DRAFT
System Reoperation Study
Tradeoff Analysis

Technical Report

Prepared for

Department of Water Resources

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by

MBK ENGINEERS

1771 Tribute Road, Suite A
Sacramento, CA 95815
916/456-4400 (phone) • 916/456-0253 (fax)

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Executive Summary

The System Reoperation Study is designed to identify potential options for the reoperation of the state's flood control and water supply systems to meet the following objectives:

- Water supply reliability
- Flood hazard reduction
- Ecosystem protection and restoration

Reoperation options include integration of flood control and water supply systems, effective conjunctive management, and improvements to existing water conveyance systems. This phase of the analysis focuses on integration of flood control enhancing water supply systems and expanded conjunctive management with existing conveyance systems.

An analysis was designed and performed with the goal of identifying potential reoperation options and to improve understanding of existing system constraints. The analysis is referred to as the tradeoff analysis in recognition of the fact that the existing flood control/water supply system is highly integrated and currently operated to meet water supply, flood control, and ecosystem purposes. Current system operations are complex and frequently constrained by flood control and ecosystem requirements and water rights and contracts for the beneficial use of water. Therefore, reoperation options designed to meet one of the three objectives of the System Reoperation Study frequently create tradeoffs with the other objectives. For example, reductions in required reservoir space for flood control may improve water supply reliability but increase risk of flood damage.

The tradeoff analysis is a reconnaissance-level study designed to help illustrate how operational changes designed for one purpose can affect other objectives. Because the existing reservoir and conveyance system is highly integrated and constrained, changes in operation for one purpose create tradeoffs with other purposes. A reconnaissance-level study can help identify these tradeoffs, some of which may be unexpected or unintended, and thereby help guide refinement of more promising options. Model simulations performed in the tradeoff analysis are not refined for the purpose of quantifying benefits or impacts, but rather are intended to illustrate how operational changes in one area affect other areas. For example, how Central Valley Project (CVP) operations can affect State Water Project (SWP) operations, and vice versa.

The tradeoff analysis focused on two potential reoperation options. The first option was additional spring releases from reservoirs for ecosystem benefits. A range of spring release volumes from Shasta and Oroville reservoirs was analyzed as a surrogate for potential ecosystem flows. Analyzing specific biological or ecological flow objectives for defined purposes was not the goal in the tradeoff analysis because there is considerable debate regarding the ecosystem needs for flows below reservoirs. Rather than entering into these debates, a range of release volumes was analyzed. For a reconnaissance-level analysis, defining only the volume and months of additional release is adequate to illustrate and understand tradeoffs. Additionally, a more general analysis can provide results applicable to a wider range of potential future programs. For example, results for additional spring releases help in understanding effects of any program designed to provide additional spring flows including a percent of unimpaired flow, flows designed to inundate floodplains, or additional flows to assist in outmigration of hatchery fish.

A second reoperation option evaluated in the tradeoff analysis was expanded conjunctive management in the Sacramento Valley. Conjunctive management was identified as an option to help meet reoperation objectives in the legislation that authorized the System Reoperation Study. Prior studies of conjunctive management in the Sacramento Valley (GCID-NHI, 2012) determined that traditional conjunctive management operations that bank groundwater when surplus surface water is available and extract groundwater when surface supplies are limited is ineffective in the Sacramento Valley. This is because aquifers in the Sacramento Valley generally recover fully during the winter season. Therefore, conjunctive management evaluated in the tradeoff analysis focused on additional groundwater pumping during periods of limited surface water availability to create potential ecosystem and water supply benefits. A reconnaissance-level analysis of this type of operation identifies tradeoffs for a variety of programs that can make additional surface water available during drought periods including groundwater substitution transfer or crop idling.

These two reoperation options, additional spring reservoir releases and conjunctive management, were also analyzed in concert to illustrate how the options may work together to meet the study objectives.

A total of 26 different scenarios were developed and analyzed as part of the tradeoff analysis. Table ES-1 is a summary of all 26 scenarios, defined by the river system analyzed and the volume of additional spring release and/or expanded conjunctive management.

Table ES-1. Tradeoff Analysis Scenario Matrix

Scenario	River System	Additional Annual Release Volume (TAF)	Release Period	Annual Conjunctive Management Volume (TAF)	Pumping Period
1	Sacramento	25	March - May	None	None
2	Sacramento	50	March - May	None	None
3	Sacramento	100	March - May	None	None
4	Sacramento	200	March - May	None	None
5	Sacramento	300	March - May	None	None
6	Sacramento	400	March - May	None	None
7	Sacramento	500	March - May	None	None
8	Feather	25	March - May	None	None
9	Feather	50	March - May	None	None
10	Feather	100	March - May	None	None
11	Feather	200	March - May	None	None
12	Feather	300	March - May	None	None
13	Feather	400	March - May	None	None
14	Feather	500	March - May	None	None
15	Sacramento	None	None	25	May – August
16	Sacramento	None	None	50	May – August
17	Sacramento	None	None	100	May – August
18	Feather	None	None	25	May – August
19	Feather	None	None	50	May – August
20	Feather	None	None	100	May – August
21	Sacramento	25	March - May	25	May – August
22	Sacramento	50	March - May	50	May – August
23	Sacramento	100	March - May	100	May – August
24	Feather	25	March - May	25	May – August
25	Feather	50	March - May	50	May – August
26	Feather	100	March - May	100	May – August

Each tradeoff scenario was simulated in CalLite. A limited set of operational assumptions was defined for both additional releases and conjunctive management. Additional releases were made only when there was adequate water supply available to limit the risk to carryover storage. Limiting risk to carryover storage helps limit potential ecosystem and water supply impacts in subsequent years. Additional conjunctive management occurs only in years when carryover storage is low in an effort to improve ecosystem and water supply conditions in subsequent years.

Table ES-2 summarizes results from the 26 tradeoff scenario simulations. Results are average annual values and average annual change from the base simulation that represents the existing flood control/water supply infrastructure and regulatory condition. Results are presented in 1,000 acre-feet for the purpose of comparison between scenarios. However, a reconnaissance-level study is not accurate to this level of precision. Results are interpreted to understand potential tradeoffs relative to the volume of additional release or conjunctive management and for comparison between scenarios.

Table ES-2. Summary of Tradeoffs

Scenario	River System	Scenario Number	Target Pulse Volume	Target Conjunctive Management Volume	Pulse Release	Expanded Groundwater Pumping	Shasta EOS Storage	Trinity EOS Storage	Folsom EOS Storage	Oroville EOS Storage	Delta Inflow (Sacramento R.)	Delta Outflow	Jones Pumping Plant	Banks Pumping Plant	North-of-Delta Agricultural Service Deliveries
							Avg. Annual Storage (TAF)				Avg. Annual Flow (TAF)				
		Base	--	--	--	--	2,680	1,396	517	1,836	17,913	15,802	2,252	2,630	233
			Additional Volume (TAF)				Change in Storage (TAF)				Change in Flow (TAF)				
Pulse Flow Only (PFO)	Sacramento	**1**	25	--	13	--	-3	2	0	1	1	4	-2	0	0
		2	50	--	25	--	-10	-5	-1	-2	4	6	-3	1	-1
		3	100	--	47	--	-24	-13	-2	-3	8	12	-5	1	-2
		4	200	--	87	--	-42	-25	-5	-3	14	25	-11	0	-5
		5	300	--	126	--	-64	-37	-7	0	18	31	-13	1	-6
		6	400	--	156	--	-79	-48	-6	4	22	39	-17	0	-9
		7	500	--	171	--	-85	-50	-5	3	22	40	-17	-1	-9
	Feather	**8**	25	--	7	--	0	2	0	-5	0	1	0	-2	0
		9	50	--	14	--	3	5	0	-12	-1	5	-1	-4	1
		10	100	--	27	--	1	3	1	-25	0	8	0	-7	0
		11	200	--	45	--	0	0	0	-40	1	14	0	-12	0
		12	300	--	59	--	-1	2	1	-52	0	18	0	-17	0
		13	400	--	56	--	-1	0	1	-49	2	21	0	-18	0
		14	500	--	49	--	0	1	1	-42	3	18	0	-15	0
Conjunctive Management Only (CM)	Sac.	**15**	--	25	--	5	6	2	2	0	3	1	2	0	1
		16	--	50	--	9	8	6	2	0	7	2	3	1	1
		17	--	100	--	18	19	8	7	0	14	5	7	2	2
	Feather	**18**	--	25	--	8	-1	1	0	6	7	1	1	5	0
		19	--	50	--	16	0	1	0	10	15	2	1	11	0
		20	--	100	--	30	-2	1	2	16	29	6	1	21	0
Pulse Flow with CM	Sac.	**21**	25	25	13	4	1	4	2	1	4	5	-1	0	0
		22	50	50	25	7	0	0	1	-2	9	8	1	1	0
		23	100	100	48	14	-8	-7	4	-4	18	15	1	2	-1
	Feather	**24**	25	25	7	9	-1	3	0	1	8	3	1	4	0
		25	50	50	14	18	3	3	0	0	17	8	-1	10	0
		26	100	100	27	37	0	0	2	-3	37	14	0	22	0

Tradeoff Observations

Results presented in Table ES-2 show several key results of the tradeoff analysis. Observations are summarized below by scenario operations.

Pulse Flow Only Scenarios

The target volume of release is not made every year. This occurs because of operational assumptions to limit risk to carryover storage. In some instances these limits can restrict additional releases for the higher volume scenarios more frequently than for lower volume scenarios, resulting in higher average annual releases under lower target volume scenarios (compare average annual Pulse Release for scenarios 12 and 14).

Pulse Flow Only (PFO) scenarios reduce carryover storage in the reservoir making the additional release. PFO scenarios on the Sacramento River affect carryover storage in all CVP reservoirs upstream of the Delta, including Trinity. Additional releases from Shasta Reservoir reduce water available in Shasta Reservoir and increase the burden on other CVP reservoirs for meeting CVP requirements. This can result in an increase in Trinity River imports, seen by the change in average annual carryover storage in Trinity Reservoir.

Reduced carryover storage in Shasta Reservoir can result in tradeoffs for both cold-water resources for water temperature management and water supply in subsequent years. A more detailed analysis of cold-water resources and effects on water temperature management is provided in the main technical report.

Reductions in water available in Shasta Reservoir create tradeoffs with water supply to CVP contractors both north and south of the Delta. North-of-Delta agricultural water service contract deliveries to the Tehama-Colusa Canal Authority are reduced in scenarios 1 through 7.

Additional releases from both Shasta and Oroville reservoirs increase Delta outflow and reduce Delta exports. Additional reservoir releases in the spring flow into the Delta during months when Delta exports are typically constrained by Old and Middle River flow requirements. Additional Delta inflow from the Sacramento River does not change Old and Middle River flows so additional spring releases increase Delta outflow.

Delta export reductions occur primarily to the project, either CVP or SWP, making the additional reservoir releases.

There can be a small increase in water supply for the project not making additional reservoir releases in some years. This occurs when additional spring releases from one project meet a portion of the required release from the other project. For example, increased spring releases from Shasta Reservoir may reduce SWP releases for meeting spring X2 requirements. These effects are seen as small increases in carryover storage and/or Delta exports.

Conjunctive Management Scenarios

Average annual conjunctive management (CM) groundwater pumping is less than the annual maximum limit or target pumping because CM pumping only occurs when reservoir carryover storage is below certain thresholds.

CM pumping makes additional surface water available in the system in some years. A portion of this may be held in upstream reservoirs on the river system where it is pumped. This increases carryover storage in these reservoirs. Increased carryover storage can provide ecosystem benefits through additional cold-water resources in subsequent years.

Increased carryover storage can also improve water supply reliability. This is illustrated through increased deliveries to North-of-Delta agricultural water service contractors and Delta exports for the CVP (scenarios 15-17) and increased Delta exports for the SWP (scenarios 18-20).

Additional CM pumping on the Sacramento River can affect operations in Shasta Reservoir and other CVP facilities including Trinity Reservoir and may reduce Trinity River imports. This illustrates how the CVP is operated as an integrated project and how changes in one division of the project will affect other divisions.

A portion of additional surface water made available through expanded CM pumping goes to increased Delta outflow. Delta outflow can also increase by the carriage water necessary to convey any CM pumping through the Delta to the export facilities.

Pulse Flow with Conjunctive Management Scenarios

There can be additional CM pumping in combined scenarios compared to CM scenarios because additional spring releases decrease reservoir storage and trigger pumping in more years.

Expanded CM may mitigate some of the tradeoffs described above for PFO scenarios. For example, combined scenarios show less change in carryover storage and Delta exports relative to PFO scenarios.

Additional spring releases reduce the benefits of expanded conjunctive management. For example, there is no increase in carryover storage or Delta exports as a result of CM when combined with additional spring pulse releases.

A higher percentage of the increased Delta inflow goes to Delta outflow in the combined scenarios compared to CM scenarios.

Purpose

The Department of Water Resources (DWR) is formulating reoperation strategies of the State's flood protection and water supply systems for the System Reoperation Study (SRS) to improve water supply reliability, flood protection, and ecosystems. This includes more effective groundwater management and greater integration of groundwater and surface water resources to achieve these goals. SRS managers recognize these goals as competing interests and have initiated a tradeoff analysis to understand system operational flexibilities to help formulate these strategies.

Strategies and Study Workflow

This study focuses on understanding the operational tradeoffs of releasing additional water for ecosystem benefit while considering system-wide regulatory requirements. Analyzing a single specific biological or ecological flow objective is not the goal in this tradeoff analysis. Instead a range of release volumes from Shasta and Oroville reservoirs was used as a surrogate for a variety of potential ecosystem purposes. Conjunctive management strategies will also be explored as a tool for reducing potential impacts of additional releases. Tradeoffs will then be identified and summarized. The level-of-detail in these studies is reconnaissance level, which aims to help the SRS team make decisions towards selecting scenarios in latter phases of the study.

Additional reservoir releases are made in the spring (March - May). Additional water released above the No-Action Scenario or Base can present a challenge in ensuring system reliability, specifically protecting carryover storage at major reservoirs. Therefore, understanding operational flexibilities and constraints with these additional releases will help pinpoint ecological targets most feasible given the goals of the SRS. A range of springtime release volumes between 25 thousand acre-feet (TAF) and 500 TAF from March through May are analyzed in the Sacramento River and Feather River systems. These scenarios are referred to hereinafter as "Pulse Flow Only (PFO)" scenarios. The range of springtime release volumes are representative of many potential ecological objectives including geomorphic flows, floodplain inundation or activation, riparian vegetation recruitment, fish habitat, fish migration and outmigration.

Conjunctive management (CM) strategies will be explored in the Sacramento and Feather River systems to understand improvements to water supply reliability, water supply yields, and potential environmental and ecosystem benefits. CM can improve storage conditions and cold water resources, and has the potential to reduce or offset impacts caused by PFO scenarios. The conjunctive management strategy analyzed in this study is groundwater pumping in-lieu of surface water diversions during periods of reduced surface water availability. Groundwater pumping is assumed to be performed by willing participants in the Sacramento Valley. Summertime conjunctive management volumes between 25 TAF and 100 TAF annually are analyzed for the Sacramento River and Feather River systems. It is understood from prior studies that 100 TAF is near the upper limit of an acceptable conjunctive management program in the Sacramento River Basin for a given year.

Finally, conjunctive management is then simulated in conjunction with pulse flow scenarios to understand how groundwater pumping will lessen water supply and carryover storage impacts from releasing spring pulse flows. Annual conjunctive management volumes will be of same magnitude as the annual pulse flow volume being explored. The tradeoff analysis scenarios are tabulated in Table 1.

Table 1. Tradeoff Analysis Scenario Matrix

Scenario	River System	Additional Annual Release Volume (TAF)	Release Period	Annual Conjunctive Management Volume (TAF)	Pumping Period
1	Sacramento	25	March - May	None	None
2	Sacramento	50	March - May	None	None
3	Sacramento	100	March - May	None	None
4	Sacramento	200	March - May	None	None
5	Sacramento	300	March - May	None	None
6	Sacramento	400	March - May	None	None
7	Sacramento	500	March - May	None	None
8	Feather	25	March - May	None	None
9	Feather	50	March - May	None	None
10	Feather	100	March - May	None	None
11	Feather	200	March - May	None	None
12	Feather	300	March - May	None	None
13	Feather	400	March - May	None	None
14	Feather	500	March - May	None	None
15	Sacramento	None	None	25	May – August
16	Sacramento	None	None	50	May – August
17	Sacramento	None	None	100	May – August
18	Feather	None	None	25	May – August
19	Feather	None	None	50	May – August
20	Feather	None	None	100	May – August
21	Sacramento	25	March - May	25	May – August
22	Sacramento	50	March - May	50	May – August
23	Sacramento	100	March - May	100	May – August
24	Feather	25	March - May	25	May – August
25	Feather	50	March - May	50	May – August
26	Feather	100	March - May	100	May – August

Models and Analytical Approach

Tradeoffs were analyzed and quantified for each scenario by simulating Central Valley Project (CVP) and State Water Project (SWP) operations using CalLite (CalLite 2012). Results were compared to results of a base simulation that depicts current operations with current regulatory requirements (2008 and 2009 Biological Opinions). The difference between model results for metrics such as water deliveries, reservoir storage, and river flows were calculated to illustrate tradeoffs.

Stream temperature tradeoffs in the Sacramento River system were analyzed and quantified using the Sacramento River Water Quality Model (SRWQM). SRWQM uses end-of-month storages and monthly releases at Trinity, Lewiston, Whiskeytown, Shasta, and Keswick reservoirs from the CalLite simulations as input. Results from SRWQM simulations of scenarios were compared to results of a base simulation. The difference between model results for metrics such as stream temperatures and cold water pool were calculated to illustrate tradeoffs.

California Department of Water Resources (DWR) engineers modified a pre-processor engine to prepare CalLite model results for use as SRWQM input. This pre-processor engine will prepare SRWQM inputs limited in extent from the upstream reservoirs to the Red Bluff Diversion Dam.

Pulse Flow Analysis and Assumptions

Sacramento River System Operations (Scenarios 1-7)

Operational flexibilities and tradeoffs from releasing spring pulse flows in the Sacramento River system are assessed in these scenarios. Spring pulse flow releases are provided from Shasta Dam. Spring pulse flow releases are made between March and May. Constraints are placed to guide operational decisions on whether or not to make a pulse flow each March, April, and May. In any March, April, or May, if water supply is insufficient in the upper Sacramento watershed, spring pulse flows will not be released. This constraint was designed to protect end-of-September (EOS) carryover storage to limit adverse effects of spring pulse flows on water supply reliability and cold water availability in subsequent years. To apply this constraint, a water supply index (WSI) was developed to quantify available water each year. WSI is the sum of beginning month's storage and cumulative inflow between each spring month through EOS and is expressed as follows:

$$WSI_t = Storage_{t-1} + \sum_{j=t}^{September} Inflow_j$$

Using May 1923 as an example, end-of-April storage was 4,344 TAF and forecasted inflow is 396 TAF, 274 TAF, 237 TAF, 212 TAF, and 209 TAF for May, June, July, August, and September, respectively. May 1923 WSI is 5.67 million acre-feet (MAF). Monthly WSI thresholds used to trigger Shasta Reservoir pulse flow releases are summarized in Table 2. In May 1923, a pulse flow would likely have been made since the WSI of 5.67 MAF exceeded the WSI threshold of 5.0 MAF. If Shasta storage and forecast inflow conditions do not exceed the WSI threshold, a pulse flow will not be released for the month. This approach attempts to carryover 2.4 MAF storage at EOS.

On the other hand, if Shasta Reservoir is regulating releases to maintain flood storage space, pulse flows will also not be released in addition to regulatory flood releases. This is to avoid potential flood impacts of making additional releases during flood control operations and to avoid claiming pulse flow release credit for mandatory flood releases.

Table 2. Sacramento River Pulse Flow Assumptions

Period	WSI Threshold (MAF)	Flood Control Storage Level (MAF)	Maximum Flow
March	5.6	3.4 – 4.5	Additional Release Volume by Scenario. See Table 1.
April	5.4	4.0 – 4.5	
May	5.0	4.5	

Monthly spring pulse release volumes can vary depending on whether or not a pulse flow was made in prior months. The annual volume is released in equal thirds over the three month period if a release is made each month. If a release is not made in one month, a portion of the missed release will be made up in subsequent months, up to a maximum of half of the annual volume. For example, if a pulse flow release is made in March, one-third of the annual pulse flow volume will be released. If flood releases are made from Shasta Dam in April, a pulse flow will not be made. However, if a pulse release is made in May, the volume will be limited to one-half of the annual pulse flow volume. Spring pulse release volume distribution by month is listed in Table 3.

Table 3. Distribution of Annual Spring Pulse Release by Fractional Units

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

[1] 2/3 x Scenario's Annual Pulse Volume

Sacramento River Water Temperature Operations (Scenarios 1-7, 15-17, & 21-23)

When releasing spring pulse flows, water temperature management on the upper Sacramento River system becomes a tradeoff. Spring pulse flow releases provided from Shasta Dam can reduce cold-water storage used to maintain stream temperatures in the summer and fall. United States Bureau of Reclamation (Reclamation) operates the Shasta Division to maintain water temperatures for habitat uses in the upper Sacramento River downstream from Keswick Dam to the Red Bluff Diversion Dam. "The Shasta Division includes Shasta Dam, Lake, and Powerplant; Keswick Dam, Reservoir, and Powerplant; and the Shasta Temperature Control Device (TCD). The TCD is designed to enable selective release of water from varying lake levels through the powerplant to manage and maintain adequate water temperatures. During mid-winter to early spring, the highest elevation gates possible are used to draw from the upper portions of the lake to conserve deeper cold-water resources. Cold-water resources are defined as accessible water in Shasta Reservoir with temperatures of 52° Fahrenheit (°F) or cooler. During late spring to summer, operators begin the seasonal progression of opening deeper gates as Shasta Lake elevation decreases and cold-water resources are being used. In late summer to fall, the TCD side gates are opened to use the remaining cold-water resources below the Shasta Powerplant elevation. The seasonal progression of the Shasta TCD operation is designed to maximize the conservation of cold-water resources deep in Shasta Lake, until the time the resource is of greatest management value to fishery management" (OCAP 2004).

Consistent with OCAP 2004 and OCAP 2008, the stream temperature target selected for evaluating temperature tradeoffs from spring pulse flows is based on the most sensitive life stage of a particular fish species. This species is the Winter Run Chinook Salmon during egg incubation from April 15th to October 31st. The target stream temperature for Winter Run Chinook Salmon egg incubation is 56°F or cooler. Under most conditions, Reclamation attempts to maintain water temperature control (56°F or cooler) on the Sacramento River at or downstream of Ball's Ferry Bridge. The temperature control location is determined annually by Reclamation and the Sacramento River Temperature Task Group (SRTTG) (OCAP 2008). In general, a key input into the SRTTG's decision on the current season's temperature control target location below Keswick Dam is Shasta Reservoir end-of-May (EOM) storage. As such, EOM Shasta Reservoir storage is a key indicator in evaluating impacts of Sacramento River pulse flow scenarios.

Feather River System Operations (Scenarios 8-14)

Feather River system pulse flow releases are provided from Oroville Dam. Similar to the approach on the Sacramento River, Oroville Reservoir spring pulse releases are contingent upon a WSI based on Oroville Reservoir storage and inflow. If the Oroville Reservoir WSI does not meet or exceed the WSI threshold for a particular March, April, or May, a spring pulse flow will not be released. The WSI threshold developed for Oroville Reservoir pulse flow releases are summarized in Table 4. These thresholds target a carryover of 1.5 MAF for EOS storage. Spring pulse releases are not made in addition to regulatory flood releases to avoid potential flood impacts.

Table 4. Feather River Pulse Flow Assumptions

Period	WSI Threshold (MAF)	Flood Control Storage Level (MAF)	Maximum Flow
March	4.3	2.8 – 3.2	Additional Release Volume by Scenario. See Table 1.
April	4.1	3.1 – 3.5	
May	3.8	3.5	

Table 5 illustrates frequency of pulse flows released and the average annual pulse release volume for the 82-year simulation period.

Table 5. Spring Pulse Frequency and Average Annual Pulse Release Volume

	Scenario	Target Pulse Volume (TAF)	Frequency (# of releases)			Average Annual March through May Pulse Release (TAF)
			March	April	May	
Sacramento River System	1	25	30	40	33	13
	2	50	28	38	32	25
	3	100	28	36	30	47
	4	200	25	34	28	87
	5	300	23	33	28	126
	6	400	21	28	27	156
	7	500	18	24	23	171
Feather River System	8	25	3	23	24	7
	9	50	3	21	24	14
	10	100	1	19	24	27
	11	200	1	15	21	45
	12	300	1	11	20	59
	13	400	1	9	14	56
	14	500	1	6	10	49

The WSI and not simulating pulse flow releases in addition to flood control releases result in infrequent March releases from Oroville Reservoir (Scenarios 8 through 14). Out of the 82-year simulation period, Oroville Reservoir was making flood control releases in March of 42 years, and in 31 years there was insufficient water supply to release a pulse flow.

Pulse Flow Only Tradeoffs

Sacramento River Pulse System Tradeoffs (Scenarios 1-7)

Monthly flow exceedance on the Sacramento River at Keswick Dam is plotted in Figure 1. Flows are increased in March, April, and May as additional releases are made under the spring pulse flow scenarios. A 500 TAF spring pulse flow target increased median Sacramento River flows at Keswick Dam by approximately 1,500 cfs, 1,400 cfs, and 700 cfs in March, April, and May, respectively. Flows can be reduced in all other months due to changes in both flood control and water supply releases from Shasta Reservoir. The average annual release from Shasta Reservoir is essentially the same across the baseline and all seven scenarios.

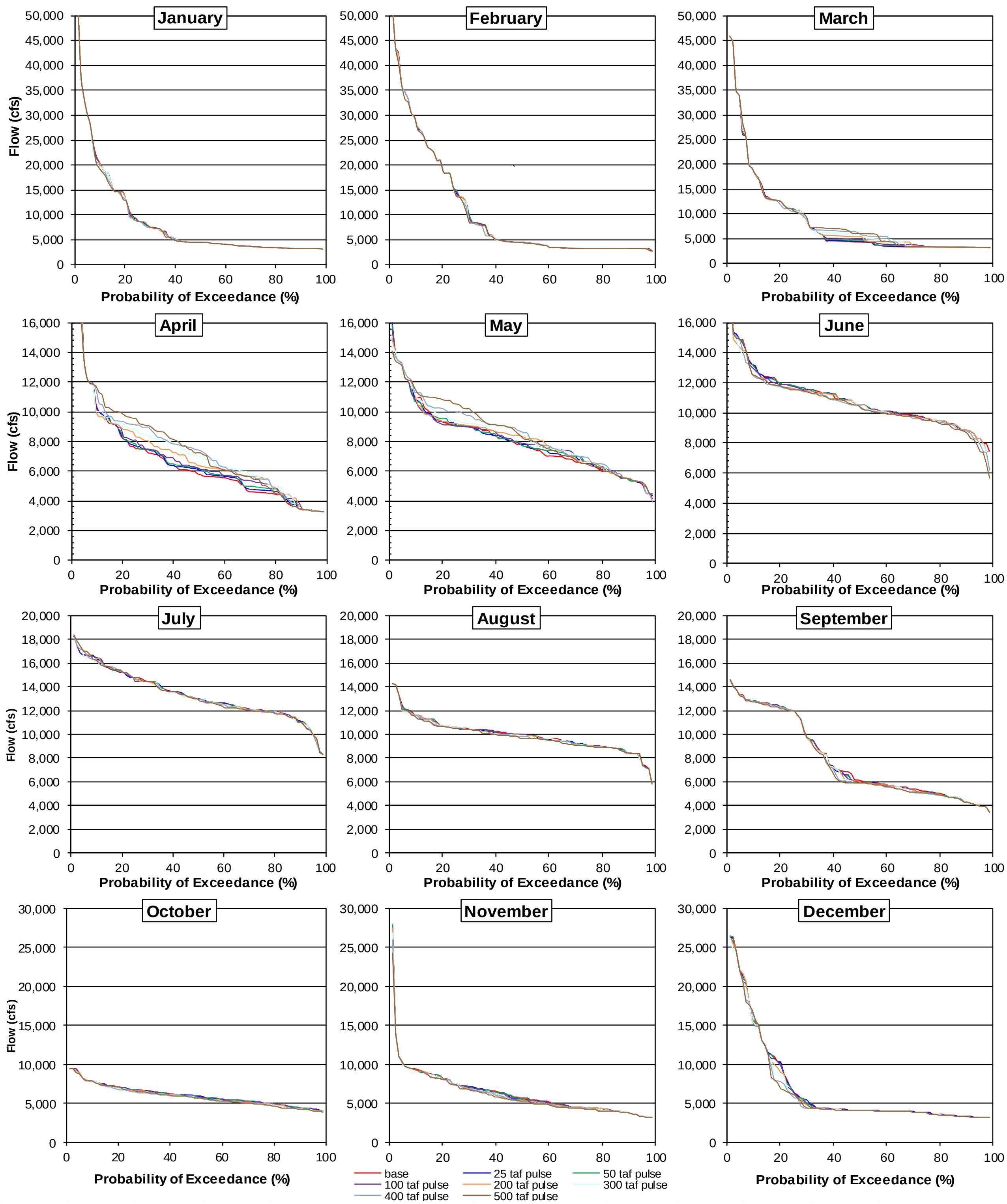

Figure 1. Monthly Flow (CFS) Exceedance on Sacramento River at Keswick Dam (Scenario 1-7)

While the average annual release from Shasta Reservoir is essentially the same, changes in flow at Keswick Dam also include changes in CVP operations and additional water imported from the Trinity River. These changes are illustrated in the average annual change in flow at Keswick Dam (Figure 2).

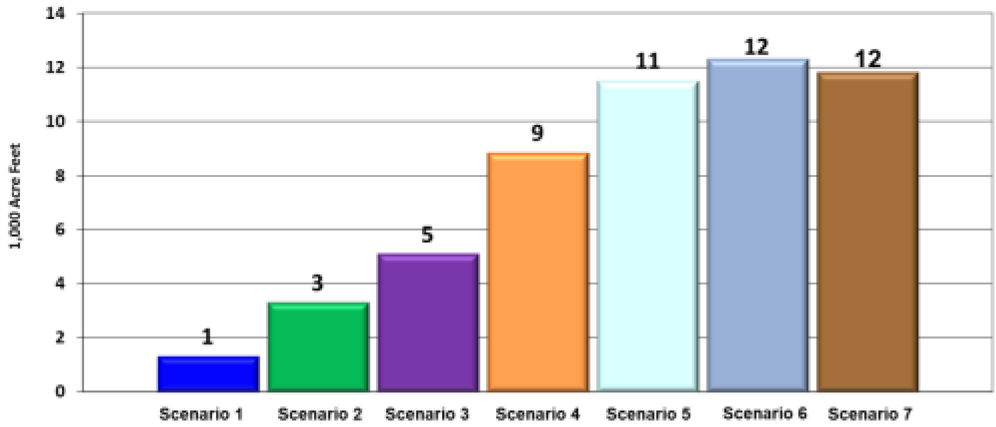

Figure 2. Change in Average Annual Sacramento River Flow at Keswick Dam (Scenario 1-7)

Additional spring releases from Shasta Reservoir decrease its storage and increase the burden on other CVP reservoirs such as Trinity and Folsom reservoirs at other times of the year.

Additional spring releases from Shasta Reservoir change monthly flows downstream on the Sacramento River similar to the changes illustrated at Keswick Dam in Figure 1. These changes persist through the Delta and change the timing of Delta outflow. Additional flows through the Delta in March, April, and May are not diverted at the export facilities due to Old and Middle River flow restrictions in those months. Therefore, additional spring releases may provide an ecosystem benefit, but also affect water supply.

Water supply tradeoffs can be characterized by changes in Sacramento Valley diversions, changes in pumping at Jones (CVP) and Banks (SWP) pumping plants (Delta exports), and EOS reservoir carryover storage. Changes in Sacramento Valley diversions and Delta exports are a direct measure of effects on water supply in a particular year. Change in EOS reservoir storage is a measure of risks to water supply availability for the following year.

Less storage in Shasta Reservoir as a result of additional spring releases creates lower allocations to CVP water service contractors. The largest effect in the Sacramento Valley is to agricultural water service contractors in the Tehama-Colusa Canal Authority (TCCA). Figure 3 illustrates the average annual change in simulated diversions to the TCCA for each of the PFO scenarios on the Sacramento River.

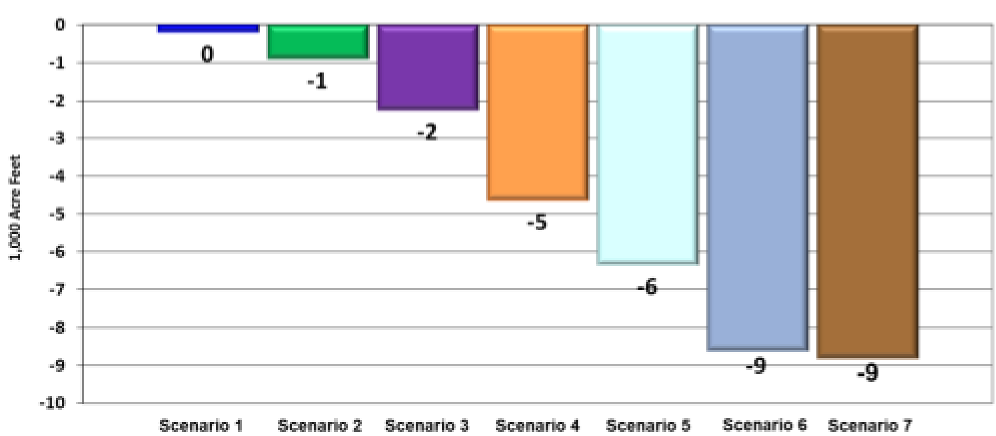

Figure 3. Change in Average Annual TCCA Deliveries (Scenario 1-7)

Moreover, less storage in Shasta Reservoir as a result of additional spring releases will increase demand for Trinity River imports. Less diversion and consumptive use of surface water in the Sacramento Valley, combined with higher imports from the Trinity River, increase Delta inflow from the Sacramento River. Additionally, lower allocations to CVP water service contractors south of the Delta and less water available in storage combine to reduce CVP Delta exports, as illustrated in Figure 4. Average annual CVP Delta exports in the No-Action Scenario are approximately 2.25 MAF. There is no significant change in SWP Delta Exports.

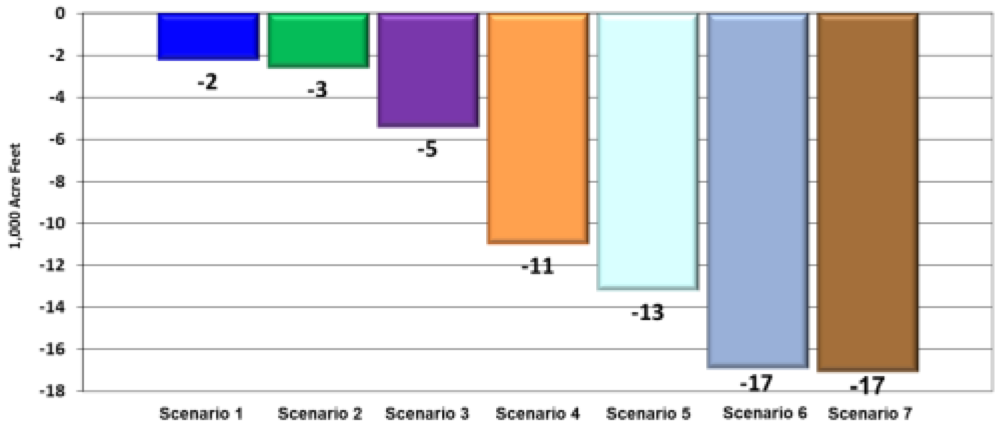

Figure 4. Change in Average Annual CVP Delta Exports (Scenario 1-7)

The combination of increased Sacramento River inflow to the Delta and reduction in CVP Delta exports increase Delta outflow for each of the PFO scenarios. The changes in the average annual Delta outflow are plotted in Figure 5. Average annual Delta outflow in the No-Action Scenario is approximately 15.8 MAF.

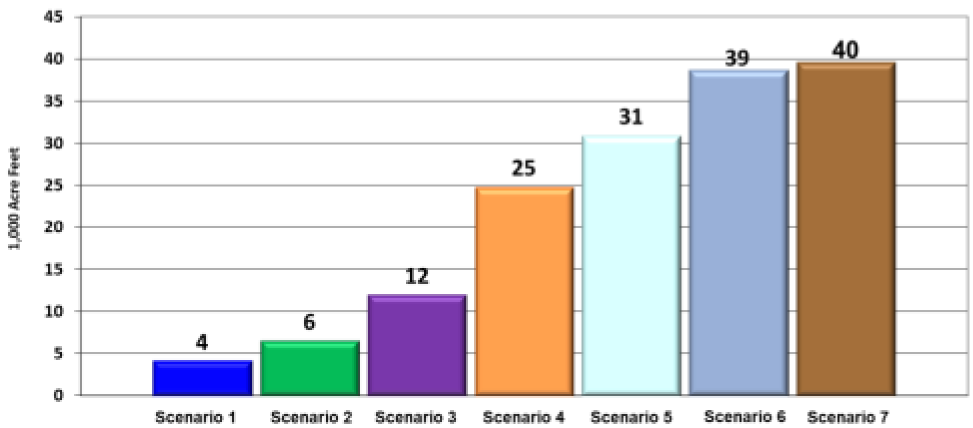

Figure 5. Change in Average Annual Delta Outflow (Scenario 1-7)

Additional tradeoffs are illustrated by comparison of EOS reservoir storage for the major CVP and SWP reservoirs. Shasta Reservoir EOS storage exceedance probability is plotted in Figure 6. EOS carryover storage in Shasta Reservoir is reduced in years when spring pulse flow releases are made. A 500 TAF spring pulse flow target reduced median EOS carryover storage in Shasta Reservoir by approximately 220 TAF.

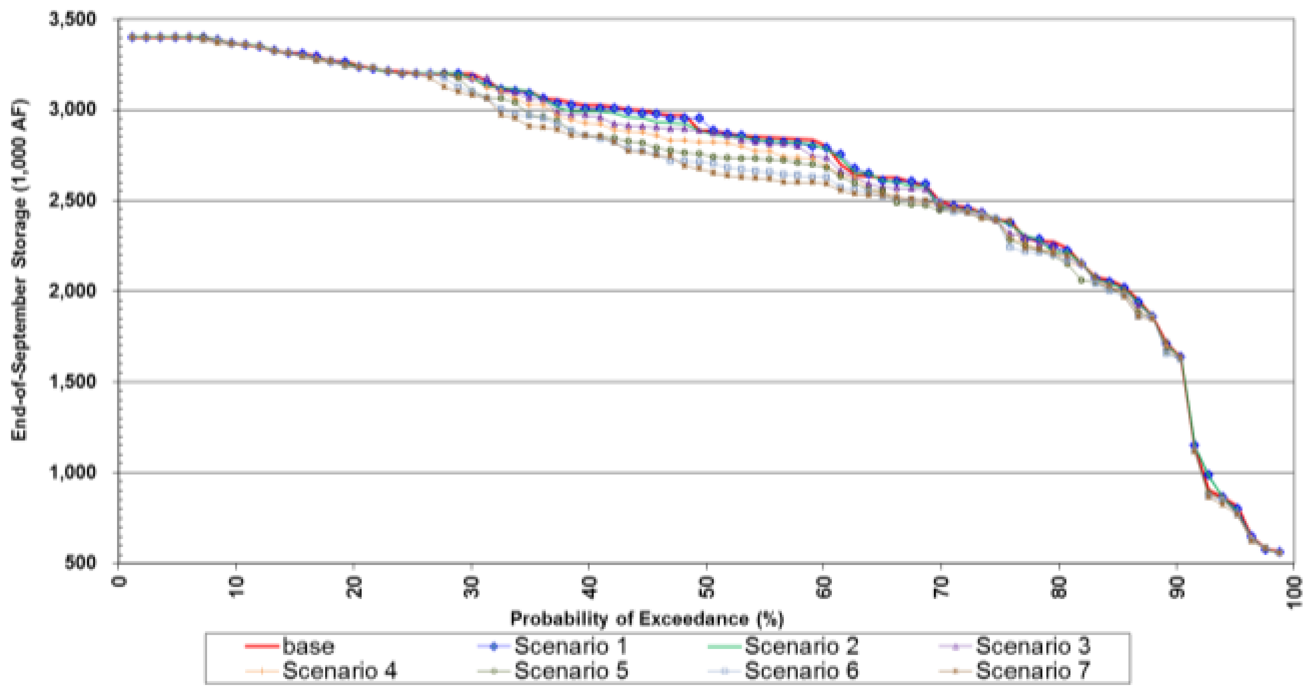

Figure 6. Shasta Reservoir End-of-September Storage (Scenario 1-7)

EOS carryover storage is plotted for Trinity Reservoir and Folsom Reservoir in Figure 7 and Figure 8, respectively. EOS carryover storage for Trinity and Folsom reservoirs will be reduced as a result of spring pulse flows. Since Shasta Reservoir is releasing for spring pulse flows, there is less water available to meet other CVP demands and other CVP facilities will be burdened to meet CVP requirements.

Conversely, EOS storage in Oroville Reservoir will increase, as illustrated in Figure 9. Spring pulse flows released from a CVP facility reduce SWP obligations for certain Delta requirements such as maintaining X2 in the months when releases are made. Additionally, higher spring outflows “freshen” the Delta and the effect can persist into summer months and thereby reduce Delta outflow required to meet Delta water quality standards.

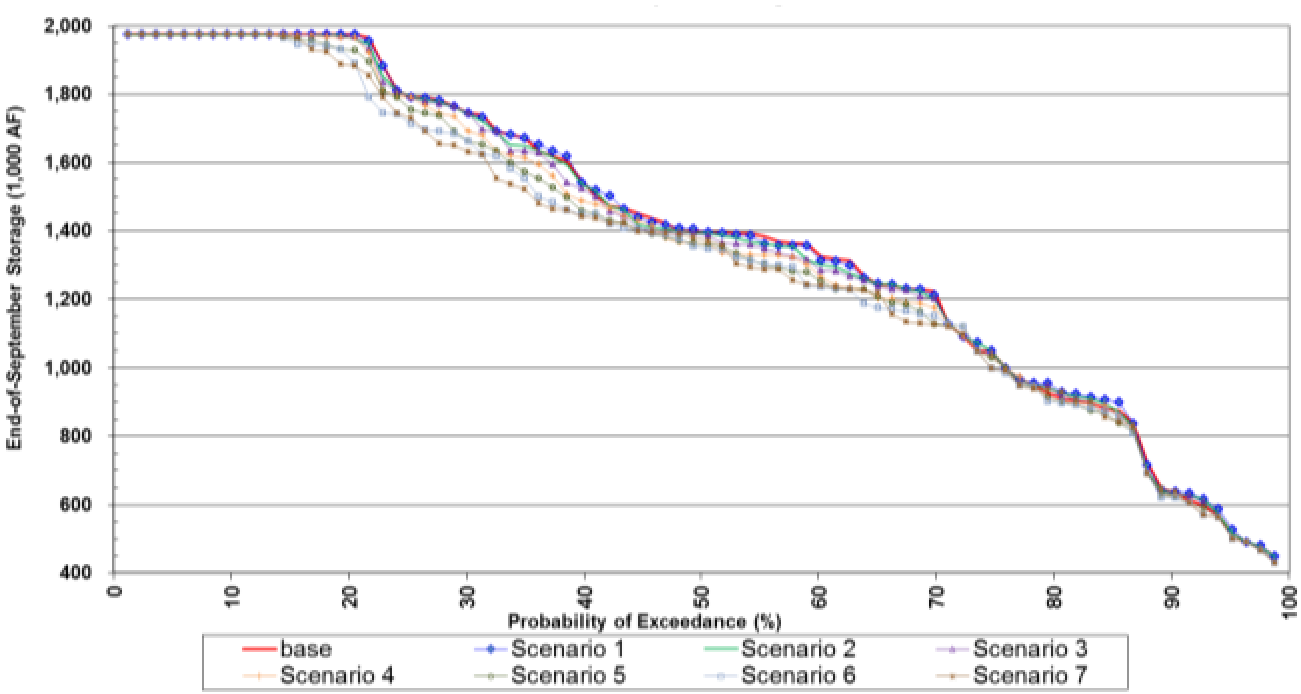

Figure 7. Trinity Reservoir End-of-September Storage (Scenario 1-7)

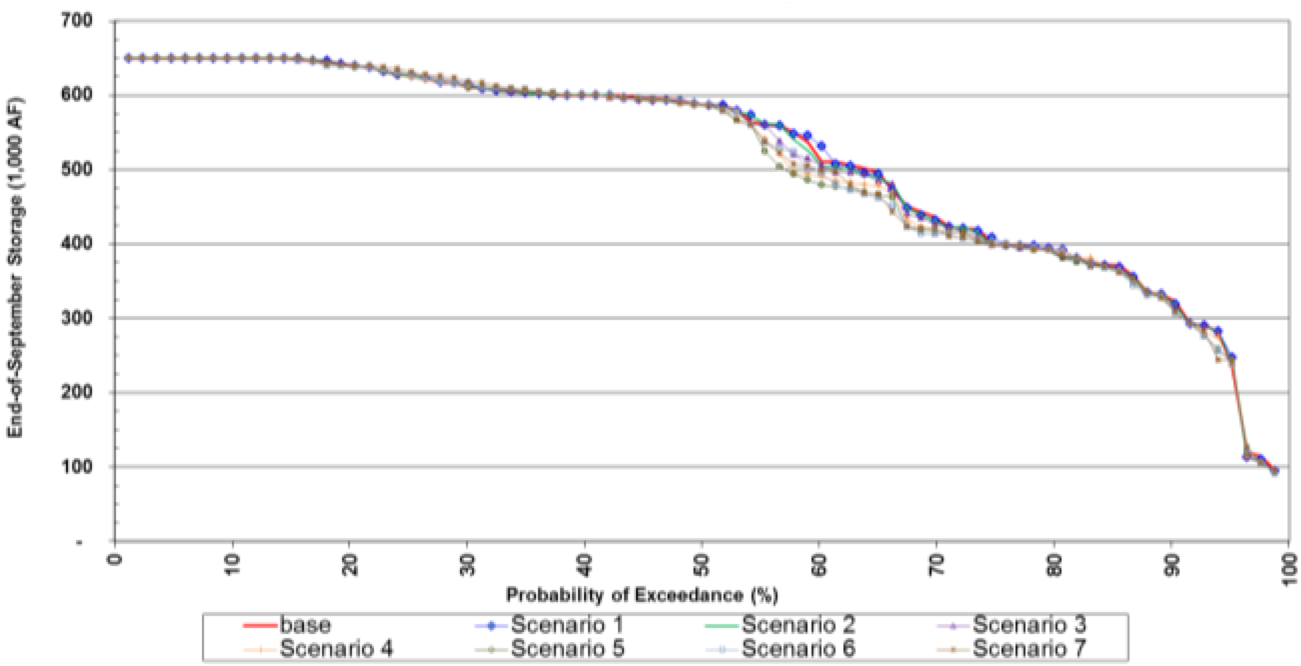

Figure 8. Folsom Reservoir End-of-September Storage (Scenario 1-7)

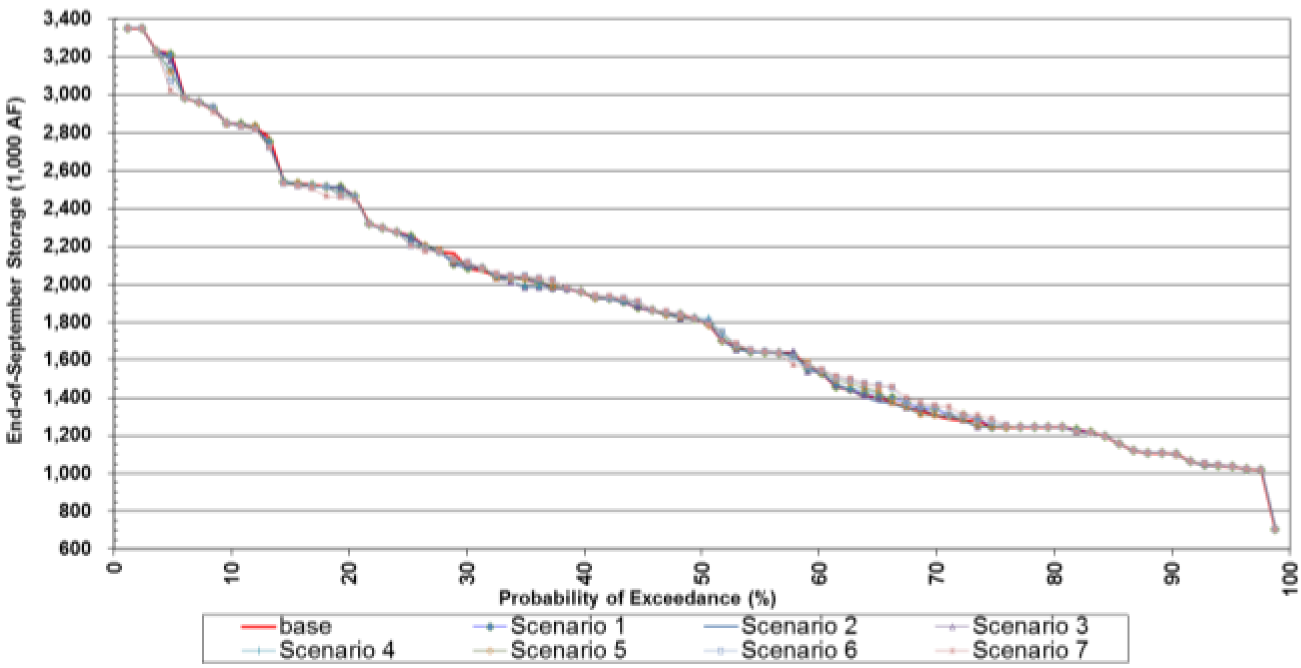

Figure 9. Oroville Reservoir End-of-September Storage (Scenario 1-7)

Sacramento River Pulse Stream Temperature Tradeoffs (Scenarios 1-7)

Spring pulse releases alter Shasta Division water temperature operations. While March through May pulse releases will provide cooler stream temperatures in the spring, these releases will also reduce cold-water resources in the summer and fall. As noted previously, a key input into the SRTTG's decision on the current season's temperature control target location below Keswick Dam is Shasta Reservoir EOM storage. Figure 10 illustrates the exceedance probabilities of EOM storage at Shasta Reservoir under the range of Sacramento River PFO scenarios. Spring pulse flows will generally reduce EOM cold-water resources in Shasta Reservoir. Reduced EOM cold-water resources present additional challenges in managing stream temperatures below Keswick Reservoir. As a result of reduced EOM cold-water resources, stream temperature target locations may need to be maintained further upstream, which reduces cold-water habitat in the upper Sacramento River system when compared to the No-Action Scenario.

It is important to point out that in most years SRWQM water temperature operations deplete Shasta Reservoir's cold water pool by mid-summer. This occurs because TCD operations are represented using predefined temperature targets set immediately downstream of Shasta Reservoir. These temperature targets are defined using four tiers based only on end-of-May Shasta storage (OCAP 2008). SRWQM then simulates Shasta TCD operations to meet stream temperature targets downstream of Shasta Reservoir as a surrogate to stream temperatures at compliance locations downstream of Keswick Dam, such as the Sacramento River at Balls Ferry or Bend Bridge. This operation does not consider air temperature, tributary and Spring Creek Conduit inflows, and many other factors used in actual operations to determine release temperature targets. Additionally, target temperatures are established in the model and not updated throughout the summer period based on remaining cold-water reserves. Therefore, care should be taken when interpreting absolute simulated stream temperatures on the Sacramento River. There is better value in understanding relative differences in simulated stream temperatures as a result of the spring pulse flow scenarios. Figure 11 through 13 illustrate the stream temperature exceedance on the Sacramento River at Ball's Ferry Bridge, Jelly's Ferry Bridge, and Bend Bridge compliance locations, respectively. For visual clarity, stream temperature exceedance probabilities are plotted only for the Base, the 100 TAF, and 500 TAF spring pulse scenarios. These figures translate the effects of reduced EOM cold-water storage to stream temperature management throughout the season. In the three compliance locations illustrated, stream temperatures are cooler in the period between March and May as additional releases are made under the spring pulse scenarios. It is noteworthy that cooling on the Sacramento River at Ball's Ferry Bridge and Jelly's Ferry Bridge during the period between March through May is occurring when stream temperatures are already relatively cooler in the No-Action Scenario.

At the three compliance locations illustrated in Figure 11 through 13, stream temperatures are warmer in the period between June and October. As additional releases are made under the spring pulse programs, cold-water resources are reduced in Shasta Reservoir in the summer and fall, which makes maintaining stream water temperatures at 56°F or cooler on the Sacramento River more difficult. By late October, stream temperatures along all compliance points for the most part reach equilibrium with ambient air temperatures and Reclamation would typically end the season's water temperature management operations.

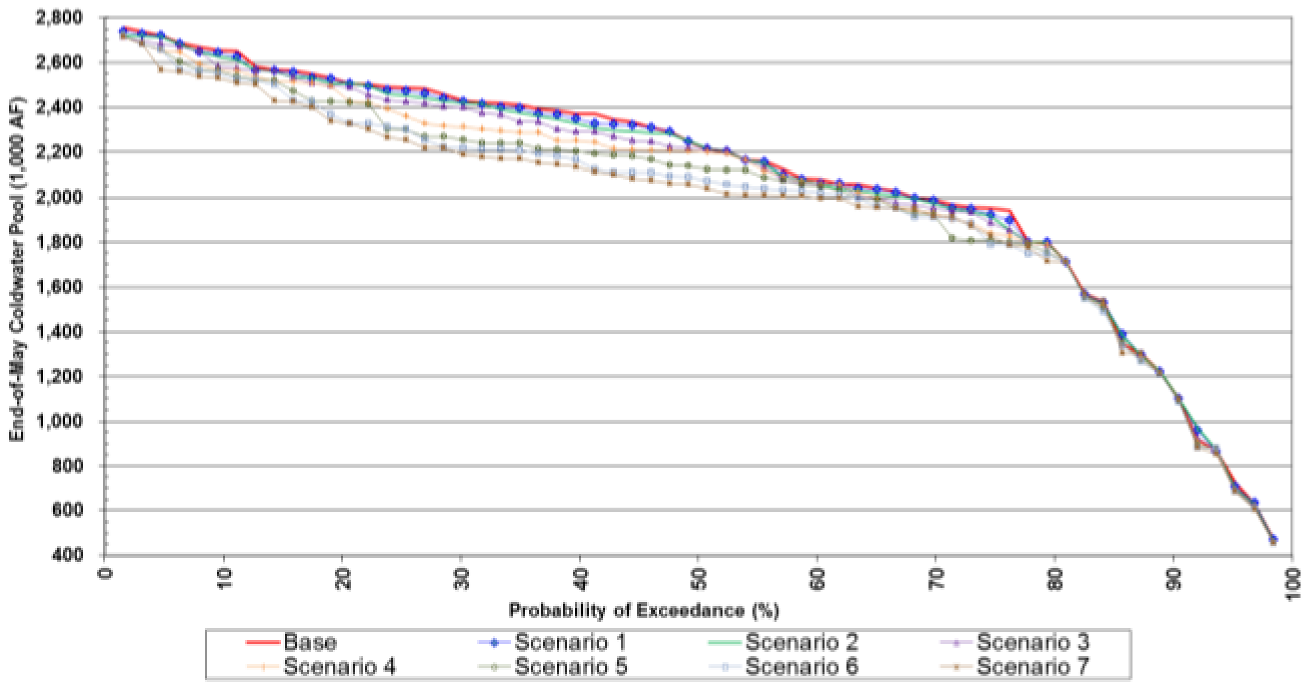

Figure 10. Shasta Reservoir End-of-May Coldwater Pool (Scenario 1-7)

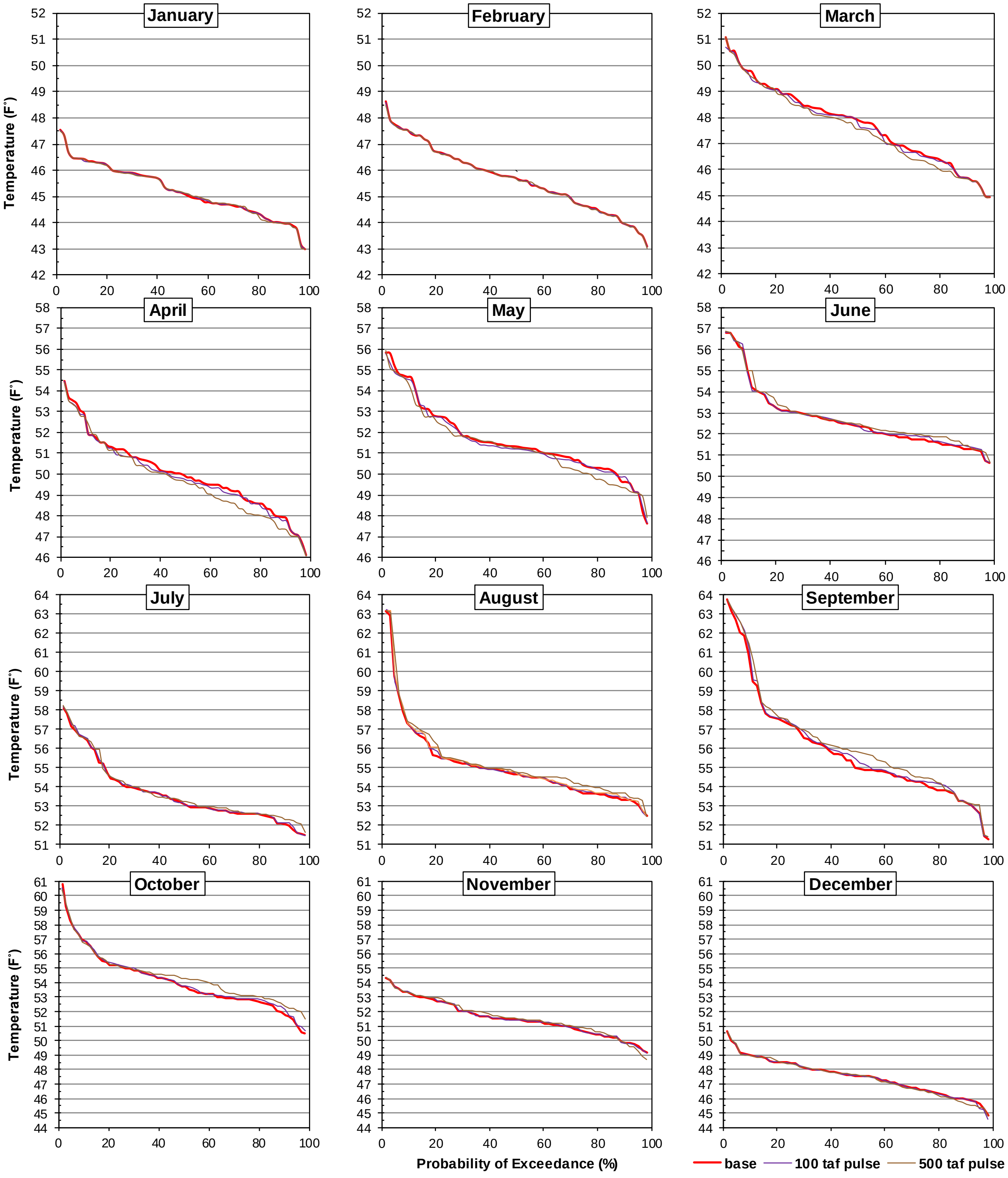

Figure 11. Monthly Temperature Exceedance at Ball's Ferry Bridge (Scenario 1-7)

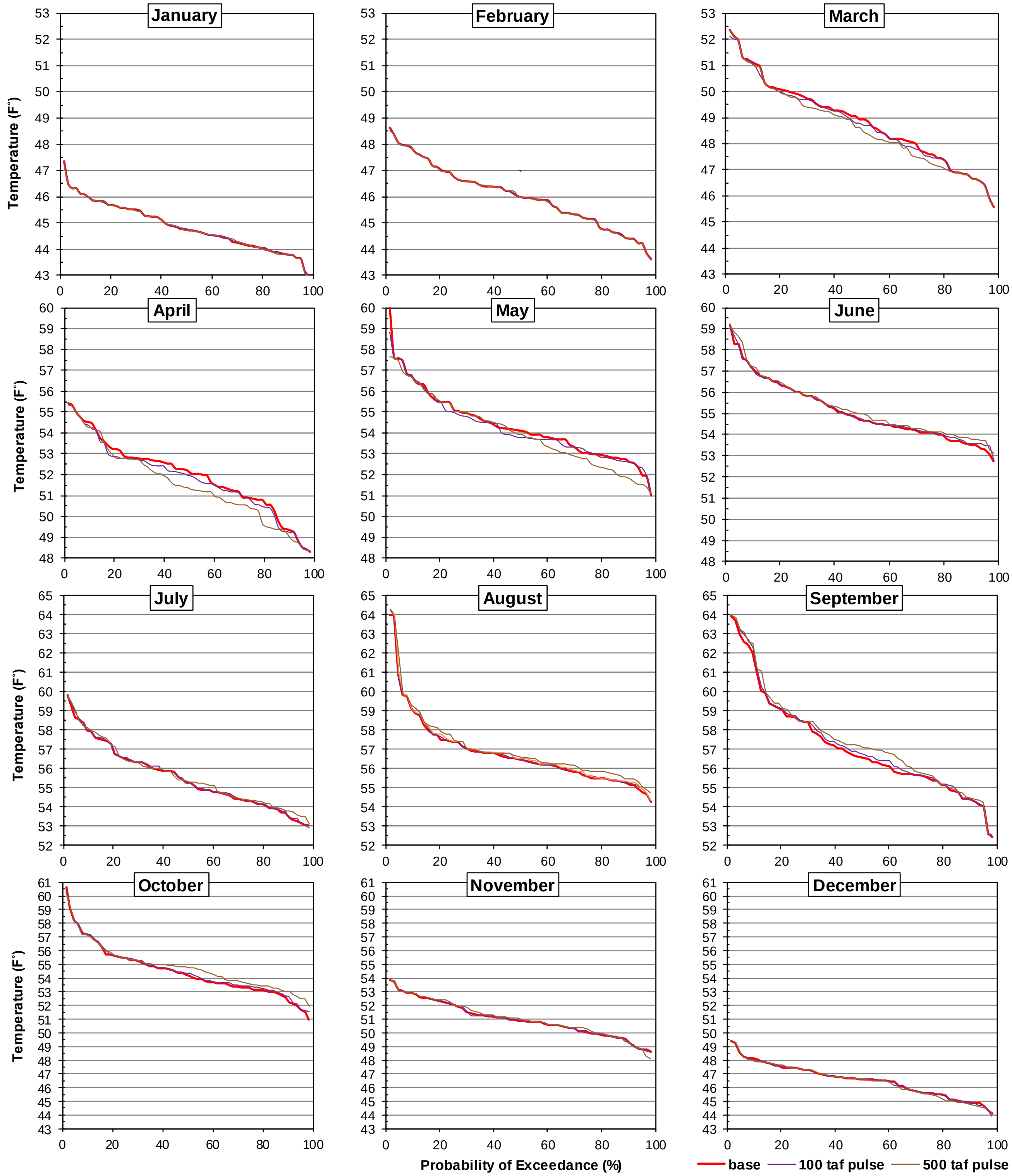

Figure 12. Monthly Temperature Exceedance at Jelly's Ferry Bridge (Scenario 1-7)

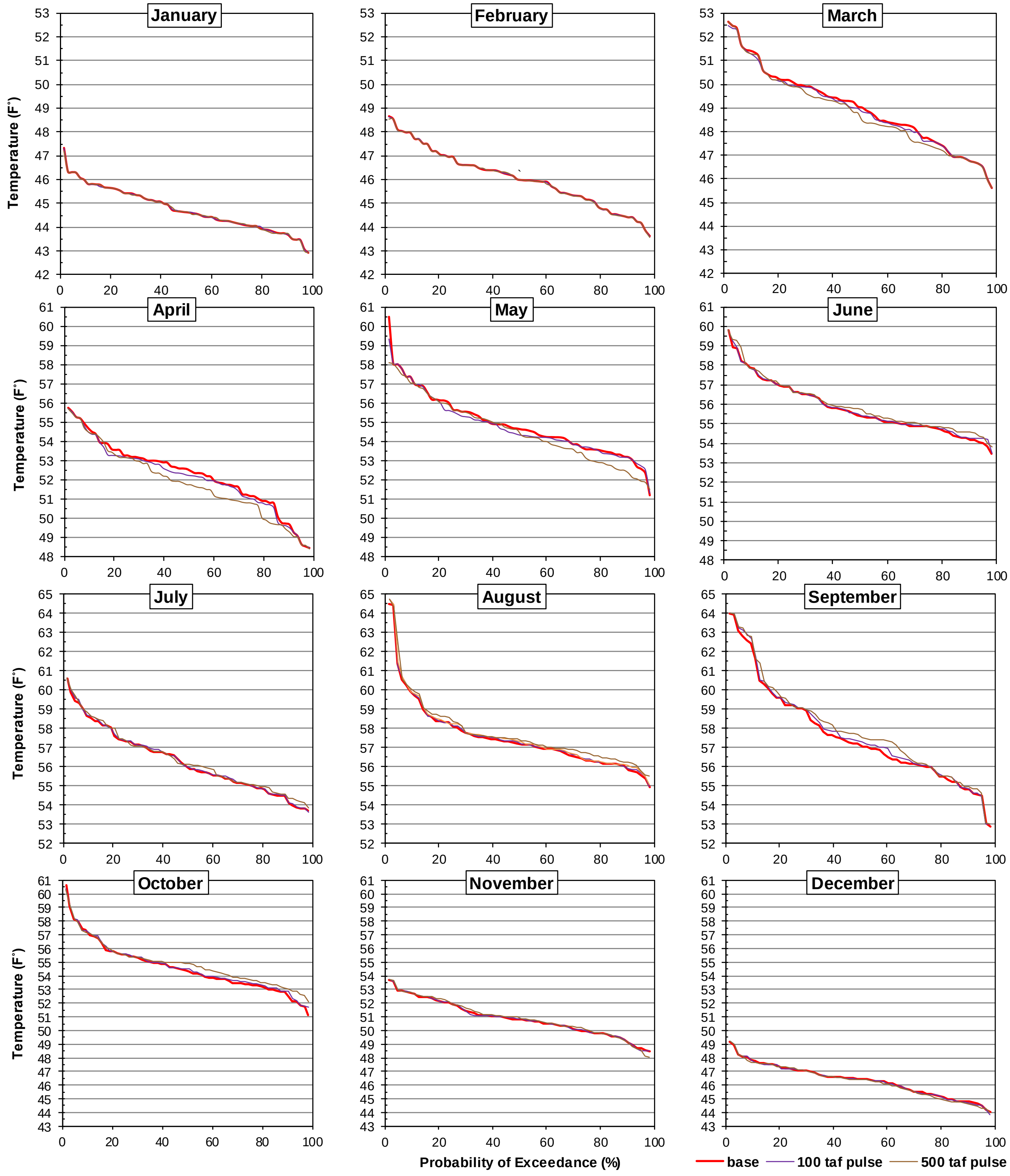

Figure 13. Monthly Temperature Exceedance at Bend Bridge (Scenario 1-7)

Feather River Pulse System Tradeoffs (Scenarios 8-14)

A similar set of PFO scenarios were simulated on the Feather River with additional spring releases from Oroville Reservoir. Monthly flow exceedance on the Feather River downstream of Thermalito Afterbay is plotted on Figure 14. Flows are increased in the period between March through May as additional releases are made under the spring pulse scenarios. An annual spring pulse flow target of 500 TAF increased median Feather River flows downstream of the Thermalito Afterbay by approximately 710 cfs, 240 cfs, and 610 cfs in March, April, and May, respectively. Flows can be reduced in all other months due to changes in flood control and water supply releases. The average annual release from Oroville Reservoir is essentially unchanged between the No-Action and all PFO scenarios.

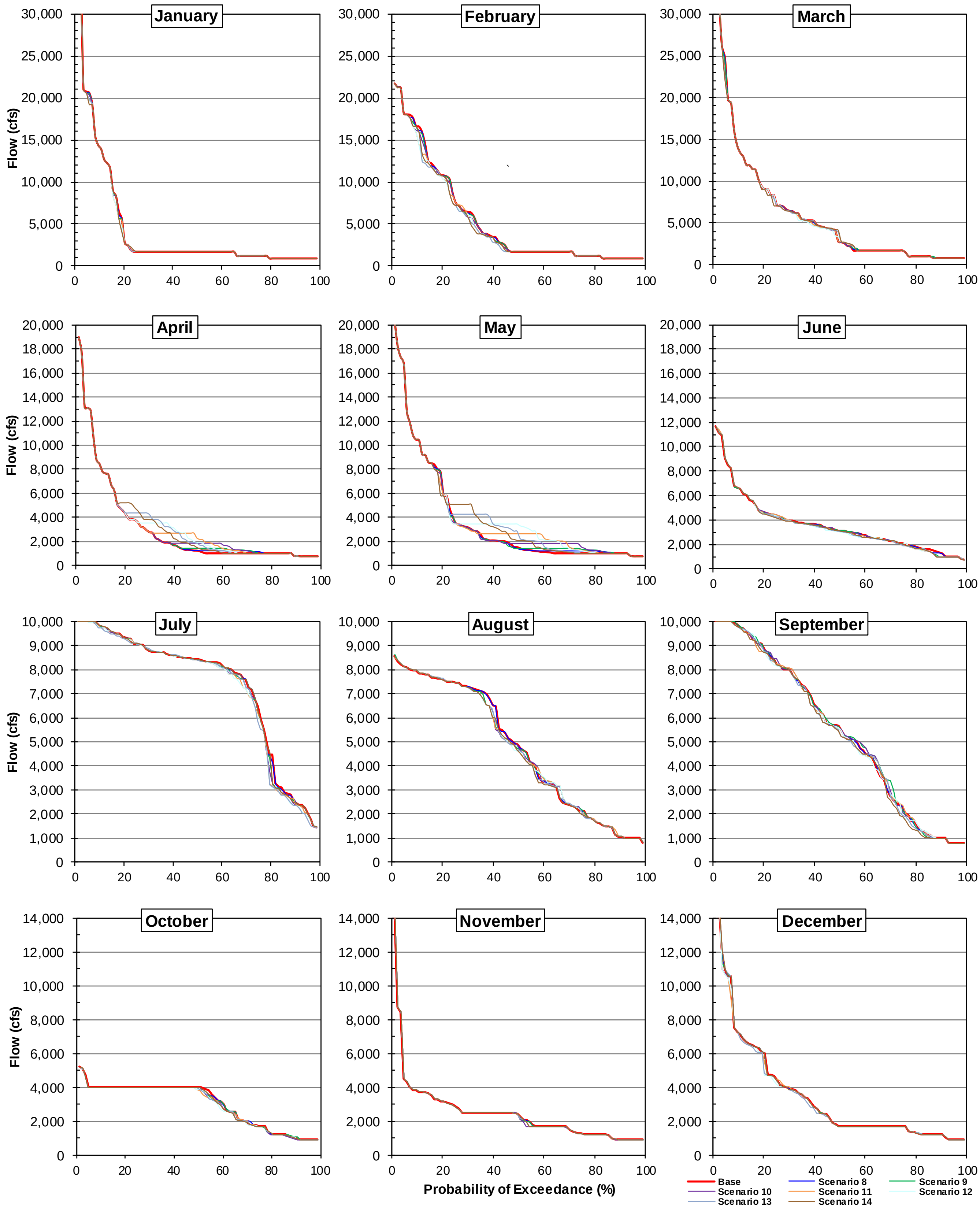

Figure 14. Monthly Flow (CFS) Exceedance on Feather River Downstream of Thermalito Afterbay from January to September (Scenario 8-14)

Changes in flows as a result of additional spring releases occur downstream and into the Delta similar to the changes in Feather River flows downstream of Thermalito Afterbay. Additional spring releases from an SWP reservoir have fewer effects on operations upstream of the Delta compared to releases from a CVP reservoir. There are only a few SWP contractors located upstream of the Delta whose allocations may be affected due to changes in Oroville storage. Therefore, there is essentially no change in SWP deliveries or the consumptive use of surface water in the Sacramento Valley. Unlike the CVP having to balance reservoir levels upstream of the Delta, there are no other SWP reservoirs that will be affected by additional releases from Oroville Reservoir.

Water supply tradeoffs for the Feather River PFO scenarios are illustrated by comparison of changes in SWP Delta exports and EOS Oroville storage. Figure 15 illustrates the average annual change in SWP Delta exports for each Feather River PFO scenario.

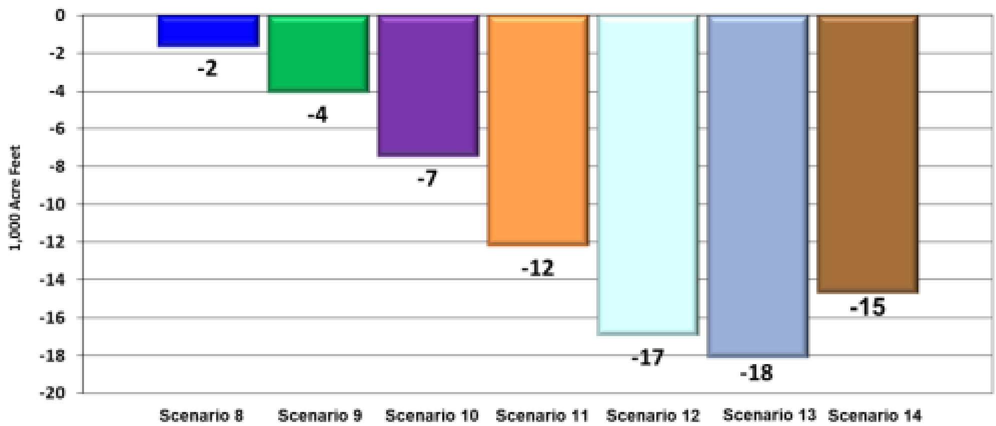

Figure 15. Change in Average Annual SWP Delta Exports (Scenario 8-14)

Additional releases from Oroville Reservoir in March, April, and May are not diverted at the export facilities due to Old and Middle River flow restrictions in those months. Therefore, additional spring releases may provide an ecosystem benefit, but also affect water supply. Additional releases reduce water available in Oroville Reservoir which results in reduced SWP delivery allocations, and thereby reduced SWP Delta exports. There are no significant changes in CVP Delta exports.

Average annual reductions in SWP Delta exports essentially mirror the average annual increase in Delta outflow, as illustrated in Figure 16. Differences between SWP Delta exports and Delta outflow for the higher volume PFO scenarios result from changes in reservoir evaporation in Oroville Reservoir.

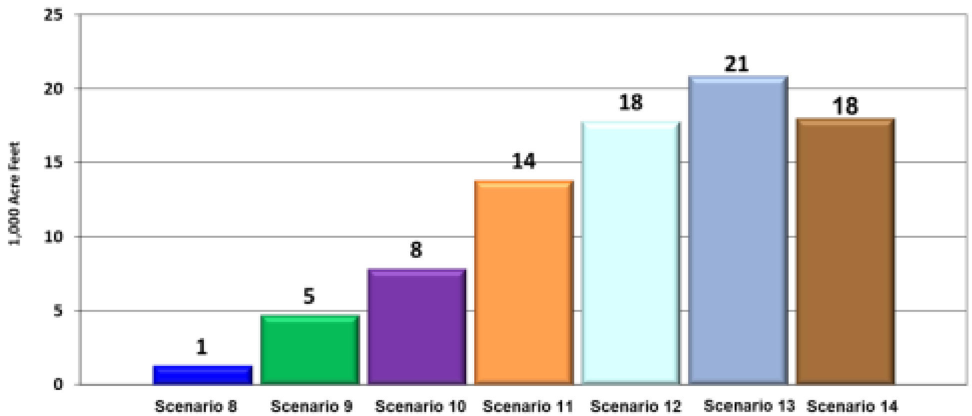

Figure 16. Change in Average Annual Delta Outflow (Scenario 8-14)

Oroville Reservoir EOS storage exceedance probability is plotted in Figure 17. Pulse flows in the spring will reduce EOS carryover storage in Oroville Reservoir. An annual spring pulse flow target of 500 TAF reduces a median EOS Oroville Reservoir carryover storage by approximately 140 TAF. EOS carryover storage for CVP storage facilities north-of-Delta show minimal change from the spring pulse flows released on the Feather River.

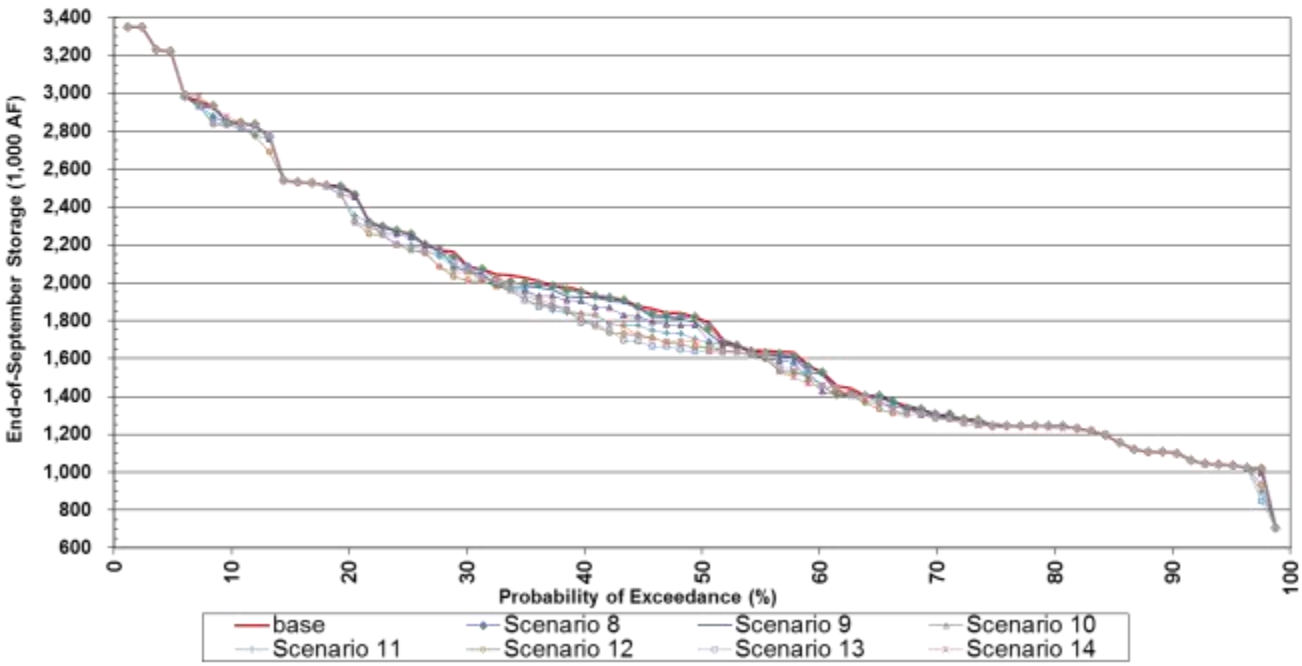

Figure 17. Oroville Reservoir End-of-September Storage (Scenario 8-14)

Conjunctive Management Scenarios and Assumptions

Conjunctive management was identified as a tool that may be used to meet the objectives of the SRS. Therefore, several scenarios using conjunctive management on the Sacramento and Feather River systems were developed to better understand how conjunctive management may be used to improve water supply reliability and the ecosystem. The conjunctive management concept involves willing

Sacramento and Feather River water users relying on groundwater to meet irrigation demands during periods of reduced surface water availability. These periods are identified when EOS storage in Shasta or Oroville reservoir is below certain target levels. Conjunctive management scenarios are shown in Scenarios 15 through 20 in Table 1. Three scenarios with annual groundwater pumping volumes of 25 TAF, 50 TAF, and 100 TAF taking place from May through August are analyzed for each of the Sacramento River and Feather River systems.

Assumptions on Groundwater Systems and Pumping

Conjunctive management pumping would reduce surface water diversions for those willing water users. On the Sacramento River system, groundwater pumping is assumed to occur in the Colusa Basin and reduce Sacramento River diversions between Red Bluff and Wilkins Slough. On the Feather River system, groundwater pumping is assumed to occur in the Feather River Service Area and reduce surface water diversions from Thermalito Afterbay. For this reconnaissance-level study, the groundwater system is assumed to not interact with the surface water system.

Sacramento River Conjunctive Management Operations

Conjunctive management was expanded in the existing operation of the system to help protect carryover storage in Shasta Reservoir. For the conjunctive management scenarios, a 2.2 MAF EOS carryover storage target for Shasta Reservoir is used as the trigger for groundwater pumping. According to Action I.2.2.A of the National Marine Fisheries Service (NMFS) Biological Opinion (BO) in 2009 (NMFS 2009), a 2.2 MAF EOS carryover target in Shasta Reservoir is linked to the potential to provide sufficient cold water to meet the Balls Ferry temperature compliance point in the following year. It is worth noting that this carryover target is different than the 2.4 MAF EOS carryover storage used in the PFO scenarios. A 2.4 MAF EOS carryover target at Shasta Reservoir provides a reasonable margin above the 2.2 MAF level to increase the likelihood that the Balls Ferry compliance point will be reached (NMFS 2009). The rationale for targeting 2.4 MAF EOS carryover storage is to be consistent with the NMFS BO and assure spring pulse flows will maintain that reasonable margin of storage above 2.2 MAF level. The rationale for targeting 2.2 MAF EOS carryover storage in the conjunctive management scenarios is to avoid the costs of groundwater pumping simply to increase storage margins above 2.2 MAF. Using these EOS carryover targets established from the NMFS BO provides consistency between this study and goals CVP operators strive for.

Figure 18 and Figure 19 illustrate the groundwater pumping pattern for the Sacramento River system. In most years the deficit between the EOS storage in the No-Action Scenario and the 2.2 MAF target exceeds the annual limit on conjunctive management pumping and annual pumping equals the maximum annual pumping for each scenario (25, 50, or 100 TAF). However, in water year 1939 of Scenario 17, groundwater pumping volume is limited to the deficit between EOS storage of the No Action Scenario and the 2.2 MAF carryover target.

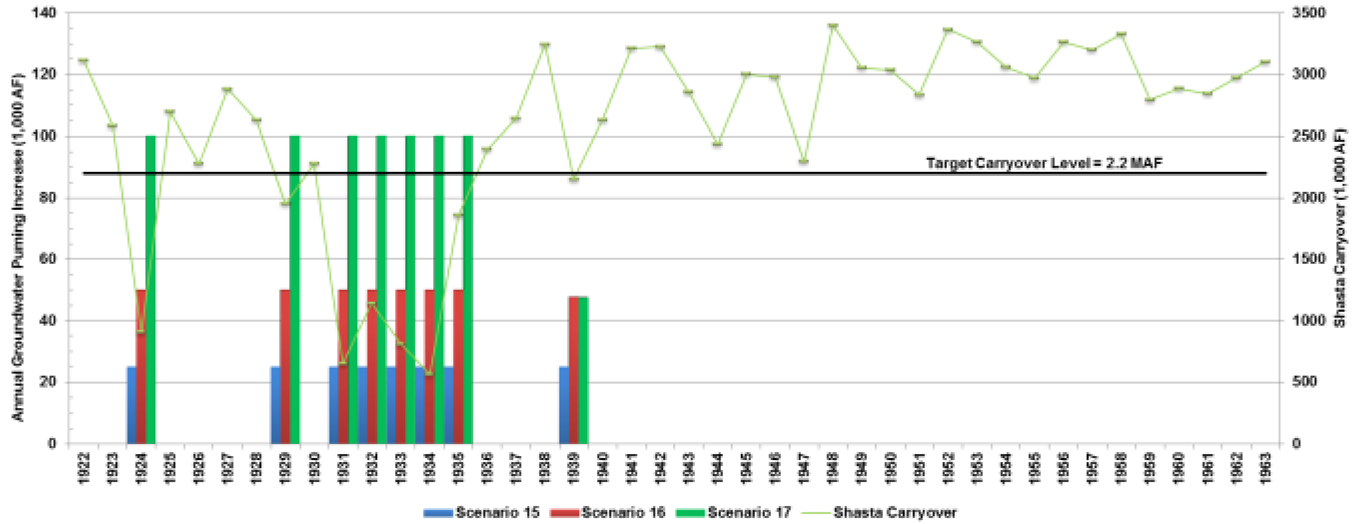

Figure 18. Sacramento River Conjunctive Use Pumping Pattern from WY 1922 to 1963

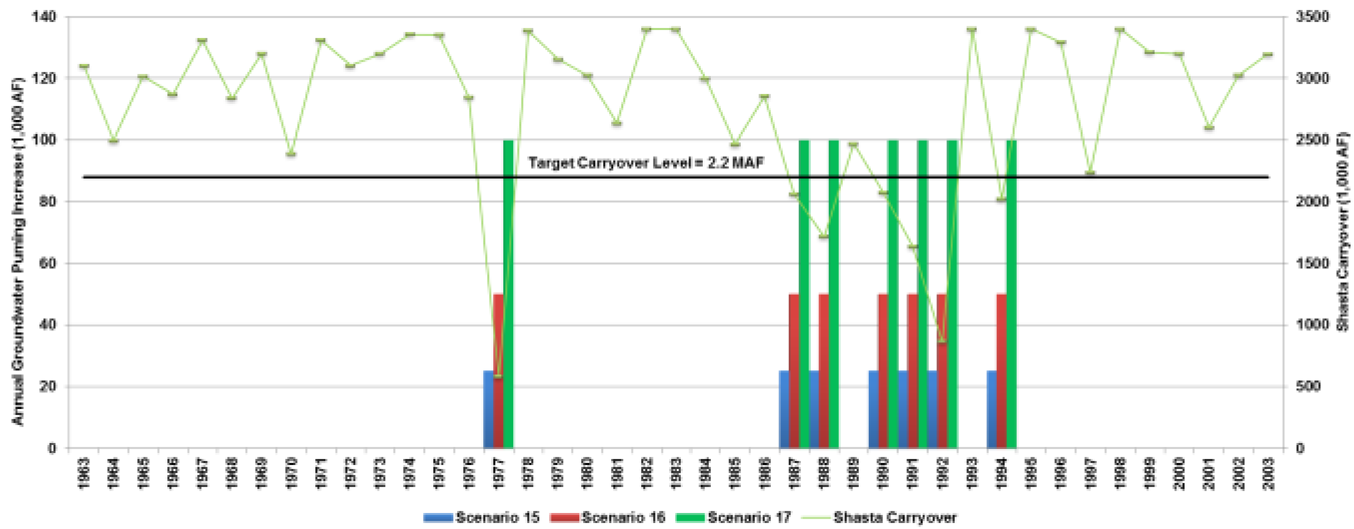

Figure 19. Sacramento River Conjunctive Use Pumping Pattern from WY 1963 to 2003

Feather River Conjunctive Management Operations

Conjunctive management in the Feather River Basin follows the same approach as described for the Sacramento River. Groundwater pumping in parts of the Feather River Service Area will be expanded in the existing operation of the system to help protect carryover storage in Oroville Reservoir. The target carryover storage is 1.5 MAF at EOS. The 1.5 MAF is considered a reasonable carryover storage target based on discussions with SWP operators. Figure 20 and Figure 21 illustrate the groundwater pumping pattern for the Feather River system.

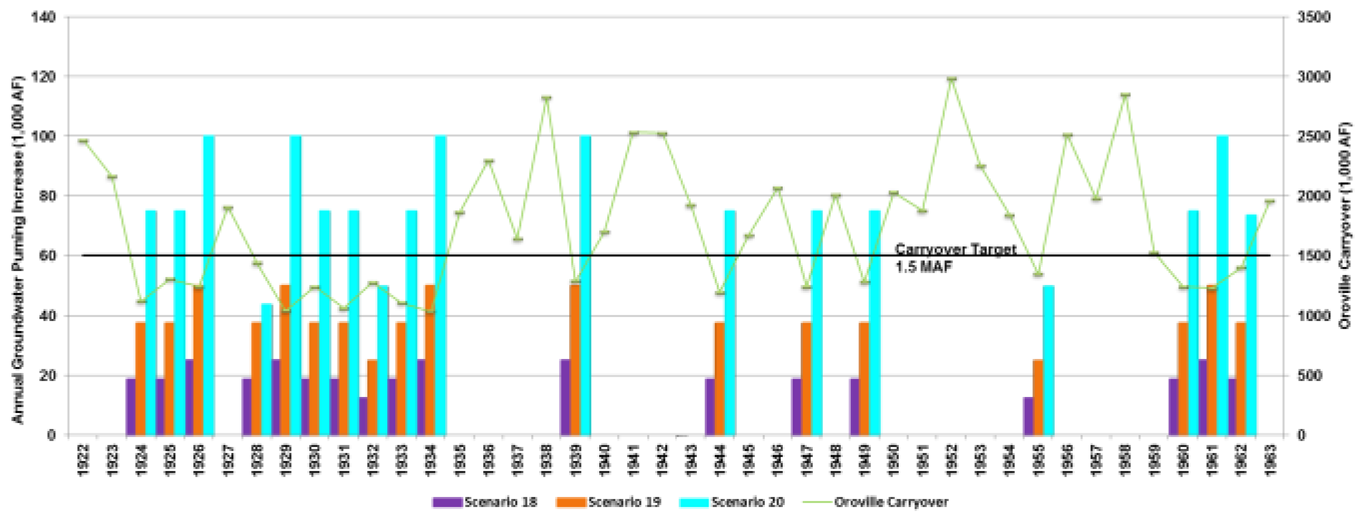

Figure 20. Feather River Conjunctive Use Pumping Pattern from WY 1922 to 1963

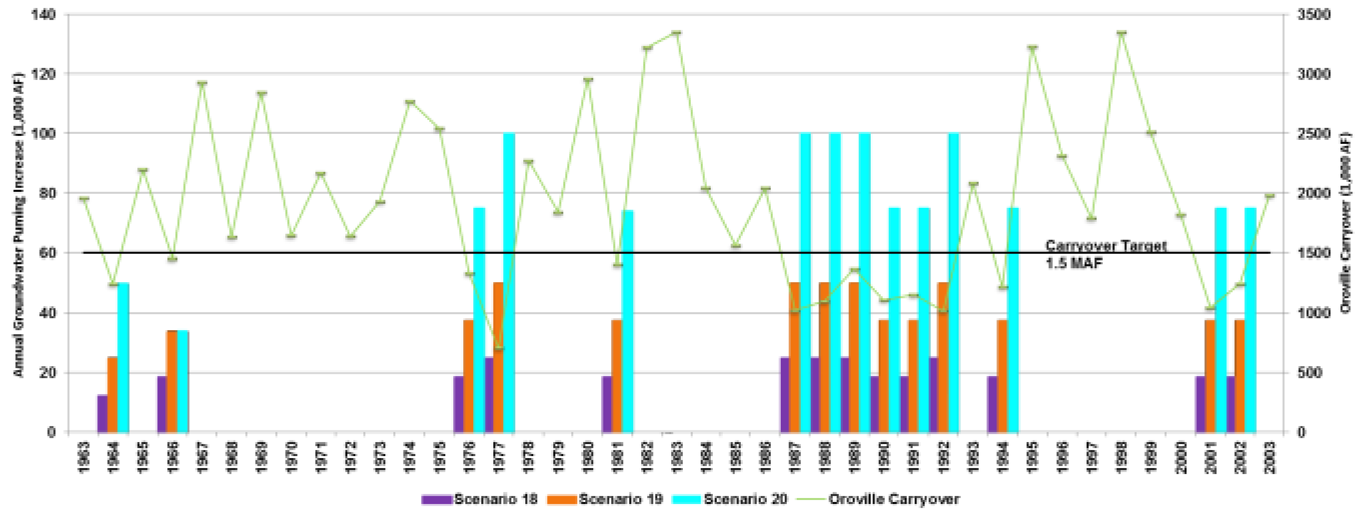

Figure 21. Feather River Conjunctive Use Pumping Pattern from WY 1963 to 2003

Sacramento River Conjunctive Management Tradeoffs (Scenarios 15-17)

The average annual groundwater pumping for each scenario represents additional surface water in the system as a result of conjunctive management due to the assumption of no interaction between surface and groundwater. Figure 22 illustrates the average annual pumping for each Sacramento River scenario.

Additional conjunctive management pumping can affect reservoir storage, river flows, and water deliveries. Additional groundwater pumping makes an equivalent volume of surface water available and results in changes to CVP and SWP operations. The following figures illustrate these operational changes in the CVP and SWP.

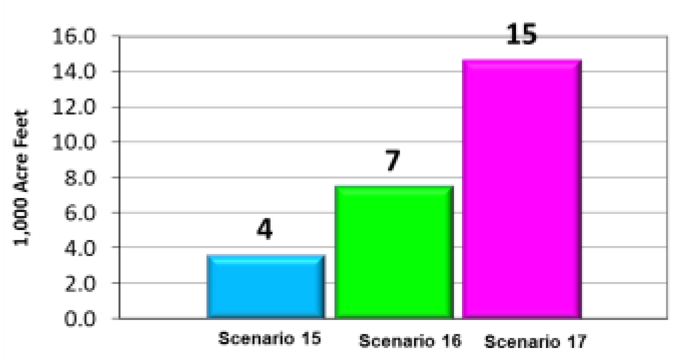

Figure 22. Average Annual Conjunctive Management Pumping (Scenario 15-17)

Additional conjunctive management pumping occurs in years when EOS Shasta storage is less than 2.2 MAF in the No-Action Scenario. It may be possible in these years to reduce releases from Shasta Reservoir when pumping occurs and hold more water in storage. If this occurs there may be an increase in carryover storage and storage in subsequent years that may provide additional cold-water resources and result in higher CVP water service contract allocations. Higher allocations would result in higher deliveries to TCCA contractors as illustrated in Figure 23.

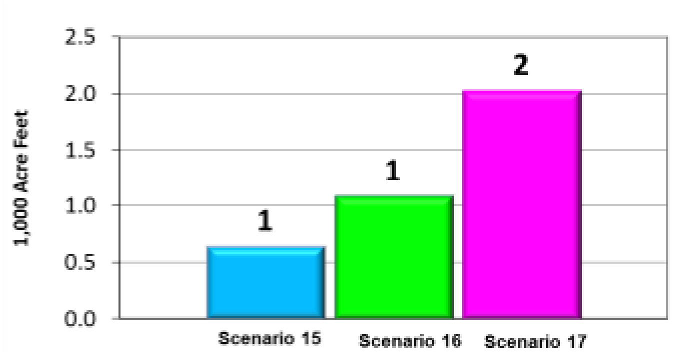

Figure 23. Change in Average Annual TCCA Deliveries (Scenario 15-17)

Average annual conjunctive management pumping minus the change in TCCA deliveries is approximately equivalent to the average annual change in Sacramento River inflow to the Delta, though the timing of inflow may differ from the timing of pumping due to upstream reservoir operations. Additional Delta inflow results in either increases in Delta outflow or exports. Both CVP and SWP export operations may be affected by a conjunctive management operation on the Sacramento River, with the majority of the change in CVP exports. Figure 24 and Figure 25 illustrate the average annual change in CVP and SWP exports, respectively.

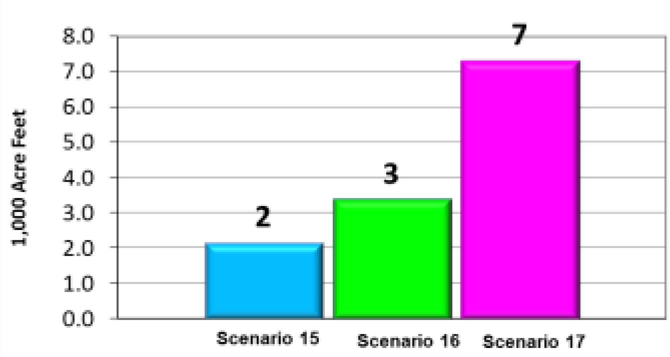

Figure 24. Change in Average Annual CVP Delta Exports (Scenario 15-17)

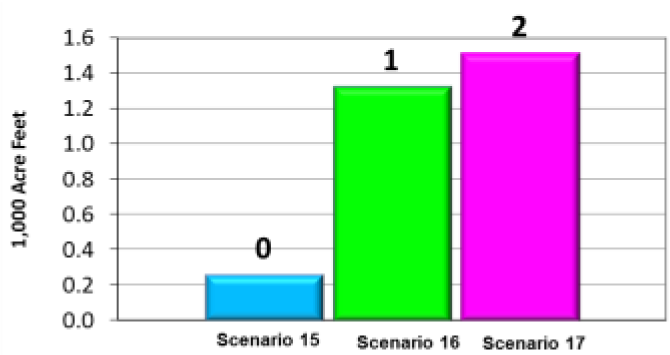

Figure 25. Change in Average Annual SWP Delta Exports (Scenario 15-17)

Approximately two thirds of the conjunctive management pumping results in increased Delta exports for each scenario. The remaining one third increases Delta outflow. The average annual changes in Delta outflow are plotted on Figure 2826. Average annual Delta outflow in the No-Action Scenario is approximately 15.8 MAF.

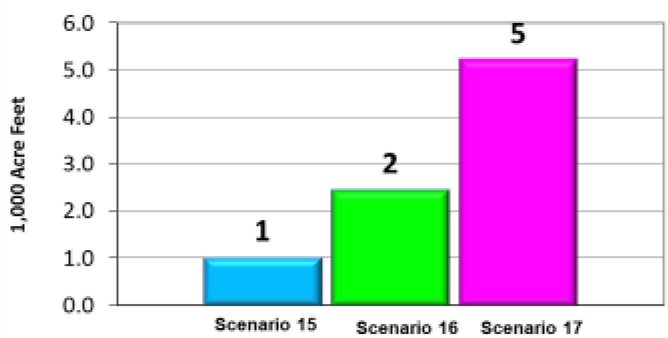

Figure 26. Change in Average Annual Delta Outflow (Scenario 15-17)

In addition to increases in water supply deliveries, there may be benefits to Shasta EOS storage and thus cold-water resources in future years. Shasta Reservoir EOS storage exceedance probabilities for Scenarios 15 through 17 are plotted in Figure 27. Groundwater pumping in the Sacramento River Basin during periods of reduced surface water availability increases EOS carryover storage in Shasta Reservoir. EOS carryover storage in Trinity Reservoir and Folsom Reservoir are plotted in Figure 28 and Figure 29, respectively. Similar to Shasta Reservoir, groundwater pumping in the Sacramento River Basin increases

EOS storage in Trinity and Folsom reservoirs. Changes in Oroville Reservoir EOS storage are insignificant under the Sacramento River Basin conjunctive management scenarios.

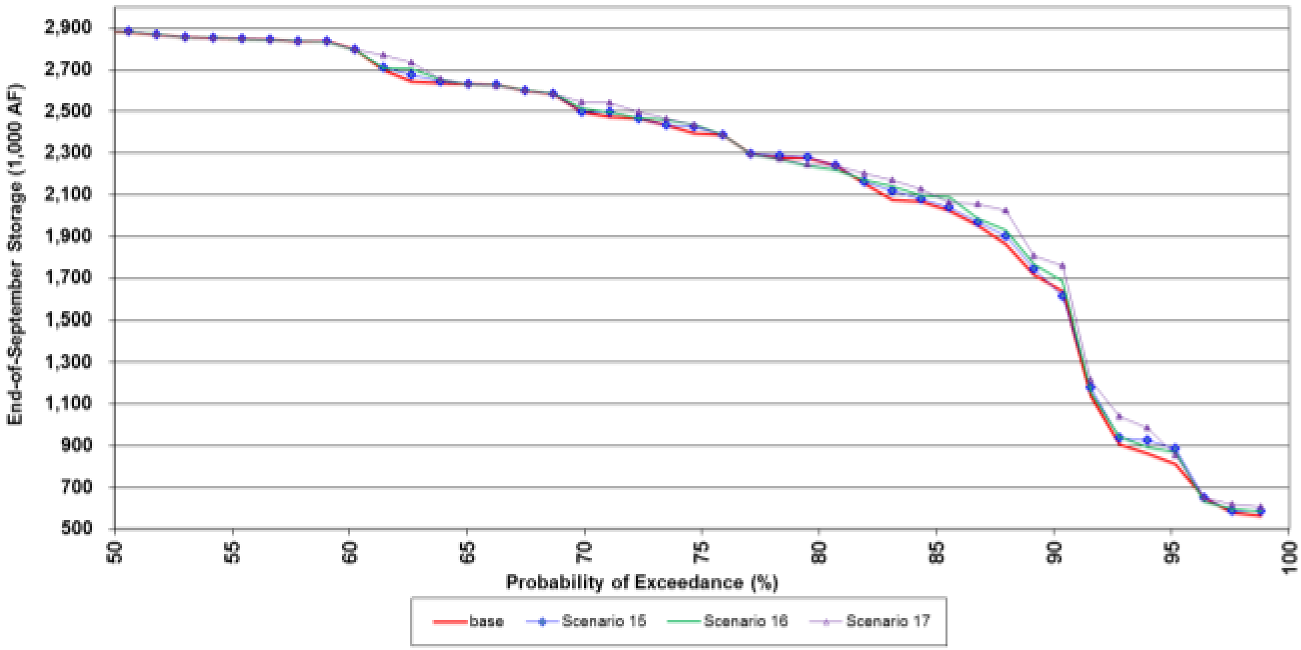

Figure 27. Shasta Reservoir End-of-September Storage (Scenario 15-17)

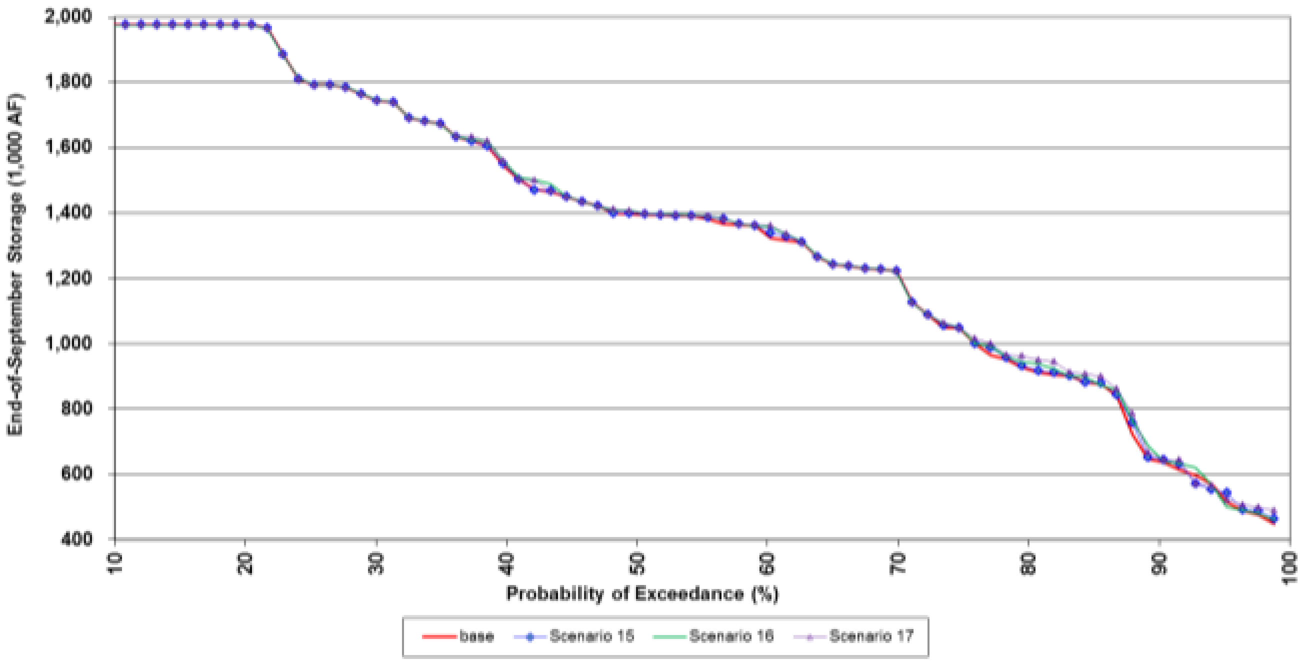

Figure 28. Trinity Reservoir End-of-September Storage (Scenario 15-17)

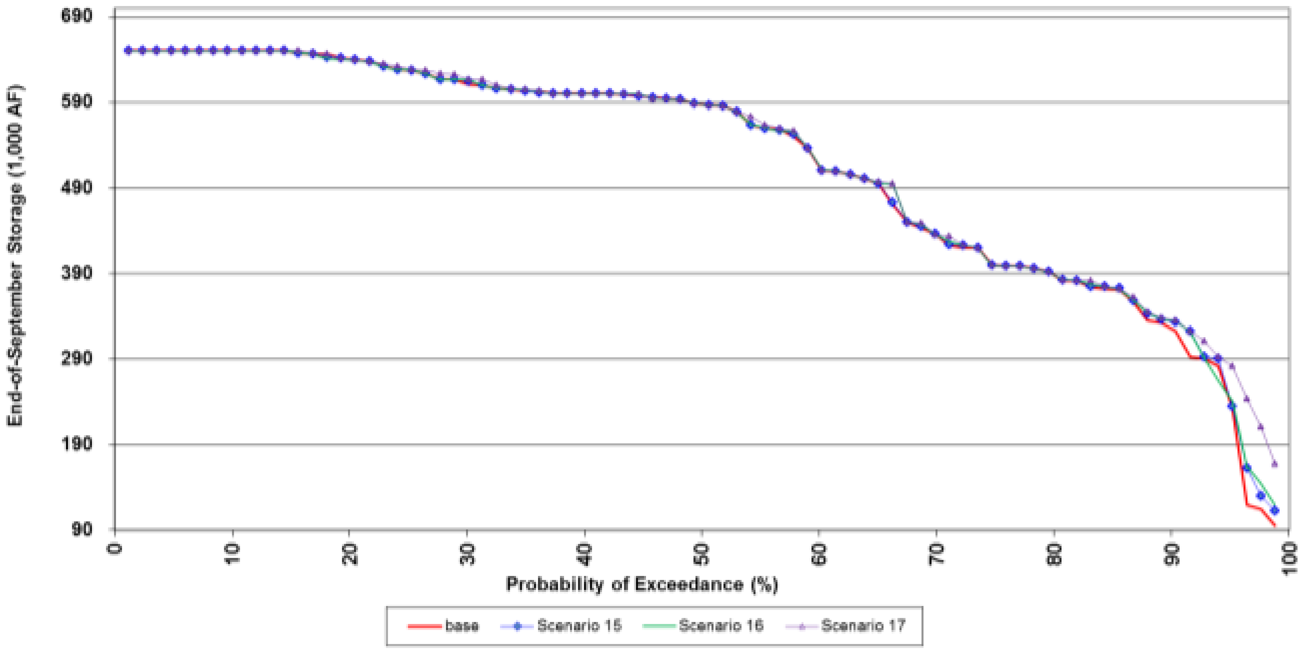

Figure 29. Folsom Reservoir End-of-September Storage (Scenario 15-17)

It should be noted that the relatively large increases in Folsom Reservoir EOS storage above the 95 percent exceedance are likely due more to model nuance than an expected change in actual operations.

Feather River Conjunctive Management Tradeoffs (Scenarios 18-20)

Results from Feather River conjunctive management scenarios are illustrated in the following figures. Results are similar to the Sacramento River scenarios with conjunctive management affecting upstream reservoir operations, increasing Delta inflow, exports, and outflow.

The average annual groundwater pumping for each scenario represents additional surface water in the system as a result of conjunctive management due to the assumption of no interaction between surface and groundwater. Figure 30 illustrates the average annual pumping for each Feather River scenario.

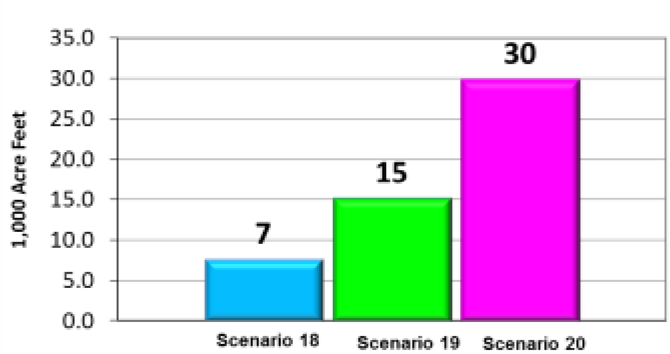

Figure 30. Average Annual Conjunctive Management Pumping (Scenario 18-20)

The average annual change in Sacramento River inflow to the Delta is approximately proportional to the average annual conjunctive management pumping in the Feather River Basin, though the timing of inflow may differ from the timing of pumping due to upstream reservoir operations. Additional Delta inflow results in increases in Delta outflow or exports. Both CVP and SWP export operations may be affected by a conjunctive management operation on the Feather River, with the majority of the change in SWP exports. Figure 24 and Figure 25 illustrate the average annual change in SWP and CVP exports, respectively.

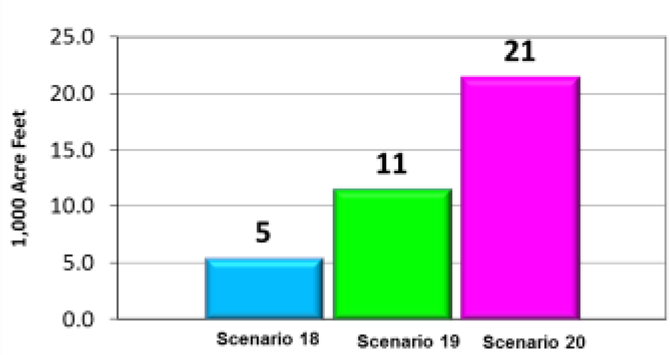

Figure 31. Change in Average Annual SWP Delta Exports (Scenario 15-17)

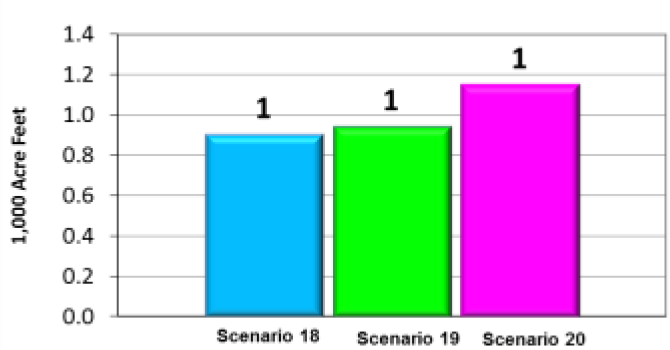

Figure 32. Change in Average Annual CVP Delta Exports (Scenario 15-17)

Approximately two thirds of the conjunctive management pumping results in increased Delta exports for each scenario. The remaining one third increases Delta outflow. The average annual changes in Delta outflow are plotted on Figure 33. Average annual Delta outflow in the No-Action Scenario is approximately 15.8 MAF.

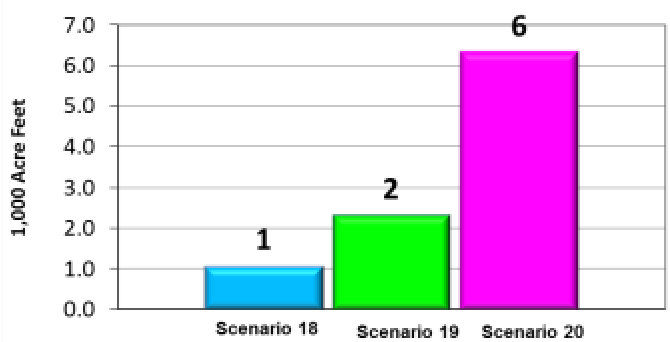

Figure 33. Change in Average Annual Delta Outflow (Scenario 18-20)

Oroville Reservoir EOS storage exceedance probability is plotted in Figure 34. Groundwater pumping in the Feather River Basin during periods of reduced surface water availability increases EOS carryover storage in Oroville Reservoir. Changes in EOS storage at CVP facilities north-of-Delta are insignificant under Feather River Basin conjunctive management scenarios.

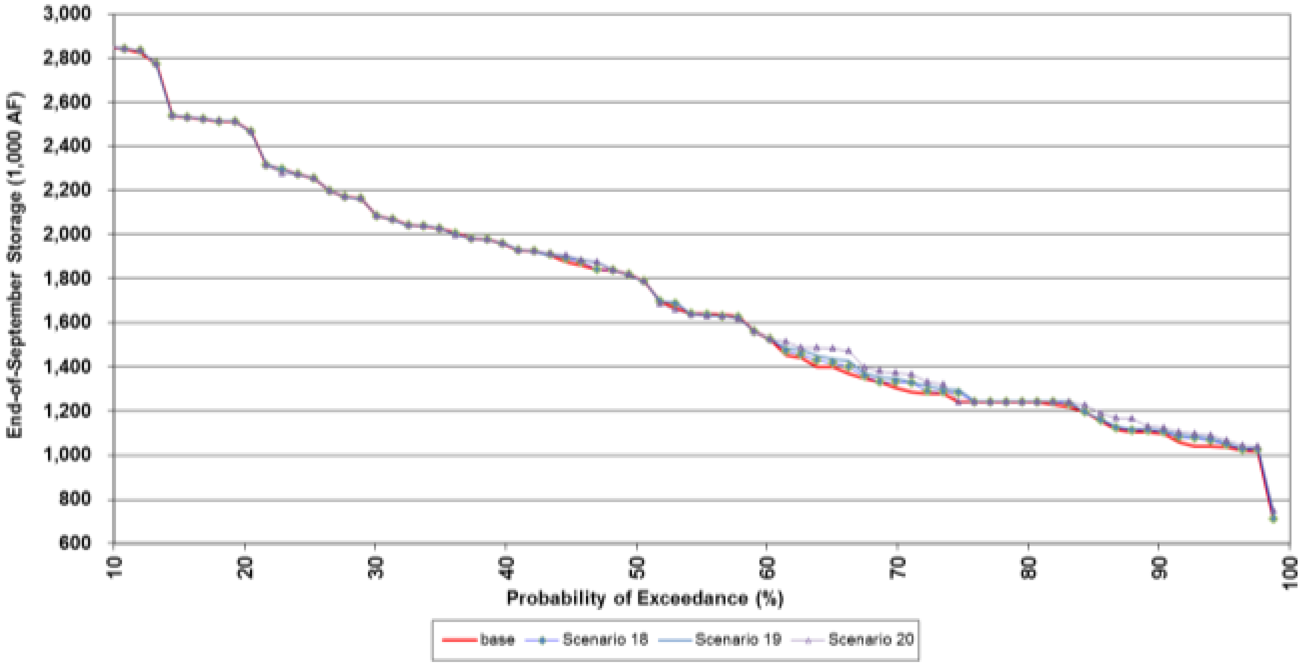

Figure 34. Oroville Reservoir End-of-September Storage (Scenario 18-20)

Conjunctive Management in Conjunction with Spring Pulse Flows

Scenarios 1 through 14 illustrate tradeoffs associated with additional spring releases from Shasta and Oroville reservoirs. Conjunctive management scenarios 15 through 20 illustrate some of the benefits that may be derived from additional conjunctive management operations in some years. Six additional scenarios of combined conjunctive management and pulse flow releases were developed to understand if some of the benefits of conjunctive management could be used to offset impacts of additional spring releases. These scenarios evaluated annual spring pulse flow volumes of 25, 50, and 100 TAF released in March, April, and May using the WSI and flood control constraints from the PFO scenarios. An equivalent volume of conjunctive management was simulated during years when the reservoir storage in the No-Action Scenario was below the 2.2 MAF and 1.5 MAF EOS storage target defined in the conjunctive management only scenarios for Shasta and Oroville reservoirs.

Sacramento River Pulse Flow and Conjunctive Management Tradeoffs (Scenarios 21-23)

The combination of additional spring releases from Shasta Reservoir and additional conjunctive management in the Colusa Basin primarily affects CVP operations. Effects can include changes in Trinity River imports, TCCA deliveries, storage in CVP reservoirs, and Delta inflows/outflows and exports. Figure 35 illustrates the change in average annual Sacramento River flow at Keswick Dam. Sacramento River flows at Keswick Dam include water imported from the Trinity River. Additional spring releases from Shasta Reservoir increase the burden on other CVP reservoirs, including Trinity Reservoir. Figure 36 illustrates the change in average annual Trinity River imports. Figure 36 illustrates the change in average annual TCCA deliveries.

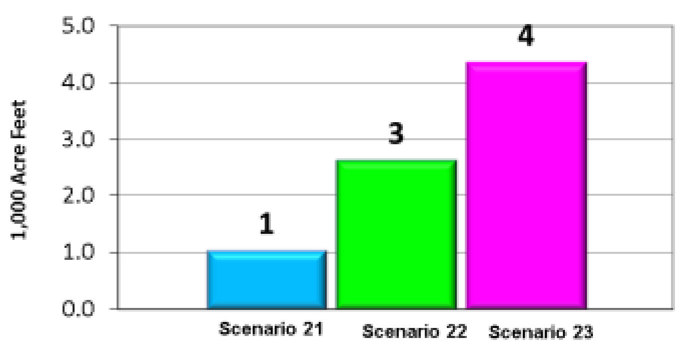

Figure 35. Change in Average Annual Sacramento River Flow at Keswick Dam (Scenario 21-23)

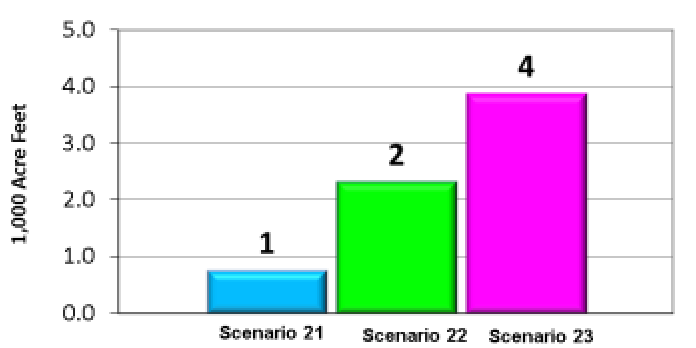

Figure 36. Change in Average Annual Trinity River Imports (Scenario 21-23)

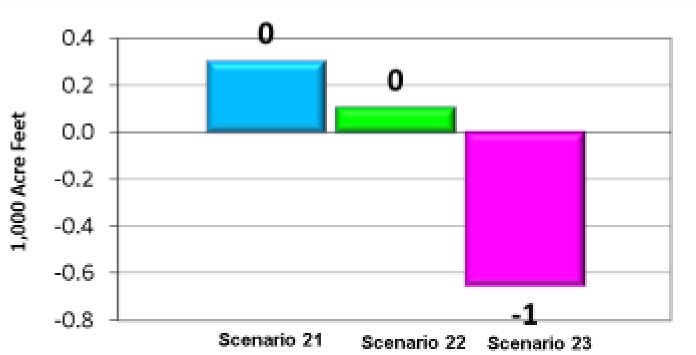

Figure 37. Change in Average Annual TCCA Deliveries (Scenario 21-23)

Additional surface water in the Sacramento River results in additional Delta inflow that can either increase Delta exports or Delta outflow. Figure 38 illustrates the average annual changes in CVP Delta exports. Changes in SWP Delta exports are insignificant for these scenarios.

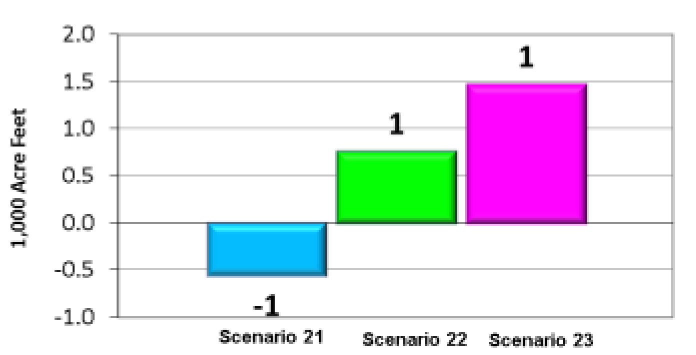

Figure 38. Change in Average Annual CVP Delta Exports (Scenario 21-23)

The average annual changes in Delta outflow are plotted on Figure 39. Average annual Delta outflow in the No-Action Scenario is approximately 15.8 MAF.

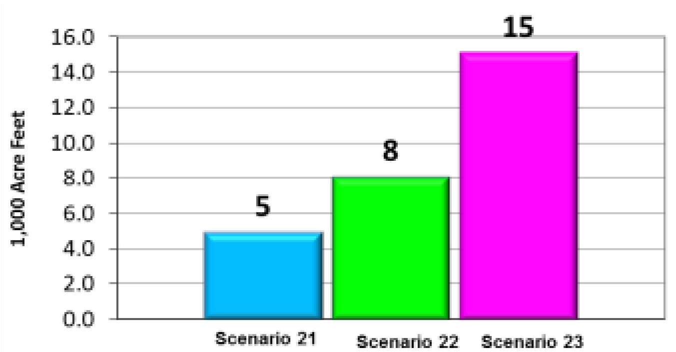

Figure 39. Change in Average Annual Delta Outflow (Scenario 21-23)

Shasta Reservoir EOS storage exceedance probabilities for Scenarios 21 through 23 are plotted in Figure 40. In years where the No-Action EOS storage exceeded 2.4 MAF, pulse flows in the spring reduced EOS carryover storage. However, in years where the No-Action EOS was below 2.4 MAF, conjunctive management increased EOS storage. Likewise, other CVP facilities, Trinity and Folsom reservoirs, are plotted in Figure 41 and Figure 42, respectively, follow a similar pattern of EOS storage reduction during years of spring pulse flows and increases in storage during years of conjunctive management. Oroville Reservoir EOS storage is not affected by the Sacramento River spring pulse flows with conjunctive management scenarios.

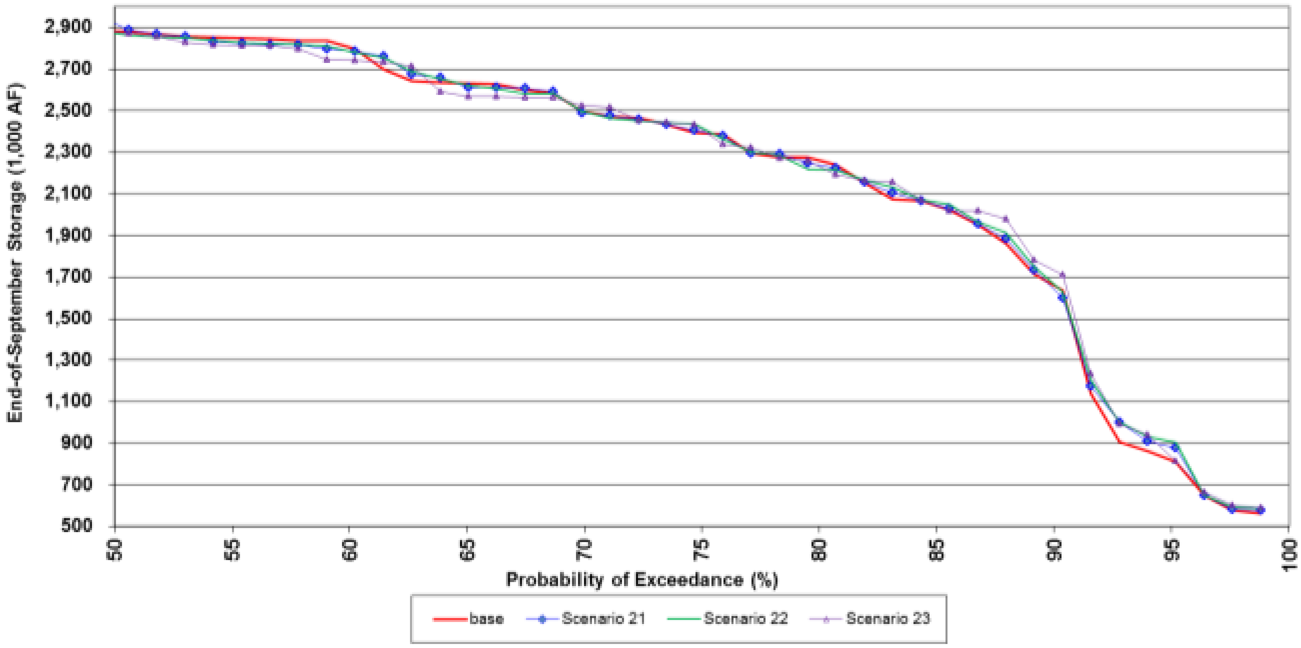

Figure 40. Shasta Reservoir End-of-September Storage (Scenario 21-23)

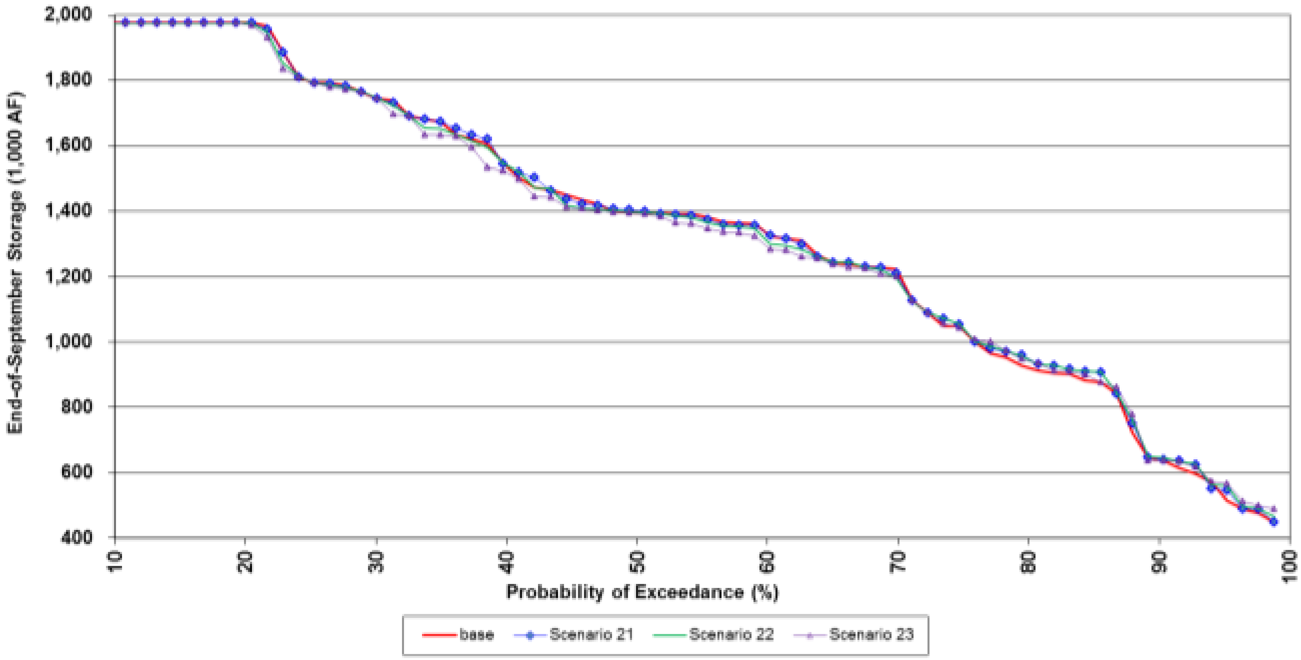

Figure 41. Trinity Reservoir End-of-September Storage (Scenario 21-23)

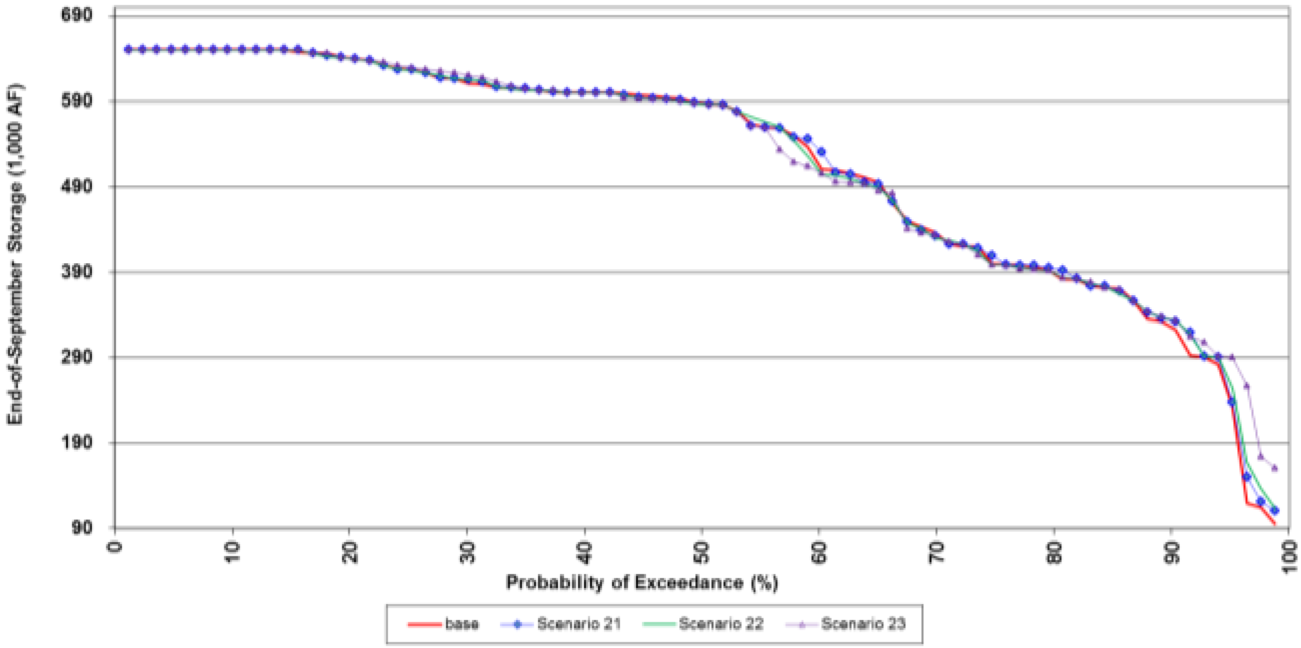

Figure 42. Folsom Reservoir End-of-September Storage (Scenario 21-23)

To evaluate cold-water resource tradeoffs, Shasta Reservoir EOM cold-water pool exceedance probabilities for Scenarios 21 through 23 are plotted in Figure 43. In years where the No-Action EOM cold-water storage exceeded 2.2 MAF, pulse flows in the spring reduce the EOM cold-water pool. However, the EOM Shasta cold-water pool increases in some years when the storage is below approximately 1.4 MAF in the No-Action simulation.

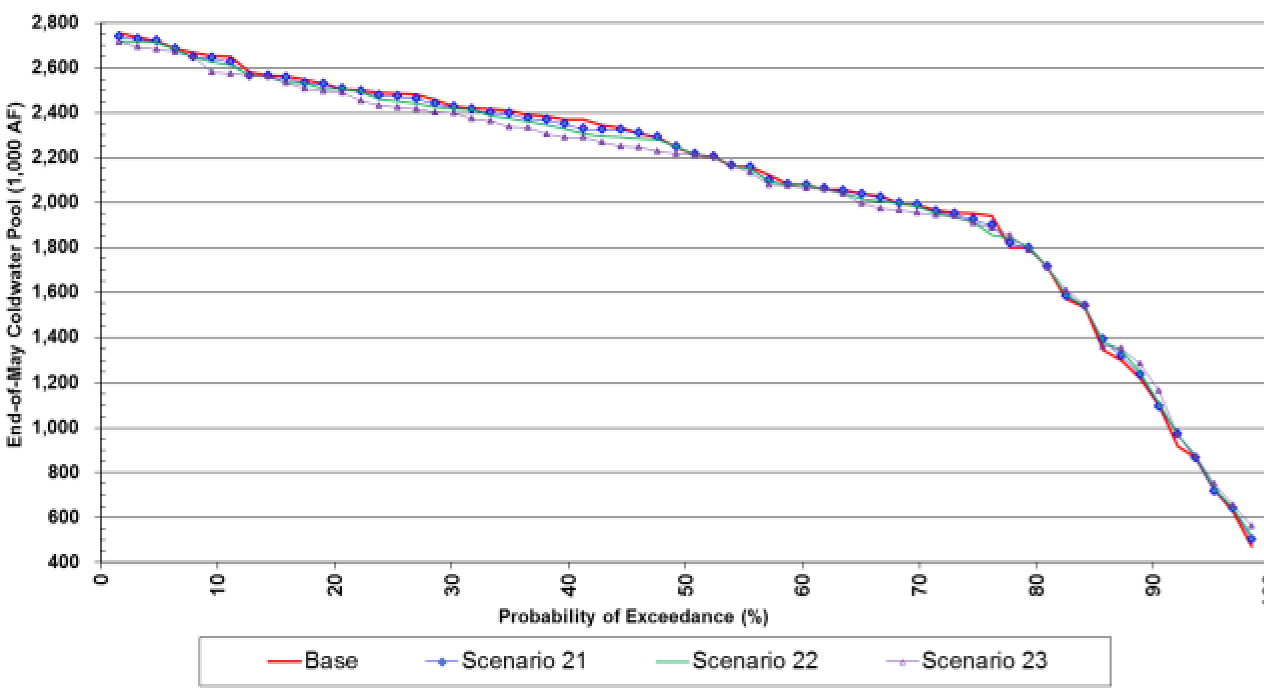

Figure 43. Shasta Reservoir End-of-May Coldwater Pool (Scenario 21-23)

Feather River Pulse Flow and Conjunctive Management Tradeoffs (Scenarios 24-26)

The combination of additional spring releases from Oroville Reservoir and additional conjunctive management in the Feather River Basin primarily affects SWP operations. The average annual change in the Feather River flow below Thermalito Afterbay (Figure 44) represents the additional conjunctive management pumping and the additional surface water in the system.

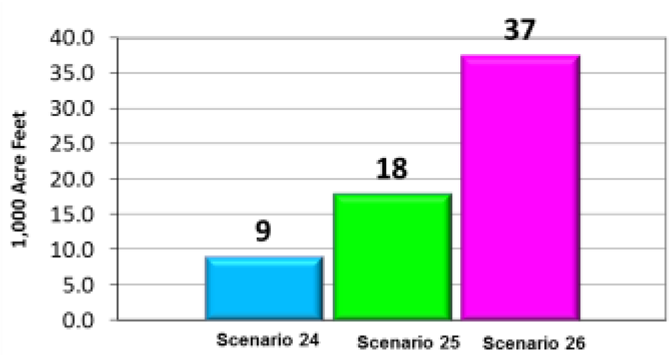

Figure 44. Change in Average Annual Feather River Flow below Thermalito Afterbay (Scenario 24-26)

Conjunctive management pumping increases in the combined scenario with pulse flows, relative to a conjunctive management only scenario because EOS Oroville Reservoir storage is below the 1.5 MAF target more frequently as a result of making additional spring releases.

Additional surface water in the Feather River results in additional Delta inflow that can either increase Delta exports or Delta outflow. Figure 45 illustrates the average annual increase in SWP Delta exports. Changes in CVP Delta exports are insignificant for these scenarios.

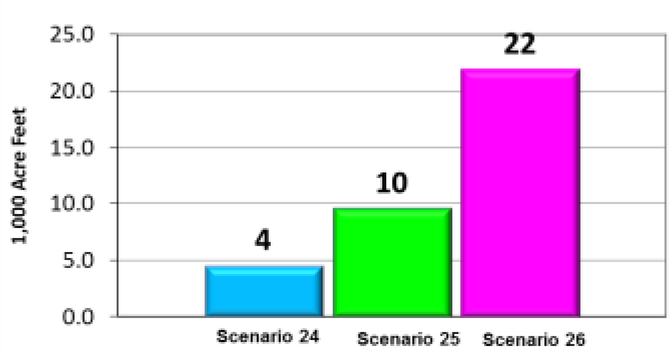

Figure 45. Change in Average Annual SWP Delta Exports (Scenario 24-26)

A lower percentage of the increase in Feather River conjunctive management pumping illustrated as additional Feather River flow below Thermalito Afterbay in Figure 44 is exported in these combined scenarios compared to the conjunctive management only scenarios. This is due in part to the additional spring releases that reduce water available in Oroville Reservoir, SWP delivery allocations, and exports. However, SWP deliveries do increase under this combined scenario demonstrating that additional conjunctive management may offset water supply impacts of additional spring releases. It should be noted that there may still be water supply reliability impacts during critical drought periods that may need to be evaluated in a more detailed study.

The average annual changes in Delta outflow are plotted on Figure 46. Average annual Delta outflow in the No-Action Scenario is approximately 15.8 MAF.

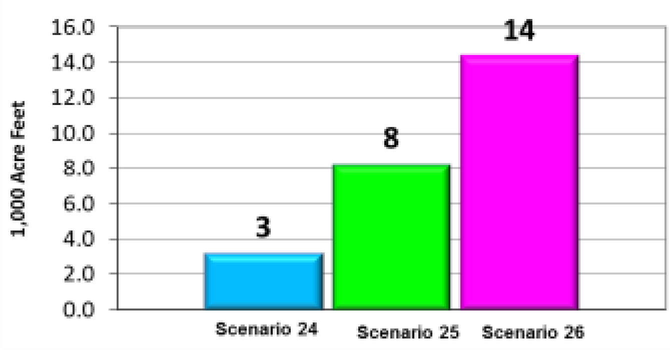

Figure 46. Change in Average Annual Delta Outflow (Scenario 24-26)

Oroville Reservoir EOS storage exceedance probabilities for Scenarios 24 through 26 are plotted in Figure 47. In years where the No-Action EOS storage exceeded 1.5 MAF, pulse flows in the spring reduced EOS carryover storage. However, storage increased in some years where the No-Action EOS was below 1.5 MAF as a result of additional conjunctive management pumping. Changes in EOS storage in CVP facilities north-of-Delta are insignificant under these scenarios.

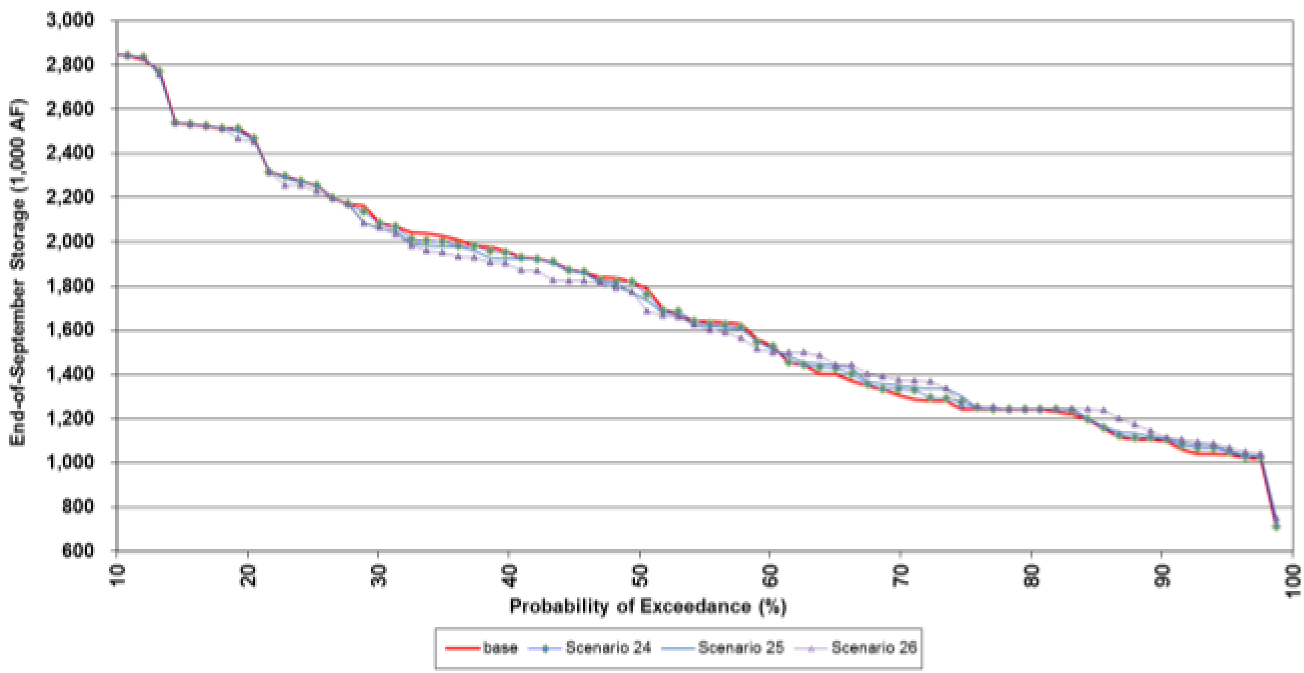

Figure 47. Oroville Reservoir End-of-September Storage (Scenario 24-26)

Table summarizes different system metrics such as EOS storage for Shasta, Trinity, Oroville, and Folsom reservoirs, Sacramento River inflow to the Delta, Delta Outflow, SWP and CVP Delta exports, and north-of-Delta agricultural service deliveries for all scenarios.

Table 6. Summary of Tradeoffs

Scenario	River System	Scenario Number	Target Pulse Volume	Target Conjunctive Management Volume	Pulse Release	Expanded Groundwater Pumping	Shasta EOS Storage	Trinity EOS Storage	Folsom EOS Storage	Oroville EOS Storage	Delta Inflow (Sacramento R.)	Delta Outflow	Jones Pumping Plant	Banks Pumping Plant	North-of-Delta Agricultural Service Deliveries
							Avg. Annual Storage (TAF)				Avg. Annual Flow (TAF)				
		Base	--	--	--	--	2,680	1,396	517	1,836	17,913	15,802	2,252	2,630	233
			Additional Volume (TAF)				Change in Storage (TAF)				Change in Flow (TAF)				
Pulse Flow Only (PFO)	Sacramento	**1**	25	--	13	--	-3	2	0	1	1	4	-2	0	0
		2	50	--	25	--	-10	-5	-1	-2	4	6	-3	1	-1
		3	100	--	47	--	-24	-13	-2	-3	8	12	-5	1	-2
		4	200	--	87	--	-42	-25	-5	-3	14	25	-11	0	-5
		5	300	--	126	--	-64	-37	-7	0	18	31	-13	1	-6
		6	400	--	156	--	-79	-48	-6	4	22	39	-17	0	-9
		7	500	--	171	--	-85	-50	-5	3	22	40	-17	-1	-9
	Feather	**8**	25	--	7	--	0	2	0	-5	0	1	0	-2	0
		9	50	--	14	--	3	5	0	-12	-1	5	-1	-4	1
		10	100	--	27	--	1	3	1	-25	0	8	0	-7	0
		11	200	--	45	--	0	0	0	-40	1	14	0	-12	0
		12	300	--	59	--	-1	2	1	-52	0	18	0	-17	0
		13	400	--	56	--	-1	0	1	-49	2	21	0	-18	0
		14	500	--	49	--	0	1	1	-42	3	18	0	-15	0
Conjunctive Management Only (CM)	Sac.	**15**	--	25	--	5	6	2	2	0	3	1	2	0	1
		16	--	50	--	9	8	6	2	0	7	2	3	1	1
		17	--	100	--	18	19	8	7	0	14	5	7	2	2
	Feather	**18**	--	25	--	8	-1	1	0	6	7	1	1	5	0
		19	--	50	--	16	0	1	0	10	15	2	1	11	0
		20	--	100	--	30	-2	1	2	16	29	6	1	21	0
Pulse Flow with CM	Sac.	**21**	25	25	13	4	1	4	2	1	4	5	-1	0	0
		22	50	50	25	7	0	0	1	-2	9	8	1	1	0
		23	100	100	48	14	-8	-7	4	-4	18	15	1	2	-1
	Feather	**24**	25	25	7	9	-1	3	0	1	8	3	1	4	0
		25	50	50	14	18	3	3	0	0	17	8	-1	10	0
		26	100	100	27	37	0	0	2	-3	37	14	0	22	0

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