During low flows, when there is no backwater effect from the spill of Tisdale Weir, water levels along the western edge of the refuge are hydraulically controlled by Weir 1 and the adjacent embankment. Modifications to the weir may influence the timing and frequency of inundation to directly adjacent wetlands.

2.8 Juvenile Habitat in the Bypass

As an anthropogenic channel of lower Butte Creek, the WBC, and the adjacent Sutter Bypass floodway are inundated by flood flows. During flood season, lower Butte Creek in the southern portions of the Butte Basin and all through the upper Sutter Bypass can receive significant overflow from the Sacramento River. Additionally, even if flood flows are not entering the Butte Basin from the Sacramento River, spill from the Sacramento River over the Tisdale Weir and through the Tisdale Bypass can back up flows on the WBC and cause the WBC to inundate the Sutter Bypass floodplain. The Sutter Bypass, therefore, serves as a significant, though anthropogenic, floodplain of Butte Creek, which benefits from Sacramento River flood flows, increasing the frequency and duration of floodplain inundation.

Lower Butte Creek, including the Sutter Bypass, provides some of the last remaining wetland and ephemeral floodplain habitat in the Sacramento Valley. The low-lying topography of these areas results in frequent flooding and access to off-channel habitat for native juvenile spring-run Chinook salmon from Butte Creek—and because of the overflow of floodwater from the Sacramento River, other runs of salmon, too. During the biologically important times of the year for emigrating juvenile Chinook salmon (December through May), the WBC and the lower Sutter Bypass provide a significant amount of inundated floodplain habitat in most (9 out of 10) years.

Hydrologic conditions typifying the ephemerally inundated floodplain appear to facilitate a dramatically higher rate of food web production observed in the floodplain and suggest that hydrologic patterns associated with seasonal flooding facilitate river food webs to access floodplain carbon sources that contribute to highly productive heterotrophic energy pathways important to the production of fisheries resources (Jeffres et al., 2020). The high inundation frequency in the Sutter Bypass could be a contributing factor explaining the relative success of the Butte Creek spring-run Chinook salmon while other populations of spring-run Chinook salmon around the state are endangered or extirpated (Cordoleani et al., 2019).

That stated, the conditions in the Sutter Bypass are not the same as the large, natural Sutter Basin through which the anthropogenic bypasses were constructed. Flows in lower Butte Creek and the WBC can get very low or cease to exist during the warmer late spring/summer irrigation season. Water temperature during the summer months is often above the limits for juvenile salmonids, and the WBC may not meet the needs of juvenile spring-run Chinook salmon. During the winter juvenile outmigration season, flood flows routed from the Sacramento River into the Sutter Bypass and Tisdale Bypass may produce conditions (relatively high velocities and lower residence times) that are probably not the same as that of the large, natural flood basin (Sutter Basin) that was here before the time of bypass construction (Cordoleani et al., 2019).

For its part, Weir 1 does not significantly drive floodplain inundation upstream of the weir. Weir 1 increases depth in the WBC during lower flow conditions, but when input hydrology upstream is so great that the capacity of the WCB is exceeded, flows spill onto the floodplain with or without Weir 1. Roughly speaking, the range of hydraulic influence that Weir 1 has on flows that may be relevant for juvenile floodplain rearing is from approximately 400 cfs to 1,000 cfs. It's important to note that during the winter rearing months, flows in the WBC are frequently higher than this level, and/or when they fluctuate between 400 cfs and 1,000 cfs, they pass through this flow range relatively quickly. In other words, Weir 1 is not presently a strong driver in the creation of floodplain inundation in this section of the Sutter Bypass.

CHAPTER 3
Alternatives Formulation and Analysis

3.1 Initial Array of Alternatives

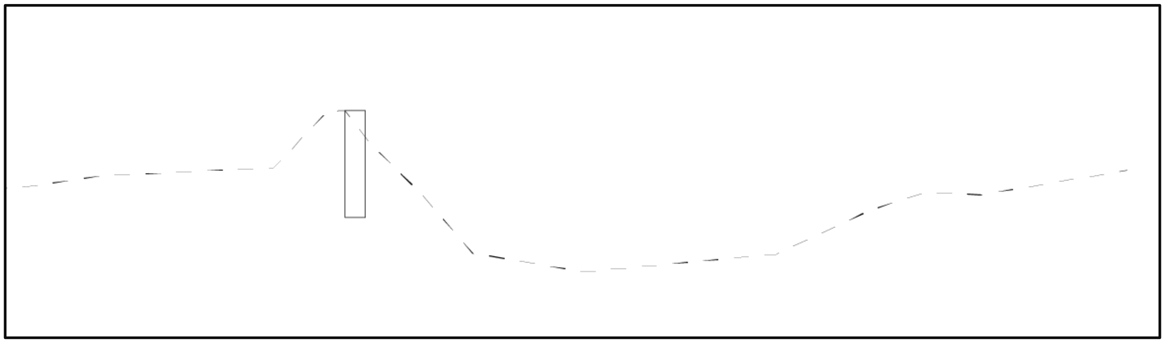
The initial alternatives for the project were described in the NOFO. ESA offered expert opinions on the conceptual design of alternatives and incorporated feedback from the TAC to revise the alternative descriptions as shown in **Table 3**.

TABLE 3
DESCRIPTION OF ALTERNATIVES

Alternative	Title	Description
0	No Action Alternative (NAA)	Abandon weir and fish ladder structures in place allow for and accept the evolution of channel and coinciding geomorphic conditions.
A	Remove Weir	Completely remove weir and fish ladder structures; regrade channel and banks to conform to existing conditions; limited placement of fill to tie disturbed areas of channel profile together between downstream and upstream work limits; allow for and accept the evolution of channel and coinciding geomorphic conditions.
B	Remove Weir with Roughened Channel	Completely remove weir and fish ladder structures; grade channel and banks to prepare the site for new channel structure; construct new roughened channel structure to connect downstream and upstream channel segments. Assume the overall elevation drop exceeds 5 feet with the integration of pools. This alternative assumes the roughened channel extends up and downstream of the existing weir location, spanning approximately 400 linear feet based on a 1% slope.
C	Modify Weir with Rock Ramp	Partial removal of weir and fish ladder structures (existing crest elevation maintained); construct passable rock ramp extending downstream of remaining weir structures and tie into downstream channel invert; extend rock ramp laterally to stabilize headcut. Assume the overall drop from the weir structure to the channel tie-in is less than 5 feet. This alternative assumes that the rock ramp extends approximately 200 linear feet downstream of the weir based on a 2% slope.
D	Operable Weir and Fish Ladder	Construction of an operable weir and fish ladder (an Obermeyer Weir and pool-chute fish ladder was recommended). Potential to manage water surface elevations at and above the existing levels. Options to pass fish unimpeded during higher flows (gate fully open) and increase the pool elevation by closing the gate (and pass fish via the ladder) during lower flows to eliminate potential impacts to upstream wetlands, water supply, and drainage operations.

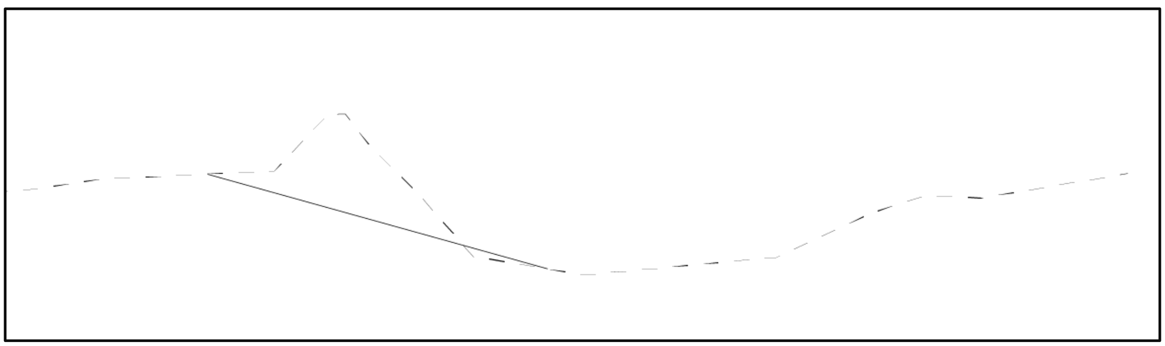
Preliminary engineering drawings of each alternative were developed using AutoCAD Civil 3D 2023. Copies of those drawings can be found in **Appendix C**. A summary of the expected functionality of the alternative and associated diagrammatic longitudinal cross-section, emphasizing upstream water surface elevations and fish passage, follows.

3.1.1 No Action Alternative



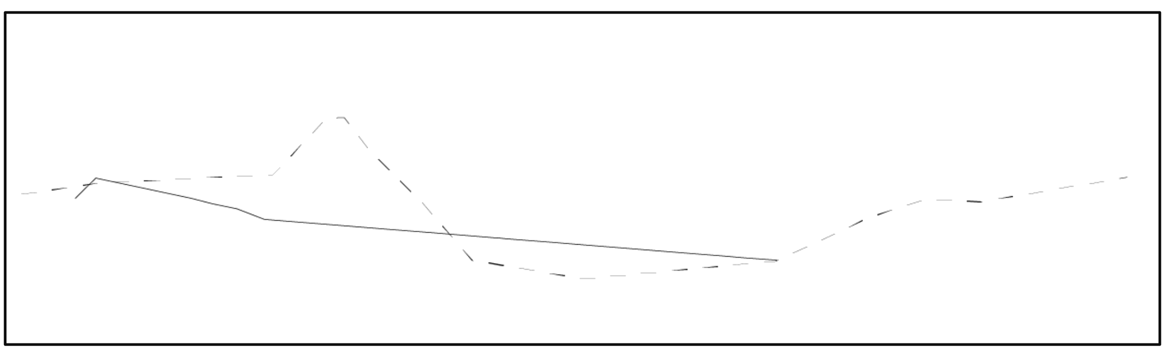
The no-action alternative leaves the weir and fish ladder in place. The headcut is expected to continue to evolve. In the past, sandbags have been deployed at the head cut to keep the fish ladder passable at low flows. Stranding and delay are expected to remain a persistent issue in low-flow periods.

3.1.2 Alternative A



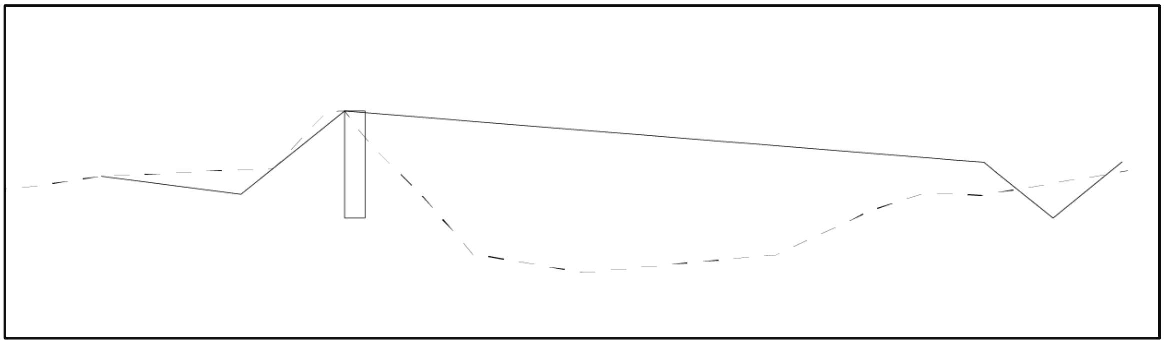
Weir and head cut removal with limited regrading of the channel. Upstream water surface elevations will be reduced. It is expected that upstream adult passage will be significantly improved. There is concern around channel stability given the change in bed slope between upstream and downstream reaches (0.0002 feet/feet vs. 0.0006 feet/feet, respectively).

3.1.3 Alternative B



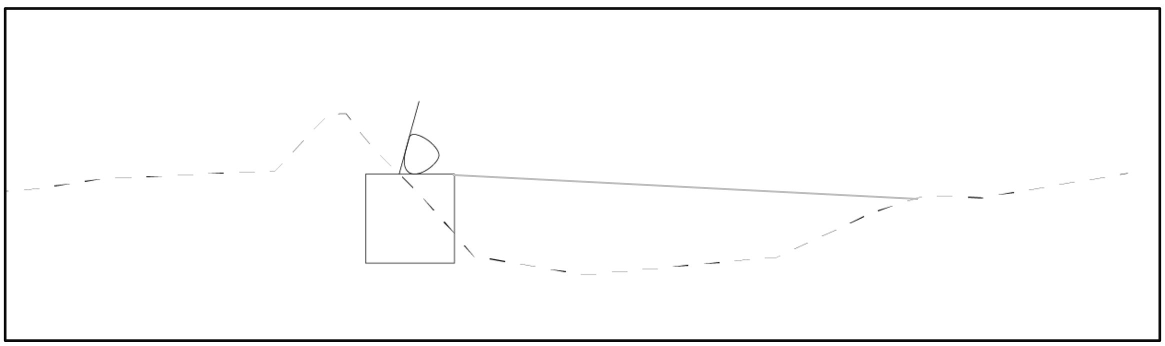
Weir removal and replacement with a roughened channel is expected to address the migration of the existing headcut. Upstream water surface elevations will be reduced. It is expected that upstream adult passage will be improved.

3.1.4 Alternative C



Partial weir degrade with a rock ramp transition from the weir crest to the downstream channel bed. Upstream water surface elevations will be maintained relative to existing conditions. It is expected that upstream adult passage will be improved.

3.1.5 Alternative D



Weir removal and replacement with an operable weir and fish ladder. Alternative D incorporates a concrete sill and an adjustable crest weir system for control of the upstream water level and resulting bifurcation of conveyance between the main channel and proposed fish ladder. This concept configuration also includes an optional split-level sluiceway, and a technical fish ladder to provide fish passage for the range of salmonids anticipated to occur at the project location. An engineering streambed will gradually transition the slope from the weir to the downstream channel bed. Depending on the final design and operations, upstream water surface elevations could be elevated relative to existing conditions. It is expected that upstream adult passage will be improved, but active management will be required.

3.2 Analytical Approach and Tools

3.2.1 Hydrologic Analysis

As noted in Section 2.3, gage data is limited within the WBC. In lieu of real-time gaged data, modeled data from the Tisdale Bypass Fish Passage Improvement Project was assessed to estimate dry and critical water year hydrology within the WBC. The Tisdale Bypass Fish Passage Improvement Project used a TUFLOW hydrodynamic model (TUFLOW model) to simulate conditions within the Sutter Bypass and adjacent canals for a period of 22 years (1997 – 2018).

The modeling results assessment was focused on low flow conditions because fish passage is not expected to be impacted by Weir 1 during high flows when the Sutter Bypass is inundated.

Ultimately, WY 2014 TUFLOW model results were selected as the hydrology within the system is representative of a "worst-case" scenario for fish passage (i.e., limited high flow events and Sutter Bypass inundation). Low, median, and high passage flows (95-, 50-, and 5-percent exceedances, respectively) were then calculated from the TUFLOW modeled data within the WBC for WY 2014 (**Table 4**). Further details of the hydrologic analysis can be found in Appendix A.

TABLE 4
FISH PASSAGE FLOWS

Flow (cfs) Spring-Run Chinook Salmon Season	Description
5	Minimum flow selected by the Technical Advisory Committee
356	Low passage flow (90% exceedance for spring-run Chinook salmon)
380	Median passage flow (50% exceedance for spring-run Chinook salmon)
953	High passage flow (5% exceedance for spring-run Chinook salmon)[1]

1 The recent publication, NOAA Fisheries Pre-Design Guidelines for California Fish Passage Projects, suggests using a 1% exceedance value for the high flow design discharge (NMFS 2023) instead of the 5% exceedance value suggested in prior publications (NMFS 2011). The high flow design discharge can be updated in future phases of the work to use the 1% exceedance flow. The 1% exceedance flow for the WBC based on TUFLOW model results for WY 2014 would be approximately 1,100 cfs.

Additionally, a stair-step, or tiered, hydrograph was utilized to evaluate wetland inundation under existing and proposed conditions. The hydrograph ranges from 550 to 1,100 cfs and is tiered by 50 cfs in between. The stair-step hydrograph was used within the 2D HECRAS model (details below in section 3.2.3 and Appendix A) to estimate the flow in which adjacent wetlands are inundated under each scenario.

3.2.2 Supplemental Field Data

A variety of new data sources were required to set up a more detailed hydraulic model of the WBC relative to the model used for the Tisdale Bypass Fish Passage Improvement Project. Key data gaps relative to the project objectives included more recent bathymetry within the WBC to evaluate 2D hydrodynamics, invert elevations of breached berms between the WBC channel and SNWR wetlands to evaluate lateral connectivity of surface water between the two waterbodies, and sediment data to support channel stability analysis for weir removal alternatives.

As detailed in Appendix A, additional bathymetry data was collected in May of 2023 using RTK-GPS and echosounder survey units from a few hundred feet upstream of Guisti Weir to the confluence of WBC with the Tisdale Bypass. Water surface elevations were also collected within the WBC and the toe drain located on the west side of the western levee of the Sutter Bypass. The bathymetry data was merged with other survey data from 2020 and LiDAR data from 2021 to develop a high-resolution existing conditions terrain model.

Wetland spill inverts and channel bed sediments were collected in August of 2023 between Hughes Rd and Weir 1. A sampling of inverts was sufficient to understand the variability of wetland activation through inundation along the WBC. Sediment samples were collected via canoe using a Petite Ponar sampler, which uses a spring-loaded, mechanical jaw that snaps shut, capturing loose sediments, once it is dropped onto the channel bed. Sampling in the WBC was complicated by the presence of consolidated "hardpan" sediments, but the field team was able to collect more recent deposits on top of the hardpan.

3.2.3 Hydraulic Analysis

The HEC-RAS modeling platform (version 6.4.1) was used to develop a two-dimensional (2D) quasi-steady hydrodynamic model. The HEC-RAS model was developed to analyze the hydraulics of the WBC under existing and alternative scenarios and evaluate each alternative's ability to provide fish passage at the Weir 1 location. In addition, modeled Water Surface Elevation (WSE) profiles for each scenario were used to evaluate potential effects of each alternative in terms of changes in flood risk, subsurface drainage, upstream habitat conditions, and fish passage at Guisti Weir. Finally, a channel stability analysis was conducted for Alternative A using the hydraulic design module in HEC-RAS. Additional details of these hydraulic analyses can be found in Appendix A.

3.3 Constructability Review

As discussed in **Section 2.5**, a preliminary geotechnical assessment was conducted for the study area (**Appendix B**). A key objective of the assessment was to evaluate the constructability of project alternatives. Constructability measures the extent to which a project or design can be successfully built or constructed from an engineering standpoint. Constructability considerations include, but are not limited to:

- Site access
- Sequencing
- Dewatering
- Over-excavation
- Material disposal
- Imported and compacted fill
- Unknown condition of weir foundation
- Real estate
- Utilities

Conclusions regarding alternative constructability are covered in **Section 4.1.4** below.

3.4 Cost Estimation

Opinions of probably construction costs (OPCCs) were developed for each alternative (**Appendix D**). Direct costs for Alternatives A, B, C include site work and demolition, in-channel work, contingencies, and a market volatility adjustment factor. For Alternative D, additional direct costs include weir and fishway, utility building, electrical system, and instrumentation and controls. Indirect costs include design services, testing, material and general, construction management services, construction inspection services, and engineering services during construction. Cost estimates for CEQA, NEPA, permitting, and mitigation were *not* developed or considered as part of the alternatives evaluation. A summary of OPCCs is provided in **Section 4.1.4** below.

CHAPTER 4
Evaluation

As noted above, the TAC refined the metrics and objectives during the first and second TAC meeting. Prior to the third meeting the TAC was asked to complete a swing weighting exercise based on a preliminary evaluation matrix. The intent of this weighting exercise was to render explicit the values that TAC members bring to their recommendations of a preferred alternative.

4.1 Alternatives Evaluation

The objectives and metrics developed in Step 1 and the alternatives developed in Step 2 formed the basis of an evaluation matrix, which shows the relative performance of alternatives (the columns) according to each objective as assessed by its associated metric (the rows). It is important to emphasize that the evaluation matrix includes both quantitative and qualitative results. These results were integrated using categories that again convey the relative performance of the alternatives assessed.

Completing the evaluation matrix required substantial research, as each of several alternatives must be assessed across numerous metrics, resulting in the need for dozens of individual findings to complete the table. Organizing objectives and metrics into an evaluation matrix was an iterative process that reflected evolving understandings of objectives and their relationships and a general desire for simplification and ease of interpretation. Ultimately, objectives were grouped into the following categories: Cost, target species effects, and negative side effects.

Evaluations were conducted using varying methods as shown in **Table 5**.

TABLE 5
EVALUATION METHODS

Metric Category	Objective	Method
Positive outcomes for adult salmonids	Improve passage for adult spring-run Chinook salmon	HEC-RAS, TUFLOW
Positive outcomes for juvenile salmonids	Improve juvenile salmonid rearing habitat	Expert judgement
	Improve juvenile salmonid outmigration	Expert judgement
Negative side effects	Avoid increased flood risk	HEC-RAS, geotechnical assessment
	Reduce potential for channel instability	HEC-RAS, Copeland method
	Minimize negative effects for upstream habitat conditions	HEC-RAS, longitudinal profile

Metric Category	Objective	Method
	Minimized negative effects for adjacent agricultural ditches/drains	Geotechnical assessment, survey data, HEC-RAS
	Minimize negative effects for adjacent wetlands	Geotechnical assessment, survey data, HEC-RAS
Feasibility	Constructability considerations	Geotechnical assessment
	Permitting considerations	Expert judgement
Maintenance burden	Minimize degree and complication of operations	Expert judgement
	Minimize consequences of maintenance deficiency	Expert judgement
Costs	Minimize capital cost	Parametric cost estimates
	Minimize annualized O&M	Expert judgement
	Minimize potential mitigation	Expert judgement

4.1.1 Target Species Effects – Adults

Passage for Adult Spring-Run Chinook Salmon

Each alternative was assessed using the 2D HEC-RAS model for low, median, high fish passage flows during a critically dry year (Table 4). In summary, Alternative A is expected to provide unimpeded passage for adult spring-run Chinook salmon through the grading footprint of the alternative. Similarly Alternative B is expected to provide passage during high passage flow. For the remaining flow scenarios, Alternatives B and C did not explicitly meet each passage criteria. However, the model results nearly met the passage criteria and suggest that with design and model refinement each alternative can be implemented with favorable passage performance. Details of the hydraulic analysis, including the passage criteria and fish passage results, are described in **Appendix A**.

4.1.2 Target Species Effects – Juveniles

Juvenile Salmonid Rearing Habitat

As stated above in **Section 2.8**, the weir does not exert a strong influence on the hydrodynamics that create juvenile habitat. The flow levels influenced by the weir (400-1,000 cfs) that also correspond to the seasonality that supports juvenile rearing (presence of out-migrating fishes, suitable temperatures) do not commonly occur—rather, flow levels are oftentimes much higher during these times (the winter season). Conceptually, any alternative that lowers the weir height means that greater flows are required to create the same level of inundation—but above around 1,000 cfs the channel begins to spill onto the floodplain with or without the weir.

Examining an anomalous year (2014, without much if any Sacramento River flood influence) allows for a worst-case assessment of the influence of the alternatives on floodplain inundation. Assessing the TUFLOW model results for water year 2014 shows that the minimum flow to provide floodplain inundation upstream of the weir, within the spring-run migration period (January through June), occurred an estimated maximum of approximately 20% of the time under existing conditions, 6% under alternatives A and B, and 22% of the time under Alternative C. Similarly, during the entire water year of 2014, floodplain inundation was estimated to have occurred approximately 10% under existing conditions and would have occurred 3-, 3-, and 12-percent of the time with alternatives A, B, and C, respectively.

TABLE 6
PERCENT OCCURRENCE OF FLOODPLAIN INUNDATION

Alternatives	WY 2014 (Jan-Jun)	WY 2014
No Action Alternative	20%	10%
Alternative A - Weir Removal	6%	3%
Alternative B - Roughened Channel	6%	3%
Alternative C - Partial Weir Removal with Rock Ramp	22%	12%

Juvenile Salmonid Out-migration

The effects of all the alternatives on juvenile salmonid out-migration were evaluated to be positive based on the elimination, in all cases,[2] of the primary hazard of falling off the weir. Falling off the weir can result in injury and confusion that makes juveniles more susceptible to predation. Research on fish ladders indicates the maximum hydraulic drop should be 1 foot or less (Bell, 1991; Clay, 1995). Alternatives A, B, C, and D are designed to avoid any hydraulic drops greater than 1 foot.

4.1.3 Negative Side Effects

Flood Risk and Levee Performance

In the context of the Sutter Bypass, flood risk can be evaluated in terms of hazard levels associated with various levee failure mechanisms including overtopping, through seepage, under seepage, landside slope stability, and waterside erosion potential. Hazard levels in the Sutter Bypass were defined and assigned as part of DWR's Levee Evaluation Program, based on geotechnical evaluations of levees associated with State Plan of Flood Control (URS 2011, 2014).

As outlined in **Appendix B**, the west levee of the Sutter Bypass is classified as Hazard Level C, which indicates that "there is a high likelihood of either levee failure or the need to flood-fight to prevent levee failure" during major flood events (see Segment 248 in URS, 2011). The ranking was attributed to under seepage (ranked the highest hazard), stability (ranked the second highest hazard) and erosion (ranked the lowest hazard). The overall rank is based on the highest hazard level found for the levee reach (under seepage). It should be noted that the west levee reach was subject to the 1997 breach that occurred due to under and through seepage. No other areas of the west levee within the SNWR were noted as having past distress in the available records reviewed in this study.

2 Note the positive effect for Alternative D assumes operation, which lowers the weir during periods of outmigration.

Our evaluation of flood risk for each of the project alternatives is largely qualitative, relying on the modeled changes in water surface elevations relative to existing conditions, our current understanding of subsurface geological conditions, and professional judgement. Because our analysis was focused on constrained fish passage conditions, no hydraulic modeling of the alternatives was conducted for flood events greater than 1,100 cfs. At flows above 1,100 cfs the hydraulic drop across the weir is less than 1.5 feet for all bypass conditions. When the Tisdale Weir and Bypass are activated, flood waters can back up into the Sutter Bypass canceling or reversing the drop across the weir. By contrast of scale, the design flood for this portion of the Sutter Bypass is 178,000 cfs. Under those conditions, the western portion of the bypass is submerged under 15 feet of water, effectively negating the hydraulic control of Weir 1.

If advanced to preliminary design, none of the alternatives considered would result in design water surface profiles greater than existing conditions. Alternatives A and B lower water surface profiles upstream of the existing weir location, while Alternatives C and D would be designed to generally mimic existing conditions. If water surfaces profiles don't change or are reduced relative to existing conditions, there is no increase in flood risk related to overtopping, seepage, or stability mechanisms. Bank erosion was not evaluated for major flood events, but an evaluation of channel stability under bankfull discharge conditions was conducted as part of the evaluation for Alternative A. With the above in mind, all alternatives were evaluated with a neutral effect on flood risk.

Channel Stability

As described in **Section 1**, Alternative A proposes to remove the weir and fish ladder structures and smooth the channel bed between upstream and downstream bed elevations allowing for unimpeded fish passage. A primary concern with this alternative is that because of the difference in grade between upstream and downstream, the channel may become unstable, incising and widening in response. Alternatives B, C, and D all include roughened channel or ramp elements that armor the bed and toe, prevent incision and bank erosion from occurring.

ESA relied on the hydraulic design module in HEC-RAS to evaluate the channel stability (**Appendix A**). Results of the stability analysis indicate that Alternative A, as currently designed, would not result in aggradation of degradation of the channel. If the channel bottom is gradually transitioned from upstream to downstream, a bed slope equivalent to the average valley channel slope of 0.0002 feet/feet is achievable. Maintaining the valley slope and average bottom width of 40 feet throughout the transition results in a stable channel design.

During the alternatives evaluation with the TAC, Alternative A was assumed to have a negative effect on channel stability because of the perceived incision and widening risk. While our preliminary evaluation shows that the channel should remain stable if the bed slope is well transitioned from upstream to downstream, more detailed analysis is required if Alternative A is selected as the preferred alternative.

Alternative B was evaluated to have a positive effect on channel stability because removal of the weir would allow for sediments trapped upstream of the existing weir location to mobilize, allowing for replenishment of sediment to more incised reaches downstream of the weir.

Alternatives C and D were evaluated to have a neutral effect on channel stability, since they either leave the weir in place (Alternative C) or replace the weir with a new operable weir and fish ladder (Alternative D).

Upstream Habitat Conditions

The effect of Alternatives A and B on upstream habitat conditions was evaluated as negative, since these alternatives lower the water surface profiles associated with fish passage flows. Primary concerns voiced by the TAC for lower water surface profiles are degraded instream habitat through additional encroachment of submerged aquatic vegetation (SAV), increased stream temperatures, and the potential for a larger drop across Guisti Weir located ~3.7 miles upstream. As shown in **Table 7**, removal of the weir could reduce water surface elevation by 0.2 feet downstream of Guisti Weir. The impact of this on fish passage is likely negligible as a new weir is being designed to replace the existing Guisti Weir and the results of this study will be shared with the Guisti Weir design team once approved by the PMT.

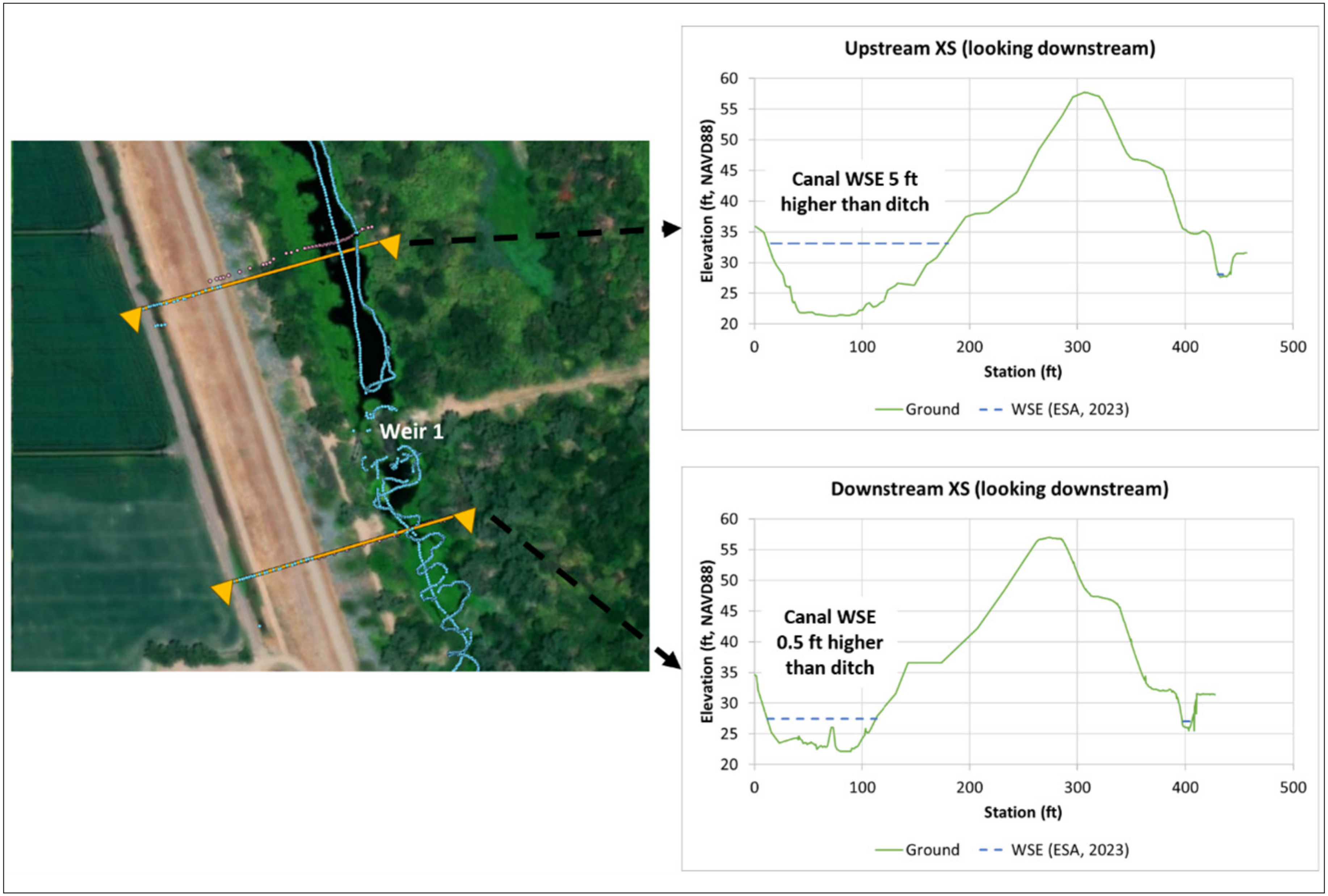
Alternatives C and D were evaluated as neutral as they are intended to maintain water surface profiles relative to existing conditions. A slight increase in WSE is shown for Alternative C, but future design iteration could reduce this increase if desired (though a slight increase would *lower* the drop at Guisti and could be seen as a beneficial effect for upstream fish passage).

TABLE 7
WSE BELOW GUISTI WEIR

Flow (cfs)	NAA	Alt A	Alt B	Alt C
WSE (ft, NAVD88)				
356	31.37	31.13	31.14	31.49
380	31.49	31.26	31.26	31.60
953	33.78	33.57	33.58	33.73
Change in WSE (Alt X - Alt 0, ft)				
356	-	-0.23	-0.23	0.12
380	-	-0.23	-0.23	0.11
953	-	-0.20	-0.20	-0.04

Adjacent agricultural ditches/drains

Under existing conditions, water surface elevations in the WBC upstream of the weir are typically greater than those typically found in the irrigation ditch located on the west side of the west levee of the Sutter Bypass (**Figure 10**). The irrigation ditch is used for water supply and drainage of agricultural fields to the west of the bypass. These conditions result in a positive hydraulic head between the WBC and the irrigation ditch. Downstream of the weir water surface elevations in the WBC are similar to those found in the irrigation ditch. During the May 2023 survey, water surface elevations in the WBC were 5 feet higher upstream and 0.5 feet lower downstream relative to those in the irrigation ditch.



SOURCE: ESA, 2023

Figure 10
Water surface elevations upstream and downstream of Weir 1. Cross-sections displayed in the downstream direction.

ESA

The effect of Alternatives A and B on adjacent agricultural ditches and drains was evaluated to be negative, as lower water surface profiles in the WBC have the potential to reverse the hydraulic head between the canal and the ditch and could induce drainage of the ditch through historic channel deposits with relatively high hydraulic conductivity (see discussion in **Sections 2.5 and 2.6**). The effect of Alternatives C and D on adjacent agricultural ditches and drains was evaluated as neutral as these alternatives would maintain upstream water surface profiles and thus groundwater levels.

Adjacent Wetlands

There are several wetlands adjacent to the West Borrow Canal in the Sutter National Wildlife Refuge as depicted in Figure 8. These wetlands are activated by the West Borrow Canal during instances of overbank (bankfull) flow. Removal or alteration of the weir lowers the water surface profile upstream of the weir location and may present negative effects in terms of accelerated draining of wetlands through surface (breached berms) and subsurface (historic channel deposits) pathways. **Figure 11** depicts the WSE profiles for the median and high passage flows as well as surveyed inverts of the breach berm or wetland "spill" locations.

The minimum flow rate required to activate the wetlands was estimated for existing conditions and each alternative (**Table 8**). Percent exceedance signifies the percentage of time or frequency with which the actual flow exceeds the specified values, informing the estimated inundation in the wetlands during a critical water year (2014).

TABLE 8
ESTIMATED BANKFULL FLOWS AND PERCENT EXCEEDANCES FOR WETLAND INUNDATION

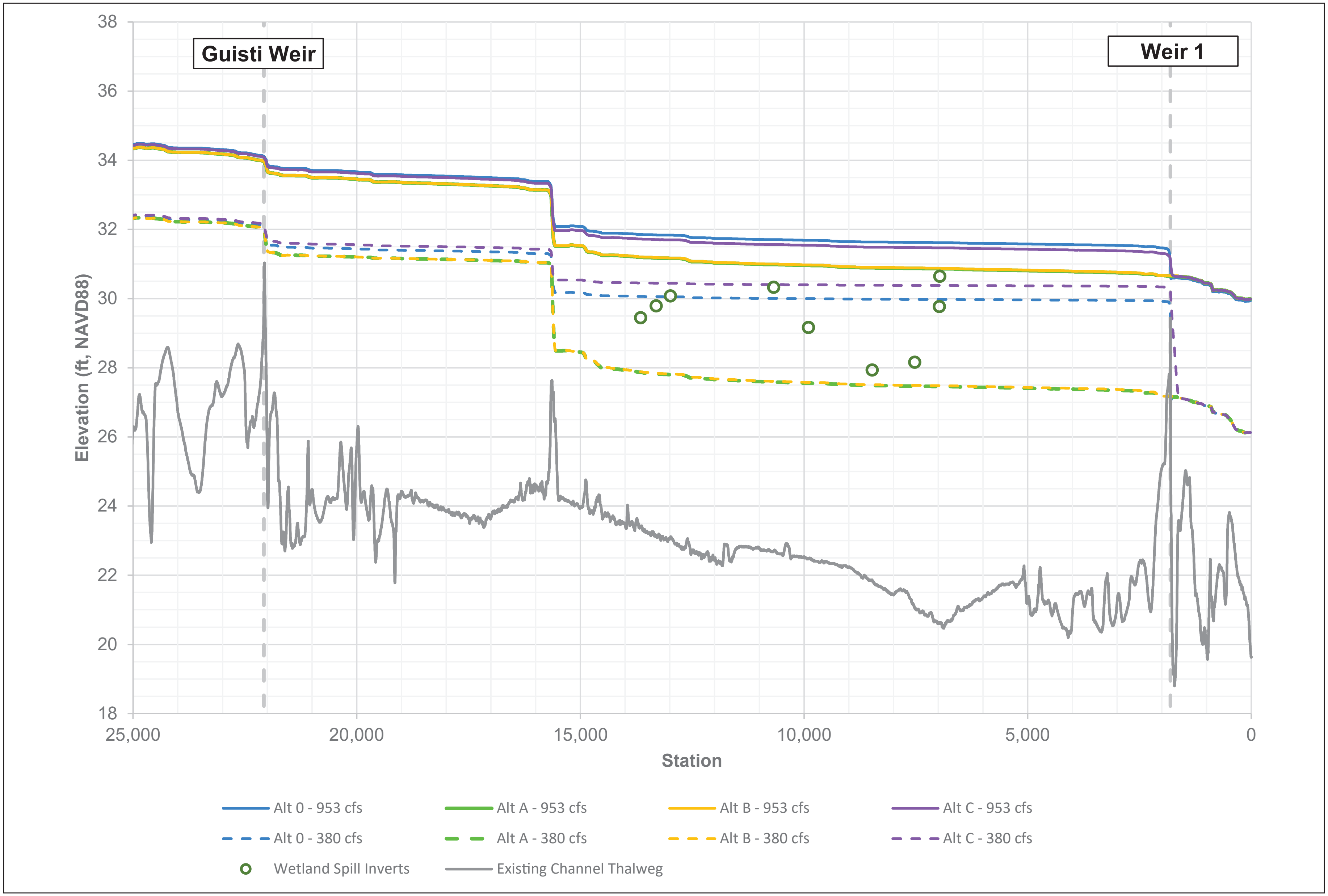
Scenario	Estimated Bankfull Discharge (cfs)	Percent Exceedance in WY 2014[a]
Existing Conditions	750	6%
Alternative A	1,000	2%
Alternative B	1,000	2%
Alternative C	550	10%

NOTES:

[a] Estimated from the TUFLOW model results within the West Borrow Canal. The TUFLOW model simulation period extends from October through July.

SOURCE: ESA 2020.

Findings of the wetlands inundation analysis suggest that Alternatives A and B would have a negative effect on wetland inundation, and we would expect those waterbodies to be relatively drier during a critical water year. In contrast, the additional roughness elements below the weir in Alternative C results in slightly wetter conditions over the course of a critical water year. It's important to note that Alternatives C and D are intended to mimic the water surface profiles of existing conditions. With that in mind, Alternatives C and D were evaluated to have a neutral effect on the SNWR wetlands.



SOURCE: ESA, 2023

Butte Creek - Sutter Bypass Weir 1 Feasibility Study and Alternatives Analysis

Figure 11
Water surface profiles and wetland inverts along the West Borrow Canal

ESA

4.1.4 Feasibility

Constructability

- The constructability of Alternative A is high as the main construction component would be the removal of the existing weir and fish ladder and the degradation of the channel to some set elevation. A drawback of Alternative A is that full weir removal would require excavation and material disposal.
- The constructability of Alternatives B and C was evaluated to be medium, as both entail additional engineering based on ecological and geotechnical considerations (Appendix B).
  - In the case of Alternative B, the weir would be removed and replaced by an engineered roughened channel. The benefit of Alternative B is that removal and replacement does not impact the west side of borrow cut along toe of levee with placement of erosion protection. The engineered roughened channel would have limited fill thickness. A drawback of Alternative B (like A and D) is that full weir removal would require excavation and material disposal. Site access will need to be created to access the bottom of the newly deepened channel. Alternative B will require cofferdams to divert water to dewater channels. Deep excavation can be more challenging from the top of existing bank.
  - In the case of Alternative C, the weir would be partially removed and connected to an engineered rock ramp. A benefit of Alternative C is that partial removal will reduce excavation and material disposal relative to A, B, and D. Alternative C will also have less impact to western borrow area slope. Construction access can be incorporated in the fill areas. Construction could be sequenced from west to east from the top of the bank. A drawback of Alternative C is the need to divert water to construct and dewater to place fill. Importation of fill will be required and fill downstream of weir will need to be designed to prevent internal erosion from subsurface flows. Foundation conditions are unknown for placement of fill and may create further constructability challenges.
- The constructability of Alternative D was evaluated to be high as it entails weir removal and replacement with an operable weir and fish ladder. Full weir removal would require excavation and material disposal. The Weir and fishway would include an Obermeyer weir, concrete weir foundation, pile foundation, seepage cutoff wall, vortex pool and shoot fish ladder and a sluiceway gate. A rock apron downstream of the adjustable weir crest will need to be constructed to limit the potential scour during high flow events. The operable weir would necessitate the construction of a utility electrical compressor building, electrical system and instrumentation and controls.

Permitting

Permitting concerns are primarily related to fish and flood issues.

- For Alternative A, the medium permitting evaluation was due to the absence of any fish-specific engineering solution, and concern around channel stability given the change in bed slope between upstream and downstream reaches.
- For Alternative B, the low permitting evaluation was due to constructing a fish-specific engineering solution (roughened ramp) supported by a geotechnical evaluation.
- For Alternative C, the medium permitting evaluation was due to constructing a fish-specific engineering solution (rock ramp) supported by a geotechnical evaluation.

- For Alternative D, the high permitting evaluation was due to the flood and endangered species risks associated with weir operation.

4.1.5 Maintenance Burden

Degree and Complication of Operation

The maintenance burden of Alternatives A, B, and C was evaluated to be negligible. Alternative D's high maintenance burden is due to the routine operation and maintenance of the operable weir and fish ladder. This alternative would require a higher level of operation and maintenance effort to maintain design intent because the flexible weir system requires utility, electrical, and control equipment to operate. The hydraulic performance of the technical fish ladder also would be negatively influenced by the accumulation of debris (primarily SAV and instream woody material) and sediment during storm events. However, the operable weir in Alternative D could be operated to facilitate debris and sediment management behind the structure.

Consequence of Maintenance Deficiencies

Because the maintenance burden of Alternatives A, B, and C was evaluated to be negligible, maintenance deficiency has no consequences. For Alternative D, the consequences of maintenance deficiency are high as inadequate maintenance or improper operation could potentially result in conditions that are worse than the current status quo.

4.1.6 Costs

Capital Costs

Our preliminary estimating shows a range of probable construction costs between $1.7M and $11.1M (**Table 9**). These costs are based on 2023 prices. The cost and relative spread for the alternatives is in the table below. All cost estimates include a 50% adjustment for undefined design and construction items and an additional 3% market volatility adjustment factor. Such large contingencies are expected at the conceptual level of design, especially when considering geotechnical uncertainties with weir foundation and overall WBC composition.

TABLE 9
PRELIMINARY OPINIONS OF PROBABLE CONSTRUCTION COSTS

Design Alternative	Relative Cost	Total Direct Cost	Total Direct and Indirect Cost
Alternative A - Weir Removal	Low	$1,360,000	$1,713,000
Alternative B - Roughened Channel	Moderate-Low	$2,719,000	$3,426,000
Alternative C - Partial Weir Removal with Rock Ramp	Moderate-High	$3,080,000	$3,881,000
Alternative D - Operable Weir and Fish Ladder	High	$8,827,000	$11,121,000

Annualized Operations and Maintenance (O&M) Costs

The annualized O&M costs for Alternatives A, B, and C are considered low due to their passive, non-operable design. The relative annualized O&M costs for Alternative D are high due to the operation and maintenance of the operable weir and fish ladder. Operations and maintenance costs for Alternative D include energy costs, replacement costs, cleaning of the fish ladder, labor for operations and maintenance, and monitoring passage.

O&M costs for Alternatives A, B, C that are not incurred with D would include monitoring for channel stability, including bed and banks. Monitoring could occur annually or after large flow events.

Potential Mitigation

The potential need for compensatory mitigation of jurisdictional wetlands was high for alternatives A and B, because weir removal would significantly lower the upstream water surface elevation and is assumed to be an impact to some relatively large area of wetlands inside the SNWR (e.g., 10 acres or more). Because the water surface elevation impacts would be greatest during the summer (low flow) time period—which is essentially coincident with the most-stressful time of year for wetland habitat should the adjacent surface water and underlying groundwater be lowered—it is assumed that these alternatives would generate relatively large impacts to wetland and thus generate the need to mitigate for these impacts. Alternatives C does not change upstream water surface elevation. It was assumed that the gated structure in Alternative D would be operated to maintain the existing upstream water surface elevation during consequential periods (e.g., summer).

4.2 Evaluation Matrix

4.2.1 Altaviz Platform

The interactive evaluation matrix was developed using Altaviz, an online platform developed to support structured decision-making (SDM). Altaviz was also used to conduct a swing weighting exercise (**Section 4.2.3**) to solicit feedback on the relative importance or weight of objectives to the decision.

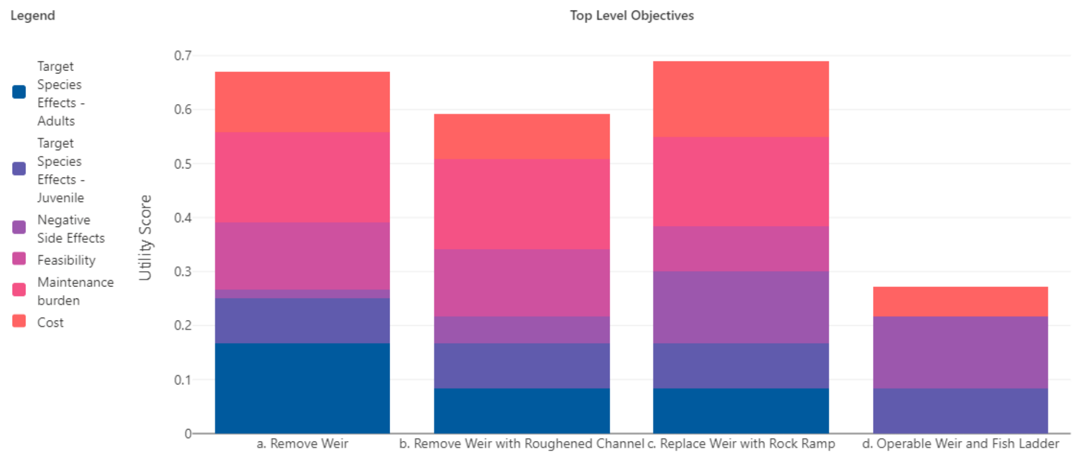
4.2.2 Objectives Rating

The final evaluation matrix (**Table 10**) was reviewed and revised through input from the TAC. The matrix shows the relative performance of alternatives by objective. The matrix is color-coded along a scale from ‘Lower’(brown) to ‘Higher’(green), with neutral or equal results in light green. These color codes are intended as a simple visual cue to highlight the comparison across each alternative for each objective.

TABLE 10
EVALUATION MATRIX

Metric Category	Objective	Alternative A	Alternative B	Alternative C	Alternative D
Target species effects - Adults	Passage for SRC	Best	Better	Better	Good
Target species effects - Juvenile	Juvenile salmonid rearing habitat	Neutral	Neutral	Neutral	Neutral
	Juvenile salmonid outmigration	Positive	Positive	Positive	Positive
Negative side effects	Flood hazard	Neutral	Neutral	Neutral	Neutral
	Channel stability	Negative	Positive	Neutral	Neutral
	Upstream habitat conditions	Negative	Negative	Neutral	Neutral
	Adjacent ag ditches/drains	Negative	Negative	Neutral	Neutral
	SNWR wetlands	Negative	Negative	Neutral	Neutral
Feasibility	Constructability	Low	Medium	Medium	High
	Permitting	Medium	Low	Medium	High
Maintenance burden	Degree and complication of operations	None	None	None	High
	Consequence of maintenance deficiency	None	None	None	High
Costs	Capital cost	Low	Medium	Medium	High
	Annualized O&M	Low	Low	Low	High
	Potential mitigation	High	High	Low	Low

The evaluation matrix can also be viewed as a bar chart by calculating the utility score of each top-level objective (**Figure 12**). To obtain a utility score, all top-level objectives are normalized from best to worst on a scale from 0-1. Those values are multiplied by the weights on each objective, totaling 100%. This comparison across alternatives is put on a 0-1 scale, where 1 represents the greatest utility/performance and 0 is the least.



SOURCE: ESA, 2023

Butte Creek - Sutter Bypass Weir 1 Feasibility Study and Alternatives Analysis

Figure 12
Utility scores of Top-Level Objectives

4.2.3 Swing Weighting

In addition to reviewing the relative performance of alternatives in an evaluation matrix, the TAC participated in a facilitated objective swing weighting exercise (**Figure 13**). The exercise was conducted after the team shared a preliminary evaluation matrix, which shows the relative performance of alternatives according to the set of objectives. Combining the poll results with the evaluation table facilitates learning how the relative performance of alternatives may change when different weights are placed on objectives.

For example, some alternatives may perform relatively well for objectives deemed less important for certain decision-makers and relatively poorly for an important objective. All else equal, this would not be a compelling alternative. Another alternative may perform poorly for a less important objective and slightly better for an important objective. Here, the shortcomings regarding the less important objectives are more than compensated for by the slight improvement in the more important objective.

Swing weighting allows for a conversation about facts, values, and their interaction in decision-making. Swing Weighting is a form of "slow thinking" where, instead of making a direct holistic choice, participants carefully weigh each objective's importance, and a calculation is made to identify the preferred ranking based on these weights. The ultimate objective is to make legible and explicit the qualitative importance of certain consequences to decision-makers.

This exercise was conducted to aid the PMT's selection of a preferred alternative by illustrating how the relative performance of alternatives responds when some objectives are given greater or lesser weight than others. The exercise was not intended to finalize decisions but to explore the implicit values that TAC members bring with their recommendations. Results should be considered provisional and reflective of confusion with the swing weighting approach. There were several participants who emphasized objectives where alternatives performed equally.

While indicative of the value they place on this objective this emphasis does not change the relative performance of alternatives, as is intended by the exercise.

Name	a. Remove Weir	b. Remove Weir with Roughened Channel	c. Replace Weir with Rock Ramp	d. Operable Weir and Fish Ladder
Person 0	0.70	0.59	0.58	0.26
Person 1	0.95	0.71	0.48	0.00
Person 2	0.62	0.62	0.80	0.32
Person 4	0.87	0.68	0.50	0.10
Person 5	0.69	0.57	0.50	0.28
Person 7	0.71	0.51	0.49	0.29
Person 8	0.64	0.55	0.63	0.33
Person 9	0.94	0.68	0.50	0.06

SOURCE: ESA, 2023

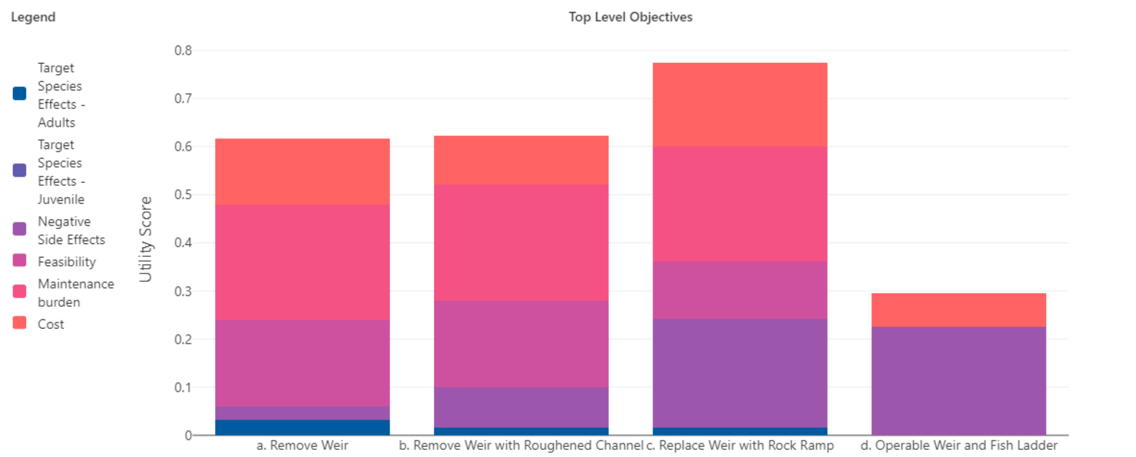
Butte Creek - Sutter Bypass Weir 1 Feasibility Study and Alternatives Analysis

Figure 13
Provisional weighting exercise results. Alternative A is in the top two choices of all respondents and Alternative D in the bottom two.

During the 3rd TAC meeting exercise results were reviewed and the TAC participated in a real-time swing weighting exercise, based on an updated evaluation matrix. Based on the analysis, the real-time swing exercise developed several hypothetical weighting scenarios, which highlighted tradeoffs between Alternative A and C, the two primary contenders.

Scenario 1: "Super Feathers"

In Scenario 1 "Super Feathers", target species effects are de-emphasized, based on the understanding that all alternatives represent an improvement over the status quo (**Figure 14**). This scenario places the highest weight on negative side effects, based on a desire to minimize negative effects on the SNWR, and a recognition that negative side effects, feasibility, maintenance burden, and cost could jeopardize project implementation.



Objectives	Prefered Direction	Unit	Worst Scenario	Best Scenario	Weights
Target Species Effects - Adults	higher				3.11%
Target Species Effects - Juvenile	higher				0%
Negative Side Effects	higher				28.25%
Feasibility	higher				24.01%
Maintenance burden	higher				24.01%
Cost	higher				20.62%

Reset

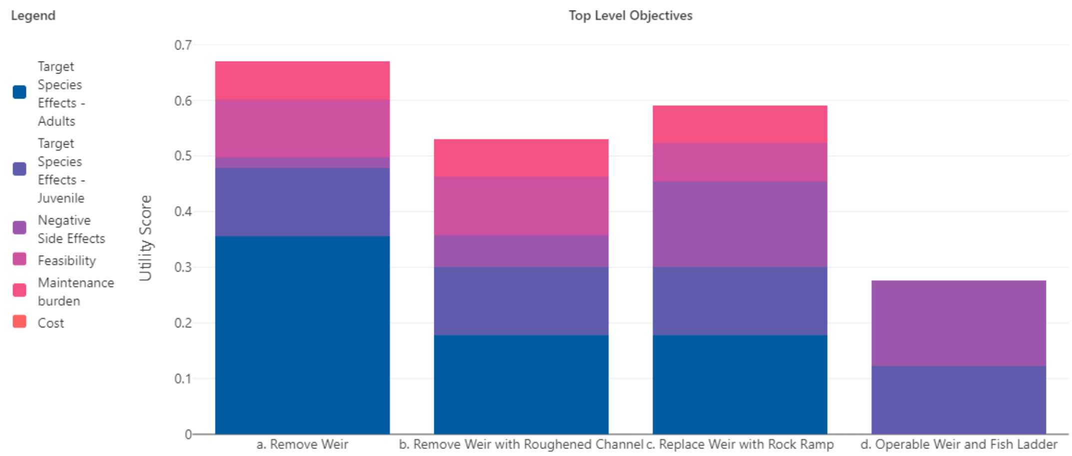
SOURCE: ESA, 2023

Butte Creek - Sutter Bypass Weir 1 Feasibility Study and Alternatives Analysis

Figure 14
Scenario 1 Utility Scores of Top-Level Objectives

Scenario 2: "Cost is no object"

Scenario 2 prioritizes feasibility and the reduction of negative side effects while taking cost out of the decision (**Figure 15**).



Objectives	Prefered Direction	Unit	Worst Scenario	Best Scenario	Weights
Target Species Effects - Adults	higher				19.79%
Target Species Effects - Juvenile	higher				13.37%
Negative Side Effects	higher				26.74%
Feasibility	higher				26.74%
Maintenance burden	higher				13.37%
Cost	higher				0%

Reset

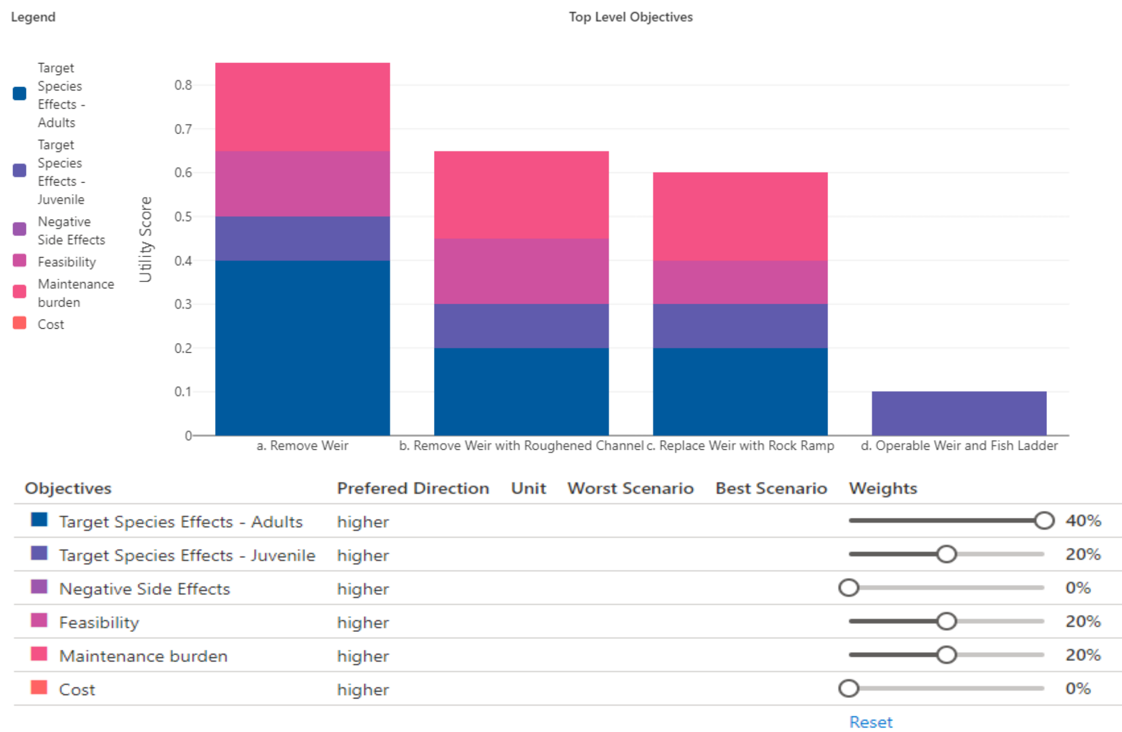
SOURCE: ESA, 2023

Butte Creek - Sutter Bypass Weir 1 Feasibility Study and Alternatives Analysis

Figure 15
Scenario 2 Utility Scores of Top-Level Objectives

Scenario 3: "Super fins"

Scenario 3 emphasizes target species effects ("fins") while taking negative side effects and cost out of the decision (**Figure 16**).



SOURCE: ESA, 2023

Butte Creek - Sutter Bypass Weir 1 Feasibility Study and Alternatives Analysis

Figure 16
Scenario 3 Utility scores of Top-Level Objectives

4.3 TAC Recommendations

The weighting survey and discussion during TAC 3 identified two preferred alternatives, Alternative A (weir removal) and Alternative C (replacing the weir with a rock ramp). Tradeoffs were discussed between these two preferred alternatives (**Table 11**).

An emphasis on the adult fish passage above all else points to Alternative A. However, there was also a recognition that Alternative C also confers significant benefits over the status quo and concerns related to negative side effects (including the complications, timeline and costs for wetland mitigation for Alternative A), maintenance burden, and feasibility are important to consider. Thus, Alternative C offers significant desirable attributes to consider.

TABLE 11
EVALUATION MATRIX WITH ALTERNATIVES A AND C

Metric Category	Objective	Alternative A	Alternative C
Target species effects - Adults	Passage for SRCS	Best	Better
Target species effects - Juvenile	Juvenile salmonid rearing habitat	Neutral	Neutral
	Juvenile salmonid outmigration	Positive	Positive
Negative side effects	Flood hazard	Neutral	Neutral
	Channel stability	Negative	Neutral
	Upstream habitat conditions	Negative	Neutral
	Adjacent ag ditches/drains	Negative	Neutral
	SNWR wetlands	Negative	Neutral
Feasibility	Constructability	Low	Medium
	Permitting	Medium	Medium
Maintenance burden	Degree and complication of operations	None	None
	Consequence of maintenance deficiency	None	None
Costs	Capital cost	Low	Medium
	Annualized O&M	Low	Low
	Potential mitigation	High	Low

TABLE 12
SIMPLIFIED EVALUATION MATRIX WITH ALTERNATIVES A & C

Metric Category	Objective	Alternative A	Alternative C
Target species effects – Adults	Passage for SRCS	Best	Better
Negative side effects	Channel stability	Negative	Neutral
	Upstream habitat conditions	Negative	Neutral
	Adjacent ag ditches/drains	Negative	Neutral
	SNWR wetlands	Negative	Neutral
Feasibility	Constructability	Low	Medium
Costs	Capital cost	Low	Medium
	Annualized O&M	Low	Low
	Potential mitigation	High	Low

A simplified evaluation matrix, displaying only those performance measures where differences exist between alternatives, clarifies the main tradeoffs (**Table 12**).

- **Alternative A** performs best in terms of Target Species Effects – Adults, measured by adult fish passage for spring-run Chinook salmon.
  - However this alternative weir removal has negative sides effects, measured by channel stabilty, upstream habitat conditions, adjacent agricultural ditches/drains, and SNWR refuges.
  - Weir removal is more feasible in terms of constructability.
  - Weir removal has low capital costs, but high costs associated with potential mitagation, including for negative side effects.

- **Alternative C** performs well in terms Target Species Effects – Adults
  - Retrofitting the weir with a rock ramp has no significant negative side effects.
  - Feasibilility in terms of constructability is medium.
  - Capital costs of replacing the weir with a rock ramp is medium, but potential mitigation costs are low.

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CHAPTER 5
Conclusion

5.1 Preferred Alternative

This document summarizes the objectives, approach, and findings of the feasibility study and alternatives analysis for Weir 1 but does not state a preferred alternative on behalf of the USFWS, the TAC, or the PMT. This document will be reviewed by the PMT and the USFWS and it is anticipated that a preferred alternative will be selected and then included in one or more Notice(s) of Funding Opportunity for the design, permitting and construction of the preferred alternative.

5.2 Lessons Learned

ESA led the TAC through a five-step process to identify the preferred alternative that addresses the fish passage issue at Weir 1 while limiting potential negative effects from which several lessons were learned.

- Improving passage for adult spring-run Chinook salmon was the primary objective that drove initial alternative formulation. Evaluation concluded that all alternatives improved passage to varying degrees. If this primary objective were to have been a screening criterion, then tradeoffs between other secondary objectives would have been more apparent.
- Maintenance burden and the consequences of maintenance deficiency were a serious concern of TAC members based on negative experiences with other in-channel structures (particularly operable structures) in the area. This concern supports alternatives with low maintenance burden and consequences of maintenance deficiency.
- The results of the weighting survey indicate diverse perspectives regarding the value of top-level objectives. However, these diverse values did not result in significant dissensus around alternative recommendations.

5.3 Next Steps

Once a decision is made by the PMT, the preferred alternative will be advanced to a 30% level of engineering design. Developing the 30% design will entail refining design details, updating and expanding cost estimates, outlining long-term O&M requirements, and potentially also creating a monitoring and/or adaptive management plan. Additional hydraulic modeling and analysis would support design development for adult and juvenile fish passage criteria and to further assess the potential for any negative impacts. Considerations for including Pacific lamprey and other native fishes (i.e., green sturgeon) as targets for setting passage criteria in the design should also be considered.

Much of the permitting and environmental compliance process associated with the preferred alternative can begin during the development of the 30% design (e.g., Lake and Streambed Alteration Agreement), but several potential consultations and applications would require more detailed design and supporting documentation associated with the ~60% level of design (e.g., a potential Central Valley Flood Protection Board encroachment permit and US Army Corps of Engineers Section 408 permission). When the permitting and environmental compliance process is complete, the project will go out to bid and construction can begin. The desired start of construction is 2025.

CHAPTER 6
References

Bell, M.C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. Fish Passage and Development Evaluation Program, U.S. Army Corps of Engineers, Portland, Oregon.

Brennan, John. Personal Communication. August 16, 2023.

Clay, C.H. 1995. Design of Fishways and Other Fish Facilities. Second Edition. Boca Raton: CRC Press.

California Department of Fish and Wildlife (CDFW). (2012). Sutter Bypass - Weir I - Fish Ladder Passage Issue/Fish Die-off. Memorandum.

California Department of Fish and Wildlife (CDFW). (2013a). Sutter Bypass - Weir 1 (Parks Weir). Memorandum.

California Department of Fish and Wildlife (CDFW). (2013b). Weir 2 and Sutter Bypass conditions May 2013. Memorandum.

California Department of Fish and Wildlife (CDFW). (2020). Weir 1 Survey Data. Mark Gard personal communication.

California Department of Fish and Wildlife (CDFW). (2023). Passage Assessment Database ID 703959. https://apps.wildlife.ca.gov/bios6/?al=ds69.

California Department of Water Resources (DWR). (2010). Central Valley Floodplain Evaluation and Delineation (CVFED) Program LiDAR.

California Trout. (2016). Butte Creek & Sutter Bypass Stream Flow Enhancement Project.

Cordoleani, F. E, Holmes and C. Jeffres. (2019). Development of baseline data for fish growth and lower trophic production on the Sutter Bypass – 2018 pilot study. Prepared for: State Water Contractors Agreement Number 63624-447552. January 2019.

Environmental Science Associates (ESA). (2020). *Tisdale Weir Rehabilitation and Fish Passage Project. Flow Analysis – Baseline Model Calibration and Validation Report*. Prepared for the California Department of Water Resources, September 2020.

Environmental Science Associates (ESA). (2018). *Tisdale Weir Rehabilitation and Fish Passage Project. Tisdale Weir Historical Fish Passage and Stranding Tech Memo*. Prepared for the f18California Department of Water Resources, October 2018.

Fugro Earth Data, Inc. (2010). DWR Central Valley Floodplain Evaluation and Delineation (CVFED), metadata prepared for California Department of Water Resources, DWR Task Order 13.

Jeffres CA, E. Holmes, T. Sommer, and J Katz. (2020) Detrital food web contributes to aquatic ecosystem productivity and rapid salmon growth in a managed floodplain. PLoS ONE 15(9): e0216019. https://doi.org/10.1371/journal.pone.0216019.

ICF Jones & Stokes (2008). Draft Butte Slough/Sutter Bypass Fish Passage and Entrainment Assessment.

Office of Governor Gavin Newsom. (2014). Governor Newsom Launches California's Salmon Strategy for a Hotter, Drier Future. https://www.gov.ca.gov/2024/01/30/governor-newsom-launches-californias-salmon-strategy-for-a-hotter-drier-future/.

Office of Governor Gavin Newsom (Office of Governor). (2024). Governor Newsom Launches California's Salmon Strategy for a Hotter, Drier Future. https://www.gov.ca.gov/2024/01/30/governor-newsom-launches-californias-salmon-strategy-for-a-hotter-drier-future/.

Photo Science, Inc. (2009). Central Valley Floodplain Evaluation and Delineation (CVFED), LiDAR metadata file.

PSOMAS. (2020). Topographic Survey Tisdale Weir Project Sutter County, California.

U.S. Fish and Wildlife Service (USFWS). (2020). Sutter National Wildlife Refuge. https://www.fws.gov/refuge/sutter/about-us.

U.S. Army Corps of Engineers (USACE). (2013). Sutter Basin Pilot Feasibility Report - Environmental Impact Report / Supplemental Environmental Impacts Statement Butte and Sutter Counties, California GEOTECHNICAL APPENDIX.

URS (2014) Geotechnical Evaluation Report, Volume 1, Existing Conditions, Sutter Bypass-Wadsworth Canal Study Area, Urban Levee Design Evaluation Project, June 16.

Quantum Spatial. (2021). Tisdale Bypass, California Lidar Technical Data Report.

Wang, R. & Ateljevich, E., Fregoso, T. A. & Jaffe, B. E. (2018). A Revised Continuous Surface Elevation Model for Modeling (Chapter 5). In Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 38th Annual Progress Report to the State Water Resources Control Board. California Department of Water Resources, Bay-Delta Office, Delta Modeling Section. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Library/Modeling-And-Analysis/Files/Modeling-and-Analysis-PDFs/FINAL6BayDelta39thProgress-Report071918.pdf.

Appendix A
Hydrology and Hydraulics Analysis

1. INTRODUCTION

The Butte Creek – Sutter Bypass Weir 1 Feasibility and Alternatives Analysis Project (Project) proposes to remove or modify Weir 1 to restore fish migration within the West Borrow Canal (WBC) of the Sutter Bypass (**Figure A-1**) without compromising agricultural operations, channel stability, and adjacent wetlands. ESA has evaluated five project alternatives for addressing fish passage at Weir 1:

- Alternative 0: No Action – No modifications to Weir 1
- Alternative A: Remove Weir – Completely remove weir and fish ladder structures
- Alternative B: Remove Weir with Roughened Channel - Completely remove weir and fish ladder structures, and construct new roughened channel structure
- Alternative C: Replace Weir with Rock Ramp – Partial removal of weir and fish ladder structures, and construct passable roughened ramp
- Alternative D: Operable Weir and Fish Ladder - Completely remove weir and fish ladder and construct an operable Obermeyer weir and pool-chute fish ladder. Alternative D was not explicitly included in the modeling analysis, as the anticipated hydraulics of the alternative can be inferred by the results of Alternative 0 (similar to a closed operable weir) and Alternative A (similar to an open operable weir) to a level suitable for comparisons between alternatives.

As part of the Project, hydrology and hydraulic analyses were assessed in relation to the existing and proposed conditions for fish passage at a level adequate for assessing project alternatives. A hydrologic analysis was conducted using estimated flow data of the WBC to better understand the duration and frequency of flows and stages relevant for fish passage. The hydrologic analysis was focused on dry and low-flow conditions within the WBC when fish passage is most limited by the hydraulic performance of the existing weir and fish ladder. During high flow events, the weir becomes submerged, no longer impeding fish passage.

A two-dimensional (2D) hydrodynamic model was developed to analyze the hydraulics of the WBC under the existing and alternative scenarios and evaluate each alternative's ability to provide fish passage and avoid negative side effects.