Appendix A

Updates to Central Valley Planning Area WEAP Model for California Water Plan Update 2023

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Technical Memorandum

Updates to Central Valley Planning Area WEAP model for California Water Plan Update 2023

December 2022

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

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Technical Memorandum: Updates to
WEAP CVPA Model for CWPU 2023

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Acronyms and Abbreviations

ANN	Artificial Neural Network
BiOp	Biological Opinion
CA	California Aqueduct
CalSim	California Water Simulation tool
COA	Coordinated Operations Agreement
CVP	Central Valley Project
CWPU	California Water Plan Update
Delta	Sacramento-San Joaquin Delta
DMC	Delta-Mendota Canal
DLL	Dynamic linked library
DSM2	Delta Simulation Model
DWR	California Department Water Resources
PA	Planning Area
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
SacWAM	Sacramento River Basin Water Allocation Model
SWP	State Water Project
TM	Technical Memorandum
UDC	User-Defined Constraint
USGS	U.S. Geological Survey
WEAP	Water Evaluation and Planning (System)
WQCP	1995 Water Quality Control Plan

1.0 Introduction

1.1 Background

The California Department of Water Resources (DWR) is using decision scaling as an analytical framework for the California Water Plan Update 2023. Central to this effort is the application of a water analysis tool for the Central Valley, referred to as the Central Valley Planning Area (CVPA) model. This tool was developed using the Water Evaluation and Planning (WEAP) software, which combines climate-driven hydrological routines with water management considerations such that it can be used to explore various alternative management responses to future climatic conditions.

The CVPA model was originally conceived of as a screening tool that takes advantage of WEAP's transparent user-interface and scenario development capabilities and was first used to support the CWPU 2008. It was designed to represent water management at a relatively coarse scale, while providing information relevant to other water modeling tools that could be subsequently used to explore management alternatives in greater detail. As such, it has been periodically updated to keep pace with changes in these other tools, often taking direct advantage of procedures developed for these tools.

For CWPU 2023, SEI worked with DWR to update the CVPA model to include key considerations that influence the movement of water across the Sacramento-San Joaquin Delta. These updates were largely taken from the SacWAM model (developed and maintained by the California State Water Resources Control Board) and included model logic to represent the Coordinated Operations Agreement (COA), project allocations for both the CVP and SWP, and the latest USFWS Biological Opinion. The updated model also includes the use of DWR's artificial neural network (ANN) for Delta salinity, which was developed for CalSim. These changes have greatly enhanced the model's ability to more accurately reflect the movement of water throughout the Central Valley in a manner consistent with its sister models and are described in detail in this document.

1.2 Document Organization

This Technical Memorandum (TM) describes the process of integrating several enhancements into the CVPA Model such that the model can more accurately represent water flows through the Sacramento-San Joaquin Delta.

Chapter 2 presents the changes to the model schematic that were necessary to implement.

Chapter 3 presents information on the general implementation of the Delta ANN within the CVPA Model.

Chapter 4 presents the implementation of the USFWS Biological Opinion within the CVPA model

Chapter 5 presents the implementation of the Coordinated Operations Agreement within the CVPA model

Chapter 6 presents the implementation of the CVP and SWP

Chapter 7 contains references.

Chapter 8 contains appendices.

2.0 Changes to Network Schematic

Previous versions of the CVPA model included a very simple representation of flows through the Sacramento-San Joaquin Delta. This configuration considered inflows from each of the main rivers – Sacramento, San Joaquin, and Mokelumne – as well as flows from the Yolo Bypass and it only considered Delta exports through the Delta-Mendota Canal and the California Aqueduct. Importantly, the model assumed that the only factors limiting exports were Delta outflow requirements (determined by D-1641) and Delta salinity considerations (determined by the G-model and Kimmerer-Monismith equations for X2).

The CVPA model required several changes to the model schematic to properly model the Delta ANN, the USFWS Biological Opinion, and the COA. These changes included the addition of:

- **Delta Cross Channel (DXC),** which diverts water from the Sacramento River to the lower San Joaquin River and influences salinity throughout the Delta
- **North Bay Aqueduct**, which is included in the calculation of SWP Delta exports.
- **Rock Slough Intake**, which exports water from the lower San Joaquin River into the Contra Costa Canal.
- **Contra Costa Canal**, which diverts water from Old and Middle River and delivers it to Contra Costa Water District.
- **Old and Middle River**, which is part of the bifurcation of the lower San Joaquin River that takes water from the main San Joaquin River below Vernalis towards the pumps for both the Delta-Mendota Canal and the California Aqueduct.
- **Reverse Flows: OMR & Qeast**, which represent the movement of water opposite the main direction of flow within the Delta.

Other changes to the schematic include the addition of:

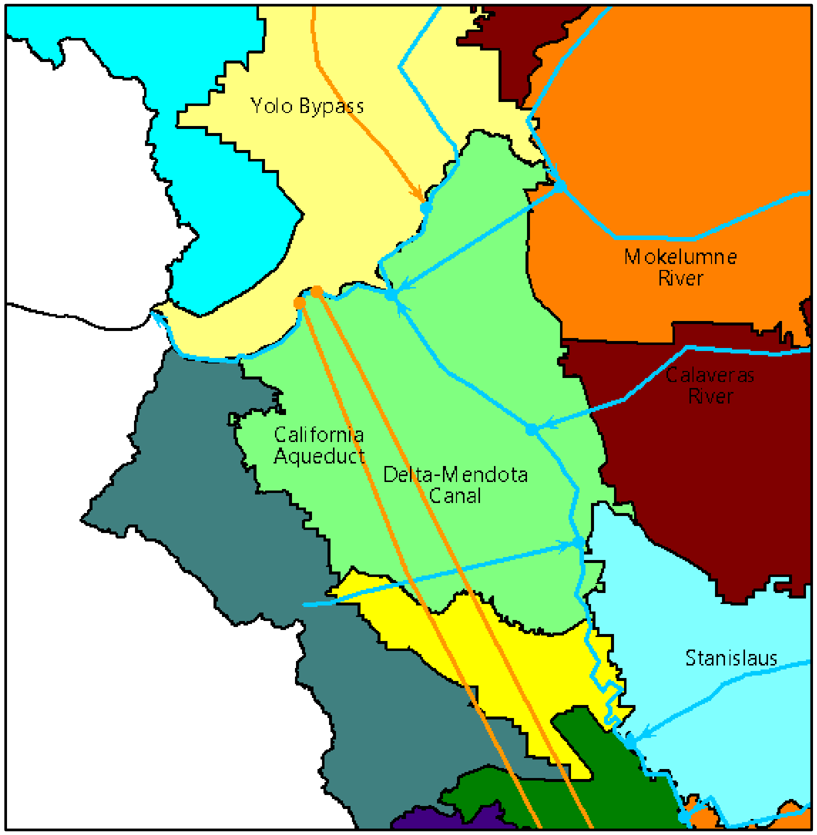
- **South Bay Aqueduct**, which draws water from the California Aqueduct.

- **Hetch Hetchy Aqueduct**, which influences flows on the Tuolumne and lower San Joaquin Rivers.
- **Mokelumne Aqueduct**, which diverts water from the Mokelumne River and delivers it to East Bay MUD.
- **Freeport Intertie**, which is used to augment EBMUD water supplies via the Mokelumne Aqueduct by diverting Sacramento River flows near Freeport.

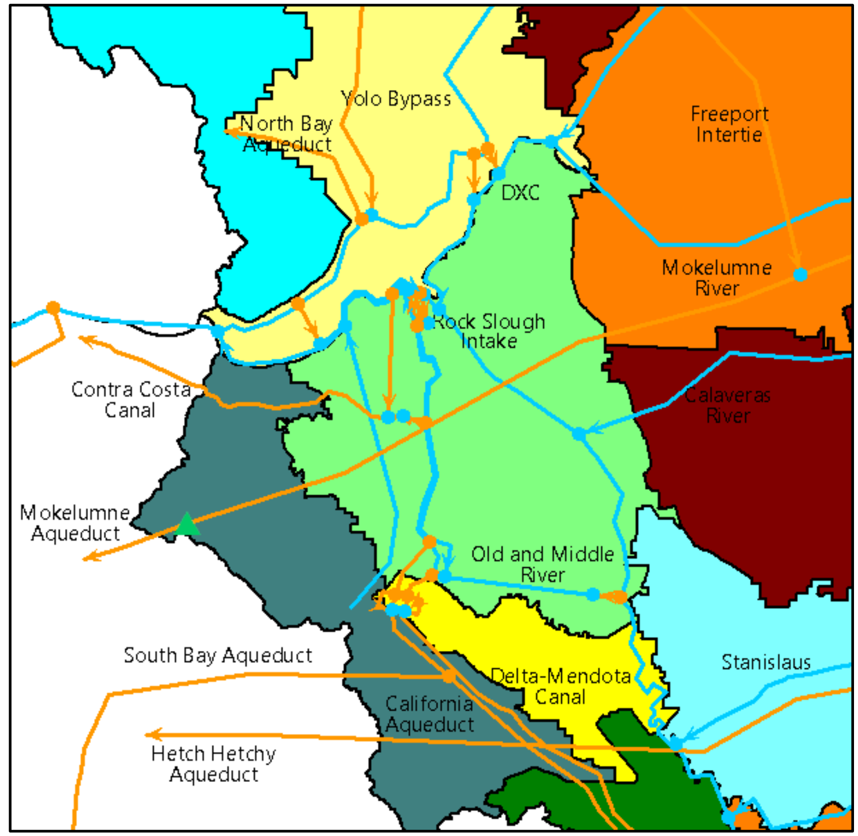
These changes are shown in Figure 1 below.

Figure 1 Updates to CVPA Model Schematic

Previous CVPA WEAP models



Current CVPA WEAP model



3.0 Planning Area Model Delta Flow Requirements and Export Constraints

3.1 Background

The previous CVPA model included a routine for estimating the outflow requirements needed to satisfy Delta salinity standards. This used the Contra Costa Water District salinity-outflow model, commonly referred to as the "G-model" (Denton and Sullivan, 1993), which is based on a set of empirical equations, developed from the one-dimensional advection-dispersion equation. The G-model predicts salinity caused by seawater intrusion at a number of key locations in Suisun Bay and the western Delta as a function of antecedent Delta outflow. The antecedent Delta outflow is a surrogate for directly modeling salinity distribution within the Delta and incorporates the combined effect of all previous Delta outflows. That is, the G-model assumes that salinity is a function of both current outflow and outflows from the previous 3 to 6 months. Because this salinity-outflow model was developed from the one-dimensional advection-dispersion equation, it accounts for the transport of salt by both mean flow (advection) and tidal mixing (dispersion).

The G-model equations were developed under current sea level conditions. While it would be possible to update these relationships to account for projected sea level rise, it is arguably easier and better to incorporate into the PA model the Delta Artificial Neural Network (ANN) model developed for CalSim, which has been trained to handle four sea level rise scenarios: 1-foot rise, 2-foot rise, 1-foot rise plus 4-inch amplitude increase, and 2-foot rise plus 4-inch amplitude increase.

The Delta ANN was added to the CVPA model as an alternative to the G-model method of setting flow targets to meet Delta water quality standards. This task required linking WEAP to the dynamic linked library (DLL) that contains the ANN functions and using the values returned from these calls to the DLL to set targets for Sacramento River flows and limits on Delta exports. This chapter provides a background and summary of inputs and some initial model results.

3.2 Delta ANN

The Delta ANN was developed in an attempt to integrate into the CalSim model a faithful representation of the flow-salinity relationships as modeled by the Delta Simulation Model (DSM2). These relationships were then used by CalSim to set Sacramento River flow targets and export limits in order to meet salinity standards at various locations in the Delta. The ANN also determines salinity (micro-mhos/cm) at these locations given estimates of Delta inflows, outflows, and exports and the position of Delta cross-channel. It is described in more detail in several DWR reports (Finch and Sandhu 1995; DWR, 2000, Hutton and Senevirante, 2001; Wilbur and Munevar, 2001; Senevirante, 2002; Mierzwa, 2002; and Smith, 2008).[1]

The basic formulation of the ANN has remained the same for some years and still relies upon the same set of modeled inputs as noted by Wilbur and Munevar (2001), who pointed out that the ANN

> "predicts salinity at various locations in the Delta using the following parameters as input: Sacramento River inflow, San Joaquin River inflow, Delta Cross Channel gate position, and total exports and diversions. Sacramento River inflow includes Sacramento River flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (East Side Streams). Total exports and diversions include State Water Project (SWP) Banks Pumping Plant, Central Valley Project (CVP) Tracy Pumping Plant, North Bay Aqueduct exports, Contra Costa Water District diversions, and net channel depletions. A total of 148 days of values of each of these parameters is included in the correlation, representing an estimate of the length of memory in the Delta."

3.3 Linking WEAP to the Delta ANN

The ANN itself is configured as a Fortran-compiled DLL that contains several functions. These functions include routines for calculating the EC at various locations for previous timesteps and for calculating the parameters used in

[1] At the time of this writing these reports were all available for download at http://modeling.water.ca.gov/delta/models/ann/index.html

equations to set flow targets and export constraints. For the purposes of linking WEAP to the ANN it was necessary to recompile the DLL such that it could be called from WEAP. This required creating new functions within the DLL that received from WEAP a single double precision array of values, rather than several individual real and integer values as it is done with CalSim. To do this, we wrote Fortran code that created new functions callable from WEAP that are essentially "wrappers" to the existing DLL functions. An example of this code is shown in Appendix 8.1. The DLL functions that are used in the PA model are:

- ANNECARRAY which calculates the salinity from the previous month at different stations within the Delta.
- ANNEC_MATCHDSM2ARRAY which calculates the salinity from two months prior at different stations within the Delta.
- ANNLINEGENARRAY which calculates the slope and intercept of the linear equation that is used to constrain Delta exports as a function of inflows from the Sacramento River and Yolo Bypass.

To access these routines within the DLL, WEAP uses a 'Call' function which takes the following form: Call(DLLFileName ! DLLFunctionName, parameter1, parameter2, ...). Where there is only one DLLFileName (e.g. Ann7inp_CS3_Base_SLR0cm_20210204.dll) for every call to the DLL; the DLLFunctionName was one of the three functions listed above; and the parameters differ between the three functions and are listed in Table 1, Table 2, and Table 3.

It should be noted here that in both CalSim and WEAP only the last function (AnnLineGen in Calsim and AnnLineGenArray in WEAP) is needed to set flow targets and export constraints. The other two functions are called only to report the estimated Delta water quality from the previous months.

Table 1 List of Parameters for ANN function AnnECArray

Parameter Number	Description	Parameter(s)
1-5	Sacramento River flows at Hood over previous 5 months	C400_5, C400_4, C400_3, C400_2, C400_1
6-10	CVP and SWP Delta Exports over previous 5 months	D409_5, D409_4, D409_3, D409_2, D409_1
11-15	San Joaquin River flows at Vernalis over previous 5 months	C639_5, C639_4, C639_3, C639_2, C639_1
16-20	Number of days the delta cross channel gates are open for each of the previous 5 months	DXC_5, DXC_4, DXC_3, DXC_2, DXC_1
21-25	Net in-Delta consumptive use over previous 5 months	net_DICU_5, net_DICU_4, net_DICU_3, net_DICU_2, net_DICU_1
26-30	Other Sacramento River Basin inflows to the Delta over previous 5 months	sac_oth_5, sac_oth_4, sac_oth_3, sac_oth_2, sac_oth_1
31-35	Other Delta Exports over previous 5 months	exp_oth_5, exp_oth_4, exp_oth_3, exp_oth_2, exp_oth_1
36-40	Suisun Marsh Salinity Control Gate over previous 5 months	SMSCG_5, SMSCG _4, SMSCG _3, SMSCG _2, SMSCG _1
41-45	Number of days in the month over previous 5 months	daysin_5, daysin_4, daysin_3, daysin_2, daysin_1
46	Station identifier*	Jersey Point (JP) = 1 Rock Slough (RS) = 2 Emmaton (EM) = 3 Collinsville (CO) = 5
47	Average type**	Monthly average = 1 Maximum 14-day value = 6
48	Previous month index	Mo = 12 if October Otherwise, Mo = TS-1
49	Previous month water year	Year = Water Year - 1 if October, Otherwise, Year = Water Year

Notes: *The ANN functions were developed to consider twelve different stations. However, only four are used.

**The average type is used for the functions that return estimates of water quality (i.e. AnnECArray and AnnEC_matchDSM2Array). There are eight different types of averages that the can be calculated by various functions within the DLL. Only two are used in both CalSim-II and WEAP.

Table 2 List of Parameters for ANN function AnnEC_matchDSM2Array

Parameter Number	Description	Parameter(s)
1-7	Sacramento River flows at Hood over previous 7 months	C400_7, C400_6, C400_5, C400_4, C400_3, C400_2, C400_1
8-12	CVP and SWP Delta Exports over previous 2 to 6 months	D409_6, D409_5, D409_4, D409_3, D409_2
13-19	San Joaquin River flows at Vernalis over previous 7 months	C639_7, C639_6, C639_5, C639_4, C639_3, C639_2, C639_1
20-24	Number of days the delta cross channel gates are open for each of the previous 2 to 6 months	DXC_6, DXC_5, DXC_4, DXC_3, DXC_2
25-29	Net in-Delta consumptive use over previous 2 to 6 months	net_DICU_6, net_DICU_5, net_DICU_4, net_DICU_3, net_DICU_2
30-34	Other Sacramento River Basin inflows to the Delta over previous 2 to 6 months	sac_oth_6, sac_oth_5, sac_oth_4, sac_oth_3, sac_oth_2
34-39	Other Delta Exports over previous 2 to 6 months	exp_oth_6, exp_oth_5, exp_oth_4, exp_oth_3, exp_oth_2
40-44	Suisun Marsh Salinity Control Gate over previous 2 to 6 months	SMSCG _6, SMSCG _5, SMSCG _4, SMSCG _3, SMSCG _2
45-51	Number of days in the month over previous 7 months	daysin_7, daysin_6, daysin_5, daysin_4, daysin_3, daysin_2, daysin_1
52	Station identifier*	Jersey Point (JP) = 1 Rock Slough (RS) = 2 Emmaton (EM) = 3 Collinsville (CO) = 5
53	Average type**	Monthly average = 1 Maximum 14-day value = 6
54	Index for 2 months prior	Mo = 11 if October Mo = 12 if November Otherwise, Mo = TS-2
55	Water year for 2 months prior	Year = Water Year - 1 if October or November, Otherwise, Year = Water Year

Notes: *The ANN functions were developed to consider twelve different stations. However, only four are used.

**The average type is used for the functions that return estimates of water quality - i.e. AnnECArray and AnnEC_matchDSM2Array. There are eight different types of averages that the can be calculated by various functions within the DLL. Only two are used in both CalSim-II and WEAP.

Table 3 List of Parameters for ANN function AnnLineGenArray

Parameter Number	Description	Parameter(s)
1-4	Sacramento River flows at Hood over previous 4 months	C400_4, C400_3, C400_2, C400_1
5-8	CVP and SWP Delta Exports over previous 4 months	D409_4, D409_3, D409_2, D409_1
9-12	San Joaquin River flows at Vernalis over previous 4 months	C639_4, C639_3, C639_2, C639_1
13	Estimate of current month's San Joaquin River flows at Vernalis	SJR_ann_est
14-17	Number of days the delta cross channel gates are open for each of the previous 4 months	DXC_4, DXC_3, DXC_2, DXC_1
18	Estimate of current month's number of days with delta cross channel gates open	DXC_est
19-22	Net in-Delta consumptive use over previous 4 months	net_DICU_4, net_DICU_3, net_DICU_2, net_DICU_1
23	Estimate of current month's net in-Delta consumptive use	Net_delta_cu
24-27	Other Sacramento River Basin inflows to the Delta over previous 4 months	sac_oth_4, sac_oth_3, sac_oth_2, sac_oth_1
28	Estimate of current month's inflow to Delta from other Sacramento River Basin sources	sac_oth_est
29-32	Other Delta Exports over previous 4 months	exp_oth_4, exp_oth_3, exp_oth_2, exp_oth_1
33	Estimate of current month's other Delta Exports	exp_oth_est
34-37	Suisun Marsh Salinity Control Gate over previous 4 months	SMSCG _4, SMSCG _3, SMSCG _2, SMSCG _1
38	Estimate of current month's San Joaquin River water quality at	VernWQFinal_est

Parameter Number	Description	Parameter(s)
	Vernalis	
39-42	Number of days in the month over previous 4 months	daysin_4, daysin_3, daysin_2, daysin_1
43	Number of days in current month	daysin
44	Water quality standards	Water year dependent, monthly varying EC standards at Jersey Point, Rock Slough, Emmaton, and Collinsville
45	Lower bound for linearization of export constraint*	JP_line_lo, CO_line_lo, EM_line_lo, RS_line_1_lo, RS_line_2_lo, RS_line_3_lo
46	Upper bound for linearization of export constraint*	JP_line_hi, CO_line_hi, EM_line_hi, RS_line_1_hi, RS_line_2_hi, RS_line_3_hi
47	Station identifier**	Jersey Point (JP) = 1 Rock Slough (RS) = 2 Emmaton (EM) = 3 Collinsville (CO) = 5
48	Constant type***	Slope = 1 Intercept = 2
49	ANN type****	Value = 1
50	Previous month index	Mo = 12 if October Otherwise, Mo = TS-1
51	Previous month water year	Year = Water Year - 1 if October, Otherwise, Year = Water Year
52	Mystery Parameter****	Value = 1 for RS linearization #1 Value = 2 for RS linearization #2 Value = 3 for RS linearization #3 Value = 4 for JP, CO, and EM

Notes: *Parameters and associated values derived directly from CalSim model inputs

**The ANN functions were developed to consider twelve different stations. However, only four are used.

***The constant type is used for the function (i.e. AnnLinGenArray) that returns to WEAP the constants that are used in equations that constrain delta exports based on Sacramento River and Yolo Bypass flows.

****No explanation could be found for parameters 49 and 52.

3.3.1 Calculating ANN Input Parameters

Each of the ANN input parameters listed in Table 1, Table 2, and Table 3 were added as user-defined variables within the CVPA model. These were added into WEAP's data tree structure under "Other Assumptions". Specifically, they were added under the branch "Other\Ops\ Delta Salinity\ANN". The WEAP expressions used to calculate values for these are shown in Table 4, where we show expressions only for calculating the previous month's values. This is easily and logically extended to earlier months using WEAP's PrevTSValue function.

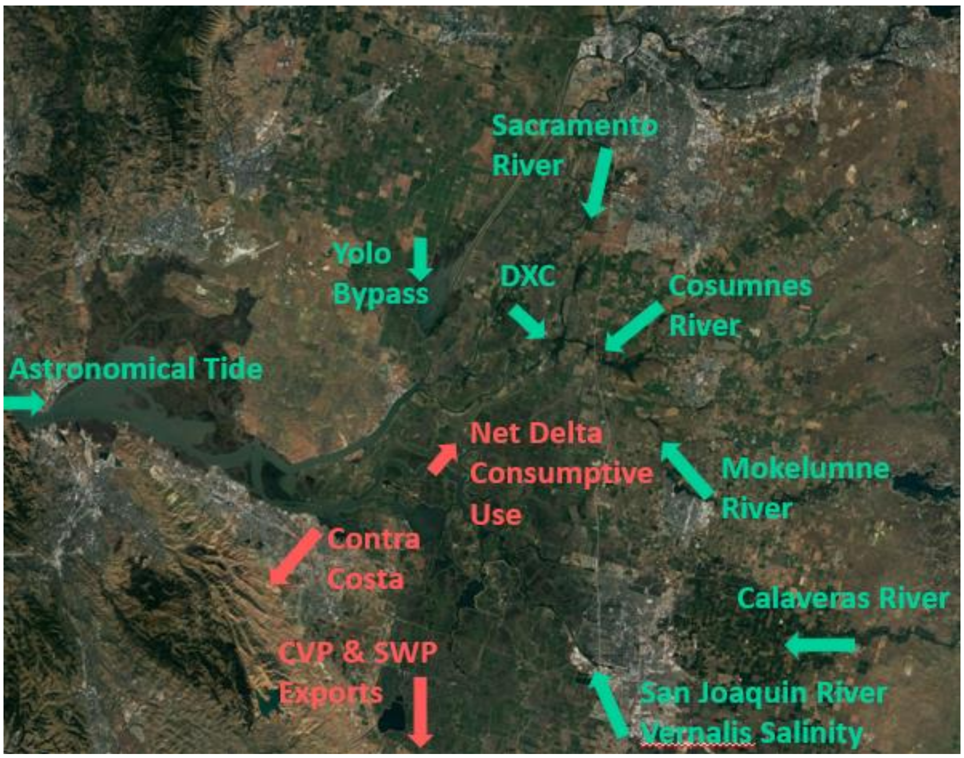


Table 4 WEAP Parameters Used as Input to Delta ANN

ANN Input Parameter	Description	WEAP Expression Used to Calculate Parameter Value
C400_1	Previous month's Sacramento River flows at Hood	PrevTSValue(Supply and Resources\River\Sacramento River\Reaches\Below SAC to PA510_outdoor:Streamflow[CFS])
D409_1	Previous month's combined CVP pumping at Tracy and SWP pumping at Banks	PrevTSValue(Supply and Resources\River\Delta Mendota Canal\Reaches\Below Delta Mendota Canal Diverted Inflow:Streamflow[CFS]) +~PrevTSValue(Supply and Resources\River\California Aqueduct\Reaches\Below California Aqueduct Diverted Inflow:Streamflow[CFS])
C639_1	Previous month's San Joaquin River flows at Vernalis	PrevTSValue(Supply and Resources\River\San Joaquin River\Reaches\Below Vernalis:Streamflow[CFS])
DXC_1	Previous month's number of days with delta cross channel open	If(C400>25000, 0, 1) * MonthlyValues(Oct, 31, Nov, 20, Dec, 16, Jan, 11, Feb, 0, Mar, 0, Apr, 0, May, 0, Jun, 26, Jul, 31, Aug, 31, Sep, 30)
Net_DICU_1	Previous month's net in-Delta consumptive use	PrevTSValue(Demand Sites and Catchments\PA510:Water Demand[CFS]) + PrevTSValue(Demand Sites and Catchments\PA602_North:Water Demand[CFS]) - PrevTSValue(Demand Sites and Catchments\PA510:Interflow[CFS]) - PrevTSValue(Demand Sites and Catchments\PA510:Base Flow[CFS]) - PrevTSValue(Demand Sites and Catchments\PA602_North:Interflow[CFS]) - PrevTSValue(Demand Sites and Catchments\PA602_North:Base Flow[CFS])
Sac_oth_1	Previous month's other Sacramento River Basin inflows to the Delta	PrevTSValue(Supply and Resources\River\Yolo Bypass\Reaches\Below Yolo Bypass to PA510:Streamflow[CFS]) +PrevTSValue(Supply and Resources\River\Mokelumne River\Reaches\Below Cosumnes River Inflow:Streamflow[CFS]) +PrevTSValue(Supply and Resources\River\Calaveras River\Reaches\Below CAL to PA603S PA603_indoor PA602_indoor:Streamflow[CFS])
Exp_oth_1	Previous month's other	PrevTSValue(Supply and Resources\Transmission Links\to

ANN Input Parameter	Description	WEAP Expression Used to Calculate Parameter Value
	exports from the Delta	PA601andCC_Indoor\from SAC to PA601andCC_Indoor:Flow[CFS]) + 0.1 * PrevTSValue(Supply and Resources\Transmission Links\to PA602_North\from SJR to PA602N:Flow[CFS])
SMSCG_1	Previous month's Suisun Marsh Salinity Control Gate status	The CVPA WEAP model includes a sub-routine that assesses the status of the Suisun Marsh Salinity Control Gate based on previous month’s salinity levels

3.3.2 Estimating Current Timestep Values

The ANN also requires estimates of current timestep values for the for each of the parameters listed in Table 4 except the first two (i.e., Sacramento River flows at Hood and combined CVP and SWP pumping from the Delta). To estimate these values, we again used a statistical approach. This time, comparing estimates to simulations from a baseline WEAP run from 1950 to 2005. The development of these estimates is described below.

San Joaquin River Flows at Vernalis

The current month's San Joaquin River flow at Vernalis is estimated by the following equation:

SJR_ann_est = 0.575 * average monthly flow at Vernalis +
(1 - 0.575) * previous month's flow at Vernalis * monthly perturbation

where the monthly perturbation is the ratio of average current month's flows over the average of the previous month's flows at Vernalis and is shown with the average monthly flows at Vernalis in Table 5. The agreement of this estimation (SJR_ann_est) with simulated values of flow at Vernalis (C639) are shown in Figure 2.

Net in-Delta Consumptive Use

The PA model estimates the current month's net in-Delta consumptive use using average monthly values derived from a 1950-2005 WEAP baseline simulation (Table 6). The agreement of this estimation (net_DICU_est) with simulated values of net in-Delta consumptive use (net_DICU) are shown in Figure 3.

Other Delta Exports

The current month's other Delta exports is estimated by the following equation:

exp_oth_est = 0.90 * average monthly 'other exports' +
(1 - 0.90) * previous month's 'other exports' * monthly perturbation

where the monthly perturbation is the ratio of average current month's 'other exports' over the average of the previous month's 'other exports' and is shown with the average monthly 'other exports' in Table 7. The agreement of this estimation (exp_oth_est) with simulated values of 'other exports' (exp_oth) are shown in Figure 5.

Other Sacramento River Basin Inflows to the Delta

The current month's other Sacramento River basin inflows to the Delta is estimated by the following equation:

sac_oth_est = 0.75 * average monthly (Mokelumne+Cosumnes+ Calaveras) inflows +
(1 - 0.75) * previous month's Mok+Cos+Cal inflows * monthly perturbation + average monthly Yolo Bypass inflows

where the monthly perturbation is the ratio of average current month's inflows over the average of the previous month's combined inflows and is shown with the average monthly values in Table 8. Average monthly Yolo Bypass inflows are shown in Table 9. The agreement of this estimation (sac_oth_est) with baseline simulated valued (sac_oth) is shown in Figure 5 and Figure 6.

It is worth noting here that the statistical approach appears to break down for the case of the Yolo Bypass, whose flows are much more irregular than other flows in the valley. Future refinements should consider developing a more deterministic approach to estimating Yolo Bypass Flows.

Delta Cross Channel Gates

Within the current timestep, the PA model uses the Water Quality Control Plan (1995) monthly varying estimate of the number of days that the gates are open (Table 10), which was taken from the CalSim-II model.

Table 5 1950-2005 Simulated Average Monthly Flow at Vernalis by San Joaquin River Water Year Type (CFS)

	Wet	Above Normal	Below Normal	Dry	Critical	Monthly Perturbation
OCT	3,371	5,132	3,566	4,296	1,921	1.15
NOV	2,303	3,008	2,584	2,657	1,730	0.68
DEC	3,182	5,512	2,822	2,771	1,643	1.29
JAN	6,655	5,964	3,378	3,273	1,665	1.46
FEB	9,715	7,033	4,006	4,157	2,208	1.34
MAR	13,620	4,573	3,106	2,996	2,181	1.10
APR	17,170	6,092	4,303	3,375	1,787	1.24
MAY	26,041	5,770	2,685	2,107	1,547	1.30
JUN	8,639	3,106	2,180	2,288	2,227	0.42
JUL	2,053	2,093	1,840	2,053	1,850	0.44
AUG	1,792	1,756	1,628	1,602	1,979	0.89
SEP	5,264	3,444	1,585	1,503	1,579	1.75

Figure 2 Statistical Estimation of San Joaquin River Flows at Vernalis

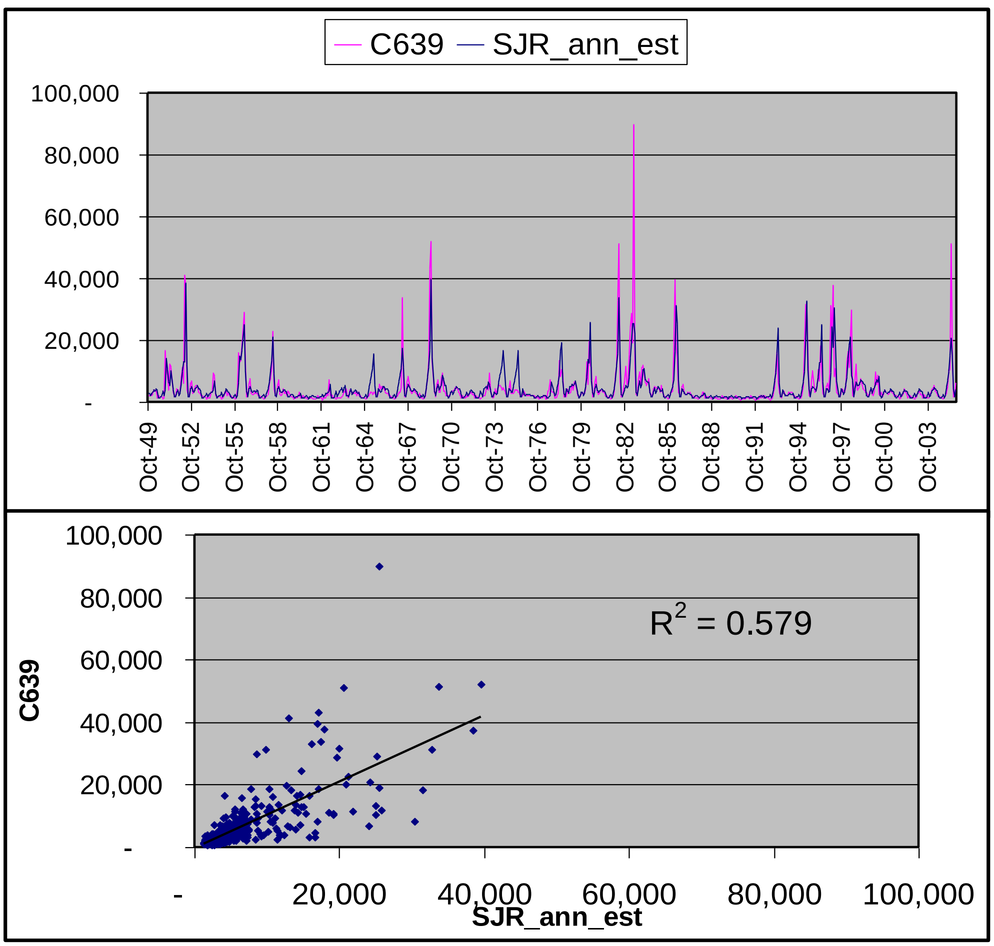


Table 6 1950-2005 Simulated Average Monthly Net in-Delta Consumptive Use by Sacramento River Water Year Type (CFS)

	Wet	Above Normal	Below Normal	Dry	Critical
OCT	208	195	422	259	204
NOV	266	338	444	387	452
DEC	(358)	(277)	(144)	(149)	(71)
JAN	(499)	(467)	(215)	(193)	(44)
FEB	(306)	(362)	(75)	149	162
MAR	104	123	601	626	739
APR	870	1,149	1,611	1,537	1,537
MAY	1,902	1,804	2,415	2,370	2,097
JUN	3,500	3,582	3,676	3,665	3,573
JUL	2,917	2,966	2,957	2,982	2,978
AUG	2,861	2,871	2,890	2,871	2,893
SEP	514	536	516	505	531

Figure 3 Statistical Estimation of in-Delta Net Consumptive Use

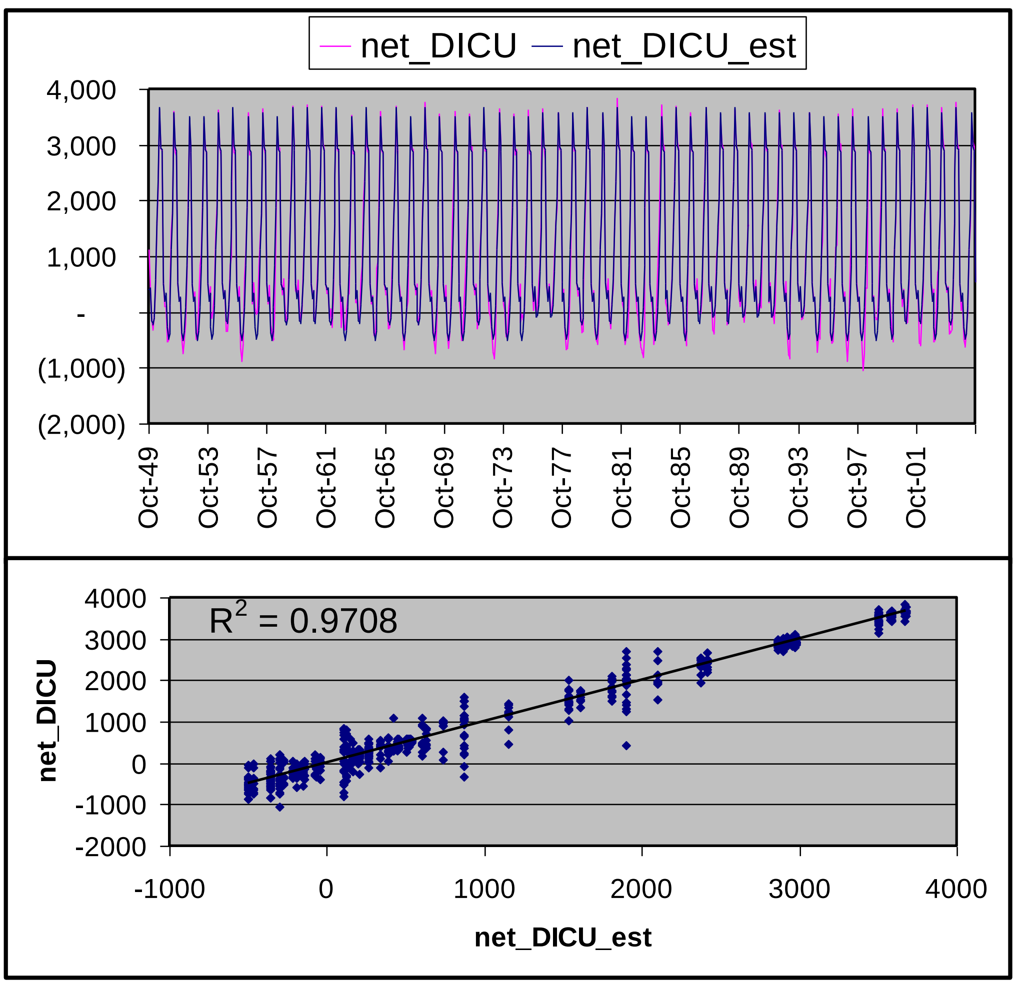


Table 7 1950-2005 Simulated Average Monthly 'Other Delta Exports' (CFS)

	Wet	Above Normal	Below Normal	Dry	Critical	Monthly Perturbation
OCT	238	238	241	238	238	0.96
NOV	262	263	266	265	266	1.11
DEC	231	231	232	232	232	0.88
JAN	231	231	231	231	232	1.00
FEB	231	231	231	234	234	1.01
MAR	253	251	267	270	274	1.13
APR	294	308	328	325	325	1.20
MAY	347	336	367	366	351	1.12
JUN	429	433	436	436	432	1.23
JUL	391	393	392	393	393	0.91
AUG	375	375	376	375	376	0.96
SEP	249	249	249	249	249	0.66

Figure 4 Statistical Estimation of Other Delta Exports

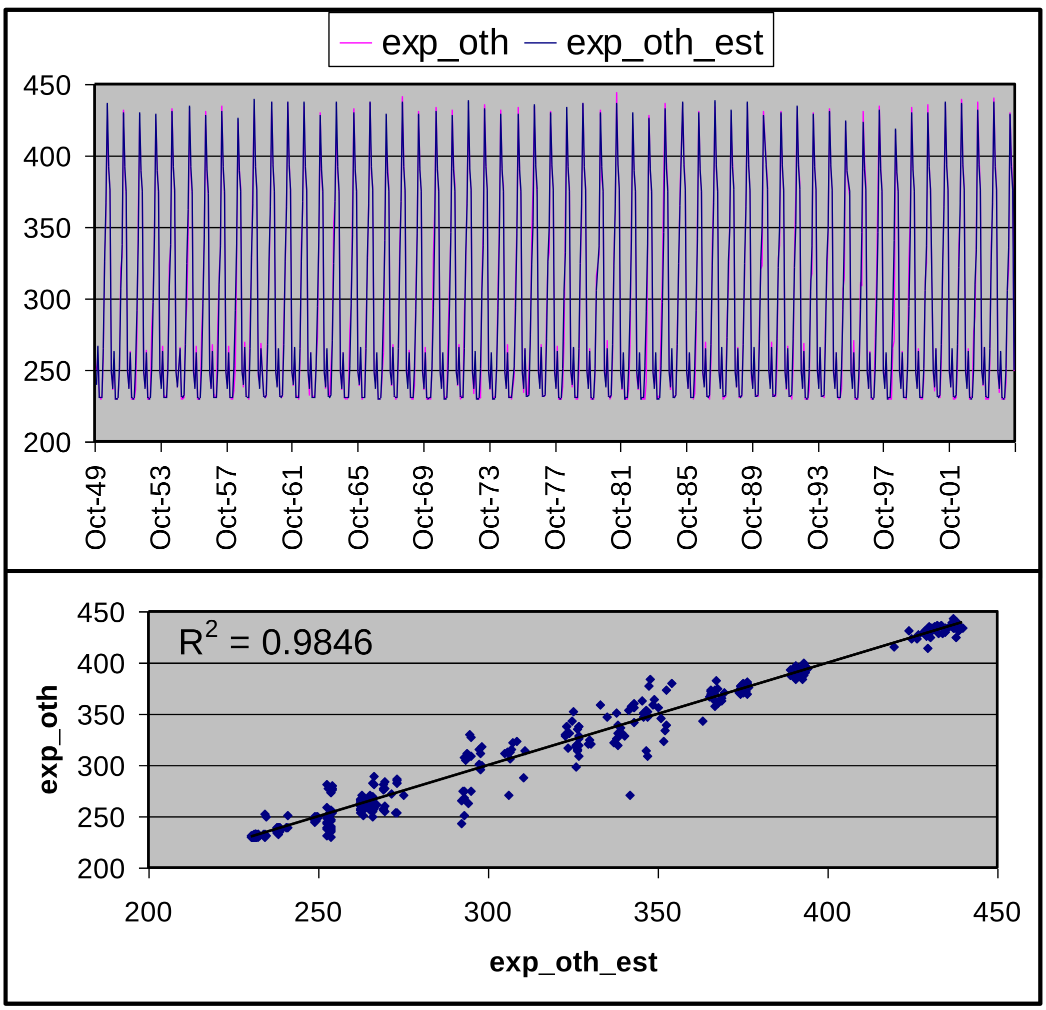


Table 8 Simulated Average Monthly Combined Mokelumne-Cosumnes-Calveras Inflows to the Delta (CFS)

	Wet	Above Normal	Below Normal	Dry	Critical	Monthly Perturbation
OCT	980	1523	937	1329	1129	2.67
NOV	688	1229	562	640	355	0.59
DEC	2619	3029	1159	1091	401	2.39
JAN	6052	3554	1804	1437	552	1.61
FEB	7078	5404	2362	2054	843	1.32
MAR	6371	3625	2080	1821	1195	0.85
APR	4773	2570	2318	1182	1029	0.79
MAY	2897	1507	1175	740	560	0.58
JUN	863	676	550	439	357	0.42
JUL	474	438	344	320	240	0.63
AUG	363	360	270	275	197	0.81
SEP	681	555	387	391	195	1.51

Figure 5 Statistical Estimation of Combined Mokelumne-Cosumnes-Calaveras River Inflows to the Delta (CFS)

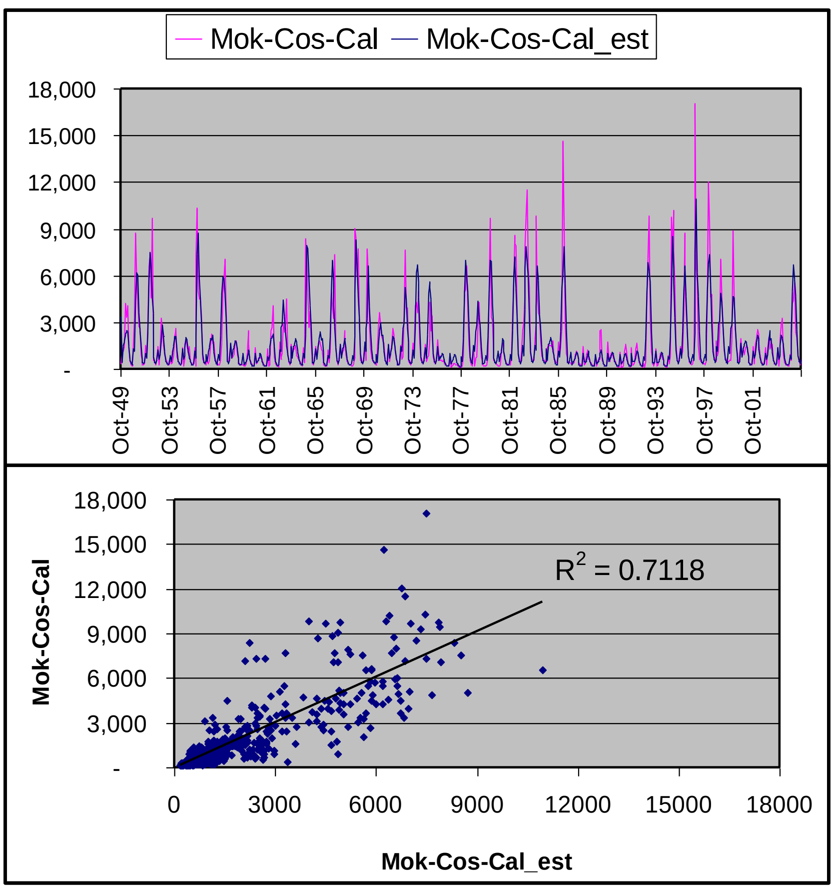


Table 9 Simulated Average Monthly Yolo Bypass Inflows to the Delta (CFS)

	Wet	Above Normal	Below Normal	Dry	Critical
OCT	381	498	249	336	304
NOV	844	950	658	692	472
DEC	6308	8285	1699	1359	708
JAN	20395	16679	5618	1997	1027
FEB	39306	18199	2890	4165	1454
MAR	21348	3050	2090	1850	1399
APR	3932	1594	1279	766	765
MAY	778	335	313	36	99
JUN	75	0	0	1	0
JUL	0	0	0	0	0
AUG	0	0	0	0	0
SEP	272	213	179	191	151

Figure 6 Statistical Estimation of Yolo Bypass Inflows to the Delta (CFS)

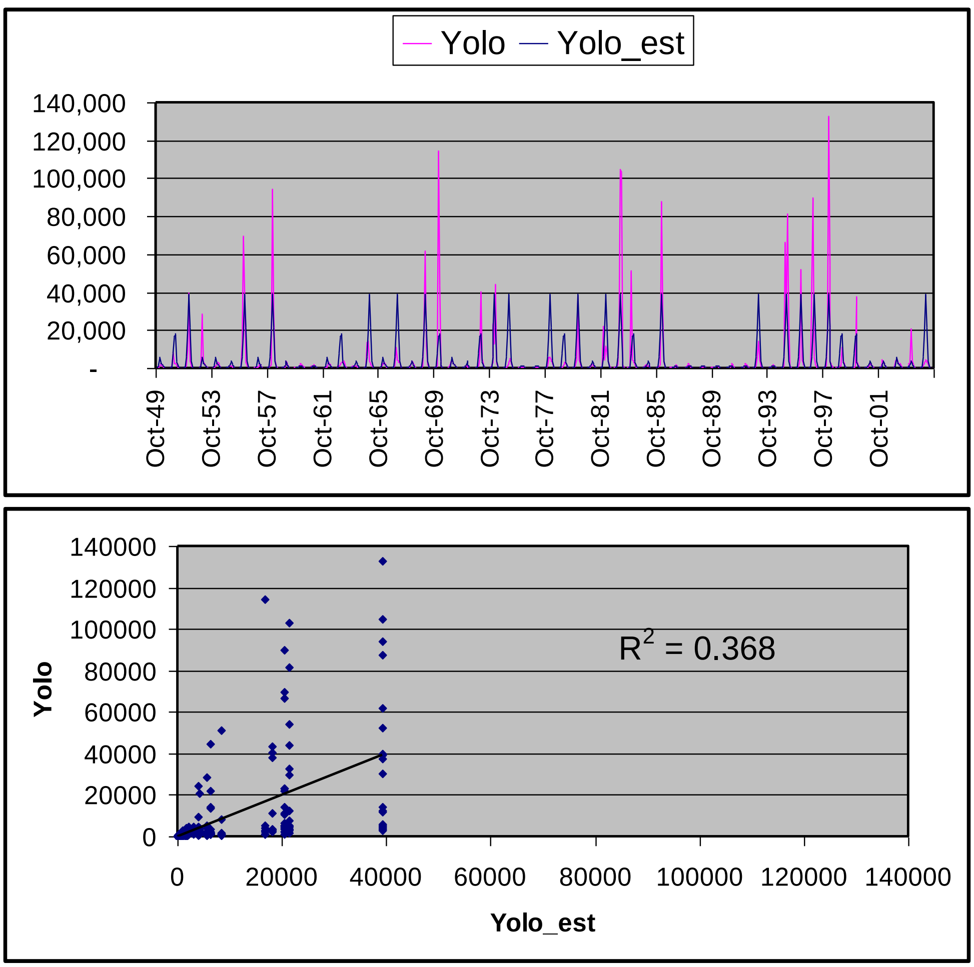


Table 10 Days Open for Delta Cross-Channel Gate (WQCP, 1995)

Month	Number of Days Open
OCT	31
NOV	20
DEC	16
JAN	11
FEB	0
MAR	0
APR	0
MAY	0
JUN	26
JUL	31
AUG	31
SEP	30

3.4 Comparison of CVPA and SacWAM Modeled Salinity

The ANN is used to set flow requirements in order to meet Delta salinity standards. For model verification purposes, we compared the flow requirement estimates to similar outputs from the SacWAM implementation of the ANN (Figure 7). It should be noted that the two models are not expected to have the same flow requirements from month-to-month, because of the differences in the way that each represents hydrology and system operations. However, we should expect that the ANN returns similar values for both models across a common historical period of analysis. The comparison below shows that the implementation of the Delta ANN within the CVPA model returns similar flow requirements to those seen in SacWAM over a period of analysis 1970-2005.

The Delta ANN also reports the estimated salinity levels at four locations in the Delta. These values are shown for both the CVPA model and SacWAM in Figure 8 through Figure 11 below. These graphs indicate that the implementation of the ANN is working similarly for both models. Differences in the values are due to many factors, including water conveyance and consumption in the Sacramento Valley, as well as differences in the way each model represents accretions and depletions within the Delta.

Figure 7 ANN Delta Salinity Flow Requirements

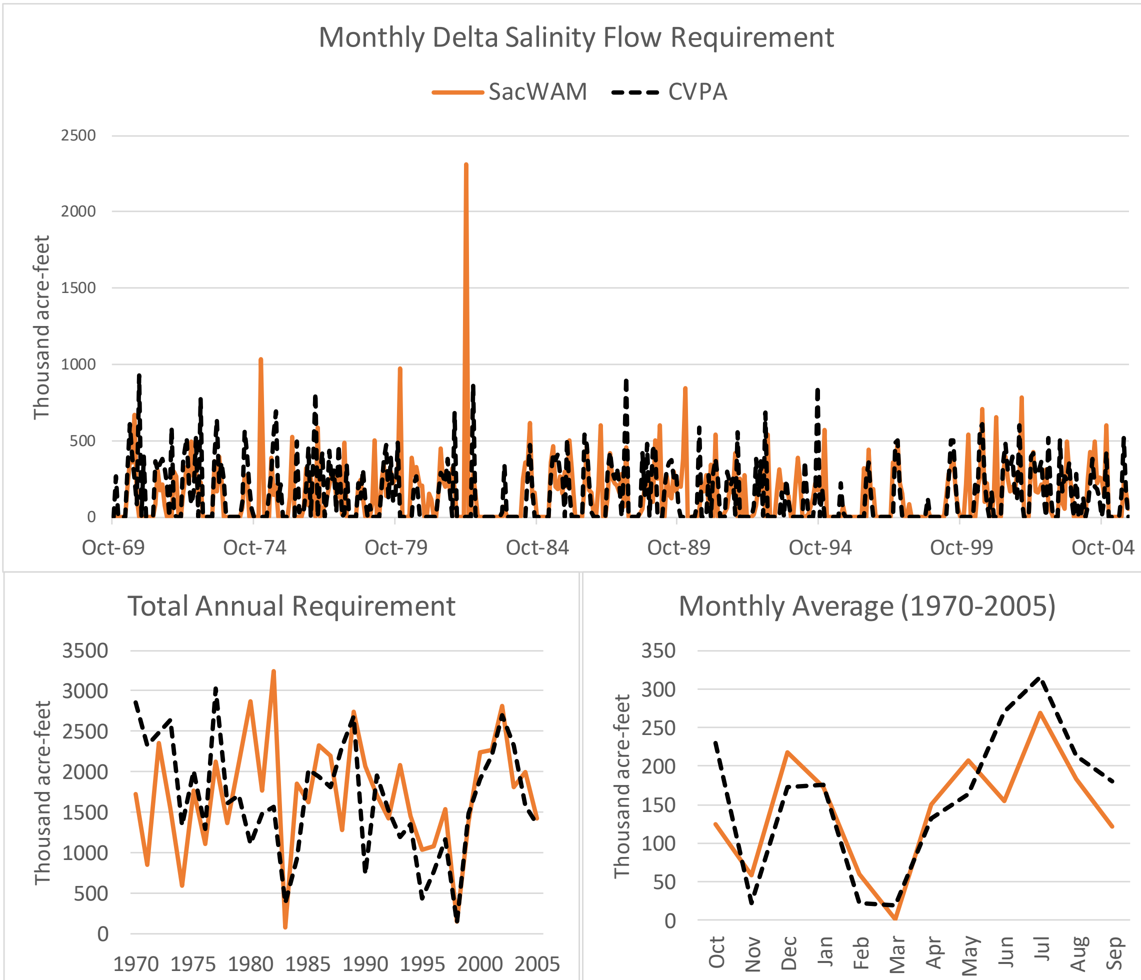


Figure 8 Simulated salinity at Collinsville

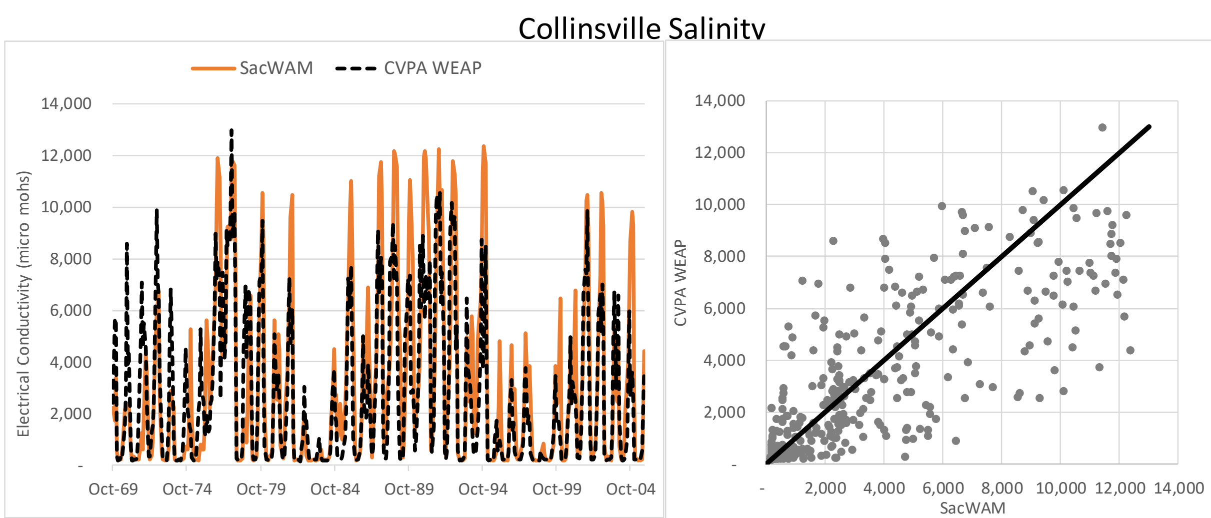


Figure 9 Simulated salinity at Emmaton

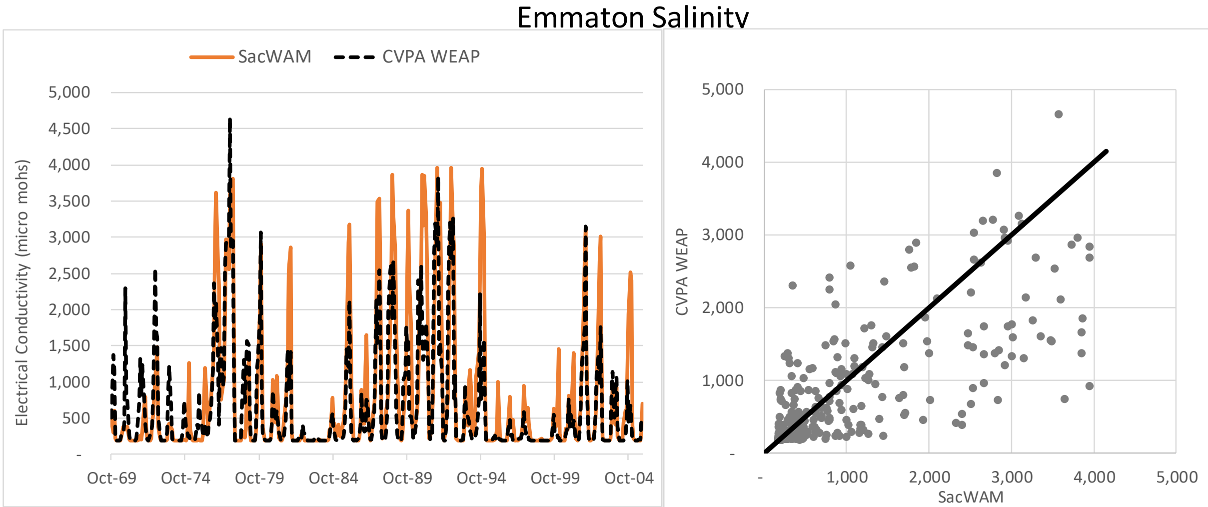


Figure 10 Simulated salinity at Jersey Point

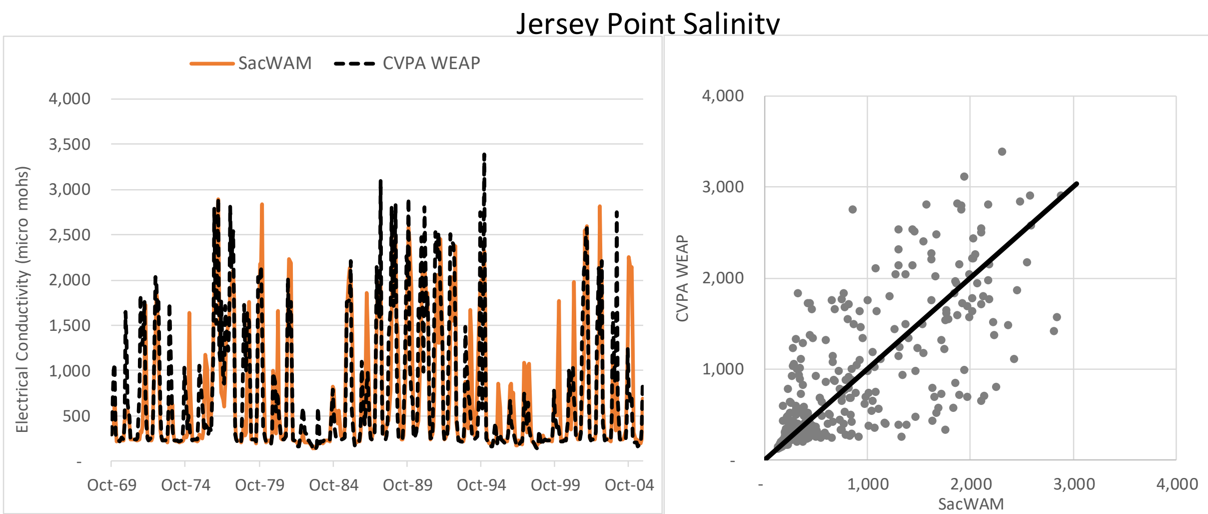
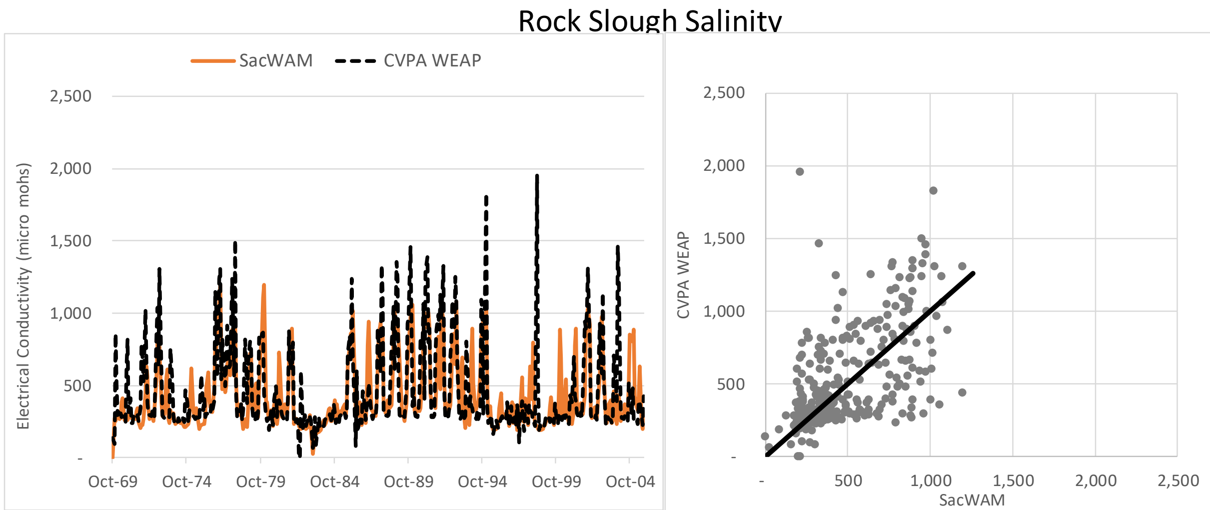


Figure 11 Simulated salinity at Rock Slough



4.0 USFW Biological Opinion

The 2008 USFWS BiOp determined that the continued operation of the CVP and SWP would likely result in adverse modification to critical habitat of the delta smelt that would jeopardize the species' existence within the Delta. This jeopardy determination led to the development of a Reasonable and Prudent Alternative (RPA) that was designed to avoid the likelihood of these threats. RPA includes Components 1 and 2 that are intended to reduce Delta exports, as indexed by the combined Old and Middle River (OMR) flows, when the entrainment risk of delta smelt increases. The implementation of these actions in the CVPA model is described in the sections below.

4.1 USFWS Action 1

Action1 provides adult delta smelt entrainment protection during the initial winter flow pulse that may occur from December through March and limits Delta exports so that OMR flows (*A1_OMR_Target*) are no more negative than -2,000 cfs for a total duration of 14 days, with a 5-day running average of -2,500 cfs. In the CVPA model, Action 1 may be triggered beginning December 21 when the three-day average turbidity at Prisoner's Point, Holland Cut, and Victoria Canal exceeds 12 nephelometric turbidity units (NTU). The CVPA model uses the unimpaired Sacramento Valley Four Rivers Index[2] (*SAC_RI*) as a surrogate for the turbidity trigger for this action, assuming 20,000 cfs (*Turbidity_Threshold*) is a conservative indicator of the 12 NTU threshold.[3] For modeling purposes, if turbidity-trigger conditions first occur in December, then the action starts on December 21; if turbidity-trigger conditions first occur in January, then the action starts on January 1; if turbidity-trigger conditions first occur in February, then the action starts on February 1; and if turbidity-trigger conditions first occur in March, then the action starts on March 1. It is assumed that once the action is triggered,

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[2] Sacramento River at Bend Bridge, Feather River at Oroville, Yuba River near Smartville, and American River at Folsom.

[3] This procedure is a modification of that implemented by DWR and Reclamation in CalSim II. Instead of the Sacramento River Index, CalSim II uses the sum of: inflows to Lake Shasta, Oroville, and Folsom, and the Yuba River flow above Daguerre Point Dam. The unimpaired Sacramento Valley Four Rivers Index is approximately 20% greater than values used by CalSim II to trigger Action 1.

it continues for 14 days. In the CVPA model, there are six water years in which Action 1 is not triggered: 1924, 1930, 1931, 1976, 1977, and 1994.

- **A1_OMR_Target**

  The parameter *A1_OMR_Target* represents the lower bound on OMR flow when Action 1 is triggered. It has a constant value of -2,000 cfs.

- **A1_TurbT**

  The parameter *A1_TurbT* indicates when Action 1 is triggered. It is calculated as a function of the month, Sacramento Valley Four Rivers Index, turbidity threshold, and whether action has been previously triggered. A value of 1 indicates Action 1 is triggered in December, 2 indicates action triggered in January, 3 for February, and 4 for March. A value of 99 indicates that Action 1 is not triggered in the current month.

- **A1_TurbTC**

  The parameter *A1_TurbTC* indicates whether Action 1 is or has been triggered (value of 1) or not (value of 0). It is calculated from the parameter *A1_TurbT*. The parameter is not referenced elsewhere in the model and is for output purposes only.

4.2 USFWS Action 2

Action 2 is implemented as an adaptive process following Action 1 and is intended to protect pre-spawning adult delta smelt from entrainment after the winter pulse. Action 2 limits Delta exports so that OMR flows are no less negative than -5,000 cfs to -3,500 cfs depending on existing conditions within the Delta, with a 5-day running average within 25 percent of the monthly criteria, i.e., no more negative than -6,250 cfs or -4,375 cfs. The CVPA model uses the previous month X2 location as an indicator of Delta conditions. Action 2 continues until the onset of Action 3.

- **OMR_Target_X2_E_Roe**

  The parameter *OMR_Target_X2_E_Roe* is the Action 2 lower bound OMR flow when the location of X2 is east of Roe Island. Although, the model is set-up to vary the requirement as a function of the Sacramento Valley Water Year Type, it currently is assigned a constant value of -3,500 cfs.

- **OMR_Target_X2_W_Roe**

  The parameter *OMR_Target_X2_W_Roe* is the Action 2 lower bound OMR flow when the location of X2 is west of Roe Island. Although, the model is set-up to vary the requirement as a function of the Sacramento Valley Water Year Type, it currently is assigned a constant value of -5,000 cfs.

- **X2_A2**

  The parameter *X2_A2* is determined based on the previous month X2 location. If this X2 location was east of Roe Island (>64 miles) the parameter is assigned a value of 1, otherwise it is set to zero.

- **A2_OMR_Target**

  The parameter *A2_OMR_Target* is the Action 2 lower bound OMR flow determined from the parameters *OMR_Target_X2_E_Roe, OMR_Target_X2_W_Roe*, and *X2_A2.* The considerations for setting the Action 2 OMR standards are summarized in Table 11.

Table 11 Action 2 Old and Middle River Standard

Sacramento Valley Water-Year Type	Minimum Flow (cfs) X2 East of Roe (X2 > 64 km)	Minimum Flow (cfs) X2 West of Roe (X2 < 64 km)
Critical	-3,500	-5,000
Dry	-3,500	-5,000
Below Normal	-3,500	-5,000
Above Normal	-3,500	-5,000
Wet	-3,500	-5,000

Key: cfs=cubic feet per second; km=kilometers

- **Vernalis**

  The parameter *Vernalis* is the San Joaquin River flow at Vernalis.

- **Vernalis_Threshold**

  The parameter *Vernalis_Threshold* is the trigger for temporary suspension of Action 2 based on the San Joaquin River flow at Vernalis. Using the Hutton relationship (2008b), the probability of occurrence of a 3-day average flow at Vernalis exceeding 10,000 cfs is 50 percent when the Vernalis monthly flow is 10,988 cfs. Therefore, *Vernalis_Threshold* is assigned a value of 10,988 cfs.

- **Vernalis_Trigger**

  The parameter *Vernalis_Trigger* is assigned a value of 1 when the parameter *Vernalis* exceeds *Vernalis_Threshold*, so indicating the end of Action 2.

- **RioVista_Threshold**

  The parameter *RioVista_Threshold* is the trigger for ending Action 2 based on the Sacramento River flow at Rio Vista. Frequency of Rio Vista 3-day flow average > 90,000 cfs equals 50% when Freeport plus Yolo Bypass monthly flow is 67,820 cfs. Using the Hutton relationship (2008b), the probability of occurrence of a 3-day average flow at Rio Vista exceeding 90,000 cfs is 50 percent when the combined monthly flow for the Sacramento River at Freeport and the Yolo Bypass at the Lisbon Weir is 67,820 cfs. Therefore, *RioVista_Threshold* is assigned a value of 67,820 cfs.

- **RPA_14day_SuspendA2**

  The USFWS BiOp Action 2 is suspended temporarily when the 3-day average flows at Rio Vista and Vernalis exceed 90,000 cfs (*RioVista_Threshold*) and 10,000 cfs (*Vernalis_Threshold*), respectively. The CVPA model uses a flow peaking analysis, developed by Hutton (2008b), to determine the likelihood of a 3-day flow average greater than or equal to 90,000 cfs in Sacramento River at Freeport and a 3-day flow average greater than or equal to 10,000 cfs in San Joaquin River at Vernalis. The model suspends Action 2 for the entire month when the probability of both of these conditions occurring exceeds 50 percent.

4.3 USFWS Action 3

Action 3 is implemented as an adaptive approach intended to protect larval and juvenile delta smelt from entrainment. Similar to Action 2, Action 3 limits Delta exports so that OMR flows are no more negative than -5,000 to -1,250 cfs based on conditions within the Delta. The CVPA model uses the previous month X2 location as an indicator of these Delta conditions.

- **OMR_Target_X2_E_Collinsville**

  The parameter *OMR_Target_X2_E_Roe* is the Action 3 lower bound OMR flow when the location of X2 is east of Collinsville. Although, the model is set-up to vary the requirement as a function of the Sacramento Valley Water Year Type, it currently is assigned a constant value of -1,250 cfs.

- **OMR_Target_X2_W_Roe**

  The parameter *OMR_Target_X2_W_Roe* is the Action 3 lower bound OMR flow when the location of X2 is west of Roe Island. Although, the model is set-up to vary the requirement as a function of the Sacramento Valley Water Year Type, it currently is assigned a constant value of -5,000 cfs.

- **OMR_Target_X2_E_Between**

  The parameter *OMR_Target_X2_Between* is the Action 3 lower bound OMR flow when the location of X2 is between Roe Island and Collinsville. Although, the model is set-up to vary the requirement as a function of the Sacramento Valley Water Year Type, it currently is assigned a constant value of -3,500 cfs.

- **X2_A3**

  The parameter *X2_A3* is determined based on the previous month X2 location. If this X2 location was east of Collinsville (>64 miles) the parameter is assigned a value of 1, if the location is west of Roe Island, it is assigned a value of 2, otherwise it is set to a value of 3.

- **A3_OMR_Target**

  The parameter *A3_OMR_Target* is the Action 3 lower bound OMR flow determined from the parameters *OMR_Target_X2_E_Roe, OMR_Target_X2_W_Roe*, *OMR_Target_X2_Between*, and *X2_A3.* The considerations for setting the Action 3 OMR standards are summarized in Table 12.

Table 12 Action 3 Old and Middle River Standard

	Minimum Flow (cfs)		
Sacramento Valley Water-Year Type	X2 East of Collinsville (X2 > 74 km)	X2 in between (64 km < X2 < 74 km)	X2 West of Roe (X2 < 64 km)
Critical	-1,250	-3,500	-5,000
Dry	-1,250	-3,500	-5,000
Below Normal	-1,250	-3,500	-5,000
Above Normal	-1,250	-3,500	-5,000
Wet	-1,250	-3,500	-5,000

Key: cfs=cubic feet per second; km=kilometers

Action 3 can be triggered either when the average temperatures from three stations within the Delta (Mossdale, Antioch, and Rio Vista) exceed 12°C or when spent female delta smelt appear in the Spring Kodiak Trawl Survey or at Banks or Jones pumping plants (*A3_Trigger_month* and *A3_Trigger_day*). These triggers are indicative of spawning activity and probable presence of larval delta smelt in the south and central Delta.

In the CVPA model, the trigger is based on temperature data, where water temperature data from the three monitoring stations has been found to be highly correlated to measured air temperature at the Sacramento Executive Airport. Therefore, the CVPA model refers to air temperature within the PA511, which includes the airport. Because the CVPA has no good way of tracking biological triggers within the model, the trigger was held constant. For present purposes, the model is set up such that biological trigger is activated each year on May 15.

Temp_Trigger_Day

The parameter *Temp_Trigger_Day* is the day of the month in which Delta water temperatures trigger the start of Action 3. For present purposes, it is set at the 15th day of the month.

Temp_Trigger_Month

The parameter *Temp_Trigger_Month* is the month in which Delta water temperatures trigger the start of Action 3. Temperature data is referenced from PA511 and triggered when it exceed the threshold of 12°C.

Bio_Trigger_Day

Set constant on 8 (i.e. May)

Bio_Trigger_Month

Set constant at 15

A3_Trigger_Day

The parameter *A3_Trigger_Day* is the day of the month in which Action 3 is triggered. It is a function of *Temp_Trigger_Day, and Temp_Trigger_Month.*

A3_Trigger_Month

The parameter *A3_Trigger_Day* is the month in which Action 3 is triggered. It is the earlier of *Bio_Trigger_Month* and *Temp_Trigger_Month*.

Action 3 is suspended after 30th June or once certain temperature thresholds have been reached, whichever comes first. The temperature off-ramp used to suspend Action 3 is triggered whenever water temperature reaches a daily average of 25^{o}C for three consecutive days at Clifton Court Forebay. Unfortunately, there is no reliable correlation between water temperature at Clifton Court and nearby air temperature stations. Thus, for now, the CVPA model uses only the temporal off-ramp criterion (June 30) to end Action 3.

Temp_Offramp_Day

The parameter *Temp_Offramp_Day* is the day of the month in which water temperature triggers the end of Action 3. It is assigned a constant value of 30.

Temp_Offramp_Month

The parameter *Temp_Offramp_Month* is the month in which water temperature triggers the end of Action 3. It is assigned a constant value of 9 (equivalent to June).

The considerations for setting the USFWS BiOp OMR actions are summarized in Table 13. Additional parameters include:

OMR_background

The parameter *OMR_background* establishes the OMR condition in computing monthly values for partial month flow requirements. It is set to -5,000 cfs from January to March and -8,000 cfs from April to December based on assumptions adopted by DWR and Reclamation for CalSim II.

RPA_14day_Ave

The parameter *RPA_14day_Ave* is the day-weighted average OMR flow requirement resulting from Action 1, Action 2, and Action 3, which are described above.

RPA_NoA1

The parameter *RPA_NoA1* is the OMR flow requirement if Action 1 has not been triggered and before the onset of Action 3.

RPA_14day

The parameter *RPA_14day* is the maximum of *RPA_14day_Ave* and *RPA_NoA1.*

RPA_5day

Flow actions specified in the 2008 USFWS BiOp place limits on OMR reverse flows in terms of 14-day averages, but with the requirement that the simultaneous 5-day averages are to be within 25% of the 14-day averages. The parameter *RPA_5day* is the 5-day average flow requirement. A value of -99999 indicates there is no flow requirement.

RPA_FWS

An analysis by Hutton (2009) investigated how frequently the 5-day OMR flows, rather than 14-day OMR flows, would controls project operation. The CVPA model uses the results of this analysis to determine the more stringent of the 14-day and 5-day OMR requirement as represented by the parameter *RPA_FWS*. *RPA_FWS* also accounts for suspension of Action 2 during high flow events.

Table 13 OMR Action Triggers

Action 1 Triggered	Action 3 Triggered	December	January	February	March	April	May	June
December	February	Background Action 1	Action 2	Action 2 Action 3	Action 3	Action 3	Action 3	Action 3
	March	Background Action 1	Action 2	Action 2	Action 2 Action 3	Action 3	Action 3	Action 3
	April	Background Action 1	Action 2	Action 2	Action 2	Action 2 Action 3	Action 3	Action 3
January	February	OMR Background	Action 1 Action 2	Action 2 Action 3	Action 3	Action 3	Action 3	Action 3
	March	OMR Background	Action 1 Action 2	Action 2	Action 2 Action 3		Action 3	Action 3
	April	OMR Background	Action 1 Action 2	Action 2	Action 2	Action 2 Action 3	Action 3	Action 3
February	February	OMR Background		Action 1 Action 3	Action 3	Action 3	Action 3	Action 3
	March	OMR Background		Action 1 Action 2	Action 2 Action 3	Action 3	Action 3	Action 3
	April	OMR Background		Action 1 Action 2	Action 2	Action 2 Action 3	Action 3	Action 3
March	February	OMR Background		Action 3	Action 3	Action 3	Action 3	Action 3
	March	OMR Background			Action 1 Action 3	Action 3	Action 3	Action 3
	April	OMR Background			Action 1 Action 2	Action 2 Action 3	Action 3	Action 3
Not triggered	February	OMR Background		Action 3	Action 3	Action 3	Action 3	Action 3
	March	OMR Background			Action 3	Action 3	Action 3	Action 3
	April	OMR Background				Action 3	Action 3	Action 3

5.0 Coordinated Operations Agreement

In 1986, the DWR and Reclamation signed the Coordinated Operations Agreement (COA) that established a framework under which the projects operate to ensure that both the CVP and SWP receive an equitable share of the Central Valley's available water, while meeting their joint responsibilities for meeting water quality standards and providing water for other (senior) legal uses of water within the Sacramento Valley (in-basin uses [IBU]). The COA defines formulae for sharing joint CVP-SWP responsibilities for meeting Delta standards (as the standards existed in State Water Board Water Right Decision 1485 [D-1485]) and other in-basin legal uses of water, and identifies how unstored flow is to be shared between the two projects.

The implementation of COA in the CVPA model requires the model to determine whether there is unstored water for export (UWFE) that may be shared by the CVP and SWP, or there is in-Basin Use (IBU) within the Sacramento Valley and Delta that must be met by storage withdrawals from project reservoirs (or import of Trinity River water through the Clear Creek Tunnel). The existence of UWFE or IBU is determined by the UDC *In Basin Use\COA Balance* that calculates the difference between project exports and project storage releases, as follows:

> *UWFE - IBU = DeltaSurplus_CVP +DeltaSurplus_SWP+ CVP_EXP1 + CCWD_EXP1 + SWP_EXP1 + (2/3)*NBA_Art21+ (2/3)*NBA_TableA - StorageRelease_SWP - StorageRelease_CVP + Unused_FS + Unused_SS*

If the releases from project storage exceed project exports from the Delta, then there is in-Basin Use within the Sacramento Valley and Delta (*IBU* is non-zero and positive). Conversely, if Delta exports are greater than storage withdrawals, then there exists unused water for export (*UWFE* is non-zero and positive). The CVPA model uses the following definitions for these calculations:

> *Shasta Storage Release = Sacramento below Keswick - Inflow to Shasta - Spring Creek Tunnel diversion.*

> *Folsom Storage Release = American below Nimbus - Inflow to Folsom.*

Whiskeytown Storage Release/Trinity Import = Clear Creek below Whiskeytown + Spring Creek Tunnel diversion – Natural inflow to Whiskeytown Reservoir.

Oroville Storage Release = Feather River below Thermalito - Inflow to Lake Oroville - Thermalito Afterbay diversions - Power Canal diversions.

CVP Delta Exports = Export of CVP water at Jones Pumping Plant + Unused_SS.

*SWP Delta Exports = Export of SWP water at Banks Pumping Water + Unused_FS + 2/3*Table A and Article 21 water delivered from the North Bay Aqueduct.*

The ability of the two projects to use their share of water under COA may be limited by the physical and permitted capacities of their pumping plant and by other regulatory constraints. The decision variables *Unused_FS* and *Unused_SS* represent one project's use of the other project's water in instances when either the CVP or SWP cannot export their share of water because of export capacity or regulatory restrictions. The user-defined integer *int_Unused_FS_SS* and the associated pair of UDCs *int_Unused_FS_SS Eqn1* and *int_Unused_FS_SS_Eqn2* prevent both *Unused_FS* and *Unused_SS* having non-zero values in the same time step.

Delta outflow is divided into (a) the part that is required to meet regulatory requirements, which is part of in-Basin Use, and (b) Delta outflow that is surplus to regulatory requirements. Delta surplus outflow is further divided into CVP share (*Delta-Surplus_CVP*) and SWP share (*Delta-Surplus_SWP*).

The user-defined integer, *Int_IBU_UWFE*, and the associated pair of UDCs *IBU_force* and *UWFE_force* prevent *IBU* and *UWFE* from both having non-zero values in the same time step.

The COA defines sharing formulae for dividing UWFE between the two projects and assigning responsibilities for meeting IBU. The CVP is entitled to 55% of UWFE and SWP entitled to 45% of UWFE. The CVP is responsible for meeting 75% of IBU; the SWP is responsible for meeting the remaining 25% of IBU. The sharing formulae are implemented in the CVPA WEAP model using the UDCs *COA_CVP* and *COA_SWP* that are reproduced below.

> *CVP_EXP1 +CCWD_EXP1 + Unused_FS = StorageRelease_CVP - 0.75*IBU + 0.55*UWFE - DeltaSurplus_CVP*
>
> *SWP_EXP1 + (2/3)* NBA_Art21 + (2/3)* NBA_TableA + Unused_SS = StorageRelease_SWP - 0.25*IBU + 0.45*UWFE - DeltaSurplus_SWP*

The use of unused Federal share (*Unused_FS)* by the SWP and unused State share (*Unused_SS*) by the CVP is controlled by a mix of constraints and priorities.

In the CVPA model, code related to COA is implemented as User-Defined LP Constraints and organized in to a set of seven subbranches, which are described below.

5.1 Delta Exports

CVP exports from the South Delta include delivery of CVP water to Contra Costa WD and flows through Jones Pumping Plant. The latter is disaggregated into components ‘exp1’ and ‘exp2’ to distinguish between diversion of CVP water and diversion of unused SWP water, respectively. Similarly, SWP exports at Banks Pumping Plant are disaggregated into components ‘exp1’ and ‘exp2’ to represent diversion of SWP water and diversion of unused CVP water, respectively. Banks pumping also includes components ‘CVP_CVC’ and ‘CVP_JPOD’ to simulate wheeling of CVP water through the pumping plant.

5.2 Delta Outflow

The *Delta Outflow* branch divides Delta outflow into two components:

- The *Delta Outflow Requirement* is the outflow needed to meet all regulatory requirements, including for water quality purposes;
- *DeltaSurplus* is outflow over and above this requirement. For the purposes of COA accounting, Delta surplus is divided in to CVP water and SWP water.

A series of five equations (*DOR Eqn 1, 2…5*) constrain Delta outflow to be greater than that needed to meet MRDO, X2, salinity requirements, and proposed State Water Board standards (*SWRCB Delta:Minimum Flow Requirement*).

For output purposes, the CVPA model schematic includes a diversion arc *Delta Surplus* that removes and then returns a portion of Delta outflow from the main channel. A pair of UDCs, *DeltaSurplusRouting1* and *DeltaSurplusRouting2*, constrain the flow in the main channel, after *Delta Surplus* outflow, to be within 1 cfs of the Delta outflow requirement.

5.3 In-Basin Use

The *In-Basin Use* branch defines the two decisions variables *IBU* and *UWFE* and contains the *COA Balance* constraint for determining the values of these variables. The integer decision variable *int_IBU_UWFE* and the associated constraints *IBU_force* and *UWFE_force* prevent *IBU* and *UWFE* from both having non-zero values.

5.4 Sharing Formulae

The *Sharing Formulae* branch contains the COA sharing formulae (*COA_CVP* and *COA_SWP*).

5.5 Storage Release

The *Storage Release* branch contains the COA definitions for storage withdrawals from Shasta (*SHADS*), Folsom (*FOLDS*), Whiskeytown (*WHSSW*), and Oroville (*StorageRelease_SWP*). Collectively, CVP storage withdrawals are set equal to the decision variable *StorageRelease_CVP*.

The 1986 COA includes Whiskeytown Reservoir in the definition of CVP storage withdrawals. However, Whiskeytown Reservoir is not included in the definition of CVP stored water. In the CVPA model, changes in Whiskeytown Reservoir storage are divided in to storage increases (*WHSSI*) and storage withdrawals (*WHSSW*). Only the decision variable WHSSW is included as part of the COA balance. The integer variable *int_WHS* and the associated UDCs *WHSSW force* and *WHSSI force* prevent WHSSW and WHSSI from both being non-zero.

5.6 Unused Water

The *Unused Water* branch contains a set of user-defined decision variables and constraints that allow the use of one party's unused water by the other party, as described in the 1986 COA. Two decision variables are defined: *Unused_FS* and *Unused_SS*. The UDCs *constrain unused FS* and *constrain* *unused SS* set these decision variables equal to the 'exp2' terms in the COA sharing formulae. Simulation of unused CVP and SWP is activated using the UDCs *Unused_FS constrain* and *Unused_SS constrain*. An integer variable, *Int_Unused_FS_SS,* and the associated UDCs *Int_Unused_FS_SS* and *Int_Unused_FS_SS* prevent *Unused_FS* and *Unused_SS* from both being non-zero.

5.7 Wheeling

The purpose of the *Wheeling* branch is to simulate wheeling of CVP water through Banks Pumping Plant and subsequently through the California Aqueduct to the Cross Valley Canal (*CVP_CVC*) and wheeling of CVP water for storage in San Luis Reservoir (*CVP_JPOD*).

CVC Wheeling

The intention of UDC *CVC Wheeling* is to route Cross Valley Canal water wheeled through Banks Pumping Plant to the demands on in the Tulare Lake HR. In the CVPA model simulation, CVC Wheeling is set to zero. Thus, it is included here only as a placeholder for future updates.

CVP JPOD

The UDC *CVP JPOD* routes CVP water diverted under the Joint Point of Diversion through Banks Pumping Plant and along the initial reaches of the California Aqueduct to be stored in San Luis Reservoir for later delivery.[4]

[4] CVP water moved under Joint Point of Diversion is conveyed through the diversion arc *CVP_JPOD* that connects the California Aqueduct to the CVP share of San Luis Reservoir.

6.0 CVP and SWP Project Allocations

The approach for allocating water to CVP contractors relies on using a series of curves to manage uncertainty in promising water to contractors. These curves are generally used as a way of mitigating the risk of promising water given an assessment of water supplies for the water year. That is, they are conditioned such that within the model the full allocations that are promised during the allocation period (February to May) are typically satisfied without drawing upstream storage below acceptable levels.

Allocations to SWP contractors are based on storage conditions, forecasted inflows, contractor requests, other demands for project water, operational and regulatory restrictions, and other factors. Simulated Table A allocations are based on the approach adopted by DWR for CalSim II and has some similarities to the method used to calculate CVP allocations.

The CVPA model was updated to implement these routines to set annual allocations for CVP and SWP, to set appropriate levels for delivery and carryover targets, and to constrain surface water deliveries. This is described in detail below.

6.1 CVP

The procedure for setting the annual allocation to CVP contractors is found in WEAP's data tree structure under *Other Assumptions\Ops\CVP Allocations*. The allocation that is the result of this procedure is referenced from each of the transmission links that divert surface water to CVP contractors. This allocation is applied to a monthly distribution of contract amounts to set an upper limit on diversions. These monthly values are based on Exhibit A of each contract, which specifies the distribution of the contractors' base supply and project water[5] over the irrigation season, April-October.

The approach for allocating water to CVP contractors relies on using a series of curves to manage uncertainty in promising water to contractors. These

[5] Base supply is the quantity of water that Reclamation agrees may be diverted, without charge, each month from April through October. Project water refers to additional quantities of water that may be diverted from April to October but are subject to pricing and other federal requirements.

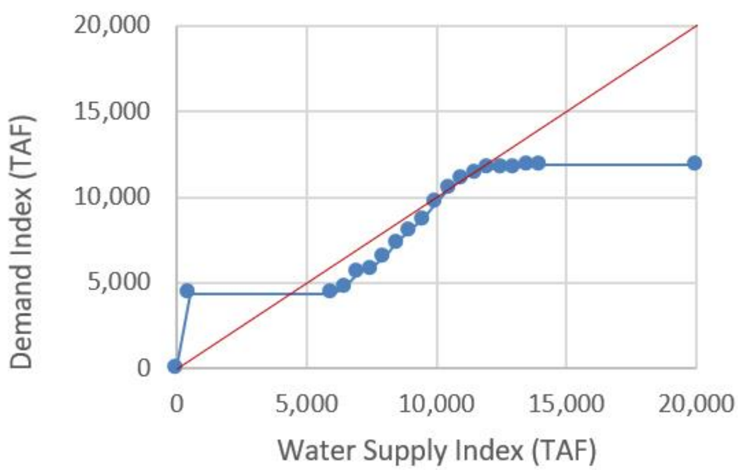
curves are generally used as a way of mitigating the risk of promising water given an assessment of water supplies for the water year. That is, they are conditioned such that within the model the full allocations that are promised during the allocation period (February to May) are typically satisfied without drawing upstream storage below acceptable levels.

The process occurs in the late winter and early spring as the water supply forecast becomes clearer. It begins by estimating the available water supplies by summing the existing water in storage and the forecasted inflows—WSI. The CVPA WEAP model then estimates the level of demand that can be met with this supply (i.e., the *DemandIndex*, or DI) using a WSI-DI curve. This is shown in Table 14 and the accompanying graph.

As the curve shows, under particularly low water supply conditions, the demand index (DI) is flat, which indicates that there exists some level of hard water demands that exist even in the driest conditions. DI is also flat at high levels of water supply because the system demand is limited, and above a certain water supply threshold, all water demand can be satisfied. Under intermediate water supply conditions, an increase in water supply translates into an increase in the water demand that can be satisfied. However, the curve often falls below the 1:1 line, suggesting that a smaller percentage of the available supply is made available to meet demand. This acknowledges that water is released from storage may not always reach demands due to regulatory and/or physical constraints, so the model is conditioned to reduce the risk of this occurring by promising to deliver less water.

Table 14 CVP Water Supply Index – Demand Index Curve

Water Supply Index (TAF)	Demand Index (TAF)
0	0
500	4,381
6,000	4,327
6,500	5,230
7,000	5,774
7,500	6,267
8,000	6,845
8,500	7,666
9,000	8,315
9,500	8,805
10,000	9,722
10,500	10,443
11,000	11,181
11,500	11,525
12,000	11,787
12,500	11,916
13,000	11,946
13,500	12,173
14,000	12,173
20,000	12,173



DI is the sum of both delivery and carryover storage demands. Thus, once the DI has been established, the model then references another lookup table to determine how this water should be partitioned between water left in storage (i.e., carryover) and water delivered. This is shown in Table 15 and the paired graph. As DI decreases, a smaller percentage of the available supply is committed to carryover storage relative to the amount that is delivered to meet current water demands. This is the second component of risk management in the allocation process. Once this delivery target has been established using the Delivery-Carryover curve, the total volume of water is evaluated relative to the total annual project demands. If the delivery target is less than the sum of these demands, then a series of cuts is applied to different water users to determine the allocations as a percentage of contracts. The sequence of these cuts is outlined in the following flowchart, Figure 12.

Table 15 CVP Demand Index — Delivery Index

Demand Index (TAF)	Delivery Index (TAF)
0	0
3,990	3,055
5,442	3,402
7,162	4,122
8,717	4,637
10,434	5,704
11,395	6,515
15,100	9,999

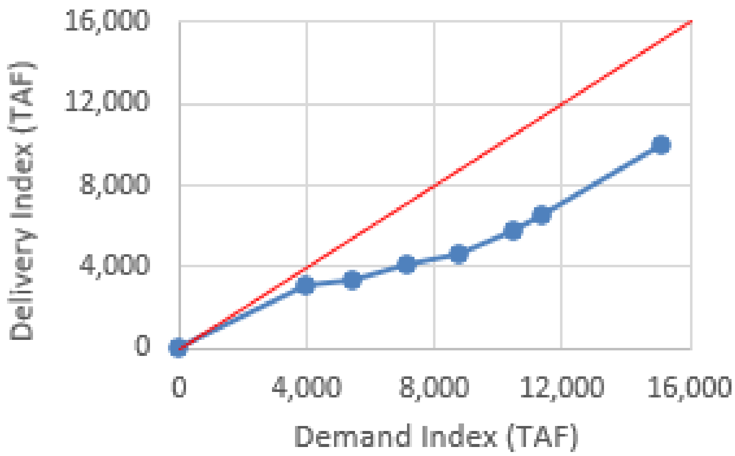
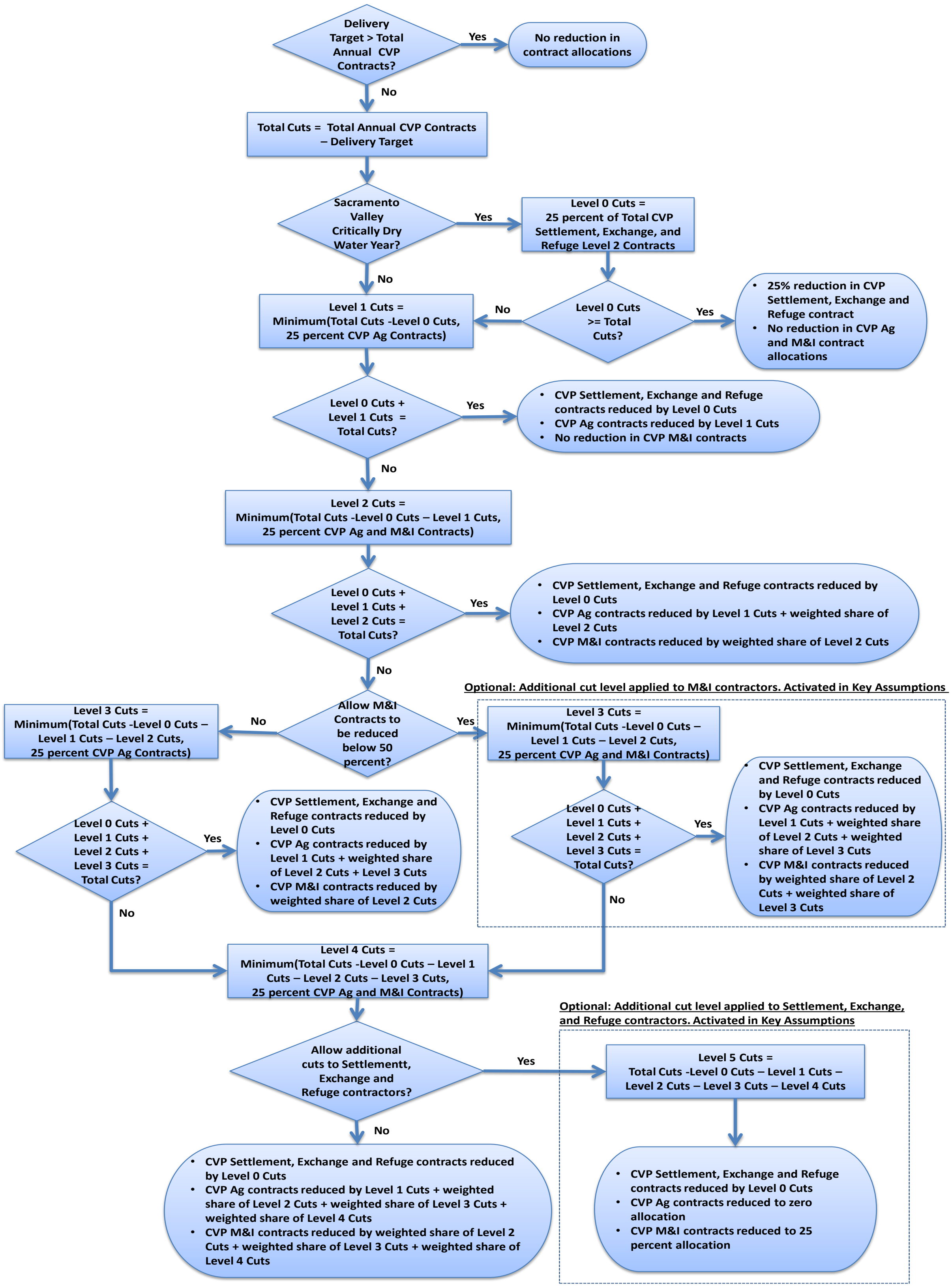


Figure 12 Central Valley Project Contract Allocation Logic



CVP Contract Types

Sacramento Valley Settlement contractors and San Joaquin Valley Exchange contractors possess water rights that were secured before the construction of CVP, which under the prior appropriation doctrine, assures them a higher level of reliability for their supplies. Per their agreement with Reclamation, Settlement and Exchange contractors receive 100 percent of their contract amount in all years except ‘critically dry’ water years, as defined by the Shasta Hydrological Index. In Shasta critical years (i.e., when the total inflow to Shasta Reservoir is below 3.2 million acre-feet [MAF]), Settlement and Exchange contractors receive 75 percent of their contract amounts.

When making annual allocations for Settlement and Exchange contractors, the CVPA WEAP model must account for the cumulative inflows into Shasta to designate the Shasta Hydrological Index. To approximate the allocation process as it occurs in reality, WEAP does not use perfect foresight to estimate inflows to Shasta for the remainder of the water year after allocations are set (i.e., April-September). Instead, the model relies on a heuristic technique to estimate this quantity of water.

In addition to Settlement and Exchange Contractors, the CVP makes annual water allocations for agricultural service contractors, municipal and industrial contractors, and refuge contractors. The total amounts for areas north and south of the Delta are listedParameters defined under the full contract amounts by contractor type, split geographically into two regions – north of Delta and south of Delta are listed below in Table 16.

Table 16 Central Valley Project Contract Allocation Logic

Parameter	Description	Contract Amount (acre-feet)
Contracts_AG_north	Agriculture north of Delta	458,155
Contracts_AG_south	Agriculture south of Delta	1,183,192
Contracts_EX	Exchange contractors	878,533
Contracts_MI_north	Municipal and industrial north of Delta	383,920
Contracts_MI_south	Municipal and industrial south of Delta	162,056
Contracts_RF_north	Refuges north of Delta	151,250
Congtracts_RF_south	Refuge south of Delta	248,638
Contracts_SC	Settlement contractors	2,092,020
Contracts_Losses	Canal losses along the Delta-Mendota Canal and California Aqueduct Joint Reach	183,700
Contracts_Total_South	Total south of Delta contract amount, excluding canal losses	3,102,419
Contracts_Total	Total north and south of Delta contract amount, excluding canal losses	6,187,764

Simulated versus Observed Values

We compared simulated annual CVP water allocations over the period 1990 to 2009 to both CalSim-II and historical values. These are presented in each of the graphs below. We found that the CVPA WEAP model captured well the allocations for Settlement and Exchange contractors, whose allocations are reduced only in critical years. For CVP Agricultural and M&I contractors, whose allocations are more variable, the CVPA model had and average difference of -4 percent and +7 percent for Agriculture and M&I, respectively.

Figure 13 Comparison of simulated and historical annual allocations to CVP Settlement Contractors

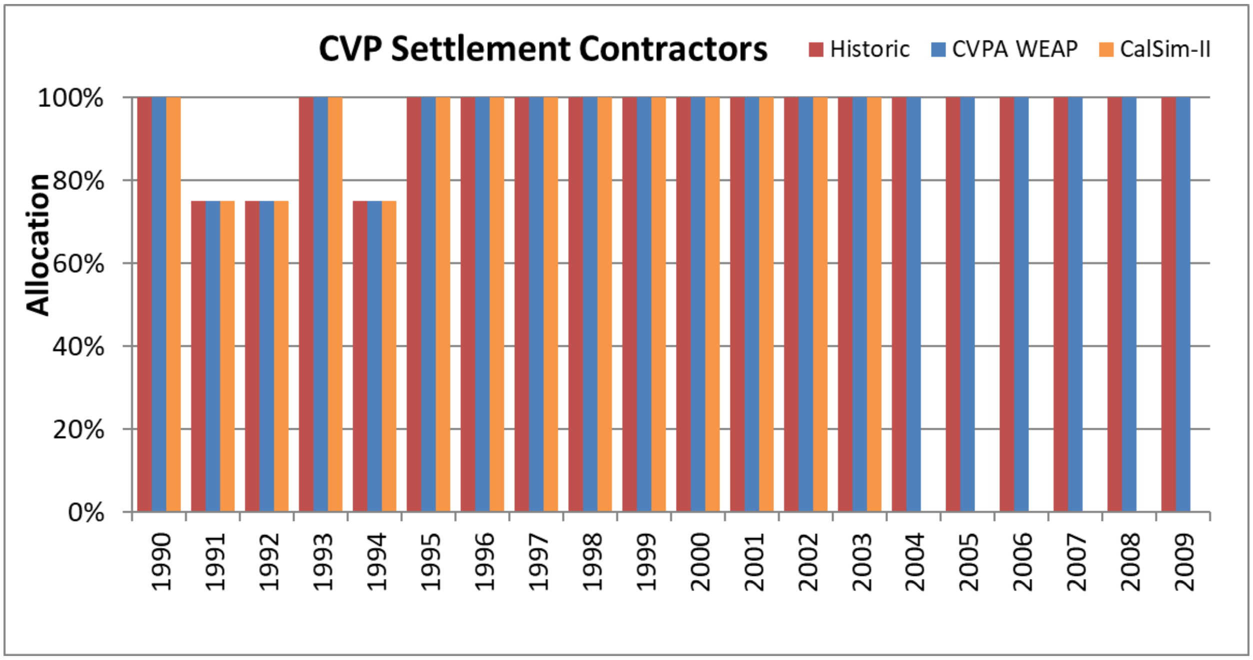


Figure 14 Comparison of simulated and historical annual allocations to CVP Exchange Contractors

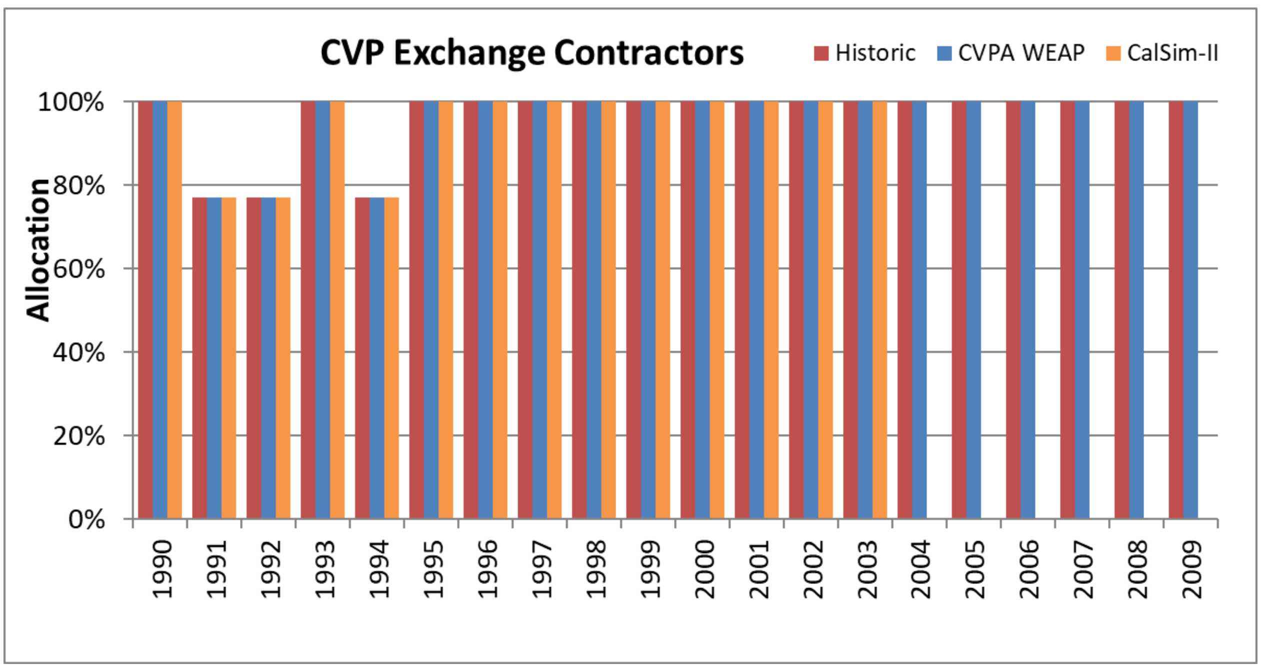


Figure 15 Comparison of simulated and historical annual allocations to CVP Agricultural Contractors

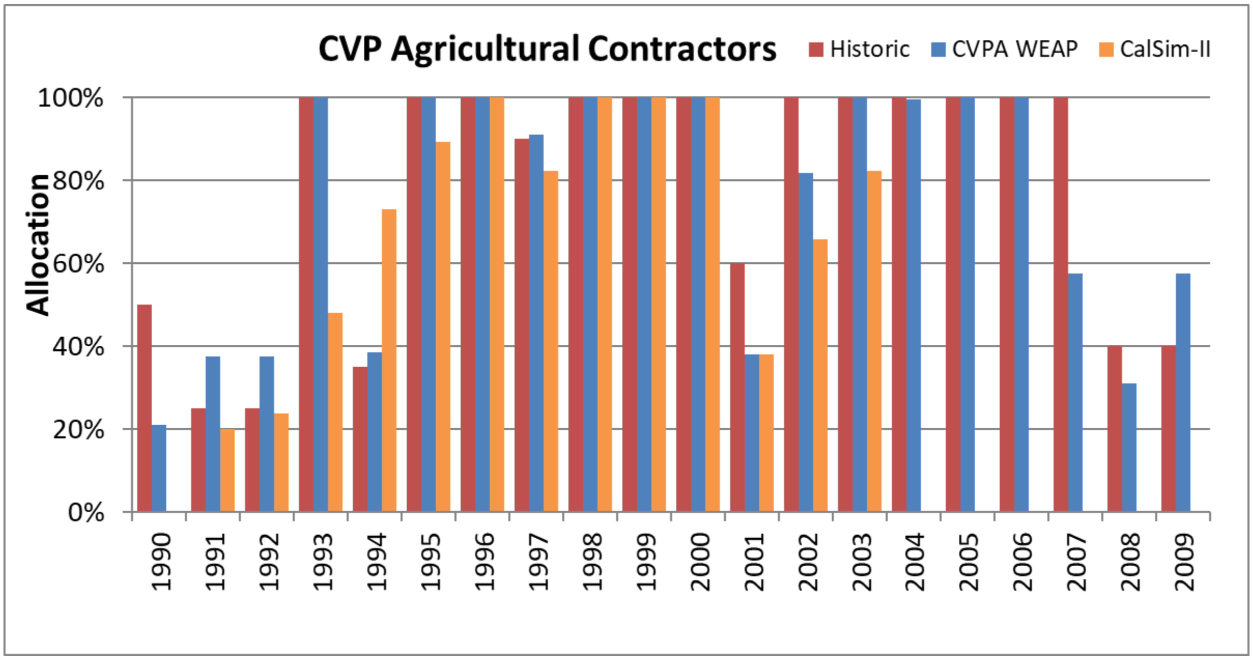
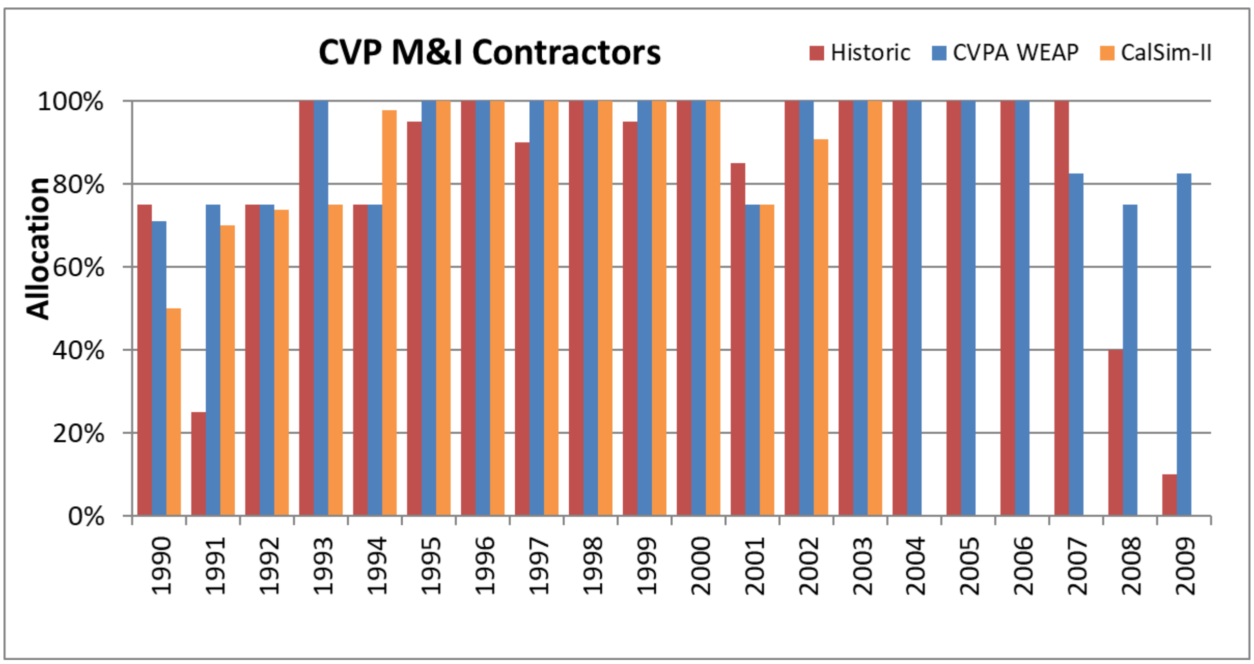


Figure 16 Comparison of simulated and historical annual allocations to CVP M&I Contractors



6.2 SWP

The CVPA WEAP model simulates SWP delivery of Table A water. However, CVPA WEAP model does not simulate the carryover provision of Article 56.[6] Delivery of Table A water is determined by the annual SWP allocation to its long-term contractors.[7] These allocations are based on storage conditions, forecasted inflows, contractor requests, other demands for project water, operational and regulatory restrictions, and other factors. Simulated Table A allocations are based on the approach adopted by DWR for CalSim II (SWP Reliability Report: DWR, 2014e) and has some similarities to the method used to calculate CVP allocations. The allocation logic starts by assessing the available water supply (*WaterSupplyEst*), which for the SWP is the sum of previous month storage in Lake Oroville and San Luis Reservoir, and the forecasted runoff (through September) of the Feather River at Oroville. This is the water supply index. Similar to the CVP allocation logic, a delivery index (*DemandIndex*) is calculated from water supply index, with values shown in Table 17 (where a linear interpolation is used between points on this curve).

[6] Articles 12(e) and 56 of the contract between DWR and its long-term SWP contractors allow the contractors to take delivery of unused annual allocation of Table A water in the first 3 months of the following year. Undelivered water stored in San Luis Reservoir may be lost to the contractor if DWR needs the storage capacity, in which case, this water is gradually converted to SWP water.

[7] Before 2014, the same Table A percent allocation applied to all 29 SWP long-term, contractors. However, starting 2014, DWR calculates a separate Table A allocation for Solano County WA and Napa County FCWCD as provided in the SCWA v. DWR Settlement Agreement, dated December 31, 2013. Currently, CVPA WEAP model does not simulate the separate North-of-Delta allocation.

Table 17 SWP Water Supply Index – Demand Index Curve

Water Supply Index (TAF)	Demand Index (TAF)
0	0
500	1,485
2,500	1,485
3,000	1,575
3,500	2,274
4,000	3,002
4,500	4,354
5,000	5,313
5,500	6,098
6,000	7,366
6,500	7,924
7,000	8,174
7,500	8,284
20,000	8,284

Unlike the procedure for the CVP, this allocation routine does not use a separate curve to separate the delivery and carryover storage components of the demand index. Instead, the routine assumes that the target carryover storage for SWP in Lake Oroville is 1,000 TAF plus half of the volume of water above 1,000 TAF carried over from the previous water year (i.e., one half end-of-September storage above 1,000 TAF). The initial allocation also assumes that the target SWP carryover storage in San Luis Reservoir is 110 TAF. Thus, the following equation was used to calculate and initial percentage allocation (*Allocation_Init*).

$$Allocation\_Init = Max\left\{0, \frac{Demand\ Index - 110\ TAF - 1000\ TAF}{SWP\ Table\ A\ + Maximum[0, \frac{1}{2}\ (Oroville\ Carryover\ Storage - 1000\ TAF)]}\right\}$$

where the numerator is the estimated total SWP delivery and the denominator is the adjusted total demand. Subsequently, the CVPA WEAP model uses this allocation estimate to update the carryover target for SWP storage in San Luis Reservoir (*SWPRuleDrainTarget*) using the following equation.

$$SWPRuleDrainTarget = Min\left\{\begin{matrix} SWP\ San\ Luis\ Storage\ Capacity, \\ 110\ TAF + Maximum[0, SWP\ Table\ A * (Initial\ Percent\ Allocation - 1) - 250\ TAF] \end{matrix}\right\}$$

The purpose of the update is to allow greater drawdown of San Luis Reservoir in dry years when SWP allocations are low. This updated SWP San Luis Reservoir carryover target is then used to update the percentage allocation (*Allocation_Adjustment*).

$$Allocation\_Adjustment = Max\left\{0, \frac{Delivery\ Index - SWP\ San\ Luis\ Drainage\ Target - 1000\ TAF}{SWP\ Table\ A\ + Maximum[0, \frac{1}{2}\ (Oroville\ Carryover\ Storage - 1000\ TAF)]}\right\}$$

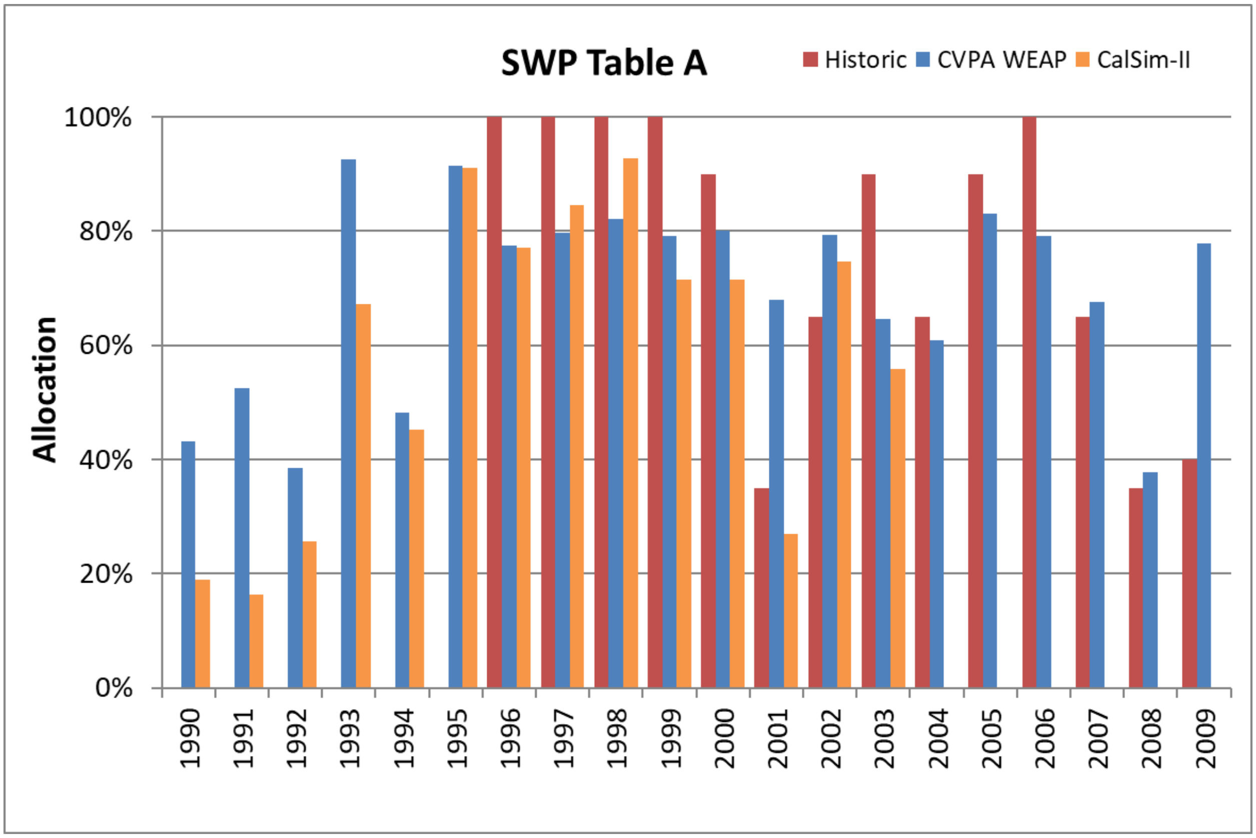
This equation forms the basis of the SWP Table A contract allocation. The allocation is first made in January, and updated February through May as the estimate of water supply becomes clearer. The allocation is also adjusted during the spring pulse period (April-May) when regulatory constraints limit the ability of the SWP to export water at the Banks Pumping Plant. The allocation of water during these two months assumes the bulk of water will be delivered from San Luis Reservoir after some minimum level of SWP export. Therefore, the April-May allocation is conditioned upon the available SWP water in San Luis Reservoir.

The procedure for setting the annual allocation to SWP Table A contractors is located in the data tree under *Other Assumptions\Ops\SWP Allocations*. The resulting allocation is referenced from each of the transmission links that deliver SWP water to the project's long-term water supply contractors. The monthly water demand for the SWP contractor demand sites is set equal to the product of their full Table A amount and monthly distribution pattern. The 'maximum flow percent of demand' property of the transmission link is set equal to the allocation.

Simulated versus Observed Values

We compared simulated annual SWP Table A water allocations over the period 1990 to 2009 to both CalSim-II and historical values. These are presented Figure 17 below. The CVPA model generally captured the changes in allocations across these years, with an average error of minus 4 percent. However, in some years (namely 2001 and 2009) the WEAP model predicted much higher allocations than what happened in reality. Conversely, the CVPA model underestimated allocations in some of the wetter years (1996-2000). However, the CVPA model compared well to CalSimII in the years where it diverged from the historical.

Figure 17 Comparison of simulated and historical annual allocations to SWP Table A Contractors



7.0 References

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Appendix A

1.1 Fortran "wrapper" code for DLL

The Fortran code below creates a new function (AnnECArray) within the DLL that can be called from WEAP, which sends to the DLL a single array of double precision values. This function then calls a pre-existing function within the DLL (AnnEC) that uses several real and integer values as arguments in its call. For WEAP to be able to call the DLL, this wrapper (and those developed for AnnEC_matchDSM2Array and AnnLineGenArray) needs to be added to the main ANN code and recompiled as a DLL.

```
real function AnnECArray(Parameters, LastElementIndex)

!DEC$ ATTRIBUTES DLLEXPORT :: AnnECArray

implicit none


real :: AnnEC


double precision, intent(in) :: Parameters(49)

integer, intent(in) :: LastElementIndex

real :: outputEC


outputEC =
AnnEC(real(Parameters(1)),real(Parameters(2)),real(Parameters(3)),real(Pa
rameters(4)),real(Parameters(5)),real(Parameters(6)),real(Parameters(7)),r
eal(Parameters(8)),real(Parameters(9)),real(Parameters(10)),real(Paramete
rs(11)),real(Parameters(12)),real(Parameters(13)),real(Parameters(14)),rea
l(Parameters(15)),real(Parameters(16)),real(Parameters(17)),real(Paramete
rs(18)),real(Parameters(19)),real(Parameters(20)),real(Parameters(21)),rea
l(Parameters(22)),real(Parameters(23)),real(Parameters(24)),real(Paramete
rs(25)),real(Parameters(26)),real(Parameters(27)),real(Parameters(28)),rea
l(Parameters(29)),real(Parameters(30)),real(Parameters(31)),real(Paramete
rs(32)),real(Parameters(33)),real(Parameters(34)),real(Parameters(35)),rea
l(Parameters(36)),real(Parameters(37)),real(Parameters(38)),real(Paramete
```

```
rs(39)),real(Parameters(40)),int(Parameters(41)),int(Parameters(42)),int(Parameters(43)),int(Parameters(44)),int(Parameters(45)),int(Parameters(46)),int(Parameters(47)),int(Parameters(48)),int(Parameters(49)))

AnnECArray = outputEC

end function AnnECArray
```