit of increased storage in Oroville would be most important (Table C.1-3). In critical years, average May to November temperatures are decreased by at least 0.3 °F.

Table C.1-3: 2015 Average May to November Feather River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Low Flow Channel	56.7	56.5	-0.2
Above Thermalito	60.7	60.6	-0.2
Below Thermalito	62.9	62.9	0.0
Gridley	63.7	63.7	0.0
Critical Years			
Low Flow Channel	58.2	58.0	-0.2
Above Thermalito	61.8	61.6	-0.2
Below Thermalito	64.7	64.5	-0.2
Gridley	65.5	65.4	-0.1

Results improve further when looking at October and November, which are the critical months for Fall Run Chinook Salmon. Feather River October to November long-term average temperature in the flow channel, above Thermalito Afterbay, below Thermalito Afterbay, and at Gridley is -0.4°F, -0.4°F, -0.3°F, and -0.3°F respectively (Table C.1-4).

Table C.1-4: 2015 Average October to November Feather River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Low Flow Channel	53.4	52.6	-0.8
Above Thermalito	54.4	53.7	-0.7
Below Thermalito	55.5	55.0	-0.5
Gridley	55.8	55.4	-0.4
Critical Years			
Low Flow Channel	53.8	53.2	-0.6
Above Thermalito	54.8	54.3	-0.5
Below Thermalito	55.7	55.4	-0.3
Gridley	56.2	55.9	-0.3

C.1.3.2 2030

Under 2030 climate conditions, the change between the with project condition and the without project condition in Feather River May to November long-term average temperature in the low flow channel, above Thermalito Afterbay, below Thermalito Afterbay, and at Gridley is -0.2°F, -0.1°F, -0.1°F, and 0°F respectively (Table C.1-5). This seasonal period has been designated as important for Spring-Run and Fall-Run Chinook Salmon. These results show a net improvement from the project based on the long-term average, especially in the Low Flow Channel and Above Thermalito where the Fall-run Chinook Salmon spawn.

However, these results do not reflect the larger reductions in Feather River temperature in critical years, when the benefit of increased storage in Oroville would be most important

(Table C.1-5). In critical years, average May to November temperatures are decreased by at least 0.3 °F.

Table C.1-5: 2030 Average May to November Feather River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Low Flow Channel	57.7	57.5	-0.2
Above Thermalito	62.1	62.0	-0.1
Below Thermalito	64.7	64.6	-0.1
Gridley	65.6	65.6	0.0
Critical Years			
Low Flow Channel	59.5	59.2	-0.3
Above Thermalito	63.4	63.1	-0.3
Below Thermalito	66.4	65.9	-0.5
Gridley	67.4	67.0	-0.4

Results improve further when looking at October and November, which are the critical months for Fall Run Chinook Salmon. Feather River October to November long-term average temperature in the flow channel, above Thermalito Afterbay, below Thermalito Afterbay, and at Gridley is -0.4°F, -0.4°F, -0.3°F, and -0.3°F respectively (Table C.1-6).

Table C.1-6: 2030 Average October to November Feather River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Low Flow Channel	55.5	55.1	-0.4
Above Thermalito	57.0	56.6	-0.4
Below Thermalito	57.8	57.5	-0.3
Gridley	58.1	57.8	-0.3
Critical Years			
Low Flow Channel	56.5	56.2	-0.3
Above Thermalito	57.5	57.2	-0.2
Below Thermalito	58.7	58.4	-0.2
Gridley	58.9	58.7	-0.2

C.1.3.3 2070

Under 2070 climate conditions, the change between the with project condition and the without project condition in Feather River May to November long-term average temperature in the low flow channel, above Thermalito Afterbay, below Thermalito Afterbay, and at Gridley is -0.3°F, -0.3°F, -0.1°F, and 0°F respectively (Table C.1-7). This seasonal period has been designated as important for Spring-Run and Fall-Run Chinook Salmon. These results show a net improvement from the project based on the long-term average, especially in the Low Flow Channel and Above Thermalito where the Fall-run Chinook Salmon spawn.

However, these results do not reflect the larger reductions in Feather River temperature in critical years, when the benefit of increased storage in Oroville would be most important (Table C.1-7). In critical years, average May to November temperatures are decreased by at least 0.4 to 0.6 °F.

Table C.1-7: 2070 Average May to November Feather River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Low Flow Channel	59.9	59.6	-0.3
Above Thermalito	64.7	64.4	-0.3
Below Thermalito	67.4	67.3	-0.1
Gridley	68.3	68.3	0.0
Critical Years			
Low Flow Channel	61.8	61.2	-0.6
Above Thermalito	65.9	65.4	-0.5
Below Thermalito	69.3	68.8	-0.5
Gridley	70.3	69.9	-0.4

Results improve further when looking at October and November, which are the critical months for Fall Run Chinook Salmon. Feather River October to November long-term average temperature in the flow channel, above Thermalito Afterbay, below Thermalito Afterbay, and at Gridley are -0.9°F, -0.7°F, -0.5°F, and -0.4°F respectively (Table C.1-8). This constitutes a relatively substantial improvement in Feather River temperatures in critical years. This also demonstrates the ability to provide benefits under future WSIP 2070 conditions when water temperature management will be more challenging due to warmer air temperatures and less snow pack runoff.

Table C.1-8: 2070 Average October to November Feather River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Low Flow Channel	61.5	60.6	-0.9
Above Thermalito	61.9	61.2	-0.7
Below Thermalito	62.5	62.0	-0.5
Gridley	62.6	62.1	-0.4
Critical Years			
Low Flow Channel	61.5	60.4	-1.1
Above Thermalito	62.1	61.2	-0.9
Below Thermalito	62.7	62.2	-0.5
Gridley	62.8	62.3	-0.5

C.1.4 References

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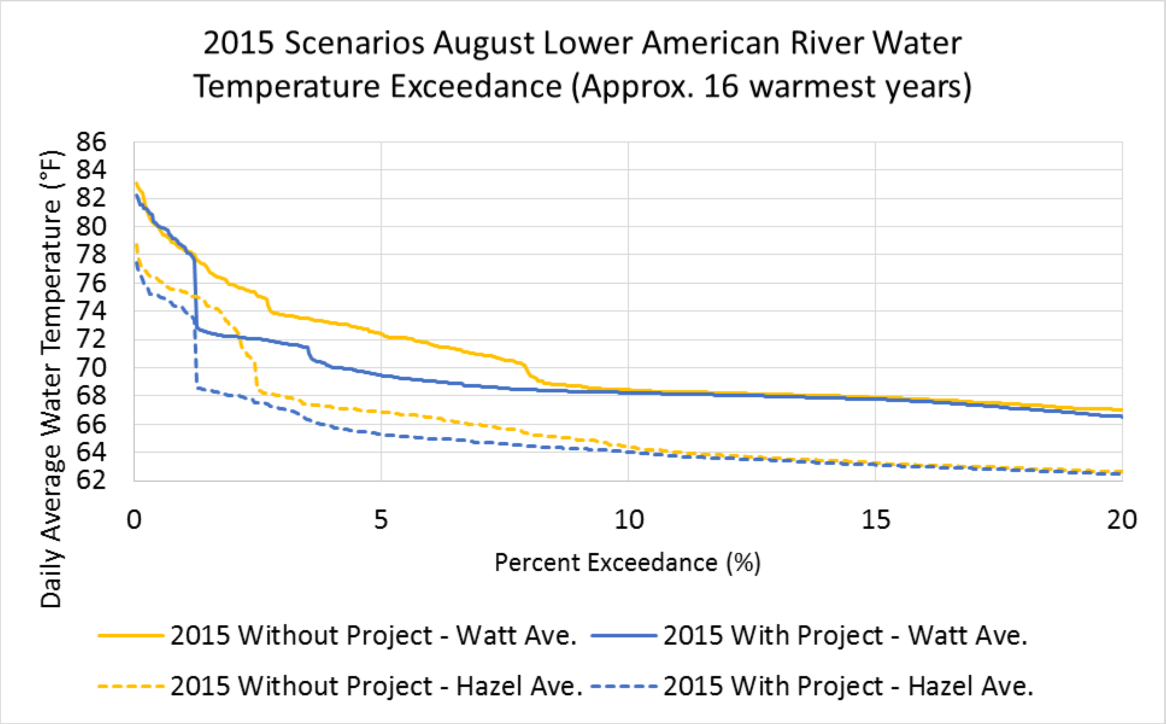
C.3 Sites Project Summary of Water Temperature Benefits to the Lower American River

The primary water temperature benefit of the Sites Project to the Lower American River (downstream of Lake Natoma) is decreased water temperature during the driest years and warmest times of year. The Sites Project previously provided supporting information for the CE-QAUL model runs for the Lower American River (see Tab A1-Modeling and associated data). The following summarizes an analysis of the temperature benefits that were intentionally created during drier periods by Sites Project operations.

Based on that information, the water temperature benefit in the American River at Watt Avenue (typical water temperature “compliance” location) and Hazel Avenue (upper portion of the reach) occurs in August and September in approximately the warmest 10% of years (8 of 82 years). The magnitude of this benefit varies between years, but for the 2015 modeling the average decrease in water temperature at Watt Avenue is approximately 2°F for August and 1.7°F for September (maximum 4.8°F and 3.9°F) (Figure C.3-1). The benefit at Watt Avenue for the 2070 run is a decrease in water temperature of 1.6°F for August and 1.5°F for September (maximum 3.7°F and 2.9°F) (Figure C.3-2). Temperature benefits also occur upstream at Hazel Avenue (Figures C.3-1 and C.3-2).

These reductions in temperature in the critically dry and warmer years would likely allow the threatened steelhead cohorts for those years to survive in the upper portion of the Lower American River, whereas, without the benefit the cohort may be lost due to high water temperatures. Upper incipient lethal temperature (50% mortality 7 days) for steelhead is in the range of 77-79 °F (McCullough et al. 2001). In the 2030 modeling the apparent benefit of the project is not as large, however, this appears to be due to an issue with the hydrological modeling that makes that run somewhat inconsistent with the 2015 and 2070 runs (Figure C.3-3).



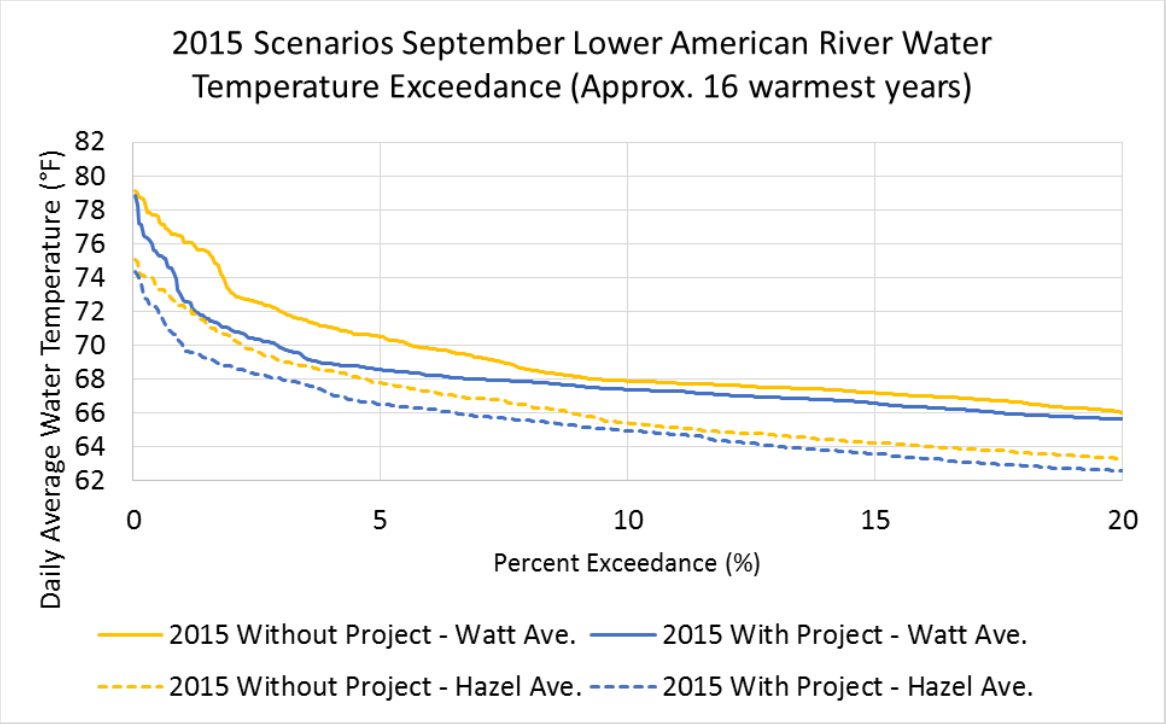


Figure C.3-1: 2015 With and Without Project August (top) and September (bottom) Daily Temperature at Watt and Hazel Avenues Exceedance Plot - Warmest 20% of the Time.

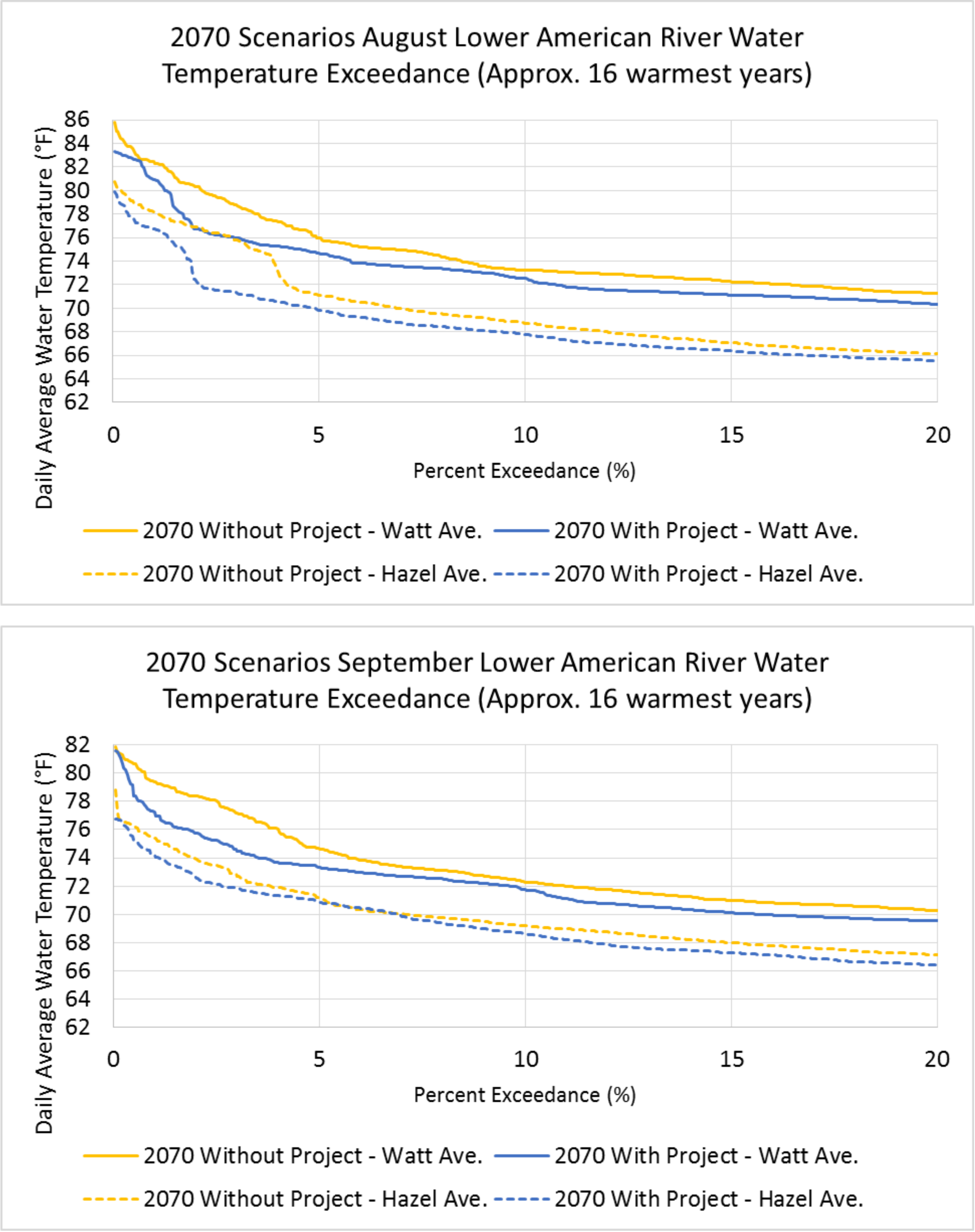
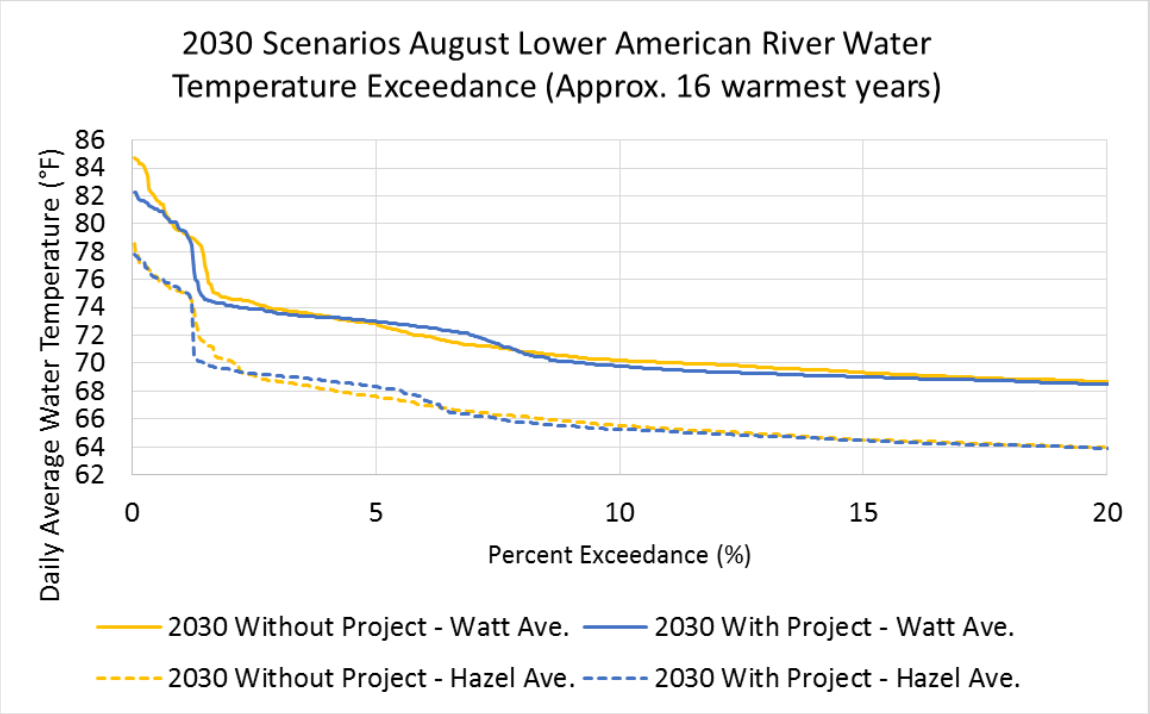


Figure C.3-2: 2070 With and Without Project August (top) and September (bottom) Daily Temperature at Watt and Hazel Avenues Exceedance Plot - Warmest 20% of the Time.



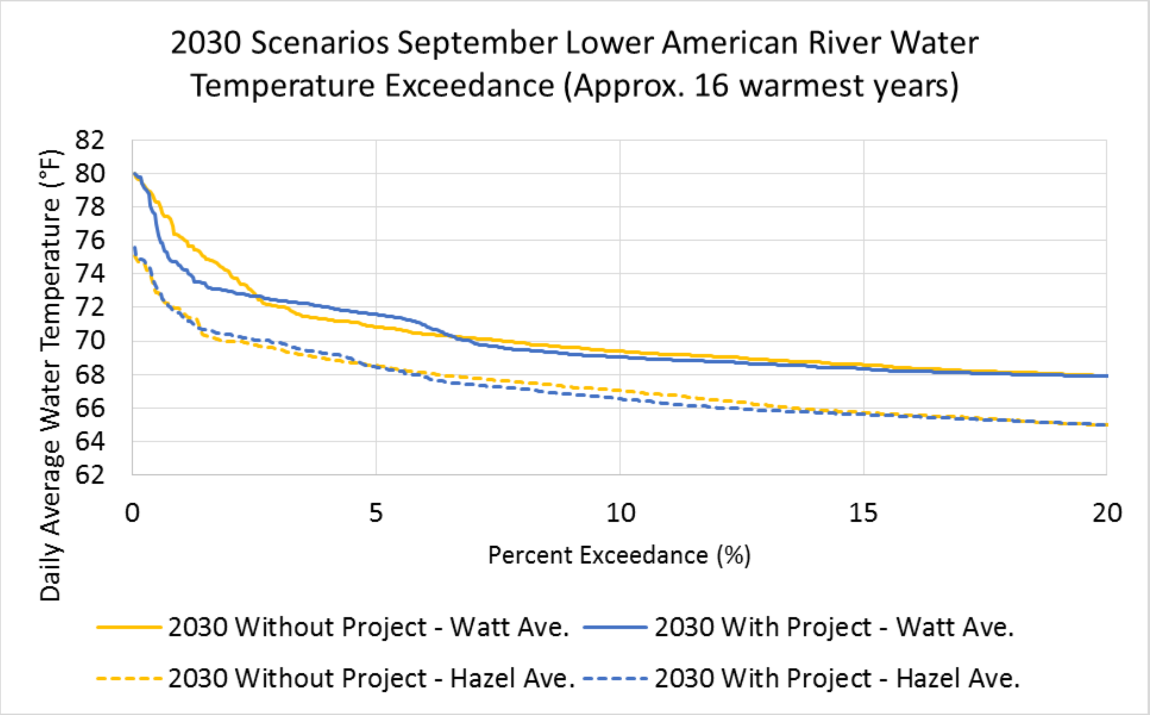


Figure C.3-3: 2030 With and Without Project August (top) and September (bottom) Daily Temperature at Watt and Hazel Avenues Exceedance Plot - Warmest 20% of the Time.

Attachment D
Water Operations Review

D.2 Development of the Bypass Flow Standard

D.2.1 Comment from PBR Review

On page 2 of 5 of the Water Operations Review for Public Benefits Ratio:

- The applicant proposed a bypass flow standard at four locations along the Sacramento River, including Red Bluff Diversion Dam, Hamilton City, Wilkins Slough, and Freeport. No flows are diverted into Sites Reservoir until the bypass flow standard at all four locations is met. The applicant claims that the standard is designed to “maintain and protect existing downstream water uses and environmental resources.” Review of the CalSim II model files confirms that the bypass flow criteria is implemented in the with project CalSim II model. However, the applicant does not provide information on the process used to develop the bypass flow standard. As a result, reviewers are unable to identify whether the proposed standard is adequate to “maintain and protect existing downstream water uses and environmental resources.”

D.2.2 Response to Comment

The proposed bypass flow protection for diversion of Sacramento River flows into Sites Reservoir is described in the Application documents:

- Section 4.1 of the Project Description (pages 4-1 through 4-3 of Sites_A3 Project Description.pdf)
- Section Diversions to Sites Reservoir of the Modeling Assumptions (pages 10 through 13 of Sites_A1 Modeling.pdf)

The information provided in these sections includes discussion of the:

1. Definition of excess flows available for diversion into Sites Reservoir
2. Proposed diversion bypass flow protection
3. Adaptive management and monitoring

The preliminary Operations Plan (Sites_A2 Operations.pdf) makes reference to these descriptions in describing the opportunity to capture water from storm events (page 10), the likely season (months) and years in which diversions to file Sites Reservoir would occur (page 11 through 14) and how diversions to fill Sites Reservoir support operations for public benefits including augmentation of summer and fall flows in the Yolo Bypass, increases in water supply for wildlife refuges, improvements to Shasta Lake Coldwater Pool and Sacramento River Temperature Control, enhancement and increased stability of upper Sacramento River flows in the fall, improvements to Folsom Lake Coldwater Pool and American River flows and improvements to Lake Oroville Coldwater Pool and Feather River flows. These benefits are derived from reoperation of existing reservoirs which could not be achieved without addition of alternative water storage in the Sacramento River watershed. The proposed restrictions on diversions to Sites Reservoir are selected to maximize the potential benefits of the project while not adversely affecting the other water user’s ability to meet existing system regulatory requirements including:

- Water rights
- Instream flow requirements
- Biological opinions

- Delta water quality requirements
- CVP and SWP requirements
- Central Valley Project Improvement Act

In addition, diversion of excess Sacramento River flow during storm events would only take place when flow and fish monitoring indicates that fish are not migrating and are not anticipated to be in the river near the three intake locations.

For CalSim II excess flows available for diversion into Sites Reservoir are determined through the use of the weights. CalSim II is based on the WRIMS platform and uses a mixed-integer linear program solver called XA. In the mathematical formulation of the model, an objective function is solved (optimized) based on a set of conditions (constraints). The determination of excess flows is done through differential weights on the objective function. The solver knows from the mathematics that diversions to fill Sites are lower priority than any other existing use of water including the use of water for upstream/downstream diverters, Delta exports and Delta outflow and salinity regulatory requirements. The diversion bypass flow protection and pulse flow protection rules are constraints directly on when and how much flow can be considered for diversion to Sites Reservoir.

A potential concern is that diversions of flow could have potential adverse effects on Delta water quality in future months and potentially increase the amount of water required from SWP and CVP reservoirs to maintain Delta salinity in compliance with the SWRCB D1641 or 2008 FWS and 2009 NMFS BiOps requirements. To address this concern, iterative analysis was done with the CalSim II and DSM2 to assess potential changes to Delta salinity and develop protective bypass flow criteria. Over many iterative simulations, a variable schedule of bypass flow criteria for the Sacramento River at Freeport was developed to minimize the potential effect of diversions to Sites Reservoir on SWP and CVP operations and Delta water quality. The bypass flow criteria specify that diversions to fill Sites Reservoir would only be allowed when a Sacramento River flow of 15,000 cfs is present at Freeport in January, 13,000 cfs in December and February through June, and 11,000 cfs in all other months.

D.3 Storm Pulse Protection Justification

Additional information is provided in the appeal responses.

The proposed pulse flow mitigation protection for diversion of Sacramento River flows into Sites Reservoir is described in the WSIP Application documents:

- Benefit Calculation, Monetization, and Resiliency Tab, Attachment 2: Operations Plan (page 10)
- Benefit Calculation, Monetization, and Resiliency Tab, Attachment 1: Modeling Assumptions, Section on Pulse Flow Protection Diversion Assumptions (pages 11 through 13)

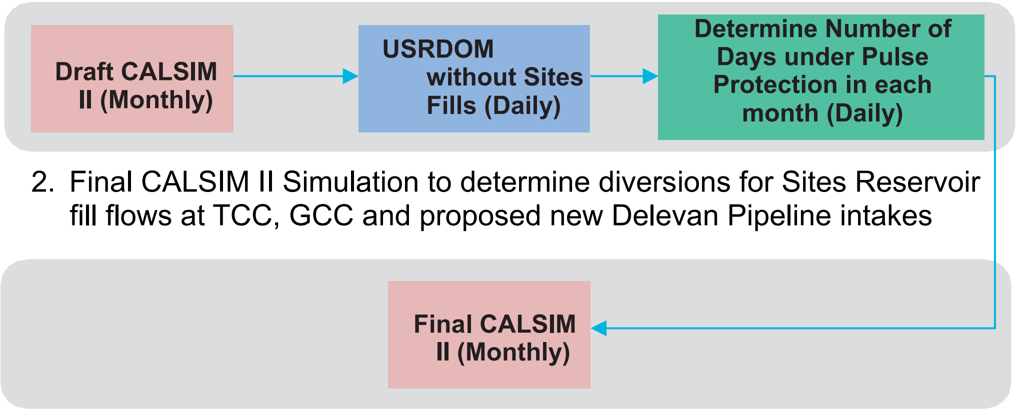
D.3.1 Modeling Approach Justification

The proposed operation includes a mitigation measure to protect out-migrating juvenile salmonids. The modeling of those operations included restrictions on diversions to limit impacts on out-migrating juvenile fish as a “surrogate” for the mitigation measure (that includes real time monitoring and adaptive management). Based on recent literature and proposed permit conditions for other diversion projects, operations modeling for the proposed Project diversions were restricted to minimize impacts to fish passage associated with pulse flow events that stimulate the observed spike in juvenile salmon outmigration. An iterative approach, developed as part of the North-of-the-Delta Offstream Storage (NODOS) Investigation was used to estimate the number of no diversion days and restrict diversions in CalSim II during pulse flow periods for modeling purposes. It is acknowledged that this approach provides a rough approximation of the potential number of days when diversions would be restricted. Actual project operations will be informed by real-time monitoring of fish presence and movement.

This methodology uses the Upper Sacramento River Daily Operations Model (USRDOM) (CH2M HILL, 2011) and the CalSim II model iteratively to generate a monthly time series that provides a monthly approximation of the number of days of no diversions to fill Sites Reservoir. Since CalSim II is a monthly timestep model, USRDOM results were used to enforce the intake operations on a sub-monthly scale. Due to the complexity in the intake operational rules, a spreadsheet tool was developed to implement the operational constraints using the daily results from the USRDOM. Further, the models were iterated to ensure all the intake operations assumptions were simulated accurately. Figure D.3-1 shows the schematic of the typical modeling process used to simulate project operations.

In the first iteration, CalSim II and USRDOM models are simulated to determine the days requiring the pulse protection. A draft CalSim II simulation was run with all the physical, regulatory and operational assumptions. The results from this “draft” CalSim II simulation were used to run the USRDOM model. The USRDOM setup included assumptions consistent with the draft CalSim II. Since this USRDOM run, termed as “No Fills run”, is used to estimate daily flows in the river to determine the days requiring pulse protection, the diversions at the Tehama Colusa Canal (TCC), Glen Colusa Canal (GCC) and proposed Delevan intakes are restricted to only meet the agricultural demands and other local uses in Colusa Basin region, and do not include the diversions to fill Sites. The results from this draft USRDOM No Fills run are used in a spreadsheet tool to determine the number of days under pulse protection in each month, over the 82-year period. In the spreadsheet tool, proposed bypass flow criteria and the pulse flow restrictions are applied to the daily Sacramento River flows from the draft USRDOM No Fills run to determine the number of days under pulse protection for each month, and daily diversion volumes to fill Sites Reservoir. In the second iteration, the draft CalSim II from the first iteration is re-run with the pulse protection data from the spreadsheet tool, to simulate the final monthly operations.

1. Draft CALSIM II and USRDOM Simulations are run to determine days requiring "pulse protection"



2. Final CALSIM II Simulation to determine diversions for Sites Reservoir fill flows at TCC, GCC and proposed new Delevan Pipeline intakes

Figure D.3-1: NODOS Operations Modeling Process used for the WSIP Evaluation

D.3.2 Pulse Flow Protection in CalSim II

The DCR2015, WSIP2030 and WSIP2070 CalSim II models recognize the variability in Sacramento River flows at key locations due to the fluctuations in daily unregulated tributary flows. This logic was implemented in CalSim II to ensure that minimum instream flow requirements were met despite daily fluctuations in the river flow. The monthly volume of daily unregulated flow above the monthly minimum instream flow requirement is provided as an input to CalSim II for key control locations along the Sacramento River. A portion of this monthly unregulated flow volume is assumed to be in the river on each day of the month. For Sites Reservoir diversion operations in CalSim II, the constraints for diversion capacity and bypass flow criteria are applied on a daily basis relying on this information.

As noted earlier, a timeseries of the number of days in each month with no diversions is provided to CalSim II, to protect any potential pulse flow events. For a given month, if there are days with no diversions specified, then the diversion capacity constraint for Sites Reservoir is adjusted by reducing the available unregulated flow for the number of no diversion days specified. This reduction in available flow is computed by assuming the days with maximum unregulated flow would not be available for diversion. Therefore, the restriction for the number of no diversion days is generally more restrictive in CalSim II (monthly basis) than in the USRDOM (daily basis).

D.3.3 Pulse Flow Protection Frequency and Duration

The Commission commented that reviewers cannot verify whether the pulse flow standard is applied for an adequate duration from the pre-processed number of no diversion days timeseries inputted in the CalSim II model. As noted above, the pulse flow standard is applied on the daily flows simulated using USRDOM and a monthly timeseries of no diversion days is processed, which is then used as input to CalSim II. It must be recognized that the operations modeling of the proposed Project included restrictions on diversions to limit impacts on out-migrating juvenile fish. As described in the Operations Plan (Sites_A2 Operations Plan and Sites_A4 Mitigation) included in the WSIP application, an approach using one qualified event per month was employed to attempt to represent the number of days that might be required based on recent literature.

Given that del Rosario et al. (2013) indicate that the first storm event was associated with a spike in salmon arrivals at Knights Landing, modeled diversions to Sites Reservoir would not be allowed during the first 7-day qualified pulse period, when flows reach 15,000 cfs during the out-migration season. For evaluation of Sites Project Reservoir operations, it was assumed that up to one qualified 7-day pulse event would occur each month during the pulse protection period from October through May, to encourage and support salmonid out-migration and minimize potential diversion impacts. Therefore, for operations modeling, diversions to Sites Reservoir storage would be restricted under the following conditions: 1) if pulse conditions exist at Bend Bridge, and a qualified pulse event has not already occurred within the given month, and 2) if Bend Bridge flows are less than 25,000 cfs during the pulse event. Diversions are allowed when flows exceed 25,000 cfs because flows of this magnitude are considered to provide lesser benefits to fish migration. Figure D.3-2 shows an example hydrograph with flow levels where the pulses are protected, and corresponding periods of no diversion.

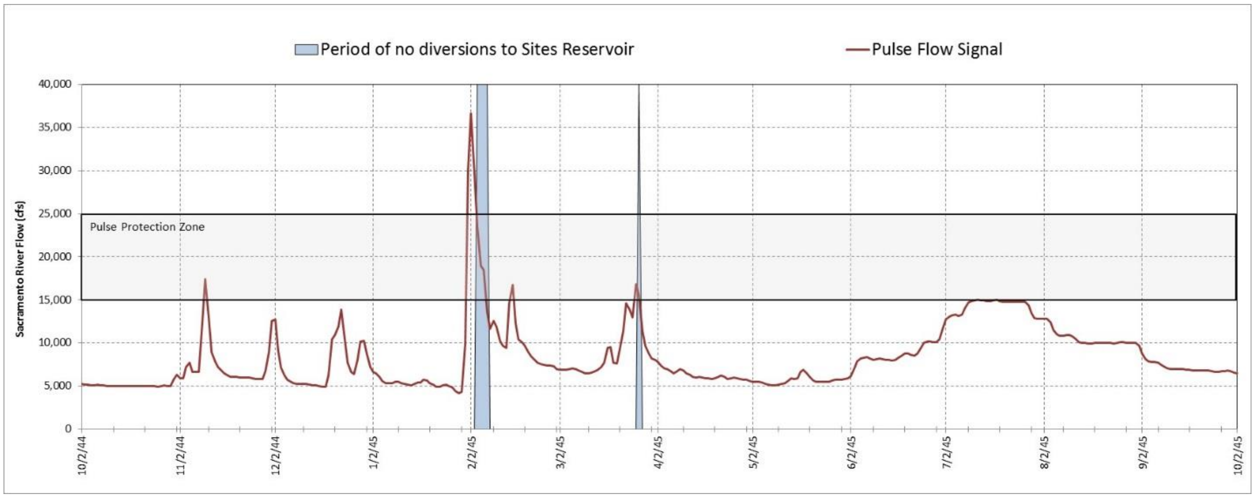


Figure D.3-2: Example of Sacramento River Pulse Protection Zone and periods of no diversions to Sites Reservoir during Pulse Conditions

Table D.3-1 shows the occurrence of months with no diversion days in the with-project condition USRDOM/CalSim II simulations for current (DCR 2015), WSIP 2030 and WSIP 2070 climate conditions. Even though the pulse criteria apply to October through May, the period of December through March is when the diversions to fill Sites Reservoir are the largest. Of those months, 44% have no diversion days in recognition of potential pulse events over the 82-year simulation period. Each potential pulse event has an average 3.5 days of pumping restrictions while the Bend Bridge flows are between 15,000 and 25,000 cfs. For a potential pulse event, often the flow will exceed 25,000 cfs or fall below 15,000 cfs in less than 7 days even though up to 7 days of protection could be provided. Approximately 200 potential pulse events are protected over the 82-year simulation period.

As described in the Operations Plan there are many sources of uncertainty in predicting future environmental conditions, particularly in light of climate change, and knowledge gaps regarding factors controlling fish population dynamics and abundance, an adaptive management approach will be required to make informed decisions about operation management for the Sites Project. Actual project operations will include restrictions on diversions to limit impacts on out-migrating juvenile fish based on for real time monitoring and adaptive management.

Table D.3-1: Occurrence of Months with No Diversion Days in CalSim II Simulations

	October	November	December	January	February	March	April	May
2015								
Months with no diversion days	2	19	37	38	39	31	19	14
Occurrence in 82-year simulation period	2%	23%	45%	46%	48%	38%	23%	17%
Average days in months with no diversion days	3.5	3.1	3.4	3.3	3.4	3.5	3.4	5.4
Maximum days in month with no diversion days	4	7	10	9	9	7	9	7
2030								
Months with no diversion days	3	17	36	38	38	33	16	5
Occurrence in 82-year simulation period	4%	21%	44%	46%	46%	40%	20%	6%
Average days in months with no diversion days	5.3	4.1	3.7	3.2	3.6	3.3	3.9	5.4
Maximum days in month with no diversion days	7	8	14	8	10	9	9	12
2070								
Months with no diversion days	2	14	37	39	37	32	16	5
Occurrence in 82-year simulation period	2%	17%	45%	48%	45%	39%	20%	6%
Average days in months with no diversion days	5.5	3.7	3.5	3.4	3.8	3.6	3.3	3.0
Maximum days in month with no diversion days	7	8	8	10	10	11	9	5

The adaptive management concept will be implemented to reduce operational uncertainty, enhance scientific knowledge, comply with the permit requirements of the Sites Project, and improve project performance in a constantly changing natural system. As with other adaptive management plans associated with major water management facilities in California, adaptive management will provide recommended operations intended to test operational hypotheses and provide input to the periodic operational reviews of the Sites Project, and will be developed with the best available science in collaboration with CDFW, USFWS, and NMFS.

D.3.4 References

CH2M HILL. 2011. Final USRDOM Development, Calibration, and Application. Prepared for Bureau of Reclamation, Mid-Pacific Region.

D.4 Augmentation of Sacramento River Fall Stability Flows

D.4.1 Comment from PBR Review

On page 2 of 5 of the Water Operations Review for Public Benefits Ratio:

- The applicant proposes to “augment flows in the Sacramento River between Keswick Dam and Red Bluff Diversion Dam to minimize dewatering of fall-run Chinook salmon redds… from October through March, particularly during fall months.” Review of the applicant’s CalSim II model results shows that the range on long-term average change in Sacramento River flows for the months between October and March between Keswick Dam and Bend Bridge varies by 0 to 5 percent under 2030 conditions, and by -5 to 3 percent under 2070 conditions; between Bend Bridge and Red Bluff Diversion Dam varies by -3 to 1 percent under 2030 conditions, and by -5 to -2 percent under 2070 conditions. These results suggest minimal or no flow augmentation to help minimize dewatering of salmon redds.

D.4.2 Response to Comment

On Page 4 of WSIP Application Program Requirements Tab, Attachment 1: Measurable Benefits in Table A1-1, the average December - February Sacramento River monthly flow below Keswick Reservoir is reported for the Full Simulation Period and Below Normal, Dry, and Critical years.

During storm events, downstream tributaries often provide enough inflow to the Sacramento River to meet downstream flow requirements. In anticipation of these storm events, releases from Shasta Lake may be reduced. This decrease in flow may expose salmon redds and lead to egg mortality.

A benefit of the Sites Project is that Environmental Enhancement Account (EEA) water backed in to Shasta Lake may be released to increase and stabilize flows in the Sacramento River below Keswick Dam to minimize dewatering of salmon redds. Augmentation of flows in the 3,250 – 5,500 cfs range stabilize the water surface elevation and improve salmon egg survival.

By adding the ability to release more water, Shasta Lake has more operational flexibility to address changes in flow and habitat conditions. The increase in Shasta storage provides operational flexibility so releases can be managed adaptively to maximize environmental benefits in accordance with WSIP Application Benefit Calculation, Monetization, and Resiliency Tab, Attachment 2: Operations Plan.

The Operations Plan defined a general window of opportunity between September and March in Above Normal, Below Normal, and Dry years for water to be released from Shasta Lake to stabilize flows in the Sacramento River when flows are between 3,250 to 5,500 cfs. This window of opportunity defined in the Operations Plan was based on current conditions. The quantification of benefits is based on modeling results under WSIP 2030 and 2070 climate conditions, and modeling analyses indicate that under future climate conditions the primary benefits of this action occur between December and February.

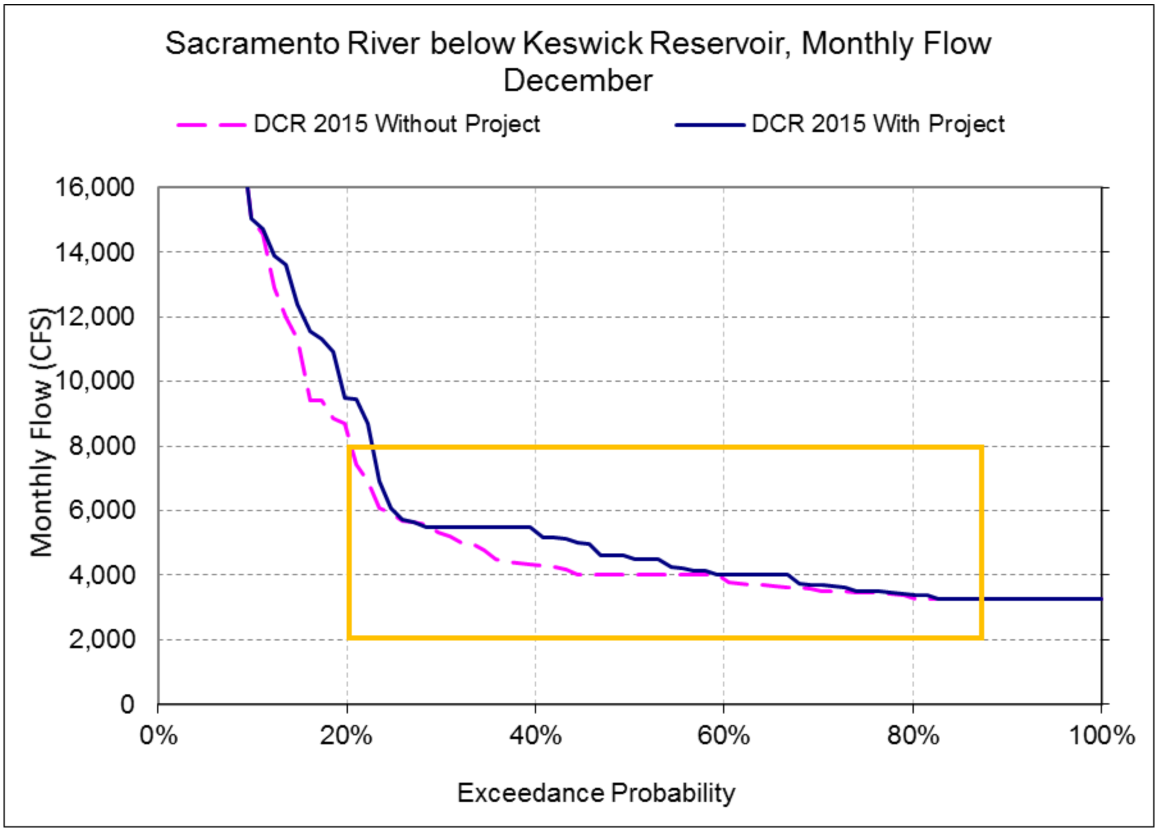
Table D.4-1 presents the average increase in releases from Keswick Dam between December and February to improve and stabilize Sacramento flows. The greatest flow improvements occur in below normal, dry, and critical years. The values in Table D.4-1 are consistent with Table A1-1 on Page 4 of WSIP Application Program Requirements Tab, Attachment A1: Measurable Benefits.

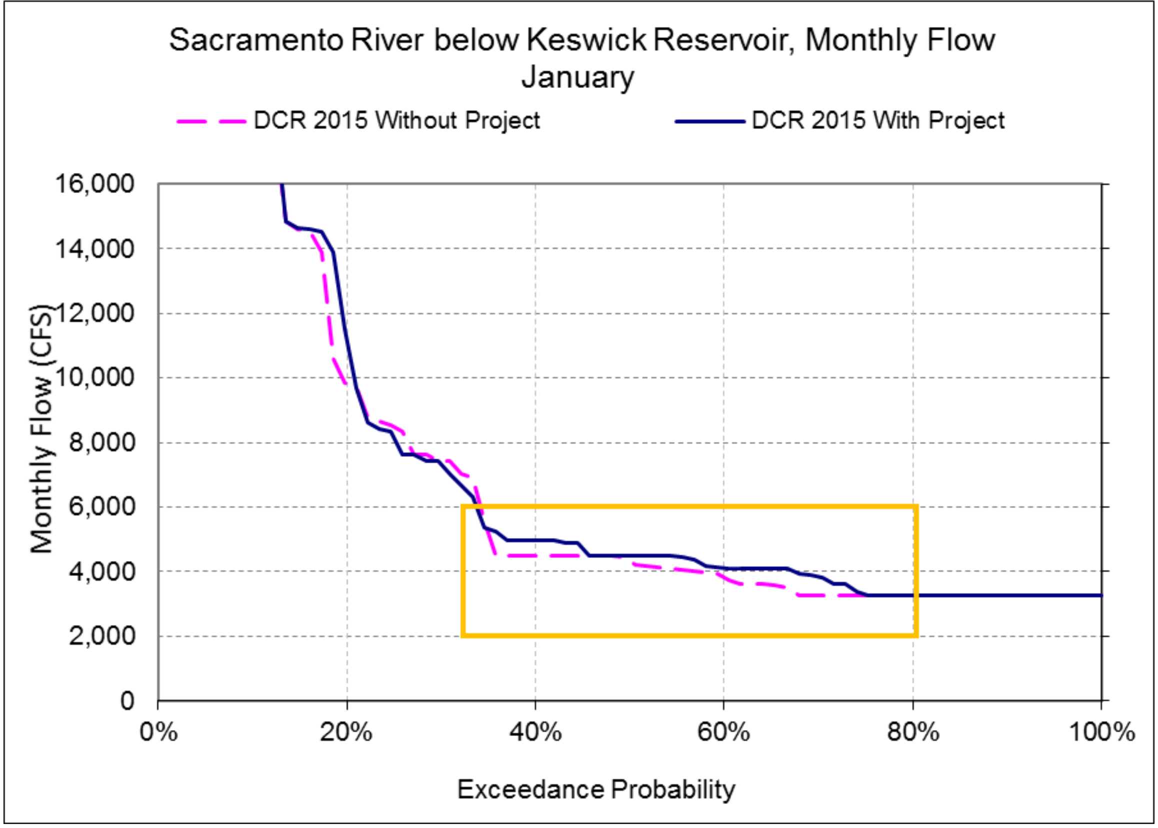
Water-year type averages do not fully demonstrate the flow augmentation benefit provided by the Sites Project. The figures below contain exceedance plots that demonstrate the flow augmentation benefits for December, January, and February for current, WSIP 2030, and WSIP 2070 climate conditions. In each month, there is an increase in Sacramento River flow in the targeted 3,250 - 5,500 cfs range.

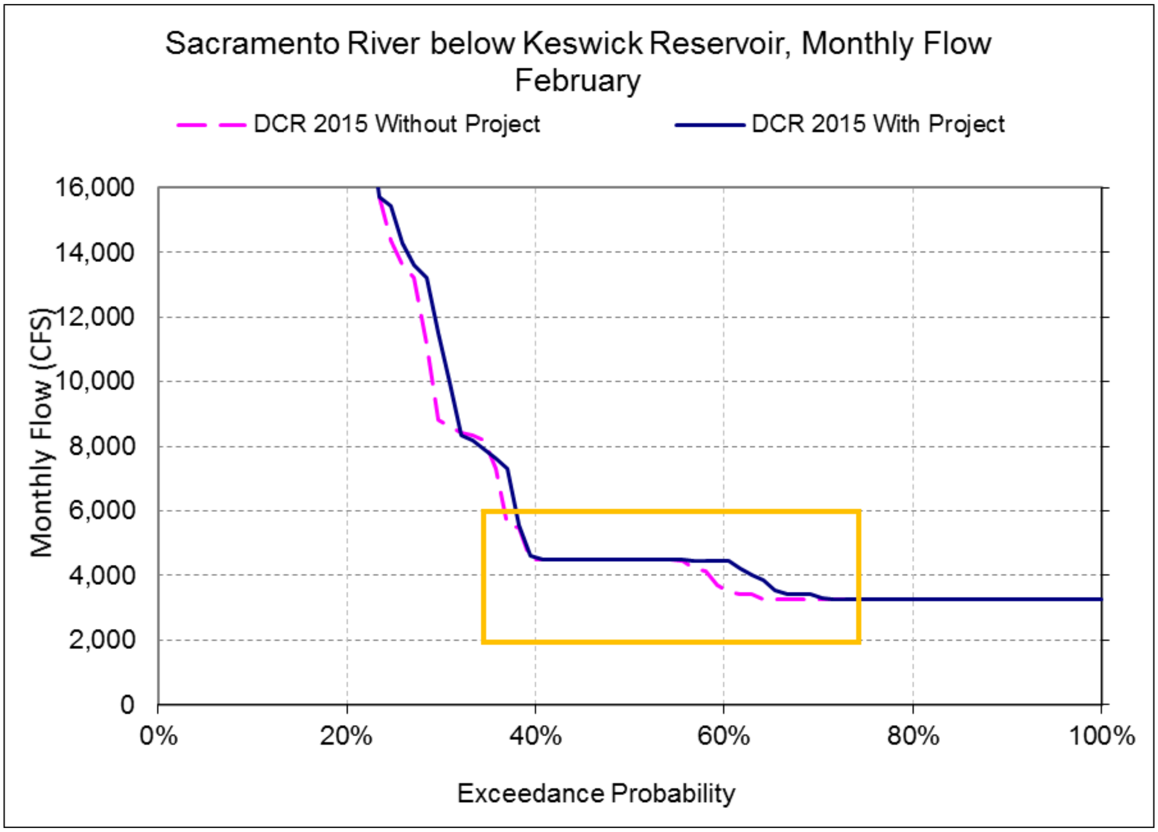
Table D.4-1: Average December-February Releases from Keswick Dam (cfs) With and Without the Sites Project

	Current				2030				2070			
	Without Project	With Project	Difference	Percent Change	Without Project	With Project	Difference	Percent Change	Without Project	With Project	Difference	Percent Change
Long-Term	8,349	8,720	372	4.4%	9,028	9,256	228	2.5%	9,459	9,617	157	1.7%
Wet	15,013	15,687	675	4.5%	17,411	17,654	242	1.4%	18,072	18,114	43	0.2%
Above Normal	9,100	9,320	220	2.4%	9,921	9,943	22	0.2%	10,680	10,779	99	0.9%
Below Normal	5,071	5,448	376	7.4%	4,711	4,889	177	3.8%	5,479	5,693	214	3.9%
Dry	3,829	4,173	343	9.0%	3,969	4,442	474	11.9%	3,736	3,964	228	6.1%
Critical	3,763	3,666	-97	-2.6%	3,532	3,679	147	4.2%	3,531	3,810	279	7.9%

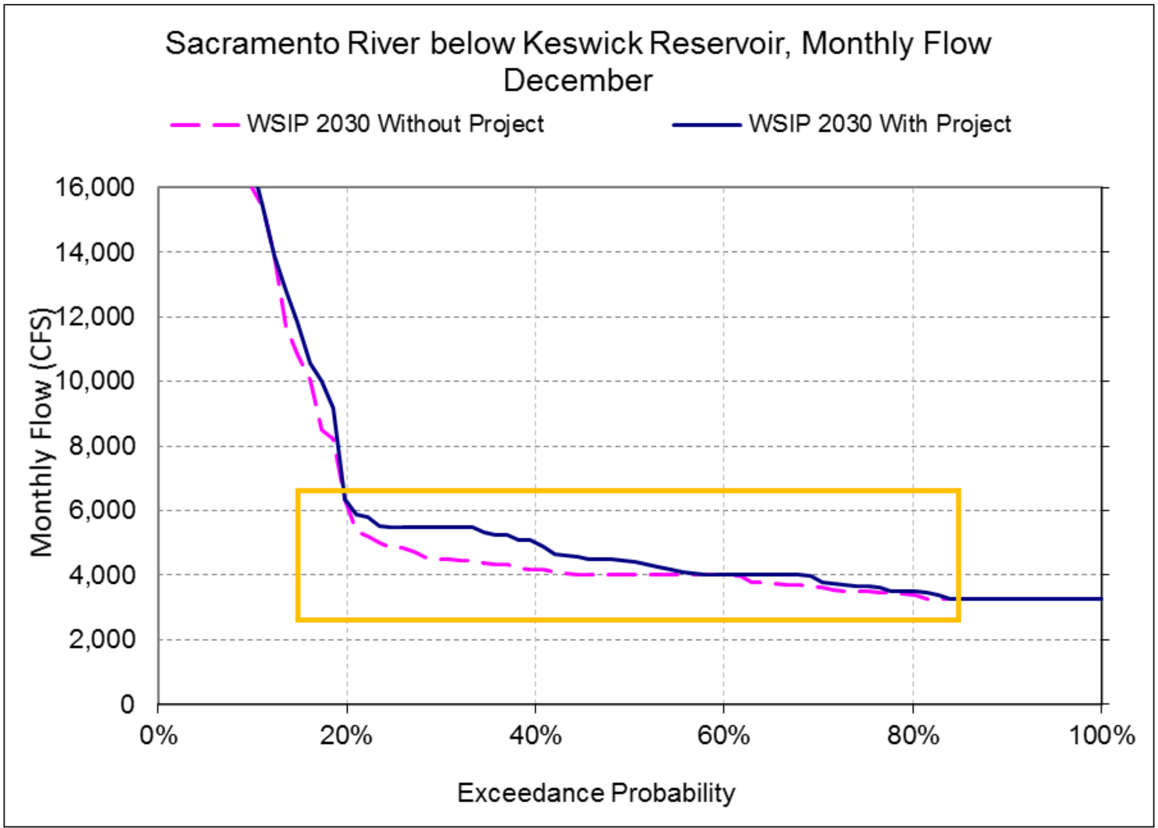
Current Conditions

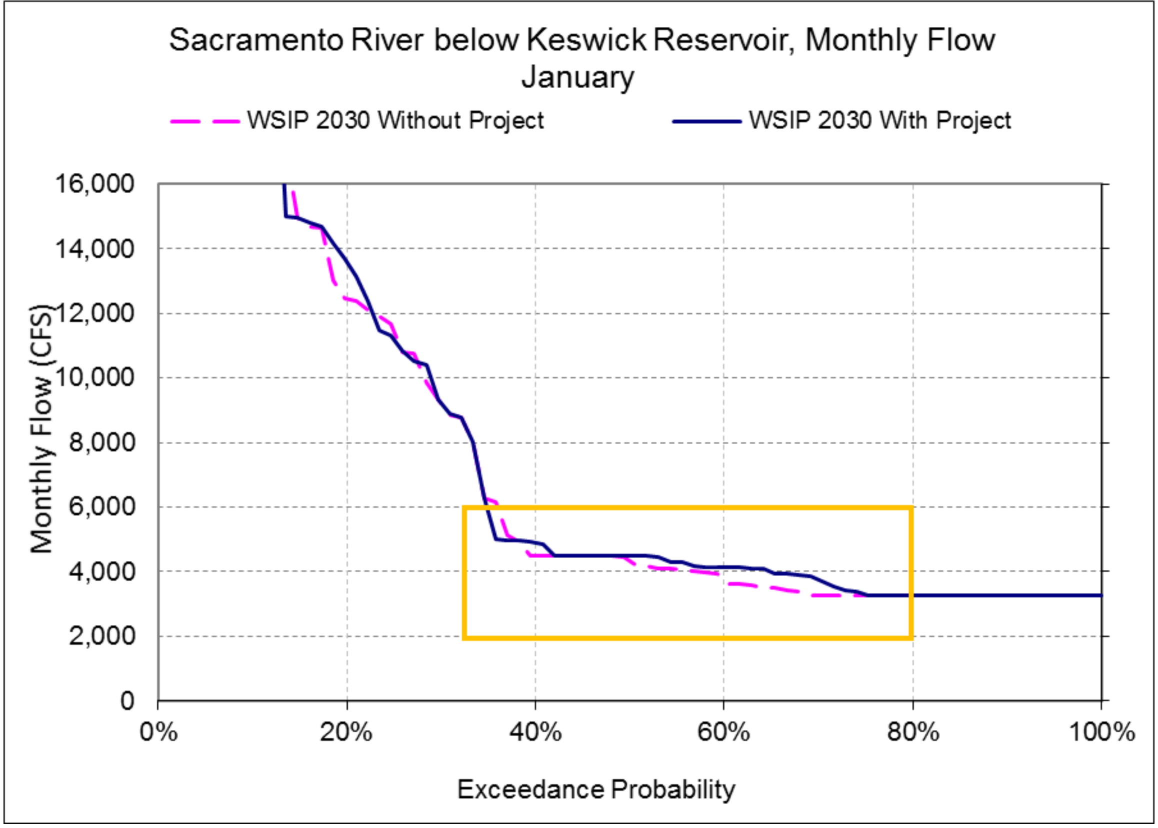


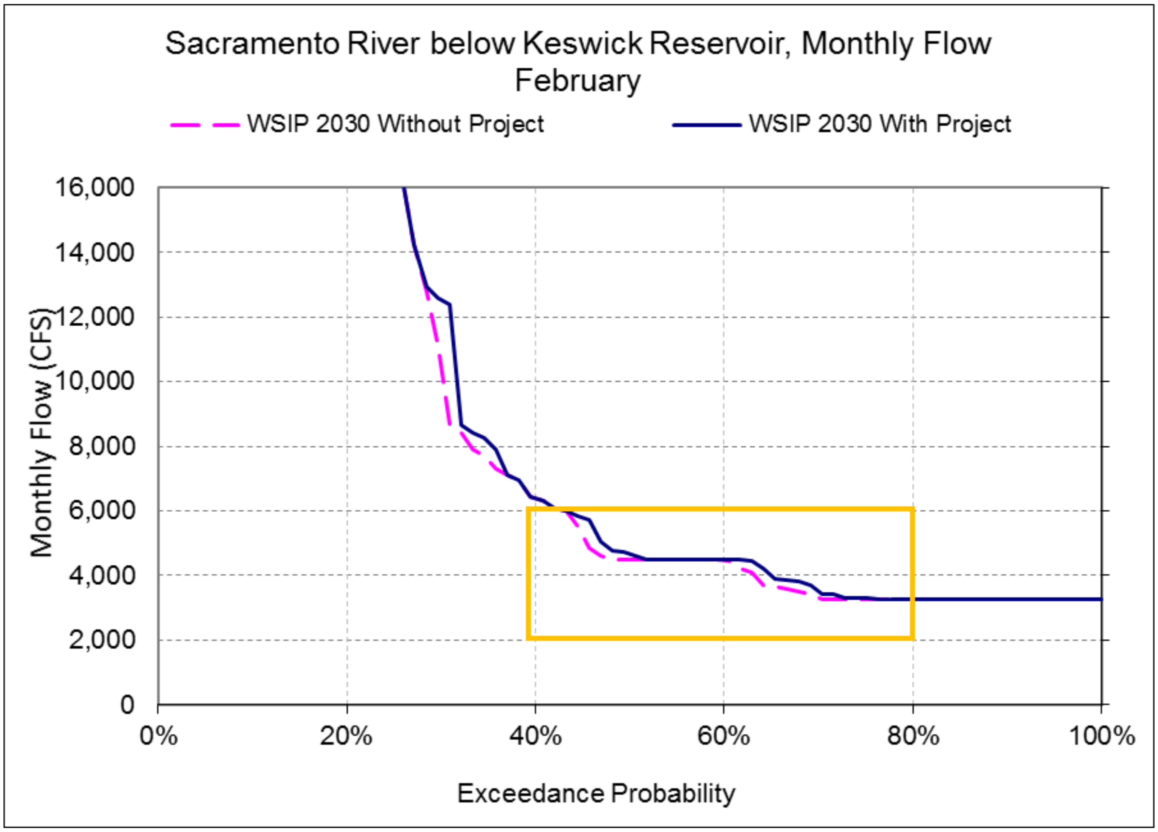



Sacramento River below Keswick Reservoir, Monthly Flow
February
DCR 2015 Without Project
DCR 2015 With Project
Monthly Flow (CFS)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0%
20%
40%
60%
80%
100%
Exceedance Probability

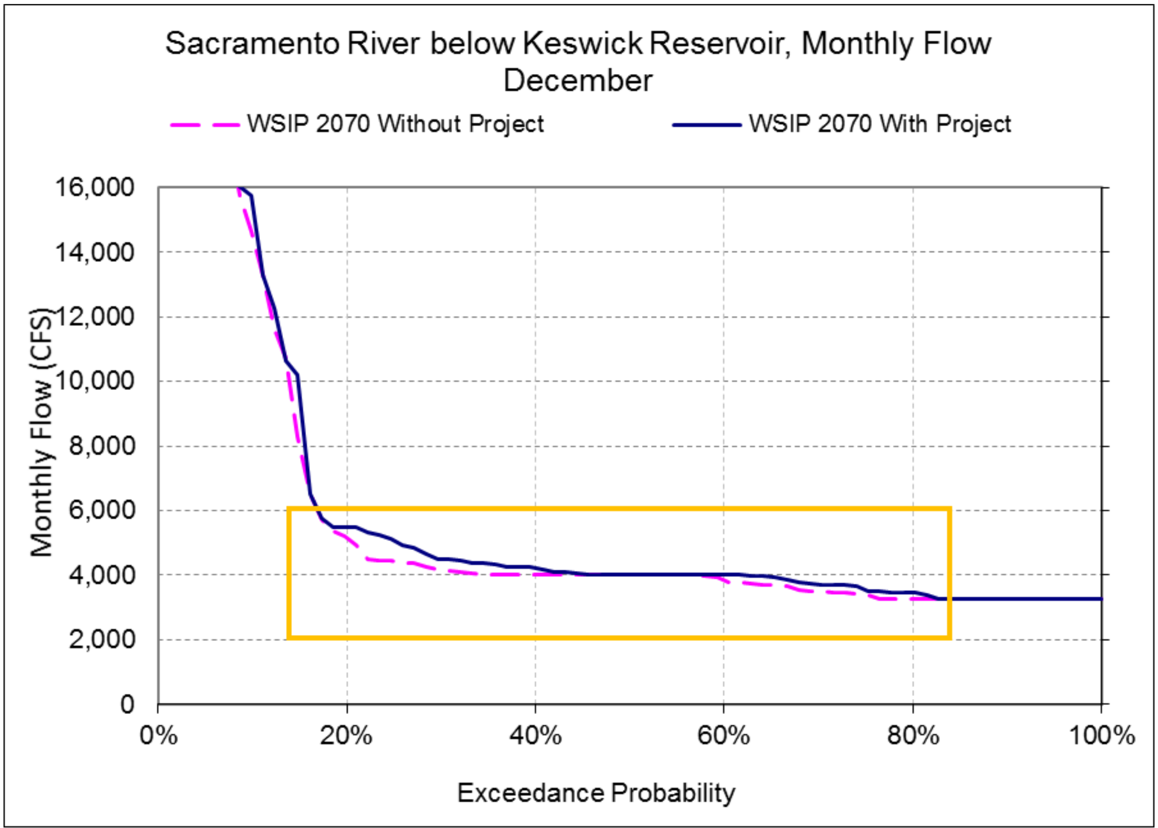
WSIP 2030 Conditions

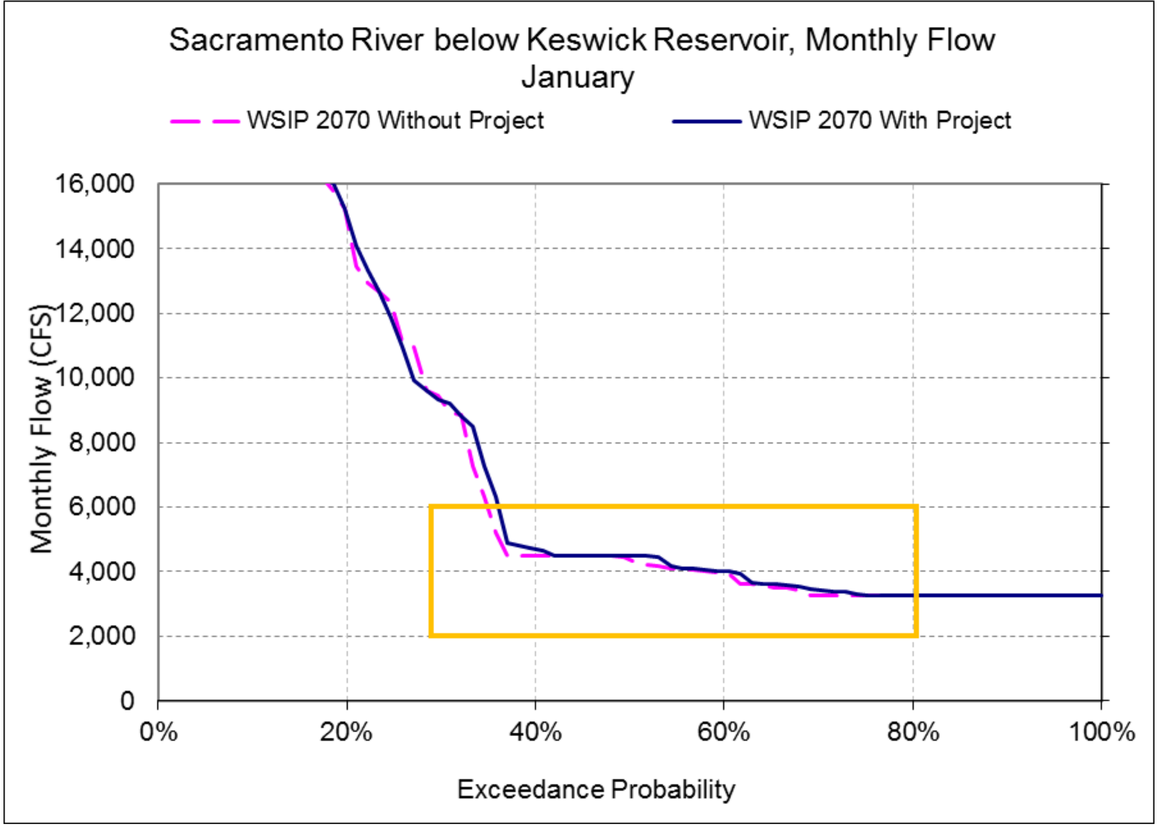


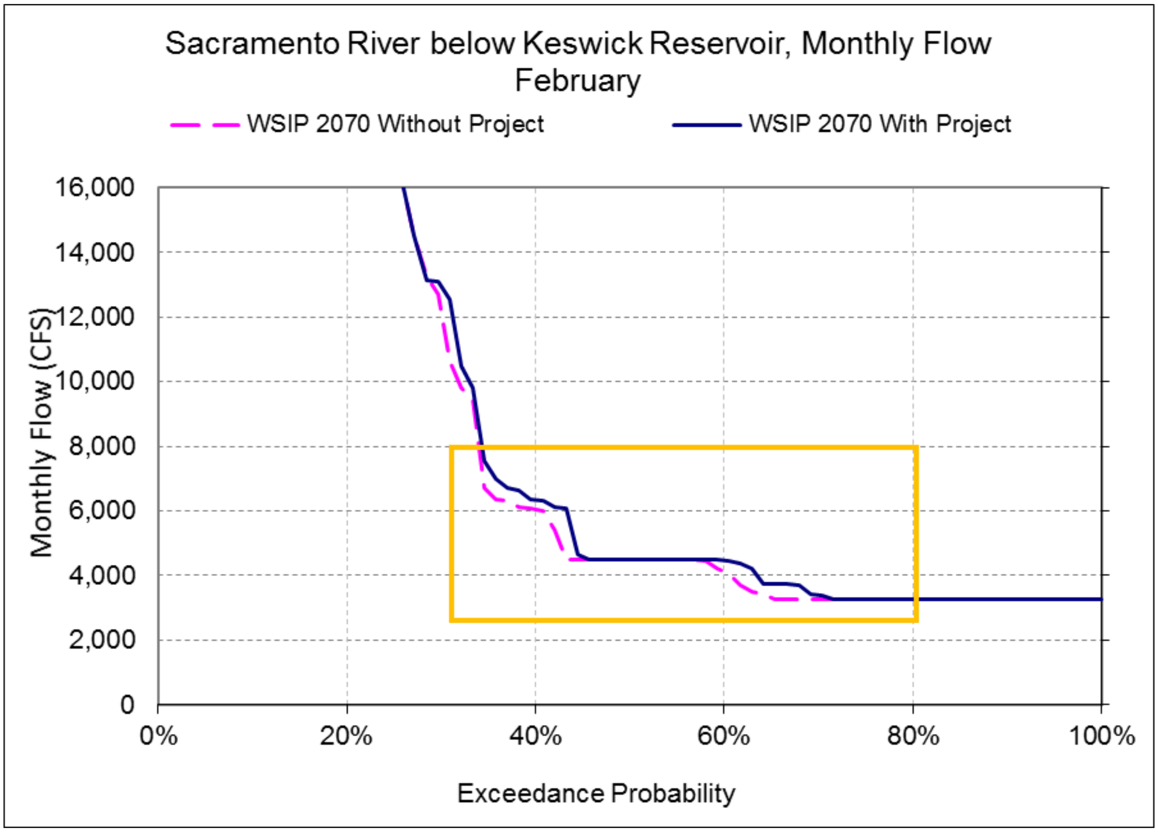



Sacramento River below Keswick Reservoir, Monthly Flow
February
WSIP 2030 Without Project
WSIP 2030 With Project
Monthly Flow (CFS)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0%
20%
40%
60%
80%
100%
Exceedance Probability

WSIP 2070 Conditions






Sacramento River below Keswick Reservoir, Monthly Flow
February
WSIP 2070 Without Project
WSIP 2070 With Project
Monthly Flow (CFS)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0%
20%
40%
60%
80%
100%
Exceedance Probability

D.5 Feather River Flow Augmentation

D.5.1 Comment from PBR review:

On page 3 of 5 of the Water Operations Review for Public Benefits Ratio:

- The applicant proposes to improve the coldwater pool storage in Lake Oroville to improve water temperature suitability for anadromous fish in the lower Feather River from May through November during all water years. Review of the applicant's CalSim II model results shows that the range on long-term average change in the lower Feather River flow decreases by 1 to 7 percent from May through August, and increases by 1 to 3 percent from September through November under 2030 conditions; flow decreases by 1 to 11 percent from June through November with no change in September, and increases by 1 percent in May under 2070 conditions. These results suggest the flow augmentation objective in the lower Feather River is not fully met during May through November.

D.5.2 Response to Comment:

Sites Reservoir releases in coordination with SWP operations could increase Lake Oroville carry over storage and operational flexibility to improve Feather River flow and water temperature management. The commission review is based on long-term average changes in Feather River flow which don't allow examination of benefits when they are needed most by salmonids. In wet and above normal water years flow and water temperature management are generally not an issue on the Feather River. Per the description included in Attachment 2: Operations Plan of the application, the most important water year types for stabilizing flows and river temperatures for salmonids are in dry and critical years with low Lake Oroville storage and a limited cold water pool. The priority objective is to utilize additional operational flexibility to manage flow releases to improve water temperatures in the lower Feather River for juvenile steelhead and Spring-Run Chinook Salmon over-summer rearing during the May to September period, as described in Table ADF-2. A secondary objective is to augment flows during dry and critical periods to minimize redd dewatering, juvenile stranding, and isolation of anadromous salmonids.

Tables 1 and 2 summarize the flow and temperature results for the Feather River to show benefits achieved in dry and critical years for WSIP 2030 and WSIP 2070 conditions. The model results demonstrate greater water temperature benefits under projected WSIP 2070 conditions when warmer air temperatures and less snow pack will make water temperature management more challenging. Lake Oroville releases are managed to reduce and increase river flows to adapt to changing hydrologic conditions and temperature needs. In general releases are reduced in June through August to preserve and maintain cold water pool, with flow augmentation releases in following months depending on storage conditions. Some periods may show decreases in average long-term river flows if more water is retained in reservoir storage.

As described in the Operations Plan there are many sources of uncertainty in predicting future environmental conditions, particularly in light of climate change, and knowledge gaps regarding factors controlling fish population dynamics and abundance, an adaptive management approach will be required to make informed decisions about operation management for the Sites Project. Actual project operations will include real time monitoring and adaptive management in coordination with SWP operations to increase Lake Oroville carry over storage and operational flexibility to improve Feather River flow and water temperature management.

Table D.5-1: Feather River below Thermalito Diversion Dam flow and temperature results for WSIP 2030

(D-1641 Sacramento Valley 40-30-30 Water Year Index for WSIP 2030 Scenario)

		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	MAY-SEP	WY AVG
Long-term Average															
FLOW (CFS)	WSIP 2030 WO PROJ	2945	1986	3101	4598	7321	7112	2613	1865	2779	7452	5138	4407	4328	4276
	WSIP 2030 W PROJ	3035	2015	3206	4663	7518	7109	2617	1828	2514	7165	4947	4507	4192	4260
	DIFF	90	28	105	65	197	-3	3	-38	-265	-287	-190	100	-136	-16
TEMP (°F)	WSIP 2030 WO PROJ	60.0	55.6	50.1	48.3	51.3	54.4	57.5	63.7	68.9	70.0	69.9	64.5	67	59.5
	WSIP 2030 W PROJ	59.6	55.4	50.2	48.4	51.4	54.4	57.5	63.6	69.1	70.2	69.9	64.7	67	59.5
	DIFF	-0.4	-0.1	0.1	0.1	0.0	0.0	0.0	-0.2	0.2	0.1	0.0	0.2	0.1	0.0
Dry															
FLOW (CFS)	WSIP 2030 WO PROJ	2846	1784	2131	1388	1547	2123	1539	1669	2951	6661	3529	2787	3519.2	2579
	WSIP 2030 W PROJ	3088	1786	2208	1388	1536	2003	1527	1685	2727	6869	3063	2985	3465.9	2572
	DIFF	242	2	77	0	-11	-121	-12	17	-224	208	-466	199	-53	-7
TEMP (°F)	WSIP 2030 WO PROJ	59.9	56.0	49.9	47.8	51.9	56.0	58.9	64.4	70.1	70.5	71.5	65.1	68.3	60.2
	WSIP 2030 W PROJ	59.4	55.8	50.1	47.9	51.9	56.0	58.8	64.3	70.0	70.3	71.3	65.7	68.3	60.1
	DIFF	-0.5	-0.2	0.2	0.1	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.2	0.6	0.0	0.0
Critical															
FLOW (CFS)	WSIP 2030 WO PROJ	2395	1671	1993	1175	1405	1465	1033	1373	2061	3481	1631	1517	2012.6	1767
	WSIP 2030 W PROJ	2339	1619	2057	1175	1325	1358	1023	1102	1838	4205	1537	1859	2108.1	1786
	DIFF	-56	-52	63	0	-80	-107	-10	-271	-223	724	-95	342	96	20
TEMP (°F)	WSIP 2030 WO PROJ	60.9	56.4	50.1	48.6	52.9	56.0	57.7	64.0	69.2	73.2	72.2	67.1	69.1	60.7
	WSIP 2030 W PROJ	60.5	56.3	50.1	48.7	52.9	55.8	57.7	63.0	68.4	72.5	71.6	66.5	68.4	60.3
	DIFF	-0.4	-0.1	0.0	0.1	0.0	-0.2	0.0	-1.0	-0.7	-0.7	-0.7	-0.5	-0.7	-0.4

Table D.5-2. Feather River below Thermalito Diversion Dam flow and temperature results for WSIP 2070

(D-1641 Sacramento Valley 40:30:30 Water Year Index based on WSIP 2070 climate scenario)

		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	MAY-SEP	WY AVG
Long-term Average															
FLOW (CFS)	WSIP 2070 WO PROJ	2748	1920	2859	5848	9110	7995	2358	1663	3107	7016	4915	4815	4303	4529
	WSIP 2070 W PROJ	2711	1882	3096	6091	9211	8094	2354	1700	2642	6493	4704	4811	4070	4482
	DIFF	-38	-38	237	243	101	99	-4	37	-465	-523	-211	-4	-233	-47
TEMP (°F)	WSIP 2070 WO PROJ	64.8	60.1	52.5	50.1	53.4	56.5	59.6	65.2	70.6	71.9	72.0	67.0	69	62.0
	WSIP 2070 W PROJ	64.0	59.9	52.7	50.2	53.5	56.5	59.6	65.1	71.0	72.3	72.0	67.0	69	62.0
	DIFF	-0.8	-0.2	0.2	0.1	0.1	0.0	0.0	-0.2	0.3	0.4	0.0	0.0	0.1	0.0
Dry															
FLOW (CFS)	WSIP 2070 WO PROJ	2597	1830	1911	1410	1848	2954	1627	1748	2779	6050	2841	2395	3162	2499
	WSIP 2070 W PROJ	2653	1813	2059	1410	1853	2995	1579	1969	2580	6057	3061	2732	3279	2563
	DIFF	56	-18	148	0	5	41	-49	222	-199	7	220	336	117	64
TEMP (°F)	WSIP 2070 WO PROJ	65.2	59.3	51.9	49.5	54.5	58.5	61.5	66.7	73.1	73.7	74.9	69.7	71.6	63.2
	WSIP 2070 W PROJ	63.9	59.6	52.5	49.8	54.3	58.1	60.5	65.1	71.6	72.6	73.0	68.6	70.2	62.5
	DIFF	-1.3	0.3	0.6	0.3	-0.2	-0.4	-1.1	-1.6	-1.5	-1.1	-1.9	-1.1	-1.4	-0.7
Critical															
FLOW (CFS)	WSIP 2070 WO PROJ	2176	1721	1828	1248	1479	1713	1212	1446	2013	3605	1983	1606	2130	1836
	WSIP 2070 W PROJ	1757	1525	1862	1212	1430	1661	1181	1250	2033	3853	1896	1717	2149	1781
	DIFF	-419	-197	34	-36	-49	-52	-31	-196	20	249	-87	111	19	-54
TEMP (°F)	WSIP 2070 WO PROJ	65.1	60.4	51.9	50.4	55.6	58.7	61.5	67.2	73.2	76.6	75.9	71.9	73.0	64.0
	WSIP 2070 W PROJ	63.8	60.2	52.8	50.7	55.5	58.2	60.1	65.2	71.0	75.1	74.2	70.3	71.2	63.1
	DIFF	-1.3	-0.2	0.8	0.4	-0.1	-0.6	-1.4	-2.0	-2.2	-1.5	-1.7	-1.6	-1.8	-0.9

D.6 Sacramento River Temperature Improvements

D.6.1 Comment from PBR Review

On page 3 of 5 of the Water Operations Review for Public Benefits Ratio:

- The applicant claims that the project would "increase cold-water pool storage in Shasta Lake, Lake Oroville, and Folsom Lake and improve temperature in the Sacramento and American Rivers during certain months at specific compliance points…" A review of the applicant's HEC-5Q model results shows minimal water temperature reduction in the upper Sacramento River. Under 2030 conditions, the long-term July through September monthly average water temperature at Bonnyview, Balls Ferry, Jellys Ferry, and Bend Bridge is reduced by 0 degrees Fahrenheit (°F), 0.1 °F, 0.1 °F, and 0.1 °F, respectively. Under 2070 conditions, the long-term July through September monthly average water temperature at all four locations is reduced by 0.5 °F. A review of the CE-QUAL-W2 model shows minimal water temperature reduction in the American River downstream from Folsom Dam to the mouth of the American River. For American River at Watt Avenue, the long-term average monthly temperature over the 82-year simulation period is reduced by 0.7 °F.

D.6.2 Response to Comment

This memo summarizes temperature results on the Sacramento River to show the temperature benefits achieved in dry and critical years due to the Sites project for current (DCR 2015), WSIP 2030, and WSIP 2070. The commission review is based on long-term average reductions in water temperature. The use of a long-term average doesn't allow examination of benefits when they are needed most by salmonids. In wet and above normal water years temperature management is generally not an issue on the Sacramento River. Per the description included in Benefit Calculation, Monetization, and Resiliency Tab, Attachment 2: Operations Plan of the application, the most important water year types for decreasing Sacramento River temperatures for salmonids are dry and critical years with low Shasta Lake storage and a limited cold water pool. The information provided below substantiates the reductions in water temperatures in dry and critical years that provide important benefits for salmonids, especially Winter-Run Chinook Salmon. The results also demonstrate greater water temperature benefits under projected WSIP 2070 conditions when warmer air temperatures and less snow pack will make water temperature management more challenging.

D.6.3 2015

Under 2015 climate conditions, the change between the with project condition and the without project condition in Sacramento River July to September long-term average temperature at Bonnyview, Balls Ferry, Jellys Ferry, and Bend Bridge is -0.5°F at all locations (Table D.6-1). The commission review used July to September as the temperature metric in its response. These results shown no net change from the project based on the long-term average.

However, these results do not reflect the larger reductions in Sacramento River temperature in dry and critical years, when the benefit to the cold-water pool in Shasta would be most important for winter-run chinook salmon. Table D.6-1 shows the average July to September flow in Dry and Critical Years at the important Sacramento River temperature locations.

Table D.6-1: 2015 Average July to September Sacramento River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Bonnyview	53.0	52.5	-0.5
Balls Ferry	54.5	54.1	-0.5
Jellys Ferry	55.9	55.4	-0.5
Bend Bridge	56.9	56.5	-0.5
Dry Years			
Bonnyview	53.5	52.9	-0.6
Balls Ferry	55.1	54.5	-0.7
Jellys Ferry	56.4	55.8	-0.6
Bend Bridge	57.5	56.9	-0.6
Critical Years			
Bonnyview	56.5	55.1	-1.4
Balls Ferry	58.0	56.6	-1.4
Jellys Ferry	59.2	57.9	-1.3
Bend Bridge	60.1	58.9	-1.2

Dry years show a decrease in average July to September temperatures at all locations of at least 0.6°F. In critical years, average July to September temperatures are decreased by at least 1.2°F. The temperature improvement at Bonnyview in critical years brings temperatures to below the 56°F threshold, which is the target temperature in the Sacramento River that Shasta currently operates to. The section of Sacramento River upstream of Bonnyview has been documented in the past as being critical for Winter-Run Chinook Salmon spawning and rearing, based on redd surveys from 2003-2014 provided David Swank of National Marine Fisheries Service in 2015. Thus, Sites provides Sacramento River temperature benefits in the most critical years for the important reach for Winter-Run Chinook Salmon.

D.6.4 2030

Under 2030 climate conditions, the change between the with project condition and the without project condition in Sacramento River July to September long-term average temperature at Bonnyview, Balls Ferry, Jellys Ferry, and Bend Bridge is 0°F, -0.1°F, -0.1°F, and -0.1°F respectively (Table D.6-2). The commission review used July to September as the temperature metric in its response. These results shown no net change from the project based on the long-term average.

However, these results do not reflect the larger reductions in Sacramento River temperature in dry and critical years, when the benefit to the cold-water pool in Shasta would be most important for winter-run chinook salmon. Table D.6-2 shows the average July to September flow in Dry and Critical Years at the important Sacramento River temperature locations.

Table D.6-2: 2030 Average July to September Sacramento River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Bonnyview	53.6	53.6	0.0
Balls Ferry	55.2	55.2	-0.1
Jellys Ferry	56.6	56.5	-0.1
Bend Bridge	57.6	57.6	-0.1
Dry Years			
Bonnyview	54.3	54.1	-0.2
Balls Ferry	55.9	55.7	-0.2
Jellys Ferry	57.3	57.0	-0.3
Bend Bridge	58.5	58.2	-0.3
Critical Years			
Bonnyview	56.6	55.9	-0.7
Balls Ferry	58.1	57.5	-0.6
Jellys Ferry	59.4	58.8	-0.6
Bend Bridge	60.3	59.8	-0.5

Dry years show a decrease in average July to September temperatures at all locations of at least 0.2°F. In critical years, average July to September temperatures are decreased by at least 0.5 °F. The temperature improvement at Bonnyview in critical years brings temperatures to below the 56°F threshold, which is the target temperature in the Sacramento River that Shasta currently operates to. The section of Sacramento River upstream of Bonnyview has been documented in the past as being critical for Winter-Run Chinook Salmon spawning and rearing, based on redd surveys from 2003-2014 provided David Swank of National Marine Fisheries Service in 2015. Thus, Sites provides Sacramento River temperature benefits in the most critical years for the important reach for Winter-Run Chinook Salmon.

D.6.5 2070

Under 2070 climate conditions, the change between the with project condition and the without project condition in Sacramento River July to September long-term average temperature at Bonnyview, Balls Ferry, Jellys Ferry, and Bend Bridge is -0.5°F for all locations (Table D.6-3). The commission review used July to September as the temperature metric in its response. These reductions show a net improvement of 0.5°F from the project based on the long-term average.

However, these results do not reflect the larger reductions in Sacramento River temperature in dry and critical years, when the benefit to the cold-water pool in Shasta would be most important for winter-run chinook salmon. Table D.6-3 shows the average July to September flow in Dry and Critical Years at the important Sacramento River temperature locations.

Table D.6-3: 2070 Average July to September Sacramento River Temperatures

Location	Without Project (°F)	With Project (°F)	Change (°F)
Long-term Average			
Bonnyview	54.8	54.3	-0.5
Balls Ferry	56.5	56.0	-0.5
Jellys Ferry	57.9	57.4	-0.5
Bend Bridge	59.0	58.5	-0.5
Dry Years			
Bonnyview	55.1	54.6	-0.5
Balls Ferry	56.9	56.3	-0.6
Jellys Ferry	58.3	57.7	-0.6
Bend Bridge	59.5	58.9	-0.6
Critical Years			
Bonnyview	60.5	58.6	-1.9
Balls Ferry	61.9	60.2	-1.7
Jellys Ferry	63.0	61.5	-1.5
Bend Bridge	63.8	62.4	-1.4

Dry years show a decrease in average July to September temperatures at all locations of at least 0.5°F. In critical years, average July to September temperatures are decreased by 1.4 to 1.9 °F. These improvements are substantial and occurring during the years when temperature improvement in the Sacramento River would be the most critical for Winter-Run. This also demonstrates the ability to provide benefits under future WSIP 2070 conditions when water temperature management will be more challenging due to warmer air temperatures and less snow pack runoff.