Appendix D

System Reoperation: Phase III

Ecosystem Evaluation

Analyses Conducted by the System Reoperation Ecosystem Evaluation Team

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1. Background and Purpose

Senate Bill (SB) X2 1 mandated and allocated resources for "planning and feasibility studies to identify potential options for the reoperation of the state's flood protection and water supply systems that will optimize the use of existing facilities and groundwater storage capacity." Specifically, SB X2 1 stipulated that the studies shall be designed to determine the potential to achieve integration of flood protection and water supply systems to increase water supply reliability and flood protection, improve water quality, and ***provide for ecosystem protection and restoration***. For this evaluation, a suite of ecosystem evaluation metrics were developed to evaluate the effects of reoperation scenarios simulated in Phases II and III of the SRP.

2. Introduction

Phase II reoperation scenarios were used to develop and test the ecosystem evaluation framework, and to quantify the effects of reoperation at Shasta and Oroville paired with conjunctive use and spring pulse flows. The next step was studying the ecosystem effects of Forecast-Based-Operation (FBO) at Shasta and Oroville combined with conjunctive use and spring pulse flows. Finally, t additional scenarios were developed and evaluated to explore the sensitivity of ecosystem performance to FBO and the potential for reoperation to enhance major ongoing ecosystem restoration efforts in the system. The purpose of this report is to document and describe the methods and results from the ecosystem evaluation to date, and to outline additional steps that could optimize reoperation scenarios for ecosystem improvement.

3. Ecological Metrics for the Central Valley

The suite of ecosystem evaluation metrics used in Phase III of the SRP includes four "families" of metrics (salmonids, non-salmonids, instream, and riparian) that span the Sacramento River and Sacramento-San Joaquin Delta (Delta) from Keswick Dam in the north to Mallard Island in the Delta. Metrics were drawn from well-vetted efforts (CALFED Bay-Delta Program, 1999; The Nature Conservancy and American Rivers, 2013; Alexander et al., 2014), with the majority of the metrics drawn from The Nature Conservancy's Ecological Flows Tool (EFT) (Alexander et al., 2014). This suite of metrics was implemented in a web-based data exploration and decision support platform to facilitate analysis of multiple system operation scenarios across varying levels of detail, from simple summaries across all metrics to single metric evaluations of baseline and scenario flows. All metrics connect system operation flow regimes to multiple species' life history needs and include parameters for flow timing, duration, and frequency (or recurrence interval). The flow frequency criteria from EFT were established as Target Threshold Frequencies (TTFs) to measure the outcome of CALSIM model results for each scenario. Metrics included special status species in the system, as well as fundamental habitat forming or maintenance processes critical to the success of these species. Figure 1 and Table 1 summarize the locations, species, and sources of each of the metrics in the Ecosystem Evaluation suite. Tables 2 through 5 summarize the flow magnitude, timing, frequency, and duration criteria for the salmonid, non salmonid, riparian, and instream metric categories, respectively.

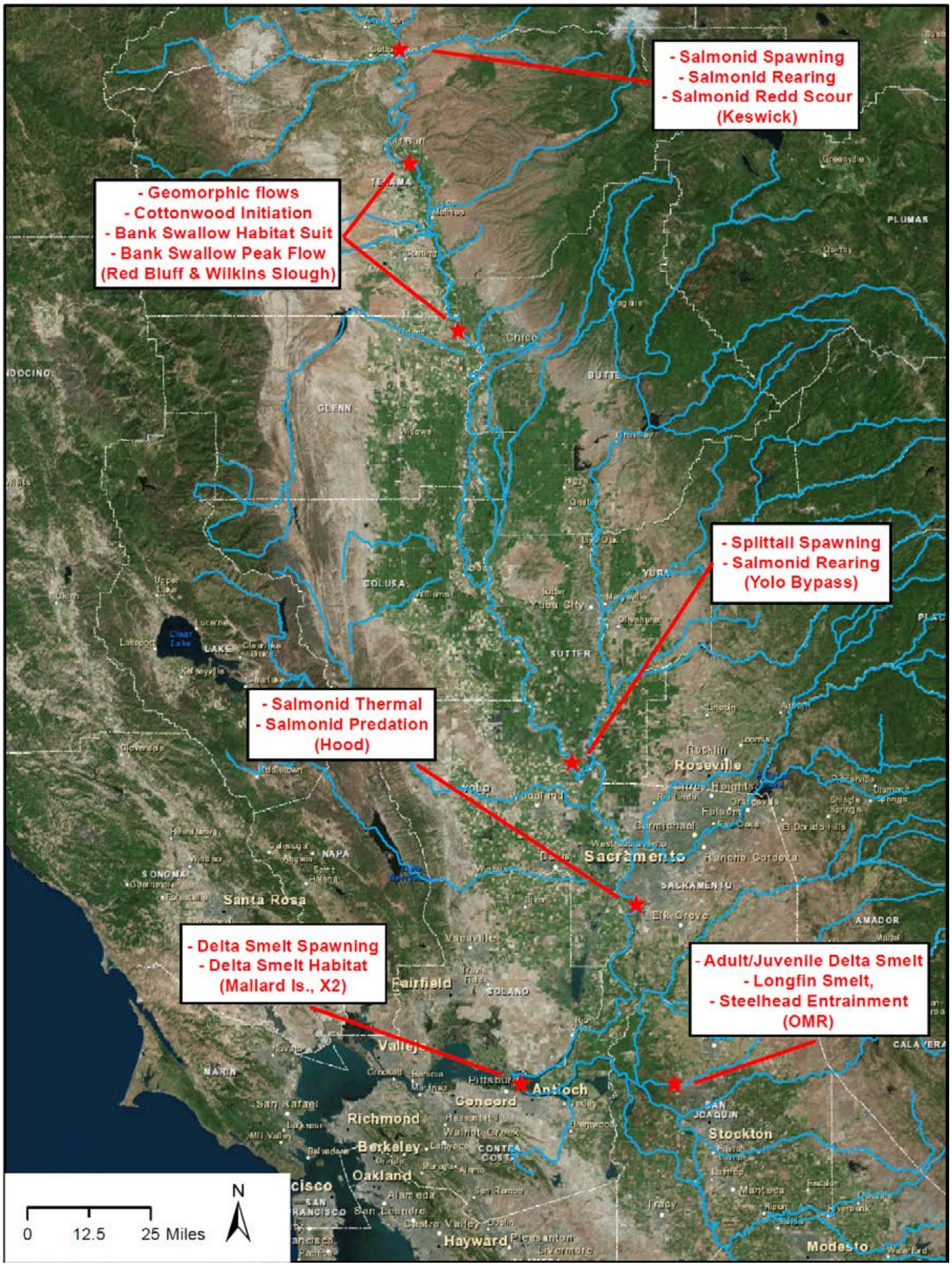

Figure 1: General location map of Ecosystem Evaluation metrics.

Table 1: Summary of suite of ecosystem evaluation metrics.

Category	Metric	Location	Species	Source
Salmonid	Spawning WUA	Keswick	All Runs	TNC (EFT CS1)
	Rearing WUA	Keswick	All Runs	TNC (EFT CS2)
	Redd Scour	Keswick	All Runs	TNC (EFT CS5)
	Yolo Growth	Yolo	All Runs	TNC (EFT CS7)
	Predation Risk	Hood	All Runs	TNC (EFT CS9)
	Temperature/Route	Hood	All Runs	TNC (EFT CS10)
Non-Salmonid	Spawning	Yolo	Splittail	TNC (EFT SS1)
	Spawning Success	Mallard Is.	Delta Smelt	TNC (EFT DS1)
	Habitat Suitability	X2	Delta Smelt	TNC (EFT DS2)
	Entrainment Risk	OMR	Delta Smelt	TNC (EFT DS4)
	OMR Entrainment	OMR	DS, LFS, SH	Herbold 2013
Instream	Geomorphic Flow	Red Bluff	N/A	DWR 2001
Riparian	Peak flow	Hamilton City	Bank Swallow	TNC (EFT BASW2)
	Initiation	Hamilton City	Cottonwood	TNC (EFT FC1)
	Scour	Hamilton City	Cottonwood	TNC (EFT FC2)

Table 2: Salmonid metric magnitude, timing, frequency, and duration parameters. [cite]

<table>
<tr><th>Name of Metric</th><th>Location</th><th>O</th><th>N</th><th>D</th><th>J</th><th>F</th><th>M</th><th>A</th><th>M</th><th>J</th><th>J</th><th>A</th><th>S</th><th>RECURRENCE</th></tr>
<tr><td colspan="15">SALMONIDS</td></tr>
<tr><td>CS5: Chinook and Steelhead, Redd Scour</td><td>Sacramento Riv Above Clear Creek</td><td></td><td></td><td></td><td>< 15k cfs</td><td>< 30k cfs</td><td>< 25k cfs</td><td></td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS5: Chinook and Steelhead, Redd Scour — Fall</td><td>Sacramento Riv Above Clear Creek</td><td></td><td colspan="4">< 15k cfs</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS5: Chinook and Steelhead, Redd Scour — Late Fall</td><td>Sacramento Riv Above Clear Creek</td><td></td><td></td><td></td><td colspan="4">< 30k cfs</td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
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<tr><td>CS1: Chinook and Steelhead — Spawning WUA</td><td>Sacramento Riv above Clear Creek</td><td></td><td>4k-8k cfs</td><td></td><td>3.5k -8k cfs</td><td>3.5k -8k cfs</td><td>3.5k-10k cfs</td><td></td><td>5k-12k cfs</td><td>5k-12k cfs</td><td></td><td></td><td>6k-10k cfs</td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS1: Chinook and Steelhead — Spawning WUA — Spring</td><td>Sacramento Riv above Clear Creek</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>6k-10k cfs</td><td>2 out of 3 years (67%)</td></tr>
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<tr><td>CS1: Chinook and Steelhead — Spawning WUA — Late Fall</td><td>Sacramento Riv above Clear Creek</td><td></td><td></td><td></td><td colspan="2">3.5k-8k cfs</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
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<tr><td>CS1: Chinook and Steelhead — Spawning WUA — Winter</td><td>Sacramento Riv above Clear Creek</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">5k-12k cfs</td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS1: Chinook and Steelhead — Spawning WUA — Steelhead</td><td>Sacramento Riv above Clear Creek</td><td></td><td></td><td></td><td colspan="3">3.5k-10k cfs</td><td></td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS2: Chinook and Steelhead, Rearing Habitat</td><td>Sacramento Riv Above Clear Creek</td><td></td><td></td><td></td><td>3,5K -6K cfs</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>3,5K-8K cfs</td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS2: Chinook and Steelhead, Rearing Habitat — Spring</td><td>Sacramento Riv Above Clear Creek</td><td></td><td></td><td></td><td colspan="4">3.5k-6k cfs</td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS2: Chinook and Steelhead, Rearing Habitat — Late Fall</td><td>Sacramento Riv Above Clear Creek</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">3.5k-9k cfs</td><td>2 out of 3 years (67%)</td></tr>
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<tr><td>CS2: Chinook and Steelhead, Rearing Habitat — Steelhead</td><td>Sacramento Riv Above Clear Creek</td><td colspan="2">3.5k-9.7k cfs</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">3.5k-9.7k cfs</td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS7: Chinook and Steelhead, Juvenile Rearing Habitat</td><td>Fremont Weir Spill to Yolo Bypass</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">> 5k cfs</td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
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<tr><td>CS7: Chinook and Steelhead, Juvenile Rearing Habitat — Late Fall</td><td>Fremont Weir Spill to Yolo Bypass</td><td></td><td colspan="6">> 5k cfs</td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
<tr><td>CS7: Chinook and Steelhead, Juvenile Rearing Habitat — Winter</td><td>Fremont Weir Spill to Yolo Bypass</td><td></td><td></td><td></td><td colspan="4">> 5k cfs</td><td></td><td></td><td></td><td></td><td></td><td>2 out of 3 years (67%)</td></tr>
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<tr><td>CS9: Chinook and Steelhead, Predation Risk</td><td>Sacramento Riv at Hood</td><td></td><td colspan="8">> 17K cfs</td><td></td><td></td><td></td><td>1 out of 3 years (33%)</td></tr>
<tr><td>CS9: Chinook and Steelhead, Predation Risk — Spring</td><td>Sacramento Riv at Hood</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">> 11k cfs</td><td></td><td></td><td></td><td>1 out of 3 years (33%)</td></tr>
<tr><td>CS9: Chinook and Steelhead, Predation Risk — Fall</td><td>Sacramento Riv at Hood</td><td></td><td></td><td></td><td></td><td></td><td colspan="4">> 17k cfs</td><td></td><td></td><td></td><td>1 out of 3 years (33%)</td></tr>
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<tr><td>CS10: Chinook and Steelhead, Thermal Stress</td><td>Sacramento Riv at Hood</td><td></td><td></td><td></td><td></td><td></td><td>> 27k cfs</td><td>> 15 k cfs</td><td>>7k cfs</td><td></td><td></td><td></td><td></td><td>1 out of 3 years (33%)</td></tr>
<tr><td>CS10: Chinook and Steelhead, Thermal Stress — Spring</td><td>Sacramento Riv at Hood</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">> 7k cfs</td><td></td><td></td><td></td><td>1 out of 3 years (33%)</td></tr>
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CS10: Chinook and Steelhead, Thermal Stress — Late Fall	Sacramento Riv at Hood		> 27k cfs										*1 out of 3 years (33%)*
CS10: Chinook and Steelhead, Thermal Stress — Winter	Sacramento Riv at Hood				> 15K cfs								*1 out of 3 years (33%)*
CS10: Chinook and Steelhead, Thermal Stress — Steelhead	Sacramento Riv at Hood						> 15k cfs						*1 out of 3 years (33%)*

Table 3: Non salmonid metric magnitude, timing, frequency, and duration parameters.

NON SALMONIDS													
BDCP: Delta Entrainment Index — Delta Smelt Adults	Old and Middle River			> 0 cfs									*Annually (100%)*
BDCP: Delta Entrainment Index — Longfin Smelt Adults	Old and Middle River			> 0 cfs									*Annually (100%)*
BDCP: Delta Entrainment Index — Longfin Juvenile	Old and Middle River					> 0 cfs							*Annually (100%)*
BDCP: Delta Entrainment Index — SJ Steelhead Outmigrant	Old and Middle River					> 0 cfs							*Annually (100%)*
DS1: Delta Smelt — Spawn Success	Suisun Bay at Mallard Island					X2 ≤ 74 km							*1 out of 2 years (50%)*
DS2: Delta Smelt — Habitat Suitability	Fall X2	X2 ≤ 74/81 km											*Annually (100%)*
DS4: Delta Smelt — Entrainment Risk	Old and Middle River							Q > 0/2K cfs					*Annually (100%)*
SS1: Splittail, Spawning Habitat Extent	Fremont Weir Spill to Yolo Bypass					100 – 2K cfs							*4 out of 10 years (40%)*

Table 4: Riparian metric magnitude, timing, frequency, and duration parameters.

RIPARIAN													
BASW2: Bank Swallow, Peak Flow during nesting period	Hamilton City							≤ 50K cfs					*1 out of 3 years (33%)*
FC1: Cottonwood Initiation	Hamilton City							> minQtarget					*1 out of 8 years (13%)*

Table 5: Instream metric magnitude, timing, frequency, and duration parameters.

INSTREAM													
Geomorphic Flow	RedBluff			> 40K cfs									*1 out of 3 years (33%)*

4. Phase II Synopsis

Phase II produced a total of 26 different operation scenarios that included different combinations of additional spring (March–May) releases and conjunctive management (Table 6).

Table 6: Phase II Operations Simulation Parameters

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

Phase II yielded two important results for the ecosystem evaluation process. First, it provided system operation modeling output that could be used to develop and refine the suite of ecosystem metrics to be sensitive to the changes in system operation likely to occur with the strategies under consideration by the SRP. Next, it demonstrated that relatively limited "pulse" flows for ecosystem benefit released between March and May, even when combined with conjunctive use, generated very few measurable benefits, and had nearly as many negative impacts as positive benefits. Figure 2 illustrates how the 26 Phase II scenarios showed very few positive benefits, and how many benefits were offset by negative impacts. Drilling deeper into this rolled-up result using the ecosystem evaluation platform, it became apparent that many of the negative impacts from scenarios were associated with extra water being captured in reservoirs outside the March to May "pulse" flow period.

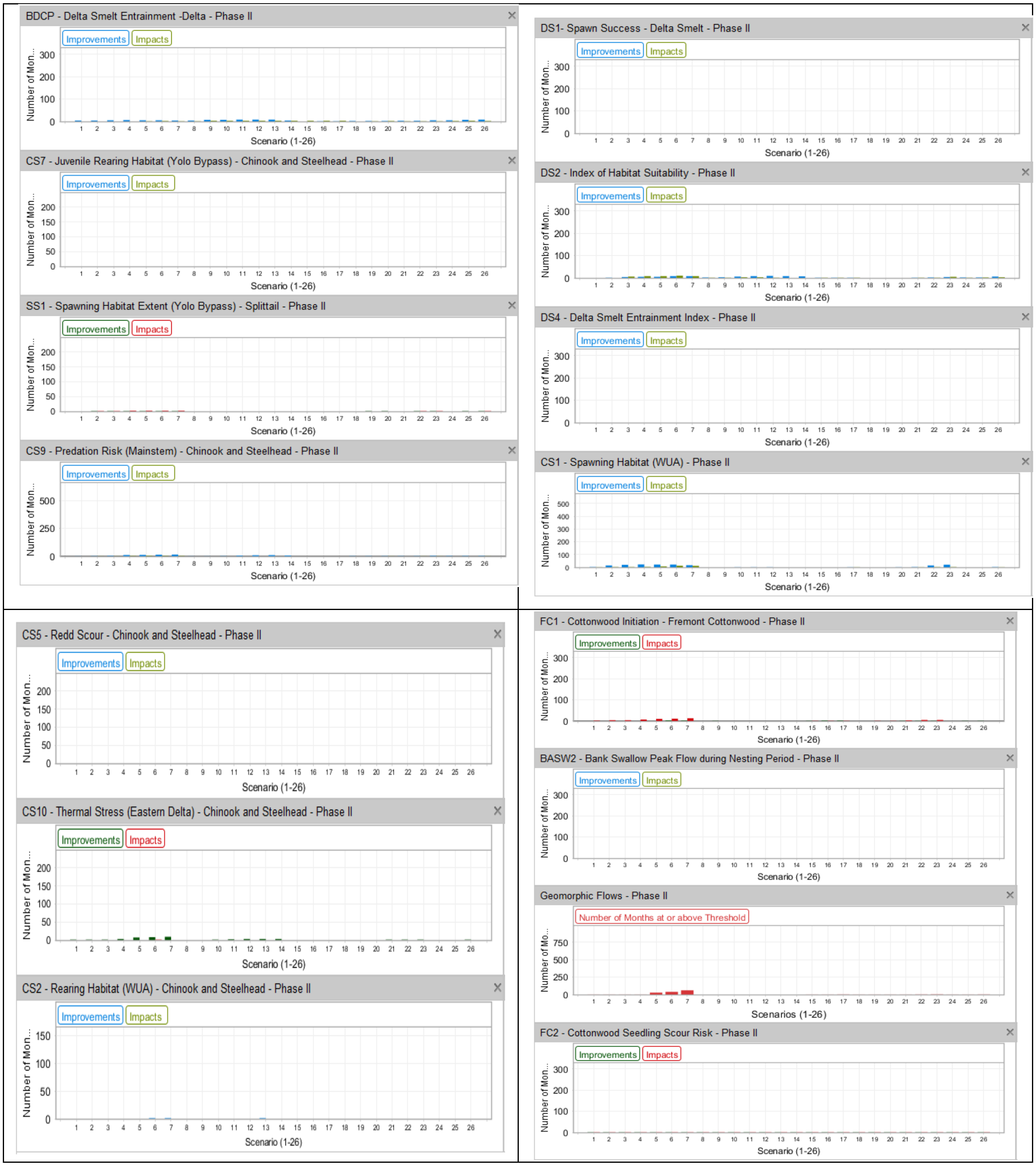

Figure 2: Roll-up summary of the number of months of improvements and negative impacts (relative to baseline conditions) for the 26 Phase II scenarios, evaluated using the suite of Ecosystem Evaluation metrics.

5. Phase III: Methods and Results

Phase III scenarios were similar to Phase II scenarios, with the addition of Forecast Based Operations (FBO) to the pulse flows and conjunctive use evaluated in Phase II. Table 7 summarizes the key components of the initial set of Phase III scenarios.

Table 7: Summary of Phase III scenarios

		Water Supply Reliability			Flood Hazard Reduction	Ecosystem Protection and Restoration
Scenario	**Reservoir**	**Sacramento CM (TAF)**	**Feather CM (TAF)**	**Forecast Based Operations**		**Annual Pulse Release (TAF)**
Baseline	None	None	None	0% Encroachment	None	None
0 (Baseline with FBO)	None	None	None	25% Encroachment	None	None
1	Shasta	50	0		Advance releases ahead of a damaging storm	50
2	Shasta	100	0			200
3	Oroville	0	50			50
4	Oroville	0	100			200
5	Shasta & Oroville	50	50			50/50 (100 Total)
6	Shasta & Oroville	100	100			150/150 (300 Total)
7 (FBO Sensitivity)	Oroville	None	None			None

A set of operation simulations were developed to evaluate the sensitivity of ecosystem performance to the level of reservoir operation rule encroachment (Table 8).

Table 8: Ecosystem evaluation system operation simulation model runs to test FBO sensitivity

		Water Supply Reliability			Flood Hazard Reduction	Ecosystem Protection and Restoration	Notes
Scenario	**Reservoir**	**Sacramento CM (TAF)**	**Feather CM (TAF)**	**Forecast Based Operations**		**Annual Pulse Release (TAF)**	
8	None	None	None	15% Encroachment	None	None	Modified from Baseline with FBO of Phase III
9	None	None	None	25% Encroachment	None	None	
10	None	None	None	25% Encroachment + 7%	None	None	
11	None	None	None	35% Encroachment	None	None	
12	Shasta	100	0	35% Encroachment	Advance releases ahead of a damaging storm	200	Modified from Scenario 2 of Phase III

Finally, in order to explore the effects of FBO on current ecosystem enhancement efforts in the Central Valley, a third set of scenarios were developed to attempt to optimize operations for red scour protection and thermal stress (note, this combination did not yield significant changes in operations from baseline conditions), and to evaluate flow into Yolo Bypass with a modified (notched) Fremont Weir. Table 9 summarizes these scenarios, and the modified Fremont Weir scenarios were designed to be consistent with notch configuration being explored in the investigations around the Central Valley Project Operations Biological Opinion. The three sets of Phase III scenarios provided an array of outputs to evaluate based on a single spring pulse event between March and May.

The error in the hydrologic model was not compared against the ecosystem results, therefore, the absolute value of improvement is unknown relative to the error of the hydrologic model. However, trends in increases and decreases in ecosystem metric scores (percentages) are identified and may represent realized improvements or impacts of evaluated flow regimes.

Increases or decreases in ecosystem metrics are relative to the baseline flow conditions from the model, represented as "Base" in the results tables and text.

Table 9: Ecosystem evaluation system operation simulation model runs to test compatibility with ecosystem enhancement efforts.

Scenario	Forecast Based Operations	Conjunctive Management	Notes
13	None	None	Optimized for metrics Chinook and Steelhead Redd Scour (CS5), and Chinook and Steelhead Thermal Stress (CS10)
14	None	None	Optimized for metric Chinook and Steelhead Yolo Growth (CS7). Weir flow is increased to 6000 cfs when Qsac = 17,819 cfs*. 15 days of weir in April and 14 days in February are turned off to not create a big difference in the total April and February spill.
15	None	None	Optimized for metric Chinook and Steelhead Yolo Growth (CS7). Weir flow is increased to 7000 cfs when Qsac = 20,317 cfs*. 15 days of weir in April are turned off so that the weir modification won't cause a big difference in the total April weir spill.
16	None	None	Optimized for metric Chinook and Steelhead Yolo Growth (CS7). Weir flow is increased to 7000 cfs when Qsac = 20,317 cfs*. 15 days of weir in April and 14 days in February are turned off to not create a big difference in the total April and February spill.
17	25%	None	Optimized for metric Chinook and Steelhead Yolo Growth (CS7). Weir flow is increased to 7000 cfs when Qsac = 20,317 cfs*. 15 days of weir in April and 14 days in February are turned off to not create a big difference in the total April and February spill. A 25% encroachment is applied

6. Phase III Summary Results

Table 10 summarizes results for a selected set of the Phase III scenarios that include: FBO; Shasta reoperation with small and big ecosystem "pulse" flows; Oroville reoperation with small and big ecosystem "pulse" flows; Shasta and Oroville reoperation with small and big "pulse" flows; Shasta reoperation with a big "pulse" flow and sensitivity to FBO with increased encroachment; and Yolo Bypass ecosystem enhancement (Fremont Weir Notch) with and without FBO. This selected set of reoperation scenarios yields more improvements in more ecosystem evaluation metrics (10–23) than negative impacts (4–7) and instances of no change from baseline conditions (3–15). However, as the following sections detail, most improvements in ecosystem evaluation metrics are for very small (< 5%) increases in the frequency with which important ecological flow conditions are satisfied. In addition, ecosystem evaluation metrics show reductions in the frequency with which important ecological conditions are satisfied; this combination of very small improvements and impacts to ecosystem conditions is somewhat an artifact of the limited range of operations modeling conducted in this phase. For example, while we see small improvements in spring-run rearing Weighted Useable Area (WUA) for most scenarios, we see impacts to fall-run spawning WUA because the ecosystem flows in the operation modeling release additional water in the spring, but recapture that water in the following fall, thereby negatively impacting ecosystem conditions outside of the pulse-flow period. Additional refined operations modeling rules could be developed to accentuate the periods showing improvement and minimize the periods showing impacts.

Table 10: Summary of ecosystem evaluation results for selected Phase II Scenarios. Symbols indicate the following change from baseline condition (+ = improvement; 0 = no change; - = negative impact). Note: "Small" and "Big" refers to the 50 TAF and 200 TAF annual pulse release targets in Table 7.

		Scenario									
		0	1	2	3	4	5	6	12	16	17
		FBO	Shasta Small	Shasta Big	Oroville Small	Oroville Big	Shasta + Oroville Small	Shasta + Oroville BIg	Shasta Big FBO Sens	Fremont Notch	Fremont Notch FBO
CS7	Yolo Growth: Spring Run	0	0	0	0	0	0	0	0	0	0
CS7	Yolo Growth: Fall Run	+	+	+	+	+	+	+	+	+	+
CS7	Yolo Growth: Steelhead	+	+	+	+	+	+	+	+	+	+
CS7	Yolo Growth: Late-Fall Run	+	+	0	+	+	+	+	0	+	+
CS7	Yolo Growth: Winter Run	+	+	+	+	+	+	+	+	+	+
CS1	Spawning Habitat (WUA)-Spring	-	-	-	0	+	0	-	-	0	-
CS1	Spawning Habitat (WUA)-Fall	-	-	-	-	-	-	-	-	0	-
CS1	Spawning Habitat (WUA)-Late Fall	+	+	+	+	+	+	+	+	+	+
CS1	Spawning Habitat (WUA)-Winter	-	-	-	-	-	-	-	-	0	-
CS1	Spawning Habitat (WUA)-Steelhead	+	+	+	+	+	+	+	+	+	+
CS2	Rearing WUA-Spring	+	+	-	+	+	+	+	-	+	+
CS2	Rearing WUA-Late-Fall	+	+	+	+	+	+	+	+	+	+
CS2	Rearing WUA-Winter	+	+	+	+	+	+	+	+	0	+
CS2	Rearing WUA-Steelhead	0	+	+	0	-	+	+	+	0	0
CS9	Predation Risk - Fall	+	+	+	+	+	+	+	+	-	-
CS9	Predation Risk - Steelhead	+	+	+	+	+	+	+	+	-	-
CS10	Thermal Stress - Late Fall	-	-	-	-	-	-	-	-	-	-
BDCP	Delta Salvage Analysis-Adult Delta Smelt	+	+	+	+	+	+	+	+	+	+
BDCP	Delta Salvage Analysis-Longfin Smelt Adult	+	+	+	+	+	+	+	+	+	+
BDCP	Delta Salvage Analysis-Longfin Juvenile	+	+	+	+	+	+	+	+	0	+
BDCP	Delta Salvage Analysis-SJ Steelhead Outmigrant	+	+	+	+	+	+	+	+	0	+
SS1	Splittail - Spawn	+	+	+	+	+	+	+	+	-	-
DS1	Delta Smelt - Index of Spawning Success	0	0	0	0	0	0	0	0	0	0
DS2	Delta Smelt - Index of Habitat Suitability	+	-	+	-	+	-	-	-	0	+
DS4	Delta Smelt Entrainment	0	0	0	0	0	0	0	0	0	0
GF	Geomorphic Flow - 1 day duration	+	+	+	+	+	+	+	+	0	+
GF	Geomorphic Flow - 3 days duration	+	+	+	+	+	+	+	+	-	+
GF	Geomorphic Flow - 7 day duration	+	+	+	+	+	+	+	+	0	+
GF	Geomorphic Flow - 14 days duration	+	+	+	+	+	+	+	+	0	+
FC1	Cottonwood initiation	+	+	+	+	+	+	+	+	0	+
TOTAL NUMBER OF IMPROVEMENTS		**22**	**22**	**21**	**21**	**23**	**22**	**22**	**20**	**10**	**19**
TOTAL NUMBER OF IMPACTS		**4**	**5**	**5**	**4**	**4**	**4**	**5**	**6**	**5**	**7**
TOTAL NUMBER OF NO CHANGE		**4**	**3**	**4**	**5**	**3**	**4**	**3**	**4**	**15**	**4**

7. Phase III Salmonid Results

Table 11 summarizes the ecosystem performance of Phase III scenarios with respect to salmonid metrics. Except for Spring Run, Fall Run, and Winter Run spawning habitat and thermal stress, most of the Phase III scenarios result in small improvements or protection of existing conditions for salmonid ecosystem evaluation metrics. Spring-run rearing WUA showed improvement (2 percent max) for most scenarios; however, fall run spawning WUA showed a decreasing trend (up to 6 percent) relative to baseline because the ecosystem flows in the operation modeling release additional water in the spring but recapture that water in the following fall, thereby negatively impacting fall-run spawning.

Table 11: Summary of Phase III scenario performance (relative to baseline) for the salmonid ecosystem evaluation metrics.

ReOp EcoEval Roll Up Results - Salmonids

	A	B	C	D	E	F	G	H	I	J	K	L	R	V	W
2	Scenario Parameters:				Base	0	1	2	3	4	5	6	12	16	17
3			FBO %		n/a	25	25	25	25	25	25	25	35	0	25
4			Shasta CM (TAF)		n/a	0	50	100	0	0	50	100	100	0	0
5			Shasta Eco (TAF)		n/a	0	50	200	0	0	50	100	200	0	0
6			Oroville CM (TAF)		n/a	0	0	0	50	100	50	150	0	0	0
7			Oroville Eco (TAF)		n/a	0	0	0	50	200	50	150	0	0	0
8			Fremont Weir Mod (Weir Q @ Sac Q)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7K @ 20K	7K @ 20K
9															
10	Code	Name	Relevant Months (# per 82 years)	Threshold Frequency	Base	FBO	Shasta Small	Shasta Big	Oroville Small	Oroville Big	Shasta + Oroville Small	Shasta + Oroville Big	Shasta Big FBO Sens	Fremont Notch	Fremont Notch FBO
11	CS7	Yolo Growth: Spring Run	164	67%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
12	CS7	Yolo Growth: Fall Run and Steelhead	328	67%	11.0%	12.2%	11.9%	11.9%	12.2%	12.5%	11.9%	11.9%	12.2%	14.6%	14.0%
13	CS7	Yolo Growth: Late-Fall Run	492	67%	20.9%	21.3%	21.1%	20.9%	21.3%	21.7%	21.1%	21.1%	20.9%	25.6%	24.0%
14	CS7	Yolo Growth: Winter Run	328	67%	17.9%	18.9%	18.7%	18.5%	18.9%	19.3%	18.7%	18.7%	18.5%	21.7%	20.7%
15															
16															
	CS1	Spawning Habitat (WUA)-Spring	82	67%	15.9%	14.6%	13.4%	13.4%	15.9%	19.5%	15.9%	13.4%	14.6%	15.9%	14.6%
	CS1	Spawning Habitat (WUA)-Fall	82	67%	46.3%	42.7%	41.5%	40.2%	42.7%	43.9%	41.5%	40.2%	40.2%	46.3%	42.7%
	CS1	Spawning Habitat (WUA)-Late Fall	164	67%	31.7%	33.5%	33.5%	32.9%	33.5%	33.5%	33.5%	33.5%	34.1%	32.3%	33.5%
	CS1	Spawning Habitat (WUA)-Winter	164	67%	53.7%	50.0%	49.4%	51.2%	49.4%	49.4%	50.0%	49.4%	49.4%	53.7%	50.0%
	CS1	Spawning Habitat (WUA)-Steelhead	246	67%	37.4%	38.6%	42.7%	40.7%	38.6%	38.6%	42.7%	41.1%	39.8%	37.8%	38.6%
	CS2	Rearing WUA-Spring	328	67%	31.7%	32.0%	34.5%	30.2%	32.3%	32.0%	34.5%	32.9%	28.7%	32.0%	32.0%
	CS2	Rearing WUA-Late-Fall	328	67%	23.2%	24.1%	24.4%	25.6%	23.8%	24.1%	24.4%	25.0%	25.9%	23.5%	24.1%
	CS2	Rearing WUA-Winter	410	67%	51.5%	52.9%	53.7%	53.9%	53.2%	52.0%	53.7%	53.4%	53.7%	51.5%	52.9%
	CS2	Rearing WUA-Steelhead	492	67%	51.6%	51.6%	52.0%	51.8%	51.6%	51.0%	52.0%	52.0%	52.4%	51.6%	51.6%
	CS9	Predation Risk - Fall Run and Steelhead	328	33%	45.1%	46.3%	46.3%	48.5%	46.3%	47.0%	46.6%	48.2%	47.9%	43.3%	44.8%
	CS10	Thermal Stress - Late Fall	492	33%	31.1%	30.5%	30.7%	30.5%	30.5%	30.7%	30.7%	30.9%	30.3%	30.1%	29.7%

8. Phase III Non-Salmonid Results

Table 12 summarizes ecosystem performance of Phase III scenarios with respect to non-salmonid metrics. Except for Delta Smelt habitat suitability, most of the Phase III scenarios result in small improvements or protection of existing conditions for non-salmonid ecosystem evaluation metrics.

Table 12: Summary of Phase III scenario performance (relative to baseline) for the non-salmonid ecosystem evaluation metrics.

ReOp EcoEval Roll Up Results - Non-Salmonids

	A	B	C	D	E	F	G	H	I	J	K	L	R	V	W
2	Scenario Parameters:				Base	0	1	2	3	4	5	6	12	16	17
3			FBO %		n/a	25	25	25	25	25	25	25	35	0	25
4			Shasta CM (TAF)		n/a	0	50	100	0	0	50	100	100	0	0
5			Shasta Eco (TAF)		n/a	0	50	200	0	0	50	100	200	0	0
6			Oroville CM (TAF)		n/a	0	0	0	50	100	50	150	0	0	0
7			Oroville Eco (TAF)		n/a	0	0	0	50	200	50	150	0	0	0
8			Fremont Weir Mod (Weir Q @ Sac Q)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7K @ 20K	7K @ 20K
9															
10	Code	Name	Relevant Months (# per 82 years)	Threshold Frequency	Base	FBO	Shasta Small	Shasta Big	Oroville Small	Oroville Big	Shasta + Oroville Small	Shasta + Oroville Big	Shasta Big FBO Sens	Fremont Notch	Fremont Notch FBO
11	BDCP	Delta Salvage Analysis-Adult Delta Smelt	328	N/A	N/A	5.8%	7.3%	6.1%	5.5%	4.9%	6.7%	6.1%	6.7%	0.9%	5.8%
12	BDCP	Delta Salvage Analysis-Longfin Smelt Adult	246	N/A	N/A	4.3%	5.8%	4.9%	4.0%	3.7%	5.2%	4.9%	5.5%	0.9%	4.3%
13	BDCP	Delta Salvage Analysis-Longfin Juvenile	164	N/A	N/A	1.5%	2.1%	1.2%	1.5%	1.2%	2.1%	1.5%	1.5%	0.0%	1.5%
14	BDCP	Delta Salvage Analysis-SJ Steelhead Outmigrant	246	N/A	N/A	1.8%	2.4%	1.5%	1.8%	1.5%	2.4%	1.5%	1.8%	0.0%	1.8%
15–16	[redacted]														

9. Phase III Riparian Results

Table 13 summarizes ecosystem performance of Phase III scenarios with respect to riparian metrics. All of the Phase III scenarios result in small improvements or protection of existing conditions for riparian ecosystem evaluation metrics. However, it is important to note that the cottonwood initiation metric is still substantially lower than the desired minimum frequency of occurrence.

Table 13: Summary of Phase III scenario performance (relative to baseline) for the riparian ecosystem evaluation metrics.

ReOp EcoEval Roll Up Results - Riparian

	A	B	C	D	E	F	G	H	I	J	K	L	R	V	W
2	Scenario Parameters:				Base	0	1	2	3	4	5	6	12	16	17
3			FBO %		n/a	25	25	25	25	25	25	25	35	0	25
4			Shasta CM (TAF)		n/a	0	50	100	0	0	50	100	100	0	0
5			Shasta Eco (TAF)		n/a	0	50	200	0	0	50	100	200	0	0
6			Oroville CM (TAF)		n/a	0	0	0	50	100	50	150	0	0	0
7			Oroville Eco (TAF)		n/a	0	0	0	50	200	50	150	0	0	0
8			Fremont Weir Mod (Weir Q @ Sac Q)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7K @ 20K	7K @ 20K
9															
10	Code	Name	Relevant Months (# per 82 years)	Threshold Frequency	Base	FBO	Shasta Small	Shasta Big	Oroville Small	Oroville Big	Shasta + Oroville Small	Shasta + Oroville Big	Shasta Big FBO Sens	Fremont Notch	Fremont Notch FBO
11	BASW2	Swallow, Peak Flow during nesting period	328	33%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
12	FC1	Cottonwood initiation	82	12%	1.2%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	1.2%	2.4%

10. Phase III Instream Results

The Phase III scenarios have the most significant impact on the instream ecosystem evaluation metrics (results summarized in Table 12) that quantify the potential to achieve more frequent geomorphic flows that form and maintain habitat. Nearly all of the selected scenarios increase the frequency of one-to-three day geomorphic flows of 50,000 cfs at Red Bluff from below the desired minimum threshold of once every three years under baseline conditions to above this threshold.

Table 14: Summary of Phase III scenario performance (relative to baseline) for the instream ecosystem evaluation metric for geomorphic flows ranging from one-to-fourteen days in duration.

ReOp EcoEval Roll Up Results - Instream

	A	B	C	D	E	F	G	H	I	J	K	L	R	V	W
2	**Scenario Parameters:**				**Base**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**12**	**16**	**17**
3			**FBO %**		n/a	25	25	25	25	25	25	25	35	0	25
4			**Shasta CM (TAF)**		n/a	0	50	100	0	0	50	100	100	0	0
5			**Shasta Eco (TAF)**		n/a	0	50	200	0	0	50	100	200	0	0
6			**Oroville CM (TAF)**		n/a	0	0	0	50	100	50	150	0	0	0
7			**Oroville Eco (TAF)**		n/a	0	0	0	50	200	50	150	0	0	0
8			**Fremont Weir Mod (Weir Q @ Sac Q)**		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7K @ 20K	7K @ 20K
9															
10	**Code**	**Name**	**Relevant Months (# per 82 years)**	**Threshold Frequency**	**Base**	**FBO**	**Shasta Small**	**Shasta Big**	**Oroville Small**	**Oroville Big**	**Shasta + Oroville Small**	**Shasta + Oroville Big**	**Shasta Big FBO Sens**	**Fremont Notch**	**Fremont Notch FBO**
11	GF	Geomorphic Flow - 1 day duration	82	33%	36.6%	42.7%	42.7%	53.7%	42.7%	42.7%	42.7%	51.2%	53.7%	36.6%	42.7%
12	GF	Geomorphic Flow - 3 days duration	82	33%	29.3%	32.9%	34.1%	40.2%	32.9%	32.9%	34.1%	36.6%	40.2%	28.0%	32.9%
13	GF	Geomorphic Flow - 7 day duration	82	33%	22.0%	26.8%	26.8%	26.8%	26.8%	26.8%	26.8%	26.8%	26.8%	22.0%	26.8%
14	GF	Geomorphic Flow - 14 days duration	82	33%	15.9%	18.3%	19.5%	19.5%	18.3%	18.3%	19.5%	19.5%	20.7%	15.9%	18.3%

11. Conclusions and Recommended Future Analyses

Future analyses would benefit from a limited number of additional ecosystem evaluation metrics to address the Feather River (it is clear that the current suite of metrics does not adequately capture the benefits of Oroville pulse flows) as well as floodplain rearing (to provide linkage to California Department of Water Resources' [DWR's] Conservation Strategy). In addition, this framework could be used to evaluate and refine a range of related potential system reoperation components, including Yolo bypass inflow scenarios[1], a wider timing window of ecosystem "pulse" flows, fish passage above major dams (by modifying carry-over storage requirements)[2], North of Delta Offstream Storage (NODOS), Delta conveyance, and climate change. While climate change effects typically overwhelm the operational scenarios considered in studies such as this (Alexander et al., 2014), alternative reoperation strategies can be evaluated to assess which is the most robust relative to a range of climate futures. Also, the approach used to quantify ecosystem performance could also be applied to more rigorously evaluate flood risk reduction performance.

[1] DWR's Yolo Bypass Habitat Restoration Program is working with federal agencies and other stakeholders on alterations to Fremont Weir to provide for more frequent inundation of the Yolo Bypass to benefit ecosystem function.

[2] DWR is identified in the biological opinion (OCAP 2009) as assisting the United States Bureau of Reclamation (Reclamation) with a Shasta Dam Fish Passage Evaluation. The National Marine Fisheries Service (NMFS) believes it is necessary for Reclamation, in cooperation with NMFS, other fisheries agencies, and DWR, to undertake a program to provide fish passage above currently impassable artificial barriers for Sacramento River winter-run, spring-run, and CV steelhead, and to reintroduce these fish to historical habitats above Shasta and Folsom dams.

Most importantly, in light of the numerous trade-offs between species and life stages that would occur under any reoperation strategy, we recommend a collaborative approach to ecosystem and water supply modeling; this approach would include iterative analyses to craft operating rules that address how frequently a species or ecosystem requires favorable conditions to support its sustainability . For example, Fremont cottonwood initiation need only occur approximately once every decade (see Table 4). Existing water-year type rules assume a one-size-fits-all approach to water releases instead of accounting for the recent natural history experienced by important species and ecosystems. Operating rules must integrate the time since a species or ecosystem has last experienced favorable conditions relative to the recurrence necessary to maintain a sustainable condition.

References

Alexander, C.A.D., D.C.E. Robinson, F. Poulsen. 2014. *Application of the Ecological Flows Tool to Complement Water Planning Efforts in the Delta & Sacramento River: Multi-Species effects analysis & Ecological Flow Criteria*. Final Report to The Nature Conservancy. Chico, California. 228 p + appendices.

CALFED Bay-Delta Program. 1999. *Flow regime requirements for habitat restoration along the Sacramento River between Colusa and Red Bluff.* Sacramento. 20 December.

The Nature Conservancy and American Rivers. 2013. *Panel Review of the Draft Bay Delta Conservation Plan*. Prepared by Saracino & Mount, LLC. August.