Final Report

BUTTE CREEK – SUTTER BYPASS WEIR 1

Feasibility Study and Alternatives Analysis

Prepared for
U.S. Fish and Wildlife Service

April 2024

ESA

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EXECUTIVE SUMMARY

Butte Creek has the largest self-sustaining wild population of threatened spring-run Chinook salmon in the Sacramento River watershed and is identified as a stronghold in the 2024 California Salmon Strategy for a Hotter, Drier Future (Office of Governor, 2024). Anadromous fish migrating to upstream spawning areas by way of Butte Creek encounter a series of anthropogenic channels (i.e., the East and West Borrow Canals in the Sutter Bypass) where they must navigate multiple fish ladders, diversion dams and weirs to make it into the canyon reach of Butte Creek (upstream of Highway 99) where the fish hold through the summer and later spawn in the autumn. Weir 1, located on the West Borrow Canal (WBC) of Butte Creek (in the Sutter Bypass), is a dilapidated weir and fish ladder structure that is no longer used to divert or deliver water and is a documented fish passage impedance (CDFW, 2012; CDFW, 2013a, 2013b; CDFW, 2023).

A Technical Advisory Committee (TAC) was formed to identify, develop, and assess the feasibility of alternatives to address fish passage at Weir 1, with facilitation and technical support provided by Environmental Science Associates (ESA). The TAC includes members from the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), and California Department of Water Resources (DWR). A subset of the TAC was identified as the project management team (PMT), the group responsible for identifying the preferred project alternative. This project report documents the alternatives analysis, evaluation process, and selection of the preferred alternative.

The TAC adopted an overall project goal to "*Improve adult and juvenile passage of anadromous fish species, specifically spring-run Chinook salmon.*" Based on this goal, fifteen project objectives were identified in the categories of 1) positive outcomes for salmonids, 2) minimization and avoidance of negative side effects, 3) feasibility, 4) maintenance and 5) cost. ESA and the TAC worked together to characterize existing conditions and formulate alternatives based on data collection and analysis and a shared understanding of current conditions and project objectives. The five alternatives are:

- No Action Alternative
- Alternative A - weir and head cut removal with limited regrading of the channel
- Alternative B - weir removal and replacement with a roughened channel
- Alternative C - partial weir degrade with a rock ramp transition from the weir crest to the downstream channel bed
- Alternative D - weir removal and replacement with an operable weir and fish ladder

ESA then evaluated each of the five alternatives relative to the project objectives using a combination of analytical approaches and expert judgement.

1) **Positive outcome for adult salmonids**: ESA developed a two-dimensional hydraulic model of the channel and weir to evaluate the potential effect of each alternative on flow conditions for adult spring-run Chinook salmon passage through the project area.
2) **Positive outcome for juvenile salmonids**: To evaluate the potential effects on juvenile salmonid rearing habitat and out-migration, ESA staff and TAC members applied expert judgement and prior experience with similar projects.
3) **Negative side effects avoidance and minimization:** Hydraulic modeling was also used to evaluate the potential effect of each alternative on flood risk, channel stability, upstream habitat conditions, adjacent agricultural ditches/drains, and adjacent wetland habitats. A geotechnical levee assessment also contributed to the flood risk evaluation (levee stability), as well as the assessment of the potential effect on agricultural ditches/drains.
4) **Feasibility:** Construction feasibility for each alternative was evaluated based on ESA expert judgement in combination with the results of the geotechnical assessment. ESA expert judgement and experience with similar projects was also applied to evaluate permitting feasibility.
5) **Maintenance:** The relative maintenance needs for each alternative, as well as potential consequences for maintenance deficiencies, were evaluated using professional judgement.
6) **Cost:** ESA estimated costs for construction and maintenance for each alternative. The potential need for compensatory mitigation for impacts during construction and/or being created by the alternative (which would add to project costs) was evaluated qualitatively based on professional judgement.

Working with the TAC, ESA developed an evaluation matrix which incorporated recommendations that emerged from their facilitated discussion of benefits and tradeoffs. The matrix was completed by assigning a rating to each alternative for each of the 15 project objectives, based on the evaluations described above. All ratings were on a 3-step scale (e.g. low, medium, high or negative, neutral, positive). The TAC also participated in a "Swing Weighting" exercise to explore how the relative performance of the alternatives responded when some objectives were given greater of lesser weight than others.

The TAC identified two preferred alternatives, Alternative A (weir removal) and Alternative C (replacing the weir with a rock ramp). When adult fish passage is emphasized above all else the evaluation points to Alternative A. However, there was also a recognition that Alternative C also confers significant benefits over the status quo and that it is important to consider concerns related to negative side effects (including the complications, timeline and costs for wetland mitigation for Alternative A), maintenance burden, and feasibility. Thus, Alternative C offers significant desirable attributes to consider.

CHAPTER 1
Introduction

1.1 Purpose

Weir 1, located on the West Borrow Canal (WBC) of Butte Creek (in the Sutter Bypass), is a dilapidated weir and fish ladder structure that is no longer used to divert or deliver water and is a documented fish passage impedance (CDFW, 2012; CDFW, 2013a, 2013b; CDFW 2023).

This study aims to identify, develop, and assess the feasibility of alternatives to address fish passage at Weir 1. This study includes an evaluation matrix completed with the support of a Technical Advisory Committee and the recommendations that emerged from their facilitated discussion of benefits and tradeoffs.

The specific project objectives include:

- Information gathering and site reconnaissance
- Project Management
- Facilitate, plan, and provide notes from Technical Advisory Committee meetings
- Data Collection and Evaluation
- Alternative development and cost estimates

This study was conducted in support of the U.S. Fish and Wildlife Service (USFWS) Red Bluff Fish and Wildlife Office (RBFWO), CVPIA Program under Grant no. F22AP03795.

Funding for this study was provided by the Central Valley Project Improvement Act (CVPIA), Title 34, Public Law 102-575 Section 3406 b(1), Anadromous Fish Restoration Program (AFRP), which is tasked with doubling the natural production of anadromous fish in CVP streams. The AFRP works toward this goal through a variety of habitat restoration projects that work to increase the spawning, rearing, and migration success of anadromous fish. Funding was approved in the FY2019 CVPIA Annual Work Plan.

1.2 Background

Butte Creek has the largest self-sustaining wild population of endangered spring-run Chinook salmon in the Sacramento River watershed and identified as a stronghold in the 2024 California Salmon Strategy for a Hotter, Drier Future (Office of Governor, 2024). The Butte Creek watershed encompasses approximately 510,000 acres. The upper watershed lies predominantly in Butte County, with smaller portions in Tehama, Glenn, and Colusa Counties. The lower

watershed is primarily in Butte and Sutter Counties. A major tributary to the Sacramento River, the stream originates in the Lassen National Forest at 7,087 feet. Butte Creek transitions from its headwaters in the Butte Meadows area approximately 25 miles through a canyon to the point where it enters the valley floor near Chico.

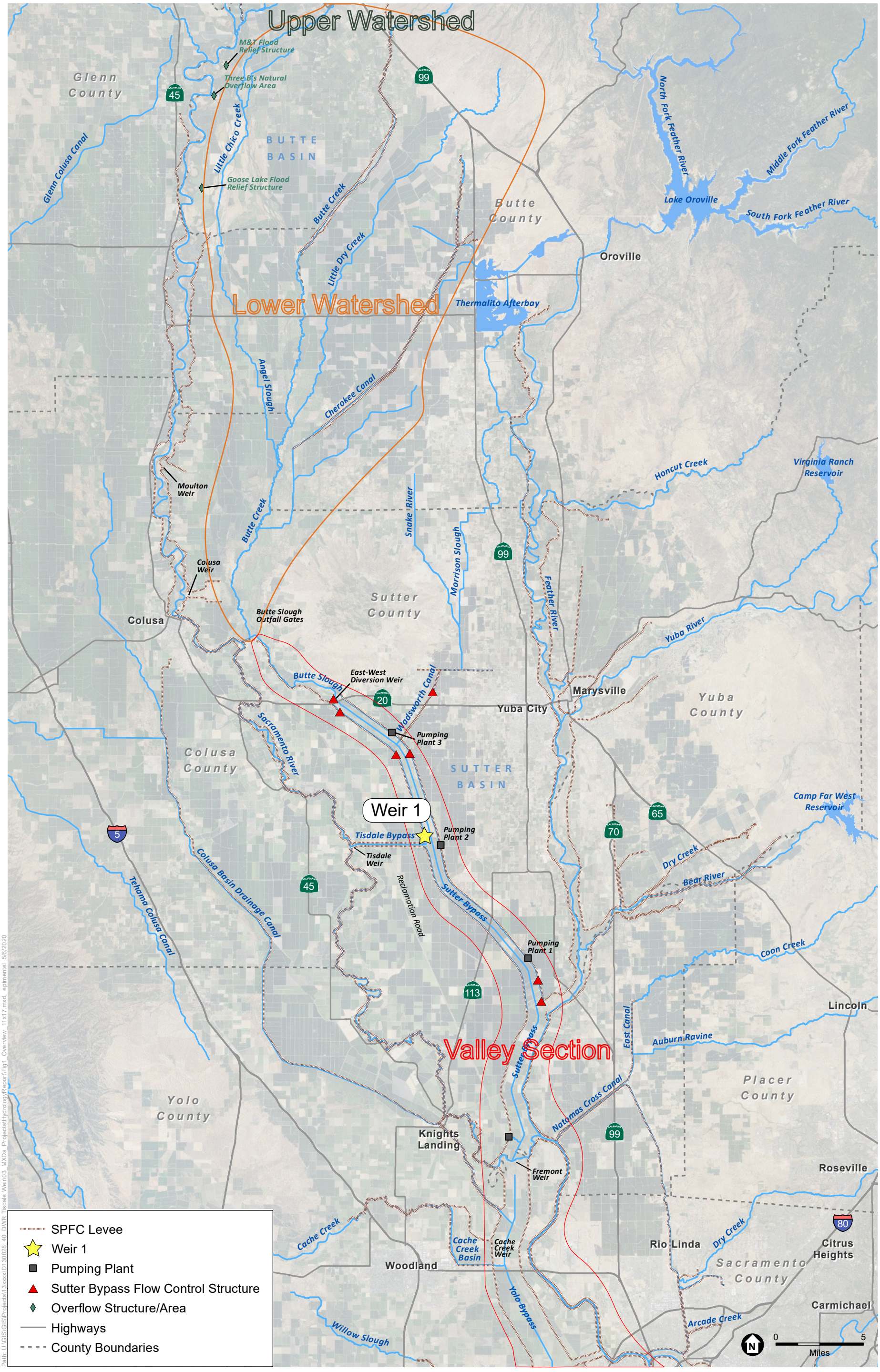
The valley section of Butte Creek, which is the focus of this project, is divided by the Sutter Buttes, located in the center of the Sacramento Valley (**Figure 1**). The upper portion (the Butte Basin) is approximately 50 miles long, extending upstream of Highway 99 near Chico to the Butte Slough Outfall Gates southeast of Colusa. Butte Creek, in this reach, is leveed and surrounded by agricultural lands and several state and federal wildlife areas. The Sutter Basin section of Butte Creek is approximately 40 miles in length. In this section, Butte Creek splits into the East and West Borrow Channels as it enters the Sutter Bypass near Highway 20.

Anadromous fish migrating to upstream spawning areas by way of Butte Creek encounter a series of anthropogenic channels (i.e., the East and West Borrow Channels) where they must navigate multiple fish ladders and diversion dams and weirs to make it into the canyon reach of Butte Creek (upstream of Highway 99) where the fish hold through the summer and later spawn in the autumn.

Spring-run Chinook salmon are especially vulnerable to delay and mortality at these passage obstacles because they migrate during spring months (primarily March through June) when water diversion from the lower Butte Creek system is most significant (California Trout 2016). At these times, fish ladders at weir structures can cease functioning, resulting in delayed migration and even dramatic fish kills. In the West Borrow Channel, Weir 1 is the first obstacle in the watershed faced by returning salmon and despite significant investments to improve fish passage in the past decades (see Section 1.2.1, below) Weir 1 is the last structure in the Sutter Bypass requiring retrofitting to facilitate the passage of spring-run Chinook salmon. Fish kills at the weir have been well-documented in recent years (CDFW, 2012; CDFW, 2013a, 2013b)[1] (**Figure 2**).

In addition to salmonids, other native species, including sturgeon and lamprey, move upstream and downstream in the Sutter Bypass and ostensibly must navigate Weir 1. During deep, flooded conditions in the Sutter Bypass Weir 1 is completely inundated, and it is likely that fishes like sturgeon and lamprey are able to simply swim over the structure in deep water to move upstream and downstream of Weir 1. During certain lower flow conditions, Weir 1 is likely a complete barrier to upstream passage for these other species (as well as the documented lack of passage for salmonids). While this project did not identify any documentation of stranding or mortality of sturgeon or lamprey below Weir 1, the structure is located very close to the Tisdale Bypass where significant sturgeon stranding is documented (ESA 2018). Consistent with sturgeon seeking to move upstream into the Sacramento River via the Tisdale Bypass, sturgeon attracted into Sutter Bypass flood flows are likely also attracted further up the East and West Borrow Canals past Tisdale Bypass when Sacramento River flood flows are entering the Butte Basin. Thus, it seems likely that sturgeon interact with Weir 1.

[1] On May 14th, 2012, a total of 32 carcasses were collected a disposed of in an adjacent riparian corridor. On April 24th, 2013, approximately 30-35 carcasses were found. On May 4th, 2013, approximately 15 carcasses were found.



SOURCE: USDA, 2016; Esri, 2018; DWR, 2019; USGS, 2019, ESA, 2020

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

Figure 1
Weir 1 Area Overview

ESA

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1.2.1 Prior Investments

In the 1990s, massive efforts were initiated to address adult fish passage and juvenile entrainment problems throughout the Butte Creek system. After significant improvements were completed in the upper Butte Basin in 1997, the Lower Butte Creek Project (LBCP) was initiated to improve passage for protected fish species throughout the Lower Butte Creek system. The LBCP was a stakeholder-driven program with participation from Butte Creek water users and resource agencies responsible for water management and fishery resource protection. The project resolved many critical fish passage and entrainment problems on the lower Butte Creek system. In all, over $60 million was spent on infrastructure improvements. Weir 1 remains one of the last major "physical fixes" still outstanding in the Butte Creek system.

SOURCE: CDFW, 2012

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

Figure 2
Fish Kill Downstream of Weir 1 (May 14, 2012)

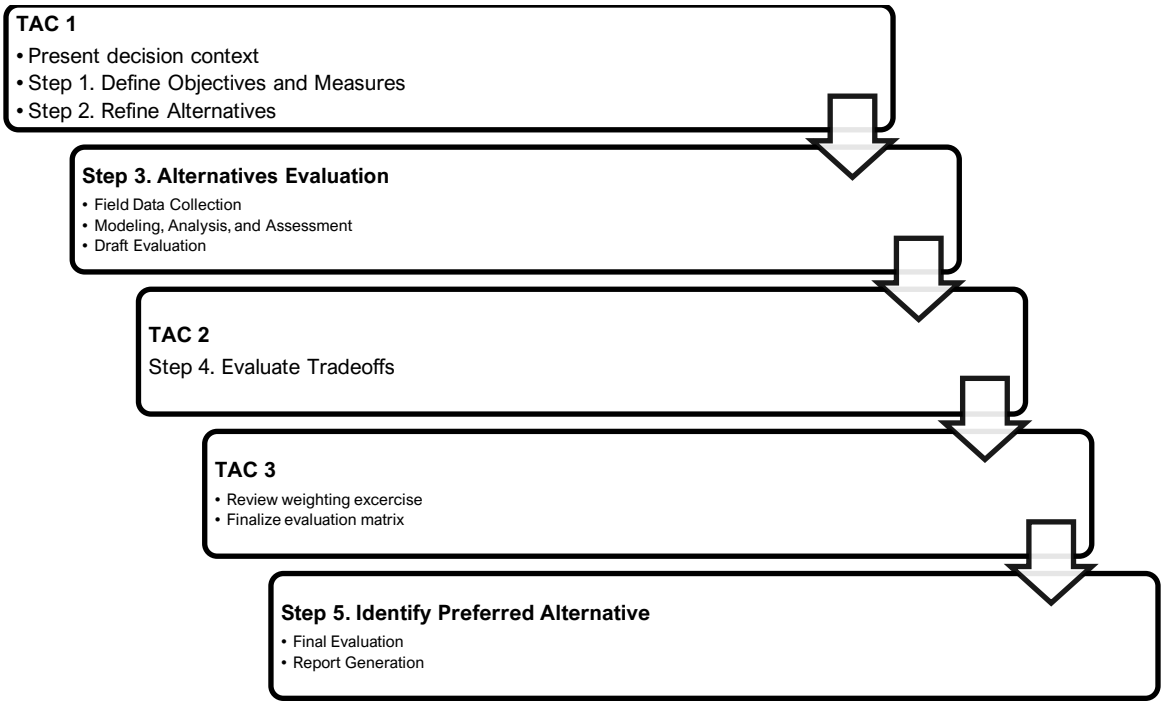
1.3 Approach

Representatives of the AFRP assembled a Technical Advisory Committee (TAC) to oversee the Weir 1 study with facilitation and technical support provided by ESA. The TAC includes members from the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), and California Department of Water Resources (DWR). A subset of the TAC was identified as the project management team (PMT), the group responsible for identifying the preferred project alternative (**Table 1**).

TABLE 1
TECHNICAL ADVISORY COMMITTEE

Name	Agency - Location
Project Management Team (PMT)	
Jim Earley	USFWS, Red Bluff
Duane Linander	CDFW, Sacramento
Mark Gard	CDFW, West Sacramento
Tracy McReynolds	CDFW, Chico
Steve Thomas	NMFS, Santa Rosa
Randy Beckwith	DWR, Sacramento
Other TAC Members	
Bjarni Serup	CDFW, Sacramento
Andy Trent	USFWS, Red Bluff
Mike D'Errico	USFWS, Willows
Jacob Byers	USFWS, Willows
Allison Bosworth	NMFS, Sacramento
Kimberly Clements	NMFS, Sacramento

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 (**Figure 3**). ESA developed and facilitated three TAC meetings to step through the process. During the first meeting, the TAC defined the objectives and measures guiding the evaluation and refined the four alternatives stipulated in the Notice of Funding Opportunity. Based on feedback from the first TAC meeting, ESA collected field data and conducted modeling, analysis, and assessment to evaluate the alternatives relative to existing conditions. The alternatives evaluation was conducted using the Altaviz framework as discussed in **Section 4.2.1**. ESA presented findings and introduced the alternatives evaluation and initial objective rankings during the second TAC meeting. Afterwards, the TAC participated in a swing weighting exercise where members offered their opinion on the relative importance of each project objective defined in **Section 1.4** below. ESA presented the results of the alternatives evaluation and weighted alternatives during the third and final TAC meeting. This project report documents the alternatives analysis, evaluation process, and selection of the preferred alternative.



SOURCE: ESA, 2023

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

Figure 3
Decision Process

1.4 Goals and Objectives

The project adopted the following as the overall project goal: "*Improve adult and juvenile passage of anadromous fish species, specifically spring-run Chinook salmon.*" Discussions with the TAC to arrive at this goal allowed for the development of specific objectives. The TAC reviewed and revised project objectives during the first two TAC meetings to arrive at the final set of objectives (to be used later as evaluation criteria) outlined in **Table 2**.

TABLE 2
OBJECTIVES FOR ALTERNATIVES ANALYSIS

Category	Objective
Positive outcomes for adult salmonids	Improve passage for adult spring-run Chinook salmon
Positive outcomes for juvenile salmonids	Improve juvenile salmonid rearing habitat
	Improve juvenile salmonid outmigration
Negative side effects	Avoid increased flood risk
	Reduce potential for channel instability
	Minimize negative effects to upstream habitat conditions
	Minimize negative effects to adjacent agricultural ditches/drains
	Minimize negative effects to adjacent wetlands

Category	Objective
Feasibility	Constructability considerations
	Permitting considerations
Maintenance burden	Minimize the degree and complication of operations
	Minimize consequences of maintenance deficiency
Costs	Minimize capital cost
	Minimize annualized operations & maintenance (O&M)
	Minimize potential mitigation

CHAPTER 2
Existing Conditions

2.1 Location and Context

Weir 1 is located downstream of the Sutter National Wildlife Refuge (SNWR) in the West Borrow Canal (WBC) of the Sutter Bypass and immediately upstream of where the Tisdale Bypass enters the Sutter Bypass. This portion of Butte Creek is formally inside an anthropogenic channel of the Sutter Bypass and lies relatively low in the Butte Creek system. Flows to the WBC come from the Butte Basin, including Butte Creek, small tributaries flowing into the Cherokee Canal, and Sacramento River flood overflows into the Butte Basin upstream of Weir 1. The Tisdale Bypass may discharge flood overflows from the Sacramento River into the WBC. See **Section 1.2** for more information.

The historical context of Weir 1 is well summarized in the passage below, reproduced from the draft Butte Slough/Sutter Bypass Fish Passage and Entrainment Assessment.

> *Weir 1 was used to provide water to the southern portion of the Sutter National Wildlife Refuge, but it does not presently serve a practical purpose in terms of providing irrigation or waterfowl habitat management benefits. Originally constructed in 1924 by the State Reclamation Board for the Northern California Land Company, USFWS rebuilt Weir 1 in 1974 and a fish ladder was added. In 2005, the weir was modified by removing the stoplog structures and reducing the weir down to the sill of the concrete box standings that once held the stoplogs. Additionally, the east abutment to the weir was breached to create a naturally flowing watercourse for fish. The fish ladder was left intact.* ***Weir 1 allows Giusti Weir, located upstream, to retain its natural fish passage channel. Without Weir 1 or a similar water control structure, a fish ladder or a series of rock groins would need to be installed at or below Giusti weir for migrating fish.*** *(ICF Jones & Stokes 2008)*

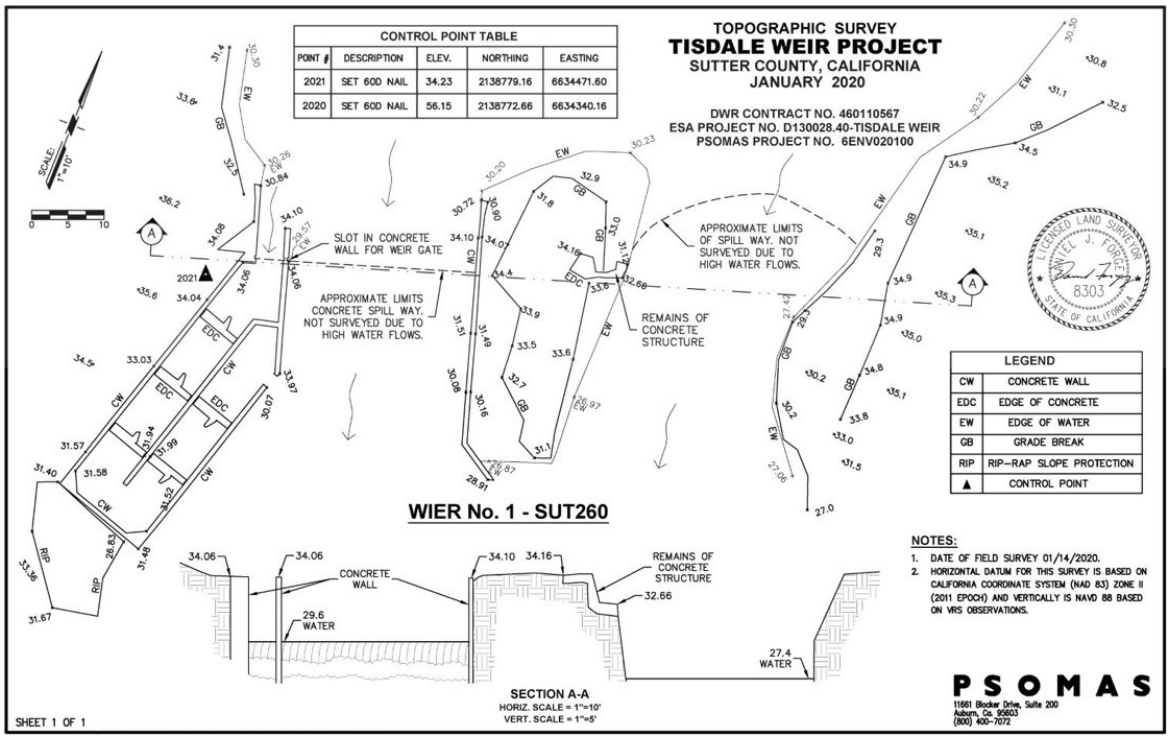
Weir 1 currently raises water surface elevations in the WBC during lower flows, which is hydrologically connected to the SNWR, which provides habitat for a variety of species, including waterfowl and juvenile spring-run Chinook salmon.

The Sutter Bypass is formed by levees on either side. A portion of the west levee near Weir 1 was reconstructed after an intentional breach (relief cut) associated with draining this portion of the Sutter Basin after an upstream levee failure south of Highway 20 occurred during the January 1997 flood event. For more information see **Section 2.5**.

2.2 Site Components and Conditions

Weir 1 comprises a concrete wall without stop logs, a fish ladder, a berm, and a flowing headcut watercourse (**Figures 4 and 5**). Removing the stoplogs resulted in water spilling over the wide opening in a shallow, dispersed manner (see the waterfall in the background of Figure 2). The breached east abutment, which created the flowing headcut watercourse, does not pass adult spring-run Chinook salmon during low flows. Together, the breach and the wide notch in the weir have worsened fish passage by dispersing flow, diminishing the attraction flow to the fish ladder, which was left in place during the modifications that took place in 2005.

During periods of low flow adult salmonids waste precious energy jumping at the essentially non-functional ladder or the "waterfall" formed by the un-engineered notches in the weir. CDFW scientists and law enforcement staff (CDFW, 2012; CDFW, 2013) have documented 1) delay in migration and poaching; 2) delay in migration and die-off (Figure 2) due to insufficient flows, low dissolved oxygen, and high-water temperatures; and 3) impaired passage and die-off in the ladder itself (impassable condition of the weir structure/ladder).



SOURCE: PSOMAS, 2020

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

Figure 4
Topographic Survey of Weir 1 (January 2020)

Note: Flow in WBC during the time of this image is estimated to be ~300 cfs based on preliminary hydraulic modeling conducted as part of this project. At lower flows in Butte Slough (around 350 cfs), the division between the East and West Borrow Canal is approximately 30 and 70 percent, respectively, based on a 2/7/20 discharge measurement by CDFW.

SOURCE: PSOMAS, 2020

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

Figure 5

Drone Image of Weir 1 Facing Upstream (North) (January 2020)

2.3 Surface Water Hydrology

As part of the Sutter Bypass system, the existing surface water hydrology of the WBC at Weir 1 is bimodal, with high flows during flooding and lower flows during non-flood events. Flood hydrology within the WBC can be primarily attributed to two flow inputs. The first is floodwaters from Butte Slough, which is diverted from the East-West Diversion Weir at the upstream end of the WBC. Butte Slough flood flows are generated from inputs in the Butte Basin, primarily from Butte Creek and inputs like Cherokee Canal (Dry Creek) however during significant events when the Sacramento River is flowing full, additional water can be diverted from the Sacramento River into the Butte Basin from the Moulton Weir or Colusa Weir or the M&T Flood Relief Structure, the Goose Lake Flood Relief Structure, or the Three B's Natural Overflow Area (ESA 2020). The second primary flow input to the WBC hydrology is the spill from the Tisdale Weir. During significant flood events, Sacramento River flood flows may also enter the Sutter Bypass downstream of Weir 1 via the Tisdale Weir and Bypass, creating a backwater effect on the WBC and providing connectivity between the borrow canals and the Tisdale and Sutter Bypasses.

During low-flow periods, hydrology within the WBC consists of primarily of flow from Butte Slough after being diverted by the East-West diversion weir. Agricultural drainage from surrounding lands is also routed through the system. During maximum flows within Butte Slough (approximately 2,000 cfs), the East-West diversion weir is operated to divide the flow to the EBC and WBC by approximately 60 and 40 percent, respectively. The Butte Slough Irrigation

Company operates the East-West diversion weir under informal coordination agreements with Sutter Bypass farmers (ICF Jones & Stokes 2008).

During high-flow periods water levels within the WBC are highly influenced by the backwater effects of flooding within the Tisdale and Sutter bypasses. It is likely that Weir 1 does not impede fish passage within the reach during flood conditions. For this reason, the assessment of dry-year hydrology within the WBC is essential to understanding the flows that hinder passage.

The Butte Slough near Meridian (BSL) DWR gage is the closest surface water gage to the project area and is located upstream of the East-West Diversion weir. Downstream of the East-West Diversion and upstream of Weir 1, several operable weirs (Weir 3 and Weir 5) within with the WBC divert water for irrigation with limited flow diversion records. Due to the scarcity of diversion records and the absence of gaged flow records within the WBC, estimated flow data was used to assess low-flow conditions.

Previous studies within the Sutter Bypass include the Tisdale Bypass Fish Passage Improvement Project, in which a TUFLOW hydrodynamic model (TUFLOW model) was used to simulate conditions within the Sutter Bypass and adjacent canals for a period of 22 years (1997 – 2018) (ESA 2020). The TUFLOW model incorporated weir gate operations for upstream structures and used a one-dimensional channel for the WBC connected to a two-dimensional mesh that represents the Sutter Bypass. The TUFLOW model results were used to estimate dry and critical water year hydrology within the WBC. Further details on the analysis can be found in **Appendix A**.

2.4 Upstream Diversions

There are no diversions, operations, or flow agreements directly within the area of relevance between Weir 1 and the Guisti Weir. Other diversions in the Sutter Bypass West Borrow Canal upstream of Guisti Weir include the Butte Slough Irrigation Company (BSIC) Gravity Diversion, the Lanza Pumps, and the Tule Basin Farms Pumps (described below). Potential flow agreements for Butte Creek could affect the project area. However, none of the project alternatives under evaluation will affect existing flow agreements. The Reclamation District 1660 gravity-fed outfall gate located downstream of Weir 1 could potentially be affected by an increase in the water surface elevation downstream of Weir 1. Installing a new pump serving the SNWR could increase water surface elevations upstream of Weir 1.

Sutter Bypass West Borrow Canal Diversions

BSIC Gravity Diversion

BSIC has a 48-inch-diameter corrugated metal pipe upstream of Weir 5 under the adjacent levee that diverts water to an irrigation canal outside the Sutter Bypass. The BSIC diversion was screened when the weir was upgraded in 2002.

Lanza Pumps

The Lanza diversion consists of two pumps that divert water from the WBC to the interior of the Sutter Bypass. One pump, with a pump capacity of 3 cfs, is about 3,500 feet upstream from Weir 3 and is occasionally used to supply water to a private wetland area immediately north of the Sutter National Wildlife Refuge. The second pump, with a design capacity of 6 cfs, is approximately 4,800 feet upstream of Weir 3 and supplies irrigation water to a rice field immediately north of the private wetland. These are unscreened diversions.

Tule Basin Farms Pumps

There are two Tule Basin Farms pumps, one located immediately upstream of Weir 3 and the other immediately upstream of the Giusti Weir.

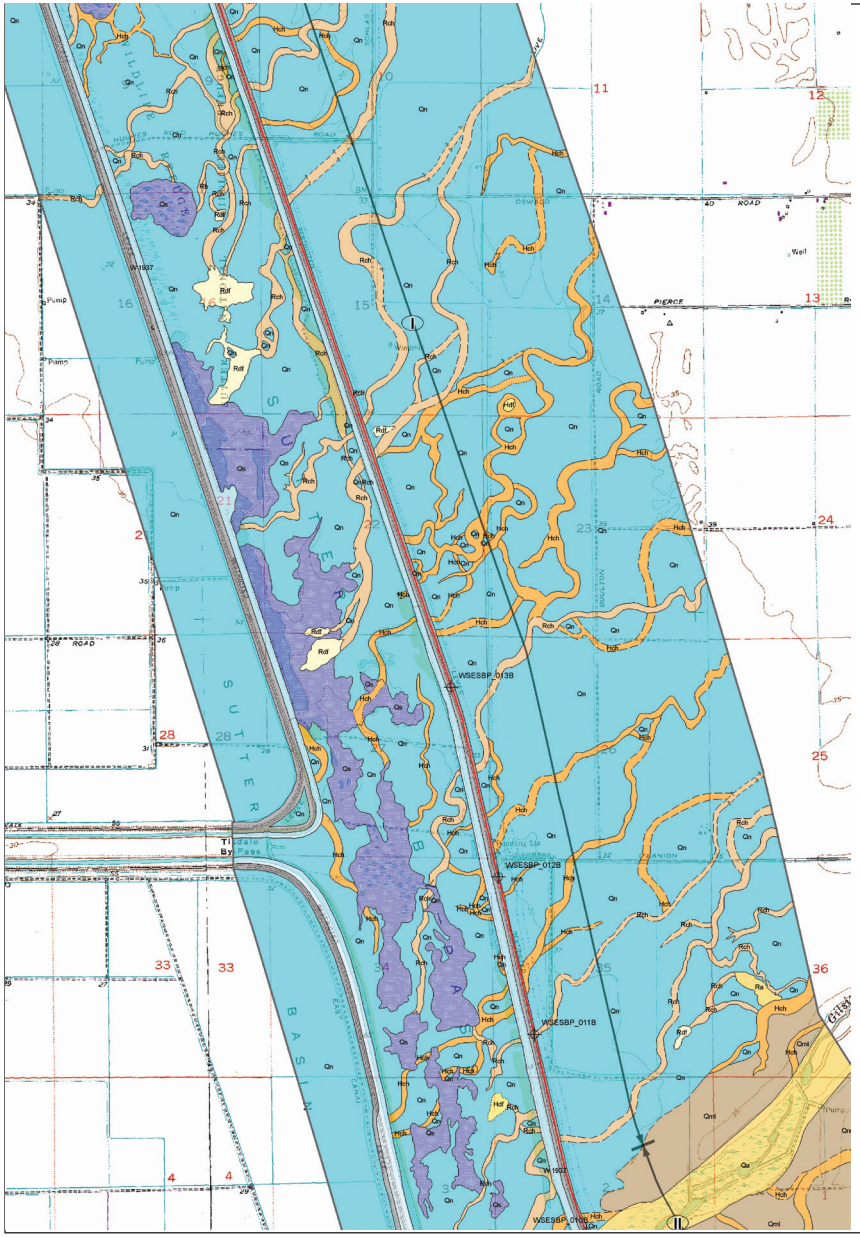
The pump upstream of Weir 3 is owned by Tule Basin Farms and operated by the BSIC as a lower diversion. According to John Brennan (landowner), the design capacity of the pump is somewhere between 3000 and 4000 gallons per minute, approximately equivalent to the higher capacity Lanza pump (Brennan personal communication, 2023).

The pump upstream of Guisti weir consists of an unscreened 48-inch-diameter pipe that diverts water under the west levee to a concrete structure housing two pumps. The combined capacity of these pumps is approximately 21 cfs. Flow through the pipe is controlled with a 48-inch slide gate on the water side of the levee. This diversion irrigates agricultural fields and manages wetlands to the west (outside) of the Sutter Bypass. The primary agricultural diversion season is from mid-April through September. Diversions for managed wetlands begin in October or November and may extend through mid-April, depending on the timing and duration of flooding.

Source: ICF Jones & Stokes (2008). John Brennan personal communication 8/16/2023.

2.5 Geotechnical Setting

The surficial geologic conditions within the study area are driven by Feather River and Sutter Basin morphology (**Figure 6**). A westward movement characterizes the localized groundwater interactions around Weir 1 because the Sutter Bypass is not a "natural channel" and is not located at the bottom of the Sutter Basin, which is located west of Weir 1. While groundwater flows towards the west, surface water can be pumped from the agricultural fields west of the weir into the WBC. As mentioned above, the western levee of the Sutter Bypass was intentionally breached as part of the 1997 Meridian flood fight.



Explanation

Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts have a resolution no better than about 30'.

Geomorphic Reaches Discussed in Text

Project Levee

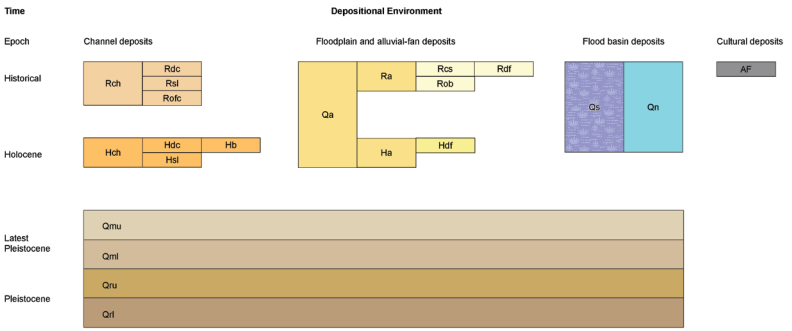
WSESBP_001B — Geotechnical borehole, approximately located.

W — Water visible on 1937 aerial photography.

Geologic Units

	AF	Artificial fill; visible on 1937 aerial photography.
HISTORICAL	Rob	Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
	Rcs	Crevasse splay deposits; fine to coarse sand, with minor lenses of clay deposited from breaching of natural or artifical levees.
	Rdf	Distributary fan deposits; sand, silt and clay.
	Rch	Channel deposits; well sorted sands and fine gravels.
	Rb	Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
	Rdc	Distributary channel deposits, trace gravel, sand, silt, and clay; channelized flow conducting sediment to floodplain.
	Rofc	Overflow channels; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
	Rsl	Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
	Ra	Alluvial deposits, undifferentiated; sand, silt, and minor lenses of fine gravel.
HOLOCENE	Hdf	Distributary fan deposits; sand, silt and clay.
	Hch	Channel deposits; sorted sands and silts; fining upward.
	Hb	Channel bar deposits; fine sand, and silt deposited in or along channel lateral margins.
	Hdc	Distributary channel deposits, sand, silt, and clay.
	Hsl	Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
	Ha	Alluvial deposits; undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
	Qa	Alluvial deposits, undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
	Qn	Basin deposits; fine sand, silt and clay, dark yellow to dark yellowish brown, under cultivation in 1937.
	Qs	Marsh deposits; silt and clay, likely organic-rich; perennially or seasonally submerged on 1937 photography.
PLEISTOCENE	Qmu	Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
	Qml	Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
	Qru	Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
	Qrl	Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally associated with strong duripan horizon.

Stratigraphic Correlation Chart



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SOURCE: USACE, 2013

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

Figure 6
Surficial Geology Map of Weir 1 Area

ESA

The near-surface geology in the Sutter Bypass area is generally characterized as follows:

- Fine-grained Holocene basin and/alluvium deposits overlie coarser late Pleistocene deposits of the Modesto and Riverbank formations.
- Typically, well-developed soil with impervious horizons (hardpan) is found at the top of the late Pleistocene deposits, the basin, and/or alluvium deposits from the underlying coarser deposits.
- Fine-grained basin and/or alluvium deposits and the hardpan generally have much lower hydraulic conductivity than the underlying late Pleistocene deposits.

More recent Holocene-aged and historical channel deposits (map units Hch and Rch) are incised into the basin deposits. These southwest-trending alluvial channel deposits locally underlie the bypass levee and result in local differences in material textures beneath the levee. The mapped channels are about 250 feet wide. In this area, the channels are estimated to be about 6 to 8 feet deep and are typically filled with sand, silt, and clay in a fining-upward sequence, i.e., coarser-grained and overlain by about 1 to 2 feet of silt and clay. This sedimentary sequence may be conducive to seepage where relatively more permeable channel sands are overlain by a relatively thin, fine-grained blanket layer (Source URS 2014).

The DWR-sponsored geotechnical investigations for the east levee of the Sutter Bypass (adjacent to the East Borrow Canal) highlighted the fine-grained lower permeability blanket layer overlying coarser late Pleistocene deposits. Due to their age, layers of very hard soil, or hard pan, can develop and were identified in the east levee exploration performed within this reach of the bypass. The borrow excavations would have extended through the hardpan layers. After performing a review of available area photography and the available information from prior studies, the following can be concluded regarding current site conditions:

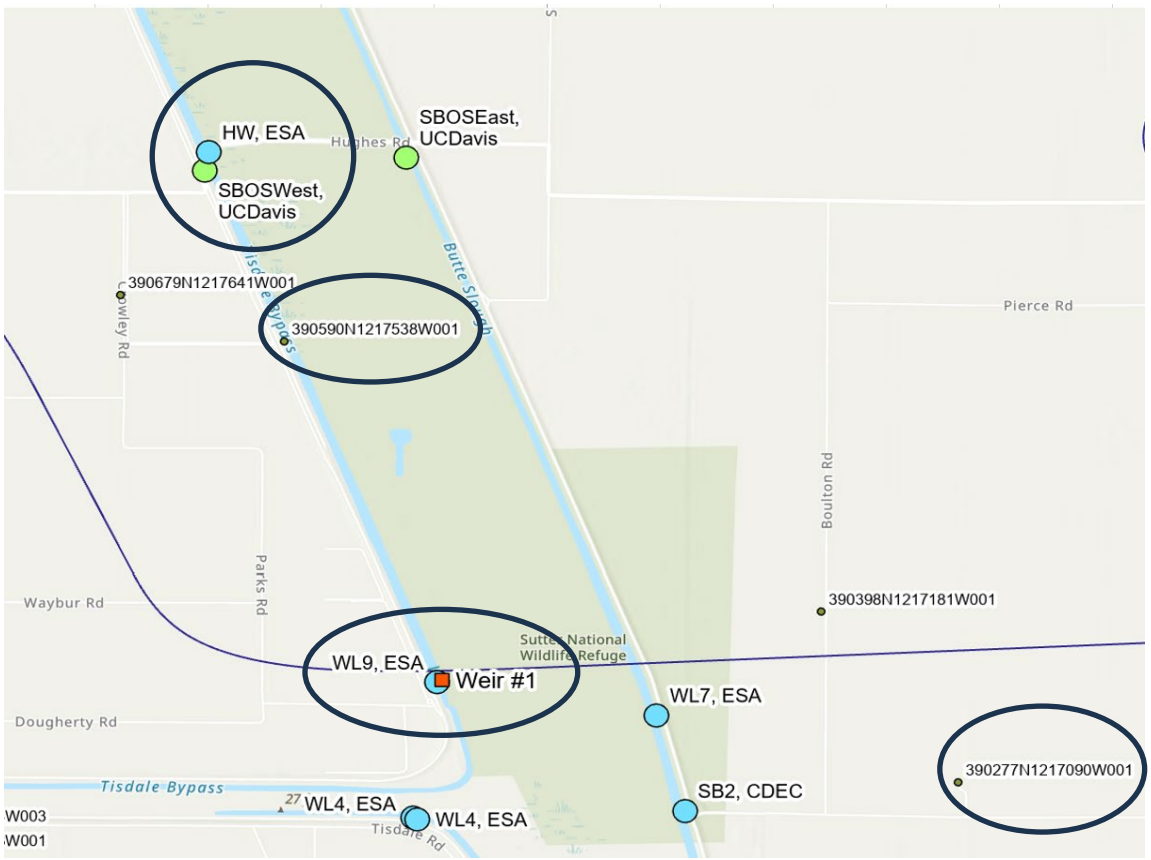
- Weir 1 is constructed on an access road remnant that extended across the refuge, and the access is still in use (bridge) at the east levee borrow area.
- The southern limit of the east dragline borrow cut (East Borrow Canal) is the deepest parallel to the levee with a shallower, variable-width bench to the east.
- Near vertical borrow cut slopes are still in place along both the east and west cut banks.
- The head cut in the embankment adjacent to Weir1 may be formed along the top of the hardpan layer (approx. Elev. +27 feet NAVD88) with the weir extending into the underlying stiff to hard clay and silt.

Knowledge of the geotechnical setting surrounding Weir 1 provides insights into the soils and sediments that define the channels and floodplain and presents important considerations for the alternatives evaluation including the potential for headcut migration and increased surface water and groundwater interactions under weir removal scenarios (Alternatives A and B). Please see **Appendix B** for additional details of the preliminary geotechnical assessment.

2.6 Groundwater Interactions

The historic channel deposits underlying the Sutter Bypass have an influence on surface water and groundwater interactions. A concern with this study is that any alteration of surface water conditions may result in unintended consequences to adjacent, hydrologically connected waterbodies, including the wetlands along the east side of the WBC and the water supply canal and toe drain that runs parallel to the western levee of the Sutter Bypass.

To better understand the relationship between surface water and groundwater interactions, ESA analyzed readily available monitoring data. ESA and the University of California Davis (UCD) maintain a series of surface water monitoring stations within the WBC, two of these upstream near Hughes Road (HW and SBOS West) and the third at Weir 1 (WL9). In addition, DWR maintains several groundwater monitoring stations near the study area, though only one is located within the West Borrow Canal. That site is approximately two miles upstream of Weir 1 (Site Code: 390590N1217538W001). The next most relevant monitoring station (based on the period of record) is located a couple of miles east of the Tisdale Bypass near Obanion Road (Site Code: 390277N1217090W001). **Figure 7** shows the location of these monitoring stations relative to Weir 1.



SOURCE: ESA, 2023

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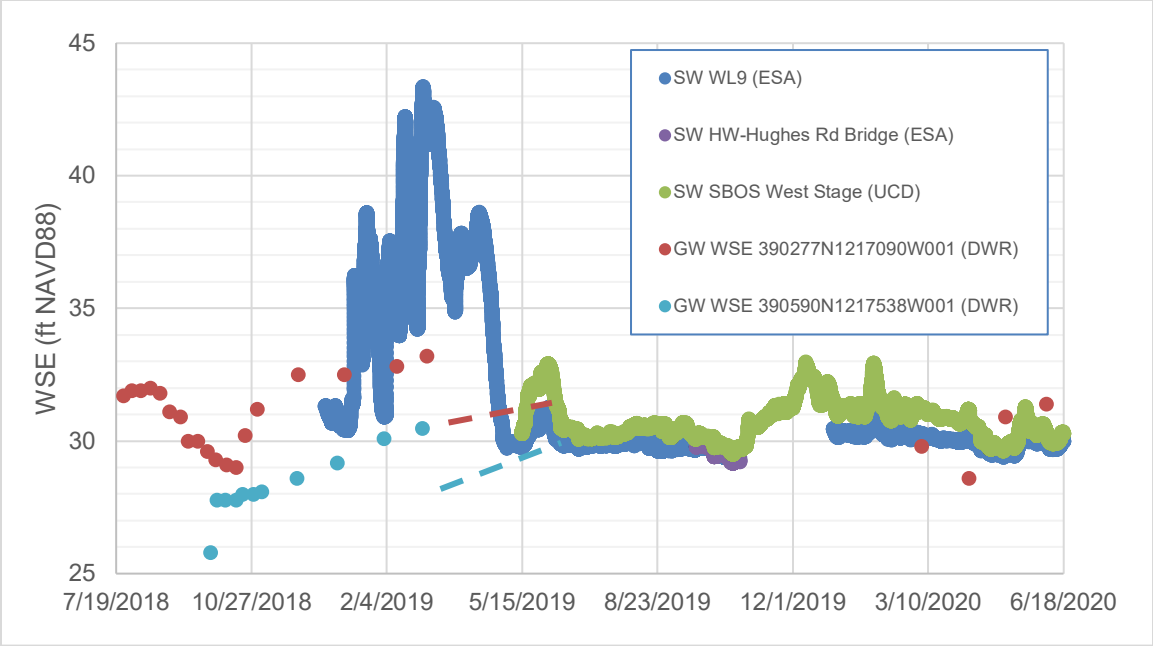
Figure 7
Relevant Monitoring Stations

There is limited overlap between the various monitoring data. Still, a comparison of data between July 2018 and June 2020 (two years of record) suggests that groundwater levels may exceed surface water levels as the Sutter Bypass drains and flows recede within the WBC (see the dashed extrapolation lines in **Figure 8**). Under these conditions, the WBC would become a gaining reach.



SOURCE: DWR, 2023; ESA, 2019, 2021; UCD 2020

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Figure 8

Surface Water and Groundwater Levels Near Weir 1. Dashed lines show potential ground water levels as the flows in the bypass recede.

2.7 Associated Wetlands

The Sutter National Wildlife Refuge (SNWR), owned and operated by the U.S. Fish and Wildlife Service, is part of the Sacramento National Wildlife Refuge complex and includes approximately 2,590 acres of managed wetlands, grasslands, and riparian habitat (**Figure 9**). About 80 percent of the refuge is in the Sutter Bypass. The SNWR is adjacent to the WBC and just upstream of the Tisdale Bypass.

During major flood events, portions of the SNWR are covered by up to 15 feet of water. The SNWR typically supports approximately 200,000 ducks and 100,000 geese from September through April, with peaks during January and February. The SNWR also provides habitat for federally listed and State-listed endangered and threatened species, such as the giant garter snake, Chinook salmon, yellow-billed cuckoo, and Swainson's hawk (USFWS 2020).