DRAFT HYDROLOGICAL AND OPERATIONS MODELING CONSIDERATIONS FOR THE PHASE II UPDATE OF THE 2006 BAY-DELTA PLAN

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Acronyms and Abbreviations

ANN	Artificial Neural Network
Bay-Delta Plan	2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary
CDEC	California Data Exchange Center
cfs	cubic feet per second
COA	Coordinated Operations Agreement
CVP	Central Valley Project
D-1641	Water Right Decision 1641
DSA	Depletion Study Area
DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
ERI	Eight River Index
FRSA	Feather River Service Area
IFR	instream flow requirement
MAF	million acre-feet
MAF/yr	million acre-feet per year
M&I	municipal and industrial
OCAP	Operational Criteria and Plan
PG&E	Pacific Gas and Electric Company
Projects	State Water Project and Central Valley Project
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Department of Interior, Bureau of Reclamation
SacWAM	Sacramento Water Allocation Model
SEI	Stockholm Environment Institute
State Water Board	State Water Resources Control Board
SVUFM	Sacramento Valley Unimpaired Flow Model
SWP	State Water Project
TAF	thousand acre-feet
TAF/yr	thousand acre-feet per year
UF	unimpaired flow
USFWS	U.S. Fish and Wildlife Service
WEAP	Water Evaluation and Planning
WRESL	Water Resources Simulation Language
WSI-DI	Water Supply Index-Delivery Index

Chapter 1
Overview

The State Water Resources Control Board (State Water Board) is in the process of updating the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan) through a phased effort. Phase II of that effort, also referred to as the comprehensive review of the Bay-Delta Plan, involves potential changes to the Bay-Delta Plan to protect fish and wildlife beneficial uses related to Sacramento River mainstem and tributary inflows, Delta eastside tributary (Calaveras, Cosumnes and Mokelumne Rivers) inflows, Delta outflows, interior Delta flows, and cold water management requirements.

The water quality control planning process must ensure the reasonable protection of beneficial uses, which requires balancing competing beneficial uses of water, including municipal and industrial (M&I) uses, agricultural uses, fish and wildlife, and other environmental uses. The process will include an analysis of the effects of any changes to the above flow requirements on the environment in the watersheds in which Delta flows originate, in the Delta, and in the areas in which Delta water is used. The Phase II update will require hydrological and operations modeling to understand the complex interaction of flows, reservoir operations, and the balancing of beneficial uses of water within the Bay-Delta Watershed.

The California Department of Water Resources (DWR) and the U.S. Department of Interior, Bureau of Reclamation (Reclamation) have developed and extensively used the CalSim II model for planning, managing, and operating the State Water Project (SWP) and Central Valley Project (CVP) (Projects). The State Water Board's potential modifications to the 2006 Bay-Delta Plan may affect Central Valley and Delta operations that are included in the CalSim II model, such as Delta inflow, Delta outflow, export/inflow ratio, Delta Cross Channel Gate closure, and Old and Middle River reverse flows. However, for its review of the Bay-Delta Plan, the State Water Board needs the following additional modeling capabilities that are not part of CalSim II's functionality: (1) the ability to predict flows at the mouths of tributaries to the Delta; (2) the ability to simulate water diversions on smaller tributaries and creeks; and (3) the ability to simulate operations of local agency reservoirs that are not part of the SWP or CVP. The State Water Board also needs a flexible, user friendly simulation tool to rapidly assess the impacts of various regulatory scenarios on flows into the Delta, within the Delta, and flows exported from the Delta. The State Water Board has developed the Sacramento Water Allocation Model (SacWAM) for this purpose. SacWAM is a hydrology and system operations model that is an application of the Water Evaluation and Planning (WEAP) system, and was a collaborative effort between the State Water Board and Stockholm Environment Institute (SEI).

This report provides a comparison of SacWAM and CalSim II for alternative operational scenarios to gauge whether SacWAM is an appropriate tool for the Phase II Bay-Delta Plan update. The model scenarios and results presented in this report do not represent alternative water quality objectives or impacts; rather, the scenarios presented here are for the sole purpose of comparing different models under alternative regulatory regimes. Further refinement of modeling scenarios will be needed before model results can be used to assess potential alternative regulatory requirements.

An alternative scenario that includes new Delta outflows and new 50% of unimpaired flow (UF) requirements (for illustrative modeling purposes only) at the mouths of each major tributary to the Sacramento River and the Delta eastside tributaries was run in CalSim II and in SacWAM. Each alternative scenario study was compared against a corresponding CalSim II or SacWAM base study. The results of this comparison highlight the limitations of the CalSim II model to be able to accurately simulate the types of alternatives that the State Water Board may consider in the Phase II update of the Bay-Delta Plan, specifically on tributaries that are not controlled by the Projects (non-Project tributaries).

This report concludes that both models represent Project operations that affect the Bay-Delta similarly, while SacWAM provides higher resolution on the Valley floor and representation of upstream watershed operations. Because of the limited representation of non-Project tributaries in CalSim II, assumptions were required that affect not only diversions and streamflows on those tributaries, but Project operations as well. Other than differences explained by non-Project tributary flows, changes to Project operations due to new flow requirements are similar between the two models. Changes to Delta outflows, Project reservoir storage, Project exports and Project contract allocations are very similar between the two models, demonstrating that detailed aspects of CalSim II such as the Artificial Neural Network, Coordinated Operations Agreement, and Project contract allocations are properly implemented in SacWAM. Modifications to CalSim II for this study took about 1 year for engineers at DWR, whereas a comparable simulation in SacWAM was crafted in less than a month by State Water Board staff, which illustrates the flexibility of the SacWAM model.

1.1 CalSim II

CalSim II is a system operations model developed by DWR and Reclamation to model the operations of the SWP and CVP. It is the official planning model of the Projects and the standard tool for examining the effects of changes to Project operations. CalSim II, and its predecessor DWRSIM, have been used for many major studies such as the 1995 Bay-Delta Plan, the Long-Term Operational Criteria and Plan (OCAP) for coordination of the Central Valley Project and State Water Project, and the California Water Fix. CalSim II has capabilities to evaluate system performance under existing conditions, at future levels of land development, and in limited climate change and sea level rise scenarios. Because CalSim II has been used for about 20 years, many additional post-processing tools exist to analyze results and to link with water temperature and Delta hydrodynamic and salinity models.

Because CalSim II is designed to simulate SWP and CVP operations, its spatial extent matches those systems. It models, in rough detail, the valley floor drainage of the Sacramento River, the San Joaquin River downstream from Friant Dam, “Project” tributaries (Feather, American, and Stanislaus rivers), and the Delta, but does not extend above SWP and CVP rim dams (e.g., Oroville, Trinity, Shasta, Folsom, New Melones, Friant). Nor does the model include very much detail about non-Project tributaries, or include water supply and distribution systems outside of the SWP and CVP system, which leaves approximately 70% of the Bay-Delta Plan study area outside of the model domain. The model also only includes a very limited representation of groundwater in the SWP and CVP service areas.

CalSim II simulates 82 years (water years 1922-2003) of operations assuming historical hydrology on a monthly time step. Model run times for the 82 years are approximately 20 minutes. CalSim II does not simulate basic hydrologic processes such as rainfall runoff and crop evapotranspiration. This information is input as water demands, stream losses and gains, rim basin inflows, and irrigation efficiency. It operates to meet the requirements established in Water Right Decision 1641 (D-1641), biological opinions, other regulations in the Delta and the Central Valley, and SWP and CVP contract obligations. Water supply delivery is governed by a user-specified weighting system. Deliveries to senior water rights holders and settlement contractors are assigned a high weight (priority). After all higher priorities are met, including instream flow and Delta outflow requirements, the remaining water is allocated to SWP and CVP contractors. Water is shared between the two Projects in accordance with the 1986 Coordinated Operations Agreement (COA). CalSim II uses an Artificial Neural Network (ANN) to statistically link Delta flows with salinity, enabling it to model compliance with the D-1641 water quality control points without having to run a separate hydrodynamic and water quality model.

CalSim II is written in the specialized Water Resources Simulation Language (WRESL) and all changes to the model require changes to the code. Minor changes, such as modifying the value of an existing flow requirement are easily accomplished by anyone with a programming background. Larger changes, such as adding new flow, storage, or delivery constraints, require a skilled WRESL programmer familiar with all or most aspects of the CalSim II code. In instances of a model error, or infeasibility, CalSim II may offer limited feedback to help the programmer locate and resolve the problem. Model operations determined by the mixed integer programming solver can be difficult to follow, and unintended actions time-consuming to resolve. For these reasons, CalSim II is considered to be a fairly inflexible tool to simulate the changes to the hydrologic system that may be analyzed as part of the Bay-Delta Plan update. CalSim II code is free and open source, however the mixed integer programming solver, known as XA, requires a license that costs approximately two thousand dollars. Full documentation of model inputs, assumptions, and limitations is not available, however limited information can be found in planning and environmental documents for many recent projects such as the California Water Fix and the 2015 Delivery Capability Report (DWR 2015a, DWR 2015b).

1.2 Sacramento Water Allocation Model (SacWAM)

SacWAM is a combined hydrology and system operations model developed by SEI and State Water Board to assess potential revisions to instream flows and other requirements specified in the 2006 Bay-Delta Plan. SacWAM was developed using the WEAP software, and is designed to easily simulate alternative regulatory scenarios. Detailed model documentation (SEI 2016) is available from the State Water Board website.

SacWAM simulates the entire water balance and includes all hydrologic processes: rainfall-runoff, snow melt and accumulation, vegetation evapotranspiration, soil moisture, and groundwater. SacWAM has a detailed model representation of the Sacramento River Watershed based on local water agency boundaries and includes all SWP and CVP operations and non-Project tributaries that affect flows in the Bay-Delta. It has the advantage of being very flexible; the model can be easily modified by clicking on an object and changing its attributes. SacWAM has the ability to simulate the upstream hydrology in one of two modes: the user can choose to calculate rainfall runoff and snowmelt driven by climate data or use DWR's and Reclamation's preprocessed unimpaired inflows. SacWAM can be run with different climate scenarios for climate change analyses, and will be refined for use in future Bay-Delta planning and implementation activities.

WEAP software licenses are free to all California public agencies; however, purchase is required for general public use. SacWAM requires the same proprietary XA linear programming solver as CalSim II. CalSim II results are frequently used as inputs to Delta salinity models, water temperature models, and economic models, whereas some post-processing will be required to link SacWAM with other models.

Chapter 2
Methods

The 2010 Flow Criteria Report recommended that a percent of UF be used to set new flow objectives for the Sacramento River and the Delta (State Water Board 2010). UF is an estimate of the hydrologic yield of a watershed after removing the effects of reservoir storage, diversions, and exports. UF includes the changes that have occurred in a watershed because of channelization and construction of levees, loss of floodplains and wetlands, and groundwater gains and losses.

The methods used to calculate UF for tributaries to the Sacramento River and the three eastside tributaries to the Delta with the Sacramento Valley Unimpaired Flow Model (SVUFM) is summarized in Appendix A. This section describes the modifications and assumptions made to CalSim II and SacWAM base study simulations to represent 50% UF and an added Delta outflow requirement.

2.1 Unimpaired Flow Requirements and Delta Outflow Requirement in CalSim II and SacWAM Alternative Operations Scenarios

New instream flow requirements (IFRs) were introduced at the mouth of each major tributary to the Sacramento River and the Delta and set equal to 50% of the unimpaired flow (50% UF). Additionally, 50% UF requirements were added to locations along the Sacramento River to ensure that additional inflow was protected against diversion before it arrived at the Delta. A full list of locations at which 50% UF was required in both models is presented in Table 1.

Table 1. List of 50% UF Requirement Locations

Instream Flow Requirement Locations
• American River above Sacramento River
• Antelope Creek above Sacramento River
• Battle Creek above Sacramento River
• Bear River above Feather River
• Big Chico above Confluence
• Butte Creek above Butte Slough
• Cache Creek above Yolo Bypass
• Calaveras River above Delta
• Clear Creek above Sacramento River
• Cosumnes River above Mokelumne River
• Cottonwood Creek above Sacramento River
• Cow Creek above Sacramento River
• Deer Creek above Sacramento River
• Feather River below Oroville Reservoir
• Feather River above Sacramento River
• Mill Creek above Sacramento River
• Mokelumne River above Cosumnes River
• Putah Creek above Yolo Bypass
• Stony Creek above Sacramento River
• Thomes Creek above Sacramento River
• Yuba River above Feather River
• Sacramento River below Keswick Reservoir
• Sacramento River at Knights Landing
• Sacramento River at Freeport

2.2 Alternative Delta Outflow Requirement

Delta outflow reflects the availability of water from the three major regions tributary to the Delta: the Sacramento River basin, the eastside tributaries to the Delta, and the San Joaquin River basin. The three regions differ in the timing of peak contributions to Delta inflow, with winter and early-spring runoff dominating in the Sacramento River basin, late spring snowmelt dominating in the San Joaquin River basin, and a mixed pattern among the eastside tributaries. Additionally, flow contributions from the San Joaquin River upstream from Vernalis are currently heavily impaired, and are being addressed through separate planning and regulatory processes. For purposes of developing the illustrative example presented here, it was assumed that San Joaquin River flows would continue to reflect existing conditions as modeled in CalSim II (DWR 2015b).

UFs were estimated using SVUFM. The modeled Delta outflow requirement was derived as follows:

1. Unimpaired Delta outflow for January through June was regressed independently for each month as a function of unimpaired inflows from the Sacramento River basin, eastside tributaries to the Delta, and San Joaquin River basin (Table 2).
2. Using the linear models obtained in (1), Delta outflow was predicted under the assumption of unimpaired Sacramento and eastside flows and existing conditions for San Joaquin River inflows at Vernalis (Figure 1).
3. A monthly linear regression was fit to predict the monthly Delta outflows obtained in (2) as functions of monthly Eight River Index (ERI) (Figure 2).
4. The values obtained in (3) were scaled by 50% to reflect the percent of unimpaired inflow being provided from the Sacramento River basin tributaries and eastside tributaries.

This procedure provided a monthly Delta outflow requirement as a function of monthly ERI. This simple model was applied to the historical ERI time series, available from the California Data Exchange Center (CDEC), for water years 1922–2003 to obtain the time series of January to June flows corresponding to the 50% unimpaired inflow from the Sacramento Basin and eastside tributaries to the Delta. This requirement was imposed as a time series of required flows at Chipps Island, in addition to the existing Water Right Decision 1641 (D-1641) requirements for Delta outflow, X2, and Delta water quality, and in addition to the U.S. Fish and Wildlife Service (USFWS) fall X2 requirements. X2 is the location of the 2 parts per thousand salinity contour (isohaline), 1 meter off the bottom of the estuary measured in kilometers upstream from the Golden Gate Bridge.

Table 2. Monthly Multiple Regression Parameters for Predicting Unimpaired Delta Outflow as a Function of Unimpaired Inflows

	Jan	Feb	Mar	Apr	May	Jun
(Intercept)(cfs)	119.7	-994.1	-927.3	-535.4	-354.4	-311.3
Sacramento	1.035	1.032	1.016	1.005	1.006	1.005
Eastside	1.042	0.9986	1.123	1.171	0.9496	0.9473
San Joaquin	1.032	1.098	1.017	0.9811	1.003	1.004

cfs = cubic feet per second

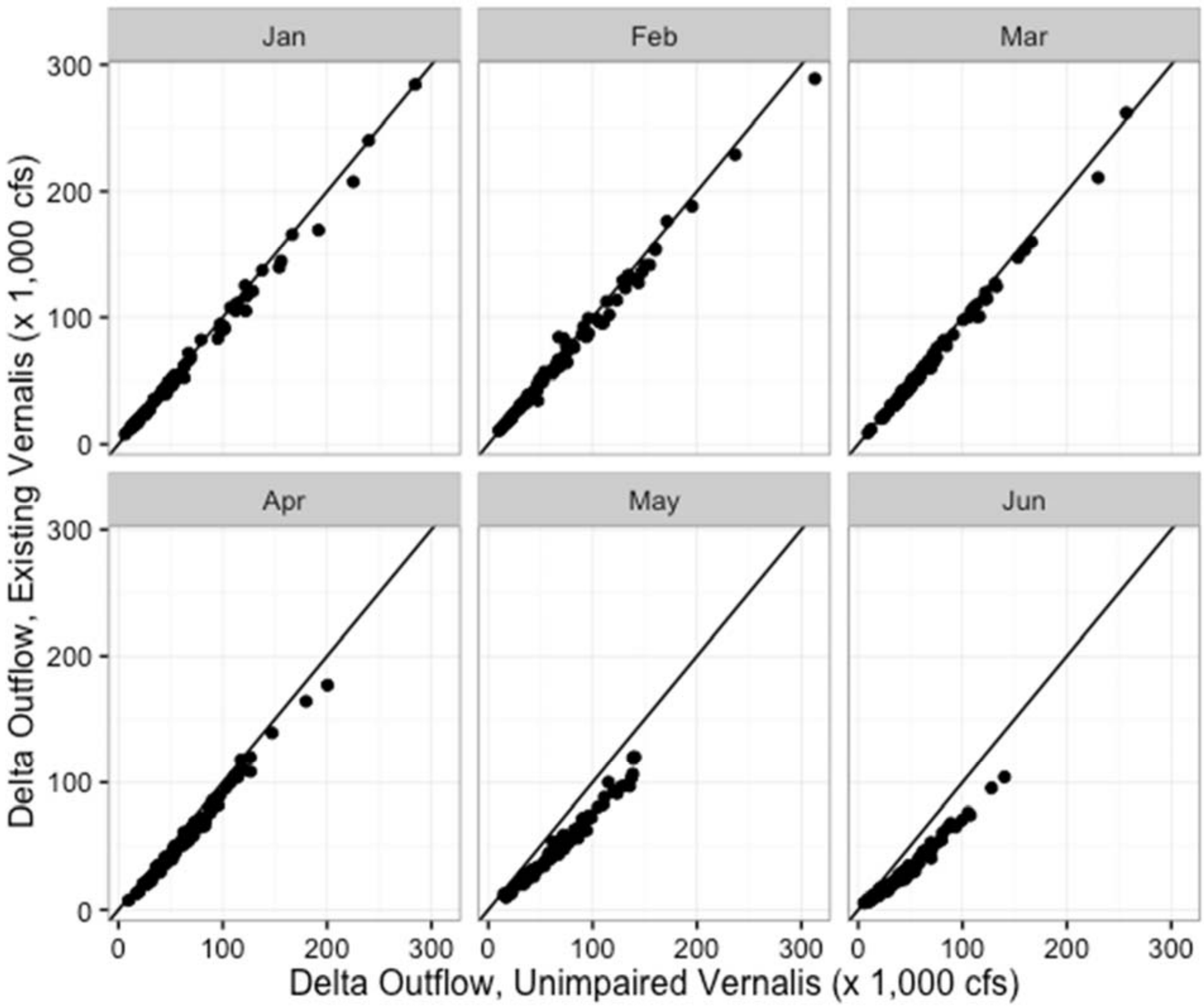

Figure 1. Delta Outflow Predicted from the Linear Model Shown in Table 1. Existing-Condition flows at Vernalis shown as a function of unimpaired Delta outflow (May and June flows fall below the one-to-one line, reflecting the effect of impaired Vernalis flows under existing conditions.)

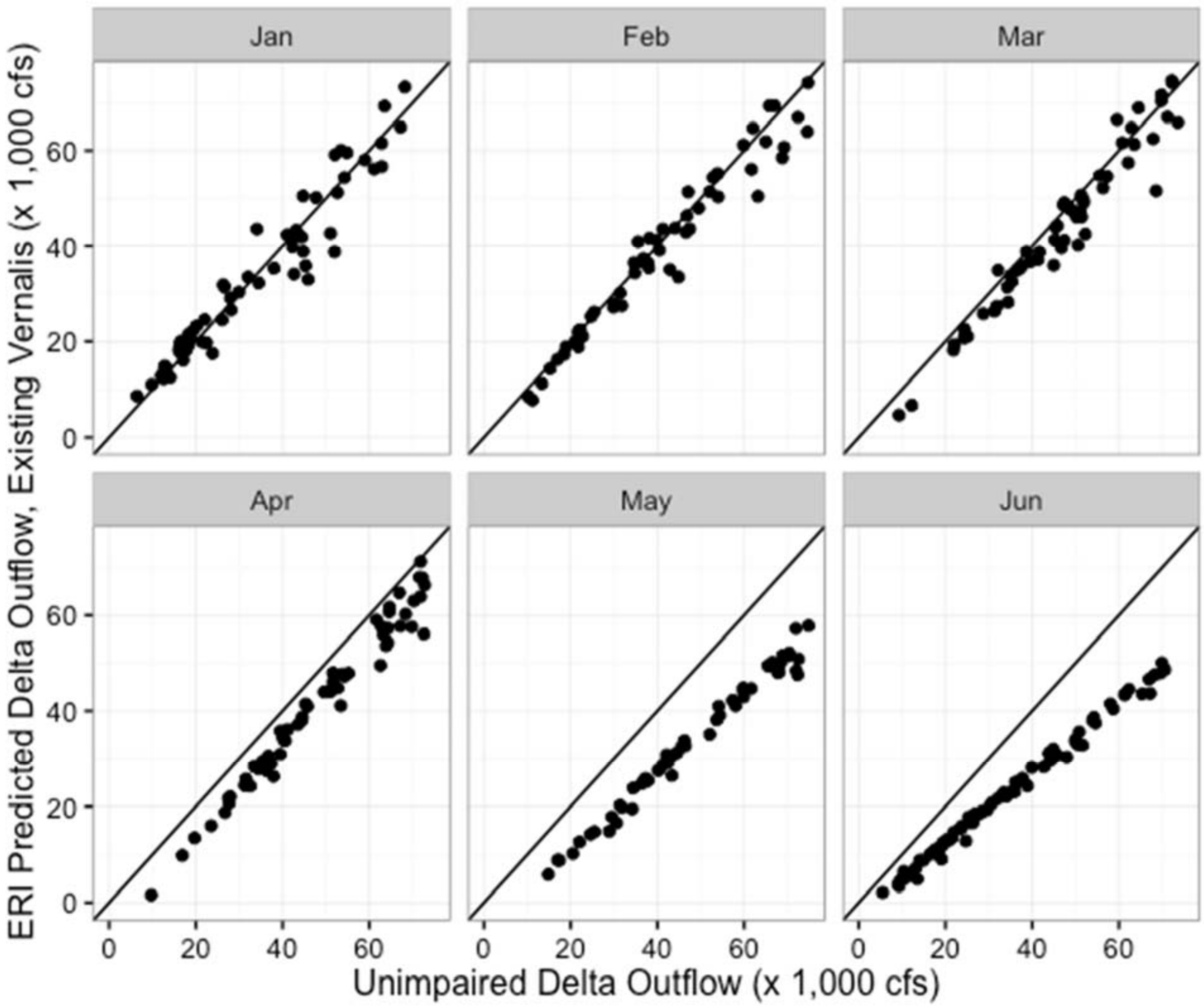

Figure 2. Predicted Delta Outflow as a Function of ERI. Existing-Condition flows assumed at Vernalis (April–June flows generally fall below the one-to-one line due to the impairment of Vernalis flows.)

2.3 Modifications to CalSim II

The 2015 Delivery Capability Report existing conditions simulation was assumed to be a base simulation in CalSim II (DWR 2015b). Modifications made to the CalSim II base simulation to simulate 50% UF, Delta outflow, demand reduction, and allocation reduction can be found in Appendix B.

2.4 Modifications to SacWAM

The SacWAM Beta Version 0.1 "existing conditions" simulation outlined in the SacWAM Documentation (SEI 2016) was assumed to represent a base simulation to which 50% UF simulation results were compared. Changes to the SacWAM base simulation were made to mimic the changes made to CalSim II as closely as reasonably possible. State Water Board staff worked with DWR over

1 year which included 30 different model runs to develop the CalSim II scenario described in Appendix B. With lessons learned in simulating 50% UF in CalSim II, the State Water Board developed the SacWAM scenario described below in approximately 2 weeks.

2.4.1 Implementation of 50% UF Instream Flow Requirements

The 50% of UFs estimated using SVUFM were applied as IFRs at the locations listed in Section 2.1. For a description of SVUFM unimpaired flows see Appendix A. The new IFRs were given a priority value of 8 which is a higher priority (lower value) than all other demands in the system other than upper watershed operations. This high priority results in the model allocating water to the IFR before other demands are met. In the case of 50% UF at Freeport and Knights Landing, SacWAM supplies water equally from the lowest priority sources, which are Shasta, Folsom, and Oroville Reservoirs, in months when non-regulated flows are insufficient to meet the flow requirement. The 50% UF requirement at Freeport and Knights Landing are not assumed to be part of the COA and therefore additional water required above what is being supplied by upstream tributary 50% UF requirements is split among all Project reservoirs (or only Shasta for the case of Knights Landing).

2.4.2 Implementation of Delta Outflow Requirement

The new Delta outflow requirement described above was applied downstream of the Sacramento-San Joaquin confluence as a time series with priority value of 8. The outflow requirement was explicitly included in the COA in the same fashion as X2 and other Delta outflow requirements. Adding the new Delta outflow requirement to the COA ensures the correct accounting of SWP and CVP water and the sharing of storage withdrawals to meet in-basin use in the ratio 75% for the CVP and 25% for the SWP.

2.4.3 Demand Reduction

Model demands and allocations were reduced for two reasons: first, to maintain similar levels of groundwater pumping as the base studies; and second, to reduce demand on reservoir storage to be able to consistently meet new 50% UF requirements. Agricultural demand reduction is achieved by reducing crop acreages and increasing fallow acreages. Urban demands were not reduced as part of this study. “Crop Area Reduction” in the Key Assumptions within SacWAM is used as a multiplicative factor to reduce the irrigated crop acreage by region. More detail on how crop area reduction is implemented in SacWAM can be found in the SacWAM Documentation (SEI 2016). All agricultural crop areas in the SacWAM domain were reduced by 20% in dry and critical years, 10% in below normal years and were not reduced in above normal or wet years.

2.4.4 Allocation Reduction

The “Allocation Reduction” reduces diversions to SWP and CVP contractors beyond reductions that the model makes based on available water supply and demand. Allocation Reduction in the Key Assumptions within SacWAM is used as a multiplicative factor to reduce the allocation by contract type. Table 3 shows allocation reduction by year type and contract type applied to SacWAM for the 50% UF scenario.

Table 3. SacWAM Allocation Reduction Factors by Contract Type and Water Year Type

Contract Type	Critical	Dry	Below Normal	Above Normal	Wet
CVP Settlement	65%	70%	75%	100%	100%
CVP Ag NOD	100%	100%	100%	100%	100%
CVP M&I NOD	100%	100%	100%	100%	100%
CVP Refuge NOD	100%	100%	100%	100%	100%
CVP Exchange	100%	100%	100%	100%	100%
CVP Ag SOD	100%	100%	100%	100%	100%
CVP M&I SOD	100%	100%	100%	100%	100%
CVP Refuge SOD	100%	100%	100%	100%	100%
SWP Settlement	65%	70%	75%	100%	100%
SWP SOD	100%	100%	100%	100%	100%

CVP = Central Valley Project
Ag = agricultural
NOD = North of Delta
M&I = municipal and industrial
SOD = South of Delta
SWP = State Water Project

The final allocation factor is taken as the product of all of the reduction factors. For example, during a Shasta critical year when the inflow to Shasta is below 3.2 million acre-feet (MAF), under base simulation, CVP Settlement contract allocations are reduced to 75%, and the allocation reductions applied under the 50% UF scenario are reduced further to 48.75% (0.65*0.75). Information on how contract allocations are determined and implemented in SacWAM can be found in the SacWAM Documentation (SEI 2016). Demand reductions in SWP and CVP Settlement Contractor service areas act in concert with allocation reductions explained below resulting in large reductions in diversions in critically dry years. The contract allocation reduction assumptions made in this study were for modeling convenience to illustrate how SacWAM and CalSim II would respond to new IFRs. These assumptions do not represent terms in current settlement contracts or define how the State Water Board would implement new flow requirements.

2.4.5 Oroville Minimum Storage

SacWAM base case minimum storage, "deadpool" or "top of inactive" storage level for Oroville Reservoir was assumed to be 29.6 thousand acre-feet (TAF) (SEI 2016), whereas in both CalSim II scenarios it is assumed to be 612 TAF. Oroville minimum storage was increased in the SacWAM alternative operations scenario from the base simulation assumption to match CalSim II. The actual deadpool storage of Oroville is 29.6 TAF, but below an elevation of 640 feet, the river valve outlet system is the only means to release the remaining 850 TAF, which has not occurred in recent times. Following an accident in 2009, the river valve outlet system was not operational, but was fixed in 2015. During 2014, no water from Lake Oroville was released for SWP water supply; all deliveries were made using water from San Luis Reservoir or other SWP reservoirs.

2.4.6 Water Supply Index – Delivery Index Curves

Water Supply Index-Delivery Index (WSI-DI) curves parameterize the relationship between water supply index and delivery index in both SacWAM and CalSim II. By adjusting the curves, the model will deliver more or less water based on the water available and other hydrologic factors. Figure 3 shows the SWP and CVP WSI-DI curves for base and for 50% UF scenarios. The SacWAM curves have been adjusted to match CalSim II curves, which were updated for the 50% UF scenario, to deliver slightly more water in drier years and slightly less water in normal and above normal years (Figure 3). The adjusted curves also deliver slightly more water in very wet years to CVP contractors.

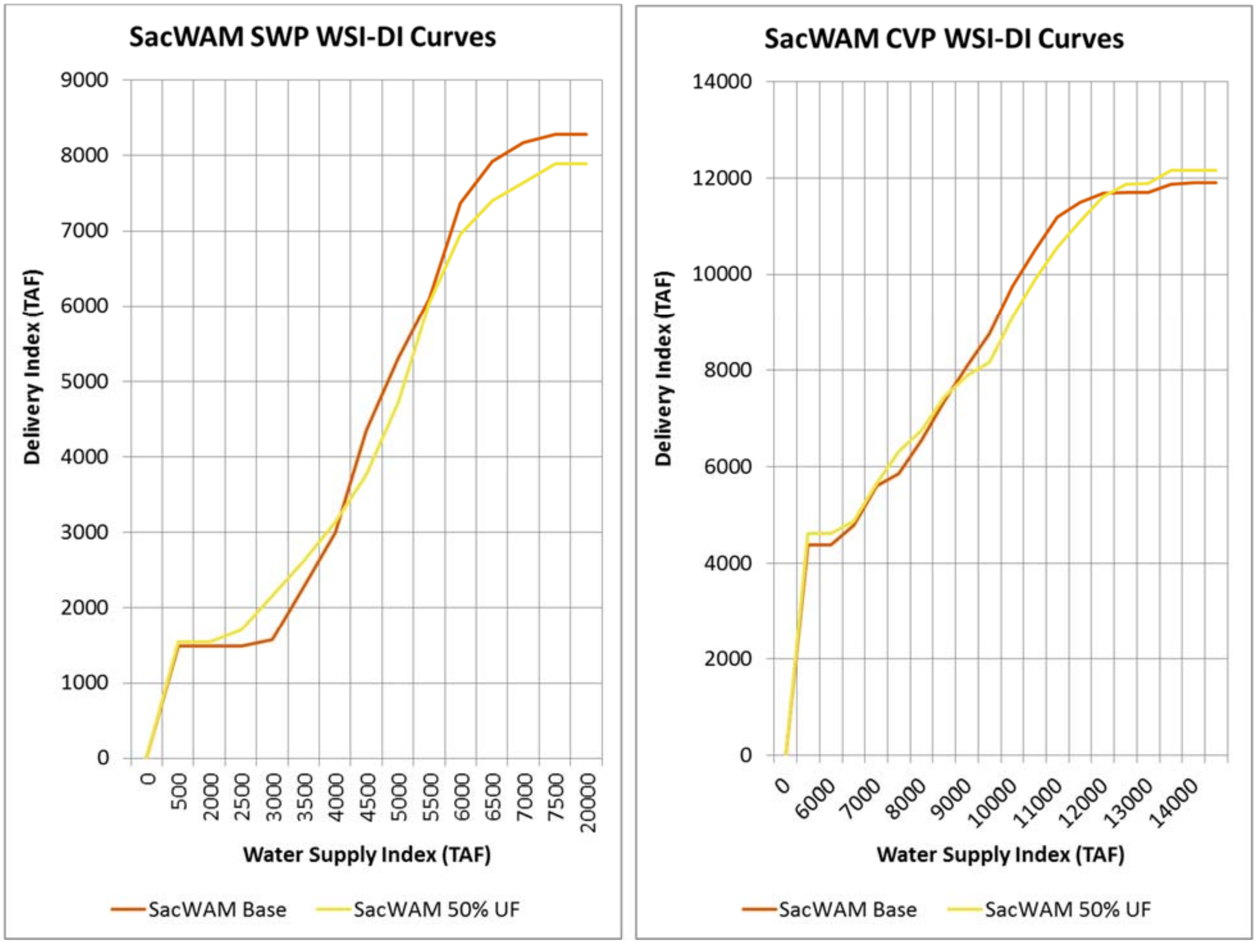

Figure 3. SacWAM WSI-DI Curves

Chapter 3
Results and Discussion

This chapter describes how CalSim II and SacWAM respond to the alternative scenario studies described in Chapter 2 that include new 50% UF requirements and new Delta outflow requirements, assuming current system demand, infrastructure, regulatory environment and historical runoff. In this comparison, a CalSim II flow alternative study is compared with a CalSim II base study, and similarly a SacWAM flow alternative study is compared with a SacWAM base study. First non-Project tributaries are compared, followed by SWP and CVP tributaries and Delta operations. The CalSim II and SacWAM base simulations used in this comparison are described and compared in the SacWAM Documentation (SEI 2016).

3.1 Frequency of Unmet Flow Requirements

Both models are unable to meet all of the new 50% UF requirements in every month of the simulation. Throughout most of the simulation period, the demand and allocation reductions are sufficient to maintain reservoir storage to be able to meet the remaining demand and the new IFRs, however both models are unable to meet 50% UF requirements in a few instances on the American River above the Sacramento River, Feather River below Oroville, and the Yuba River above the Feather River (Table 4) during times of extreme drought. SacWAM does not meet the IFR on Clear Creek in 20 months because of constrained operations of Whiskeytown Reservoir. Additionally, SacWAM has a relatively high number of months with unmet 50% UF IFRs on Cache Creek (69) and 8 months of unmet 50% UF on Putah Creek, while CalSim II does not simulate these creeks. Additional demand reductions or allocation reduction logic would be required in SacWAM to meet these 50% UF in all months.

CalSim II fails to meet the 50% UF on the Calaveras River in 9 months, Feather River above Sacramento in 5 months, and Stony Creek above the Sacramento River in 9 months (Table 4).

Table 4. Frequency of Unmet Instream Flow Requirements (# of months)

Instream Flow Requirement	SacWAM 50% UF Count of Months with unmet IFRs	CalSim II 50% UF Count of Months with unmet IFRs
American River above Sacramento River	3	6
Antelope Creek above Sacramento River	0	0
Battle Creek above Sacramento River	0	0
Bear River above Feather River	0	0
Big Chico above Confluence	0	0
Butte Creek above Butte Slough	0	0
Cache Creek above Yolo Bypass	69	N/A
Calaveras River above Delta	0	9
Clear Creek above Sacramento River	20	0
Cosumnes River above Mokelumne River	0	0
Cottonwood Creek above Sacramento River	0	0
Cow Creek above Sacramento River	0	0
Deer Creek above Sacramento River	0	0
Feather River below Oroville Reservoir	1	2
Feather River above Sacramento River	0	5
Mill Creek above Sacramento River	0	0
Mokelumne River above Cosumnes River	0	0
Putah Creek above Yolo Bypass	6	N/A
Stony Creek above Sacramento River	0	9
Thomes Creek above Sacramento River	0	0
Yuba River above Feather River	1	3
Sacramento River below Keswick	0	0
Sacramento River at Knights Landing	0	0
Sacramento River at Freeport	0	0
Delta Outflow	0	0

SacWAM = Sacramento Water Allocation Model
UF = unimpaired flow
IFR = instream flow requirement
N/A = not applicable

3.2 Groundwater Pumping

Changes to groundwater pumping at local and regional scales are difficult to compare between the two models because the models define groundwater regions or basins differently. In CalSim II, groundwater pumping is aggregated to Depletion Study Areas (DSAs). In SacWAM, groundwater regions are defined based on DWR's Bulletin 118 groundwater basins. In SacWAM, groundwater pumping is calculated for the eastside tributaries to the Delta. CalSim II does not simulate groundwater pumping in the Cosumnes and Mokelumne Watersheds, therefore, the Cosumnes and eastern San Joaquin Basins from SacWAM are not included in the comparison.

The purpose of reducing the demand was to maintain similar groundwater pumping levels as in the base simulation while maintaining sufficient reservoir storage to be able to consistently meet new 50% UF requirements. In both models, when diversions are reduced without reducing demand, the models will increase groundwater pumping to replace the reduced surface supply. Both models show very little change in groundwater pumping from base simulations. SacWAM shows a reduction in annual groundwater pumping (-61 thousand acre-feet per year [TAF/yr], -1.8%), whereas CalSim II shows an increase in annual groundwater pumping (27 TAF/yr, 1.2%) under the 50% UF scenario (Figure 4). The slight differences in groundwater pumping are due to differences in the way the demand reduction was implemented in each model.

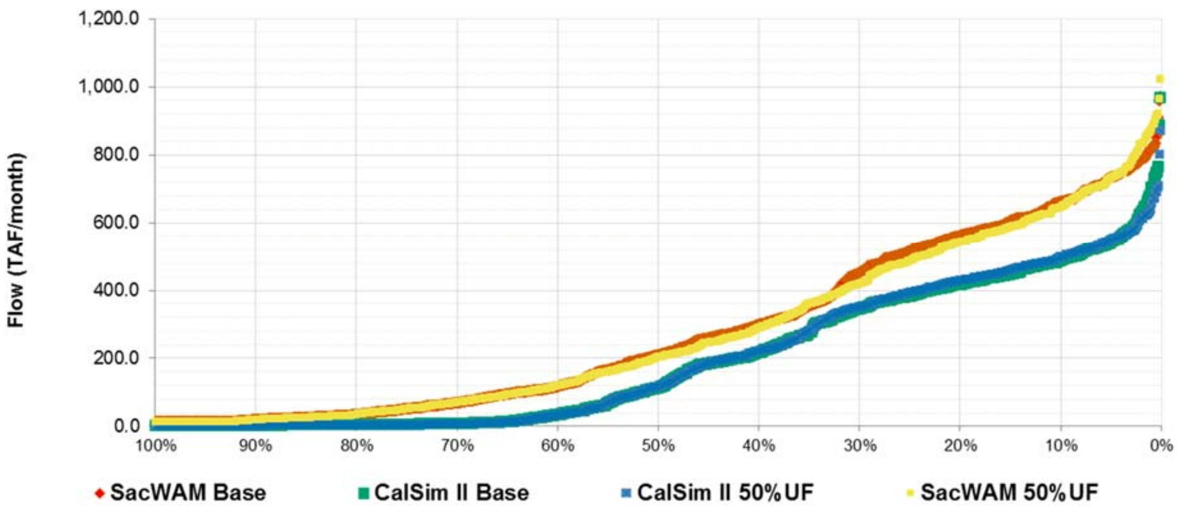

Figure 4. Sacramento Valley Groundwater Pumping Monthly Exceedance Plot

3.3 Non-Project Tributaries

Non-Project tributaries make up over 70% of the tributaries of interest for Phase II of the Bay-Delta Plan and are modeled very differently in CalSim II and SacWAM. In CalSim II, reservoirs on non-Project tributaries are not simulated, flows below the rim dams are preprocessed typically based on historical operations or decades-old simulation models. In SacWAM, all major reservoirs including those on non-Project tributaries are operated including upstream hydropower reservoirs.

The first tributaries compared are non-Project tributaries with no storage regulation (non-regulated) followed by non-Project tributaries with storage regulation (regulated).

3.3.1 Non-Project, Non-Regulated Tributaries

The 50% UF requirements have minimal effect on non-regulated tributaries because the base simulation flows are typically higher than 50% UF. Non-regulated tributaries that may be affected by the Phase II effort include: Battle Creek, Cow Creek, Cottonwood Creek, Thomes Creek, Mill Creek, Deer Creek, Elder Creek, Big Chico Creek, and Cosumnes River[1]. Many of these tributaries have been aggregated in CalSim II and therefore are compared as such below (Table 5, Figure 5).

Table 5. Non-Project, Non-Regulated Tributary Average Annual Flows

	Comparison of CalSim II Base and 50% Scenario				Comparison of SacWAM Base and 50% Scenario			
	Mean Annual Values WY 1922-2003		Mean Annual Difference WY 1922-2003		Mean Annual Values WY 1922-2003		Mean Annual Difference WY 1922-2003	
	CalSim-II Base	CalSim-II 50% UF	Change from Base		SacWAM Base	SacWAM 50% UF	Change from Base	
	TAF	TAF	TAF	Percent	TAF	TAF	TAF	Percent
Non Project - Non Regulated Tributaries								
Cottonwood Creek at Confluence	599	602	3	0%	549	548	0	0%
Thomes and Elder Creeks at Confluence	274	272	2	-1%	325	329	4	1%
Cow Creek at Confluence	453	456	3	1%	411	413	2	0%
Bear Creek at Confluence	-	-	-	-	60	60	0	0%
Battle Creek at Confluence	337	337	0	0%	353	353	0	0%
Paynes Creek at Confluence	46	49	3	8%	53	53	0	0%
Mill, Deer and Antelope Creeks at Confluence	497	519	23	5%	509	520	11	2%
Big Chico Creek at Confluence	97	97	0	0%	102	102	0	0%
Cosumnes River at Confluence	361	362	1	0%	344	344	0	0%
Total Unregulated Tributary Streamflow	**2,663**	**2,695**	**31**	**1%**	**2,815**	**2,830**	**15**	**1%**

[1] Cosumnes River is regulated by Jenkinson Reservoir in the upper watershed, however historical operations of Jenkinson Reservoir have minimal effect on streamflows on the Cosumnes River above the Mokelumne River Confluence.

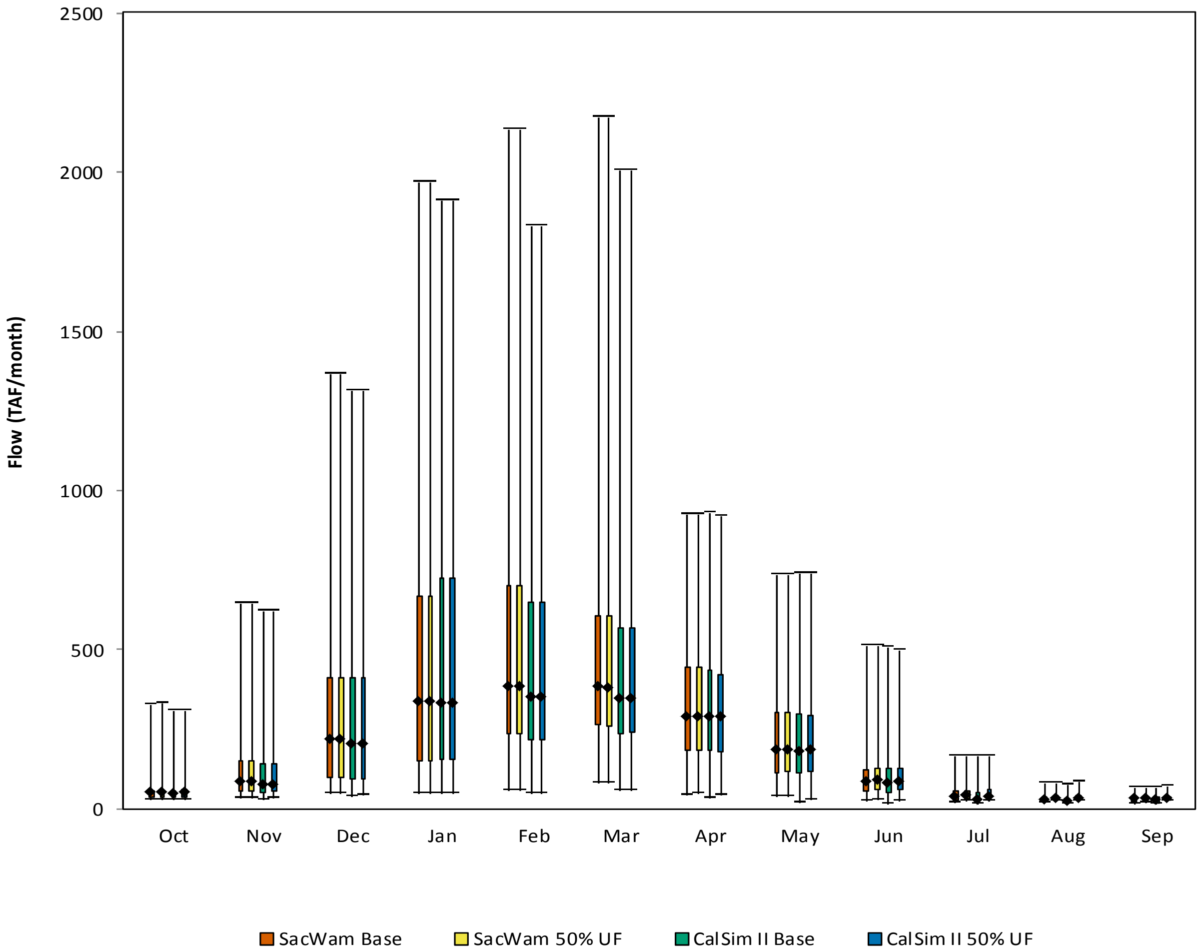

Figure 5. Total Non-Project Non-Regulated Tributary Streamflow Monthly Box Plot

Regulated tributaries are tributaries that have large regulatory reservoirs or other operations (e.g., imports and exports) that affect the flow regime that are not part of the SWP and CVP. These tributaries include Stony Creek, Butte Creek, Bear River, Yuba River, Cache Creek, Putah Creek, Mokelumne River and Calaveras River. Except for Stony Creek and Calaveras River, these tributaries and reservoirs are not explicitly modeled in CalSim II. To account for the new 50% UF in CalSim II, base study preprocessed monthly time series were increased to meet the requirement (see Appendix B for more details). Other months or other locations were not decreased correspondingly. This approach results in an increase in average annual flows (Table 6). Increased annual flows on regulated non-Project tributaries affect not only flows on these tributaries but also affect Delta operations and Project storage as well.

Table 6. Non-Project, Regulated Tributary Average Annual Flows

	Comparison of CalSim II Base and 50% Scenario				Comparison of SacWAM Base and 50% Scenario			
	Mean Annual Values WY 1922-2003		Mean Annual Difference WY 1922-2003		Mean Annual Values WY 1922-2003		Mean Annual Difference WY 1922-2003	
	CalSim-II Base	CalSim-II 50% UF	Change from Base		SacWAM Base	SacWAM 50% UF	Change from Base	
	TAF	TAF	TAF	Percent	TAF	TAF	TAF	Percent
Non Project - Regulated Tributaries								
Stony Creek at confluence	237	266	29	12%	264	275	11	4%
Butte Creek above Butte Slough	207	216	9	4%	725	673	-52	-7%
Bear River at Confluence	268	325	58	21%	218	214	-5	-2%
Yuba River at Confluence	1,453	1,624	171	12%	1,506	1,568	62	4%
Cache Creek above Yolo Bypass	-	-	-	-	325	371	46	14%
Putah Creek above Yolo Bypass	-	-	-	-	78	178	100	128%
Mokelumne River above Cosumnes River	304	467	164	35%	421	518	97	23%
Calaveras River at Confluence	104	111	7	7%	52	72	20	38%
Total Non-Project Regulated Inflow to Sacramento River/Delta	**2,572**	**3,009**	**437**	**17%**	**3,589**	**3,867**	**278**	**8%**

3.3.2 Stony Creek

Stony Creek is unique in CalSim II because it is primarily a non-Project tributary that includes reservoir operations, whereas all other reservoirs in the CalSim II within the Sacramento Watershed are operated solely as part of the SWP and CVP. CalSim II assumes that releases from Black Butte Reservoir are diverted in to the Tehama-Colusa Canal through the Constant Head Orifice to supplement water supplies because biological opinions affected Red Bluff Diversion Dam (RBDD) operations and associated diversions into the head of the canal. Since the decommissioning of the RBDD and completion of the new pumping plant at the head of the Tehama-Colusa Canal in 2013, Black Butte Reservoir has not been operated to meet CVP demands. CalSim II still operates Black Butte to meet CVP demands whereas under base and 50% UF scenarios, SacWAM has this logic turned off. Both models deliver agricultural water as part of the Reclamation Orland Project.

Both models respond to the demand reduction and 50% UF scenario similarly with an increase in instream flow of 29 TAF/yr (CalSim II) and 11 TAF/yr (SacWAM) (Figure 6), a reduction in carryover storage of 40–60 TAF (Figure 7), and a reduction in diversions of 16 TAF/yr (CalSim II) and 10 TAF/yr (SacWAM) to Orland Project users.

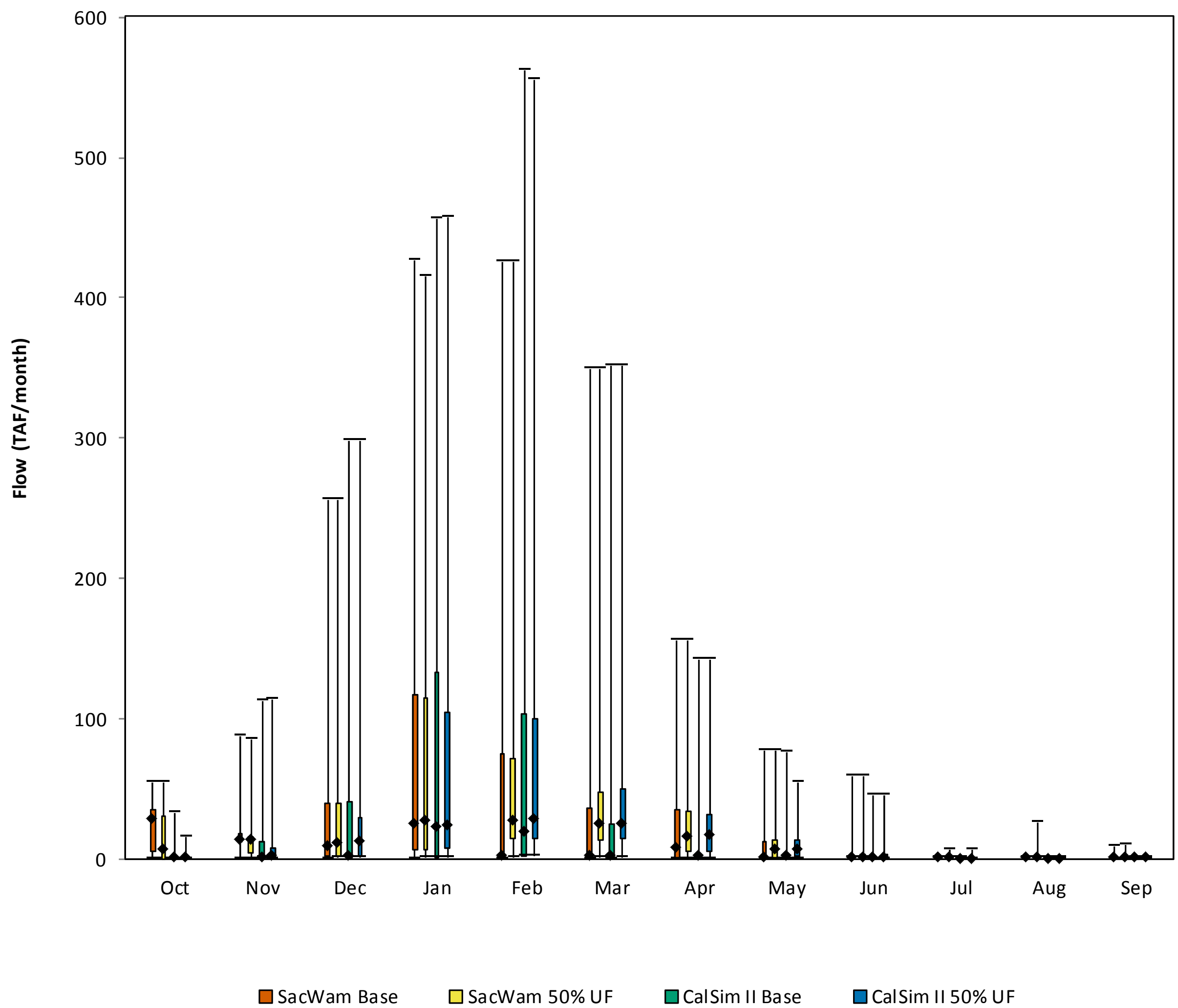

Figure 6. Stony Creek above Confluence with Sacramento River Monthly Box Plot

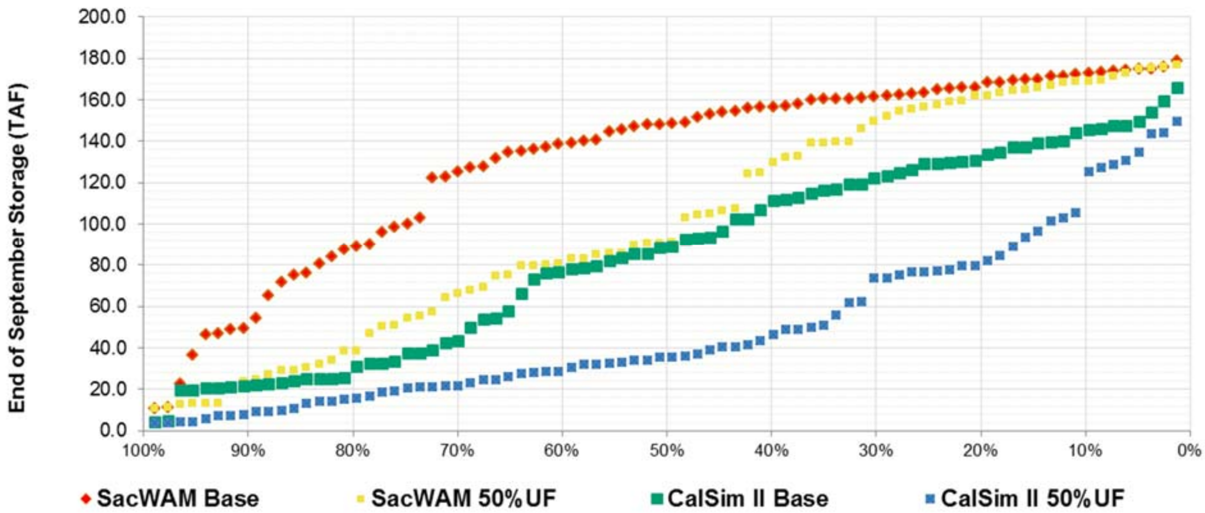

Figure 7. Total Reservoir Storage on Stony Creek including East Park, Stony Gorge and Black Butte Reservoirs Annual Carryover Storage Exceedance Plot

3.3.3 Butte Creek

Butte Creek is modeled very differently in CalSim II and SacWAM which affects not only flows on Butte Creek but also affects flows on the Feather River. In CalSim II, return flows from irrigated lands on the right bank of the Feather River are routed back to the Feather River (except for return flows from refuges and managed wetlands that are routed to the Sutter Bypass). SacWAM has a more detailed and realistic representation of this region in which return flows from rice fields in the Feather River Service Area (FRSA) are routed to Butte Creek or the Sutter Bypass. Butte Creek flows are much higher in SacWAM than in CalSim II under base and 50% UF scenarios because of these return flows (Figure 8). In CalSim II 50% UF scenario the flows are higher in Butte Creek than in the base scenario to account for the new IFR. In SacWAM, the base simulation flows are much higher than the new flow requirement and decrease under the 50% UF scenario because diversions to rice fields in the FRSA have been reduced therefore return flows are reduced. The inaccurate representation of the hydrology in this region in CalSim II is further discussed below under the Feather River.

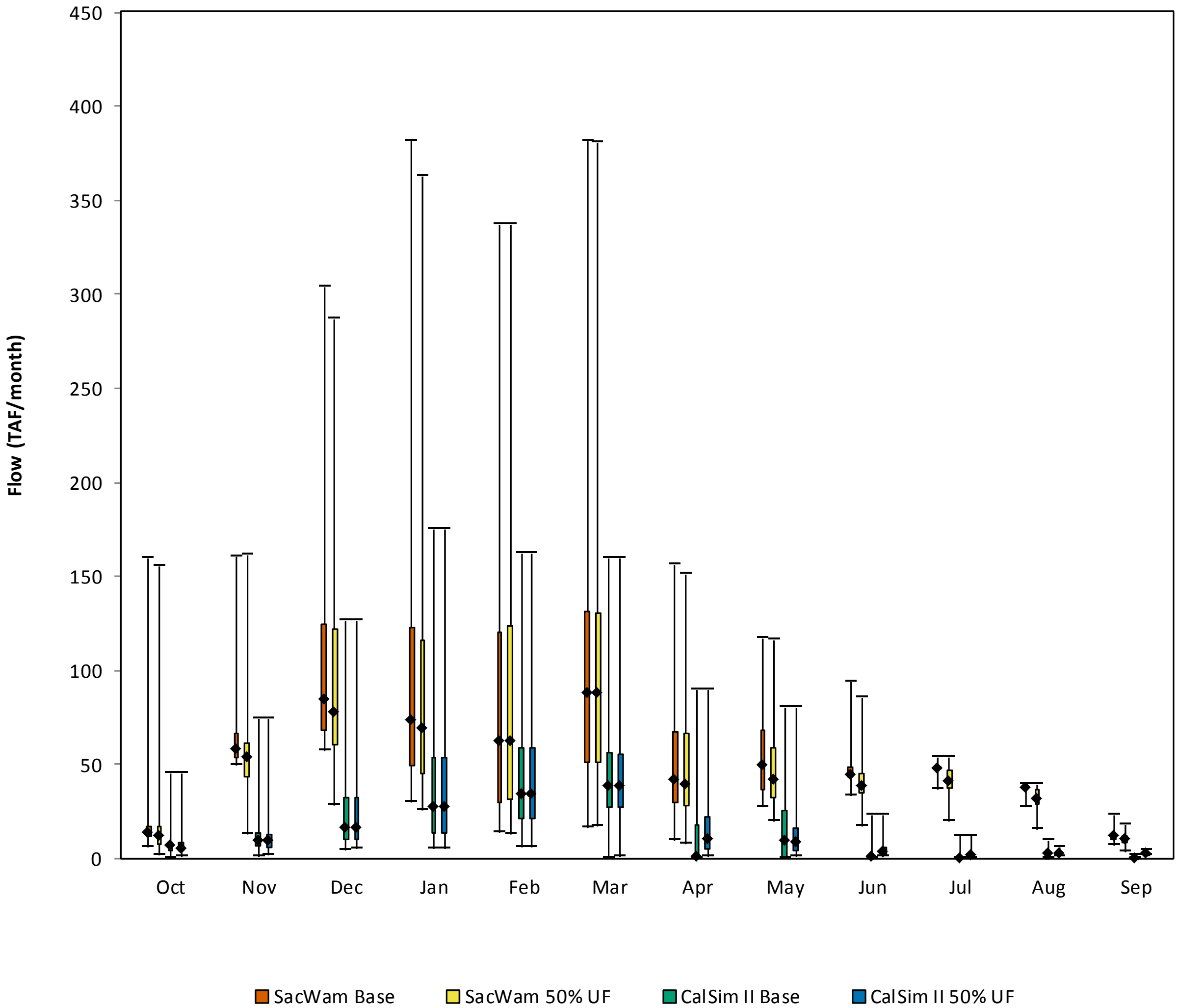

Figure 8. Butte Creek above Butte Slough Monthly Box Plot

3.3.4 Bear River

The Bear River is a regulated non-Project tributary that is minimally represented in CalSim II but is fully represented in SacWAM. The method used in CalSim II to provide flows into the model for the new 50% UF requirement without re-operating upstream reservoirs and hydropower operations results in erroneously adding water into the system on an annual scale. In CalSim II, the Bear River at the confluence with the Feather increases from 268 TAF/yr to 325 TAF/yr under the 50% UF scenario where as SacWAM shows a decrease from 218 TAF/yr to 213 TAF/yr, because slightly less water is transferred from the Yuba River (Table 6). By operating the upstream reservoirs, SacWAM shifts flows from the summer months to the spring, where in CalSim II the spring months are simply increased without decreasing the flow in other months (or other locations like the Yuba River because Yuba water is transferred to the Bear upstream) (Figure 9). In CalSim II during months where reducing diversions does not provide enough water to meet the 50% UF requirement, additional inflow is added without reducing inflow in other months which increases the total water in the system (Figure 10).

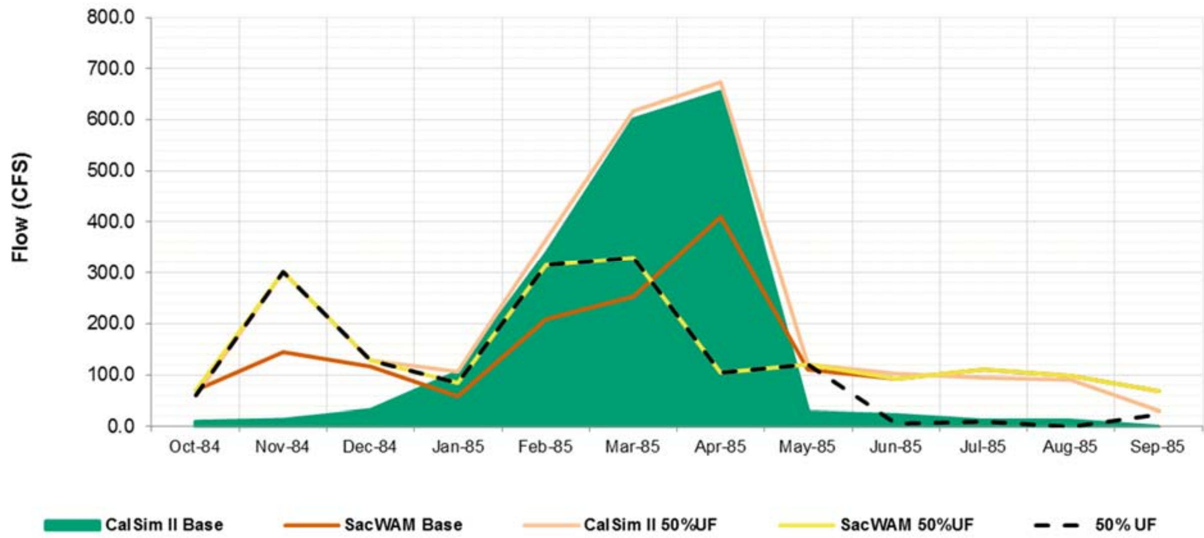

Figure 9. Bear River above Feather River Monthly Time Series of Flows for Water Year 1985

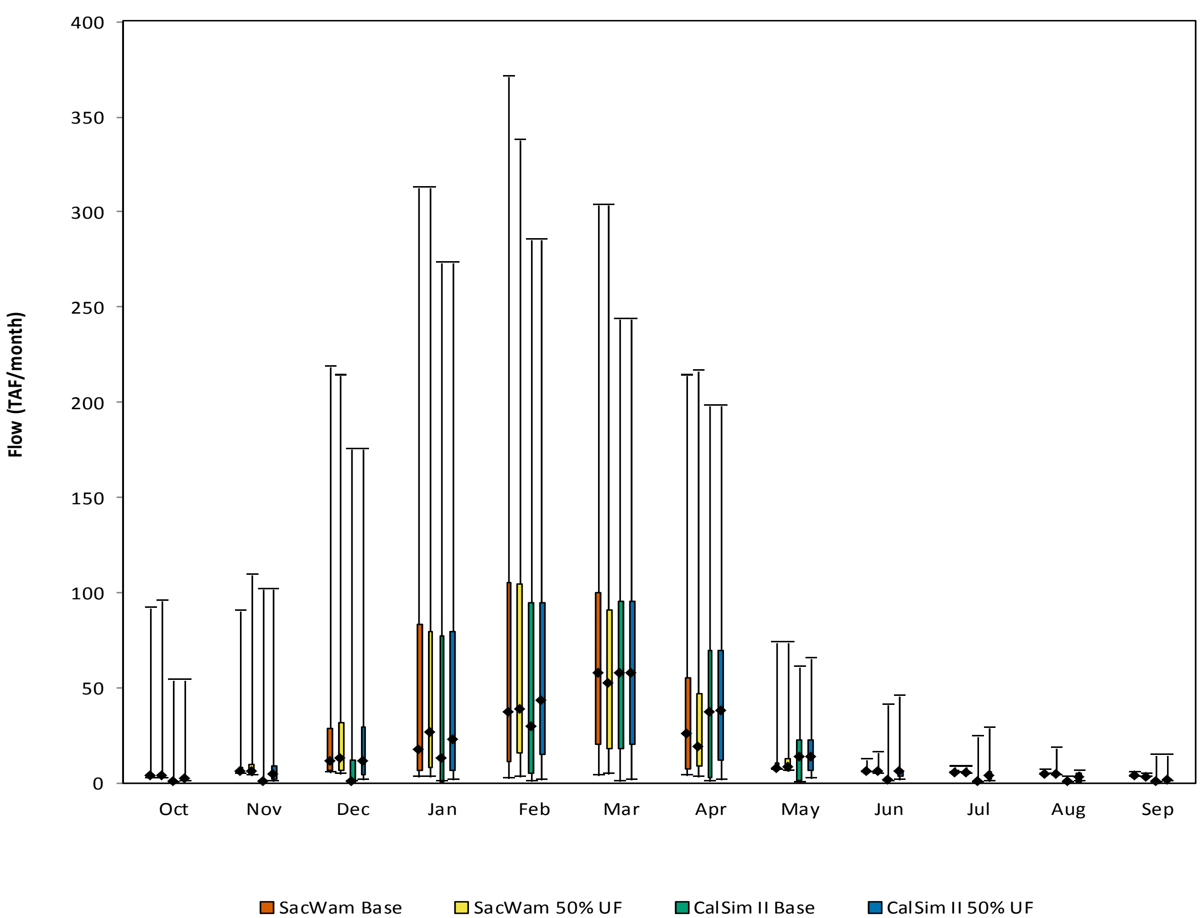

Figure 10. Bear River above Feather River Monthly Box Plot

3.3.5 Yuba River

The Yuba River Watershed has been developed for both hydropower generation and for water supply. This large regulated non-Project tributary has a simplified representation in CalSim II but is further developed in SacWAM. Like in the Bear River, the method used in CalSim II to provide flows into the model for the new 50% UF requirement without re-operating upstream reservoirs and hydropower operations results in erroneously adding water into the system on an annual scale. In CalSim II the Yuba River at the Confluence with the Feather increases from 1,453 TAF/yr to 1,624 TAF/yr under the 50% UF scenario where as SacWAM shows a much smaller increase from 1,506 TAF/yr to 1,568 TAF/yr (Table 6, Figure 11). By operating New Bullards Bar Reservoir, SacWAM shifts flows from the summer months to the spring where in CalSim II the spring months are simply increased without decreasing the flow in other months (or other locations like the Bear River because Yuba water is transferred to the Bear upstream) (Figure 12). SacWAM more realistically reduces diversions throughout the irrigation season to meet the new IFR rather than in CalSim II where diversions are only reduced in the months to meet the new requirements (Figure 13). In CalSim II during months where reducing diversions do not provide enough water to meet the 50% UF requirement, additional inflow is added without reducing inflow in other months which increases the total water in the system.

The additional water added to the Feather River from the Yuba in CalSim II not only misrepresents the impacts of the new flow requirement on the Yuba River, but also incorrectly reduces the amount of water required from Oroville to meet IFRs on the Feather. This results in additional inflow to the Delta, which can affect exports and cause problems throughout the system.

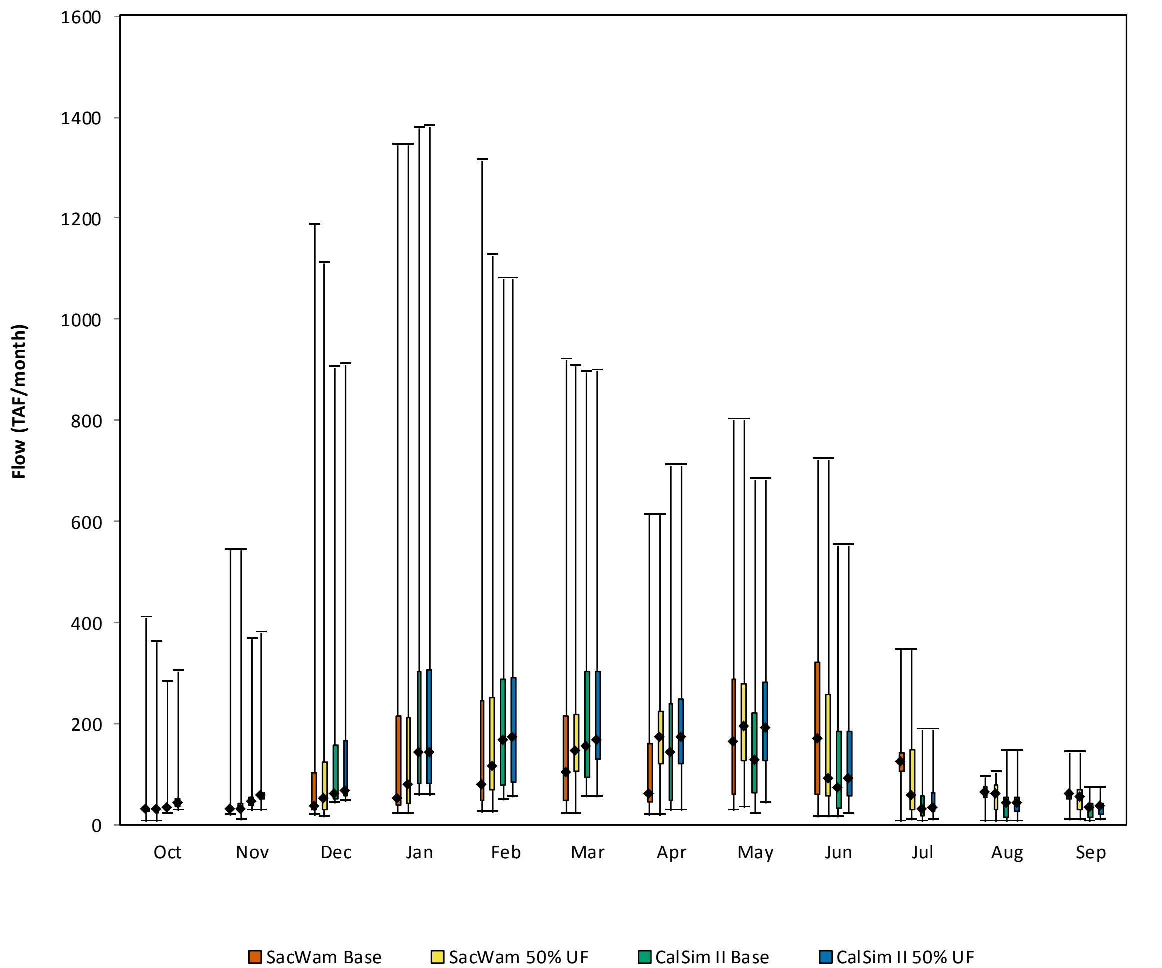

Figure 11. Yuba River above Feather River Monthly Box Plot

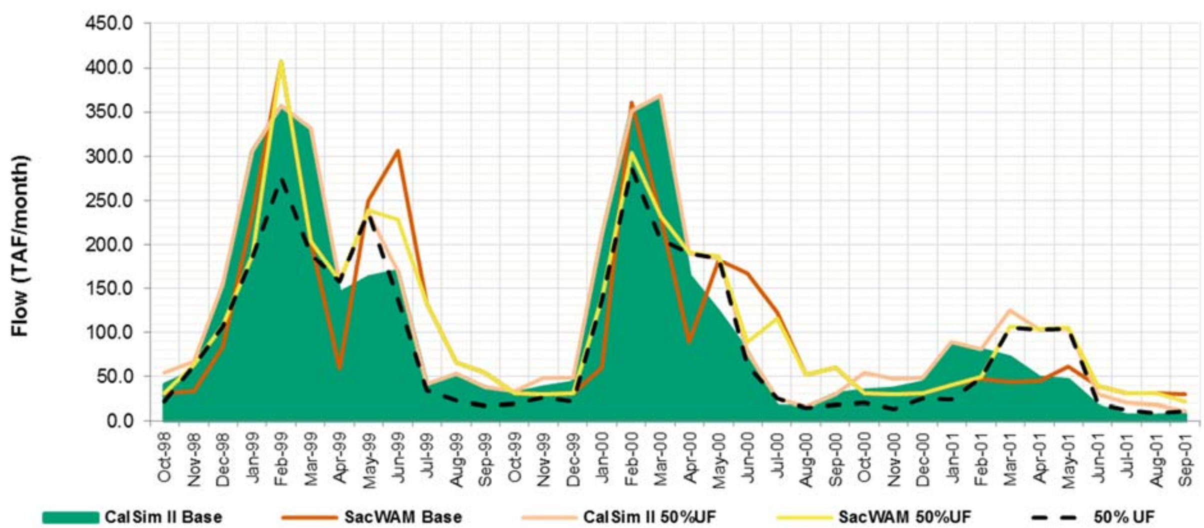

Figure 12. Yuba River above Feather River Time Series of Monthly Flows for the for Water Years 1999–2001

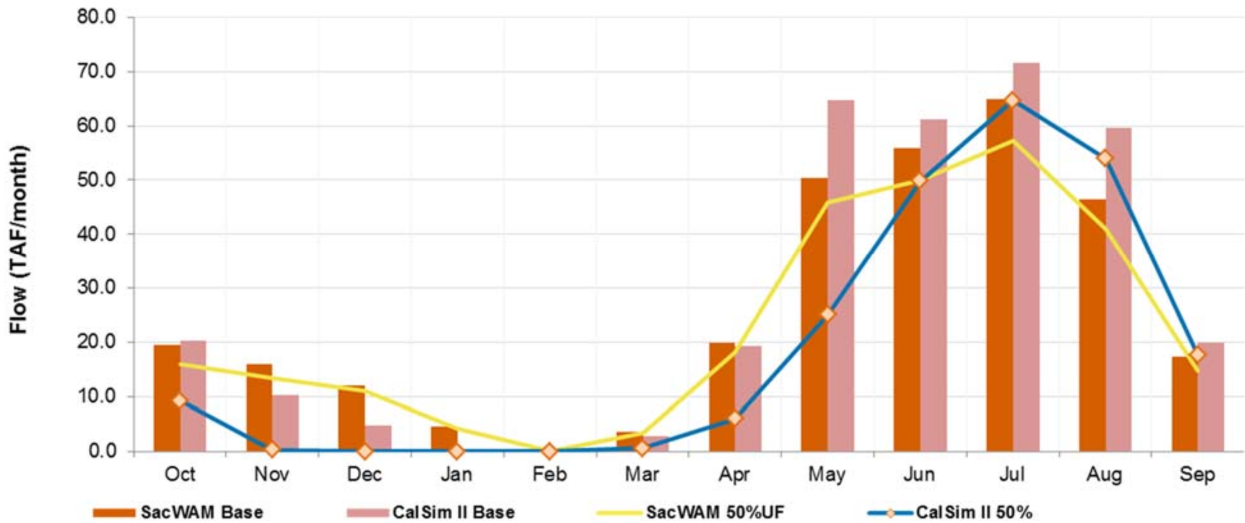

Figure 13. Lower Yuba River Monthly Average Diversions

3.3.6 Cache and Putah Creeks

Cache Creek and Putah Creek are not directly represented in CalSim II. The model represents all water supplies generated by these watersheds as a single inflow arc. This makes model comparison very difficult. Cache and Putah Creeks provide very little water to the Delta except during flood events; however in SacWAM under 50% UF scenario, these tributaries provide an additional 146 TAF/yr of water to the Delta which helps meet Delta requirements (Table 5). In CalSim II, by not accounting for this additional water under the 50% UF scenario, more water is required from Project reservoirs to meet the new Delta outflow requirement. Additionally, in CalSim II it is not possible to estimate the impacts of additional flow requirements on Cache Creek and Putah Creek.

3.3.7 Mokelumne River

The Mokelumne River is represented in CalSim II by a preprocessed inflow time series which hinders the assessment of any impact of changed IFRs on reservoir storage or diversions to East Bay Municipal Utility District (EBMUD). As discussed in the methods section (Chapter 2), to accommodate a 50% UF scenario in CalSim II, the monthly time series was increased any month that the base simulation flow was lower than the 50% UF requirement. SacWAM shifts reservoir releases from the summer-fall months to the winter-spring months to meet the new flow requirement resulting in an average annual increase in flow of 97 TAF/yr where in CalSim II spring flows are simply increased resulting in an increase of flow in the Mokelumne River of 164 TAF/yr (Table 6, Figure 14). Both models show a large increase in streamflows from the base studies in the March–June months (Figure 15).

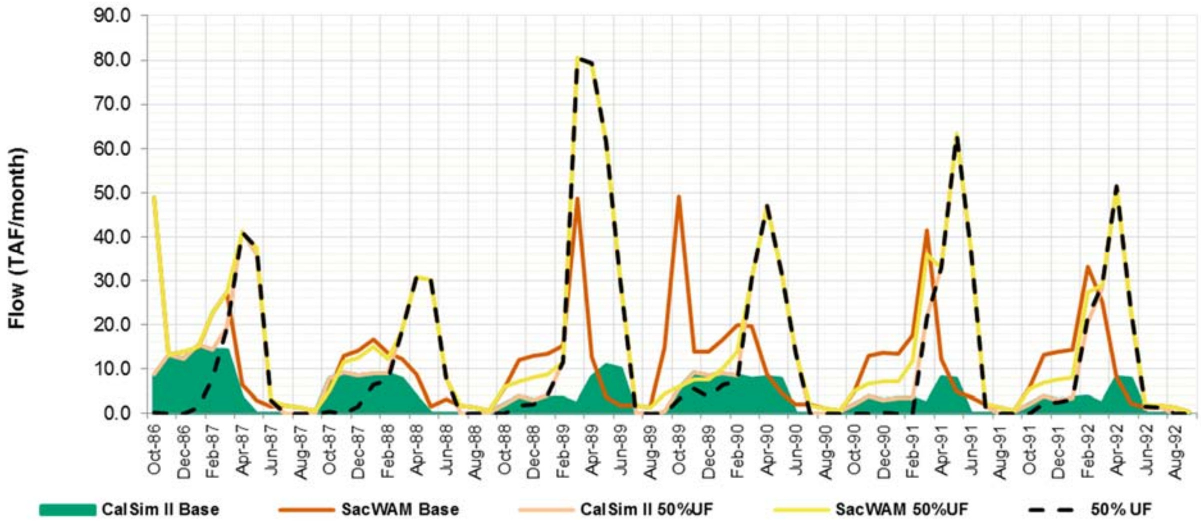

Figure 14. Mokelumne River above Cosumnes River Monthly Time Series of Water Years 1987–1992

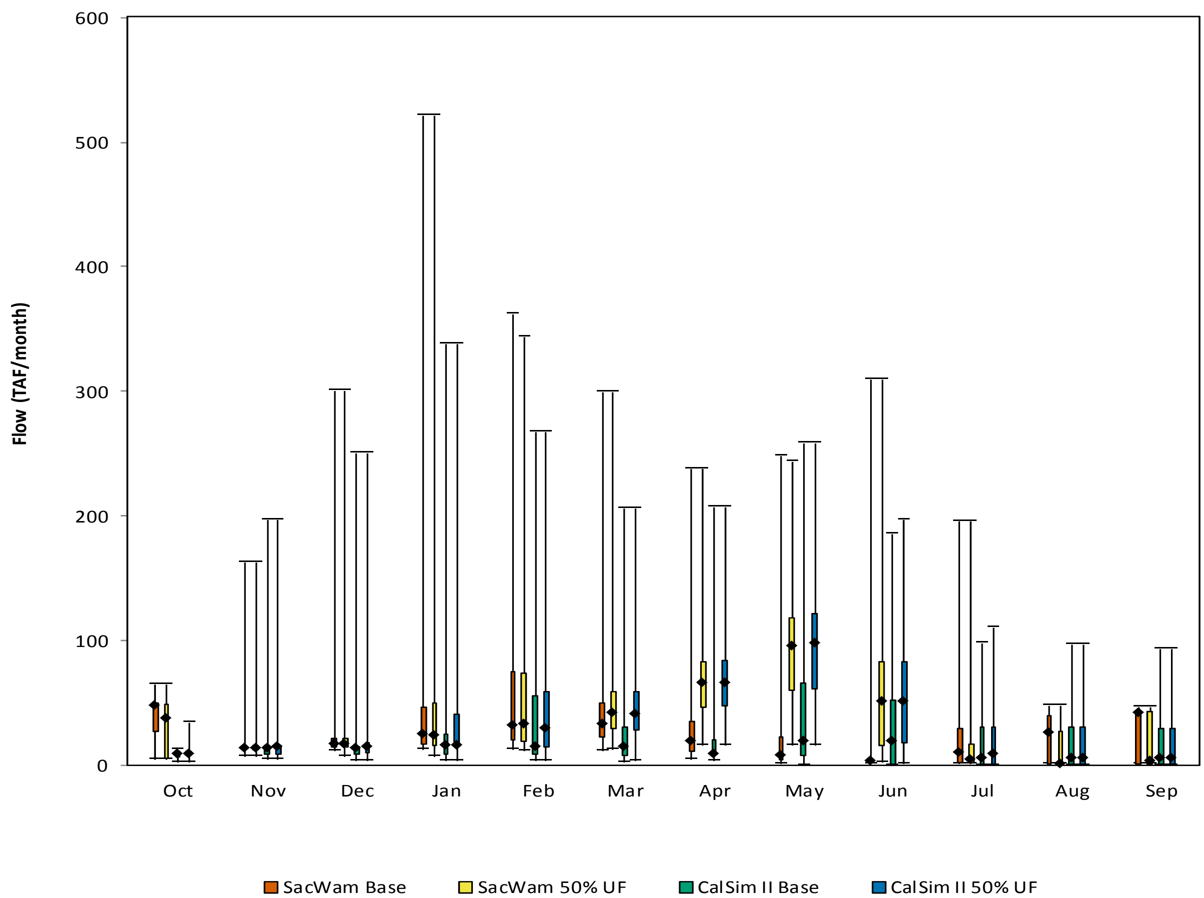

Figure 15. Mokelumne River above Cosumnes River Monthly Box Plot

3.3.8 Calaveras River

The Calaveras River is a relatively small regulated non-Project tributary that is more simply represented in CalSim II than in SacWAM. Both models include operations of New Hogan Reservoir; however, CalSim II does not account for stream losses on the lower river (which are about 30 TAF/yr in SacWAM) and SacWAM assumes higher M&I demand from the lower Calaveras than CalSim II. This results in higher base simulation flows at the mouth of the Calaveras in CalSim II than SacWAM (Figure 16). Under the 50% UF scenarios, a larger change from the base simulation is required in SacWAM therefore SacWAM shows lower storage in New Hogan and greater reductions in diversions to meet the new requirement (Figure 17).

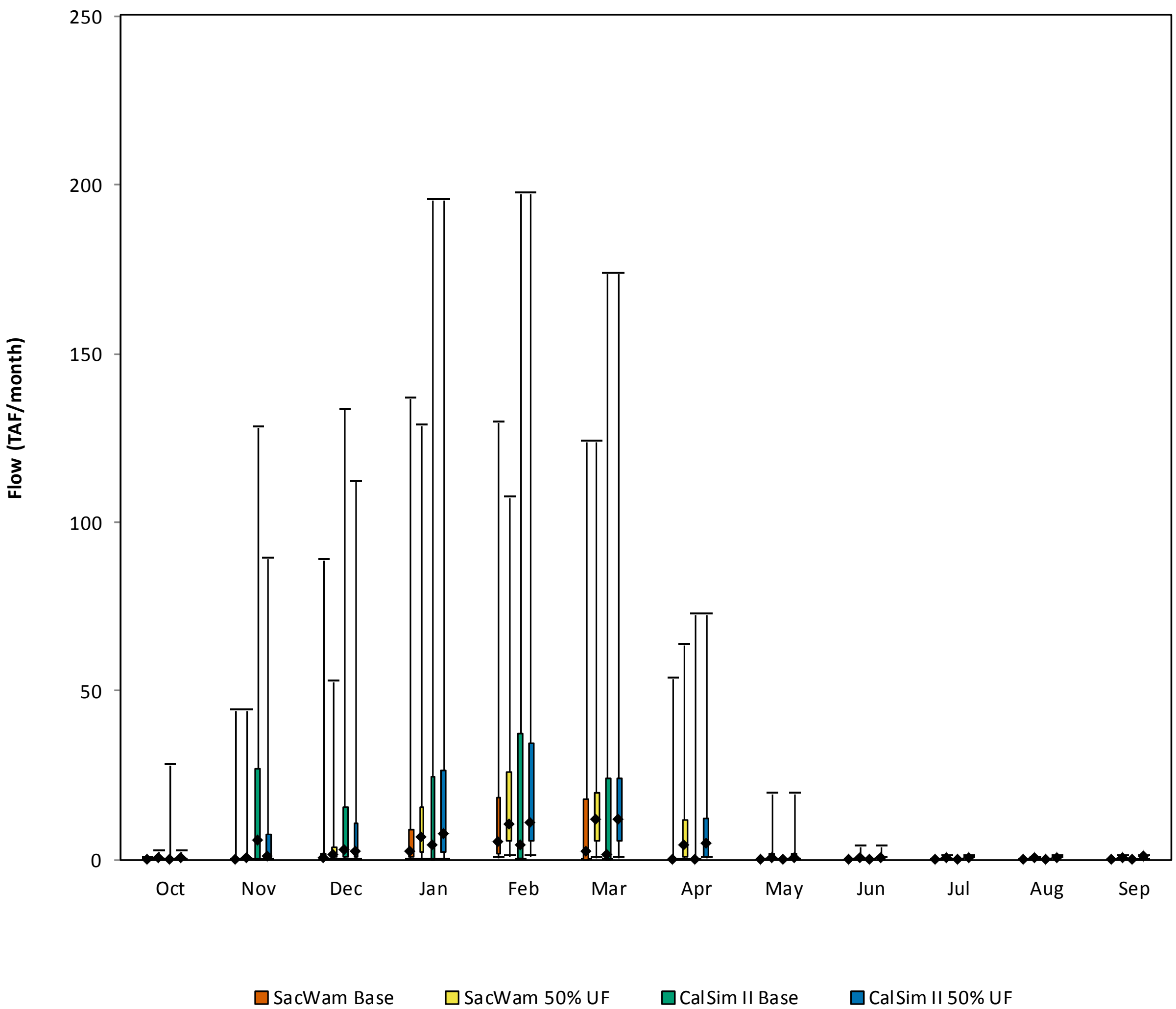

Figure 16. Calaveras River above Delta Monthly Box Plot

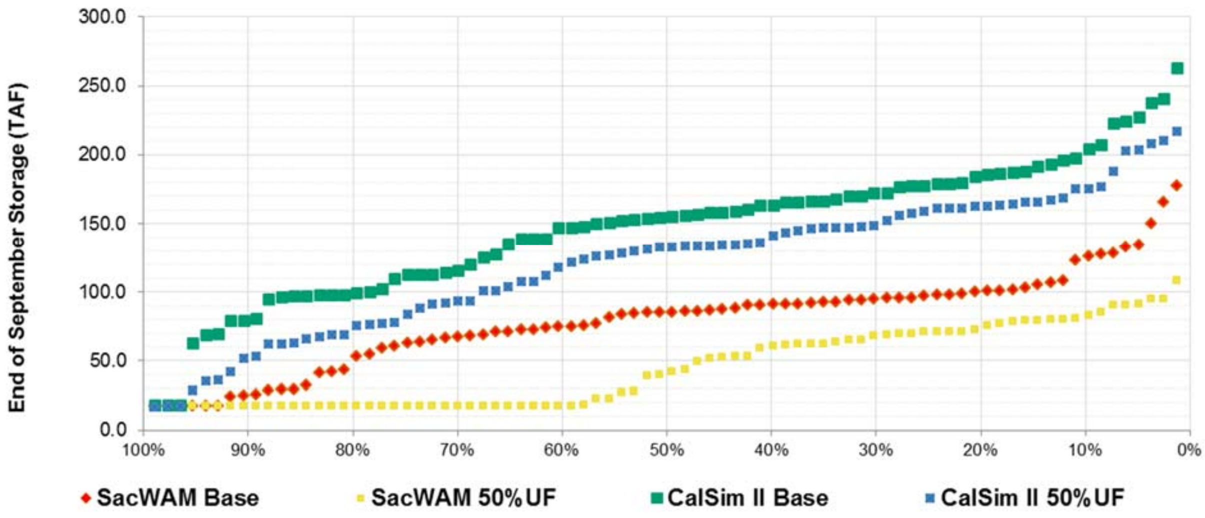

Figure 17. New Hogan Reservoir Annual Carryover Storage Exceedance Plot

3.4 Project Tributaries and Delta Operations

Project rivers and tributaries include the American River, Feather River, Sacramento River, and Clear Creek. Delta operations compared here include Delta inflow, Delta outflow, and Project exports. CalSim II has been developed to model Project tributaries and Delta operations and has been the only available tool for studies involving the SWP and CVP for about two decades. The assumptions described above regarding allocation reduction, demand reduction, alternative Chipps Island requirement and 50% UF requirements on Project tributaries affect flows on these rivers.

Table 7 shows that responses to the new flow requirements are very similar in SacWAM and CalSim II on an annual scale.

Table 7. SWP and CVP Tributary Average Annual Flows and Other Project Operations

	Comparison of CalSim II Base and 50% Scenario				Comparison of SacWAM Base and 50% Scenario			
	Mean Annual Values WY 1922-2003		Mean Annual Values WY 1922-2003		Mean Annual Values WY 1922-2003		Mean Annual Values WY 1922-2003	
	CalSim-II Base	CalSim-II 50% UF	Change from Base		SacWAM Base	SacWAM 50% UF	Change from Base	
	TAF	TAF	TAF	Percent	TAF	TAF	TAF	Percent
Project Operations and Flows								
Trinity River Import	542	544	2	0%	613	613	0	0%
Shasta Reservoir Release	5,556	5,567	11	0%	5,556	5,559	3	0%
Sacramento River below Keswick Dam	6,262	6,187	-75	-1%	6,333	6,270	-63	-1%
Clear Creek at Confluence	127	215	88	69%	148	215	67	46%
Sacramento River at Knights Landing (below Colusa Basin Drain)	7,095	7,411	316	4%	6,926	7,197	271	4%
Sacramento River Settlement Contractor Diversions	1,862	1,535	-327	-18%	1,989	1,744	-245	-12%
Feather River below Oroville Dam	3,931	3,948	18	0%	4,161	4,185	25	1%
Feather River Diversions Oroville to	1,343	1,141	-202	-15%	1,147	980	-167	-15%
Feather River at Confluence with Sacramento River	5,357	5,728	371	7%	5,183	5,407	224	4%
Folsom Reservoir Release	2,412	2,447	35	1%	2,579	2,602	23	1%
American River at Confluence	2,168	2,211	43	2%	2,413	2,428	14	1%
Lower American River Diversions	491	455	-37	-7%	290	292	2	1%
Sacramento River below Freeport	15,709	16,405	696	4%	15,470	16,017	546	4%
Total Delta Inflow	21,836	22,721	886	4%	22,092	22,792	700	3%
Delta Inflow less Project Storage Release	21,307	22,175	867	4%	21,364	22,032	668	3%
Total Delta Outflow	15,700	17,078	1,378	9%	15,870	16,982	1,112	7%
Delta SOD Exports	4,940	4,484	-456	-9%	4,897	4,510	-387	-8%
North Bay Aqueduct	101	97	-4	-4%	85	82	-3	-3%
Jones Pumping Plant	2,233	2,240	7	0%	2,171	2,140	-31	-1%
Banks Pumping Plat	2,708	2,244	-463	-17%	2,726	2,370	-356	-13%
San Luis Reservoir Storage	945	908	-37	-4%	858	795	-63	-7%
Total SWP SOD Table A Deliveries	2,410	1,950	-461	-19%	2,573	2,191	-382	-15%
CVP Exchange Contractor Deliveries	853	853	0	0%	819	816	-3	0%
CVP SOD Deliveries Including Losses	2,328	2,349	21	1%	2,430	2,397	-33	-1%

3.4.1 American River

The American River is a medium to large tributary represented in CalSim II. CalSim II inflows to Folsom Lake are preprocessed (including inflow from Pacific Gas and Electric Company's [PG&E's] South Canal). However, operations of Folsom Lake and Lake Natoma, diversions to the Folsom South Canal, and diversions from the lower American River by Carmichael Water District and the City of Sacramento are dynamically simulated in the model. In SacWAM, upstream hydropower operations and inter-basin transfers are modeled but are not modified in this study. Additionally, SacWAM diversions from Folsom Lake and the lower American River are driven by municipal water demands, whereas CalSim II uses water rights and contract agreements as surrogates for water demands. In the 50% UF scenario, CalSim II shows a reduction in diversions from the lower American River because diversions are assumed to be limited by the contract allocations whereas in SacWAM diversions are not reduced because diversions are based on urban demand which have not been limited in this study.

The two models show a similar response to the new IFRs with little change in flows December–March, increase in streamflows in April–June and slightly reduced streamflows July–September

(Figure 18). CalSim II shows an annual average increase in outflow from the American of 43 TAF/yr (2%) and SacWAM shows an increase of 14 TAF/yr (1%) (Table 7).

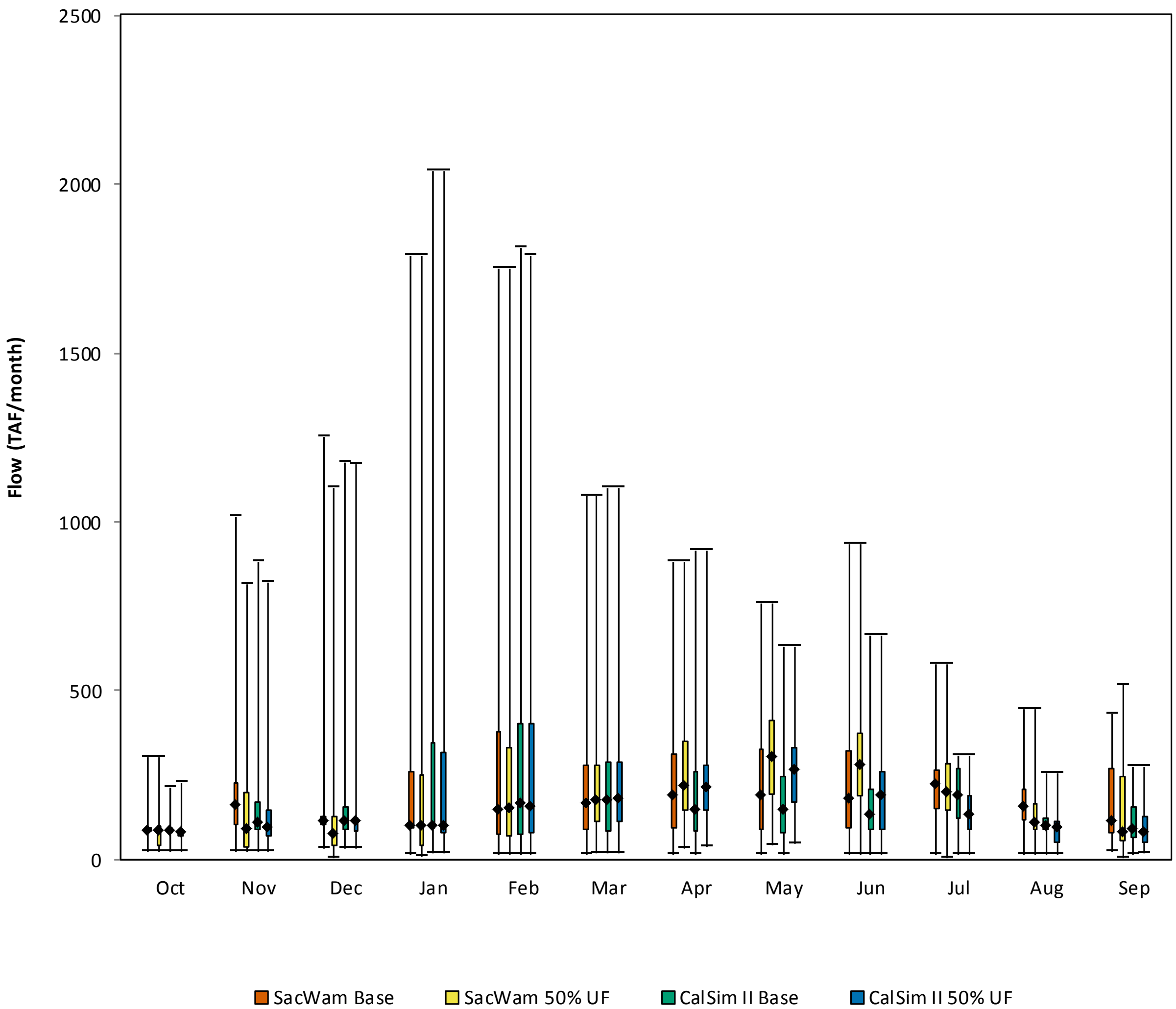

Figure 18. American River above Sacramento River Monthly Box Plot

SacWAM draws Folsom Reservoir down more than CalSim II under the 50% UF scenario (Figure 19). This is because SacWAM will prefer to release water from Folsom Lake than release from Lake Shasta during times of shortage for Delta CVP needs because there is less stream loss to groundwater from Folsom to the Delta than from Shasta to the Delta. This assumption of favoring Folsom over Shasta during times of shortage aligns with actual CVP operations to maintain storage in Shasta to meet Sacramento River temperature requirements below Keswick Reservoir.

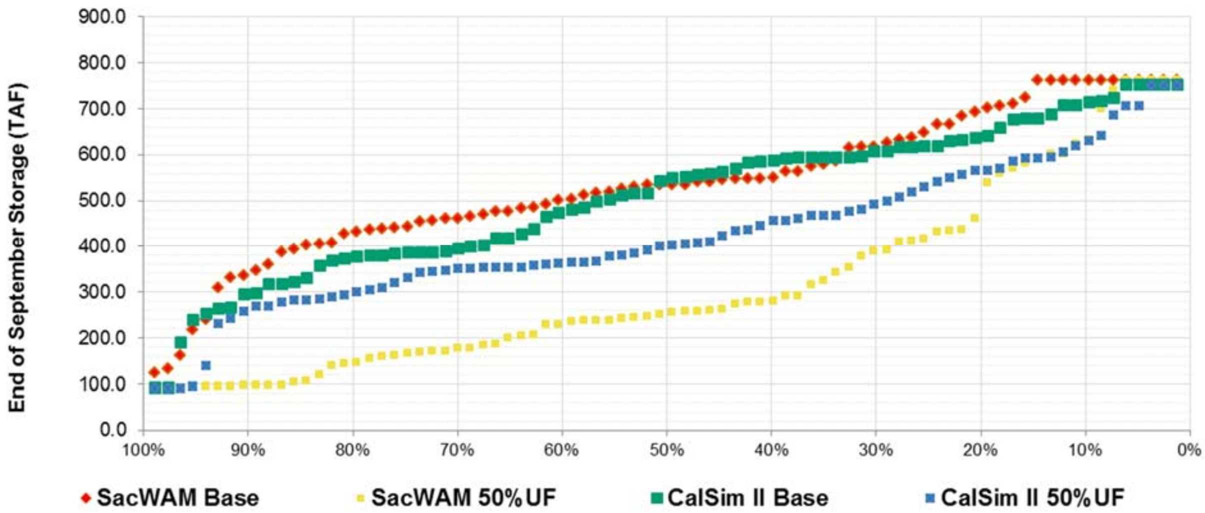

Figure 19. Folsom Reservoir Annual Carryover Storage Exceedance Plot

3.4.2 Feather River

Streamflows on the Feather River are primarily controlled by SWP operations. Releases from Oroville Reservoir and diversions to FRSA contractors control most of the flows and diversions from the lower Feather River. The 50% UF requirement at the mouth of the Feather frequently controls streamflows on the lower river shown in Figure 20 by the black dotted line that is frequently at the top of the hydrograph in the spring.

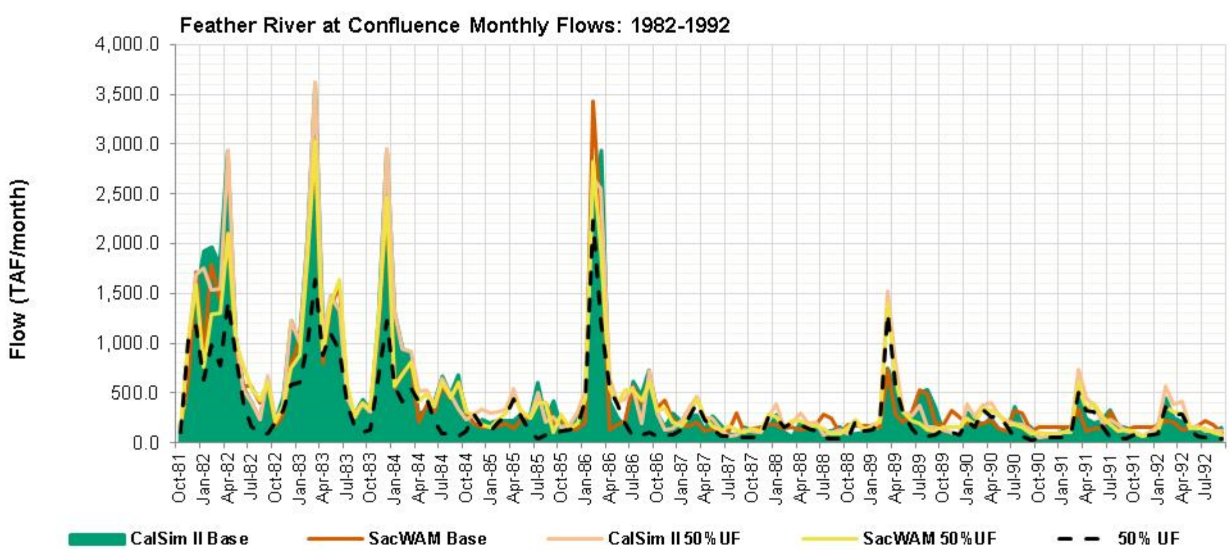

Figure 20. Feather River above Sacramento River Monthly Time Series of Water Years 1982–1992

Changes in releases from Oroville Reservoir are similar between the two models where both models show similar increases in releases December–June and decreases July–November (Figure 21). In July, CalSim II shows a decrease in releases from Oroville due to extra water entering from the Yuba and Bear River during these months as discussed above (Figure 11) and because CalSim II misrepresents the return flows from FRSA diversions by routing the flows back to the Feather River. In reality these return flows are routed to Butte Creek as discussed above. This physical misrepresentation results in an overestimate of streamflows on the lower Feather River available to meet the new 50% UF requirement in CalSim II. Storage in Oroville reservoir is reduced under the 50% UF scenario in both models, however SacWAM is reduced more than CalSim II. The lower releases in CalSim II during the summer months result in CalSim II having a larger decrease than SacWAM in months when it is more full (spring), and less of a decrease in months when the reservoir is lower (end of summer-fall) (Figure 22). In the SacWAM base simulation, Oroville deadpool is assumed to be 30 TAF whereas in CalSim II it is assumed to be 612 TAF. The level of deadpool was increased in the 50% UF scenario to match CalSim II as discussed in the methods section (Chapter 2).

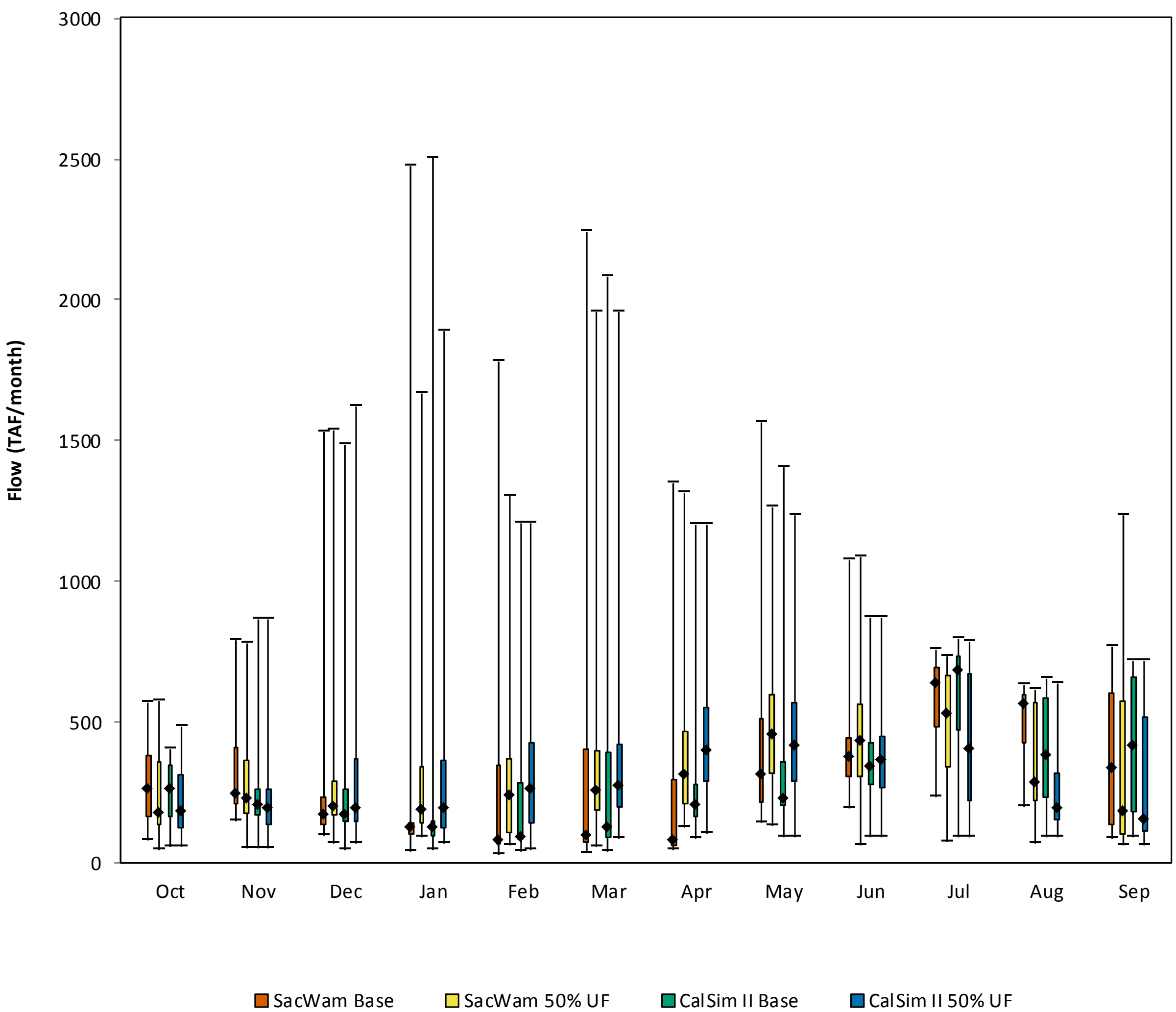

Figure 21. Feather River below Oroville Reservoir Monthly Box Plot

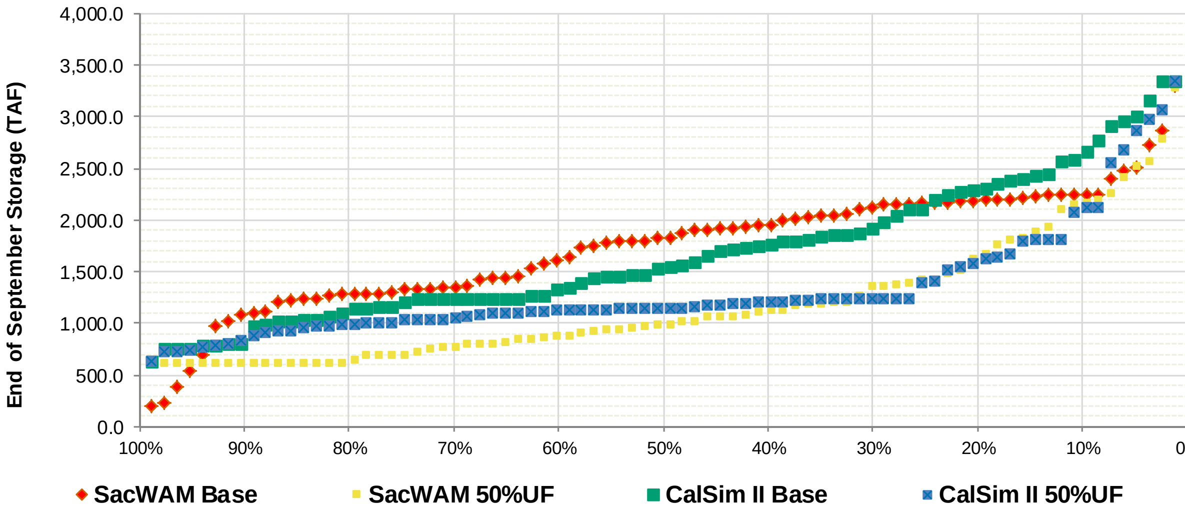

Figure 22. Oroville Reservoir Annual Carryover Storage Exceedance Plot

Diversions from the lower Feather River are primarily to FRSA contractors from the north side of the river and from Thermalito Afterbay. SacWAM assumes much higher agricultural demand in the fall for rice decomposition from the Feather than CalSim II; however, changes in diversions under 50% UF scenarios are very similar between the two models. CalSim II shows a reduction of 202 TAF/yr (15%) and SacWAM 167 TAF/yr (15%) (Table 7, Figure 23). Both models show that the largest reductions in diversions occur during the summer irrigation months.

Above the confluence with the Sacramento, the change in streamflow is very similar between the two models which is controlled by the 50% UF requirement, Delta outflow requirements, and south of Delta exports (Figure 24).

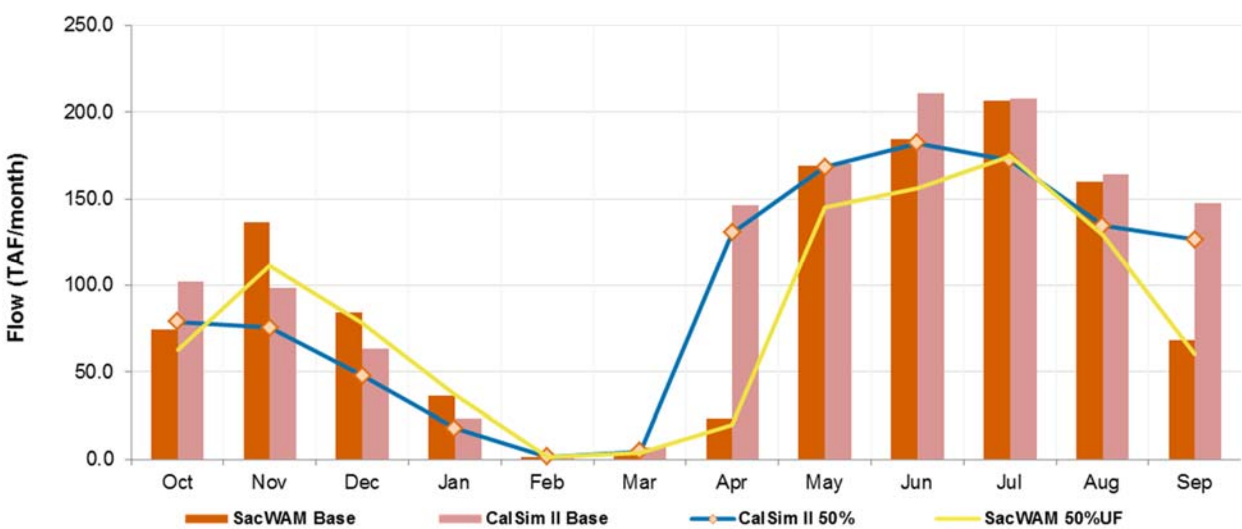

Figure 23. Lower Feather River Total Diversion Monthly Average Plot

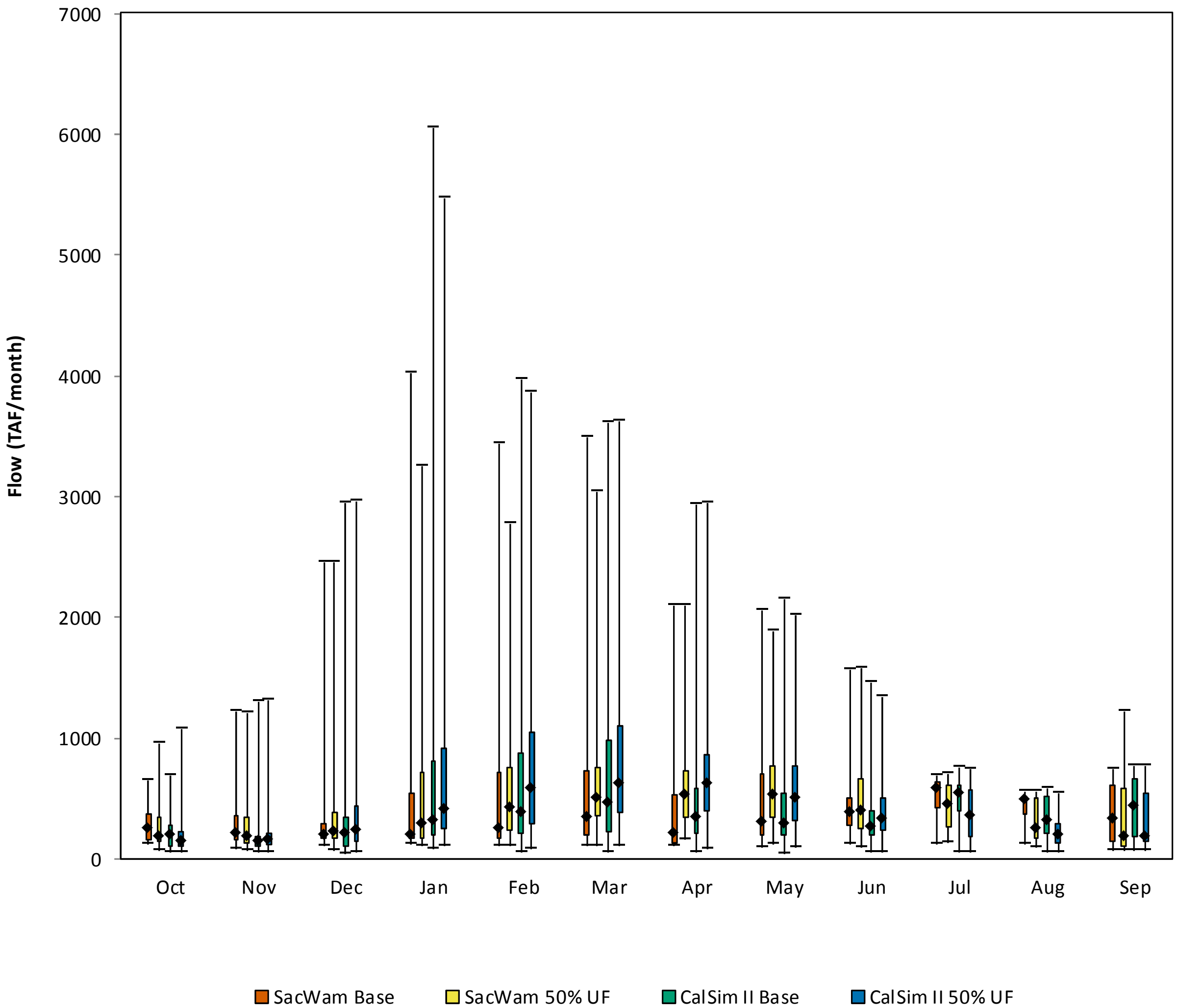

Figure 24. Feather River above Sacramento River Monthly Box Plot

3.4.3 Sacramento River

Changes to flows in the Sacramento River are very similar between both models due to the addition of 50% UF requirements and new Delta outflow requirements. Releases from Shasta show very little change from the base simulations of both models on an annual scale (CalSim II 11 TAF/yr, SacWAM 3 TAF/yr), however releases from Keswick are reduced in both models because Trinity River imports are routed through Clear Creek to meet the 50% UF requirement on Clear Creek, rather than being routed to Keswick via the Clear Creek Tunnel (Table 6). Minor changes in releases from Shasta result in relatively minor changes in storage in Shasta shown in Figure 25.

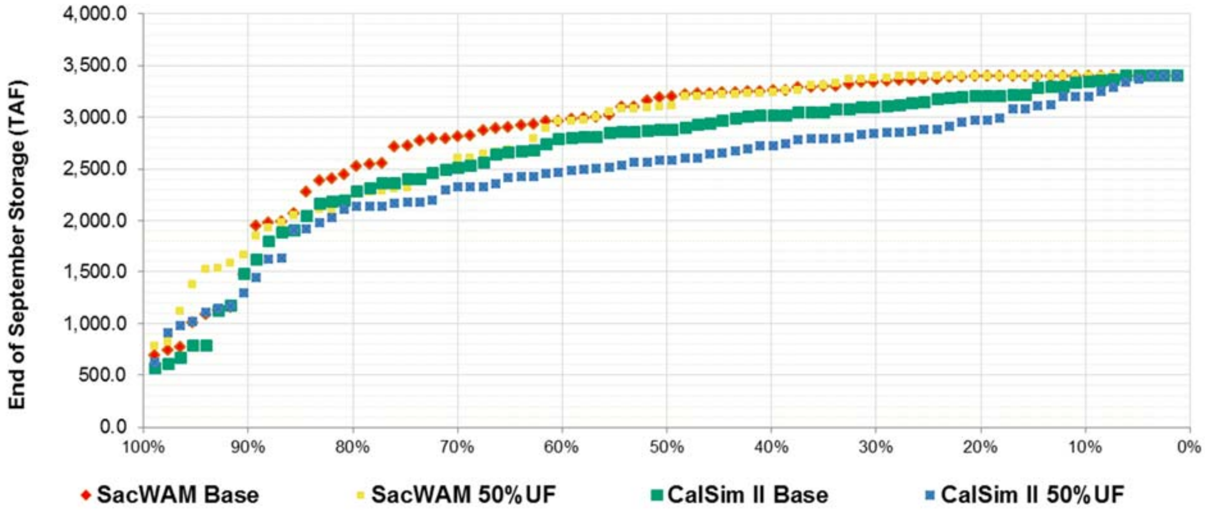

Figure 25. Shasta Reservoir Annual Carryover Storage Exceedance Plot

Both models show changes in monthly flows at Bend Bridge primarily caused by the increased outflow requirements, increased contributions from non-Project tributaries, and reductions in CVP settlement contractor allocations (Figure 26). Under base model conditions, the Sacramento River at Knights Landing is above 50% UF (shown below in black dotted line) in nearly all months because of Trinity imports and many non-regulated tributaries in the upper watershed (Figure 27). Sacramento CVP settlement contractor diversions make up the bulk of the water diverted from the Sacramento River. In the 50% UF scenarios, both models show a similar reduction in deliveries during the contract period (April–October) due to allocation reduction as well as the rest of the year due to less water available and demand reduction applied (Figure 28).

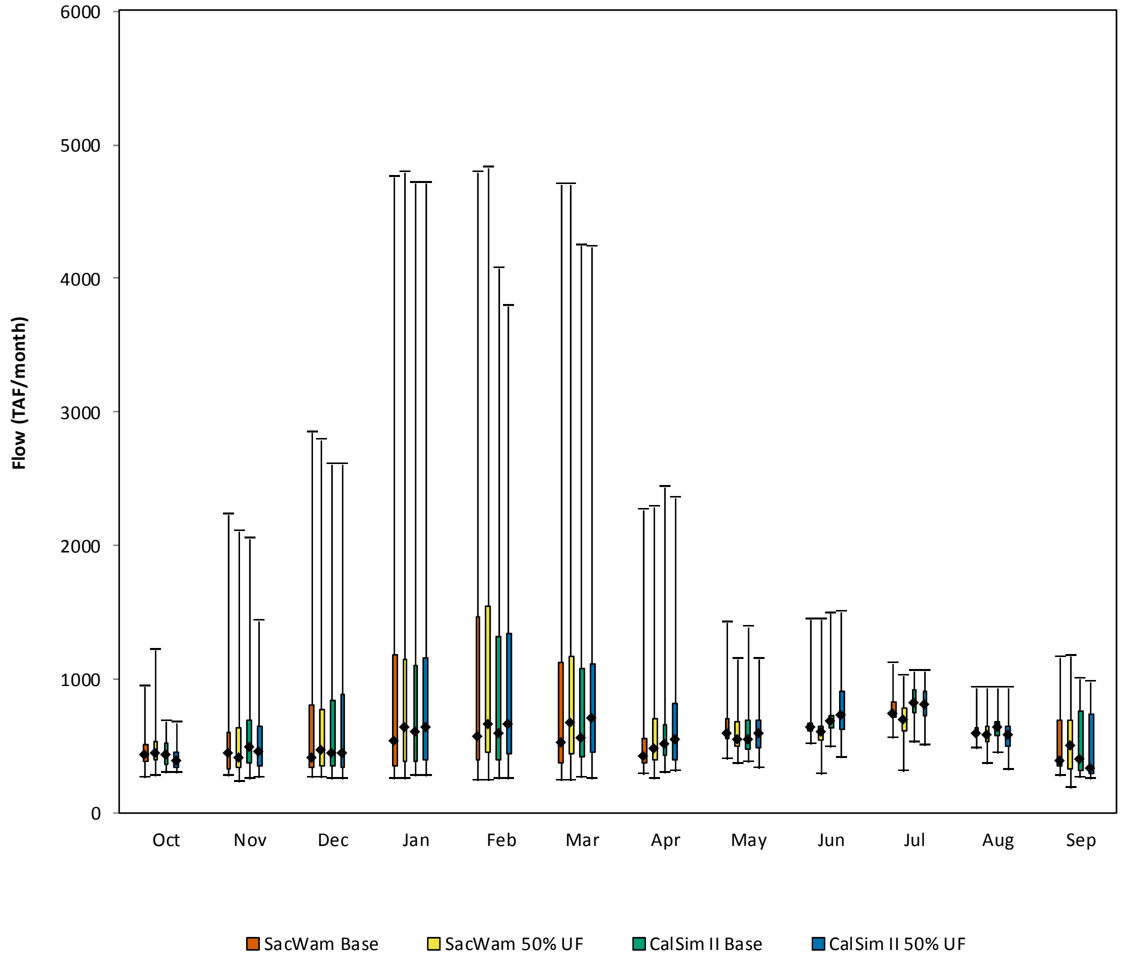

Figure 26. Sacramento River at Bend Bridge Monthly Box Plot

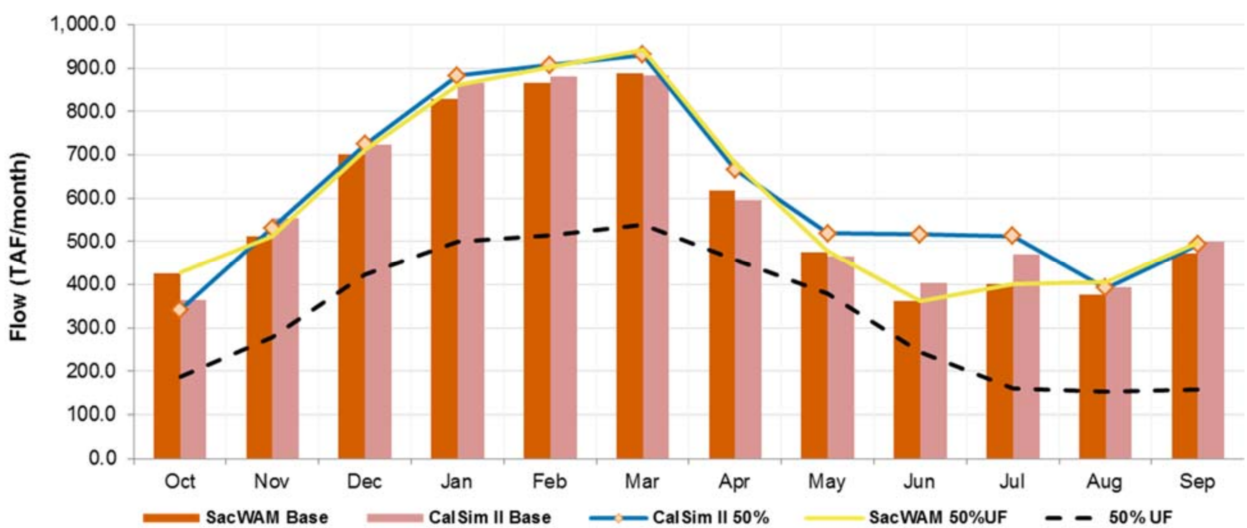

Figure 27. Sacramento River at Knights Landing Monthly Average Streamflow

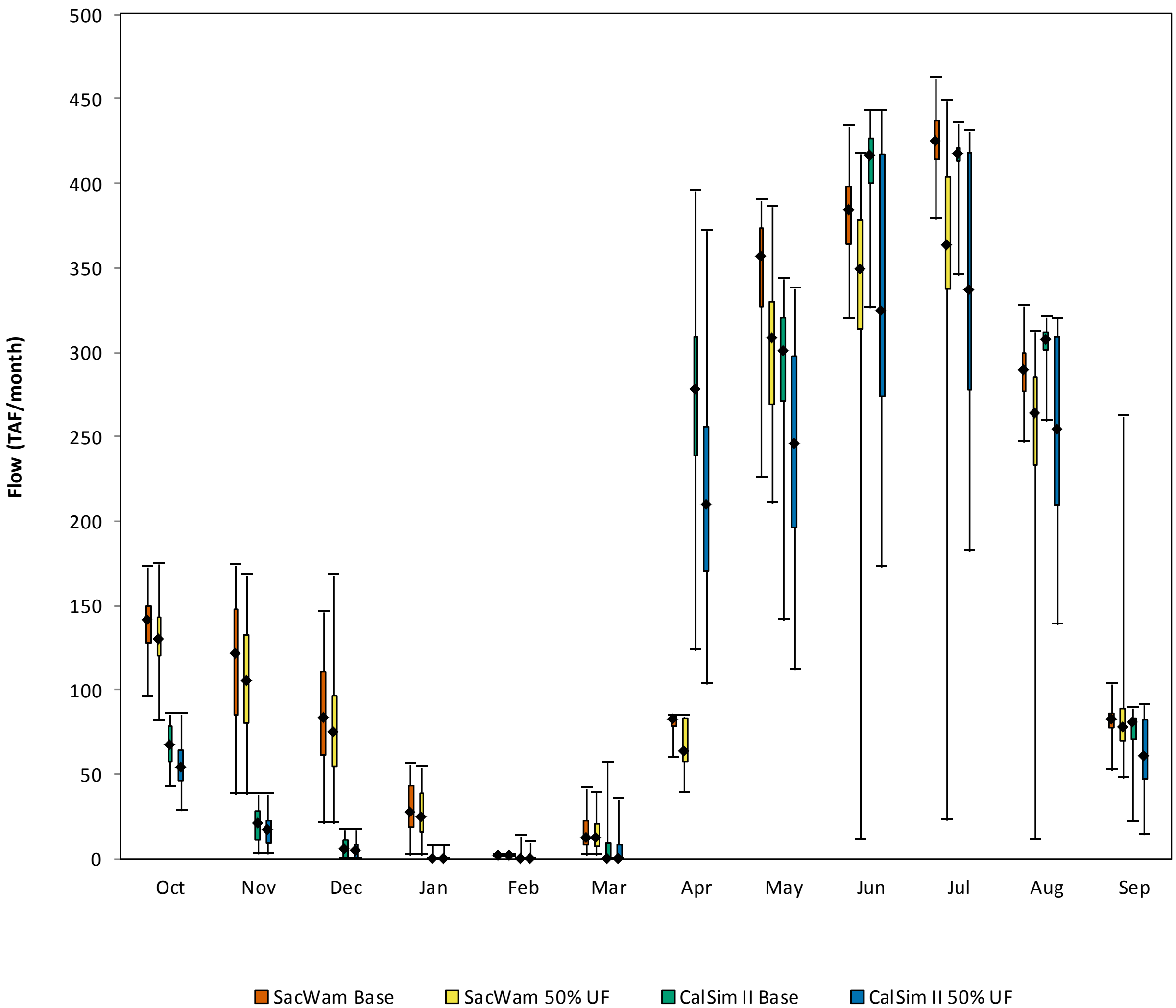

Figure 28. Sacramento River CVP Settlement Contractor Diversion Monthly Box Plot

3.4.4 Delta Inflow

Changes in Delta inflow are similar between the two models with CalSim II estimating an increase of 886 TAF/yr (4%) and SacWAM estimating an increase of 671 TAF/yr (3%) (Figure 29); however, the source of this inflow is different. As discussed above in the regulated non-Project tributary section (Section 3.3), many non-Project tributaries in CalSim II have larger increases in streamflow contributing to Delta inflow (160 TAF/yr more in CalSim II than SacWAM) and some non-Project tributaries such as Cache and Putah Creeks only show increases in SacWAM (146 TAF/yr). The differences in changes in Delta inflow between the two models would be greater but multiple limitations in the CalSim II simulation cancel each other out. To illustrate that the larger increase in Delta inflows in CalSim II is due to non-Project tributaries, the effects of Project operations can be removed, as shown by Delta inflow less storage release.

Delta inflow less storage release is calculated by removing upstream Project operations from Delta inflow by subtracting Trinity imports and change in Project reservoir storage (Shasta, Oroville, and

Folsom Reservoirs). Both models show an increase in Delta inflow less storage release with an annual average increase of 867 TAF/yr (4%) by CalSim II and 668 TAF/yr (3%) by SacWAM and monthly distribution shown in Figure 30. The small change in the response of each model to the 50% UF requirements when the effects of upstream Project operations are removed indicates that the different responses of the models are due to contributions from non-Project tributaries.

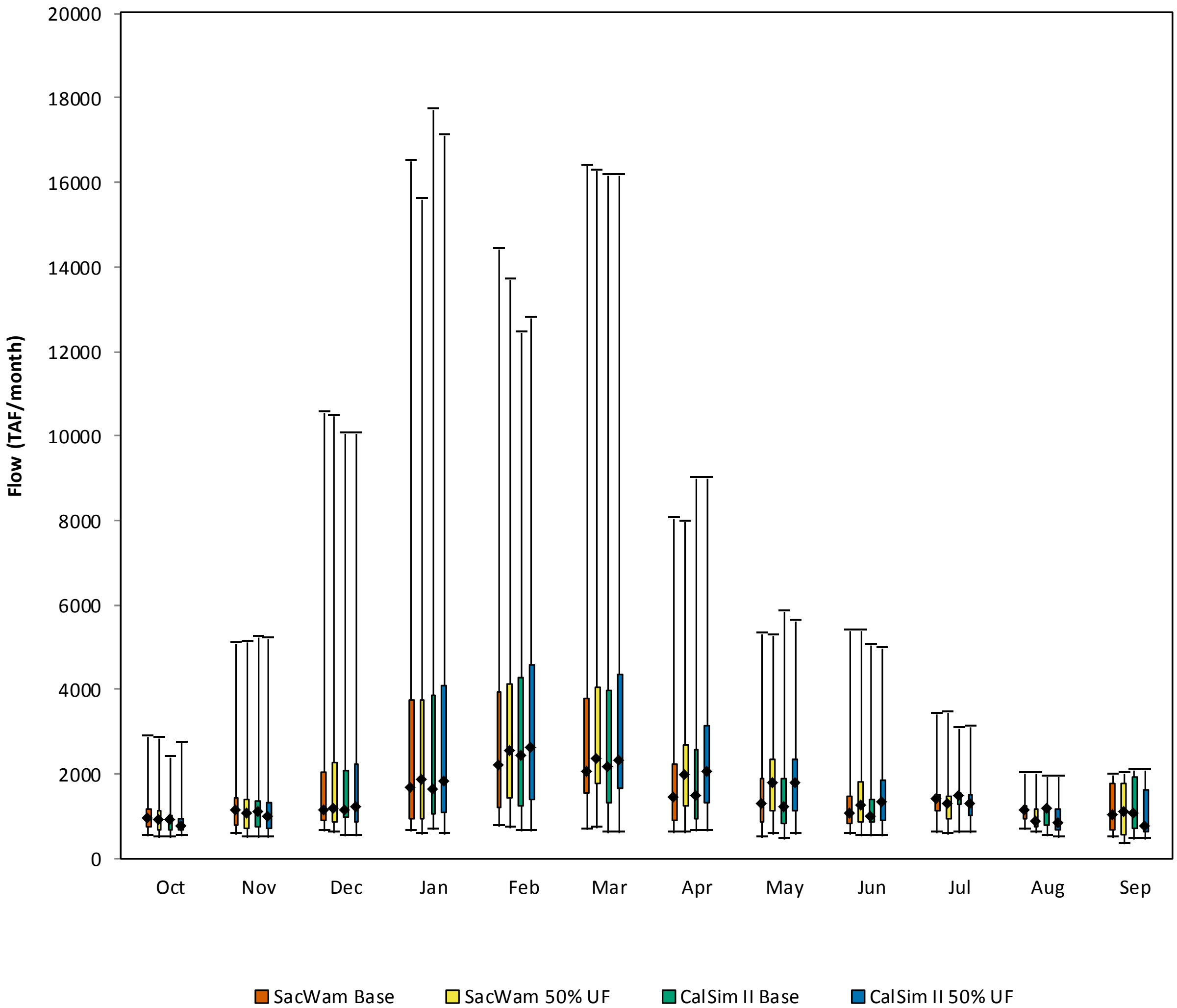

Figure 29. Total Delta Inflow Monthly Box Plot

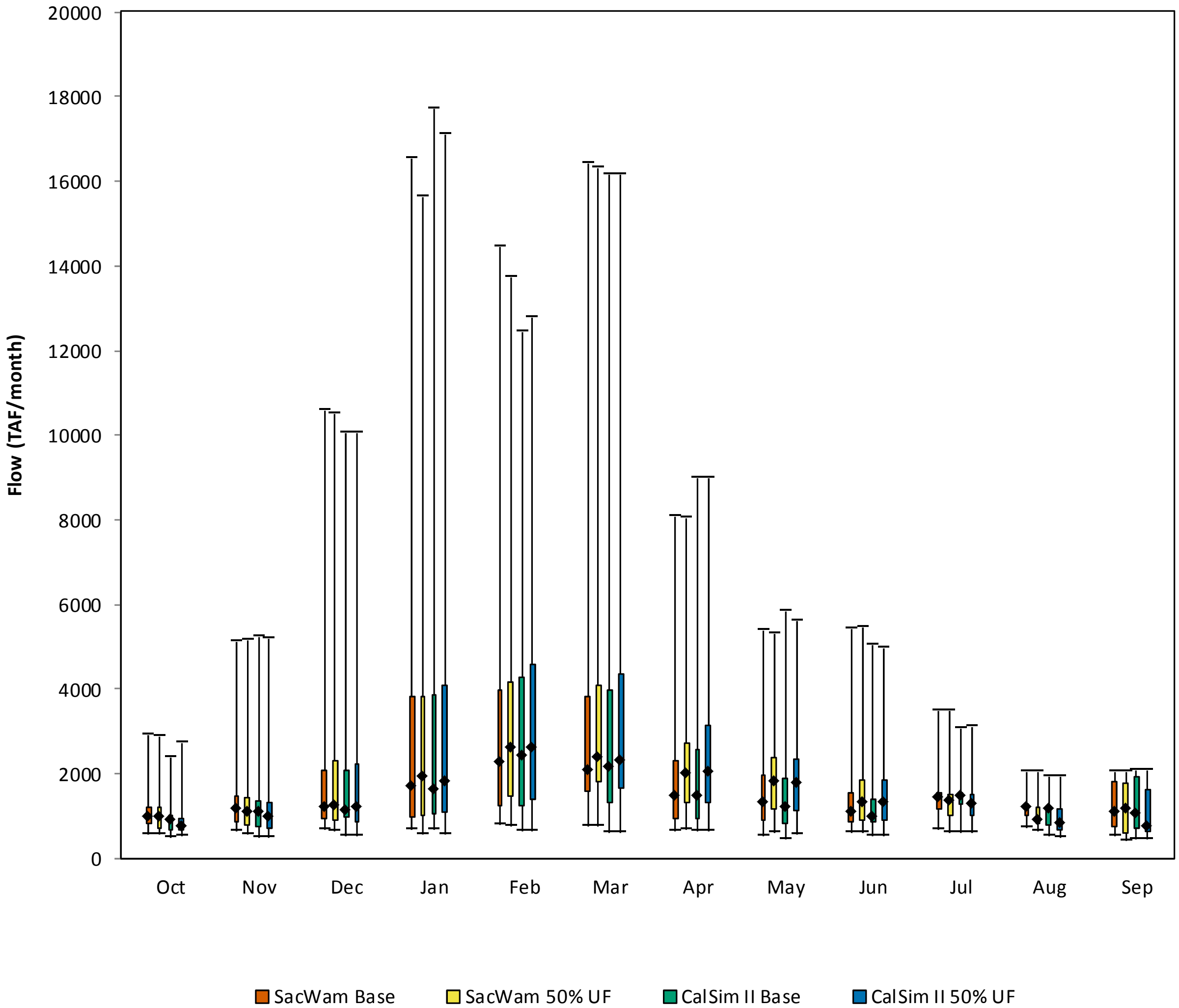

Figure 30. Total Delta Inflow Less Project Storage Release Monthly Box Plot

3.4.5 Delta Outflow

CalSim II and SacWAM show very similar changes to Delta outflow due to new flow requirements on upstream tributaries and at Chipps Island. CalSim II shows an average increase of 1.38 million acre-feet per year (MAF/yr) (9%) and SacWAM shows an average annual increase of 1.11 MAF/yr (7%). The slightly larger increase in outflow in CalSim II (266 TAF/yr) can be primarily attributed to the increase in increases in regulated non-Project tributaries (160 TAF/yr) and a slight reduction in exports (69 TAF/yr) (see below) with slight differences in hydrology, demands and Project tributaries making up the rest of the difference (37 TAF/yr). Both models show little change to outflow during October–December, increases in outflow January–June with the largest increases in April and May, slight decreases in outflow in July and little change in August (Figure 31). SacWAM shows a slight increase in outflow in September while CalSim II shows a slight decrease in outflow in September.

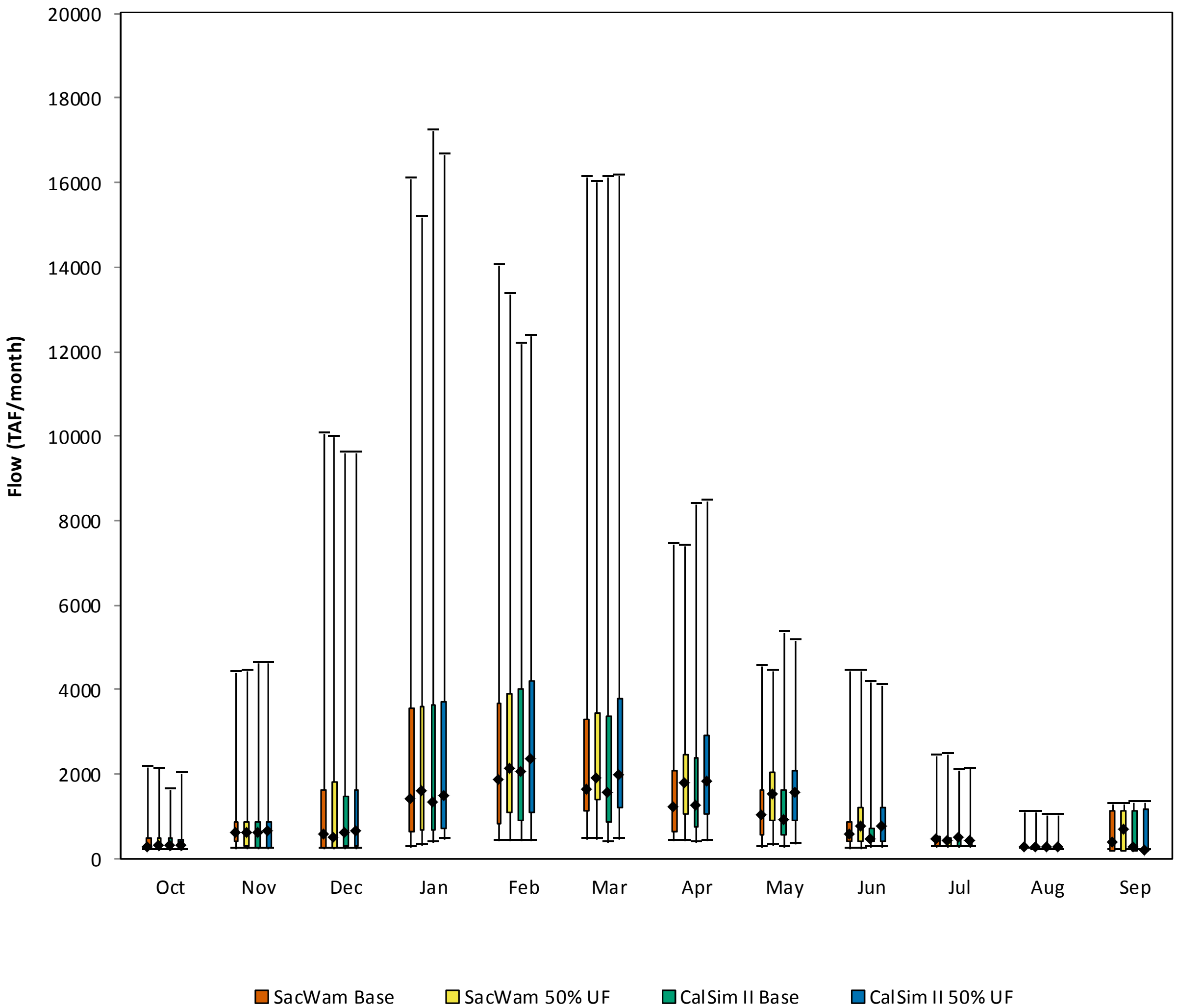

Figure 31. Delta Outflow Monthly Box Plot

3.4.6 Project Allocations

SacWAM uses similar logic to CalSim II to simulate SWP and CVP percent contract allocations, which are based on Project reservoir storage, forecasted inflows, a measure of the ability to move Project water across the Delta, and in the 50% UF scenarios, allocation reduction factors. However, SacWAM does not differentiate between north of Delta SWP Table A allocations and south of Delta Table A allocations. CalSim II contains separate logic to simulate allocations to SWP long-term contractors located north of the Delta, following a new agreement signed in 2013. In both models, allocations to water right holders in the FRSA are determined separately, based on inflows to Lake Oroville.

In the base studies, CVP settlement contracts are only reduced when the forecasted inflow to Shasta Lake is less than 3.2 MAF, or the total accumulated deficiencies below 4.0 MAF in the immediately prior water year, or series of successive prior water years (each of which had inflows of less than 4.0 MAF), together with the forecasted deficiency for the current water year, exceed 0.8 MAF. When this occurs, CVP settlement contract allocations are reduced to 75%. Both models show identical annual allocation reductions as a result of the allocation reductions applied to the 50% UF scenario (Figure 32). Changes in CVP M&I allocations are similar between the two models, with both models showing increased or constant allocation in the drier years due to the updated WSI-DI curves, and reduced allocation in many above normal years (Figure 33). CVP south of Delta agriculture allocations also show similar trends in changes between both models from base simulations. Both models show no change to allocations in the wet years, a reduction in 40%–60% of the years and an increase or no change for the driest 10%–20% of the years (Figure 34). SWP allocations also show very similar changes under the 50% UF scenario. Both models reduce allocations during droughts but also in below normal and dry years (Figure 35).

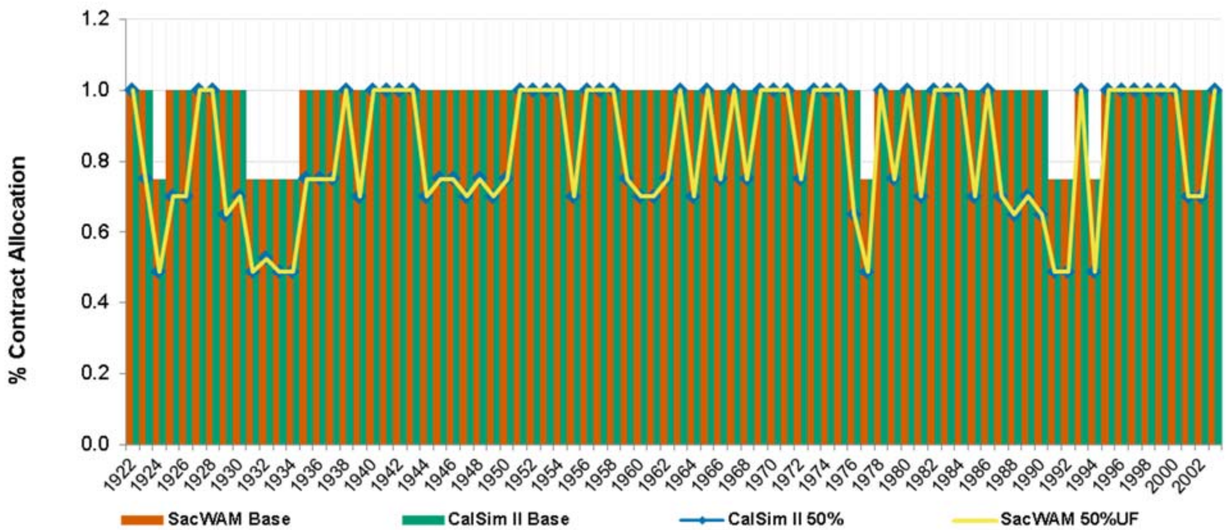

Figure 32. April CVP Settlement Contract Allocation (%)

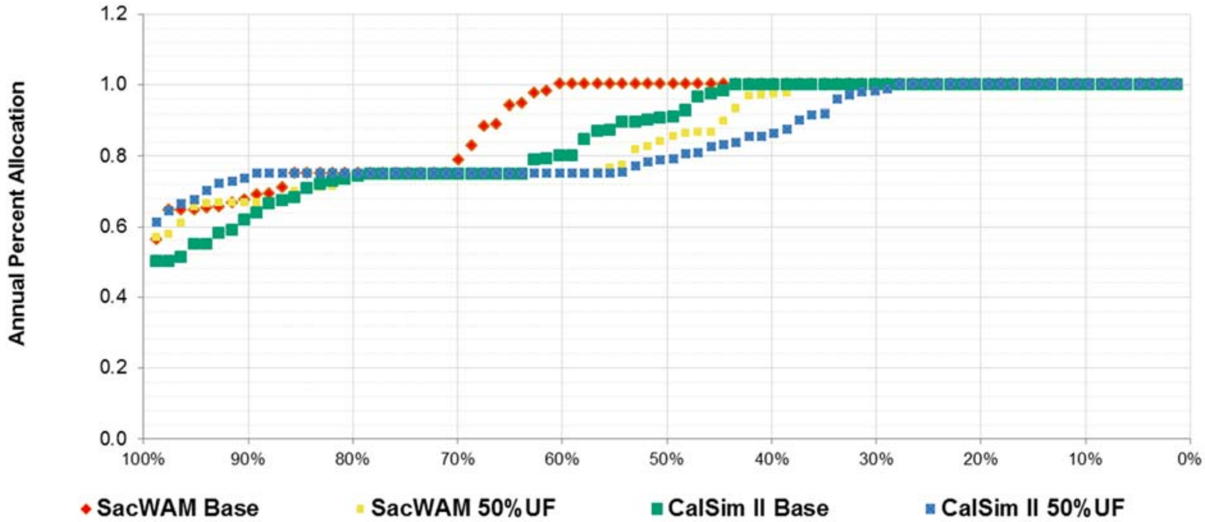

Figure 33. CVP Municipal and Industrial Annual Contract Allocation (%)

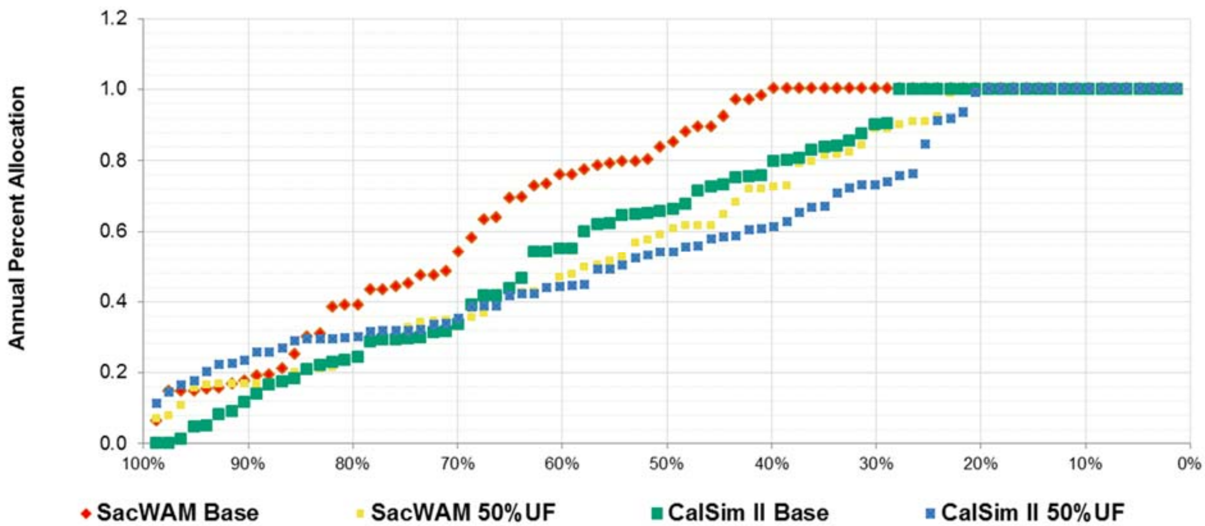

Figure 34. CVP South of Delta Agricultural Annual Allocation (%)

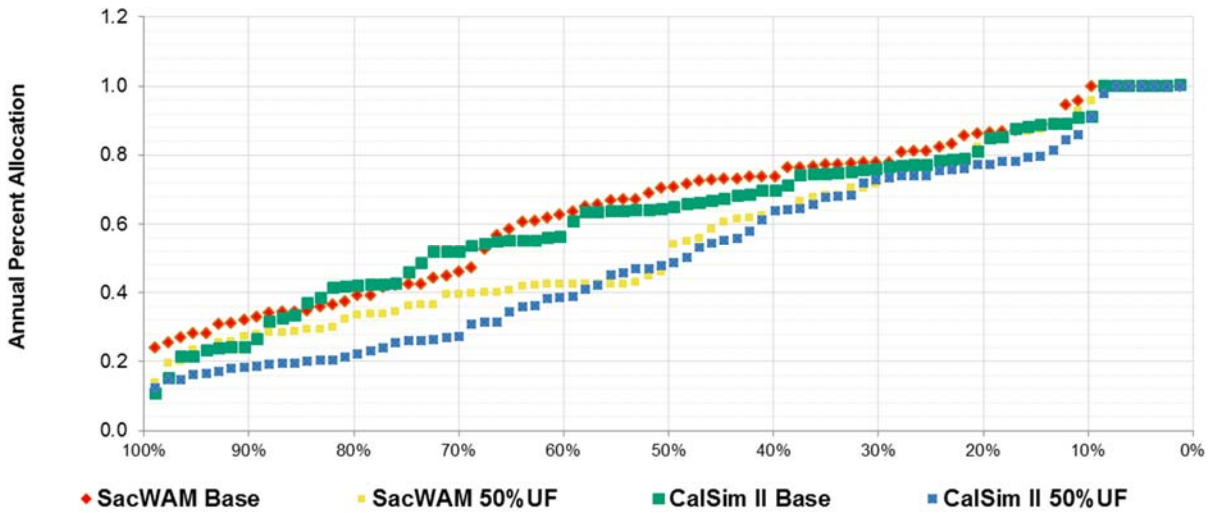

Figure 35. SWP Percent Allocation Annual Exceedance Plot

3.4.7 SWP and CVP South Delta Exports and San Luis Reservoir

Under the alternative scenario, south of Delta Project exports are reduced in a similar manner by both models. CalSim II south of Delta exports are reduced by 456 TAF/yr (9%) on average and in SacWAM they are reduced by 387 TAF/yr (8%). In both models the reductions in total exports occur in below normal to wetter years and the models show little change in the drier 25% of years and the wettest 10% of years (Figure 36). CalSim II shows a slight increase in CVP exports at Jones Pumping Plant (7 TAF/yr, 0.3%) while SacWAM shows a slight decrease in CVP exports (31 TAF/yr, 1%) (Figure 37). The relatively small difference in CVP exports can be attributed to differences in CVP north of Delta storage during drier years. SWP south of Delta exports show similar decreases in both models with CalSim II decreasing 463 TAF/yr, 17% and SacWAM decreasing 356 TAF/yr, 13% (Figure 38). The differences in SWP south of Delta exports can be attributed to SacWAM having lower storage in Oroville than CalSim II because CalSim II underestimates the demand on Oroville to meet the 50% UF requirement on the Feather River (see Section 3.4.2). Both models show a similar slight reduction in San Luis Reservoir monthly storage shown in Figure 39.

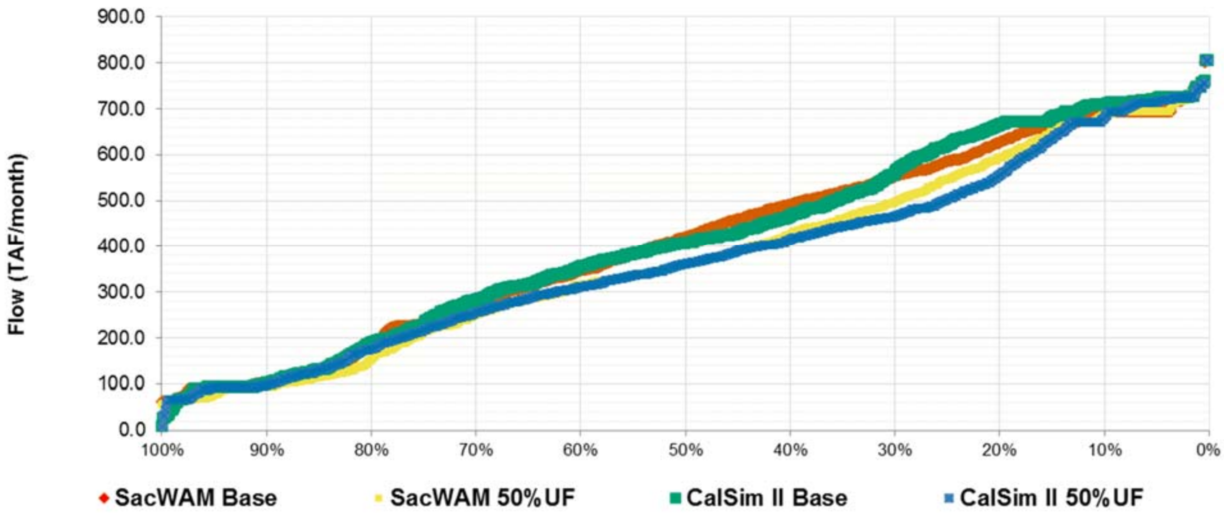

Figure 36. Total Project South of Delta Export Monthly Exceedance Plot

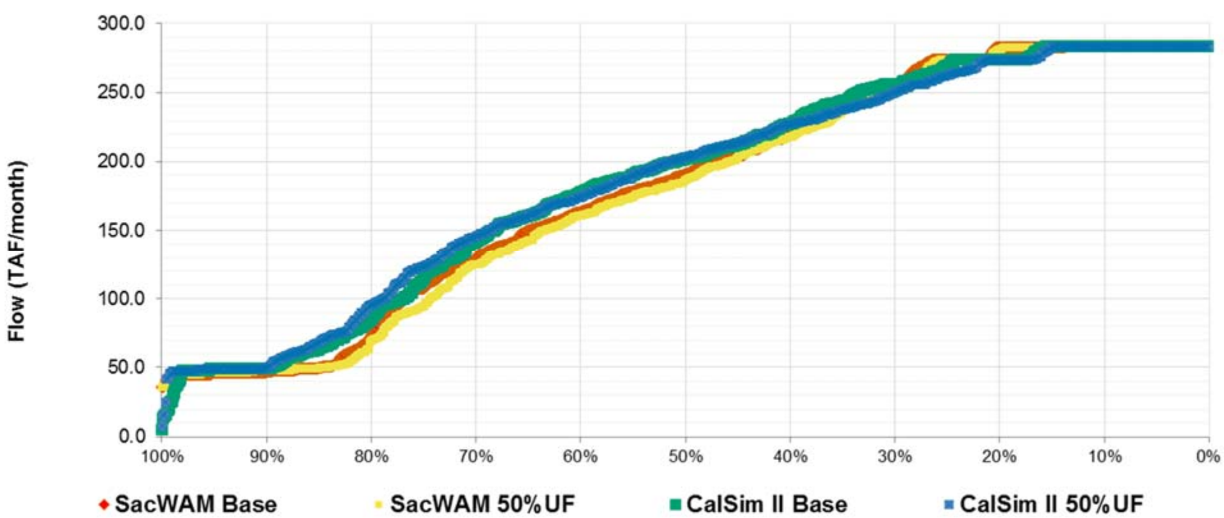

Figure 37. CVP South of Delta Exports at Jones Pumping Plant Monthly Exceedance Plot

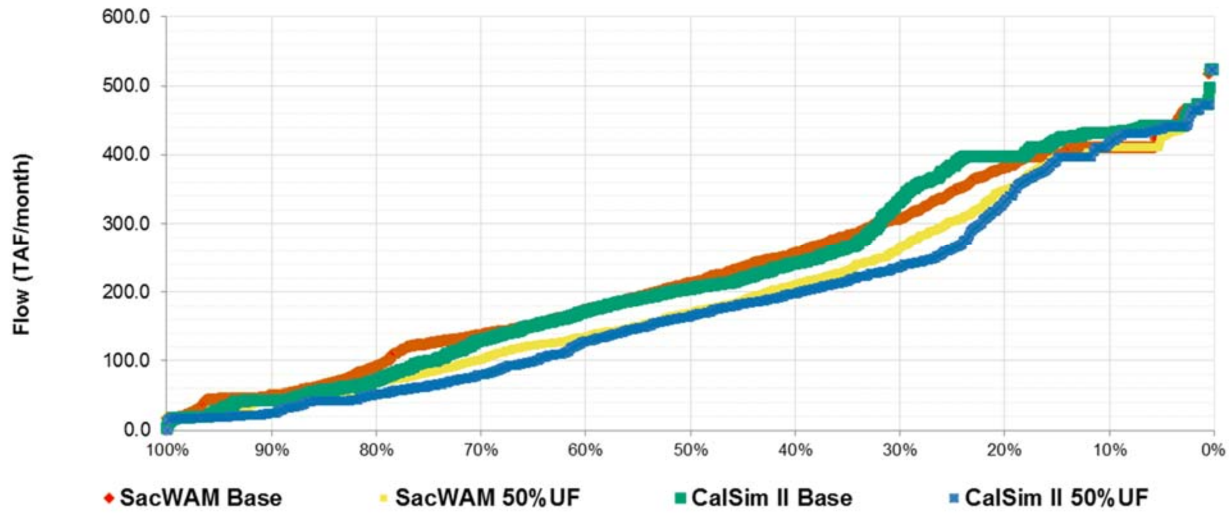

Figure 38. SWP South of Delta Exports at Banks Pumping Plant Monthly Exceedance Plot

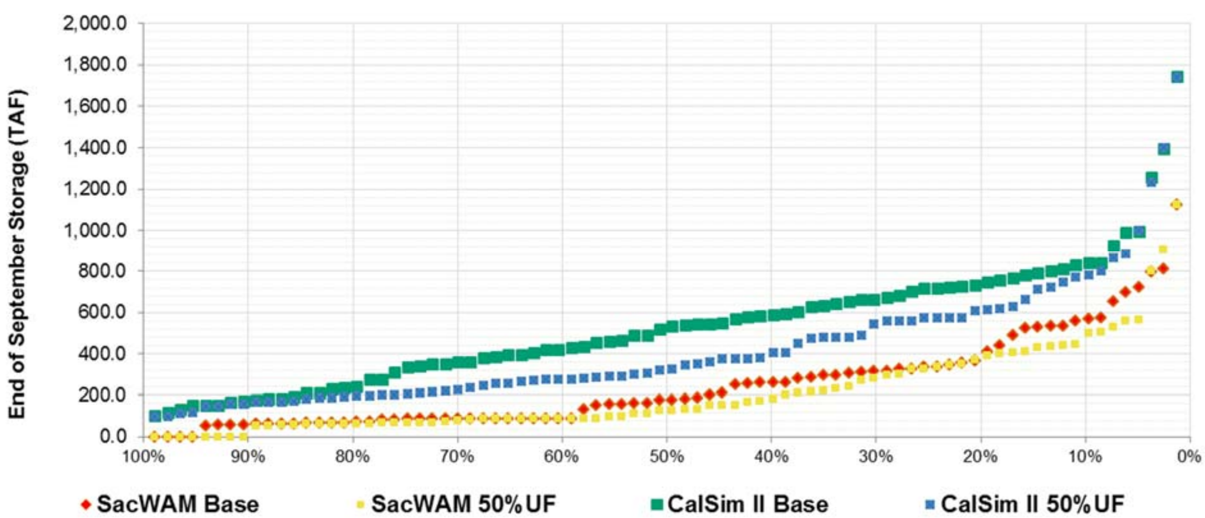

Figure 39. San Luis Reservoir Total Annual Carryover Storage Exceedance Plot

Chapter 4
Conclusions

This comparison highlights limitations of the CalSim II model for simulating the types of alternatives that the State Water Board may consider in the Phase II update of the Bay-Delta Plan, specifically on non-Project tributaries. Both models represent Project operations that affect the Bay-Delta similarly, while SacWAM provides higher resolution on the Valley floor and ability to modify upstream watershed operations. Modifications to CalSim II took about 1 year by engineers at DWR to complete, whereas a comparable simulation in SacWAM was crafted in less than a month by State Water Board staff, which illustrates the flexibility of the SacWAM model.

CalSim II is not able to accurately model 50% UF requirements on regulated non-Project tributaries because reservoirs are not operated on these tributaries in CalSim II. In CalSim II, tributaries such as the Yuba River, Bear River, and Mokelumne River under the 50% UF scenario add over 200 TAF/yr to the system more than SacWAM. Additionally, CalSim II does not accurately represent FRSA return flows to Butte Creek and does not explicitly represent Putah Creek and Cache Creek. Inaccurate representation of regulated non-Project tributaries under the 50% UF scenario affects not only flows on these tributaries but also affects Delta operations and Project storage as well.

Given the differences in non-Project tributaries between CalSim II and SacWAM, changes to Project operations under the alternate scenario are very similar between the two models summarized in Table 8. Changes to Delta outflow, Project reservoir storage, exports, and allocations are very similar between the two models demonstrating that detailed aspects of CalSim II such as the ANN, COA, and contract allocations are correctly implemented in SacWAM.

Table 8. Changes in Annual Average Delta Inflow, Outflow and South of Delta Exports

	CalSim II Change from Base		SacWAM Change from Base	
	(TAF/yr)	(percent)	(TAF/yr)	(percent)
Total Delta Inflow	886	4.1%	700	3.2%
Total Delta Outflow	1378	8.8%	1112	7.0%
Total South of Delta Project Exports	-456	-9.2%	-387	-7.9%

TAF/yr = thousand acre-feet per year

Chapter 5
References

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