Appendix 11P Riverine Flow-Survival

Appendix 11P Riverine Flow-Survival

11P.1 Introduction

This appendix discusses methods applied to assess potential effects of Red Bluff and Hamilton City diversions on juvenile Chinook salmon riverine survival in the Sacramento River as a function of flow. Section 11P.2, *Flow Threshold Survival Analysis to Assess Potential Effects of Sites Reservoir Project Diversion Criteria Based on Historical Juvenile Chinook Salmon Monitoring Data*, provides an assessment of Project diversion criteria by application of published flow-survival relationships to daily flow data while accounting for historical fish migration patterns as represented in monitoring data. Section 11P.3, *Flow Threshold Survival Analysis to Assess Potential Effects of Sites Reservoir Project Mitigation Measure FISH-2.1*, provides an assessment of Mitigation Measure FISH-2.1 using the same methods as applied in Section 11P.2. Section 11P.4, *References Cited*, provides the references cited in the appendix.

11P.2 Flow Threshold Survival Analysis to Assess Potential Effects of Sites Reservoir Project Diversion Criteria Based on Historical Juvenile Chinook Salmon Monitoring Data

To assess potential effects of Project diversions on juvenile Chinook salmon as a result of flow-survival relationships, the flow thresholds from Michel et al. (2021) were applied to Sacramento River at Wilkins Slough. The flow thresholds and corresponding probability of survival (from Deer Creek confluence to Feather River confluence) were as follows[1]:

- 0–4,259 cubic feet per second (cfs): 0.030 (i.e., 3%)
- 4,259–10,712 cfs: 0.189 (i.e., ~19%)
- 10,712–22,872 cfs: 0.508 (i.e., ~51%)

This analysis covers water years 2009–2018, which are included in the Sites Reservoir Daily Divertible & Storable Flow Tool (version 20210309) Excel workbook. That spreadsheet-based tool is for illustrating potential Project diversions under various facility and regulatory

[1] Michel et al. (2021) found that probability of survival above 22,872 cfs decreased to 0.353 (i.e., ~35%) but noted that this may have represented the effect of river bank overtopping and fish entering Sutter Bypass, thereby potentially reducing survival or ability to detect the fish. Given the focus on riverine flow-survival in this effects analysis, the 22,872-cfs threshold was not included in this effects analysis.

assumptions (see Attachment 11P-1), consistent with the alternatives[2]. Facility and regulatory assumptions used in the workbook are provided in Tables 11P-1 and 11P-2. A notable assumption is a conservatively low level of Sites Reservoir storage at the start of each year's diversion period (i.e., 200,000 AF), which results in relatively high potential for diversions when other diversion criteria are met. Diversions included flow/fish pulse protection based on flow criteria, and there was no inclusion of diversion criteria based on fish monitoring. Both the assumption of conservatively low Sites Reservoir storage and the assumption of no diversion criteria based on fish monitoring would tend to result in estimates of flow-survival effects that are conservatively high relative to what would be expected to occur with implementation of actual operations of the Project.

Table 11P-1. Facility Assumptions for Daily Divertible & Storable Flow Tool (version 20210309).

Parameter	Assumption
Sites Storage Capacity	1.5 MAF
Initial Sites Storage	200 TAF
Sites Diversion Season	November–May
Red Bluff Diversion Capacity	2,100 cfs
Red Bluff Bypass Flow	3,250 cfs
TC Canal Minimum Pumping Level	125 cfs
Hamilton City Diversion Capacity	1,800 cfs
Hamilton City Bypass Flow	4,000 cfs
GCID Main Canal Minimum Pumping Level	100 cfs
GCID Main Canal Maintenance Window	January 25–February 7
Fremont Weir*	Fremont Weir Notch included

Notes: cfs = cubic feet per second; MAF = million acre-feet; TAF = thousand acre-feet.
*Facility not operated as part of Project.

Table 11P-2. Regulatory Assumptions for Daily Divertible & Storable Flow Tool (version 20210309).

Parameter	Assumption
Bend Bridge Pulse Protection Season	October–May
Bend Bridge Pulse Protection Initiation Criteria	3-day average Sacramento River must exceed 8,000 cfs; 3-day average tributary flow must exceed 2,500 cfs
Bend Bridge Pulse Protection Duration	7 days upon initiation

[2] Although Alternative 2 includes a 1.3-MAF reservoir compared to a 1.5-MAF reservoir under Alternatives 1 and 3, the assumption of initial annual Sites storage of 200 TAF during 2009–2018 did not result in any years exceeding 1.3 MAF in storage; therefore the analysis presented herein is representative of all the alternatives.

Parameter	Assumption
Bend Bridge Pulse Protection Resetting Criteria	After completion of pulse protection period, resetting criteria must be met for another pulse protection period to commence: 3-day Sacramento River flow must go below 7,500 cfs for 7 consecutive days; 3-day moving average tributary flow must go below 2,500 cfs for 7 consecutive days
Wilkins Slough Bypass Flow	8,000 cfs April–May; all other times, 5,000 cfs
Fremont Weir Notch Criteria	Prioritize the Fremont Weir Notch, Yolo Bypass preferred alternative, flow over weir within 10% when spill range between 600 cfs and 6,000 cfs; first 600 cfs of spill are protected within 1%
Flows into the Sutter Bypass System	None
Freeport Bypass Flow	None
Surplus Delta Outflow	7 days of flow availability in February–March is required before diversions can be made in those months
SWP Incidental Take Permit Delta Outflow	44,500 cfs April– May

Note: cfs = cubic feet per second; SWP = State Water Project.

The analysis estimated an annual mean probability of juvenile Chinook salmon survival in the Sacramento River from the Deer Creek confluence to the Feather River confluence, with annual mean survival being calculated from daily survival estimates. Michel et al. (2021) focused on the spring period (March 15–June 15), whereas for this analysis the period from January 1 to May 31 was used to capture the main period of Sites diversions, while reflecting annual input data commencing January 1 provided by Michel (pers. comm.). The analysis was run by adapting code provided by Michel (pers. comm.) to include the January 1–May 31 period, to replace Michel et al.'s (2021) with the flow scenarios described below, and to calculate additional summary quantiles as described below.[3] This code implements parametric bootstrapping, where the pertinent logit-transformed survival distribution from the Michel et al. (2021) Cormack-Jolly-Seber model (given flow levels at Wilkins Slough for that day) was resampled corresponding to the expanded daily total juvenile Chinook salmon catch at the RBDD rotary screw traps. The mean logit-scale survival was estimated across all days of the January 1–May 31 period, and then re-scaled (inverse-logit transform). For missing RBDD rotary screw trap daily catch values, catch was imputed using a linear interpolation of the time-series[4]. As an example, if the RBDD screw trap collected 5,000 juvenile Chinook salmon on a given day, the calculation produced 5,000 parametric bootstrapped estimates for survival on that day, based on the mean and standard

[3] Michel et al. (2021) applied this analytical framework to assess the potential effects of rearranging historical flows/reservoir releases in a pattern tied more directly to movements of fish, or augmenting historical flows with reservoir releases, in order to maximize juvenile Chinook salmon survival based on their flow-survival threshold relationships.

[4] The linear interpolation used by Michel et al. (2021) and employed for this effects analysis estimated the screw trap catch on a given missing sampling date as the predicted value based on a linear regression of the catch on the prior and following sampled days versus dates.

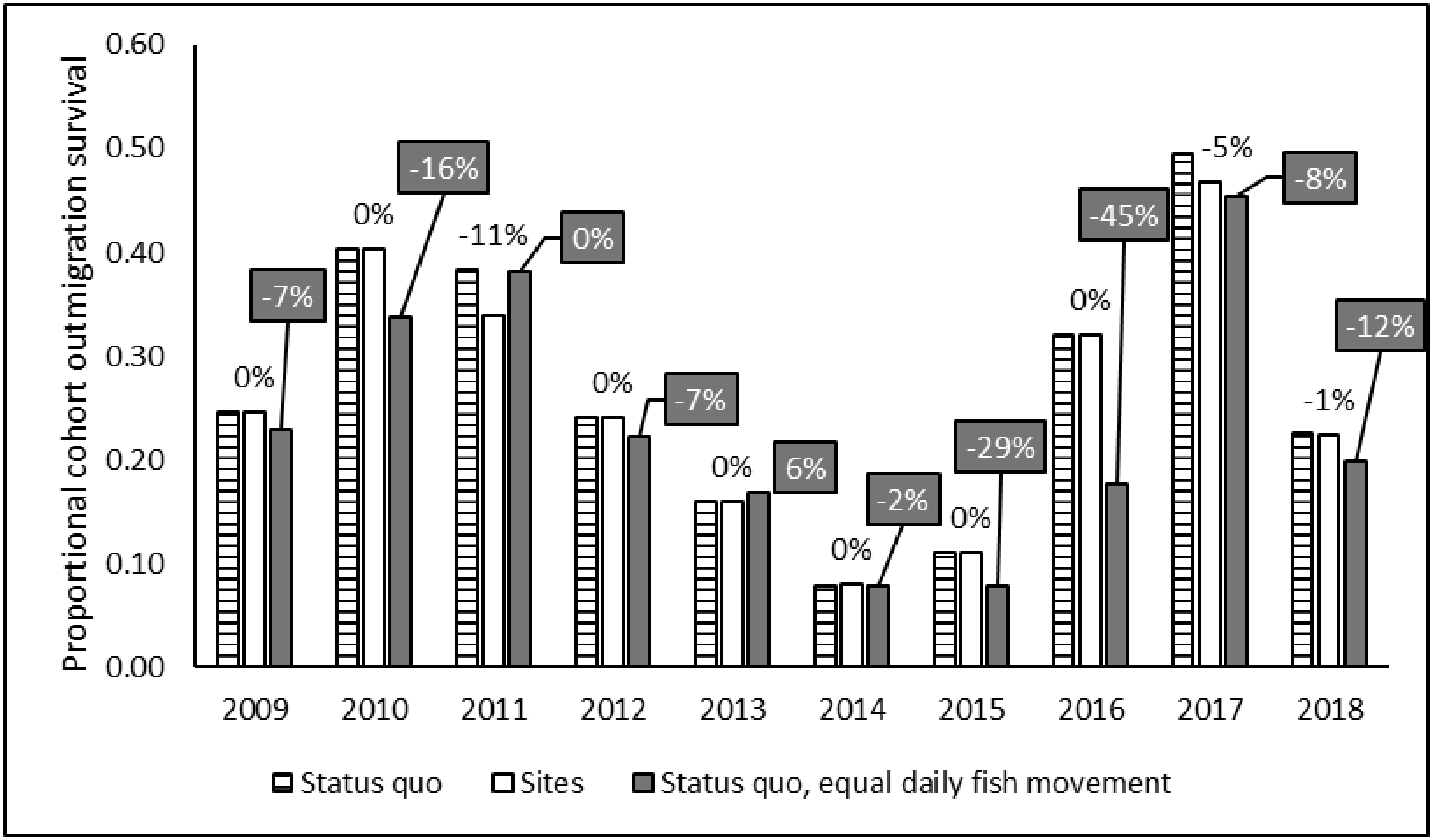
error for a given flow found by Michel et al. (2021). This process was repeated for all days in each year. All of the combined bootstrapped estimates were for each year were then used to calculate annual mean survival probability, and the 5th and 95th percentiles were also calculated to illustrate the variability in survival by year.

The Sites Reservoir Daily Divertible & Storable Flow Tool provided daily Sacramento River at Wilkins Slough flows for the flow-survival analysis, which include daily diversions by the Red Bluff and Hamilton City diversions based on the assumptions documented in Attachment 11P-1. In order to provide a representation of historical flow (Michel et al. 2021), the Red Bluff and Hamilton City diversions were added to the Sacramento River at Wilkins Slough flows. Thus, the two main scenarios included a representation of historical flows (termed “Status quo” for consistency with Michel et al. [2021]) and flows applying Sites diversion criteria. These were the two main scenarios that were compared to assess potential effects of Sites diversion criteria.

An additional scenario to provide context to the importance of incorporating pulsed movement of fish into diversion criteria (as the Project does) was undertaken by substituting a uniform daily number of fish[5] as opposed to the actual screw trap catch into the above flow-survival calculations using the status quo flows. This procedure gave what is referred to below as “Status quo, equal daily fish movement.”

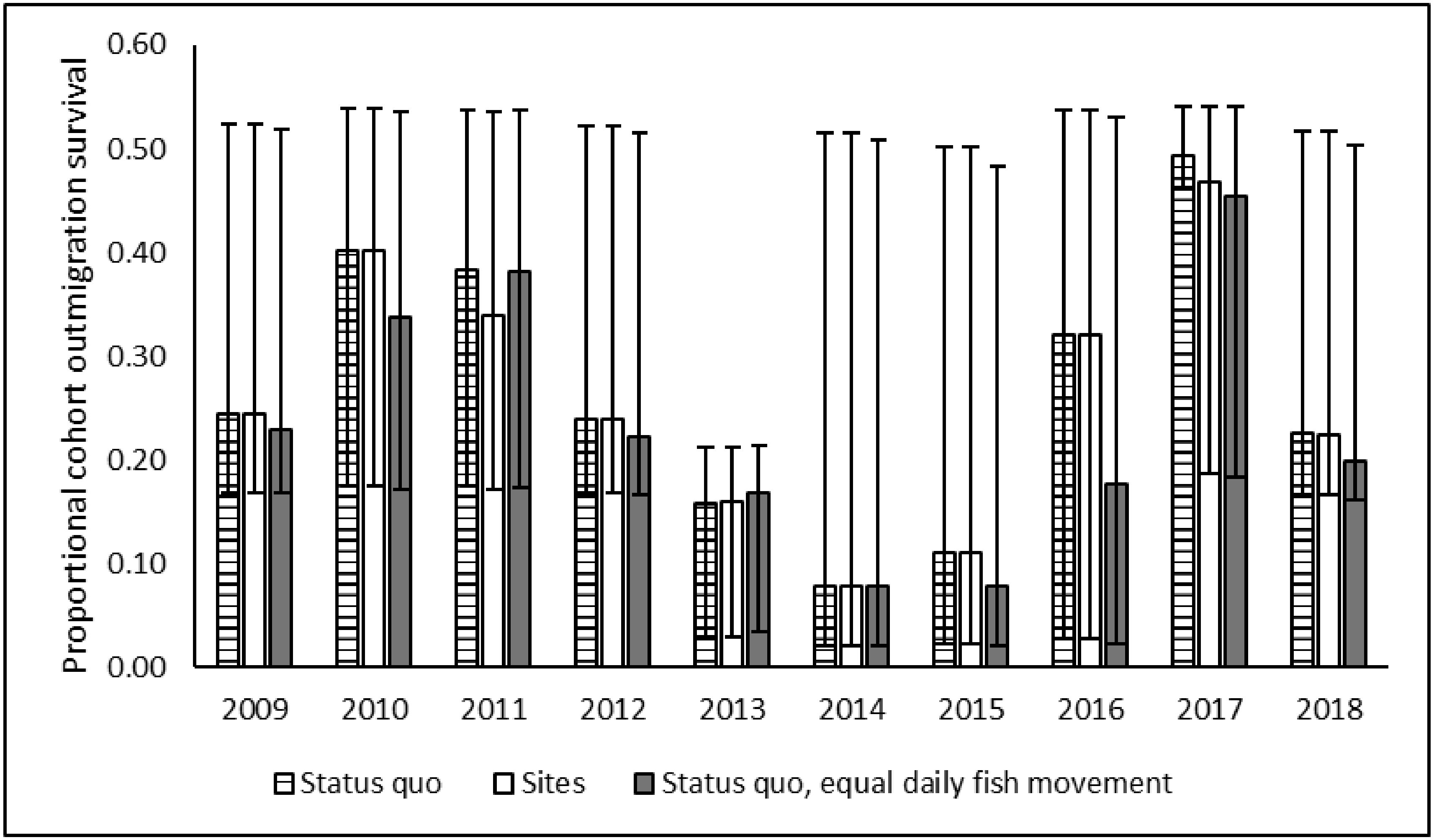
The analysis showed that estimated survival for the Status quo and Sites scenarios was largely similar (Figure 11P-1), with exception of 2 wet years (2011 and 2017). This illustrates that the Sites diversion criteria generally minimize diversions during the historical periods of fish movement as reflected in Red Bluff rotary screw trap data, and application of the flow-threshold criteria from Michel et al. (2021) suggests that flow-survival effects on juvenile Chinook salmon would be reduced by the diversion criteria. Incorporation of fish monitoring data (e.g., from screw traps at Red Bluff and Hamilton City) would allow adaptive management of monitoring data to minimize flow-survival effects. Additional context for the effectiveness of Sites diversion criteria representing pulses of flow and fish is provided by the results of the Status quo, equal daily fish movement scenario, for which there were several large negative differences relative to the Status quo scenario (Figure 11P-1). These patterns emphasize that fish are mostly moving during initial periods of higher flows, which correspond with periods during which the Sites diversion criteria are focused on limiting diversions to minimize potential flow-survival effects. The range from the 5th to 95th percentiles overlapped between all three scenarios in all years (Figure 11P-2).

[5] The daily number assumed in the analysis was 1,000, although any number with equal number per day would have served the same purpose.



Note: Percentages above bars indicate differences compared to Status quo flows for (1) Project (black text, no box) and (2) Status quo flows with equal daily fish movement (white text in grey box with callout). Mean represents mean of annual parametric bootstrapped values.

Figure 11P-1. Mean Annual Proportional Juvenile Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool.



Note: Mean represents mean of annual parametric bootstrapped values. Error bars represent 5th and 95th percentiles of annual parametric bootstrapped values.

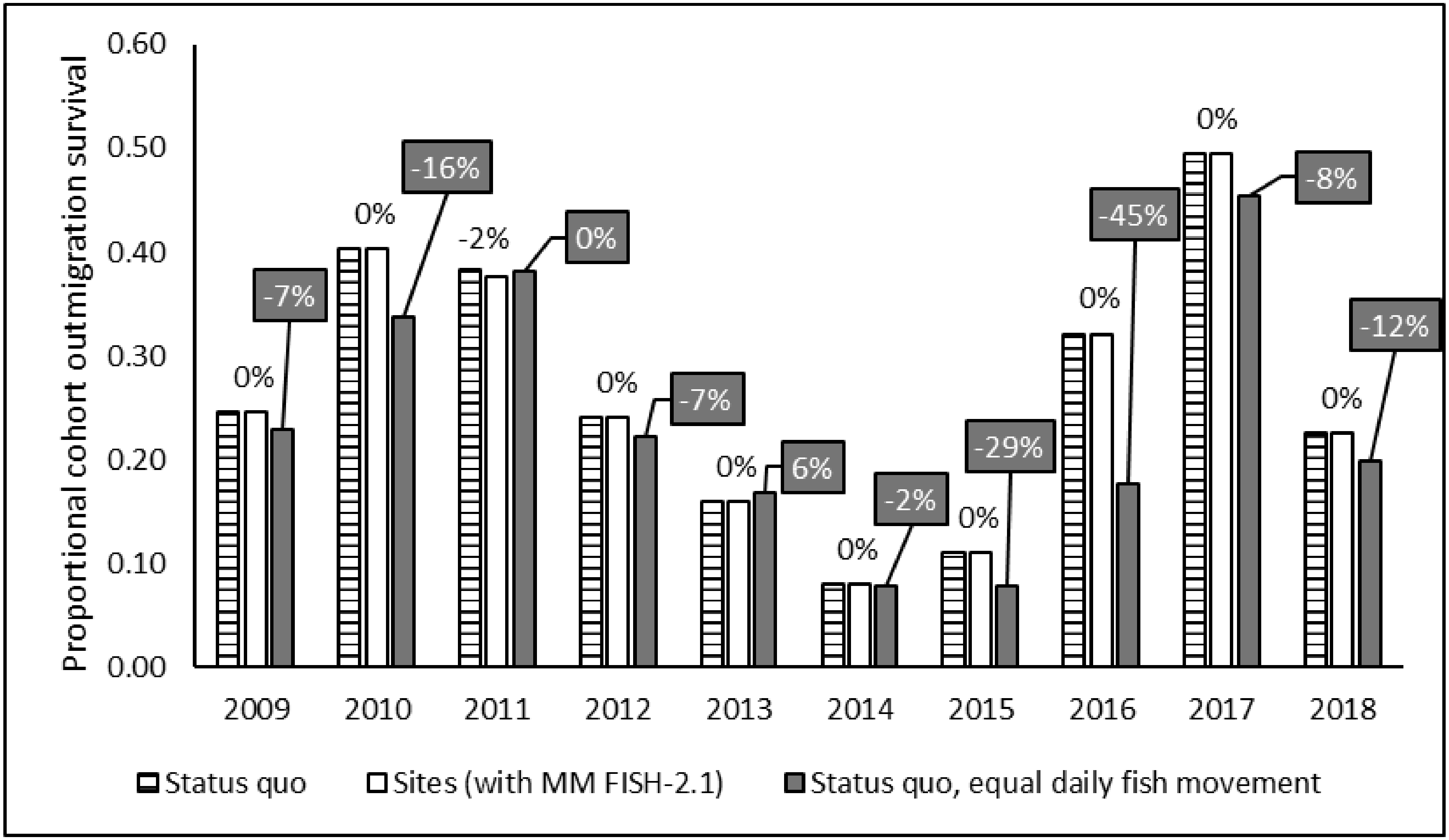
Figure 11P-2. Mean Annual Proportional Juvenile Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including 5th and 95th Percentiles.

11P.3 Flow Threshold Survival Analysis to Assess Potential Effects of Sites Reservoir Project Mitigation Measure FISH-2.1

To assess potential effects of Project Mitigation Measure FISH-2.1 *Wilkins Slough Flow Protection Criteria* on juvenile Chinook salmon as a result of flow-survival relationships, the above analysis using the flow thresholds from Michel et al. (2021) was repeated, except that the regulatory assumptions (Table 11P-2) were adapted to reflect the Mitigation Measure FISH-2.1 criteria as follows:

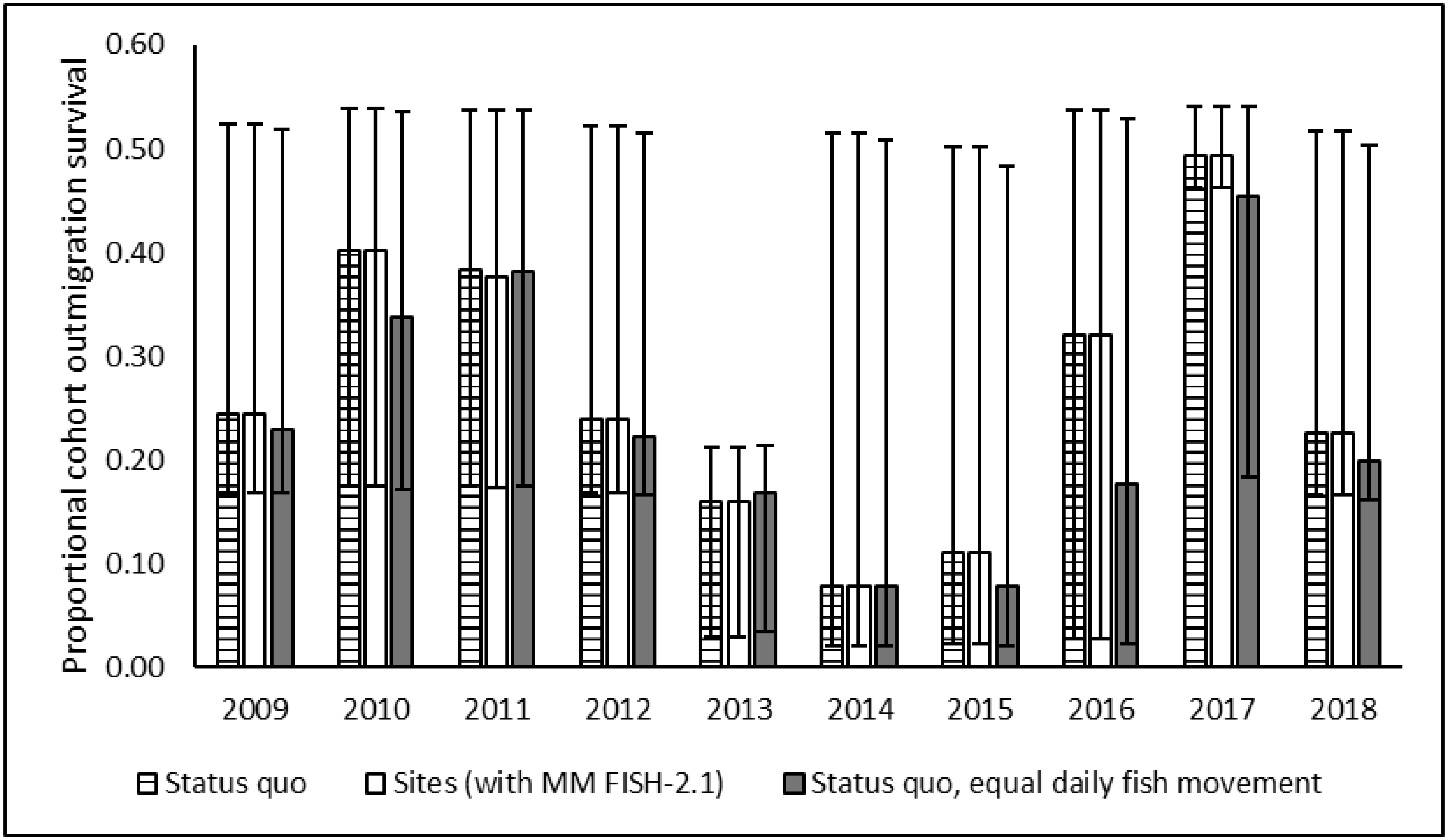
- Wilkins Slough Bypass Flow = 10,712 cfs March–May;
- No Fremont Weir Notch Criteria, March–May

The results of the analysis showed that the Sites Mitigation Measure FISH-2.1 criteria reduced the difference between the Status quo and Sites scenarios to 0–2% (Figures 11P-3 and 11P-4) relative to the difference between the Status quo and Sites scenarios without the mitigation measure criteria (Figures 11P-1 and 11P-2).



Note: Percentages above bars indicate differences compared to Status quo flows for (1) Project (black text, no box) and (2) Status quo flows with equal daily fish movement (white text in grey box with callout). Mean represents mean of annual parametric bootstrapped values.

Figure 11P-3. Mean Annual Proportional Juvenile Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including Mitigation Measure (MM) FISH-2.1.



Note: Mean represents mean of annual parametric bootstrapped values. Error bars represent 5th and 95th percentiles of annual parametric bootstrapped values.

Figure 11P-4. Mean Annual Proportional Juvenile Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including Mitigation Measure (MM) FISH-2.1 and 5th and 95th Percentiles.

11P.4 References Cited

Michel, Cyril. Assistant Project Scientist. University of California, Santa Cruz; affiliated with Southwest Fisheries Science Center – Fisheries Ecology Division, National Marine Fisheries Service, Santa Cruz, CA. February 23, 2021—Email providing R code and related input files to reproduce Michel et al. (2021) analysis to Marin Greenwood, Aquatic Ecologist, ICF.

Michel, C., J. Notch, F. Cordoleani, A. Ammann, and E. Danner. 2021. Nonlinear Survival of Imperiled Fish Informs Managed Flows in a Highly Modified River. *Ecosphere* 12(5). DOI: 10.1002/ecs2.3498.

Attachment 11P-1 Sites Reservoir Daily Divertible & Storable Flow Tool

Sites Reservoir Daily Divertible & Storable Flow Tool

1. Objective

The Daily Divertible & Storable Flow Tool (Divertible Flow Tool/Daily Modeling Tool) has been developed to evaluate and test diversion criteria in a real-time operations context. The Divertible Flow Tool determines daily divertible and storable flow for the Project during October 1, 2008–May 31, 2018, based on water availability and user-specified conveyance constraints and diversion criteria. The spreadsheet generates time series of diverted and stored flow at two intake locations: Red Bluff and Hamilton City. The Daily Divertible & Storable Flow Tool was originally developed when bypasses at the Delevan intake location were considered as part of the Project; this is no longer the case. Therefore, at the Delevan intake location diversions are defaulted to zero. Furthermore, the Divertible Flow Tool can be used to supplement CalSim II by:

- Representing the effects of operations criteria on a daily timestep
- Allowing for relative comparisons between monthly and daily approaches
- Providing results for more recent years (water years [WY] 2009–2018)

Several differences between CalSim II and the daily Divertible Flow Tool should be considered when both models are used in conjunction to evaluate Project operations. First, CalSim II yields results on a monthly timestep, and the Divertible Flow Tool operates on a daily timestep. Different approaches are sometimes necessary to simulate monthly conditions as opposed to daily conditions and implementing operation criteria on a daily timestep tends to be more conservative. Additionally, the two modeling tools include different simulation periods. CalSim II includes WY 1922–2003 while the Divertible Flow Tool includes WY 2009–2018. Table 1-1 shows the difference in proportion of water year types (WYTs) for each modeling tool. As shown, the Divertible Flow Tool includes a drier period than does CalSim II.

Table 1-1. Proportion of Water Year Types in CalSim II and the Daily Divertible Flow Tool

WYT	CalSim II (1922–2003)	Divertible Flow Tool (2009–2018)
Wet	32%	20%
Above Normal	15%	0%
Below Normal	17%	40%
Dry	22%	20%
Critically Dry	15%	20%

WYT = water year type.

Another key difference is that CalSim II provides a continuous simulation over an 82-year period, while the Divertible Flow Tool simulates each year as a separate event. Furthermore, the daily modeling tool only provides estimated fill volumes, whereas CalSim II also includes release operations.

With the above considerations in mind, the daily Divertible Flow Tool serves as a valuable resource that can supplement CalSim II by evaluating Project operations in real-time.

2. Available, Divertible, and Storable Flow

The Divertible Flow Tool uses outputs from the Flow Availability Tool, which estimates flow available for potential diversion to Sites Reservoir, subject to hydrology and regulations outside the scope of Project operations (i.e., Delta outflow standards, downstream water quality regulations, and other criteria from D-1641). The Divertible Flow Tool can then be used to evaluate various combinations of hydrology and Project-related operations criteria. Divertible and storable flow are defined as follows:

- Divertible Flow = Flow available for potential diversion to Sites Reservoir subject to flow requirements and conveyance constraints associated with Project.

- Storable Flow = “Divertible flow” subject to storable capacity.

3. User Specifications and Input Assumptions

Figure 3-1 shows a snapshot of the Divertible Flow Tool’s dashboard, where users can specify various regulations and constraints corresponding to Project operations. The table situated in the top-center displays monthly available, divertible, and storable flows associated with user specifications. The charts show daily hydrographs for the Sacramento River and the divertible and storable flow available at each intake.

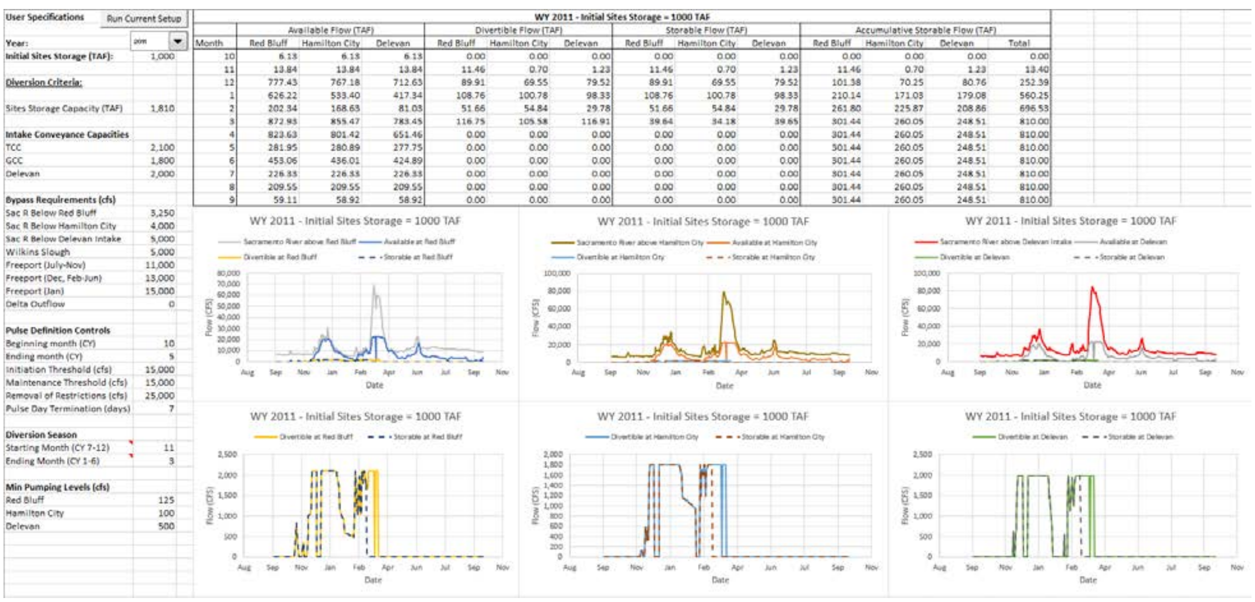


Figure 3-1. Snapshot of the Divertible Flow Tool’s User Dashboard.

The dashboard gives users the ability to specify the following:

- Year (hydrology) (WY 2009–2018)

- Initial Sites Reservoir Storage (end of September storage)

- Sites Reservoir Storage Capacity (TAF)

- Intake Conveyance Capacity (cubic feet per second [cfs])

    - Red Bluff (TCC)

    - Hamilton City (GCC)

- Delevan

- Bypass Flow Requirements (cfs)
  - Sacramento River at Red Bluff
  - Sacramento River at Hamilton City
  - Sacramento River at Delevan
  - Sacramento River at Wilkins Slough
  - Sacramento River at Freeport
- Pulse Flow Criteria at Bend Bridge
  - Initiation Flow Threshold
  - Maintenance Flow Threshold
  - Pulse Duration Limit
- Delta Outflow Criteria
- Fremont Weir Notch (on/off switch)
- Weir Spill Protection
  - Fremont Weir Spills
  - Aggregate Weir Spills to Sutter Bypass (from Moulton Weir, Colusa Weir, & Tisdale Weir)
- Minimum Pumping Level (cfs)
  - Red Bluff (TCC)
  - Hamilton City (GCC)
  - Delevan
- Low-Level Pumping (diversion rate at each intake when Sacramento River flow at a certain location is less than its associated bypass flow requirement) (cfs)
  - Wilkins Slough Bypass override
  - Freeport override
  - Bend Bridge pulse protection override
- Intake Prioritization
- Diversion Season (range of months)
- Intake Season (specify when diversions are permitted at each intake) (range of months)
- Surplus Outflow (February–March)

3.1 Year (Hydrology)

Users can toggle through 10 different WYs—2009 through 2018. However, WY 2018 only includes information up to May 31. Each year provides a different hydrologic condition. The water year hydrologic classifications associated with each year are provided in Table 3-1. Each year is associated with flow availabilities that were estimated in the Flow Availability Tool.

Table 3-1. Water Year Hydrologic Classification Index.

Water Year	Water Year Type
2009	D
2010	BN
2011	W
2012	BN
2013	D
2014	C
2015	C
2016	BN
2017	W
2018	BN

Source: California Data Exchange Center. 2019. T WRWSIHIST 2104121329/ Department of Water Resources, California Cooperative Snow Surveys. Chronological Reconstructed Sacramento and San Joaquin Valley, Water Year Hydrologic Classification Indices. Available: https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST.

BN = Below Normal; C = Critically Dry; D = Dry; W = Wet

3.2 Initial Sites Reservoir Storage (End of September)

Initial Sites Reservoir storage has potential to affect the quantity of flow that is stored in the reservoir. Through a range of initial Sites Reservoir storages, users can evaluate the duration for the reservoir to reach capacity, which occurs when storable flow no longer equals divertible flow. In drier years, storage capacity may never be reached even when initial storage is set relatively high. The default initial storage is 200 TAF.

3.3 Sites Reservoir Storage Capacity

The default Sites Reservoir storage capacity is 1.5 MAF. However, users can enter any desired value.

3.4 Intake Capacity

The default intake capacities of the TC Canal (Red Bluff intake), GCID Main Canal (Hamilton City intake) are 2,100 cfs and 1,800 cfs, respectively. However, users can enter any desired value.

3.5 Bypass Flow Requirements

A bypass flow requirement can be specified along the Sacramento River at five locations:

1. Red Bluff (default = 3,250 cfs)
2. Hamilton City (default = 4,000 cfs)
3. Delevan (default = none)
4. Wilkins Slough (default = 8,000 cfs in April–May)
5. Freeport (default = none)

Furthermore, users can specify a range of months at which the Wilkins Slough and Freeport bypass requirements are implemented (by entering the starting month in column C and entering the ending month in column D). Freeport includes four different cells at which bypass criteria can be entered. The first cell ("B22") dictates bypass criteria over a user-specified range of months. The next three cells ("B23:B25") dictate bypass criteria that persist under the primary Freeport bypass criteria for various times of the year.

3.6 Pulse Flow Criteria at Bend Bridge

The pulse flow criteria at Bend Bridge were developed to protect fish migration during naturally occurring, storm-induced, pulse flow events in the Sacramento River. Pulse flows are defined as extended peak river flows at Bend Bridge that originate from storm event tributary inflows downstream of Keswick Dam. A pulse is initiated once the 3-day running average flow at Bend Bridge exceeds the "Initiation Threshold." The pulse persists as long as the 3-day running average flow at Bend Bridge remains above the "Maintenance Threshold." If the 3-day running average flow at Bend Bridge exceeds the "Removal of Restrictions Threshold," then Sites Reservoir diversions are permitted if flow at Bend Bridge remains above the Maintenance Threshold. The "Reset Threshold" represents the value at which the 3-day moving average flow at Bend Bridge must not exceed for a given number of days before another pulse protected event can be triggered. The "Pulse Protection Duration" can be used to set the number of consecutive days that a pulse period can last before the protection criteria is removed. For example, if the Pulse Duration Limit is set to 7 days, then diversions to Sites Reservoir are permitted after flow at Bend Bridge exceeds the pulse flow threshold for over 7 consecutive days. The Bend Bridge pulse protection criteria can be further modified in the "BB_Pulse_Definitions" tab. The current set of criteria assumes the following:

1. Season:
    a. Pulse protection can be initiated in October through May
2. Initiation:
    a. 3-day moving average Sacramento River flow at Bend Bridge must exceed 8,000 cfs,
    b. And the 3-day moving average tributary flow upstream of Bend Bridge (Cow Creek, Cottonwood Creek, and Battle Creek) must exceed 2,500 cfs
3. Duration:
    a. Pulse protection lasts for 7 days upon initiation
4. Resetting condition:
    a. After completion of a pulse protection period, the following conditions must occur before another pulse event is triggered:

i. 3-day moving average of Bend Bridge flow was less than 7,500 cfs for 7 consecutive days,
ii. 3-day moving average tributary flow upstream of Bend Bridge (Cow Creek, Cottonwood Creek, and Battle Creek) was less than 2,500 cfs for 7 consecutive days

3.7 Delta Outflow Criteria

The Divertible Flow Tool includes a few options to constrain Sites Reservoir diversion based on Delta outflow requirements. "Delta Outflow (SWP ITP)" is intended to represent the 44,500 cfs flow requirement included in the 2020 SWP Incidental Take Permit. "Delta Outflow (Additional)" is intended for any supplemental Delta outflow constraints.

Users can also turn on or off NDOI criteria, which implement Delta outflow targets for a specified period (default of March 1 through May 31) based on WaterFix longfin smelt protection criteria (Incidental Take Permit No 2081-2016-055-03, WaterFix, California Department of Fish and Wildlife, page 186). Outflow targets are determined based on a table derived from a linear relationship between the 50% exceedance forecast for the current month's Eight River Index (8RI) and recent historic Delta outflow (1980–2016). These tables have been stored in the "Ref. Tables" tab. The NDOI criteria is set off by default.

3.8 Fremont Weir Notch Spill Protection

The Fremont Weir Notch and its associated flow protection criteria can be turned on or off in the Divertible Flow Tool. Spills over the Fremont Weir Notch are based on a rule curve used in CalSim II. Furthermore, the Sites Reservoir diversion criteria protects spills of 6,000 cfs from November 1 through March 15 and spills of 600 cfs from March 16 through April 30. Figure 3-2 and Figure 3-3 demonstrate the effect of the Fremont Weir Notch and its associated protection criteria on spills and diversions to Sites Reservoir in an example scenario for WY 2010. The notch protection criteria cause a reduction in diversions to Sites Reservoir, most notably in February when nearly all diversions are restricted because notch spills range from 0–6,000 cfs for most of the month.

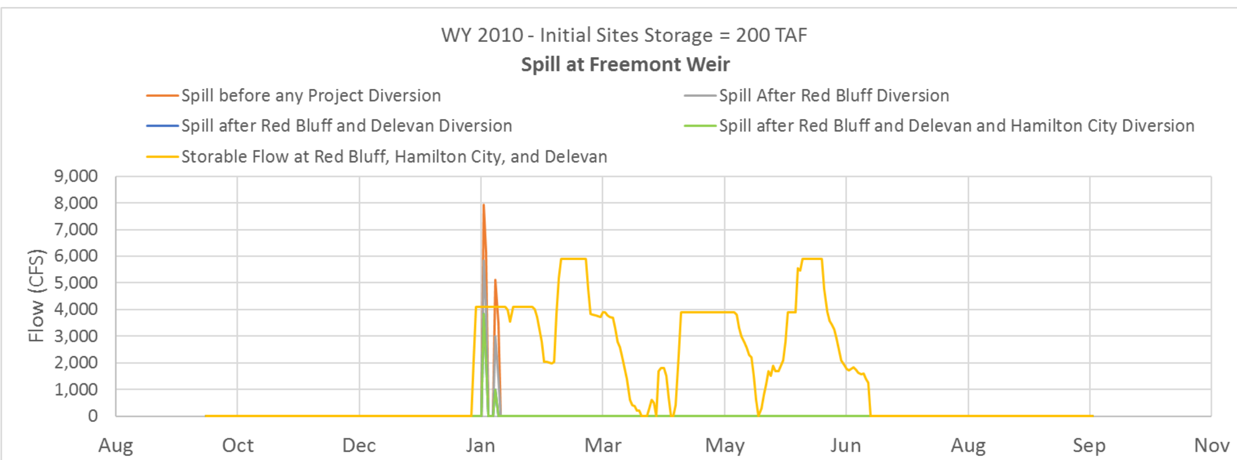


Figure 3-2. Spill at Fremont Weir vs. Storable Flow—Without the Fremont Weir Notch.

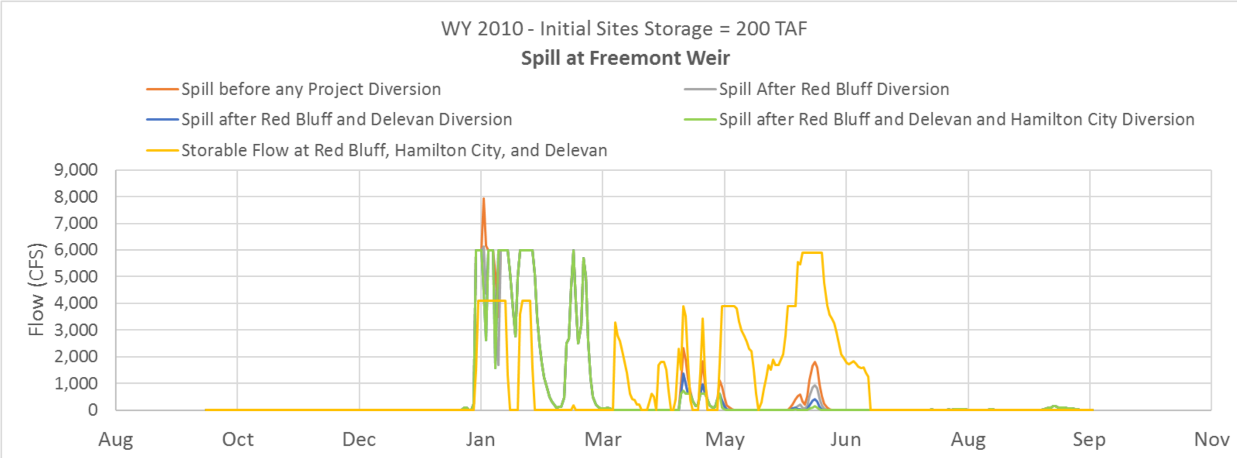


Figure 3-3. Spill at Fremont Weir vs. Storable Flow—With the Fremont Weir Notch (and Associated Protection Criteria).

In the daily modeling tool, users may specify buffer values for Fremont Weir Notch protection. Two buffer values may be specified: one for spills between 0 and 600 cfs (low-spill buffer) and one for spills between 600 and 6,000 cfs (high-spill buffer). The buffer values are entered as percentages of flow above certain thresholds that may be diverted to Sites Reservoir. For example, consider a case where the user enters a low-spill buffer of 1% and a high-spill buffer of 10%. The following would take effect:

- November 1–March 15
  - When spills range between 0 and 600 cfs, 1% of the flow above 600 cfs may be diverted
  - When spills range between 600 and 6,000 cfs, 10% of the flow above 6,000 cfs may be diverted
- March 16–April 30
  - When spills range between 0 and 600 cfs, 1% of the flow above 600 cfs may be diverted

3.9 Protection of Aggregate Weir Spills to the Sutter Bypass

The Divertible Flow Tool provides users the ability to implement protection of spills into the Sutter Bypass via Colusa Weir, Moulton Weir, and Tisdale Weir. Users can specify the upper bound of the total spill range that must be protected, a buffer on the specified spill range, and the percent of spill that can be diverted to Sites Reservoir in the specified spill range. Aggregate Sutter Bypass weir spill protection is set off by default.

3.10 Minimum Pumping Level

Each intake is assigned a minimum level of flow that can be diverted into Sites Reservoir. If flow availability is below an intake's minimum pumping level, then the intake will not be utilized. The smallest pumps at Red Bluff and Hamilton City have capacities of 125 cfs and 100 cfs, respectively.

3.11 Low-Level Pumping

Users can specify low-level pumping rates when Sacramento River flow at a certain location is less than its associated bypass flow requirement and above the user-specified "low level pumping initiation flow." For example, if the low-level pumping rate at Red Bluff is set to 300 cfs, the initiation flow rate at Wilkins Slough is 5,000 cfs, the bypass flow rate at Wilkins Slough is 10,000 cfs, and the actual flow rate at Wilkins Slough is 8,000 cfs, then the Red Bluff intake can divert up to 300 cfs from the river. Low-level pumping rates can be used to override three bypass flow criteria: Bend Bridge pulse protection, Wilkins Slough bypass flows, and Freeport bypass flows. Low-level pumping is set off by default.

3.12 Intake Prioritization

Intake prioritization is not modifiable in this version of the Divertible & Storable Flow Tool. The current setup prioritizes diversions at Red Bluff and then at Hamilton City (by default, Delevan is not used in version 2021-03-09).

3.13 Diversion Season

A diversion window can be defined to constrain the months in which the Divertible Flow Tool will attempt to allocate water into Sites Reservoir. Users can enter a starting month (from July through December) and ending month (from January through June). The default diversion season is November through May. Diversions to Sites Reservoir would not be expected in June through October, as this is the period that coincides with the season of Sites Reservoir deliveries.

3.14 Intake Season

The intake season refers to the months in which diversions are permitted at each intake. For example, if the Red Bluff starting month is set to 1 and its ending month is set to 6, then diversion through the Red Bluff intake can only be made from January through June. By default, the Red Bluff and Hamilton City intakes are only limited by the diversion season (default = November through May), while the intake season for Delevan is turned off.

3.15 Freeport Pulse and Post-Pulse Protective Criteria

Pulse and post-pulse criteria based on the 2016 CWF ITP[1] have been integrated into the daily Divertible Flow Tool. These criteria are set off by default. If specified by users, Sites Reservoir intakes can be operated within a range of pulse protection and post-pulse protection levels (1 through 3) in place when winter run Chinook salmon (CHNWR) and spring run Chinook salmon (CHNSR) migration is occurring. The post-pulse protection operations are defined in Sub Table A of the CWF ITP. In the daily modeling tool, two interpretations of the criteria for transition among pulse-protection levels are included:

- Fish presence (Knights Landing Catch Index (KLCI)) (CWF ITP)
- Sacramento River flow at Freemont (CalSim II based logic)

Table 3-2 identifies the assumptions implemented in the CWF ITP (criteria based on fish presence) and the assumptions implemented in CalSim II.

Table 3-2. Pulse and Post-Pulse Assumptions of CWF ITP vs. CalSim II.

CWF ITP	CalSim II
• **All pulses** of CHNWR and CHNSR shall be protected from October 1–June 30.	• **One or two pulses** shall be protected from October 1–June 30 (depending on whether a pulse ends before December 1).
• Beginning October 1, whenever the initial pulse begins, low-level pumping takes effect.	• Beginning October 1, whenever the initial Sacramento River pulse begins, low-level pumping takes effect.

[1] California Department of Fish and Wildlife. 2016. Incidental Take Permit No. 2081-2016-055-03. Construction and Operation of Dual Conveyance Facilities of the State Water Project.

CWF ITP	CalSim II
• A Sacramento River pulse is determined based on real-time monitoring of juvenile fish movement (see Condition of Approval 9.9.5.1). A fish pulse is defined as a **Knights Landing Catch Index (KLCI) ≥ 5** where KLCI = (# of CHNWR + # of CHNSR)/(Total Hours Fished/24). • Pulse protection operations shall be implemented within 24 hours of detection of a fish pulse.	• The initiation of the pulse is defined by the following criteria: (1) **Wilkins Slough flow changing by more than 45% within a 5-day period** and (2) **Wilkins Slough flow becomes greater than 12,000 cfs**.
• Pulse protection ends after **5 consecutive days of daily KLCI < 5**.	• The pulse protection and the low-level pumping continues until (1) **Wilkins Slough returns to pre-pulse flows** (flow on first day of the within-5-day increase), (2) **Wilkins Slough flows decrease for 5 consecutive days**, or (3) **Wilkins Slough flows are greater than 20,000 cfs for 10 consecutive days**.
• Number of allowable pulses is not specified; ASSUME ALL ELIGIBLE PULSES (KLCI ≥ 5) ARE PROTECTED.	• Number of allowable pulses is unlimited; ASSUME ALL ELIGIBLE PULSES ARE PROTECTED.
• Once the pulse protection ends, **post-pulse bypass flow operations may remain at Level 1 diversion depending on fish presence, abundance, and movement in the north Delta**; however, the exact levels will be determined through initial operating studies evaluating the level of protection provided at various levels of diversions.	• After a pulse has ended, the allowable diversion will go to post-pulse operations through June that can transition through three levels of protection.
• The criteria for transitioning between and among pulse-protection, **Level 1, Level 2, and/or Level 3 operations are based on real-time fish monitoring** and hydrologic/ behavioral cues upstream of and in the Delta that will be studied as part of the Project's Adaptive Management Program. Based on the outcome of the studies pursued under that program, additional information about appropriate triggers, off-ramps, and other RTO management of NDD intake operations may be integrated into the Test Period Operations Plan and the Full Project Operations Plan.	• After the initial pulse(s), **Level I post-pulse bypass rules are applied until 15 days of bypass flows above 20,000 cfs have accrued since the pulse ended**. Then **Level II post-pulse bypass rules are applied until 30 days of bypass flows above 20,000 cfs have accrued** since the pulse ended. Then Level III post-pulse bypass rules are applied.
• **The NDDTT shall develop criteria for transitioning between and among pulse protection, Levels 1, 2 and 3 based on best available science**. The NDDTT shall recommend transitional criteria to the TOT and IICG for consideration through the Adaptive Management Program, to ensure that the Project will achieve the objectives of Biological Criteria 1 and 2.	• Under the post-pulse operations allowable diversion will be greater of the low-level pumping or the diversion allowed by the following post-pulse bypass flow rules.

Note: cfs = cubic feet per second; CHNSR = spring run Chinook salmon; CHNWR = winter run Chinook salmon; IICG = Interagency Implementation and Coordination Group; NDD = North Delta Diversions; NDDTT = North Delta Diversions Technical Team; RTO = Real Time Operations; TOT = Technical Oversight Team.

Bold and highlighted text identifies differences between CWF ITP and CalSim II assumptions.

Taken from the "Pulse_Post-Pulse_Figs" tab of the daily modeling tool, Figure 3-4 and Figure 3-5 demonstrate the difference in pulse and post-pulse protection levels under the two interpretations. In Figure 3-4, the purple dots represent the KCLI for winter run and spring run Chinook salmon. Whenever the KCLI exceeds 4, pulse protection operations are initiated, as represented by the red shading. In the daily modeling tool, users may specify KCLI thresholds to determine pulse and post-pulse conditions. In this example, post-pulse Levels 1 and Level 2 have KCLI thresholds of 3 and 1, respectively. Thus, if the KCLI for a given day is between 3 and 5, Level 1 is implemented. If the KCLI is between 1 and 3, Level 2 is implemented. Finally, if the KCLI is 0, Level 3 operations take effect.

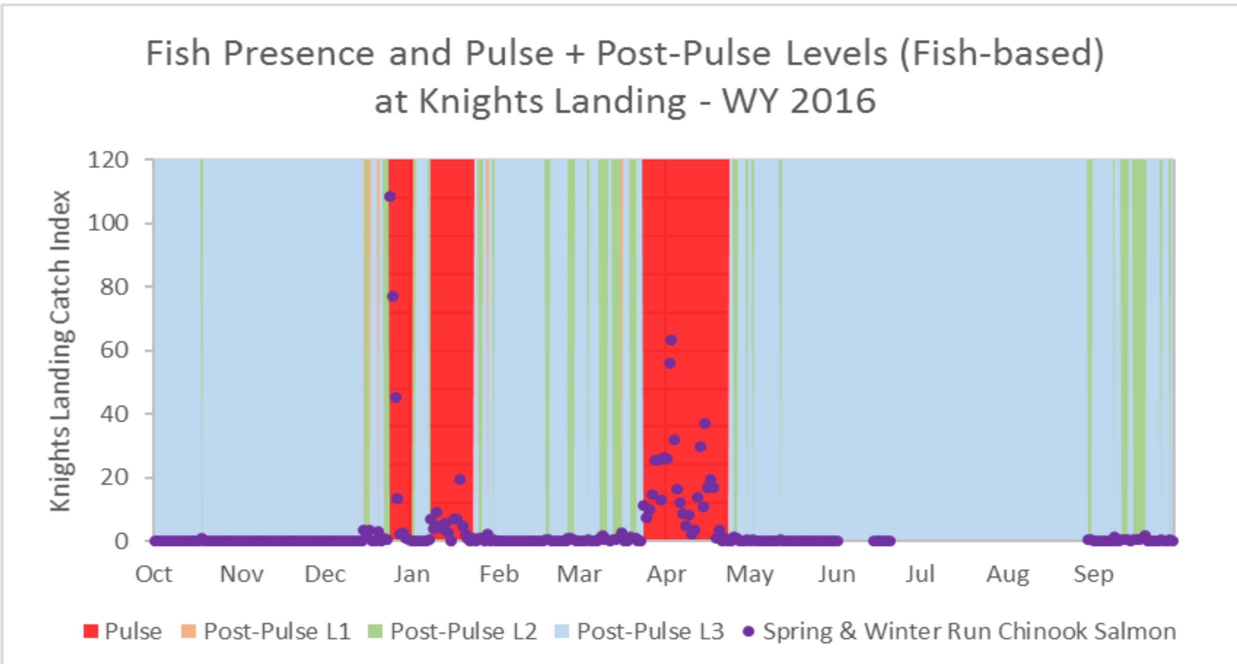


Figure 3-4. Fish-Based Pulse and Post-Pulse Protection Levels in WY 2016.

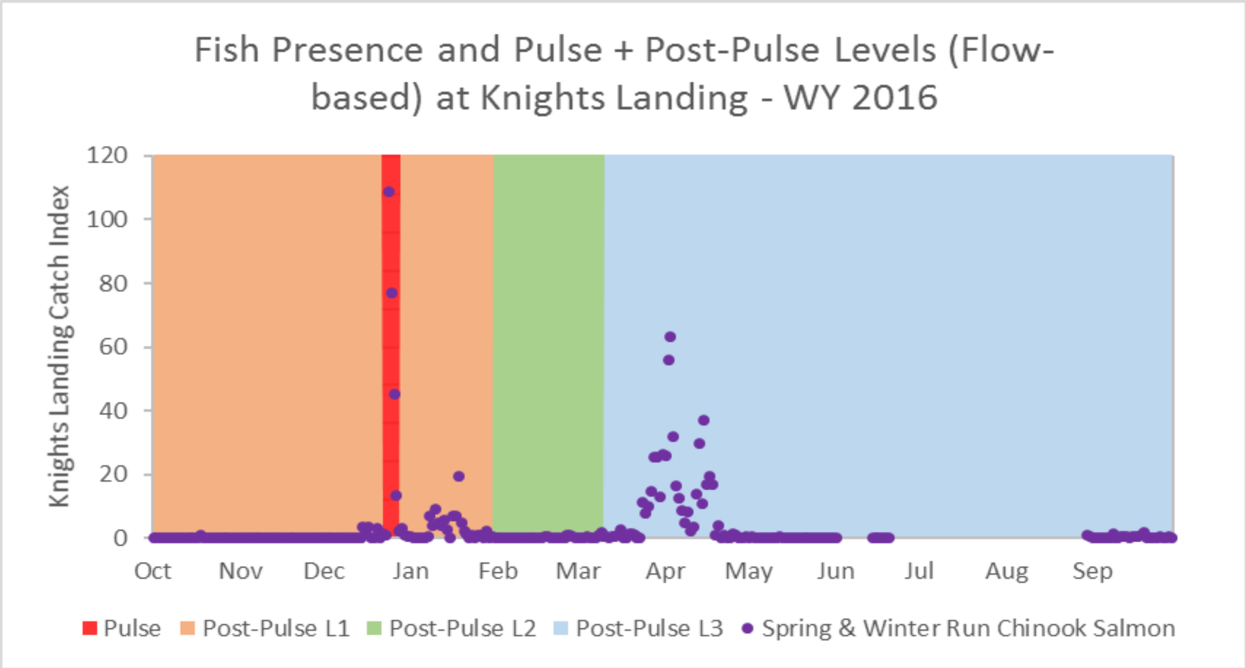


Figure 3-5. Flow-Based (CalSim II) Pulse and Post-Pulse Protection Levels in WY 2016.

In the daily modeling tool, users may specify starting and ending months of the pulse and post-pulse protection periods (i.e., the October through June period defined in the CWF ITP may be modified).

3.16 Surplus Outflow (February–March)

This criterion provides a margin of safety to prevent shifting the regulatory burden of X2 onto SWP or CVP operations. It is only applied to February and March. Diversions are only permitted after a specified number of days that flow is available in February through March (default = 7 days).

3.17 Additional Protective Criteria

The “Table1” and “ProtectiveCrit” tabs include additional protective criteria to limit Project diversions under user-specified flow conditions and time periods. The table in “Table1” can be used to implement a set of rules to limit diversion at each intake to a certain percentage of total Sacramento River flow, based on local conditions. Inputs to this table can be specified in the “Protective Criteria & Ramp Down Specs” section of the “User_Specifications” tab.

The tables in “ProtectiveCrit” perform similar functions; however, diversions are instead limited to a proportion of total intake conveyance capacity.

The additional protective criteria are set off by default and are only activated if Cell B91 in the “User_Specifications” tab is set to “Yes.”

4. Results

The Divertible Flow Tool evaluates various combinations of hydrographs, diversion regulations, and initial storage conditions. For example, users can manipulate pulse flow protection criteria, minimum pumping levels, or intake diversion seasons to generate different divertible and storable flow results under a range of hydrologic conditions. Consequently, the tool may be useful in evaluating the effects of varying operations criteria on diversions to Sites Reservoir.

4.1 Sacramento River Flow, Delta Outflow, and X2

Monthly available, divertible, and storable flow results for a given water year are displayed in the table and figures of the “User_Specifications” tab. The table also includes accumulated storage, representing the total amount of water diverted into Sites Reservoir throughout the year.

The “Hydrographs” tab includes figures that show Sacramento River flows before and after Project diversions at the following locations:

- Red Bluff
- Hamilton City
- Delevan
- Wilkins Slough
- Knights Landing
- Spill at Fremont Weir
- Freeport

The “Hydrographs” tab also includes the figures demonstrating the effect of Sites Reservoir diversions on Delta outflow and X2 position. Figure 4-1 through Figure 4-9 demonstrate example charts from the “Hydrographs” tab.

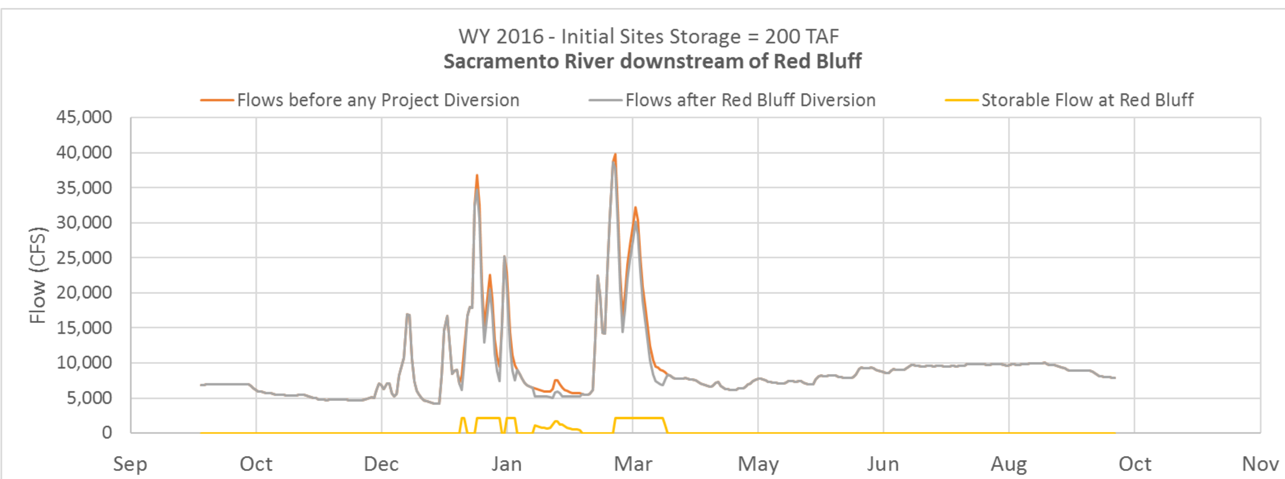


Figure 4-1. Sites Reservoir Storable Flow Effect on Sacramento River Flow at Red Bluff – WY 2016.

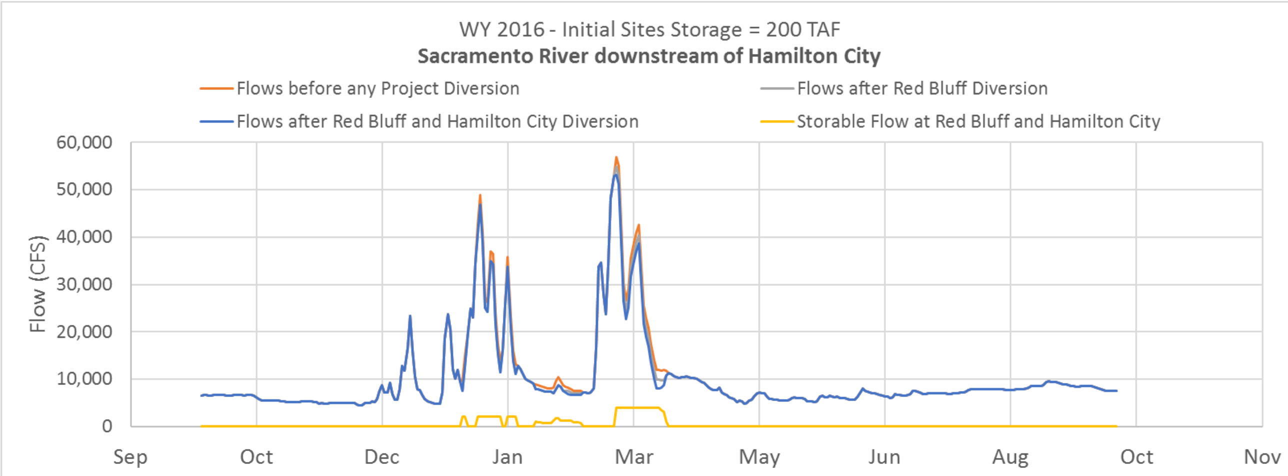


Figure 4-2. Sites Reservoir Storable Flow Effect on Sacramento River Flow at Hamilton City – WY 2016.

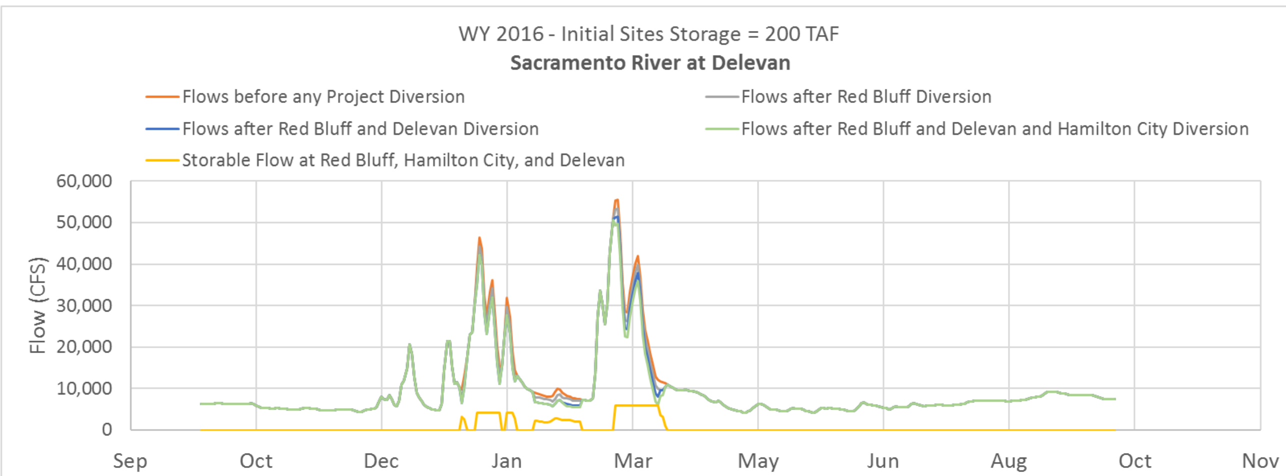


Figure 4-3. Sites Reservoir Storable Flow Effect on Sacramento River Flow at Delevan – WY 2016.

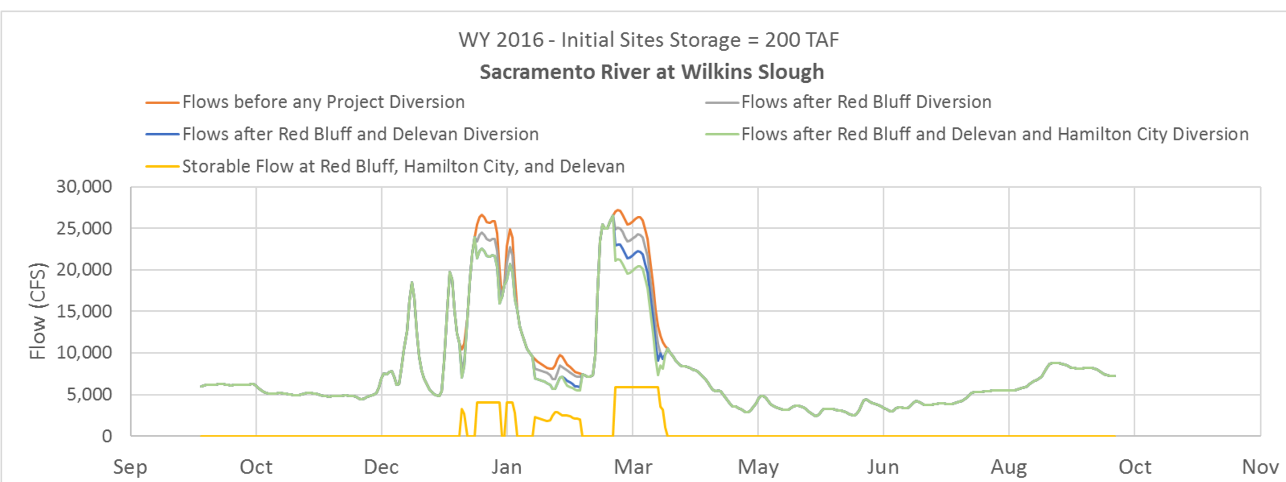


Figure 4-4. Sites Reservoir Storable Flow Effect on Sacramento River Flow at Wilkins Slough – WY 2016.

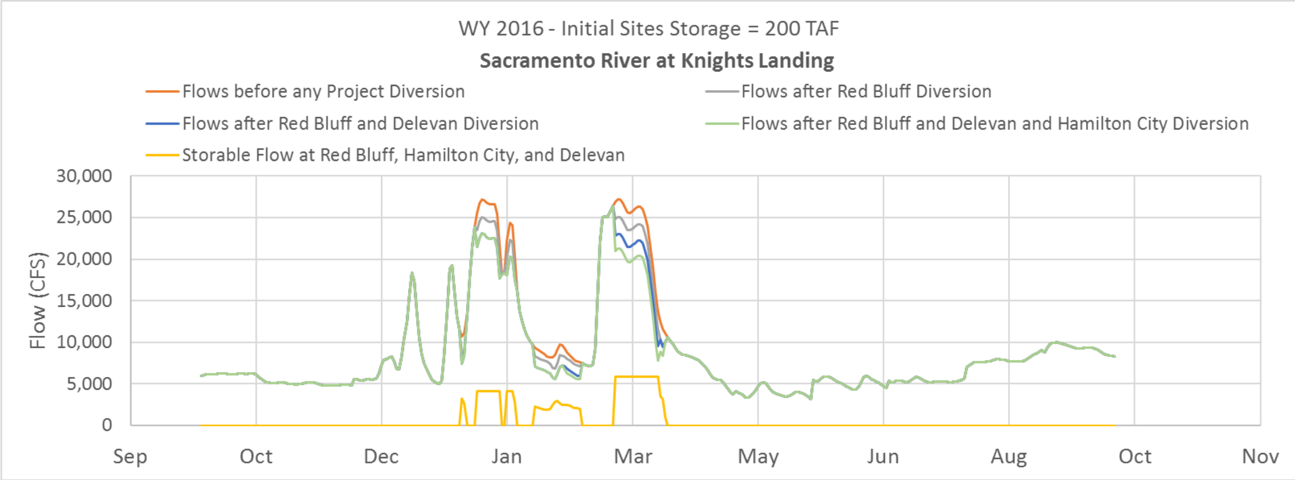


Figure 4-5. Sites Reservoir Storable Flow Effect on Sacramento River Flow at Knights Landing – WY 2016.

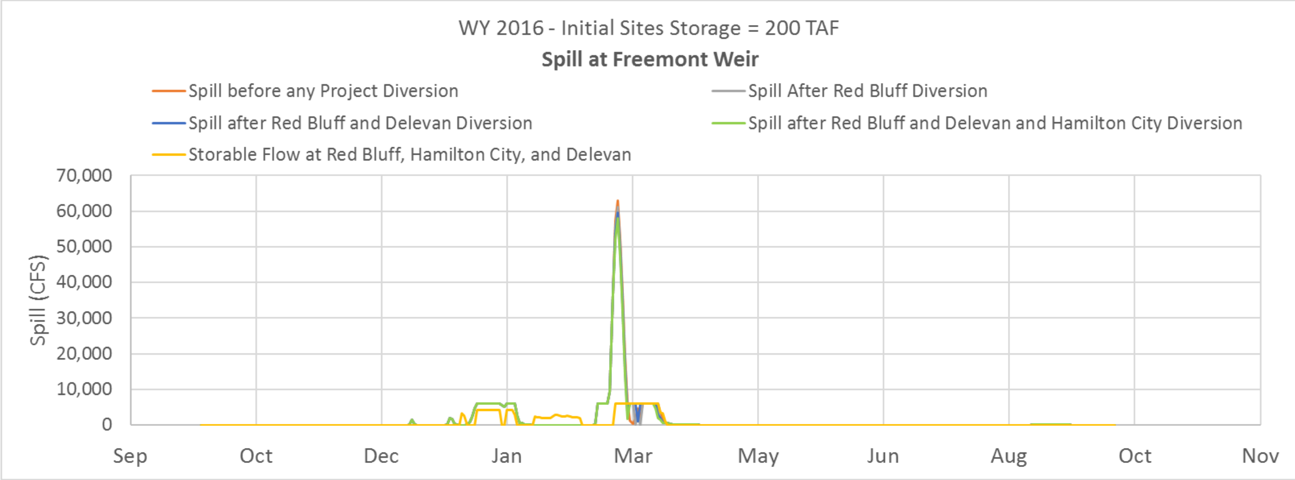


Figure 4-6. Sites Reservoir Storable Flow Effect on Fremont Weir Spills – WY 2016.

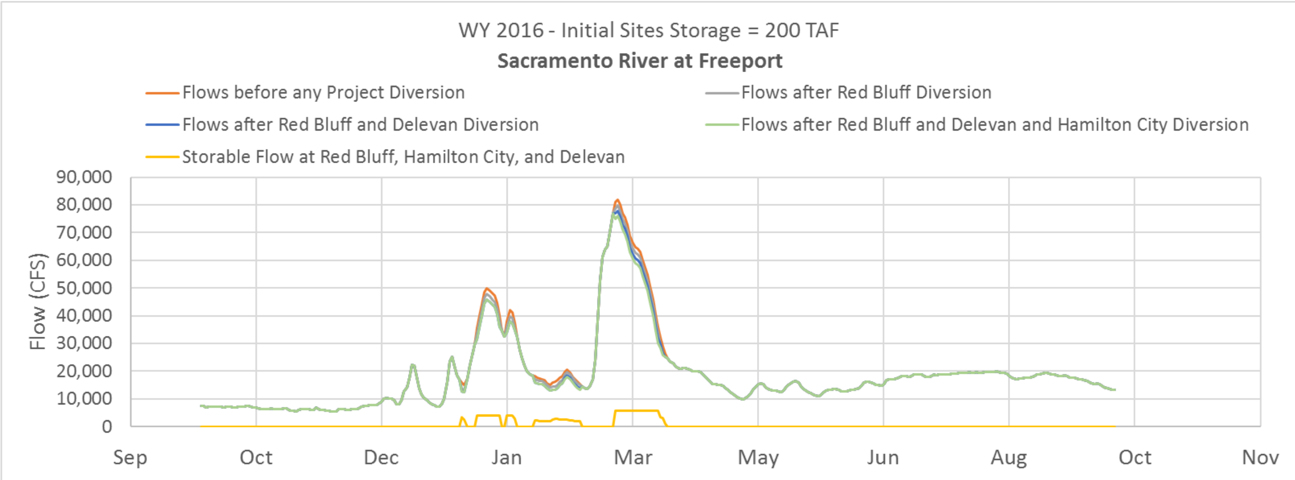


Figure 4-7. Sites Reservoir Storable Flow Effect on Sacramento River Flow at Freeport – WY 2016.

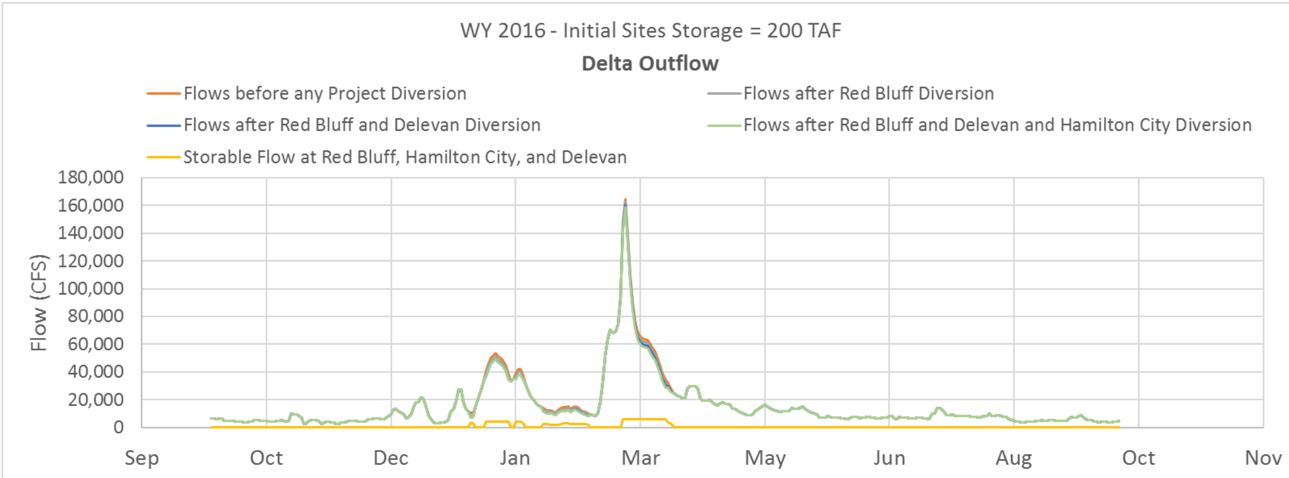


Figure 4-8. Sites Reservoir Storable Flow Effect on Delta Outflow – WY 2016.

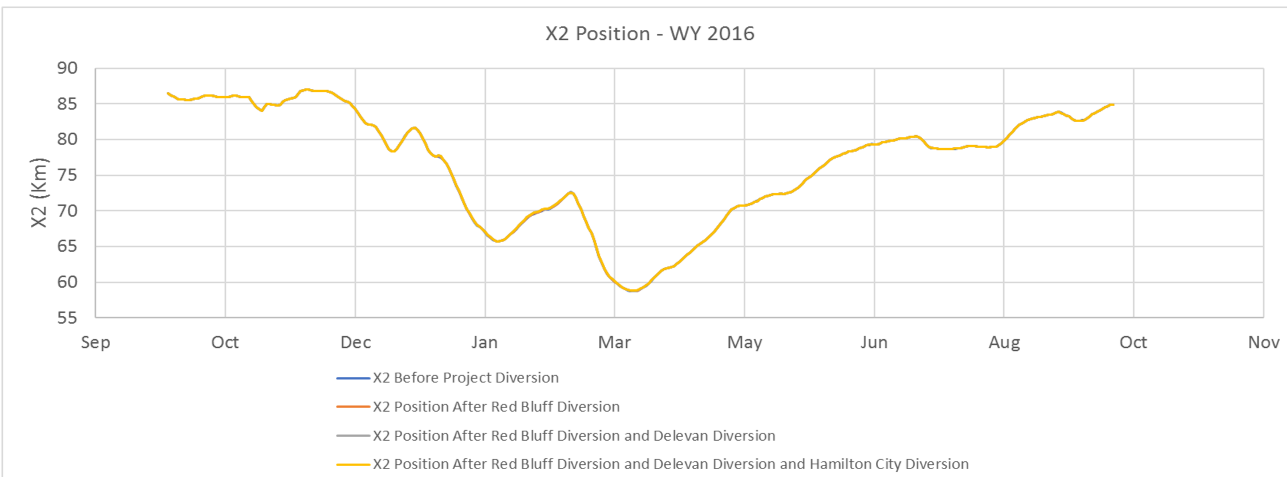


Figure 4-9. Sites Reservoir Storable Flow Effect on X2 – WY 2016.

4.2 Fish Presence

Sacramento River fish data has been collected and integrated into the Divertible Flow Tool at the following locations:

- **Red Bluff Dam** (October 1, 2008–May 31, 2018)
  - Source: Red Bluff Fish & Wildlife Office, USFWS (collated into a spreadsheet by LeAnne Rojas, 4/15/2019, using data from: http://www.cbr.washington.edu/sacramento/data/query_redbluff_daily.html)
- **Hamilton City** (March 2, 2013–May 31, 2018)
  - Source: GCID (collated into a spreadsheet by LeAnne Rojas on 4/16/2019, based on data provided by GCID (Josef Loera) via John Spranza (HDR) on 4/1/2019)
- **Tisdale** (July 7, 2010–May 31, 2018)

- Source: CDFW (collated into a spreadsheet by LeAnne Rojas on 4/18/2019, from data provided by Diane Coulon (DFW) on 4/11/2019)

- **Knights Landing** (October 1, 2008–May 31, 2018)
  - Source: CDFW (collated into a spreadsheet by LeAnne Rojas based on workbooks provided by Jason Julienne (DFW) on 4/24/2019)

The relationship between flows and fish presence can be evaluated in several tabs towards the back of the spreadsheet. The “Fish_Count_OneYr” tab include figures of Sacramento River flow and storable flow vs. fish count at the four locations listed above. Figure 4-10 demonstrates an example figure from this tab. At Red Bluff, the term “fish count” is defined as the estimated daily number of fish passage through the Sacramento River at Red Bluff. At Hamilton City, Tisdale, and Knights Landing, “fish count” is defined as the estimated daily number of fish caught in rotary screw traps at each location.

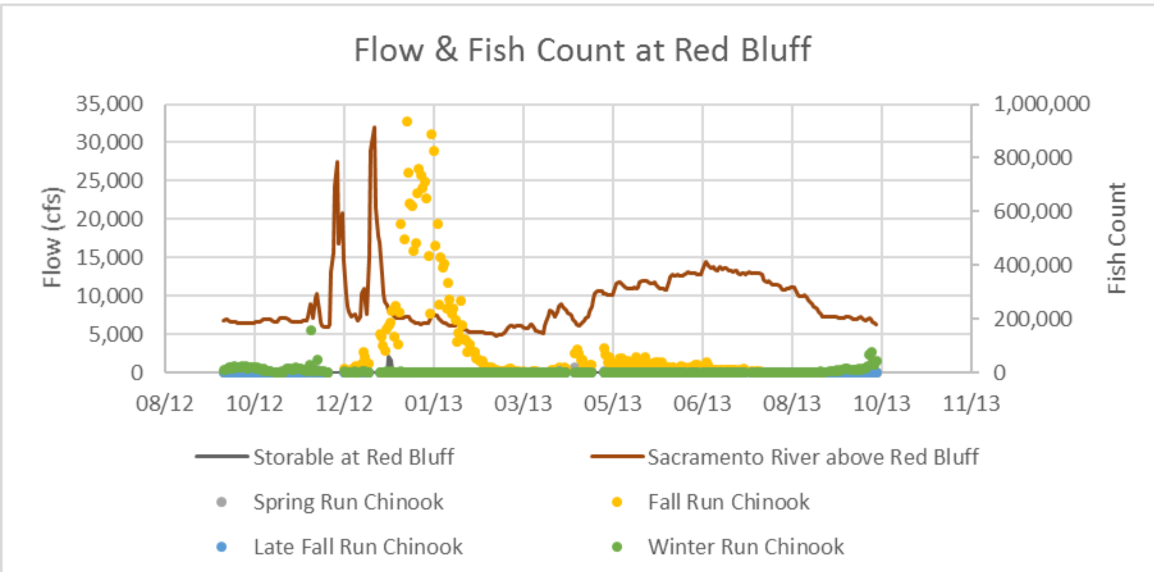


Figure 4-10. Sacramento River Flow vs. Fish Presence at Red Bluff in WY 2013.

4.3 Controlling Constraints

The “Controls” tab includes tables displaying the number of instances each constraint controls the quantity of storable flow in each month of the selected year. A controlling constraint is defined as the primary limiter of storable flow to Sites Reservoir. For example, if no flow is available for the Project because the river is in “Balanced Conditions,” then the controlling constraint is identified as “Balance” in the Divertible Flow Tool. A table of controls has been developed for each intake location (Red Bluff, Hamilton City, and Delevan) in the “Controls” tab. Additionally, daily time series of controlling constraints can be viewed in columns “BG:BH” of the “Divertible_Flow_OneYr” tab.

4.4 Annual Simulations

On the “User_Specification” tab, users can generate results for all 10 years (WY 2009–2018) by clicking on the “Run Current Setup” button at the top of the page. This button will simulate available flow, divertible flow, and storable flow for each year under current user specifications. Furthermore, the initial Sites Reservoir storage will be reset at the start of each year. Daily inputs and outputs will be copied into the “ScenID_Main” tab, monthly results are populated in the “Monthly_Report” tab, and annual inputs and outputs are populated in the “Ann_Fills” tab.

The Excel spreadsheet includes several macros to iterate through multiple combinations of years and input conditions (user-specified constraints). Before running one of these macros using the “Run Full Simulation Period” button on the “User_Specifications” tab, the macros should be updated to accommodate for whatever analysis is desired. The daily, monthly, and annual results will be copied into the “ScenID_Main” tab, “Monthly_Report” tab, and “Ann_fills” tab. Each 10-year period will be assigned a Scenario ID number corresponding to a particular set of inputs.