MBK ENGINEERS

Water Resources ◆ Flood Control ◆ Water Rights

TECHNICAL MEMORANDUM

DATE: July 16, 2015

SUBJECT: Improvements to CalSim San Luis Operations

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MBK Engineers was tasked with improving San Luis operations in CalSim. At the December 2014 scoping meeting with CalSim modelers and Central Valley Project (CVP) and State Water Project (SWP) operators, issues with CalSim San Luis operations were outlined, and it was decided that there was not sufficient budget to resolve all issues under this task order. As such, the three key items listed below were selected for MBK to address and determine whether significant improvements could be made.

1. Reduce frequency of drawing San Luis to dead pool and shorting South-of-Delta (SOD) contract deliveries by improving the export forecasts used in SWP and CVP allocations.
2. Reduce excessive carryover in CVP San Luis during the critical period (particularly the 1930's) through reasonable increases in service contractor allocations.
3. Refine rulecurve formulations used to balance storage between North-of-Delta (NOD) project reservoirs and San Luis Reservoir.

While the problems outlined at the meeting have been present in CalSim for years, MBK used Reclamation's latest CalSim baseline generated on January 27, 2015 as a starting point. For the rest of this document, this baseline will be referred to as CalSim_27JAN2015, and the model edited to address the above three issues will be referred to as CalSim_27JAN2015_Revised. Any reference to CalSim in general includes CalSim_27JAN2015 and preceding versions.

REFINEMENT OF CVP AND SWP EXPORT FORECASTS USED IN CALSIM ALLOCATION LOGIC TO REDUCE SOD CONTRACT DELIVERY SHORTAGES

Since implementation of the smelt and salmon biological opinions, CalSim tended to over-allocate water to SOD CVP and SWP contractors in many years of the simulation. Although this does not occur in every year, it happens enough to skew results in water supply planning analysis. Over-allocation can result in breaking San Luis (drawing San Luis down to dead pool) and shorting project contractors. Figure 1~~Figure 1Figure 1~~ and Figure 2~~Figure 2Figure 2~~ relate annual SOD contractor shortages and San Luis low point for both the CVP and SWP, respectively, as simulated by CalSim_27JAN2015. CVP San Luis storage is drawn to dead pool (dashed line) in 15 years of the 82-year simulation; SWP San Luis storage is drawn to dead pool in 21 years of the simulation. Annual shortages to CVP contractors range as high as 100 thousand acre-feet (TAF). Running debt to SWP contractors reaches higher than 400 TAF in year 1995 of the simulation and greater than 100 TAF in several other years.

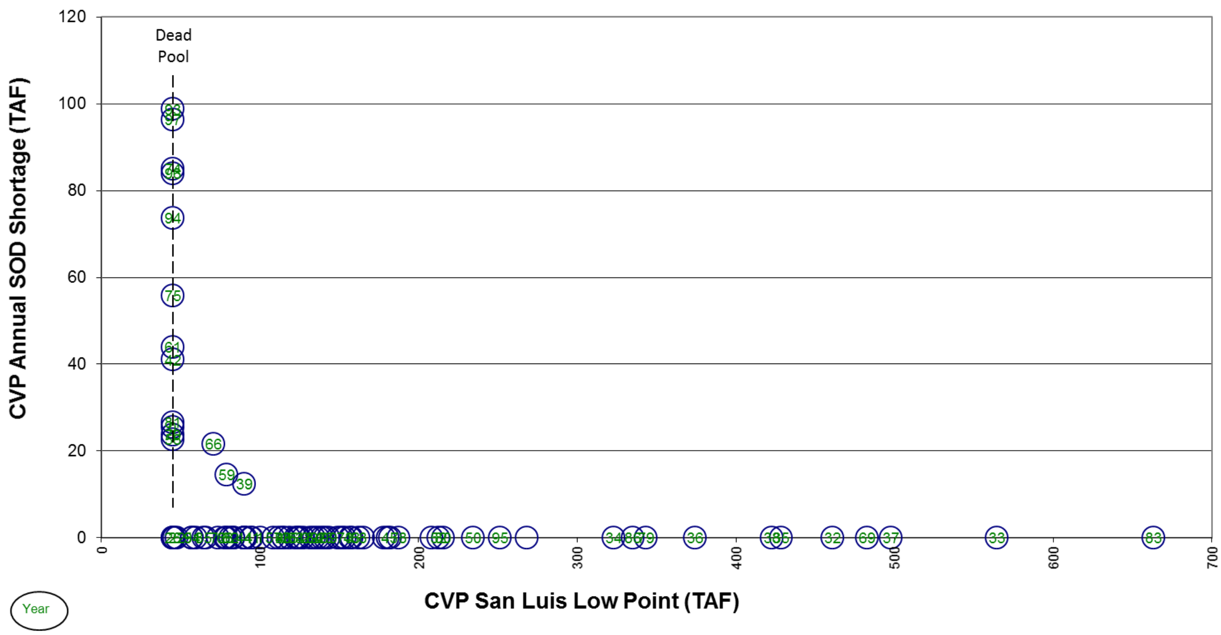

Figure 1. CVP annual SOD shortage versus CVP San Luis storage low point as simulated in CalSim_27JAN2015

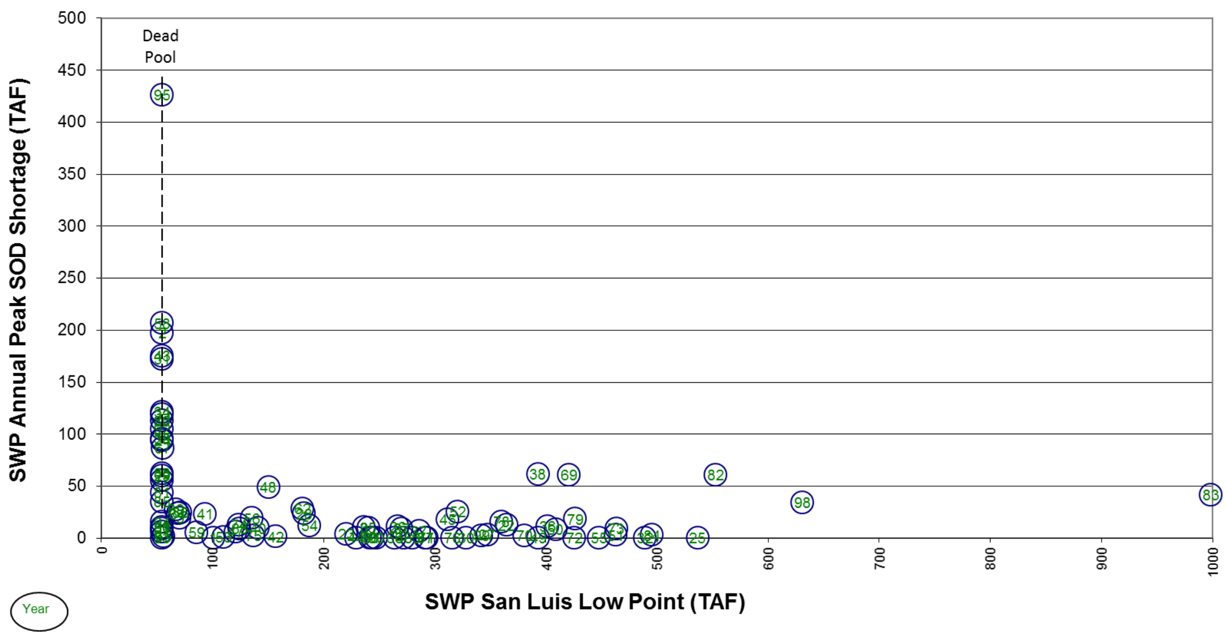

Figure 2. SWP annual maximum SOD shortage versus SWP San Luis storage low point as simulated in CalSim_27JAN2015

Over-allocation in CalSim can be traced back to the model methodology used for both the SWP Table A allocations and CVP SOD Agriculture (Ag) and Municipal and Industrial (M&I) allocations. The CalSim allocation methodology (used for both the CVP and SWP) combines the Water Supply Index – Delivery Index (WSI-DI)–based allocation with an export forecast–based allocation. The minimum of the two is the final allocation for each project in each contract year. (Note that the CalSim model allocation methodology bears minimal resemblance to the methodology used in real-time allocations.)

The WSI-DI–based allocation assesses aggregate supply (forecasted inflow plus storage), but it does not adequately address limitations of available export capacity necessary to move the NOD supply to SOD contractors. Conversely, the export forecast–based allocation is intended to address export capacity limitations, but the current implementation has limited accuracy. Also, the export forecast–based allocation does not consider demand for export capacity. In other words, the export estimate does not consider whether or not the projects would release stored water from upstream reservoirs to make use of the available export capacity. If NOD storage is low, the projects will not want to release stored water to support exports. This should be explicitly incorporated into the allocation decisions, and it currently is not in CalSim.

The purpose of combining the WSI-DI allocation with an export forecast–based allocation was to have each allocation method cover the weaknesses of the other. However, as seen in current CalSim results (Figure 1~~Figure 1Figure 1~~ and Figure 2~~Figure 2Figure 2~~), this has not been accomplished. Ideally, the allocation methodology used in CalSim should better reflect real-time operations methodologies where consideration of supply, demand, conveyance capacity, and carryover in upstream reservoirs are physically integrated. This has been attempted by the Department of Water Resources (DWR) in the form of its Forecast Allocation Model (FAM), but it is beyond the scope of this contract.

The objective is to improve allocation decisions with the current methodology thereby preventing drawing San Luis to dead pool and shorting contractors. The most appropriate improvement is to create a more accurate export forecast—one that takes into account both the availability of and the demand for export capacity. However, before potential improvements are discussed, it is important to examine the CVP and SWP export forecast currently used in CalSim.

During the CVP allocation season (March–May), the current version of CalSim has only two possible export forecasts: one when it is a wet year as classified by the San Joaquin River (SJR) 60-20-20 index; and another when it is critical, dry, below normal, or above normal year classification. Table 1~~Table 1Table 1~~ shows the export estimates for each month from March to August. The export forecast–based allocation sums the export estimates from the current month through August.

In Table 1~~Table 1Table 1~~, only April, May, and June are conditioned on the SJR 60-20-20 index because those are the months where exports are most likely controlled by either the SJR inflow-export (IE) ratio or Old and Middle River (OMR) flow requirements. The sum total of the export estimates from April to June in a wet year is 516 TAF (2,000 cubic feet per second [cfs], 2,000 cfs, and 4,600 cfs); in a non-wet year the sum total is 240 TAF (1,000 cfs, 1,000 cfs, and 2,000 cfs). Such a coarse export estimate does not adequately account for the variability in SJR hydrology or in the conditionality of the SJR IE ratio or OMR flow regulations. It also does not reflect the information that operators have at hand to refine their forecasts, which include current SJR flows at Vernalis, forecasted operations on the SJR and its tributaries, and ongoing discussions with the U.S. Fish and Wildlife Service (FWS) about fish take, trawl data and expected OMR flow requirements.

Table 1. Monthly CVP export estimates found in the CalSim_27JAN2015 lookup table ExportEstimate_CVP

CalSim Baseline CVP Export Forecast for SOD Ag and M&I Allocation			
Month	Export Estimate (cfs)	Wet SJR Export Estimate (cfs)	Delivery Pattern Fraction
MAR	2500	0	0.68
APR	1000	2000	0.622
MAY	1000	2000	0.553
JUN	2000	4600	0
JUL	4600	0	0
AUG	4600	0	0

The July and August export estimates for the CVP are listed in Table 1~~Table 1~~Table 1 at 4,600 cfs, which is Jones Pumping Plant's full capacity. Obviously this will never be an underestimate of simulated Jones pumping in July and August, but it is often an overestimate. Even though 4,600 cfs capacity is available, the CVP does not always want to release water from upstream reservoirs to fill that capacity. CalSim overestimates exports in these months with the expectation that the WSI-DI–based allocation will prevent an over-allocation. The WSI-DI does serve as a backstop in many years, but there are many years when it does not limit the export estimate based on available supply.

Figure 3~~Figure 3~~Figure 3 compares annual CVP SOD delivery shortage with the error in the CVP export forecast used in the export forecast–based allocation. The CVP export forecast error is calculated as the April–August CVP export forecast minus the modeled total April–August CVP Jones Pumping Plant exports. As shown in Figure 3~~Figure 3~~Figure 3, the error is both negative and positive but skews positive. There are no shortages when the export forecast is an underestimate of exports (negative error). There are 15 years with shortages when the forecast is an overestimate. However, the shortages in three of those years — 1939, 1959, and 1966, the three lowest shortages not equal to zero — have nothing to do with over-allocation but a quirk in the SJR model formulation. The remaining 12 are all due to over-allocation, both from the WSI-DI–based approach and the export forecast approach.

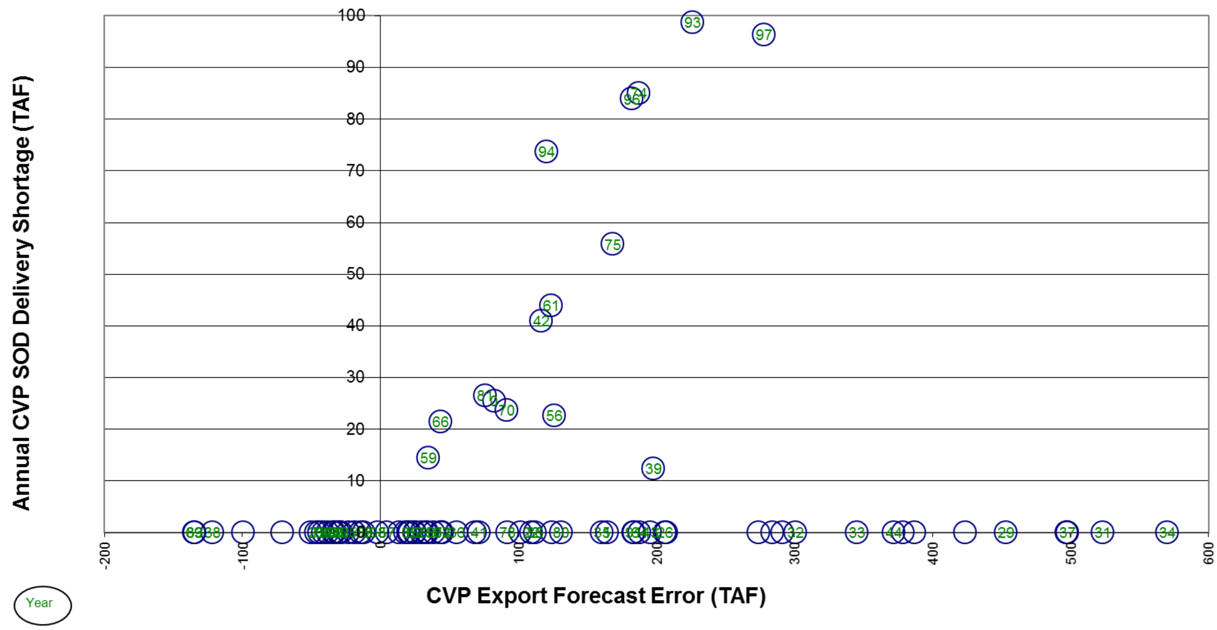

Figure 3. Annual CVP SOD delivery shortage versus CVP export forecast error in CalSim_27JAN2015

Problems with the SWP export forecast are similar to those explained above for the CVP. Table 2~~Table 2Table 2~~ lists the monthly SWP export estimates from January to August. Whereas the CVP contract year begins in March, the SWP contract year begins in January along with SWP allocations. Like the CVP, export estimates are conditioned on the SJR 60-20-20 index in April, May, and June. Unlike the CVP, the SWP export forecast logic adds a flood condition on the SJR in April and May. The flood condition is triggered when flow at Vernalis exceeds 16,000 cfs in March, April, or May. However, even with this added nuance, this is still a very coarse export forecast that does not capture the refinement inherent in real-time operations or what is needed in the model.

Table 2. Monthly SWP export estimates found in the CalSim_27JAN2015 lookup table ExportEstimate_SWP

CalSim Baseline SWP Export Forecast for Table A Allocation				
Month	Export Estimate (cfs)	Wet SJR Export Estimate (cfs)	Flood SJR Export Estimate (cfs)	Delivery Pattern Fraction
JAN	3750	0	0	0.737
FEB	4250	0	0	0.721
MAR	4250	0	0	0.695
APR	1000	2000	6000	0.657
MAY	1000	2000	6000	0.566
JUN	2500	6000	0	0
JUL	7000	0	0	0
AUG	7000	0	0	0

The SWP export forecast for July and August is 7,000 cfs as listed in Table 2~~Table 2Table 2~~. This exceeds permitted capacity of 6,680 cfs in these months, and simulated SWP exports in CalSim_27JAN2015 never exceed permitted capacity in July and August. In fact, simulated July and August SWP exports are often significantly below permitted capacity. The explanation for this is the same as it was for the CVP: just because capacity is available does not mean the SWP wants to use it; that depends on the storage condition of Oroville, and the export forecast in Table 2~~Table 2Table 2~~ does not consider such details.

Figure 4~~Figure 4Figure 4~~ compares SWP SOD shortage with export forecast error. Export forecast error was again calculated by subtracting April–August total SWP exports from the forecasted exports. Only 1979 had an underestimate of forecasted exports, and that underestimate was slight. In all other years the SWP export forecasts were overestimates with some errors greater than 1 million acre-feet (MAF). The greatest delivery shortage occurred in a wet year, 1995 (Figure 4~~Figure 4Figure 4~~). The delivery shortage was approximately 425 TAF; it was the result of a 500 TAF overestimate of exports. (Many of the shortages shown that are below 70 TAF in Figure 4~~Figure 4Figure 4~~ are not due to over-allocation and breaking San Luis; they are due to insufficient California Aqueduct capacity to meet the assumed demand pattern. These are of less concern than the shortages caused by breaking San Luis.)

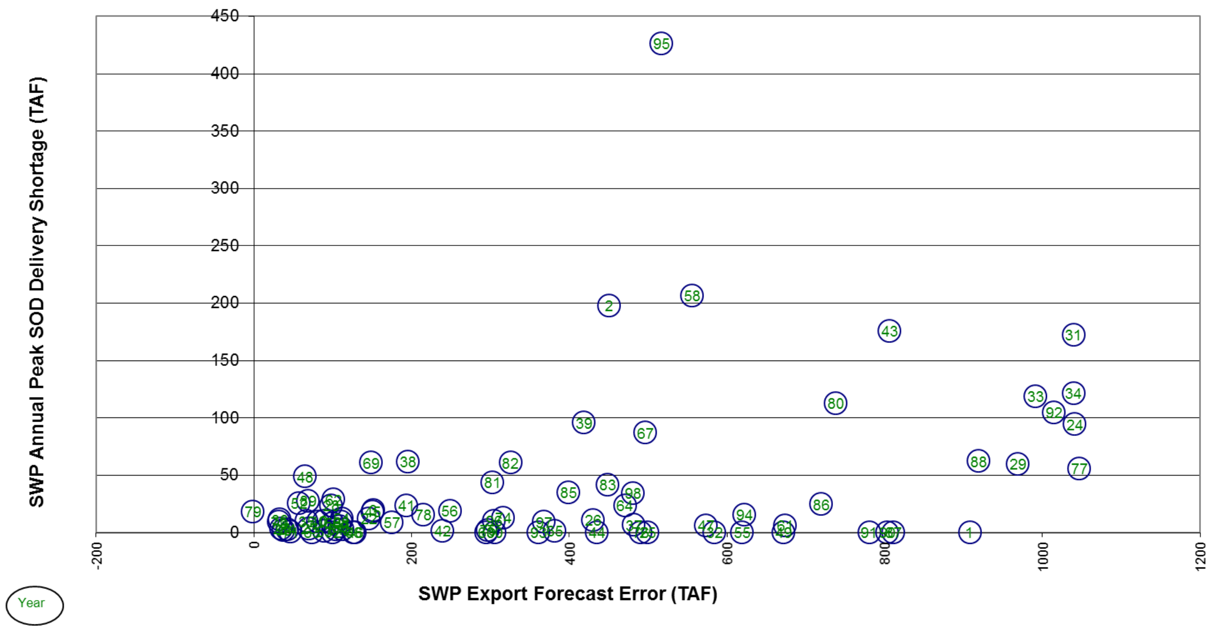

Figure 4. SWP annual peak SOD delivery shortage versus SWP export forecast error in CalSim_27JAN2015

To improve on the export forecasts, it is recognized that more detail is necessary. The two CVP and three SWP export forecast possibilities currently provided in CalSim do not adequately cover the different circumstances found from one year to the next. What follows is a proposal for deriving export forecasts that vary by year and month that will take into account hydrologic, regulatory, and operational variability. The methodology is similar to the WSI-DI procedure in that it requires infrequent iterations of CalSim, and it is best described as a series of steps.

Step 1

Set the CVP and SWP export forecasts equivalent to Health and Safety (H&S) minimum export levels (800 cfs for the CVP and 300 cfs for the SWP). As such, the respective April to August export forecasts are approximately 240 TAF for the CVP and 90 TAF for the SWP. Run CalSim with this initial export forecast.

Step 2

Use the CalSim CVP and SWP export results (D418 and D419_SWP, respectively) from Step 1 as new export estimates and re-run CalSim. Repeat until the maximum difference between aggregate export estimates and cumulative simulated exports is less than 100 TAF. Many previous trials indicate this will likely take three iterations. The first iteration (Step 1) uses the H&S export estimate, and the second and third use the CalSim-generated export estimates. A spreadsheet has been set up to process CalSim output into export forecast input for the purpose of expediting this process.

Step 3

Refine export estimates as necessary to achieve desired balance of contract deliveries and storage carryover. This refinement of export forecasts can be done by an automated procedure or manually. A combination of both was employed in this analysis.

Ideally, the procedure would stop at Step 2. Understanding why the procedure progresses to Step 3 requires an understanding of the logic of the first two steps. Starting with the H&S export forecast in Step 1 ensures very low allocations for both projects in all years of that simulation. As such, export of available Delta supplies without supplemental reservoir release – or export of incidental Delta inflow – are sufficient in almost every year to meet allocated deliveries and San Luis carryover targets. So the final result of that first iteration and the iterations that follow in Step 2 is a lower bound on the SWP and CVP export forecasts. In any year that moving additional water from NOD reservoirs is not desired, the final export forecast derived in Step 2 also represents an upper bound. But in those years where NOD stored water and SOD export capacity are available, the export forecast must be increased to drive higher allocations and movement of that additional water through rulecurve. (Rulecurve will be discussed later in this memo.) There are also very wet years such as 1983, when a full San Luis prevented additional exports during the iterative process. A boost in the export forecast increases allocations and deliveries, which allows for higher exports when San Luis is full. Given the reasons for refinement, the only changes to the export forecasts going from Step 2 to Step 3 were increases.

The final CVP and SWP export forecasts derived from the three-step methodology are listed in Table 3~~Table 3Table 3~~ and Table 4~~Table 4Table 4~~. While these forecasts extend through the period of record (1922–2003), the tables show a small sample (1922–1931) for the sake of brevity. Each export forecast provided by year and month represents cumulative exports from the given month through August. As such, the export forecast can easily be retrieved from a lookup table or DSS timeseries (either data retrieval mechanism will work) and directly input into the current SWP and CVP export-based allocation logic (some minor edits were made for the new format of the export forecasts). Note the variability of the SWP and CVP export forecasts from a wet year like 1922, to a below-normal year like 1928, and to a critical year like 1931 (all SJR 60-20-20 index–based classifications). This is a significant change from the rough forecasts found in CalSim_27JAN2015.

Table 3. Sample CVP export forecast derived from the three-step process and used in CalSim_27JAN2015_Revised

Modified CVP Export Forecast for SOD Ag and M&I Allocation (cumulative from current simulation month to August)			
	Cumulative Export Estimate (TAF)		
Year	MAR	APR	MAY
1922	1255	972	901
1923	1083	883	817
1924	388	269	180
1925	1039	856	784
1926	622	339	271
1927	1062	835	775
1928	935	652	592
1929	501	338	269
1930	551	395	329
1931	325	261	189

Table 4. Sample SWP export forecast derived from the three-step process and used in CalSim_27JAN2015_Revised

Modified SWP Export Forecast for Table A Allocation (cumulative from current simulation month to August)					
	Cumulative Export Estimate (TAF)				
Year	JAN	FEB	MAR	APR	MAY
1922	2025	1805	1729	1409	1325
1923	1634	1413	1318	1117	1038
1924	412	232	111	93	75
1925	1227	1029	1049	800	709
1926	1179	981	1015	990	905
1927	1687	1542	1425	1192	1119
1928	1695	1482	1432	1132	1062
1929	684	482	299	136	67
1930	1209	1061	922	767	704
1931	508	308	152	88	71

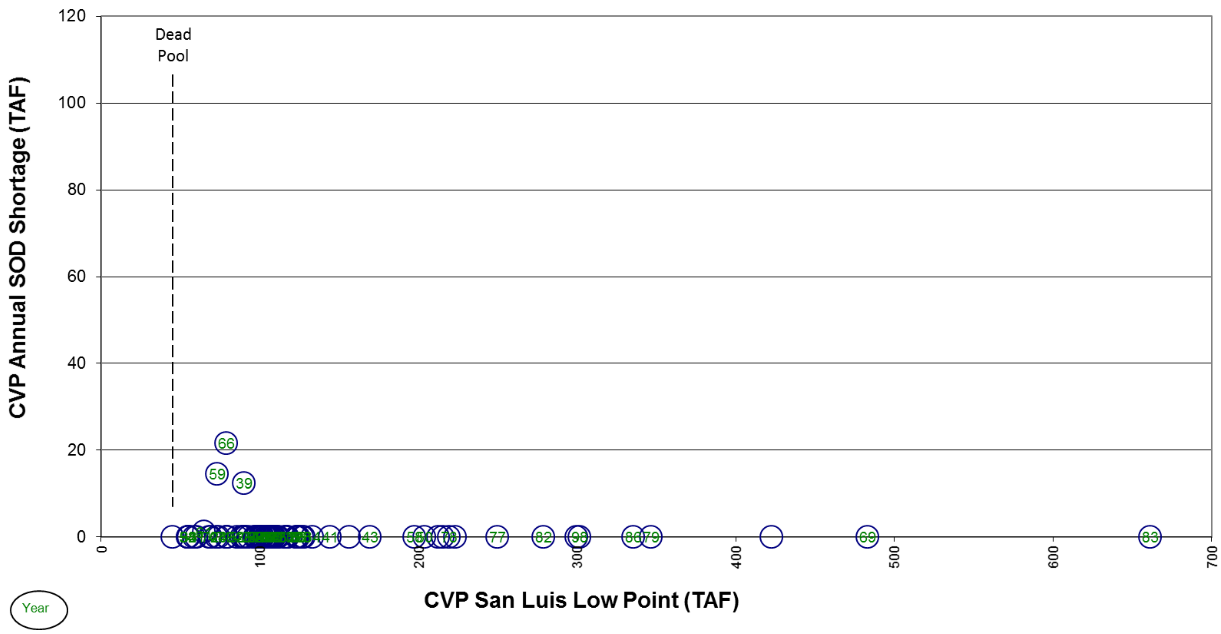

Figure 5. CVP annual SOD shortage versus CVP San Luis storage low point as simulated in CalSim_27JAN2015_Revised

Figure 5~~Figure 5Figure 5~~ and Figure 6~~Figure 6Figure 6~~ compare annual shortage and San Luis low point as simulated in CalSim_27JAN2015_Revised with the updated export forecasts listed above. CVP San Luis is drawn to dead pool only once and no shortage occurs in that year. The only years with CVP SOD shortages are 1939, 1959, and 1966; as discussed previously, the shortages are not caused by over-allocation but a quirk in the SJR model formulation. The SWP is drawn to dead pool in four years, but there are shortages in only two of them. (The two dead pool data points where the shortage is zero overlap.) All SWP shortages shown are reasonably small and are almost entirely caused by insufficient California Aqueduct capacity to meet the simulated delivery pattern. This type of shortage is of less concern than those caused by breaking San Luis. To gage the improvement in San Luis operations and reductions in project SOD delivery shortages due to the updated export forecasts, compare Figure 5~~Figure 5Figure 5~~ to Figure 1~~Figure 1Figure 1~~ and Figure 6~~Figure 6Figure 6~~ to Figure 2~~Figure 2Figure 2~~.

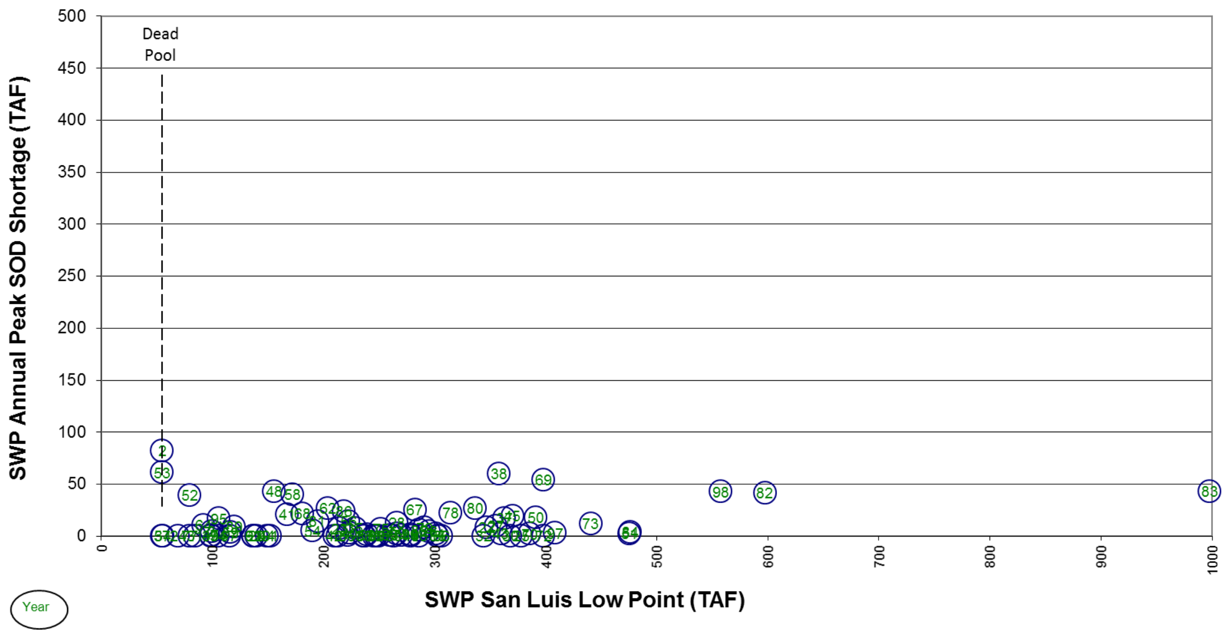

Figure 6. SWP annual maximum SOD shortage versus SWP San Luis storage low point as simulated in CalSim_27JAN2015_Revised

Export forecast error was shown to be large for both the CVP (Figure 3~~Figure 3Figure 3~~) and SWP (Figure 4~~Figure 4Figure 4~~) in CalSim_27JAN2015. Reducing export forecast error was essential to the prevention of breaking San Luis and shorting SOD contractors. Figure 7~~Figure 7Figure 7~~ relates CVP SOD delivery shortage to CVP export forecast error in CalSim_27JAN2015_Revised. As shown, most of the CVP export forecast errors fall under 100 TAF. Those errors above 100 TAF were edited in Step 3 of the proposed export forecast methodology to refine the balance between deliveries and carryover. Figure 8~~Figure 8Figure 8~~ relates SWP SOD delivery shortage to SWP export forecast error in CalSim_27JAN2015_Revised. The forecast error in three years is above 200 TAF: 1952, 1982, and 1983. It was recognized that in all three of these years there was sufficient water and export capacity to meet a 100% Table A allocation. The export forecast in each was set sufficiently high so that it would not prevent a full allocation. The rest of the SWP export forecast errors were less than 200 TAF. The refinements in Step 3 were responsible for pushing the errors above 100 TAF.

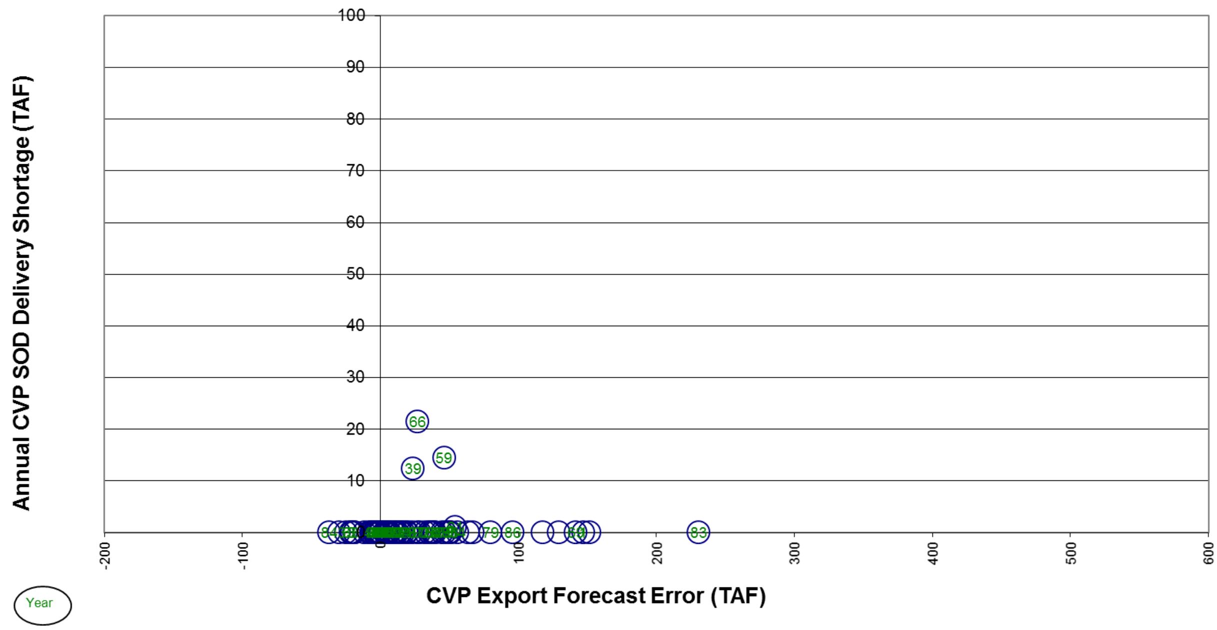

Figure 7. Annual CVP SOD delivery shortage versus CVP export forecast error in CalSim_27JAN2015_Revised

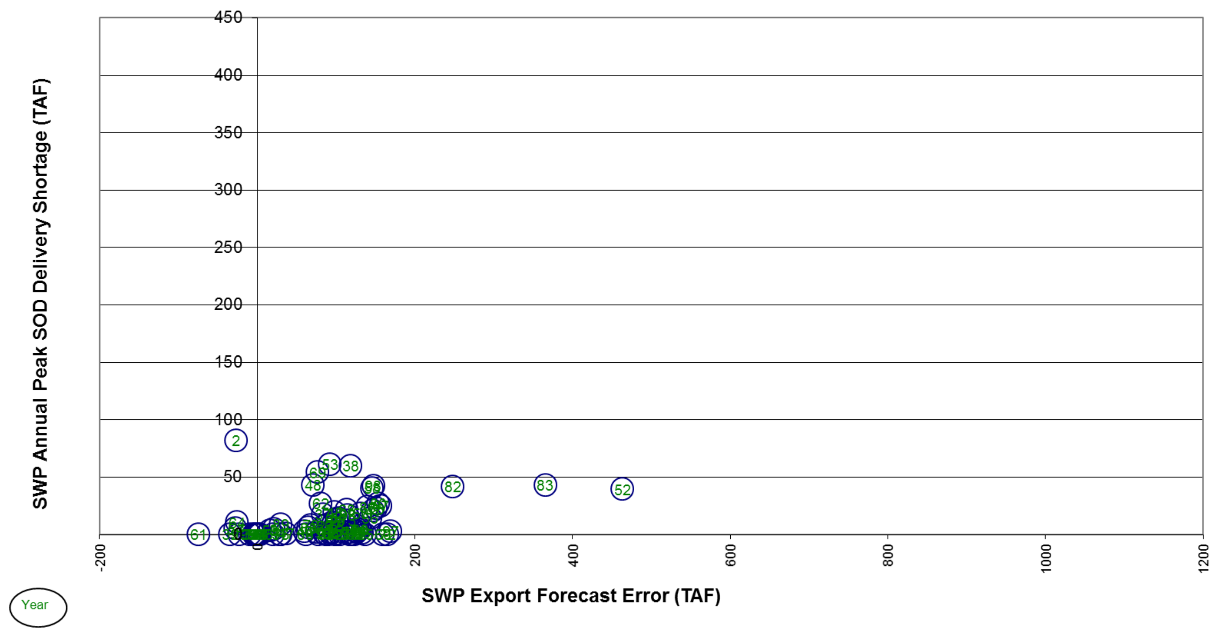

Figure 8. SWP annual peak SOD delivery shortage versus SWP export forecast error in CalSim_27JAN2015_Revised

CalSim CVP Allocation Logic Refinement

Other adjustments were made to CalSim_27JAN2015_Revised in addition to the update of the export forecasts used in CVP and SWP allocations. One was a refinement to the CVP allocation procedure to reduce instances where there are low CVP SOD service contract allocations in years that end in excessively high San Luis carryover. Figure 9~~Figure 9Figure 9~~ links CVP San Luis low point with combined Shasta and Folsom carryover as simulated in CalSim_27JAN2015. Six of the annual data points are highlighted in red due the relatively high San Luis low point and low CVP SOD Ag Service allocation (see Figure 10~~Figure 10Figure 10~~ for the allocation associated with each data point). The highlighted years are 1932–1937, and the SOD Ag Service allocations in these years range from 4% in 1932 to 43% in 1936. The San Luis low point is above 300 TAF throughout this period and reaches almost 600 TAF in 1932. San Luis also fills during critical periods, thereby constraining CVP export of valuable winter surplus. Clearly, higher deliveries could be made SOD without impacting upstream storage; so it is advantageous to determine why the current model does not perform this operation, and what change can be made to more efficiently use available water.

The problem within the model is caused by dry conditions north of the American River and wetter conditions from the American River south. Such a hydrologic imbalance leaves Shasta and Trinity storage low but keeps San Luis storage high through export of surplus originating on the American and San Joaquin Rivers. Low Shasta and Trinity storage results in a low WSI-DI–based allocation. A low WSI-DI allocation supersedes a higher export-based allocation (recall that the model uses the minimum), and SOD service contractor allocations end up being governed by the dry conditions to the north even though there is sufficient water SOD to meet higher demand.

In the end, this is entirely the result of a modeling artifact. It is standard policy within the CVP that NOD service contractor allocations will be equal to or greater than SOD service contractor allocations. The issue lies with how this policy is applied in the model. NOD service contractor allocations are calculated using the WSI-DI method; SOD service contractor allocations are calculated as the minimum of the WSI-DI–based allocation and the export forecast–based allocation. This, at times, artificially constrains system-wide allocations based solely on low conditions at Shasta and Trinity.

In other words, the model ignores the details that operators would consider in developing a real-time service contractor allocation. Note that NOD Ag Service contracts along the Sacramento River total 377 TAF. As such, a NOD Ag Service allocation increase of 1 percent would expose Shasta and Trinity to a combined 4 TAF of additional drawdown. Also consider that SOD Ag Service contracts total 1,987 TAF. Therefore a 1 percent increase in SOD Ag Service allocations would require 20 TAF of combined drawdown in San Luis and/or increased exports. If in actual operations the CVP operators see the potential to boost SOD Ag Service allocations by 100 TAF due to high San Luis storage levels—an allocation increase of approximately 5 percentage points. There may be concern about boosting NOD Ag Service allocations by an equal percentage, but the operators would understand that such an increase would only result in an additional 20 TAF of load on Shasta and Trinity. There are certainly cases where such a tradeoff would be made, and years 1932–1937 as simulated in CalSim_27JAN2015 appear to be such cases.

The modification applied in CalSim_27JAN2015_Revised was to conditionally reformulate CVP Ag Service allocations in contract years 1932–1937. In these years, allocations for both NOD and SOD service contractors are allowed to be driven by the export-based methodology when appropriate. This does not circumvent the standard policy of maintaining NOD service contractor allocations at or above SOD allocations; this policy is maintained. The result of this change in allocation formulation is shown in Figure 11~~Figure 11Figure 11~~ and Figure 12~~Figure 12Figure 12~~. The data points highlighted in red correspond to the same annual data points highlighted in Figure 9~~Figure 9Figure 9~~ and Figure 10~~Figure 10Figure 10~~. The San Luis low point in these years has been significantly reduced in CalSim_27JAN2015_Revised as compared to CalSim_27JAN2015 and the impact to upstream carryover is acceptable.

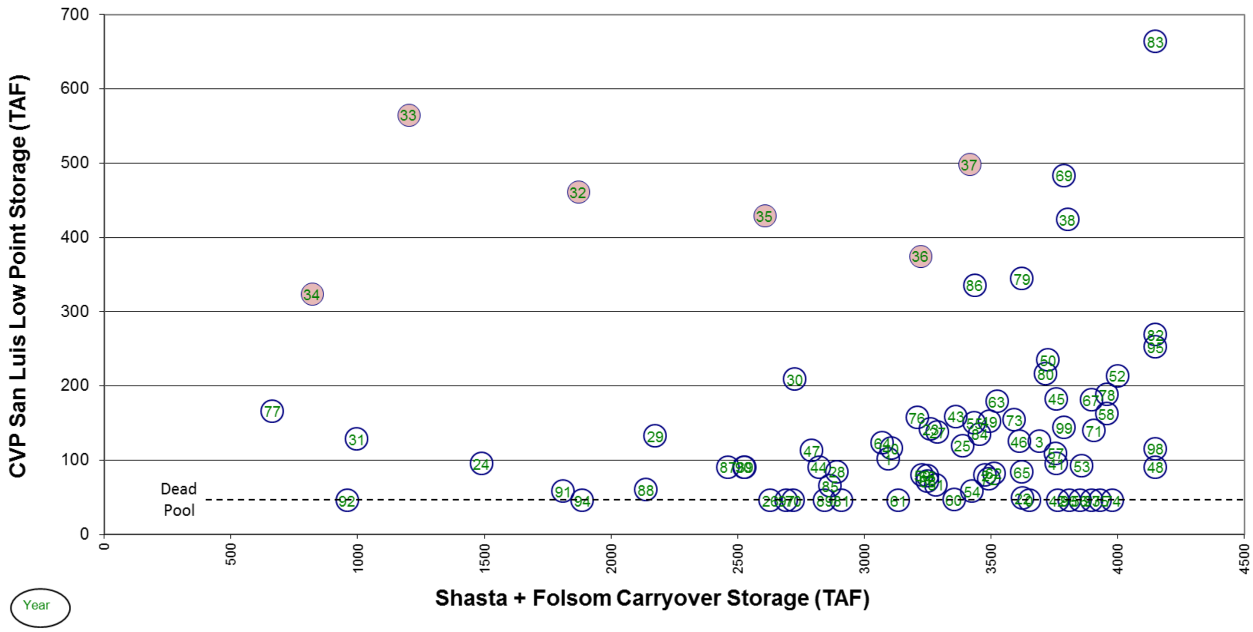

Figure 9. CVP San Luis low point storage versus combined Shasta and Folsom carryover in CalSim_27JAN2015 with contract year data label

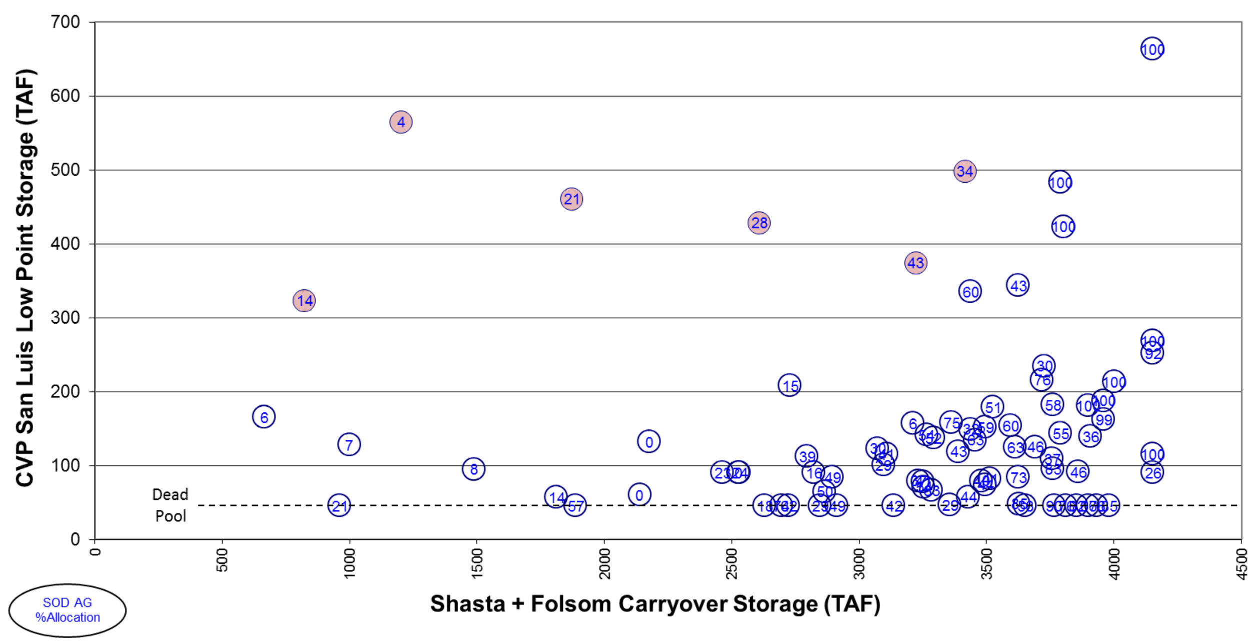

Figure 10. CVP San Luis low point storage versus combined Shasta and Folsom carryover in CalSim_27JAN2015 with SOD Ag Service allocation data label

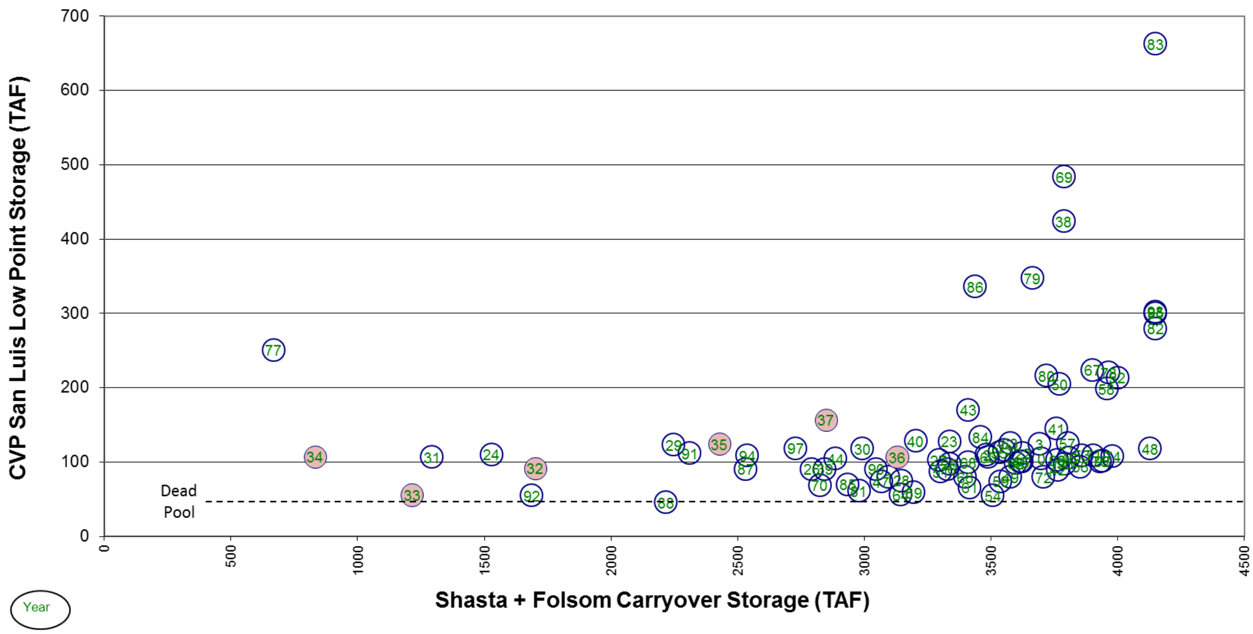

Figure 11. CVP San Luis low point storage versus combined Shasta and Folsom carryover in CalSim_27JAN2015_Revised with contract year data label

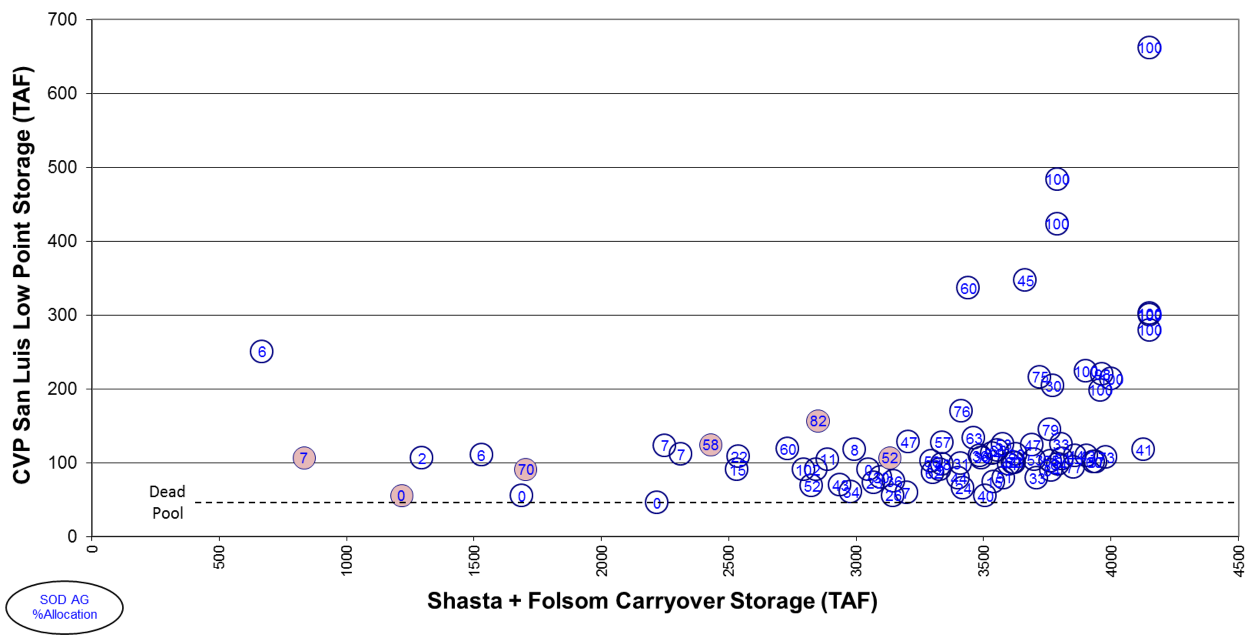

Figure 12. CVP San Luis low point storage versus combined Shasta and Folsom carryover in CalSim_27JAN2015_Revised with SOD Ag Service allocation data label

As discussed above, CalSim_27JAN2015_Revised results as plotted in Figure 5~~Figure 5Figure 5~~, Figure 6~~Figure 6Figure 6~~, Figure 7~~Figure 7Figure 7~~, Figure 8~~Figure 8Figure 8~~, Figure 11~~Figure 11Figure 11~~, and Figure 12~~Figure 12Figure 12~~ were significantly influenced by the revised export forecast used in CVP and SWP allocations and the reformulation of CVP allocation logic in 1932–

1937. Two more changes were also made to CalSim_27JAN2015_Revised that affected results. However, while important to NOD-SOD storage balance, these changes are less significant than those already discussed. The first of these additional edits is refinement of San Luis rulecurve for the SWP and CVP, and the second is an adjustment to operational logic under an ANN negative carriage constraint; these edits are detailed below.

RULECURVE

The purpose of rulecurve is to prioritize balance between NOD storage and San Luis for both the CVP and SWP. Rulecurve controls upstream release for export when there is a choice between storing water in upstream reservoirs and releasing water for export and storing it in San Luis. Operational constraints such as flood pool, minimum instream flow requirements, export regulations, H&S pumping requirements, and physical pump capacity override rulecurve; and when any of these control operations, choices for balancing NOD storage are limited.

During the winter, rulecurve is set to encourage the filling of San Luis though it rarely controls. Incidental Delta inflow typically drives San Luis filling during the rainy season. Upstream reservoir releases are often controlled by flood pool or minimum flow requirements, and exports are controlled by OMR flow requirements or maximum pumping capacity. Since rulecurve does not play a significant role in driving winter San Luis operations, there was no need to modify wintertime rulecurve logic.

Where rulecurve does make a difference (or should make a difference) is during irrigation season when there are windows of opportunity to coordinate upstream reservoir releases with Delta exports. During the summer, SOD project demand typically exceeds Delta exports. As such, SOD project demand is met with a combination of Delta exports and San Luis releases, and if rulecurve is controlling, it influences the balance between Delta exports and San Luis reservoir releases. If rulecurve is set lower, exports decrease and San Luis releases increase. When set higher, the opposite occurs. Ideally the combination of San Luis releases and project exports over the irrigation season is sufficient to satisfy project allocations and San Luis targeted carryover storage, and rulecurve should be set to encourage the appropriate balance.

Therefore, formulation of rulecurve during the irrigation season should boil down to an export scheduling problem, to be solved by determining how much to export within a season to achieve delivery and carryover goals, how to distribute these exports from month to month, and where to set SWP and CVP rulecurve to encourage those Delta exports and the supporting upstream releases. The problem with the current irrigation season rulecurve formulations in CalSim is that they do not consider the amount of exports needed over the season. In fact, for both the SWP and CVP, the rulecurve formulation assumes exports of 60 TAF per month whether that is sufficient to meet operational objectives or not. Rulecurve levels are driven by this export assumption.

The implemented fix to the irrigation season rulecurve formulation is to incorporate export scheduling in CalSim_27JAN2015_Revised; SWP and CVP formulations vary slightly. With the CVP, exports need to be scheduled to ensure the project can meet peak summer demand and prevent San Luis low point issues through the end of September. The SWP has similar concerns, but must also consider Article 56 carryover into the next calendar year with the added complication of

Feather River flow limitations for half of October and all of November that can interfere with the State's ability to make Oroville releases for export. So while the CVP's export scheduling formulation extends from May through September, the SWP's starts in April and extends through December. As an example, the SWP export schedule–based rulecurve formulation for the months of April–December is outlined below.

First, needed exports are calculated from the beginning of the current month of the simulation through the end of December (Required_Exports_NowtoDec (TAF)).

(1) Required_Exports_NowtoDec = max(0, remainDem_SOD + remain_evap + remain_loss + max(110, carryover_final + 55) – Beg_Month_SWP_San_Luis_Storage)

Where

- remainDem_SOD is the remaining Table A allocations to be delivered from now to the end of December (TAF)
- remain_evap is an estimate of total evaporation over the rest of the calendar year (TAF)
- remain_loss is an estimate of the total California Aqueduct losses over the rest of the calendar year (TAF)
- 110 is the SWP San Luis carryover target (TAF)
- carryover_final is the quantity of water needed in San Luis at the end of December to make Article 56 deliveries (TAF)
- 55 is SWP San Luis dead pool capacity (TAF)
- Beg_Month_SWP_San_Luis_Storage is SWP San Luis storage at the beginning of the current month of simulation (TAF)

Next, the amount that should be exported this month (Required_Exports (TAF)) in order to achieve the export goal for the remainder of the calendar year (Required_Exports_NowtoDec) is calculated. Assume exports will be scheduled uniformly over the remaining months of the calendar year, except for half of October and all of November due to Feather River flow restrictions. During the Feather River flow restrictions, we assume Banks pumping is held to the H&S level (300 cfs), which equals approximately 27 TAF over 1.5 months or 18 TAF over 1 month. So the formulation varies by month:

For the months April–September, the formulation is:

(2a) Required_Exports = (Required_Exports_NowtoDec - 27)/(remain_months - 1.5)

For the month of October, the formulation is:

(2b) Required_Exports = (Required_Exports_NowtoDec - 18)/(remain_months - 1)

And for the months of November–December the formulation is:

(2c) Required_Exports = Required_Exports_NowtoDec/remain_months

Where

- remain_months is the number of months remaining in the calendar year starting from the beginning of this month of simulation to the end of December

At this point in the calculation, SWP exports could be prioritized up to Required_Exports such that Oroville releases would be made to support those exports. But that is not the modeling technique used in CalSim. As discussed, the balance of upstream storage and San Luis storage is guided with rulecurve; so to prioritize SWP exports up to Required_Exports, rulecurve must be appropriately set. Expected change in San Luis storage (Change_San_Luis_Storage (TAF)) if exports equal Required_Exports is now calculated. The formulation is:

(3) Change_San_Luis_Storage = Required_Exports – This_Month_Forecasted_Delivery – This_Month_Forecasted_Loss – This_Month_Forecasted_Evap

Where

- This_Month_Forecasted_Delivery is this month's estimated Table A deliveries (TAF)
- This_Month_Forecasted_Loss is this month's estimated California Aqueduct losses (TAF)
- This_Month_Forecasted_Evap is this month's estimated SWP San Luis evaporation (TAF)

Given the calculated Change_San_Luis_Storage, the rulecurve (SWP_Rulecurve (TAF)) that will encourage sufficient Oroville releases to support SWP exports at Required_Exports is determined as follows:

(4) SWP_Rulecurve = Beg_Month_SWP_San_Luis_Storage + Change_San_Luis_Storage

Negative Carriage Operations

Delta carriage is the additional Delta outflow above minimum required Delta outflow (MRDO) necessary to meet D-1641 salinity standards. When salinity is controlling, an increase in exports requires an increase in release from upstream reservoirs to the Delta that equals the export increase plus carriage. In other words, carriage is the water cost of Delta exports when salinity standards are controlling. While higher exports typically result in higher carriage, there are times of the year when Rock Slough and Emmaton salinity standards can be met with higher exports and negative carriage. Essentially, when a negative carriage salinity constraint is controlling, a unit increase in Delta exports is supplied partially by a decrease in carriage (decrease in Delta outflow) and the remainder by an increase in upstream reservoir release. While negative carriage might be counterintuitive, it is an actual phenomenon observed in Delta operations.

Negative carriage in CalSim presents problems of prioritization. In CalSim, Delta outflow above MRDO, whether the outflow is surplus or carriage, is given a highly negative weight (low priority). The intent is to discourage any Delta outflow in excess of MRDO. So when a negative carriage salinity constraint is controlling operations, CalSim will operate to minimize Delta outflow even though it might cause an imbalance between NOD and SOD storage. Delta outflow is reduced through increased exports, but some water still has to be released from upstream reservoirs to support part of the increased export. If NOD reservoirs are relatively full, this could be a desirable operation, but if NOD reservoirs are low and further exports are not needed to support this year's allocation, minimizing Delta outflow at the expense of upstream storage is an unwarranted operational decision. During the critical periods, CalSim makes several of these decisions that result in the transfer of NOD storage to San Luis when the water would be better kept NOD.

The implemented negative carriage operation fix in CalSim_27JAN2015_Revised is to remove the model flexibility to make an unwarranted decision. In CalSim, SWP and CVP export estimates are made to guide operations when salinity standards are controlling (C400_MIF logic). This is used to ensure that needed exports are made even if positive carriage must be paid. In CalSim_27JAN2015_Revised, similar export estimates are now used to limit how much carriage can be reduced through increases in exports under a negative carriage constraint. Essentially, under an Emmaton or Rock Slough negative carriage constraint, the carriage is held at the level to support the estimated export – no more and no less. CalSim does not get an objective function benefit of releasing more water from upstream storage for a fractional reduction in Delta outflow.

Comparison of CalSim_27JAN2015 and CalSim_27JAN2015_Revised Results

The revisions in CalSim_27JAN2015_Revised change the storage balance between Oroville and SWP San Luis. Figure 13~~Figure 13Figure 13~~ and Figure 14~~Figure 14Figure 14~~ relate SWP San Luis low point storage to Oroville carryover in each year of the CalSim_27JAN2015 simulation. The only difference between the two figures is that data in Figure 13~~Figure 13Figure 13~~ is labeled by year and data in Figure 14~~Figure 14Figure 14~~ is labeled by Table A allocation. Note the years that SWP San Luis low point is at dead pool. This occurs over a wide spectrum of Oroville carryover and Table A allocations. Also note the four data points highlighted in red—1925, 1932, 1949, and 1955 with Table A allocations of 37%, 28%, 29%, and 38%, respectively. Ideally, higher allocations would have been made in these years, reducing San Luis low point storage. Figure 15~~Figure 15Figure 15~~ and Figure 16~~Figure 16Figure 16~~ relate SWP San Luis low point storage to Oroville carryover storage in each year of the CalSim_27JAN2015_Revised simulation. Compare Figure 15~~Figure 15Figure 15~~ and Figure 16~~Figure 16Figure 16~~ to Figure 13~~Figure 13Figure 13~~ and Figure 14~~Figure 14Figure 14~~, respectively to see the effect of the model edits (export forecast, rulecurve, and negative carriage) on the overall San Luis-Oroville storage balance. Note that the San Luis low point has been largely lifted above dead pool in CalSim_27JAN2015_Revised. Also note the red highlighted data points in Figure 15~~Figure 15Figure 15~~ and Figure 16~~Figure 16Figure 16~~, which correspond to the same years highlighted in red in
Figure 13~~Figure 13Figure 13~~ and Figure 14~~Figure 14Figure 14~~. The combined effect of the model edits creates a more ideal balance between Oroville storage, SWP San Luis storage, and Table A allocations.

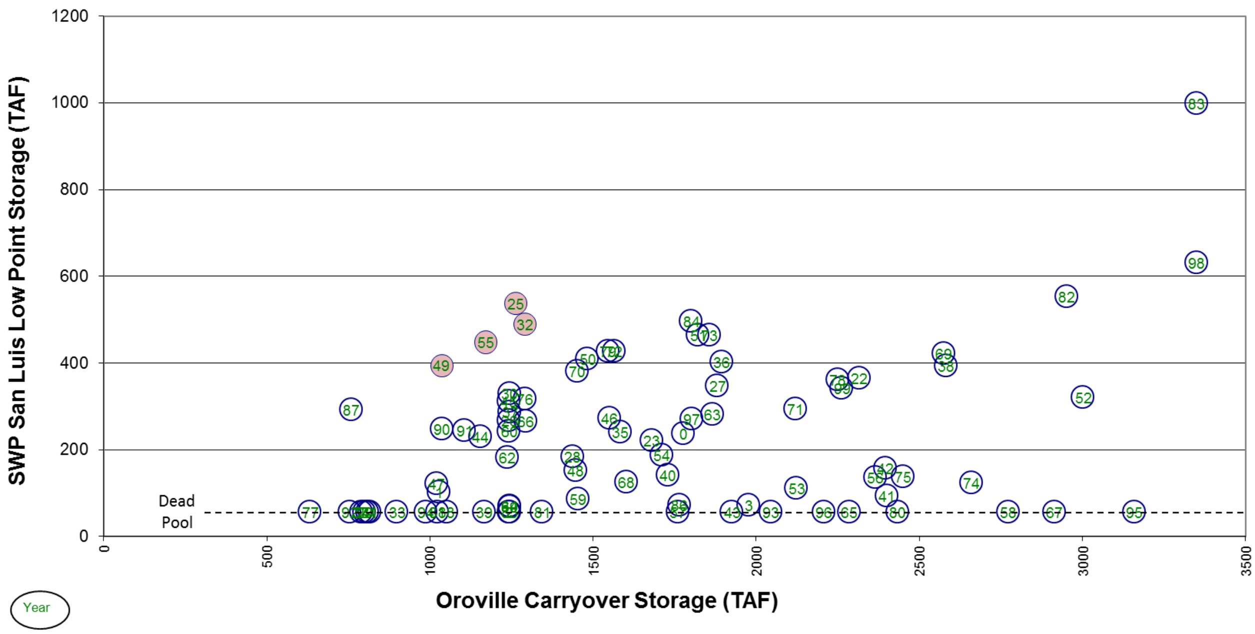

Figure 13. SWP San Luis low point storage versus Oroville carryover in CalSim_27JAN2015 with contract year data label

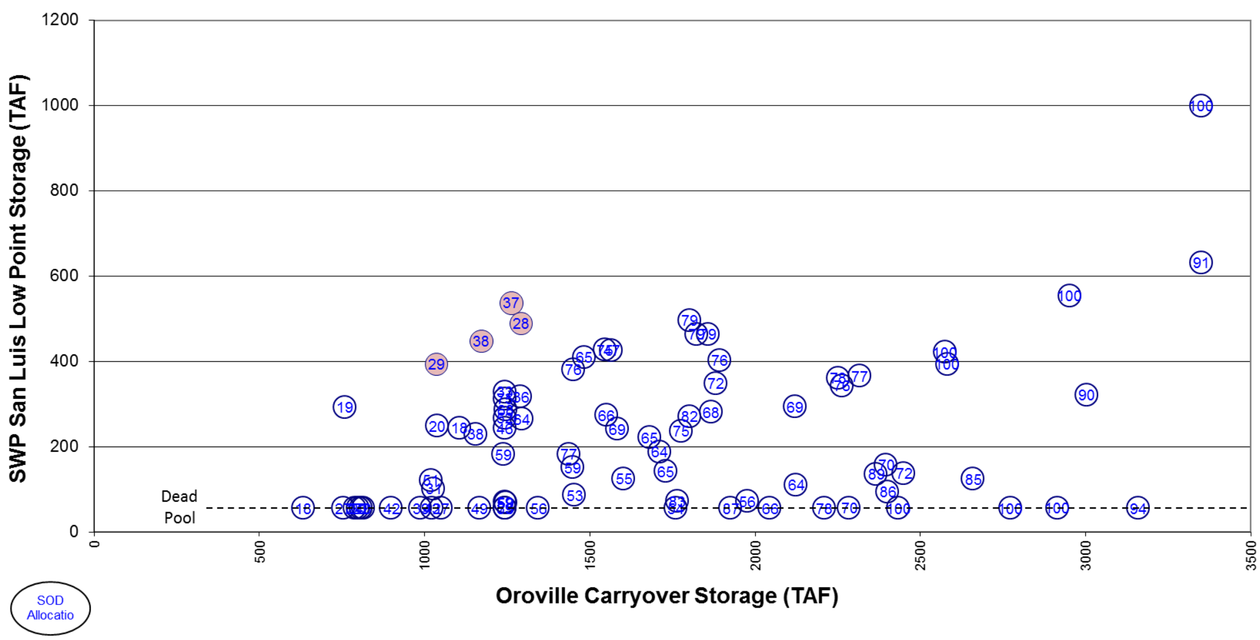

Figure 14. SWP San Luis low point storage versus Oroville carryover in CalSim_27JAN2015 with Table A allocation data label

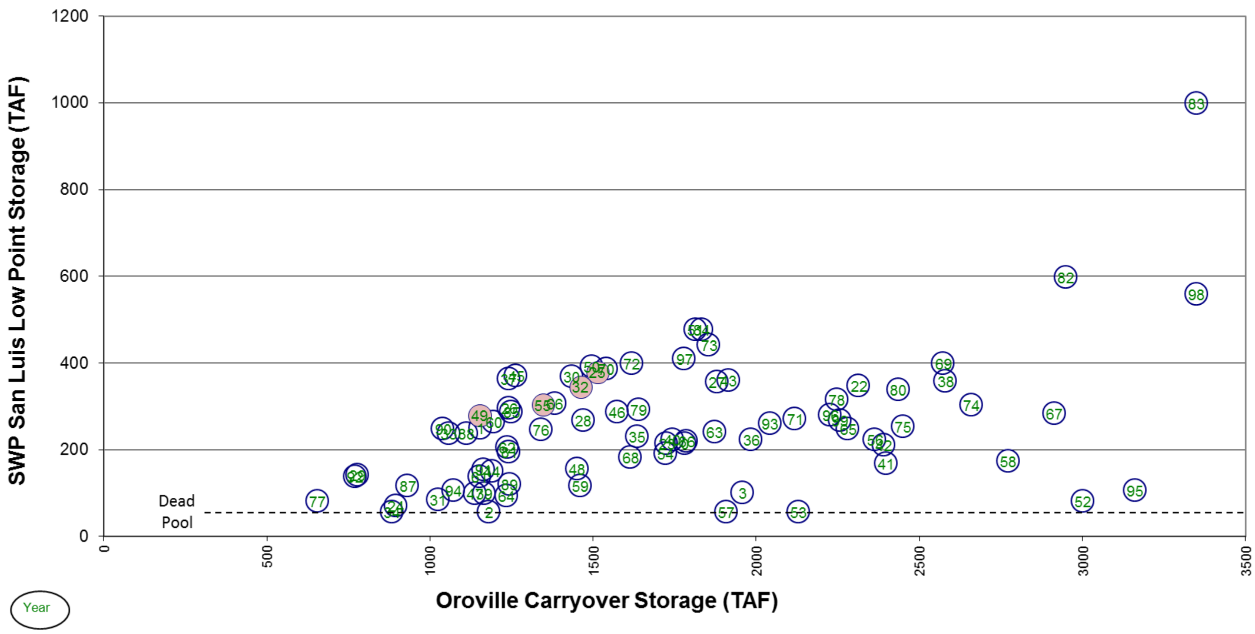

Figure 15. SWP San Luis low point storage versus Oroville carryover in CalSim_27JAN2015_Refined with contract year data label

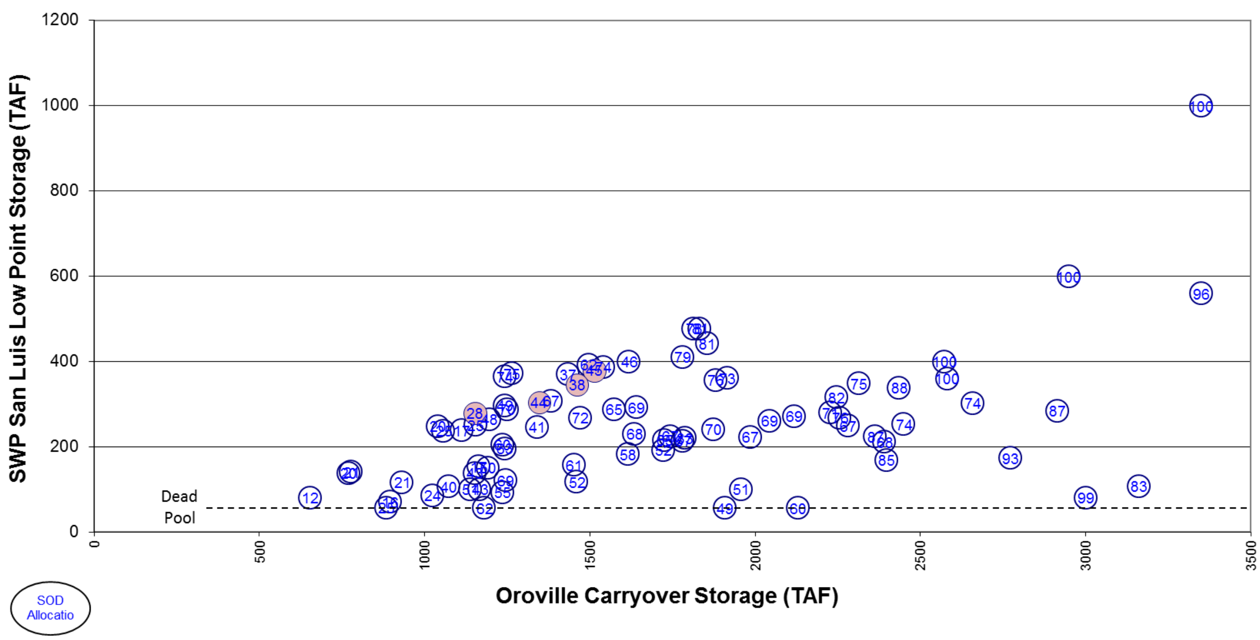

Figure 16. SWP San Luis low point storage versus Oroville carryover in CalSim_27JAN2015_Revised with Table A allocation data label

CVP San Luis storage often hits its annual low point in August. Figure 17~~Figure 17Figure 17~~ compares CVP San Luis end of August storage probability of exceedance curves for CalSim_27JAN2015 and CalSim_27JAN2015_Revised. In CalSim_27JAN2015, there is an almost 20% chance that end of August CVP San Luis storage is at dead pool; there is only slightly more than a 1%

chance in CalSim_27JAN2015_Revised. Also, in CalSim_27JAN2015_Revised, CVP San Luis is consistently drawn down to the 90 TAF low point target used in the CVP SOD export forecast allocation logic, whereas CalSim_27JAN2015 tends to diverge from this target.

SWP San Luis storage often hits its annual low point in October. Figure 18~~Figure 18Figure 18~~ compares SWP San Luis end-of-October storage probability of exceedance curves for CalSim_27JAN2015 and CalSim_27JAN2015_Revised. In CalSim_27JAN2015, there is a greater than 16% chance that end-of-October SWP San Luis storage is at dead pool; there is only a 3% chance in CalSim_27JAN2015_Revised. The low point target used in SWP export forecast allocation logic is 110 TAF. There is no obvious drawdown to this target in Figure 18~~Figure 18Figure 18~~ because of Article 56 carryover. CalSim_27JAN2015_Revised does a better job of preserving Article 56 requested by contractors. This is more evident when comparing CalSim_27JAN2015_Revised and CalSim_27JAN2015 Article 56 deliveries.

Model revisions also affect NOD carryover storage (end of September). Figure 19~~Figure 19Figure 19~~ through Figure 22~~Figure 22Figure 22~~ show the CalSim_27JAN2015 and CalSim_27JAN2015_Revised carryover storage probability exceedance curves for Trinity, Shasta, Folsom, and Oroville reservoirs, respectively. As shown, the model revisions had a largely positive effect on upstream carryover storage.

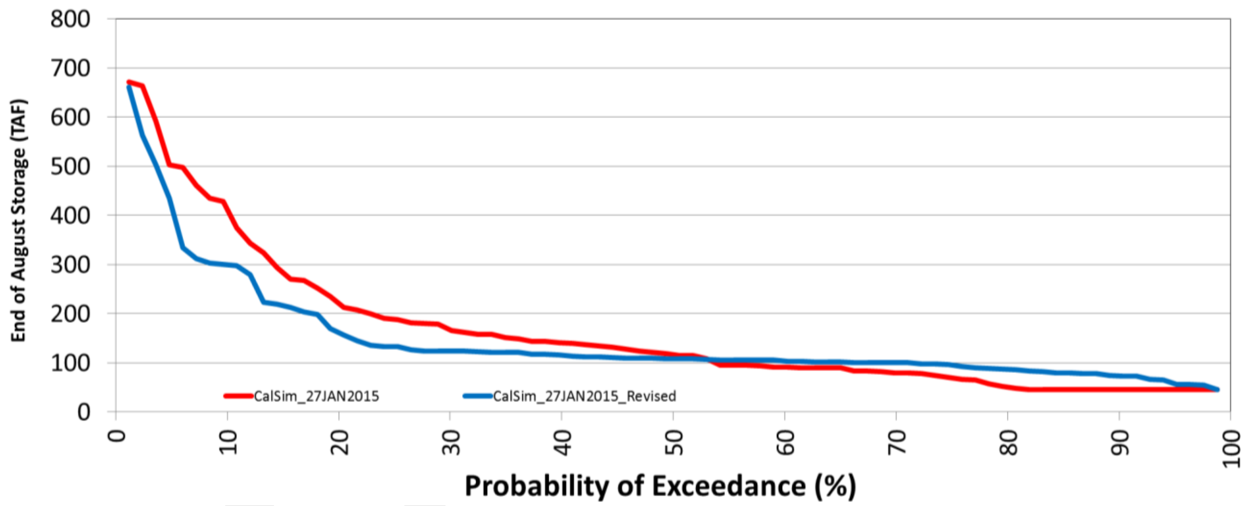

Figure 17. CVP San Luis end of August storage probability of exceedance for CalSim_27JAN2015 and CalSim_27JAN2015_Revised

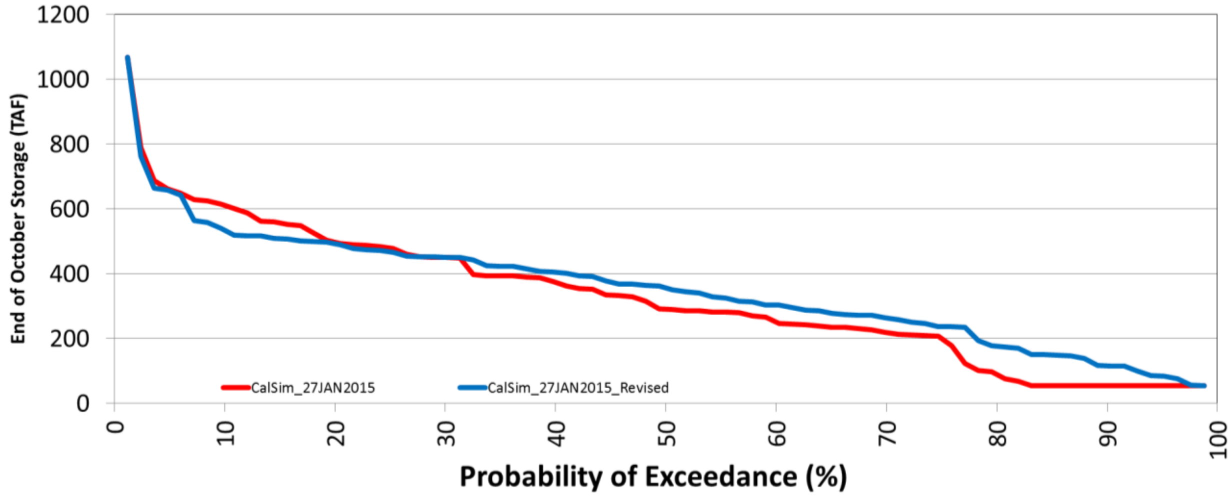

Figure 18. SWP San Luis end of October storage probability of exceedance for CalSim_27JAN2015 and CalSim_27JAN2015_Revised

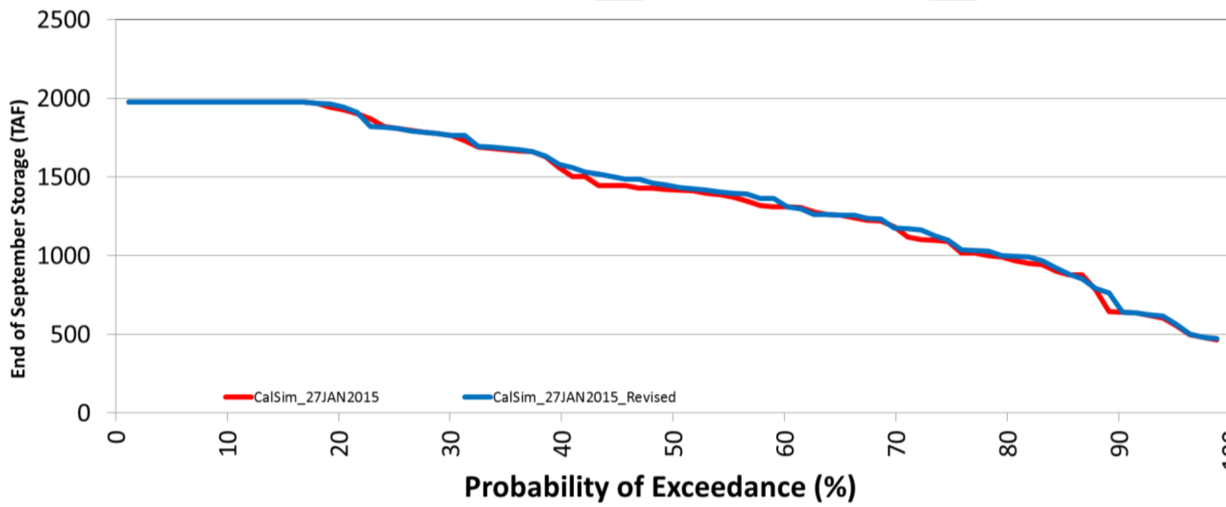

Figure 19**. Trinity carryover storage probability of exceedance for CalSim_27JAN2015 and CalSim_27JAN2015_Revised**

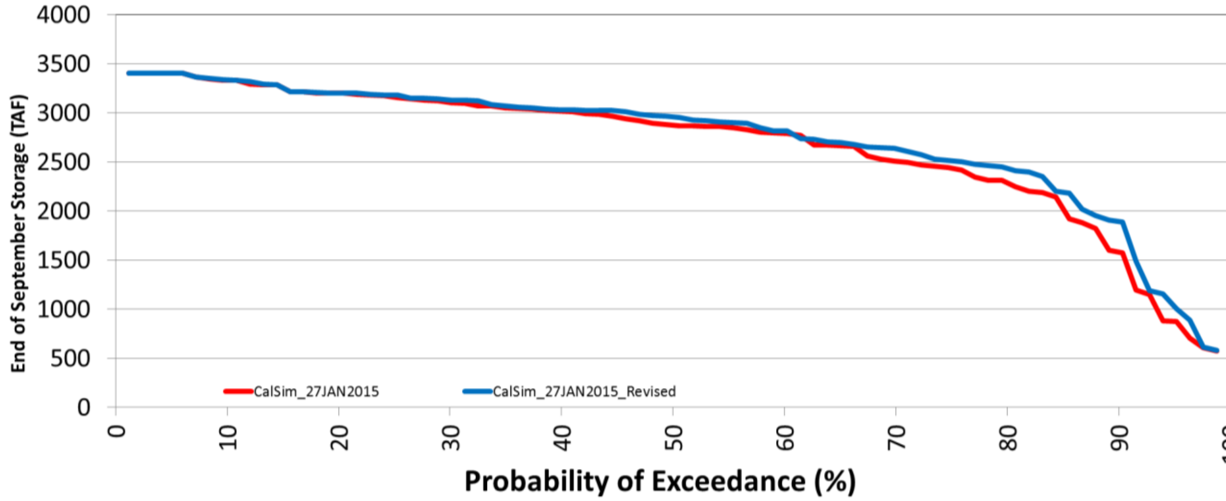

Figure 20. Shasta carryover storage probability of exceedance for CalSim_27JAN2015 and CalSim_27JAN2015_Revised

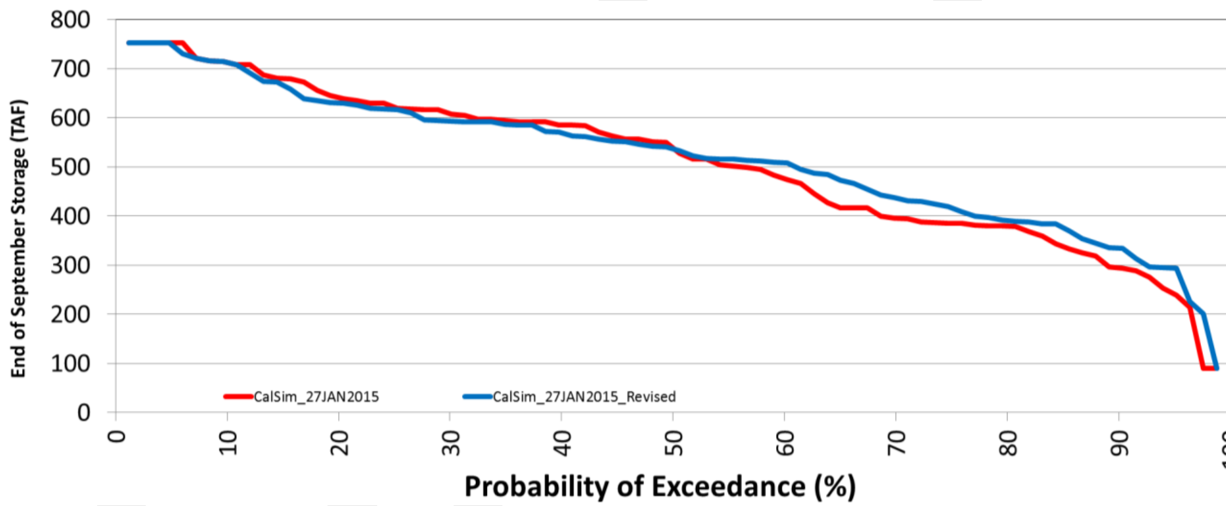

Figure 21. Folsom carryover storage probability of exceedance for CalSim_27JAN2015 and CalSim_27JAN2015_Revised

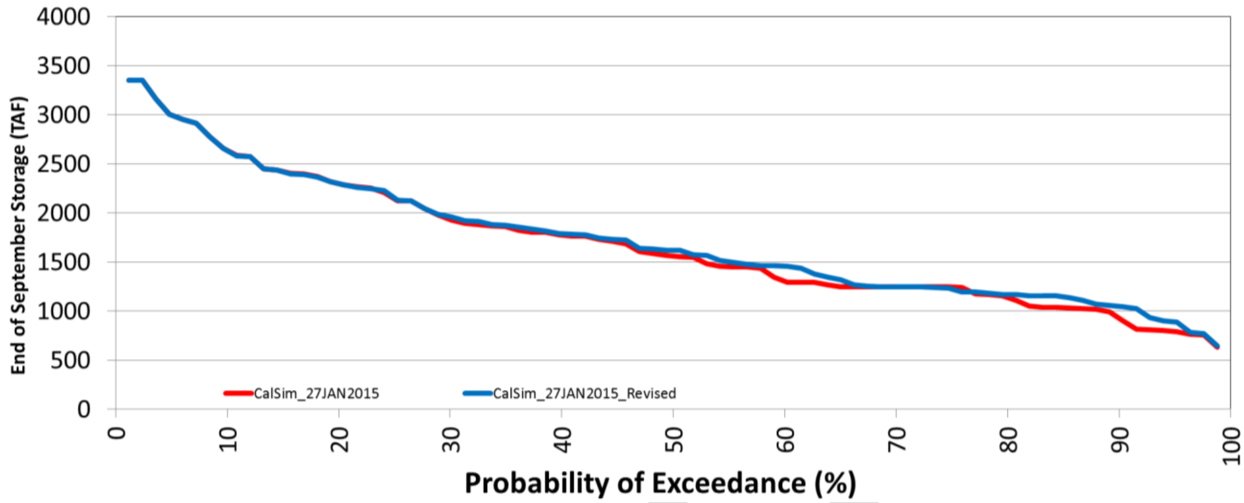

Figure 22. Oroville carryover storage probability of exceedance for CalSim_27JAN2015 and CalSim_27JAN2015_Revised

Significant changes in project reservoir operations necessarily affect project deliveries. Table 5~~Table 5Table 5~~ and Table 6~~Table 6Table 6~~ quantify the difference in CVP NOD and SOD project deliveries by month and water year type. Overall, CVP NOD project deliveries increased by 13 TAF, whereas CVP SOD project deliveries decreased by 25 TAF.

Table 5. Change in total CVP NOD project deliveries between CalSim_27JAN2015_Revised and CalSim_27JAN2015 (TAF)

Indx	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
W	0	0	0	0	0	0	0	0	0	0	0	0	2
AN	0	0	0	0	0	0	1	1	2	2	2	1	8
BN	0	0	0	0	0	0	2	5	7	8	7	3	34
D	0	0	0	0	0	0	2	2	3	4	3	1	16
C	1	0	0	0	0	0	1	1	1	2	1	1	10
All	0	0	0	0	0	0	1	2	2	3	2	1	13

Table 6. Change in total CVP SOD project deliveries between CalSim_27JAN2015_Revised and CalSim_27JAN2015 (TAF)

Indx	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
W	-2	-1	-2	-3	-4	2	-3	-3	-5	-6	11	-2	-18
AN	-3	-2	-3	-5	-5	4	-4	-5	-8	-10	3	-2	-41
BN	0	0	0	-1	-1	9	8	9	14	18	13	4	73
D	0	0	0	0	0	1	-6	-8	-13	-16	-9	-4	-57
C	-1	-1	-1	-2	-2	-4	-7	-12	-17	-22	-13	-6	-89
All	-1	-1	-1	-2	-2	2	-2	-4	-6	-7	2	-2	-25

Table 7~~Table 7Table 7~~ through Table 9~~Table 9Table 9~~ quantify the difference in SWP Table A, Article 56, and Article 21 project deliveries by month and water year type. Overall, Table A deliveries decreased 44 TAF, Article 56 deliveries increased 7 TAF, and Article 21 deliveries decreased 11 TAF. It is expected that reduced Table A allocations would result in fewer Article 56 requests. The reason for higher Article 56 deliveries is that the improved San Luis operation results in fewer Article 56 shortages.

Table 7. Change in SWP Table A deliveries between CalSim_27JAN2015_Revised and CalSim_27JAN2015 (TAF)

Indx	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
W	-2	6	-2	1	-3	11	-10	-11	-11	-8	-7	-6	-41
AN	21	-10	-25	1	0	1	-12	-13	-15	-16	-16	-12	-97
BN	0	-3	-14	8	-6	-6	-4	-3	-1	0	0	0	-30
D	-9	-6	-40	1	1	2	15	9	7	6	14	14	13
C	10	7	-6	0	0	-1	-1	-18	-30	-39	-38	17	-97
All	2	0	-16	2	-2	3	-3	-6	-9	-9	-7	2	-44

Table 8. Change in SWP Article 56 deliveries between CalSim_27JAN2015_Revised and CalSim_27JAN2015 (TAF)

Indx	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
W	0	0	0	6	4	2	0	0	0	0	0	0	11
AN	0	0	0	-4	-2	-1	0	0	0	0	0	0	-7
BN	0	0	0	3	2	2	0	0	0	0	0	0	7
D	0	0	0	3	3	2	0	0	0	0	0	0	9
C	0	0	0	4	4	1	0	0	0	0	0	0	9
All	0	0	0	3	2	1	0	0	0	0	0	0	7

Table 9. Change in SWP Article 21 deliveries between CalSim_27JAN2015_Revised and CalSim_27JAN2015 (TAF)

Indx	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
W	0	0	0	-7	-6	7	-2	0	0	0	1	0	-7
AN	0	0	-1	-2	-1	-1	0	0	0	0	1	0	-4
BN	0	0	0	0	-1	-25	0	0	0	0	0	0	-25
D	0	0	0	0	-4	-2	0	0	0	0	1	0	-6
C	0	0	0	0	-14	-7	0	0	0	0	0	0	-20
All	0	0	0	-2	-5	-4	-1	0	0	0	1	0	-11

Table 10~~Table 10Table 10~~ quantifies the difference in Feather River Settlement Contractor fall rice decomposition deliveries by month and water year type. The annual average difference between the CalSim_27JAN2015_Revised and CalSim_27JAN2015 is 8 TAF. CalSim meets less than the rice decomposition demand when Oroville storage drops below 1.2 MAF. Since CalSim_27JAN2015_Revised maintains higher Oroville storage than CalSim_27JAN2015, the revised study is able to meet more of the rice decomposition demand annually.

Table 10. Change in Feather River Settlement Contractor rice decomposition deliveries between CalSim_27JAN2015_Revised and CalSim_27JAN2015 (TAF)

Indx	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
W	2	2	1	0	0	0	0	0	0	0	0	0	5
AN	-2	-2	-1	-1	0	0	0	0	0	0	0	0	-6
BN	4	6	4	2	0	0	0	0	0	0	0	0	16
D	4	4	2	1	0	0	0	0	0	0	0	0	12
C	4	5	3	1	0	0	0	0	0	0	0	0	12
All	2	3	2	1	0	0	0	0	0	0	0	0	8