ZANKER FARM SALMONID HABITAT RESTORATION PROJECT

100% DESIGN REPORT

Grant Agreement Numbers - Q1940405-02 and Q2140407

Final

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LIST OF ABBREVIATIONS AND ACRONYMS

2-D	Two-dimensional
A	Access Roads
ADV	Acoustic Doppler Velocimeter
ASTM	A370 Standard Test Methods
BCH	Baitidae, Chironomidae, Hydropsychidae
BMI	Benthic macroinvertebrates
BOB	Bobcat Flat Phase III
°C	Degrees Celsius
C	Contractor Use and Staging Areas
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CVFPB	Central Valley Flood Protection Board
d	diameter
DEM	Digital Elevation Model
dtDEM	Detrended Digital Elevation Model
DTM	Digital Terrain Model
ESA	Endangered Species Act
EPT	Ephemeroptera, Pleocoptera, Trichoptera
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FYFAM	Foothill Yellow-legged Frog Assessment Model
FYLF	Foothill Yellow-legged Frog
FP	Floodplain Bench
ft	feet
ft/ft	feet per foot
ft^2	square foot
GCP	Ground Control Points
GM	Silty Gravel
GMA	Graham Matthews and Associates
GPS	Global Positioning System
GW	Well-graded Gravel
GW-GM	Well-graded Gravel to Silty Gravel
GW-SW	Well-graded Gravel to Well-graded Sand
HEC-RAS	Hydrologic Engineering Center–River Analysis System

HSC	Habitat Suitability Criteria
HSI	Habitat Suitability Index
HSI_i	Weighted HSI Value
HVT	Hoopa Valley Tribe
HWM	High Water Mark
IC	In-channel Feature
in	inches
in^3	cubic inches
lb	pound
lb/ft^2	pound per square foot
LiDAR	Light Detection and Ranging
MA	McBain Associates
ML	Silt
NDPP	New Don Pedro Project
NDP	New Don Pedro
PP	Photopoint
R	Riffle
RM	River Mile
RTK	Real Time Kinematic
s	second
SC	Side Channel
SRP	Special Run Pool
SW	Well-graded Sand
TIN	Triangular Irregular Network
TP	Test Pit
TRC	Tuolumne River Conservancy, Inc.
U	Upland Areas
UAV	Unmanned Aircraft Vehicle
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
W	Wetland
WSE	Water Surface Elevation
WUA	Weighted Usable Area
yd^3	cubic yards

Executive Summary

The Zanker Farm property includes approximately 1.5 miles of the Tuolumne River (RM 45.2 to RM 46.8), between Turlock Reservoir and Basso Bridge at the downstream end of the dominant spawning reach of the Tuolumne River. Adult Chinook Salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* (which includes Central Valley steelhead and resident Rainbow Trout) use the few existing riffles in this reach to spawn. Restoration of the property aims to replace a single large, homogeneous, deep, bedrock-bottom pool with a diversity of riffles, pools, gravel bars, side channels, and floodplain habitats to increase salmonid spawning habitat and benefit all life stages of salmonids. Outside of the channel, the Project aims to remediate the impacts of historical dredger mining, which inverted the soil profile and left floodplain and terrace surfaces armored with gravel and cobble. The Project will excavate remnant scraped dredger mine tailings from floodplain and terrace surfaces on the Zanker Farm, wash and sort the gravel, and then place the gravel in-channel. The remaining excavated floodplain surfaces will be restored to a finer sediment substrate, providing rearing habitat at higher flows as well as opportunities for riparian forest recovery.

The Project will place 85,370 yd^3 of gravel as in-channel features and excavate 12.7 acres of new floodplain and side channel habitat. In-channel features include 17 new riffles and 16 new gravel bars in the Tuolumne River. Riffles are generally designed with (1) 0.2–2.0% slope to promote sediment transport and geomorphic function, or (2) 0.15–0.25% slope for spawning and benthic macroinvertebrate production. Hydraulic modeling results showed 0.5–3 feet (ft) depth and 0.9–4.5 feet per second (ft/s) velocity throughout the 100% design riffles, which falls within the range of suitable habitat for *O. mykiss* and Chinook Salmon life stages. These design features will increase spawning habitat for salmonids.

Both side channels and floodplain habitats will be constructed to provide rearing habitat for salmonids. Approximately 7.3 acres of side channels will be added along with 5.4 acres of floodplain habitat. These surfaces will inundate at approximately 300 cfs, providing stage resilient areas of low velocity refuge, primary and secondary production, and cover. Floodplain habitats are designed to gently slope to provide continuous shallow water habitat on the ascending and descending limbs of flow pulses. This stage resiliency provides habitat regardless of the exact flow that is released from New Don Pedro Dam. Salmonid habitat was analyzed by first determining the limiting life stages in the Project area. Spawning habitat is most limiting for both Chinook Salmon and *O. mykiss*. Therefore, this Project focused on improving spawning habitat for both species. To evaluate success, the weighted usable area of suitable habitat was calculated. These calculations use species- and life-stage specific habitat suitability indices – i.e., a curve of suitability between 0 and 1 that describe the relative suitability of physical habitat attributes, such as depth, velocity, cover, and substrate. Each parameter’s habitat suitability is then multiplied together to determine an overall habitat suitability for that area, then summed across the site. Adult spawning habitat and fry and juvenile rearing habitat for both species, as well as adult *O. mykiss* habitat, were evaluated. The Project as designed will increase spawning habitat for both species, fry rearing habitat for both species, and *O. mykiss* juvenile rearing habitat at flows relevant for these life stages. The Project will decrease Chinook Salmon juvenile habitat at some relevant flows, as this life stage thrives in the existing deep pools in the Project site. The Project will add spawning gravel to the existing pools, making these areas shallower, to address the spawning habitat limitation.

Benthic macroinvertebrates are an important component of riverine ecology and associated food webs, as they are a primary food source for many organisms including rearing juvenile salmonids, amphibians and reptiles, and terrestrial animals including bats and birds. Benthic macroinvertebrates were evaluated using the same methods as salmonid habitat, ranking substrate, depth, and velocity on a 0 to 1 scale and then multiplying each parameter’s index for each area. Then the weighted indices are summed for the entire Project area to obtain the weighted usable area for two different metrics – diversity and biomass. Both diversity and biomass of benthic macroinvertebrates generally increased in the 100% design compared to existing conditions.

Two species of turtles are known to occur in the Zanker Farm Project area: the native Northwestern Pond Turtle (*Actinemys marmorata*), and the invasive Red-eared Slider (*Trachemys scripta elegans*). Observations in summer 2022 and reports from the landowner indicate the invasive Red-eared Slider is well established and appears to be more abundant in the area than the native Northwestern Pond Turtle. Returning functional alluvial river elements to the river through the design may give a competitive advantage to the Northwestern Pond Turtle. Under the existing condition, without restoration, it is likely that over time, the invasive Red-eared Slider will displace and ultimately replace the Northwestern Pond Turtle.

In addition to turtles, the design was evaluated for Foothill Yellow-legged Frog populations, which are extirpated from the lower Tuolumne River. The design should have minimal implications for Foothill Yellow-Legged Frog, which has not been observed on the Project site or nearby.

The 100% design for the Zanker Farm Project will benefit riparian vegetation. The designed side channel and floodplain surfaces will lower elevations, bringing plant root zones closer to the groundwater table. The 100% physical designs will convert 0.7 acres of land below the estimated groundwater table, 10.8 acres of the riparian–upland transition zone, and 9.1 acres of upland zone to 13.5 acres of emergent/channel margin zone, 3.8 acres of low riparian zone, and 3.4 acres of high riparian zone. These changes will provide more ground surfaces with suitable groundwater conditions to promote riparian plant initiation and survival. Riparian recruitment was estimated using the TARGETS model to evaluate how the design improves passive seedling recruitment. The riparian recruitment model incorporates streamflow magnitude, timing, duration, and rate of change, in combination with site topography, stage–flow relationships, root growth rates, and seed dispersal periods to forecast seedling survival during the modeled time period. Modeling showed that the design surfaces will be low enough to support early life stages for willows and cottonwoods. The design increased seedling survival across all modeled water year types for both species as compared to existing conditions.

The Project is estimated to cost approximately $14.2 million dollars at the 100% cost estimate level, including gravel, equipment, labor, large wood and boulder purchases, plant material purchases, supplies, construction management, inspection, and monitoring. This Project would likely be constructed over two years, to allow in-water work to fit within the June to October in-water work window. Plant acquisition needs to begin 1–2 years before the year the revegetation plan is implemented.

1 INTRODUCTION

The Zanker Farm is located along a 1.5-mile reach of the lower Tuolumne River, from approximately river mile (RM) 45.2 to 46.7 upstream of the confluence of the Tuolumne River with the San Joaquin River (Figure 1). The Zanker Farm Salmonid Habitat Restoration Project (Project) is situated in the Dominant Salmon Spawning Reach of the Tuolumne River, a reach defined by high salmon spawning use, agricultural land use, low valley confinement during high flows, moderate slope, and a gravel-bedded channel, as described in the *Habitat Restoration Plan for the Lower Tuolumne River Corridor* (M&T 2000). Restoration of the Zanker Farm Project area was identified as high priority in the *Restoration Plan* due to degraded channel and habitat conditions following gold mining and streamflow regulation.

During the first half of the 1900s, the Tuolumne River channel and floodplain were dredged for gold. The gold dredges excavated channel and floodplain alluvial deposits to the depth of bedrock or sand (up to 25 feet [ft]) and often realigned the river channel. After recovering the gold, the dredges deposited the remaining tailings back onto the floodplain, creating large, cobble-armored windrows separated by dredger sloughs. By the end of the gold mining era, the majority of the area's floodplains, including some of this Project area, had been converted to dredger tailings. In the 1960s, many of the tailings were excavated to provide construction material for New Don Pedro Dam. These areas remain largely barren, unproductive surfaces with exposed coarse sediment/cobble and little or no soil layer.

Adult Chinook Salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* (which includes Central Valley steelhead and resident Rainbow Trout) use the few existing riffles in this reach to spawn. Restoration of the property aims to replace a single large, homogeneous, deep, bedrock-bottom pool with a diversity of riffles, pools, gravel bars, side channels, and floodplain habitats to increase salmonid spawning habitat and benefit all life stages of salmonids. Outside of the channel, the Project aims to remediate the impacts of historical dredger mining, which inverted the soil profile and left floodplain and terrace surfaces armored with gravel and cobble. The Project will excavate remnant scraped dredger mine tailings from floodplain and terrace surfaces on the Zanker Farm, wash and sort the gravel, and place the gravel in-channel. Additional gravel will be purchased as needed. The remaining excavated floodplain surfaces will be restored to a finer sediment substrate, providing rearing habitat at higher flows and opportunities for riparian forest recovery.

Restoration at Zanker Farm began in 2021 with a grant from the California Department of Fish and Wildlife (CDFW). Zanker Phase I was funded by CDFW grant agreement number Q1940405, with a 30% design developed in early 2022. Also in 2022, a second grant was obtained, and restoration planning began for Zanker Phase II, funded by CDFW grant agreement number Q2140407. Phase II was also developed to the 30% design level, and then Phase I and Phase II were combined into a single Project, the Zanker Farm Project, based on agency and landowner input (McBain Associates 2023). This document updates the 65% design with several refinements (Figure 2, Figure 3). Important documents produced during the design stages at Zanker Phase I and Phase II include:

- *Zanker Farm Salmonid Habitat Restoration Project Existing Conditions Report.* Grant Agreement Number Q1940405-01, completed in April 2021 (McBain Associates 2021)
- *Zanker Farm Salmonid Habitat Restoration Project 30% Design Report.* Grant Agreement Number Q1940405-01, completed in April 2022 (McBain Associates 2022a)
- *Zanker Phase II Salmonid Habitat Restoration Project Existing Conditions and Options Analysis Report.* Grant Agreement Number Q2140407, completed in October 2022 (McBain Associates 2022b)
- *Zanker Phase II Salmonid Habitat Restoration Project 30% Design Report.* Grant Agreement Number Q2140407, completed in December 2022 (McBain Associates 2022c)

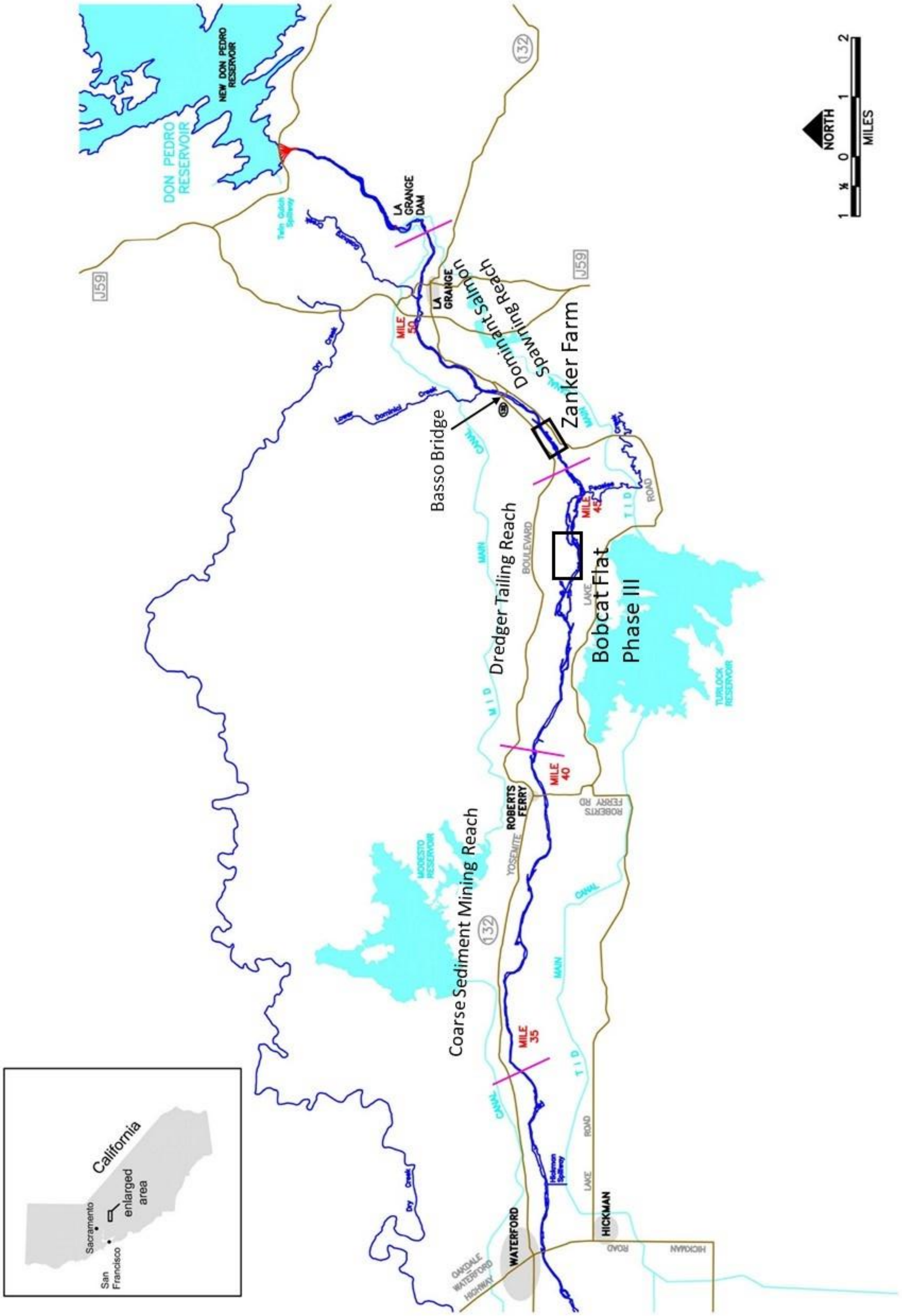

Figure 1. Zanker Farm Project (RM 45.2 to RM 46.7) location map showing nearby cities of Waterford and La Grange, and close proximity to Basso Bridge, the Bobcat Flat Phase III restoration site, Turlock Reservoir, and La Grange Dam. Also shown are the Coarse Sediment Mining Reach, Dredger Tailing Reach, and Dominant Salmon Spawning Reach as described in M&T (2000).

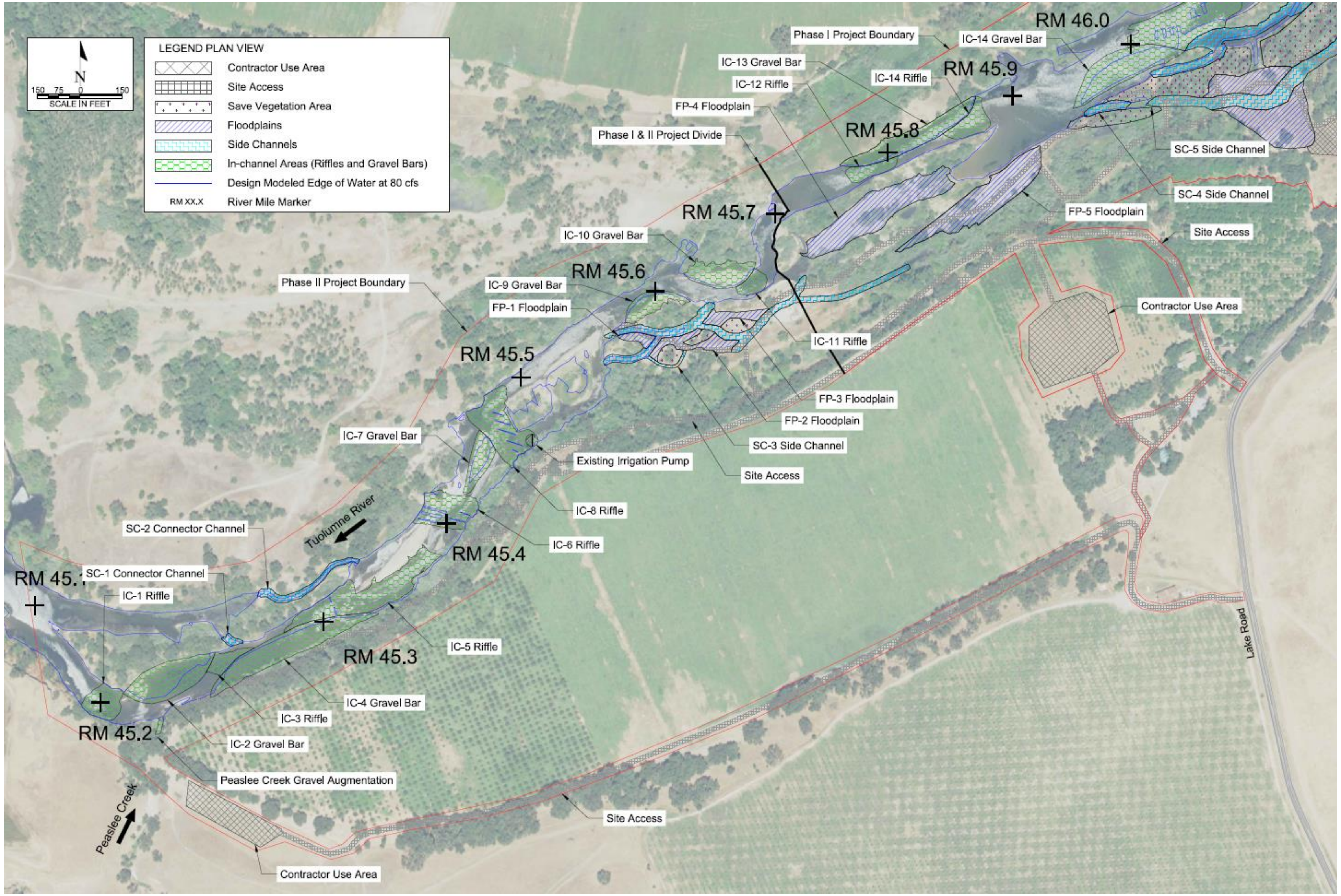

Figure 2. Overview map of the downstream end of the Zanker Farm Project area and 100% design features.

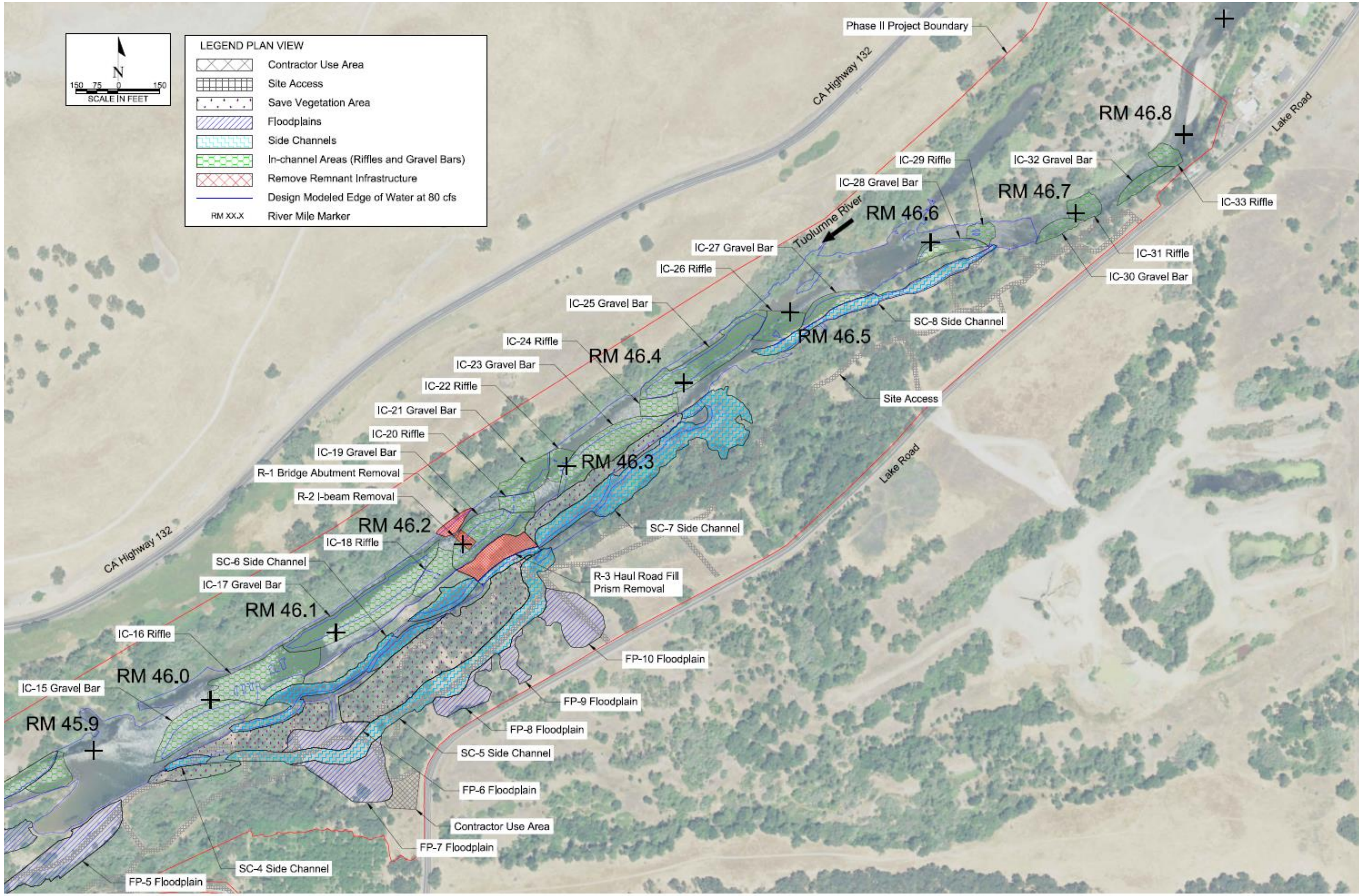

Figure 3. Overview map of the upstream end of the Zanker Farm Project area and 100% design features.

This document describes the 100% design for the channel and floodplain restoration of the Zanker Farm property (Figure 2, Figure 3). It includes both Zanker Phase I and Phase II. The design includes adding a substantial amount of gravel to the Tuolumne River channel to create 33 in-channel gravel bars and riffles to increase the amount of Chinook Salmon and *O. mykiss* spawning habitat available in the reach. In addition, two existing dredger sloughs will be regraded to function as a single side channel. Several additional side channels will be created adjacent to floodplain habitat, providing increased suitable habitat for juvenile salmonid rearing. Floodplain habitat will be created, and predator habitat will be reduced in Peaslee Creek and former dredger pools. Chinook Salmon fry and juvenile and *O. mykiss* fry suitable habitat increase with the project.

The Project will also benefit non-salmonid species. Lowered floodplains are expected to promote passive (i.e., natural) recruitment of native riparian plant species and provide suitable growing conditions for riparian plantings. The increased riparian vegetation will benefit native wildlife species and provide material for aquatic primary and secondary production. For herpetofauna, the Project will decrease the quiescent habitat favored by invasive Red-eared Sliders, without significantly changing the amount of habitat for the native Northwestern Pond Turtle.

1.1 Site Conditions

The Zanker Farm Project area extends along approximately 1.5 miles of the Tuolumne River upstream of Peaslee Creek (Figure 4) Approximately half of the mainstem Tuolumne River within the Zanker Farm Project area consists of two different straight sections of channel having little topographic complexity, with channel depths ranging from 4–15 ft at low flows (80 to 300 cfs). The channel in these areas is primarily a deep, low velocity, straight (no sinuosity) pool with a predominantly bedrock bottom. The upstream straight section is hydraulically controlled in the middle by remnants of a historical haul road bridge and at the downstream end by a steep riffle, the Phase 1 control riffle. The downstream straight section extends to just upstream of the Peaslee Creek confluence. The mainstem Tuolumne River near the confluence of Peaslee Creek includes areas of sand. Peaslee Creek flows only during wet years, but the Tuolumne River backs water up into the Peaslee Creek confluence and fine sediments deposit in this backwater area.

The haul road, located in the upstream straight pool section, was built during the construction of New Don Pedro Dam but has since been decommissioned and the bridge removed. What remains is a concrete abutment on the right bank, multiple I-beams driven into the middle of the channel, and the fill prism of the haul road on both banks (Figure 4). The abutment and I-beams are effectively rubble in the channel, which poses a hazard to recreational boaters and swimmers at low water. The haul road bisects what was once a dredger slough, creating two off-channel slough features. At summer baseflow conditions, the sloughs are deep, zero-velocity alcoves that cause deposition of fine sediment and organic matter, contain substantial filamentous algae, and have high water temperatures. These conditions provide habitat for warm-water species such as Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Striped Bass (*Morone saxatilis)*, and American Bullfrog (*Lithobates catesbeianus*), all of which prey on salmonids, as well as invasive plant species such as water hyacinth (*Eichhornia crassipes*).

Field reconnaissance revealed exposures of what is assumed to be Mehrten Formation sandstone, a soft bedrock, in various locations within the wetted channel and on adjacent banks (Figure 4). The sandstone is light gray to tan and friable, with grab samples easily crumbled by hand. Most of the sandstone is on the south (left) bank in the middle of the Project area, but it also occurs on the mainstem channel bottom and in the banks of Peaslee Creek, all at an elevation of 146–148 ft. The sandstone is a constraint on excavation depths during construction.

The Zanker Family Farm runs a pump that diverts water from the Tuolumne River to irrigate an adjacent pear orchard, cow and calf pasture, and a commercial sprinkler-irrigated walnut orchard. The Zanker Farm pump intake is located at the downstream end of a prominent side channel

(Figure 4). Currently the pump draws air when flows are low, and the landowner has requested increased pool depth to maintain pump function. The pump intake is fitted with a debris screen, which will be retrofitted to a fish screen as part of this Project. The 1,000 gallon per minute (approximately 4 cfs) pump supplies an 18-inch pipeline that crosses over the existing 11-ft wide ranch road to reach the cow and calf pasture on the upland terrace. The water pipe prevents construction vehicle access as it only has 9 ft of vertical clearance. Alternate access routes around the pump and pipe have been identified and discussed with and agreed to by the landowner.

Vegetation within the Zanker Farm Project area is characteristic of Central Valley rivers. There are agricultural lands interspersed with undeveloped areas of oak savannahs and woodlands and vast expanses of foothill annual grasslands. The riparian corridor consists of a mix of trees such as cottonwoods, tree willows, shrub willows, valley oak trees, and various understory species.

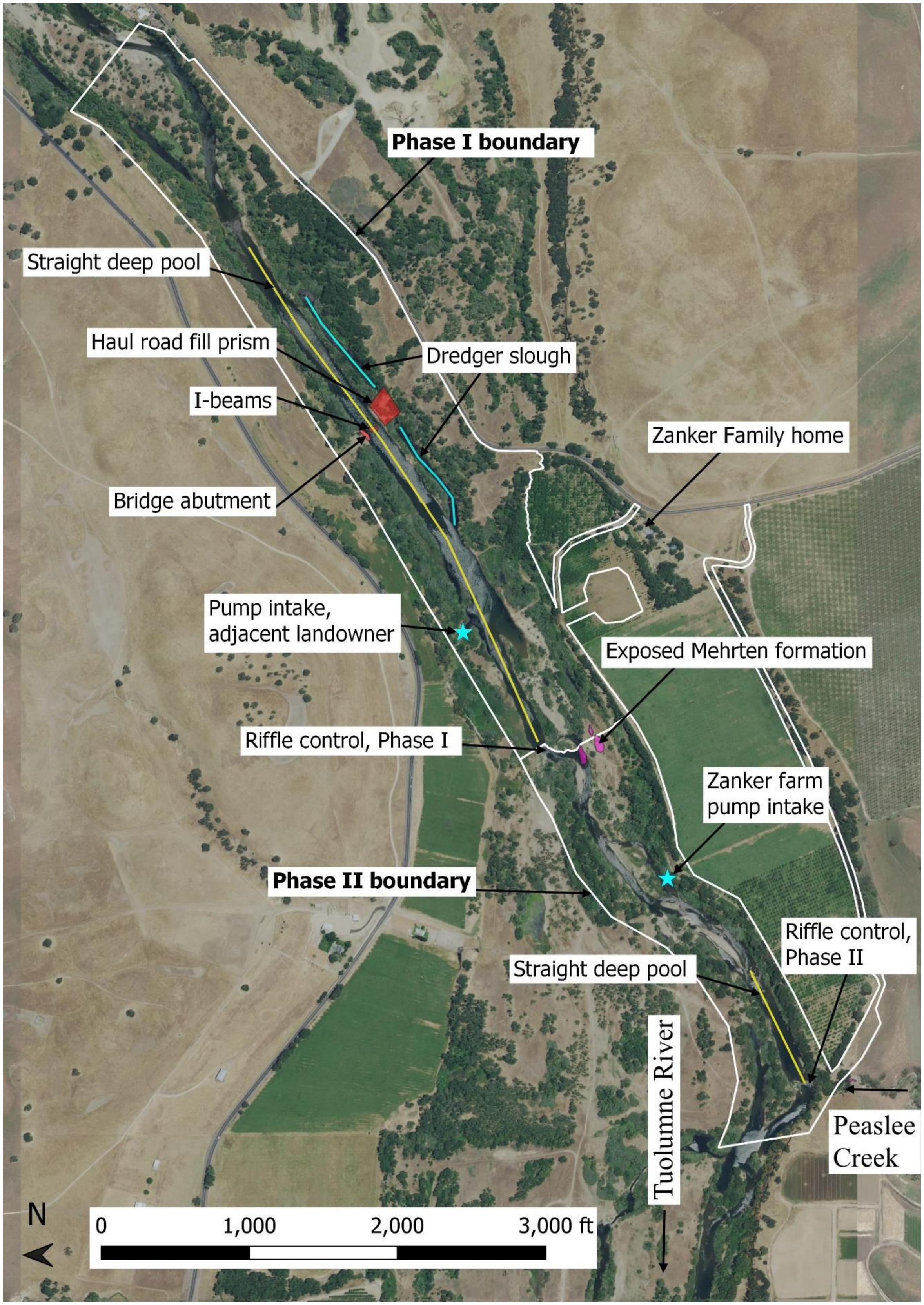

Figure 4. Zanker Farm Project overview map showing the Phase I and Phase II boundaries and notable Project features. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

1.1.1 Hydrology

The New Don Pedro Project is currently undergoing a Federal Energy Regulatory Commission (FERC) relicensing. Changes to flows in the Tuolumne River are expected as a result of the relicensing. Permitting and associated litigation is ongoing, and therefore future flows are uncertain. However, the FERC Environmental Impact Statement, published February 2019, provides a comparison of the existing and proposed future flows for different water year types (Table 1, Table 2). The Districts (Turlock Irrigation District and Modesto Irrigation District) proposed future flows both with and without infiltration galleries in the FERC relicensing. Only the proposed flows with infiltration galleries are shown in the tables in this report for brevity. In general, proposed flows will increase baseflow levels in Below Normal, Dry, and Critically Dry water year types to 175 cfs (Table 1, Table 2). In Wet and Above Normal water year types, the proposed flows are sometimes higher than existing and sometimes lower than existing baseflows (Table 1).

In addition to these baseflows, both the existing and proposed flows include a flow volume for fall pulse flows or gravel flushing flows of 5,950 acre-feet (ac-ft) on or around October 5, 6, and 7. In existing conditions, the fall pulse volume is reduced in Below Normal water year types, while in the proposed future condition, the fall pulse will be 1,000 cfs for 3 days, up to 5,950 ac-ft. Proposed volumes in wetter years would be significantly higher than those required under existing project flow requirements. The Districts would also provide spring pulse flows to facilitate outmigration of juvenile fall Chinook Salmon. The spring and fall pulse flows would be adaptively managed.

Chinook salmon spawn between mid-October and December. Therefore, the minimum spawning flow for Chinook salmon under existing conditions is approximately 150 cfs (dry and critically dry years), and this increases to 200 cfs (critically dry years) under proposed FERC flows with infiltration galleries (Table 2). Salmonid spawning (Chinook and *O. mykiss*) occurs from mid-October through April, and therefore minimum salmonid spawning flows increase from 150 cfs to 175 cfs with the proposed FERC flows (Table 2). Summer baseflows increase under the proposed FERC license flows from 50 cfs under critically dry years under existing conditions to 200 cfs or more under FERC license flows.

Table 1. Existing New Don Pedro Project (NDPP) flow requirements and proposed instream flows with infiltration galleries for Wet, Above Normal, and Below Normal Water Years at River Mile 51.7, the Tuolumne River at La Grange Bridge USGS gaging station (11-289660).

Time period	**Wet and Above Normal Water Years**		**Below Normal Water Years**	
	Proposed flows with infiltration galleries	**Existing NDPP flow requirements**	**Proposed flows with infiltration galleries**	**Existing NDPP flow requirements**
October 1–October 15	350	300	350	200
October 16–December 31	275	300	275	175
January 1–February 28/29	225	300	225	175
March 1–April 15	250	300	250	175
April 16–May 15	275	300	275	175
May 16–May 31	300	300	300	175
June–June 30	200	250	200	75
July 1–September 30	350	250	350	75

Table 2. Existing New Don Pedro Project flow requirements and proposed instream flows with infiltration galleries for Dry and Critically Dry Water Years at River Mile 51.7, the Tuolumne River at La Grange Bridge USGS gaging station (11-289660).

Time period	**Dry Water Year**		**Critically Dry Water Year**	
	Proposed flows with infiltration galleries	**Existing NDPP flow requirements**	**Proposed flows with infiltration galleries**	**Existing NDPP flow requirements**
October 1–October 15	300	150	300	100
October 16–December 31	225	150	200	150
January 1–February 28/29	200	150	175	150
March 1–April 15	225	150	200	150
April 16–May 15	250	150	200	150
May 16–May 31	275	150	225	150
June 1–June 30	200	75	200	50
July 1–September 30	300	75	300	50

After reviewing the flow data, ecological linkages, and analyses performed for this Project (McBain Associates 2021, 2022a, 2022b), the Project team selected a subset of flows to guide the restoration design and permitting processes (Table 3). These flows were selected based on their biological and statistical significance relative to the various design features and stated goals of the Project. Design side channels generally target inundation between 150 cfs (low range of spawning flows under existing conditions (Table 2)), and 275 cfs (high range of spawning flows under existing and future conditions (Table 1)). Design floodplain surfaces target inundations between 150 cfs and 1,580 cfs (Q_5 21-day duration during juvenile rearing period).

Table 3. List of hydraulic model flows used for habitat and vegetation analyses of existing conditions. Descriptions of each flow selected, and sources used to arrive at these flow magnitudes, are included.

Flow (cfs)	Description	Source/analysis/citation
80	Approx September low flow period min under existing conditions $Q_{1.5}$ 30-day duration, growing season	Hydrograph component analysis conducted for riparian planting Minimum flows used to determine depth to groundwater as described in Bair et al. (2021)
110	Calibration flow	Flow during MA calibration data collection
150	Low range of Chinook Salmon spawning flows under existing conditions (Dry and Critically Dry Water Year types) Q_2 21-day duration during seed dispersal period	Table 2 Flow duration analysis (McBain Associates 2021)
300	High range of Chinook Salmon spawning flows under existing conditions (wetter water year types) Roughly $Q_{2.5}$ 21-day duration during juvenile salmonid rearing period	Table 1 Flow duration analysis (McBain Associates 2021)
500	Index flow for habitat analyses	Selected to improve shape of habitat curve (McBain Associates 2021)
633	Roughly Q_4 21-day duration during juvenile salmonid rearing period	Flow duration analysis (McBain Associates 2021)
750	Index flow for habitat analyses	Selected to improve shape of habitat curve (McBain Associates 2021)
800	Index flow for habitat analyses	Selected to improve shape of habitat curve (McBain Associates 2021)
1,130	Q_5 30-day duration for juvenile salmonid rearing period Approximate existing floodplain inundation threshold	Flow duration analysis (McBain Associates 2021) *Lower Tuolumne Instream Flow Study* (Stillwater Sciences 2013)
1,580	Q_5 21-day duration for juvenile salmonid rearing period	Flow duration analysis (McBain Associates 2021)
3,000	Low threshold for bed mobility Low magnitude pulse flow	*Coarse Sediment Management Plan for Lower Tuolumne River* Figure 21 (M&T 2004) *Restoration Plan* Section 3.2.2 (M&T 2000)
5,400	Channel forming flow Moderate magnitude winter power generation flow	*Restoration Plan* Section 3.2.2 (M&T 2000)
7,050	Waters of US/state based on current ACOE assessment Close to high threshold for bed mobility (6,880 cfs)	Clean Water Act Section 401 Water Quality Certification for Tuolumne River (M&T 2000)
9,600	Index habitat flow	Selected to improve shape of habitat curve (McBain Associates 2021)
11,500	Q_{10} instantaneous peak flow	Flood frequency analysis Bulletin 17C (England et al. 2019)
44,000	Q_{100} peak flow	Central Valley Flood Protection Board (https://gis.bam.water.ca.gov/bam/)

1.2 Design Approach, Goals, and Objectives

The general restoration approach is to substantially increase the spawning gravel in the river and opportunistically create side channel and floodplain surfaces where possible between existing mature vegetation and bedrock. Floodplain excavations on-site in dredger mined areas will re-establish the pre-dredging soil profile with fine rather than coarse sediment at the surface, and provide coarse sediments for in-channel features.

The specific objective of Zanker Phase I, as stated in CDFW Grant Q1940405, is to prepare 100% design plans, ultimately leading to enhancement and restoration of up to 32.3 acres of channel, floodplain, riparian, wetland and upland habitats and floodplain and riparian ecosystem processes to benefit multiple species including native juvenile and adult salmonids.

The project design goals are as follows:

1. Improve the quantity and quality of spawning habitat for adult salmonids by resizing the river channel morphology and bedforms to function within the current flow regime and rebuilding the riverbed with appropriately sized substrate to create salmonid spawning habitat.
2. Improve the quantity and quality of juvenile salmonid rearing habitat by excavating remnant dredger tailings to lower adjacent upland areas and increase the frequency and duration of overbank floods, removing a remnant haul road plug to create connectivity between two sloughs adjacent to the main river channel, and reconnecting existing off-channel wetlands.
3. Reduce main channel habitats potentially conducive to invasive fish species, especially those that may prey on juvenile salmonids, by rebuilding the riverbed with coarse gravel and cobbles to eliminate slow, deep areas conducive to invasive predators.

The specific objective of Zanker Phase II, as stated in CDFW Grant Q2140407, is to design 100% design plans that will rehabilitate approximately 26 acres of channel, floodplain, riparian, wetland and upland habitats and floodplain and riparian ecosystem processes to benefit Chinook Salmon Oncorhynchus tshawytscha and California Central Valley (CCV) steelhead O. mykiss spawning and rearing habitat.

The Zanker Phase II Project design goals include:

1. Augment suitable sized spawning gravel at up to eight riffles in the main channel to create or enhance adult salmonid spawning habitat;
2. Excavate and grade perched floodplain and remnant dredger channels to increase inundation of ~16.2 acres of diverse, high-quality rearing habitat to support an additional 20,000735,000 juvenile salmonids;
3. Restore the main channel and off-channel areas to eliminate warm water habitat conducive to nonnative salmonid predators and provision off channel refugia to reduce juvenile salmonid predation.

These project-specific and salmonid focused design goals have been combined and expanded to meet additional goals to improve physical and biological processes of the Tuolumne River. As stated in the design reports (McBain Associates 2022b, McBain Associates 2022c), the primary objectives of the Project are as follows:

1. Scale surfaces adjacent to the mainstem channel (i.e., upper bars and floodplains) and reconnect the river to its floodplains so they can function under the contemporary regulated flow regime.
2. Create low-gradient riffles with a slope of less than 0.2% by redistributing the elevation drop in the short, steep riffles to restructure the lake–cascade channel morphology (Figure 5) to a more natural pool–riffle morphology (Figure 6).

3. Reduce aquatic non-native predator habitat.
4. Increase off-channel fry and juvenile salmonid rearing habitat via construction of low-flow side channels and annually inundated floodplain benches.

A fifth Project goal was added in response to earlier design stages and subsequent landowner concerns:

5. Replace existing trash rack on Zanker Farm river pump diversion (~4 cfs pump) with a cone fish screen.

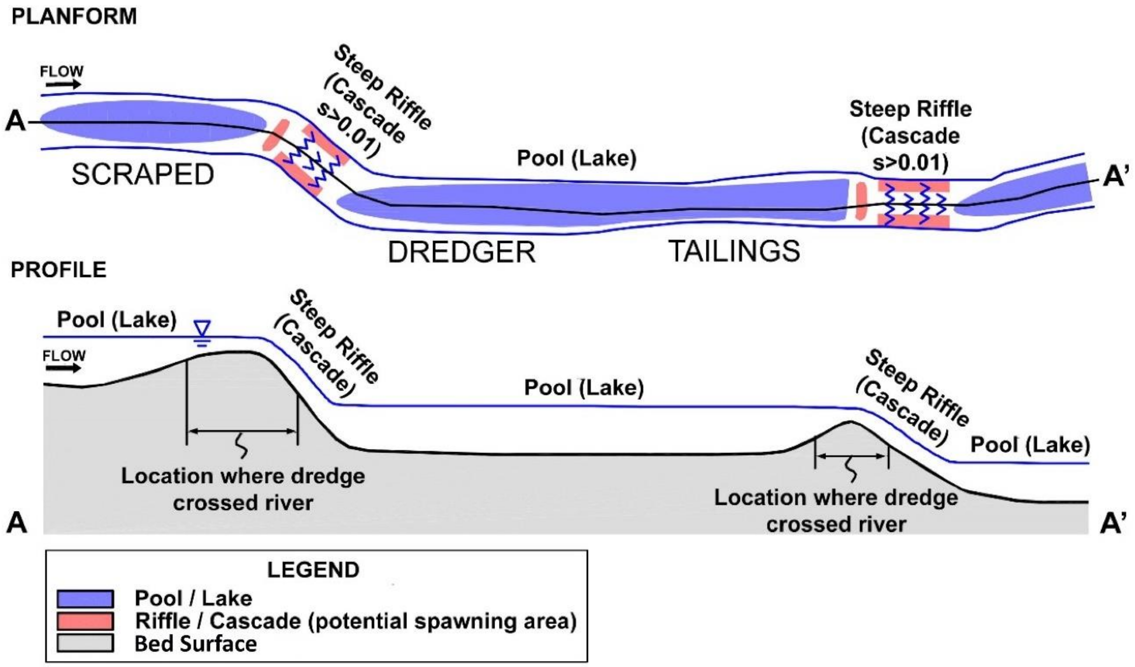

Figure 5. Post-gold dredge mining planform and longitudinal profile conceptual model showing the impacts of mining on the channel through the disruption of natural pool–riffle segments and creation of long pools separated by over-steepened riffles.

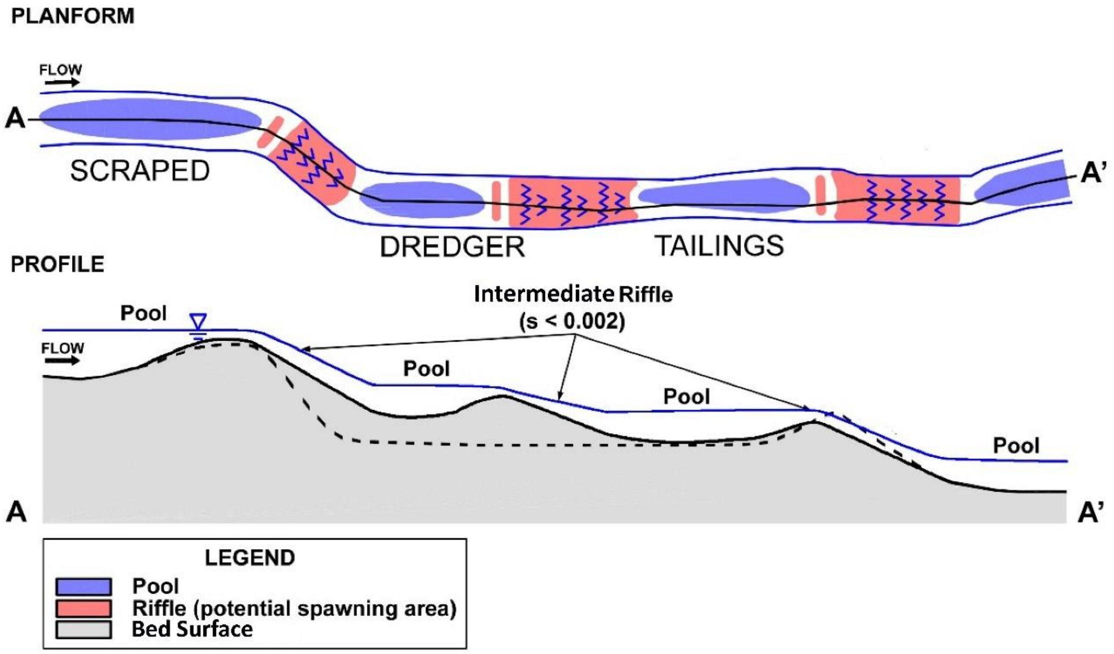

Figure 6. Example of riffle slope redistribution from steep riffles associated with existing lake–cascade channel morphology by constructing intermediate riffles and bars that backwater into the steep upstream riffle (compare to dashed line representing the bed surface from Figure 5).

1.3 Design Process

This Project combines Zanker Phase I and Zanker Phase II. The Zanker *Phase I 30% Basis of Design Report* completed in April 2022 included 2 alternatives (McBain Associates 2022a). Alternative 2 was selected to move forward, based on comments from the Tuolumne River Conservancy and CDFW. The *Zanker Phase II Salmonid Habitat Restoration Project 30% Design Report* described a single 30% design (McBain Associates 2022c). The Zanker Phase I Alternative 2 and Zanker Phase II 30% design were then combined into the *Zanker Farm Salmonid Habitat Restoration Project 65% Design Report* (McBain Associates 2023). This document also incorporates changes based on comments from CDFW, the Tuolumne River Conservancy, and the landowner on the 65% designs. Please see Section 2.2 for a description of the comments received and revisions made.

2 100% DESIGN

The 100% design for the Zanker Farm Salmonid Habitat Restoration Project includes 33 in-channel riffles and gravel bars that will increase spawning habitat at spawning flows. Riffles are generally designed with (1) 0.2–2.0% slope to promote sediment transport and geomorphic function, or (2) 0.15–0.25% slope for spawning and benthic macroinvertebrate production. In addition, the Project will increase fry and juvenile rearing habitat for *O. mykiss* and Chinook Salmon at spring rearing flows of a few hundred to a few thousand cfs by creating several new side channels and some areas of floodplain habitat. This section describes the basis of design and revisions made in the 100% design based on 65% design comments, and then describes the design.

2.1 Basis of Design / Physical Design Parameters

The basis of design at 100% includes hydraulic modeling of the proposed design (Section 2.1.1), sizing of gravel bars based on modeled shear stresses over constructed gravel bars (Section 2.1.2), and large wood stability calculations (Section 2.1.3). The revegetation basis of design includes the relationship between existing vegetation, its distribution on the landscape, and depth to groundwater (Section 2.9.2).

2.1.1 Hydraulic Modeling Results

A 2-dimensional hydraulic model was developed for the 100% design conditions based on previous hydraulic modeling efforts for existing conditions (McBain Associates 2021, McBain Associates 2022b), the Phase I and Phase II 30% designs (McBain Associates 2022a, 2022c), and the 65% design (McBain Associates 2023). The model simulated design conditions at a range of streamflows (Table 3) and produced depth, velocity, water surface elevation, and shear stress results to inform various engineering and habitat analyses. A detailed description of the design hydraulic model development and results can be found in Appendix A.

The 100% design will improve hydraulics (i.e., depth and velocity) over existing conditions (Figure 7 to Figure 10). Typical hydraulic model outputs for the range of spawning flows used in the salmonid habitat analysis (Section 3.1) were selected to show how the 100% design hydraulics compared to existing conditions (Figure 7 to Figure 10). In general, the hydraulic model results illustrated that most of the channel under existing conditions is a deep pool with near-zero velocities, particularly in the Phase I area but also at the downstream end of Phase II. The 100% design will improve these conditions by creating bars and riffles that narrow the channel width, increase sinuosity, and achieve depths and velocities in riffles that are more suitable for salmonid spawning. Some of the existing deep pool habitat will be maintained between riffles and in cutoff channels of gravel bars to provide holding habitat under design conditions. A detailed analysis of salmonid habitat under 100% design conditions is presented in Section 3.1. Overall, the 100% design will create more diverse hydraulic conditions compared to existing conditions, providing more habitat under a wider range of flows for multiple life stages.

The shear stress modeling results were used to determine necessary grainsize distributions for gravel bars to keep these features stable up to a 10-year flow (11,500 cfs, Figure 11). The 10-year recurrence interval flow was also the design flow for the large wood stability analysis. Figure 11 illustrates the spatial distribution of shear stress throughout the site, which in turn informed how design features will respond to hydraulic forces and where additional stability was needed.

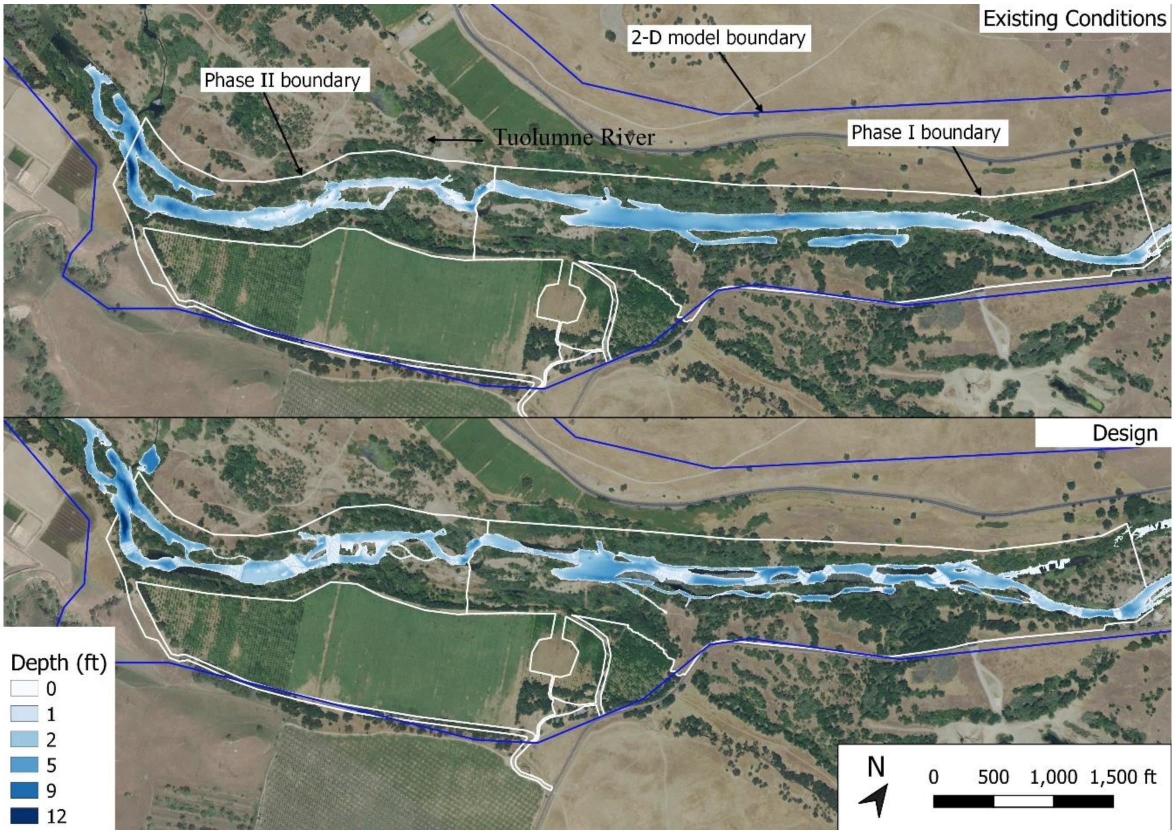

Figure 7. Existing conditions and 100% design conditions hydraulic modeling depth results for 150 cfs, the low range of existing salmonid spawning flows. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

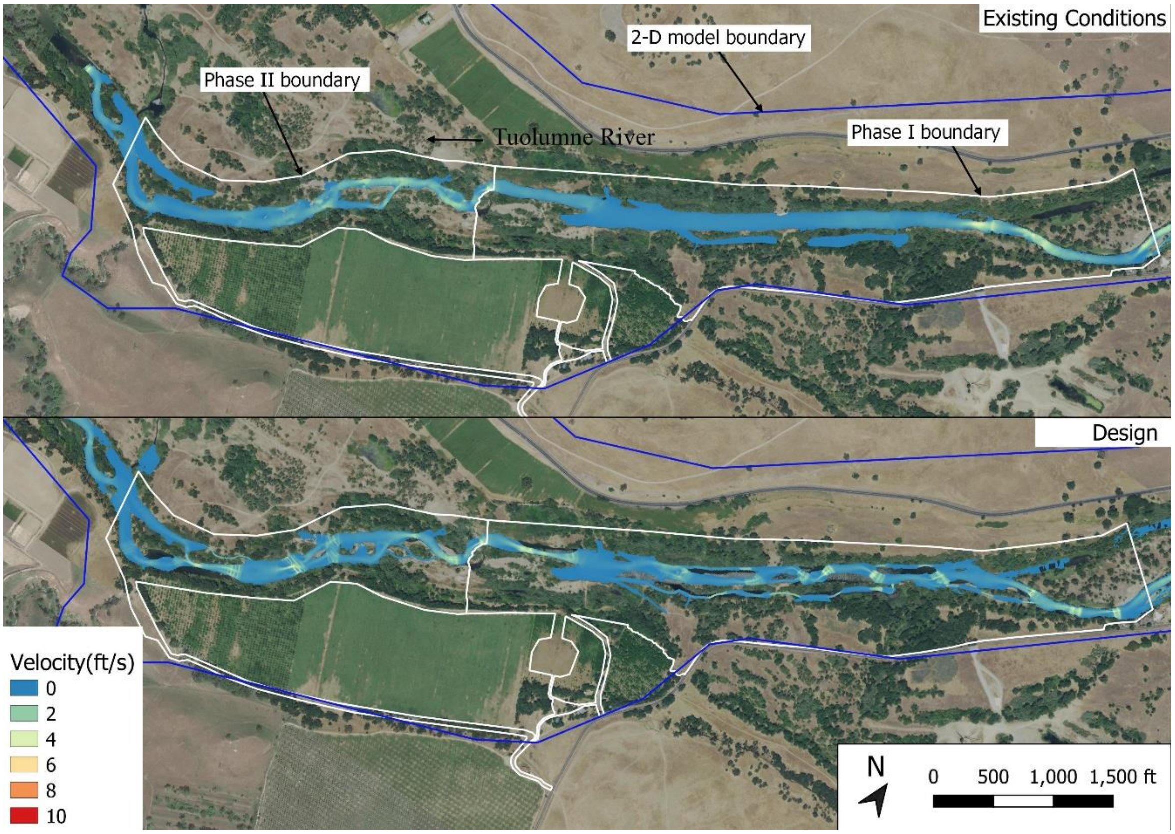

Figure 8. Existing conditions and 100% design conditions hydraulic modeling velocity results for 150 cfs, the low range of existing salmonid spawning flows. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

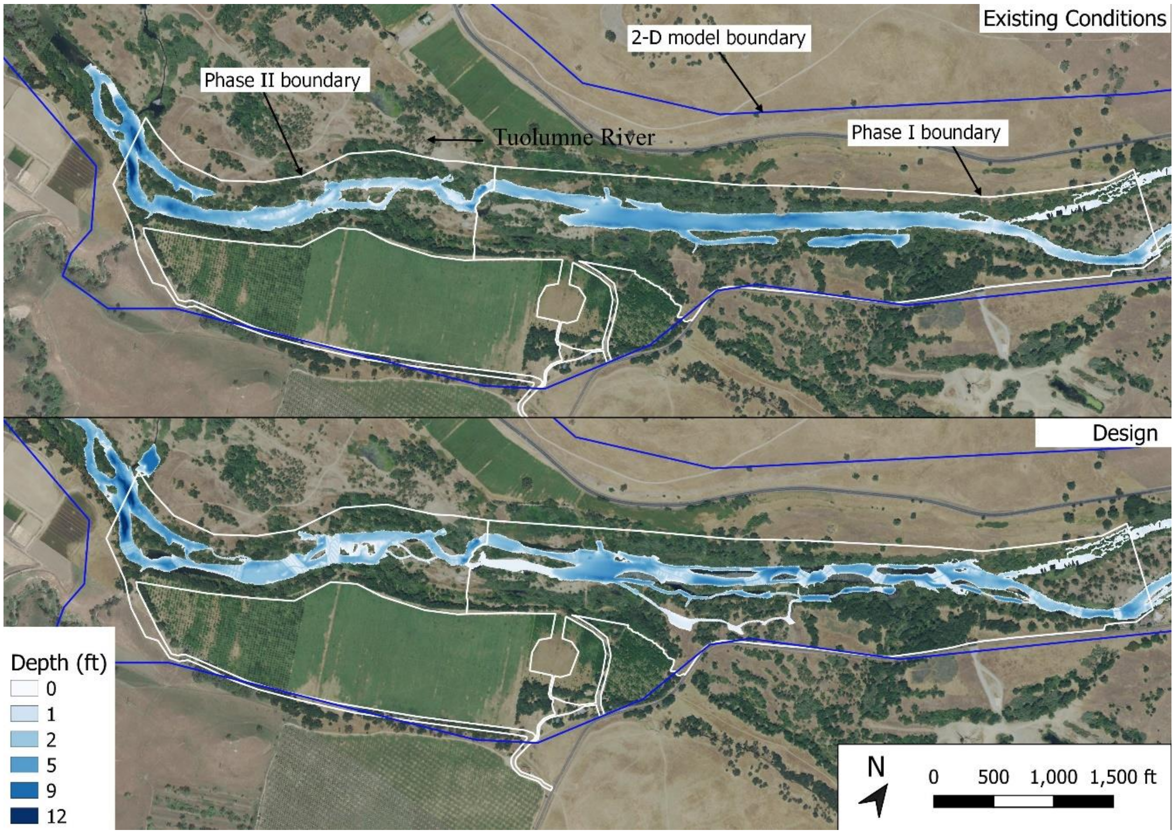

Figure 9. Existing conditions and 100% design conditions hydraulic modeling depth results for 300 cfs, the high range of existing salmonid spawning flows. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

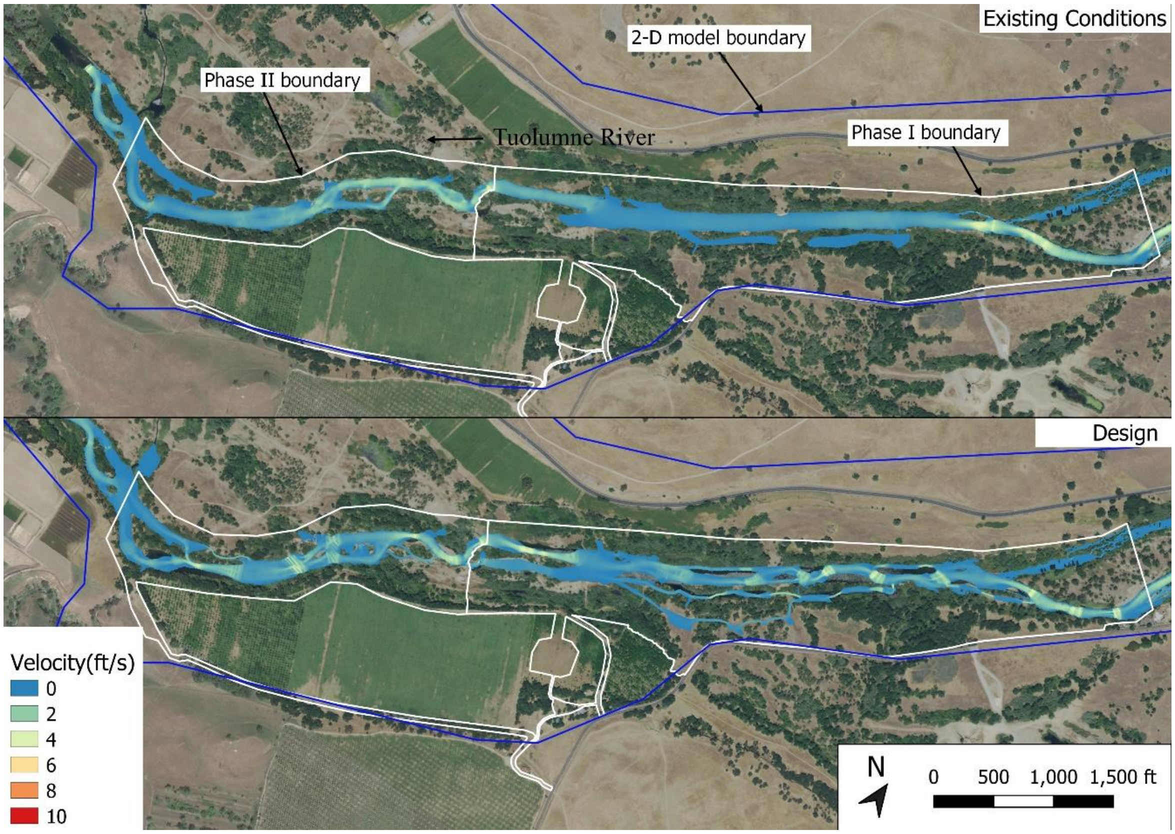

Figure 10. Existing conditions and 100% design conditions hydraulic modeling velocity results for 300 cfs, the high range of existing salmonid spawning flow. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

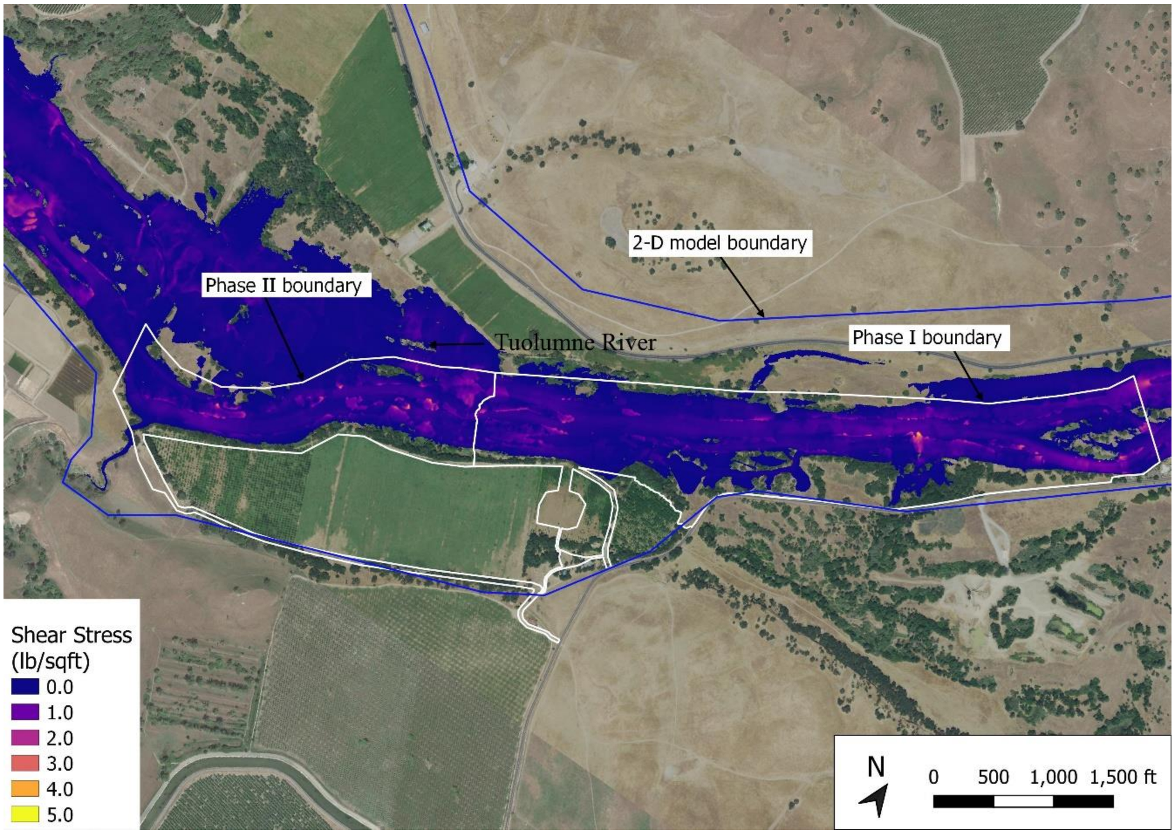

Figure 11. Hydraulic modeling shear stress results for 100% design conditions at 11,500 cfs, the 10-year recurrence interval flow and the design flow for the large wood stability analysis and grain size analysis. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

2.1.2 Mobility Threshold Analysis and Substrate Sizing

Proposed coarse sediment bars and riffles have been designed to mobilize when certain flow thresholds are reached, so channel features will persist while still allowing for some dynamic evolution over time. Design specifications for bars and riffles were developed by predicting the bed mobility threshold of these features over a range of selected streamflows. To do this, representative grain sizes were estimated using hydraulic model output (shear stress) and a dimensionless value used for particle entrainment calculations (Shields parameter). These grain sizes were then used as a basis to develop the coarse sediment mixtures from which the design features would be built.

Shields parameter τ_* is a dimensionless ratio of the modeled mobility force (or boundary shear stress, τ_o) to the grain resisting force:

$$\text{Shields parameter} \approx \frac{\text{mobility force}}{\text{grain resisting force}}$$

which can be expressed as the following equation:

Shield’s Parameter τ_* is defined as follows:

$$\tau_{*DS} = \frac{\tau_o}{(\rho_s - \rho_w) g D_s}$$

Where:

τ_{*Ds} = Shields parameter, specific to grain size D_s
τ_o = average boundary shear stress (Pa), computed from 2-D hydraulic model
ρ_s = sediment density (2,650 kg/m^3, assumed and typical of alluvium)

ρ_w = water density (1,000 kg/m^3)
g = gravitational acceleration (9.81 m/s^2)
Ds = particle diameter in a cumulative distribution for which "s" percent is finer (m)

The spatial distribution of shear stress throughout the project area was provided by the hydraulic model. Using this output for a range of selected streamflows, combined with an assigned Shields parameter value, allows for a particle size to be calculated that is theoretically mobilized at that particular streamflow. The above equation can be rearranged to isolate and solve for particle size as follows:

$$D_s = \left(\frac{1}{\tau_{*Ds}(\rho_s - \rho_w)g}\right)\tau_o = C\ \tau_o$$

Where: *C* = a constant equivalent to the value in parentheses, which is equal to 5.82 for these assumptions and parameters as listed above.

A value of 0.02 was used for Shields parameter to solve for grain size (D_s) across the project site. The Shields parameter value is based on Parker et al. (1982) and Andrews (1983), and represents a value for particle incipient motion (stable < 0.02, mobile ≥ 0.02); therefore, D_s represents the critical grain size at which incipient motion begins. Many studies have used the D_{84} (particle size in a cumulative distribution where 84% is finer) as a representative grain size that controls bed mobility, using the concept that the D_{84} represents a key "framework" particle size that, when mobilized, unlocks the adjacent bed material and initiates complete bed mobility. This same concept was applied as a basis for developing substrate sizing for this project, and D_s was assigned the D_{84} value. The spatial distribution of D_s throughout the Project area was then calculated as a function of the hydraulic model shear stress output.

The shear stress results for flows of 11,500 cfs (10-year event) were analyzed to determine the necessary D_{84} for bed stability of each in-channel design feature. Shear stress results from the hydraulic model were imported to GIS and each raster pixel was multiplied by *C* to produce a spatial distribution of D_{84}. A shapefile of the design activity area boundaries was overlaid on the D_{84} raster, and the average and maximum D_{84} values within each riffle and bar activity area were calculated (Table 4). Most in-channel features would require a D_{84} of 2-5 inches to maintain stability until a 10-year flow and then become mobile, while some areas would require a D_{84} of up to 11-24 inches (Figure 12 and Figure 13).

Table 4. Results of the shear stress analysis showing calculated D_{84} values by design feature for a flow of 11,500 cfs and expected stability of individual design features.

Design Activity Area	Feature Type	Calculated D_{84} (inches)		Feature Stability*
		Q_{10} - 11,500 cfs		
		Average	Max	
IC-1	Riffle	1.5	2.6	Mobile
IC-2	Gravel Bar	2.7	6.8	Stable up to Q_{10}
IC-3	Riffle	3.5	4.4	Mobile
IC-4	Gravel Bar	2.9	5.7	Stable up to Q_{10}
IC-5	Riffle	1.9	8.4	Mobile
IC-6	Riffle	1.6	3.4	Mobile
IC-7	Gravel Bar	1.0	2.3	Stable up to Q_{10}
IC-8	Riffle	1.9	13.9	Mobile
IC-9	Gravel Bar	3.3	12.6	Stable up to Q_{10}

Design Activity Area	Feature Type	Calculated D_{84} (inches)		Feature Stability*
		Q_{10} - 11,500 cfs		
		Average	Max	
IC-10	Gravel Bar	1.1	9.0	Stable up to Q_{10}
IC-11	Riffle	1.9	4.6	Mobile
IC-12	Riffle	2.6	4.0	Mobile
IC-13	Gravel Bar	2.5	9.0	Stable up to Q_{10}
IC-14	Riffle	1.6	2.7	Mobile
IC-15	Gravel Bar	1.7	2.9	Stable up to Q_{10}
IC-16	Riffle	2.3	3.2	Mobile
IC-17	Gravel Bar	2.8	9.8	Stable up to Q_{10}
IC-18	Riffle	2.5	3.7	Mobile
IC-19	Gravel Bar	2.3	3.4	Stable up to Q_{10}
IC-20	Riffle	3.0	4.0	Mobile
IC-21	Gravel Bar	2.7	6.2	Stable up to Q_{10}
IC-22	Riffle	3.6	6.5	Mobile
IC-23	Gravel Bar	4.1	22.7	Stable up to Q_{10}
IC-24	Riffle	4.4	9.3	Mobile
IC-25	Gravel Bar	3.6	11.8	Stable up to Q_{10}
IC-26	Riffle	3.1	4.0	Mobile
IC-27	Gravel Bar	2.2	3.4	Stable up to Q_{10}
IC-28	Gravel Bar	3.1	13.5	Stable up to Q_{10}
IC-29	Riffle	3.1	13.5	Mobile
IC-30	Gravel Bar	5.0	6.5	Stable up to Q_{10}
IC-31	Riffle	7.1	9.4	Mobile
IC-32	Gravel Bar	4.6	9.6	Stable up to Q_{10}
IC-33	Riffle	4.3	7.9	Mobile

*Feature stability refers to whether coarse sediment comprising a design riffle or gravel bar is expected to be transported downstream or remain in place (i.e., stable). The coarse sediment mixtures for all gravel bars were designed to remain stable up to the 10-year recurrence interval flow. The top layer of all riffles is comprised of spawning gravel, which is expected to transport downstream and be replenished from upstream over a range of flows below the Q10. The bottom 1/2 to 2/3 of all riffles is comprised of a structural mix of both spawning gravel and large (greater than six-inch) rock, which will increase stability and allow design riffles to persist long-term.

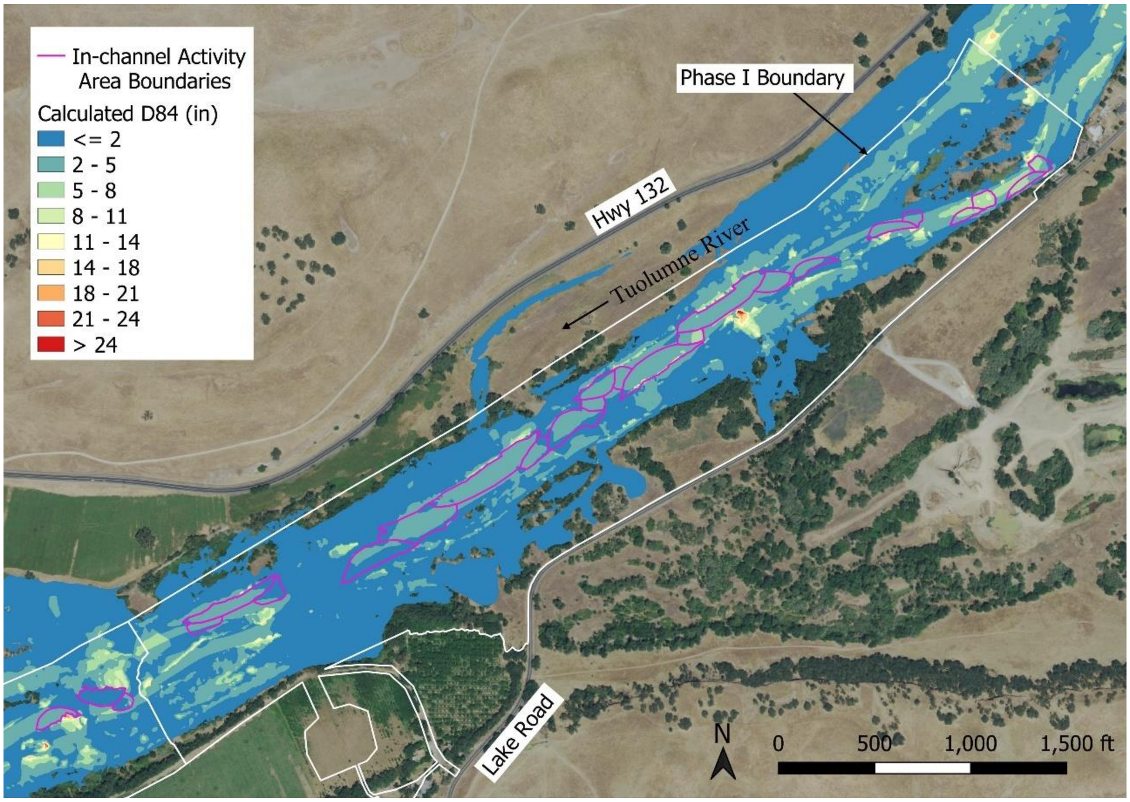

Figure 12. Calculated D_{84} values for design conditions in the Phase I area at 11,500 cfs (10-year recurrence interval).

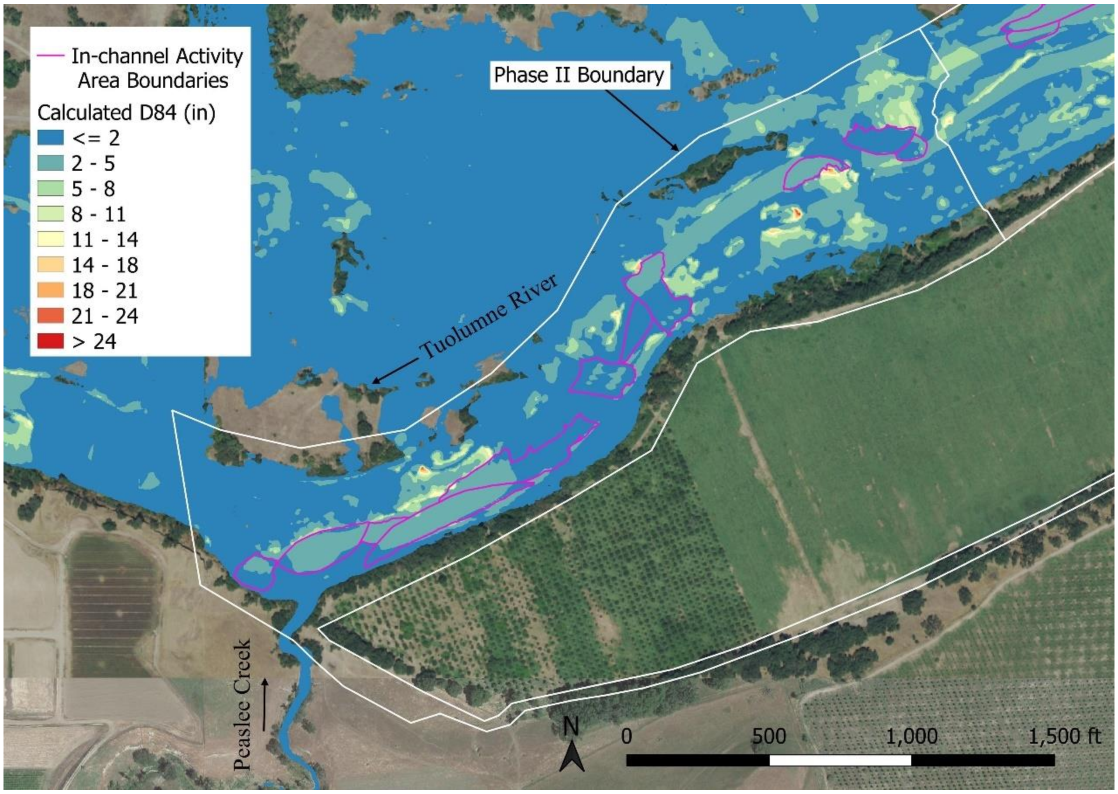

Figure 13. Calculated D_{84} values for design conditions in the Phase II area at 11,500 cfs (10-year recurrence interval).

Coarse sediment mixtures were developed for in-channel design features based on the results of the shear stress analysis (Table 4, Figure 12, Figure 13). Two spawning-sized coarse sediment mixes (standard mix and finer mix, Table 5) prescribed in the *Coarse Sediment Management Plan* (McBain and Trush 2004) were used, as well as an oversized mix to increase stability in design features where needed to maintain planform complexity over time. The oversized mix consisted of the standard spawning mix augmented with oversized (6 inch to 24 inch) rock to increase the D_{84} of the total mixture. The ratio of standard spawning mix to oversized rock varied by design feature based on specific stability requirements of each feature. Stable features (Project gravel bars) used a combination of the fine spawning, standard spawning and oversized mixes, which include gravel and cobble for stability, while mobile features (Project riffles) used the fine or standard spawning mix to maximize Chinook salmon spawning habitat. These three mixes were applied in areas of each gravel bar based on calculated shear stress / D_{84} results. Some gravel bars will require oversized mix in discrete areas of high shear stress and standard mix in the remaining area.

Calculated D_{84} values based on shear stress at the 10-year flow (Figure 12, Figure 13) and the information in Table 4 were used to identify the substrate size required for stability at a flow of 11,500 cfs (10-year recurrence interval) for each design feature. In general, substrate was sized based on the maximum D_{84} required for stability. In some cases, the average value was used if it was determined to be more representative of the stability requirements of a given design feature or if sizing to the maximum value would require an excessive volume of oversized rock that would inhibit deformation and evolution of the feature over time. Coarse sediment mixtures and target D_{84} values were selected so channel complexity will persist while still allowing for some dynamic evolution and changes to channel morphology over time. Specific quantities for coarse sediment mixture volumes broken down by design feature and area are shown in the 100% design planset (Appendix H, Sheet C-4 to C-9).

Table 5. Recommended particle size distributions for salmonid spawning as prescribed in the Coarse Sediment Management Plan for the Lower Tuolumne River (M&T 2004).

Particle size (in)	Percent of total composition	
	Standard mix	**Finer mix**
2 1/2 to 5	20	0
2 1/2 to 4	0	20
1 1/4 to 2 1/2	35	30
5/8 to 1 1/4	30	30
5/16 to 5/8	15	12
1/8 to 5/16	0	8
D84 (in)	***2.8***	***2.4***
D50 (in)	***1.4***	***1.3***

2.1.3 Large Wood Force Balance Calculations

Large wood habitat features were designed to provide immediate cover habitat as well as allow the constructed channel morphology to evolve over time. The 100% design large wood habitat features include logs with rootwads (henceforth referred to as “rootwad logs”) 20- to 30-ft long and, if available, whole trees. Habitat features will be embedded into the banks or bars with sufficient burial depth and length to keep them in place for a flow of 11,500 cfs (10-year recurrence interval event). Habitat features may be a single log or multiple logs embedded together with slash and boulders. Branches and rootball should be kept intact to the extent possible and the rootball should be buried or interlaced with standing trees on the banks along with boulder ballast for anchoring.

Pin logs and boulder ballast may be added to rootwad logs or whole tree placements as needed to provide additional resisting force.

The depth and velocity results from the 2-D hydraulic model (Appendix A) were used to evaluate stability and determine appropriate embedment specifications for the design wood placements. The large wood stability analysis was conducted for a subset of large wood features based on log length and diameter to provide a general set of embedment parameters for individual logs or whole trees and to determine necessary resisting forces to be supplied by ballast (i.e., pin logs and boulders).

Force–balance calculations were performed using the *Large Wood Structure Stability Analysis Spreadsheet* tool, Version 1.1, developed specifically for large wood features (Rafferty 2017). The tool accounts for vertical, horizontal, and moment forces according to the NRCS NEH 654 Technical Supplement 14J (2007). The tool evaluates all forces acting on an idealized log and rootball: buoyant force, rotational and horizontal force due to the flow, resisting forces of the channel bank material, ballasting forces provided by coarse substrate and/or boulders on top of the log, and interaction forces with adjacent logs (Figure 14).

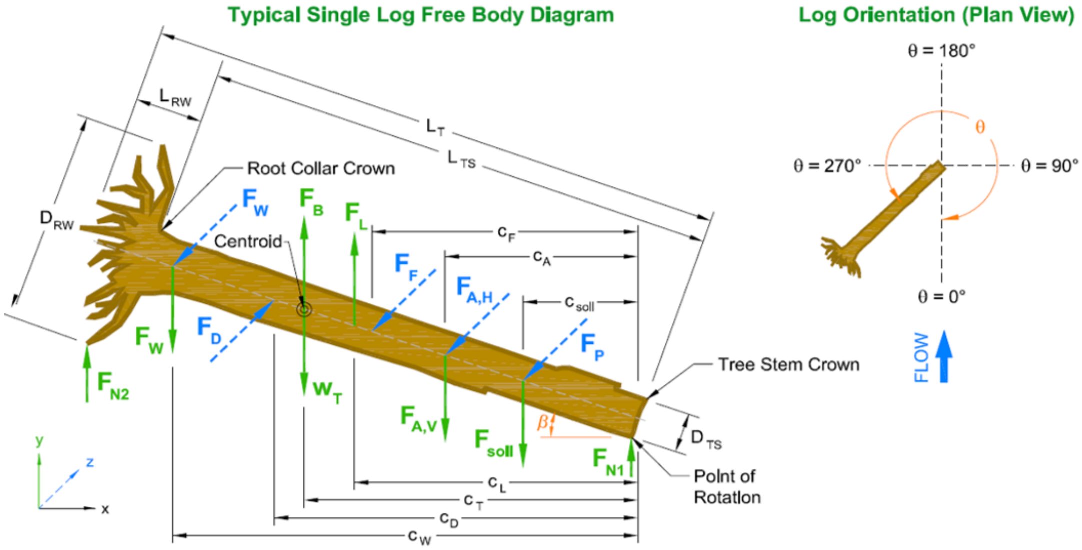

Figure 14. Typical single log free body diagram (from Rafferty 2017), showing all forces acting on an idealized log and rootball: buoyant force, rotational and horizontal force due to the flow, resisting forces of the channel bank material, ballasting forces provided by coarse substrate and/or boulders on top of the log, and interaction forces with adjacent logs.

The spreadsheet tool requires user-input parameters to accurately calculate forces acting on a large wood structure, including hydraulic and hydrologic parameters, soil properties, log species and geometry, channel cross-sectional geometry, embedment specifications of the log, and placement of any anchoring or ballast material. For some user-input parameters, the spreadsheet contains lookup tables to assume values for additional parameters based on published sources (e.g., if a user selects Fremont cottonwood, the spreadsheet will assume air-dried and green densities based on a U.S. Department of Agriculture research publication).

- Hydraulic and hydrologic parameters such as maximum depth and average velocity were obtained for the design flow from hydraulic modeling results (Appendix A). Cross-sectional geometry was pulled from the design terrain surface at four representative wood placement locations throughout the Project area including Station (Sta) 16+00, Sta 29+00, Sta 31+00, and Sta 80+50.
- Since large wood features will be placed in constructed coarse sediment bars or along existing banks, streambed D_{50} and bank soil type were assumed based on properties of the

coarse sediment mixtures and existing bank material type. The stability calculations are not highly sensitive to the differences in D_{50} between the standard spawning, fine spawning, and oversized mixes used for design features, so the embedment specifications produced by this analysis can be applied to logs placed in any of these mixes.

- All logs are assumed to have a specific gravity (SG) of 0.48. This value is in the middle of the range of specific gravity for species that would likely be used to construct habitat features such as Oregon ash (SG=0.56), White alder (SG=0.45), interior live oak (SG=0.68), and Fremont cottonwood (SG=0.4). In general, the stability analysis spreadsheet is not highly sensitive to small changes in specific gravity.
- Rootwad logs were oriented 90° (perpendicular) to flow to represent the highest possible horizontal driving forces on the log (i.e., a rootwad log oriented at a less than 90° will experience lower horizontal driving forces than what is listed in Table 7). This provides conservative embedment specifications for stability. Vertical driving forces on the log will be the same regardless of this orientation.
- Pin logs were assumed to be oriented 60° relative to the channel bottom (where 90° represents a completely vertical pin log). This is a realistic angle at which pin logs may be oriented in the field.
- Two rootwad log sizes and a range of possible embedment depths were analyzed to account for variability in materials and conditions encountered in the field (Table 7).
- Three pin log sizes and four boulder sizes were analyzed as well to account for variability in materials used to provide resisting forces (Table 8).

A summary of the different factor of safety (FOS) values recommended for design of large wood features based on risk profile and failure mode is shown in Table 6 (Knutson and Fealko 2014). Given little to no public access to this reach of river, there is a low safety risk to the public. Furthermore, the nearest bridge downstream of the Project is Robert’s Ferry bridge, which is located approximately 5.4 miles away. The main span of the bridge spans approximately 150 ft across the river and completely spans the wetted channel at 1,200 cfs. The bridge decking is over 20 ft above the water surface elevation at a flow of 1,000 cfs. There are two approximately four-foot diameter pylons on the floodplain at each side of the river. As seen in Figure 15, the channel geometry at the bridge is wide and free of obstructions presenting very low potential for large wood to become pinned or racked on the bridge. In the event that a large wood member did get pinned or racked on the bridge, it would likely have very little effect on flow conveyance due to the large open cross-sectional area under the bridge. For example, considering the common TID flood release flow of 10,000 cfs, hydraulic modeling indicates that the WSE at this flow is on average approximately four to six feet higher than the WSE at 1,000 cfs. Robert’s Ferry bridge is not within the hydraulic modeling domain for this project, so it is assumed that the modeled WSE profiles for the Zanker Farm reach and Bobcat Flat reach are similar enough to the Robert’s Ferry bridge reach to be representative. Given these modeled WSE’s and observations made at the bridge, there will be approximately 14 to 16 feet of freeboard between the water surface and the bottom of the bridge at 10,000 cfs. This provides ample clearance for logs or other debris to pass under the bridge without racking or pinning. For these reasons, there is a low property damage risk. Therefore, a factor of safety of 1.5 was used and a selected stability design flow of 11,500 cfs (10-year flood, Table 6). This 1.5 safety factor is the highest factor recommended in Table 6 of all of the failure modes for the low property and low safety risk scenario. The stability analysis worksheets were used to calculate the ratios of resisting to driving forces for individual log members; burial depths and lengths were then adjusted until this ratio was higher than the 1.5 safety factor. Since the embedment specifications calculated in this analysis equate to stability with respect to vertical, horizontal, and moment forces with a 1.5 safety factor for an individual log, a wood feature comprised of two logs placed to meet the sum of the resisting forces required for each individual log will also be stable with a 1.5 safety factor.

Based on the stability analysis, vertical (buoyancy) stability was generally the limiting factor for habitat features. When vertical stability was met, logs were stable with respect to moment forces far beyond a 1.5 safety factor; therefore, moment forces are not presented or discussed again.

Figure 15. Photo of the Tuolumne River channel under Robert's Ferry bridge taken on October 13, 2023 at a flow of 1,000 cfs. The geometry of the bridge (e.g., the span, height, location of pylons) is not expected to present any issues in terms of large woody debris racking.

Figure 16. Photo of the overbank area under Robert's Ferry bridge taken on October 13, 2023 at a flow of 1,000 cfs. The geometry of the bridge (e.g., the span, height, location of pylons) is not expected to present any issues in terms of large woody debris racking.

Table 6. Factor of Safety (FOS) values recommended for large wood feature design based on risk profile and failure mode (Knutson and Fealko 2014). Based on public safety and property damage risk, the blue shaded row was selected for use in this Project's stability analysis.

Public safety risk	**Property damage risk**	**Stability design flow criteria**	**Failure mode**		
			FOS $_{sliding}$	**FOS $_{buoyancy}$**	**FOS $_{rotation}$** **FOS $_{overturning}$**
Low	Low	10-year	1.25	1.5	1.25
Low	Moderate	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
High	Low	25-year	1.5	1.75	1.5
High	Moderate	50-year	1.5	1.75	1.5
High	High	100-year	1.75	2.0	1.75

Table 7. Wood stability analysis results for rootwad logs with rootballs, showing a variety of embedment configurations with no pin logs or boulder ballast. If the embedment configuration is not stable, the additional resisting force required for stability is given for the vertical and horizontal direction. Rootwad logs are assumed to be oriented 90° (perpendicular) to flow. Moment (i.e. rotational) forces are not shown because when vertical stability was met, moment forces beyond a 1.5 safety factor were also met.

Rootwad log size	**Embedded length (ft)**	**Embedded depth, avg (ft)**	**Additional resisting force required (lbf)**		**Description**
			Vertical (i.e. to resist buoyancy)	**Horizontal (i.e. to resist sliding)**	
30-ft length, 2-ft diameter	0	0	7,190	770	Large log, unembedded
	15	1	4,660	Stable	Large log, low embedment
	15	2	2,230	Stable	Large log, low embedment
	15	3	150	Stable	Large log, low embedment
	20	1	3,950	Stable	Large log, medium embedment
	20	2	990	Stable	Large log, medium embedment
	20	3	Stable	Stable	Large log, medium embedment
	25	1	3,250	Stable	Large log, high embedment
	25	2	Stable	Stable	Large log, high embedment
	25	3	Stable	Stable	Large log, high embedment
	30	0.5	4,610	Stable	Toe log, fully embedded
20-ft length, 1.5-ft diameter	0	0	2,490	450	Small log, unembedded
	10	1	1,240	Stable	Small log, low embedment
	10	2	470	Stable	Small log, low embedment
	10	3	Stable	Stable	Small log, low embedment
	13	1	1,160	Stable	Small log, medium embedment

Rootwad log size	**Embedded length (ft)**	**Embedded depth, avg (ft)**	**Additional resisting force required (lbf)**		**Description**
			Vertical (i.e. to resist buoyancy)	**Horizontal (i.e. to resist sliding)**	
	13	2	Stable	Stable	Small log, medium embedment
	13	3	Stable	Stable	Small log, medium embedment
	15	1	940	Stable	Small log, high embedment
	15	2	Stable	Stable	Small log, high embedment
	15	3	Stable	Stable	Small log, high embedment
	20	0.5	1,530	Stable	Toe log, fully embedded

Table 8. Stability analysis results for pin logs and boulder ballast. The resisting forces supplied in the vertical and horizontal directions are the excess force supplied to pinned/ballasted elements after meeting a 1.5 safety factor.

Pin log size	**Embedded length (ft)**	**Resisting force supplied (lbf)**	
		Vertical	**Horizontal**
10 ft × 1 ft	5	450	2,940
15 ft × 1 ft	10	2,630	12,310
20 ft × 1.5 ft	15	12,640	56,140
Boulder ballast diameter	**Position**	**Resisting force supplied (lbf)**	
		Vertical	**Horizontal**
1 ft	Above	50	–
1 ft	Behind	–	50
2 ft	Above	420	–
2 ft	Behind	-	420
3 ft	Above	1,440	–
3 ft	Behind	–	1,440
5 ft	Above	6,690	–
5 ft	Behind	–	6,690

Stability of single or multi-log placements can be determined in the field using Table 7 and Table 8, by following these steps.

1) The rootwad logs should be placed with the greatest embedment length and depth as possible while still keeping the rootwad exposed to flow to create cover and habitat. Ideally, stability of the structure should be achieved through embedment only, to minimize the need for pin logs and boulder ballast.

2) The additional resisting forces required for the structure can be determined by summing the vertical and horizontal forces for each individual log in the structure found in Table 7. A range of log sizes and embedment specifications are provided to allow for interpolation if needed.

3) Next, add pin logs and boulder ballast so the sum of the resisting forces supplied is greater than or equal to the additional resisting force required for the structure. Interpolation between the values provided in the tables may be required by the on-site Engineer of Record or designee. Variability in field conditions may require deviation from the specifications presented in Table 7 and Table 8. For example, if a 10-ft pin log cannot be driven 5 ft deep at a given location, additional pin logs, boulder ballast, or embedment will be required for that wood structure.

This methodology provides a reasonable general guideline for constructing each wood structure and determining the number of pinning or ballasting members needed while providing flexibility to account for variations in field conditions.

2.2 Design Feedback and Revisions

Comments on the Zanker 65% designs were received from CDFW, the Tuolumne River Conservancy, and Ron Zanker, the landowner. Table 9 shows the comments as well as responses to those comments. The most significant changes made to the design based on 65% design comments were (1) to modify the SC-5 side channel and associated floodplains to inundate at 300 cfs, and (2) to modify in-channel habitats to avoid a decrease in adult *O. mykiss* habitat that was modeled at the 65% design level.

Table 9. 65% design comments and how those comments were addressed in the 90% design.

Commenter	Comment	Comment response
Tuolumne River Conservancy	Modify design to ensure no decrease in adult *O. mykiss* habitat	At the 65% design level, there was up to a 7% decrease in adult *O. mykiss* habitat at certain flows. As part of the 90% design update, in-channel features were modified to ensure there is no decrease in adult *O. mykiss* habitat.
Tuolumne River Conservancy	Widen and deepen riffle thalwegs to three feet deep, ten feet wide	Modifications were made as requested.
Ron Zanker	Modify SC-5 and FP-6, FP-7, FP-8, FP-9, and FP-10 so they all begin inundating at 300 cfs	These features were modified so that SC-5 flows at 300 cfs, and FP-6, FP-7, FP-8, FP-9, and FP-10 all begin inundating at 300 cfs.
CDFW	Page 59, Table 12 Please add row at end with totals.	A row was added to the end of Table 12 with totals for area and volumes.

Commenter	Comment	Comment response
CDFW	Page 59, Table 14 Please consider increasing the amount of large wood. Doubling the amount of large wood would only result in a 3.5% increase in the total budget. An appropriate target may be 300 m^3/ha, based on Napolitano (2014).	The 65% design included 39 individual wood members, which equates to approximately 13.5 m^3/ha. The wood loading target of ≥ 300 m^3/ha presented in Napolitano (2014) was developed for channels where the adjacent valley floor and/or hillslopes are vegetated primarily by coastal redwood forest. Napolitano (2014) also describes a target of ≥ 100 m^3/ha for hardwood reaches, which are defined as channels where the adjacent valley flat is vegetated by some combination of willow species, white alder, California bay laurel, bigleaf maple, tan oak, and/or Oregon ash. The Zanker Project site is more accurately described as a hardwood reach. Therefore, based on Napolitano (2014), a target of ≥ 100 m^3/ha may be more appropriate than ≥ 300 m^3/ha. A total of 300 wood pieces would be required to satisfy the ≥ 100 m^3/ha target, which would present a significant increase in large wood material and implementation cost. An additional factor to consider is the reluctance of the Central Valley Flood Protection Board to allow large wood in the channel. For these reasons, the original quantity of 39 wood members will be kept for the current 100% design. We propose increasing the total number of large wood pieces in an amended 100% design if other projects have successfully received permits to use large wood pieces..
CDFW	Page 63, Table 18 Calculating adults from AUC gives erroneous results, since there is a units mismatch AUC is cfs × acres, whereas adults should be calculated from acres or square feet. This can be seen comparing the increase of 6,615,615 adults for Chinook Salmon spawning in Table 18 versus 3,798 adults under 3.1.2.1. CDFW would recommend recalculating the numbers of adults using WUA at 300 cfs. A second option would be to present index values, where the numbers in Table 18 are divided by the largest value. A third option would be to calculate a habitat time series and use the 50th percentile of the habitat time series instead of AUC.	Table values in Table 18, now Table 17, were converted to index values for the 90% design report per the second option suggested by CDFW.
CDFW	Page D-31, Section 1.5.4 CDFW recommends implementing the suggested vegetation and bedrock overlay for the 90% design.	TARGETS was used to illustrate the vegetation recruitment response magnitude between existing and design conditions. We used a fixed number of seeds that were uniformly distributed (3,000,000). We know, for instance, that seeds are not uniformly

Commenter	Comment	Comment response
		distributed. We were not trying to create a "realistic" scenario that actually predicted where seedlings would establish. Constraining TARGETS results to unvegetated areas that are not underlain by bedrock would reduce the number of seedlings but would not change the magnitude of the result relative to existing conditions. We could further develop a more realistic model using female cottonwood locations and model seed dispersal relative to female tree locations. We could use a more constrained model for answering specific biologic questions, but the extra work to create the more realistic model would not change the initial results that the design conditions greatly improve recruitment opportunities for cottonwoods.
CDFW	Page E-27, Figure 11 Why is there no proposed planting in the lower half of the project area?	The design does not create floodplain habitat suitable for planting riparian vegetation in the downstream half of the project. The design at the downstream end of the project is focused on in-channel features including riffles and gravel bars. The low floodplain locations that do occur on Civil Design Sheet C-5 are generally not included in the revegetation design due to the underlying bedrock substrate in this section of the channel. This substrate is not suitable for planting riparian species into groundwater. The areas of existing vegetation in this section of the project will be avoided. Emergent/channel margin and low riparian planting is included in side channels SC-1 and SC-2 (Civil Design Sheet C-4, Revegetation Design Sheet R-3). Emergent/channel margin planting and a small area of low riparian planting is also included for the lower section of Peaslee Creek, near the creek confluence (Revegetation Design Sheet R-3). Willow clumps will also be planted at the mouth of Peaslee Creek where feasible, and willow trenches are included in the design and shown on the Civil Design Sheet C-4. Rapid passive recruitment of hardwoods is expected on the low-lying design features.

Minimal comments were received at the 90% design stage. Table 10 shows the 90% design comments as well as responses to those comments. These comments did not necessitate any changes to the grading plan, civil design, or revegetation design.

Table 10. 90% design comments and how those comments were addressed in the 100% design.

Commenter	Comment	Comment response
CDFW	Section 2.1.3, page 25 It would be good to add information about the height and pier placement of downstream bridges to support the	The nearest bridge downstream of the Zanker Farm project is Robert's Ferry bridge, which is located approximately 5.4 miles away. Field observations and photos of bridge height, span, and pier placement were made on October 13 and were

Commenter	Comment	Comment response
	assessment of low property damage risk.	incorporated into the 100% design report to support the risk assessment (Section 2.1.3). The main span of the bridge spans approximately 150 ft across the river and completely spans the wetted channel at 1,200 cfs. The bridge decking is over 20 ft above the water surface elevation at a flow of 1,000 cfs. There are two four-foot pylons on the floodplain at each side of the river. These dimensions and the included images (Figure 15 and Figure 16) illustrate how the channel geometry at the bridge is wide and free of obstructions presenting very low potential for large wood to become pinned or racked on the bridge. In the event that a large wood member did get pinned or racked on the bridge, it would likely have very little effect on flow conveyance due to the large open cross-sectional area under the bridge. These observations help support the use of a 1.5 safety factor for the wood stability design flow of 11,500 cfs.
CDFW	Section 2.8, page 47 It is not apparent from the text which of the three scenarios was selected for use in the design. We would recommend scenario 3. From the plans on sheet C-30, it looks like scenario 2 was selected.	Scenario 3 was used per CDFW recommendation. The 100% design report text was updated to clearly indicate which scenario was selected. Sheet C-30 and C-31 were updated to depict the two-foot fabricated steel base.

2.3 In-channel Features

The in-channel design features consist of gravel bars and riffles designed to increase sinuosity, narrow channel width, and enhance coarse sediment storage within the mainstem (Figure 2, Figure 3). Design gravel bars will slope into the mainstem channel at gentle angles to create variable depths and hydraulic conditions over a range of flows. Many gravel bars include small cutoff channels with pools at existing channel elevations to preserve existing pool depths in the cutoff channels and utilize existing overhanging bank vegetation to maintain pool habitat, cover, and shade. Design riffles will redistribute slope throughout the length of the Project area and create suitable velocities for salmonid spawning, as well as benthic macroinvertebrate production. Riffles will also have a dune morphology to increase in-channel topographic complexity and provide immediate habitat benefits for salmonids. Dunes should be approximately 3 ft in height from trough to crest, with approximately 30 ft between dune crests. Gravel bars will be constructed with the standard or fine spawning mix (Table 5) specified in the *Coarse Sediment Management Plan* (M&T 2004), or the standard mix augmented with oversized (6 inch to 12 inch) rock to achieve a D_{84} needed for stability based on the grain size calculations for a 10-year flow (Section 2.1.1). Riffles are designed to maximize spawning habitat with spawning sized substrate and will mobilize under 10-year flow events. Riffles will be constructed with either the standard or fine spawning mix and the surface layer of all riffles will be comprised purely of spawning mix with a minimum layer thickness of two feet. Approximately 1/2 to 2/3 of the bottom (subsurface) layer of all riffles will be comprised of a structural mix, in which large (greater than six-inch) rock is combined with spawning gravel mix to provide a structural component. The structural subsurface layer of a given riffle may be less than half of the total riffle height if necessary to ensure that the spawning gravel layer is at least two feet thick.

Existing spawning areas will be protected and no gravel or cobble will be added to existing spawning areas.

2.3.1 Area IC-1

IC-1 is a 12,960 ft^2 area downstream of the confluence of Peaslee Creek and the mainstem Tuolumne River extending from Station 4+25 to 5+30. IC-1 is located just downstream of an existing riffle, in the upstream portion of a large deep pool with a compact matrix of cobble and sandstone bottom that supplies little to no coarse sediment to downstream riffles and runs. The area has a simple, wide channel morphology and low velocities. A substantial portion of the existing deep pool will remain in place for holding habitat.

The design objective for IC-1 is to construct a riffle with 0.15% to 0.25% slope by placing 1,360 yd^3 of clean coarse sediment to provide a short-term source of coarse sediment intended to restore in-channel storage and maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing and proposed FERC license flows and be suitable for adult salmon and *O. mykiss* spawning. The IC-1 riffle control elevation will redistribute the channel slope by backing water into the downstream end of the existing riffle at the mouth of Peaslee Creek and forming a pool at existing channel elevations between the two riffles. The IC-1 riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at approximate summer baseflows of 150 cfs to allow fish passage and navigability by watercraft.

2.3.2 Area IC-2

IC-2 is a 31,340 ft^2 area extending from Station 6+00 to 10+00 at the downstream end of the Project area on the right bank just upstream of the confluence of Peaslee Creek and the mainstem Tuolumne River. IC-2 is in a wide and deep slow-water area. The bed is comprised of a compact matrix of cobble with a large shelf of exposed sandstone that supplies little to no coarse sediment to downstream riffles and runs. The area has a simple, wide channel morphology and extremely low velocities.

The design objective for IC-2 is to construct a right bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve suitable adult and juvenile salmonid habitat. The IC-2 point bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. Approximately 4,910 yd^3 of clean coarse sediment will be placed at IC-2.

2.3.3 Area IC-3

IC-3 is a 6,630 ft^2 area extending from Station 9+45 to 10+15 immediately upstream of IC-2. Area IC-3 is in a pool with a compact matrix of cobble and sandstone bottom and a large shelf of exposed sandstone that supplies little to no coarse sediment to downstream riffles and runs. The existing channel has a simple, wide morphology with little to no velocity at typical summer and winter baseflows.

The design objective for IC-3 is to construct a riffle with 0.5% to 1.0% slope by placing 800 yd^3 of clean coarse sediment that will restore in-channel storage and provide coarse sediment for downstream alluvial features. Coarse sediment will be sized to mobilize under the existing and proposed FERC license flows. IC-3 will also increase macroinvertebrate production to improve food resources for foraging salmonids. The IC-3 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-5. The SC-1 side channel connector (Section 2.4.1) will be hydraulically controlled by IC-3. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.4 Area IC-4

IC-4 is a 43,100 ft^2 area extending from Station 9+00 to 15+50 on the left bank of the river at the downstream end of the Project upstream of the confluence of Peaslee Creek and the mainstem Tuolumne River. The existing channel bottom is an exposed sandstone shelf that supplies no coarse sediment to downstream riffles and runs and offers poor habitat for salmonids. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-4 is to construct a left bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-4 point bar will slope into the channel at approximately 6:1 and will remain partially dry at baseflow conditions. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. Approximately 6,910 yd^3 of clean coarse sediment will be placed at IC-4.

2.3.5 Area IC-5

IC-5 is a 42,390 ft^2 area extending from Station 12+50 to 18+25 at the upstream end of a large pool. The existing channel bottom is a cobble and clay hardpan matrix or sandstone bedrock with a layer of deposited fines and an exposed sandstone shelf that supplies no coarse sediment to downstream riffles and runs and offers little to no habitat for salmonids. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-5 is to construct a riffle with a variable slope ranging from 0.2% to 1.0% by placing 1,770 yd^3 of clean coarse sediment to restore in-channel storage and maintain downstream alluvial features. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmon and *O. mykiss* spawning and benthic macroinvertebrate production. The IC-5 riffle control elevation will redistribute the channel slope by backing water into the downstream end of riffle IC-6. The SC-2 side channel connector (Section 2.4.2) will be hydraulically controlled by IC-5. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at approximate summer baseflows of 150 cfs to allow fish passage and navigability by watercraft.

2.3.6 Area IC-6

IC-6 is a 21,740 ft^2 area in the center of the river extending from Station 19+50 to 21+00 near a sequence of existing medial bars. The existing channel bottom is a cobble and clay hardpan or sandstone matrix with a layer of deposited fines. The section of channel has some geomorphic complexity due to flow splits around gravel bars, a small alcove on the right bank, and a range of depths and velocities. The left bank of the river in this area hosts mature, overhanging riparian vegetation that provides existing cover and shade that is beneficial to salmonids.

The design objective for IC-6 is to construct a riffle with a variable slope ranging from 0.2% to 2.0% by placing 1,730 yd^3 of clean coarse sediment to restore in-channel salmonid habitat, coarse sediment storage, and maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmonid spawning and benthic macroinvertebrate production. The IC-6 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-8 and form complex pool habitat between the two riffles. The riffle will have a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.7 Area IC-7

IC-7 is a 12,540 ft^2 area in the central part of the Project area in the middle of the channel extending from Station 21+00 to 24+00. The area is immediately downstream of a prominent side channel and adjacent to the Zanker Farm irrigation pump intake. The area includes an existing medial gravel bar, with most of the flow in the channel on river left (looking downstream).

The design objective for IC-7 is to enhance the existing medial gravel bar with 870 yd^3 of clean coarse sediment that will increase storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve salmonid habitat. The IC-7 bar is designed to redistribute flow between the two existing split-flow channels and create more suitable velocities to promote natural geomorphic processes. The IC-7 bar will slope into the existing channel at approximately 6:1 and tie into the IC-8 riffle at the upstream end.

2.3.8 Area IC-8

IC-8 is a 29,650 ft^2 area in the central part of the Project area in the middle of the channel extending from Station 23+00 to 25+20. The area includes the downstream end of a prominent side channel and is directly adjacent to the Zanker Farm irrigation pump intake. The existing channel bottom is a cobble matrix with discrete sand deposits.

The design objective for IC-8 is to construct a riffle with 0.15% to 0.25% slope by placing 2,080 yd^3 of clean coarse sediment that will provide immediate benefit to salmonids, increase in-channel storage, and help maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under the existing flows and proposed FERC license flows and be suitable for adult salmonid spawning and macroinvertebrate production. The IC-8 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-11 and form a pool between riffles IC-11 and IC-8. The IC-8 riffle is designed to evenly distribute flow between the two split-flow channels formed by the IC-7 medial bar, as both sides of the flow split are controlled by the IC-8 riffle crest elevation. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.9 Area IC-9

IC-9 is a 12,150 ft^2 area on the left bank of the river extending from Station 30+25 to 33+25. The existing channel bottom is a cobble matrix with a layer of deposited fines. The area encompasses an existing left bank point bar. The section of channel is wide with simple morphology and extremely low velocity. The right bank of the river across from this area hosts mature, overhanging riparian vegetation that provides existing cover and shade that is beneficial to salmonids.

The design objective for IC-9 is to enhance the existing point bar with 920 yd^3 of clean coarse sediment that will increase storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve the existing right bank habitat. The IC-10 bar will slope into the channel at approximately 6:1 and will remain partially dry during low flow periods. The IC-9 bar will create a channel width of approximately 40 feet and depths of 2.5 to 3 feet at 150 cfs.

2.3.10 Area IC-10

IC-10 is a 17,790 ft^2 area on the right bank of the river extending from Station 33+00 to 36+50. The area encompasses an existing right bank point bar with a small cutoff channel. The mainstem channel near IC-10 is primarily exposed sandstone with small pockets of coarse sediments. Based on observations from the landowner, this section of the mainstem has degraded over the years and the existing point bar has not been replenished by sediment transport from upstream. The mainstem is narrower here than in other parts of the Project area and has some of the highest velocities within the Project area.

The design objective for IC-10 is to enhance the existing right bank point bar with 1,210 yd^3 of clean coarse sediment that will increase storage, narrow the low-flow channel width, and increase channel sinuosity and complexity. The IC-10 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. The IC-10 gravel bar has a cutoff channel that is 10 feet wide and between half a foot to a foot deep at flows of approximately 500 cfs and will daylight into existing ground on the right bank. The IC-10 bar will create a channel width of approximately 50 feet and depths of approximately 2 feet at 150 cfs.

2.3.11 Area IC-11

IC-11 is a 6,180 ft^2 area in the center of the channel extending from Station 35+00 to 35+75. The existing channel bottom is primarily exposed sandstone that transitions into a cobble and sand matrix in a deep pool at the upstream end. Based on observations from the landowner, this section of the mainstem and the proposed gravel bar area at IC-10 have degraded in sediment storage over the years and have not been replenished by sediment transport from upstream sources. The mainstem is narrower here than in other parts of the Project area and has some of the highest velocities within the Project area.

The design objective for IC-11 is to construct a riffle with 0.5% to 1.0% slope by placing 180 yd^3 of clean coarse sediment that will restore in-channel storage and maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-11 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of the primary riffle control for Phase I of the Project but not raise water surface elevations so high that it becomes the hydraulic control of the Phase I area. The IC-11 riffle crest will control flow into the upstream-most inlet to the SC-3 side channel. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.12 Area IC-12

IC-12 is a 7,860 ft^2 area located at Station 41+50 near the primary riffle control for the Phase I area. IC-12 has a compact matrix of cobble and sandstone bottom that supplies little to no coarse sediment to downstream riffles and runs. The area has a simple, wide channel morphology and low velocities.

The design objective for IC-12 is to construct a riffle with 0.5% to 1.0% slope by placing 320 yd^3 of clean coarse sediment to restore in-channel storage and replenish existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-12 riffle control elevation will redistribute the channel slope by backing water into the downstream end of riffle IC-14 and forming a pool at existing channel elevations between the two riffles. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.13 Area IC-13

IC-13 is a 27,910 ft^2 area extending from Station 41+00 to 46+75 on the right bank near the primary riffle control for the Phase I area. IC-13 has a cobble matrix and sandstone bedrock bottom that supplies little to no coarse sediment to downstream riffles and runs. The area has a simple, wide channel morphology and low velocities.

The design objective for IC-13 is to construct a right bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-13 point bar will slope into the channel at approximately 6:1 and will remain partially dry at baseflow conditions. Approximately 3,860 yd^3 of clean coarse sediment will be placed at IC-13. The IC-13 bar will create a channel width of approximately 35 feet and depths of 2 to 3.5 feet at 150 cfs.

2.3.14 Area IC-14

IC-14 is an 11,120 ft^2 area located Station 45+50 near the primary riffle control for the Phase I area. IC-14 has a cobble matrix and sandstone bedrock bottom that supplies little to no coarse sediment to downstream riffles and runs. The area has a simple, wide channel morphology and low velocities.

The design objective for IC-14 is to construct a riffle with 0.15% to 0.25% slope by placing 420 yd^3 of clean coarse sediment to restore in-channel storage and replenish existing alluvial features downstream over time. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmonid spawning. The IC-14 riffle control elevation will redistribute the channel slope by backing water into the downstream end of riffle IC-16, forming a pool between the two riffles. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.15 Area IC-15

IC-15 is a 34,470 ft^2 area extending from Station 49+50 to 54+00 located on the left bank of the river near the outlet of the existing dredger slough. The existing channel bottom is a cobble matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-15 is to construct a left bank point bar with a cutoff channel to increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-15 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. Approximately 6,530 yd^3 of clean coarse sediment will be placed at IC-15. Existing overhanging vegetation on the left bank will be preserved to provide immediate cover and shade for salmonids within the cutoff channel. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. The SC-6 side channel reconnects to the mainstem in the IC-15 cutoff channel. The IC-15 cutoff channel will maintain existing channel elevations and will have a water depth of approximately five feet and width of approximately 40 feet at 150 cfs.

2.3.16 Area IC-16

IC-16 is a 46,450 ft^2 area at the outlet of the existing dredger slough. The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-16 is to construct a riffle with 0.15% to 0.25% slope by placing 6,380 yd^3 of clean coarse sediment to restore in-channel storage and replenish existing alluvial features downstream over time. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmonid spawning. The IC-16 riffle control elevation will redistribute the channel slope by backing water into the downstream end of riffle IC-18 and forming a pool between the two riffles. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at summer baseflow to allow fish passage and navigability by watercrafts.

2.3.17 Area IC-17

IC-17 is a 56,650 ft^2 area extending from Station 55+50 to 63+00 located on the right bank of the river just upstream of the outlet of the existing slough. The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity. The right bank of the river in this area hosts mature, overhanging riparian vegetation that provides existing cover and shade that is beneficial to salmonids.

The design objective for IC-17 is to construct a right bank point bar with a 10-ft wide cutoff channel between the bar and bank that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-17 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. The cutoff channel will run along the right bank at existing channel elevations and have a water depth of three to five feet at 150 cfs, tying into the pool downstream of IC-16. Flow into the IC-17 cutoff channel will occur at baseflow conditions and be controlled by the IC-18 riffle elevation. The existing mature riparian vegetation along the bank and existing channel elevations will be preserved in the cutoff channel. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. Approximately 9,300 yd^3 of clean coarse sediment will be placed at IC-17.

2.3.18 Area IC-18

IC-18 is an 13,260 ft^2 area at Station 61+00 immediately downstream of the remnant bridge infrastructure (R-2 I-beams, R-1 bridge abutment, and R-3 haul road). The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-18 is to construct a riffle with 0.5% to 1.0% slope by placing 1,540 yd^3 of clean coarse sediment intended to restore in-channel storage and maintain existing alluvial features downstream via coarse sediment transport over time. Coarse sediment is sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-18 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-20 and forming a pool between the two riffles. The IC-18 riffle will also control flow into the IC-17 cutoff channel. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2.5 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.19 Area IC-19

IC-19 is a 30,400 ft^2 area extending from Station 62+50 to 66+00 located on the left bank directly adjacent to the remnant haul road fill prism and I-beams in the center of the channel, and on the opposite bank from the R-1 remnant bridge abutment (Section 2.6.1). The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-19 is to construct a left bank point bar with a 10-ft wide cutoff channel between the bar and bank that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-19 bar is intended to direct velocity into the right bank at high flows to encourage natural geomorphic processes and coarse sediment transport. Removal of the bridge abutment (Area R-1) will be necessary to allow such processes to occur. The IC-19 bar will slope into the channel at approximately 6:1 and will remain partially dry at baseflow conditions. Flow into the IC-19 cutoff channel will occur at baseflow conditions and be controlled by the IC-20 riffle elevation. Existing channel elevations will be preserved in the cutoff channel and water depth will be between 2.5 to 5 feet at 150 cfs. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. Approximately 4,330 yd^3 of clean coarse sediment will be placed at IC-19. The R-2 I-beams in the center of the channel (Section 2.6.2) will need to be removed to construct IC-19.

2.3.20 Area IC-20

IC-20 is a 7,740 ft^2 area extending from Station 65+50 to 67+00 located immediately upstream of the remnant bridge infrastructure (I-beams, bridge abutment, and haul road). The existing channel bottom is a cobble and clay hardpan matrix. The section of channel is wide and deep with simple morphology and extremely low velocity.

The design objective for IC-20 is to construct a riffle with 0.15% to 0.25% slope by placing 1,330 yd^3 of clean coarse sediment to restore in-channel storage and maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmonid spawning. The IC-20 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-22 and forming a pool between the two riffles. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs to allow fish passage and navigability by watercraft.

2.3.21 Area IC-21

IC-21 is a 16,090 ft^2 area extending from Station 65+25 to 69+00 located on the right bank of the river upstream of the R-2 remnant bridge abutment. The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-21 is to construct a right bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-21 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. Approximately 2,560 yd^3 of clean coarse sediment will be placed at IC-21.

2.3.22 Area IC-22

IC-22 is a 7,220 ft^2 area located at Station 68+00 on the right bank of the river upstream of the R-2 remnant bridge abutment. The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-22 is to construct a riffle with 0.5% to 1.0% slope by placing 760 yd^3 of clean coarse sediment to restore in-channel storage and replenish existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-22 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-24 and forming a pool between the two riffles. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at 150 cfs, approximate summer baseflow, to allow fish passage and navigability by watercraft.

2.3.23 Area IC-23

IC-23 is a 37,510 ft^2 area extending from Station 67+50 to 73+00 located on the left bank of the river downstream of the inlet to the existing dredger slough. The existing channel bottom is a cobble and clay hardpan matrix with a layer of deposited fines. The section of channel is wide with simple morphology and extremely low velocity. The left bank of the river in this area hosts mature, overhanging riparian vegetation that provides existing cover and shade that is beneficial to salmonids.

The design objective for IC-23 is to construct a left bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-23 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. No cutoff channel is proposed for IC-23, as the intent of this feature is to encourage geomorphic processes and natural channel evolution by directing flow towards the right bank. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. Approximately 6,750 yd^3 of clean coarse sediment will be placed at IC-23.

2.3.24 Area IC-24

IC-24 is an 8,970 ft^2 area located at Station 72+25 in the mainstem immediately downstream of the existing dredger slough inlet. The existing channel bottom is a cobble and clay hardpan matrix. The section of channel is wide with simple morphology and extremely low velocity.

The design objective for IC-24 is to construct a riffle with 0.5% to 1.0% slope by placing 1,170 yd^3 of clean coarse sediment intended to restore in-channel storage and replenish existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-24 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-26 and forming a pool between the two riffles. The SC-8 side channel will reconnect with the mainstem channel at this pool. Flow will enter side channel inlet SC-7 via this pool. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at summer baseflows of approximately 150 cfs to allow fish passage and navigability by watercraft.

2.3.25 Area IC-25

IC-25 is a 42,980 ft^2 area extending from Station 72+25 to 78+50 located on the right bank of the river opposite the inlet to the existing dredger slough and SC-7 side channel (Section 2.4.6). The existing channel bottom consists of a cobble and clay hardpan matrix and the section of channel is wide and lacking topographic complexity. The right bank of the river in this area hosts mature, overhanging riparian vegetation that provides existing cover and shade that is beneficial to salmonids.

The design objective for IC-25 is to construct a right bank point bar with a 10-ft wide cutoff channel between the bar and bank that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-25 bar will slope into the channel at approximately 6:1 and will remain partially dry at baseflow conditions. Flow into the IC-25 cutoff channel will occur at baseflow conditions and be controlled by the IC-26 riffle elevation at the upstream end and the IC-24 riffle elevation at the downstream end. The existing mature riparian vegetation along the bank and existing channel elevations will be preserved in the cutoff channel and water depths in the cutoff channel will be between three to five feet at 150 cfs. Willow trenches will be installed at the upstream end of the bar to dissipate energy and stabilize the bar at high flows. Approximately 9,260 yd^3 of clean coarse sediment will be placed at IC-25.

2.3.26 Area IC-26

IC-26 is a 13,890 ft^2 area located at Station 75+50 downstream of an existing riffle near the upstream end of the Project area. The existing channel bottom has a cobble and clay hardpan matrix. The section of channel is wide and lacking topographic complexity.

The design objective for IC-26 is to construct a riffle with 0.15% to 0.25% slope by placing 2,170 yd^3 of clean coarse sediment intended to restore in-channel storage and maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmonid spawning. The IC-26 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of the existing upstream riffle and forming a pool at existing channel elevations between the two riffles. The IC-26 riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at approximate summer baseflows of 150 cfs to allow fish passage and navigability by watercraft.

2.3.27 Area IC-27

IC-27 is an 11,800 ft^2 area extending from Station 79+00 to 82+00 located on the left bank of the river immediately downstream of an existing riffle. The existing channel bottom is medium to large cobble and the section of channel features a bar with a cutoff channel on the right bank. Velocities are higher in this area because of the existing riffle.

The design objective for IC-27 is to construct a left bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-27 bar is intended to direct velocity into an existing bar on the right bank at high flows to encourage natural wood and coarse sediment recruitment. The IC-27 bar will slope into the channel at approximately 6:1 and will remain partially dry at baseflow conditions. Approximately 1,350 yd^3 of clean coarse sediment will be placed at IC-27.

2.3.28 Area IC-28

IC-28 is an 11,010 ft^2 area extending from Station 64+00 to 87+00 located on the left bank of the river upstream of an existing riffle on the inside of a slight meander. The existing channel bottom is medium to large cobble. Velocities are higher in this area because of the existing riffle.

The design objective for IC-28 is to construct a left bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-28 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. Approximately 990 yd^3 of clean coarse sediment will be placed at IC-28.

2.3.29 Area IC-29

IC-29 is a 5,990 ft^2 area located at Station 86+00 near the upstream end of the Project area. The existing channel bottom consists of a cobble and clay hardpan matrix. Channel geometry lacks complexity.

The design objective for IC-29 is to construct a riffle with 0.15% to 0.25% slope by placing 210 yd^3 of clean coarse sediment to restore in-channel storage and replenish existing alluvial features downstream. The riffle will have a thalweg at existing channel elevations running along the right bank and will also maintain existing ground at the inlet to side channel SC-8. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and be suitable for adult salmonid spawning. The IC-29 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-31 and forming a pool at existing channel elevations between the two riffles. Flow will enter side channel SC-8 via this pool. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at approximate summer baseflows of 150 cfs to allow fish passage and navigability by watercraft.

2.3.30 Area IC-30

IC-30 is a 6,990 ft^2 area extending from Station 88+50 to 90+00 located on the left bank of the river near the upstream end of the Project area on the outside of a meander in a pool. The existing channel bottom is a matrix of cobble and clay hardpan that supplies little to no coarse sediment to downstream riffles and runs.

The design objective for IC-30 is to construct a left bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-30 bar will slope into the channel at approximately 8:1 and will remain partially dry at baseflow conditions. Approximately 470 yd^3 of clean coarse sediment will be placed at IC-30.

2.3.31 Area IC-31

IC-31 is an 8,300 ft^2 area located at Station 90+00 in a mainstem meander near the upstream end of the Project in a pool. The existing channel bottom is a matrix of cobble and clay hardpan that supplies little to no coarse sediment to downstream riffles and runs.

The design objective for IC-31 is to construct a riffle with 0.5% to 1.0% slope by placing 510 yd^3 of clean coarse sediment intended to restore in-channel storage and replenish existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-31 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of riffle IC-33 and forming a pool at existing channel elevations between the two riffles. The riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at approximate summer baseflows of 150 cfs to allow fish passage and navigability by watercraft.

2.3.32 Area IC-32

IC-32 is an 8,600 ft^2 area extending from Station 91+50 to 93+75 located on the left bank of the river near the upstream end of the Project area on the outside of a meander in a deep pool. The existing channel bottom is a matrix of cobble and clay hardpan that supplies little to no coarse sediment to downstream riffles and runs. In some areas, the channel bottom has been scoured down to the underlying bedrock.

The design objective for IC-32 is to construct a left bank point bar that will increase coarse sediment storage, narrow the low-flow channel width, increase channel sinuosity and complexity, and improve habitat. The IC-32 bar will slope into the channel at approximately 6:1 and will remain partially dry at baseflow conditions. Approximately 730 yd^3 of clean coarse sediment will be placed at IC-32.

2.3.33 Area IC-33

IC-33 is a 7,160 ft^2 area located at Station 93+50 in a mainstem meander at the upstream end of the Project in a deep pool. The existing channel bottom is a matrix of cobble and clay hardpan that supplies little to no coarse sediment to downstream riffles and runs. In some areas, the channel bottom has been scoured down to the underlying bedrock.

The design objective for IC-33 is to construct a riffle with 0.5% to 1.0% slope by placing 730 yd^3 of clean coarse sediment to restore in-channel storage and maintain existing alluvial features downstream. Coarse sediment will be sized to mobilize under both existing flows and proposed FERC license flows and will also encourage macroinvertebrate production. The IC-33 riffle control elevation is designed to redistribute the channel slope by backing water into the downstream end of the existing riffle upstream and forming a pool between the two riffles. The IC-33 riffle will have a dune morphology and a 10-ft wide thalweg with a depth of approximately 2 ft at approximate summer baseflows of 150 cfs to allow fish passage and navigability by watercraft.

2.4 Side Channel Features

The design includes several side channel features that will create off-channel habitat area at low flows and hydraulically connect design floodplain features with the mainstem at higher flows (Figure 1, Figure 2). The largest side channel complex will convert the two existing dredger sloughs in the Phase I project area into a continuous, sinuous, low-flow side channel by removing the R-3 haul road and then adding fill material to create a bar and riffle sequence that narrows the channel width and increases velocities. Another large side channel complex near the boundary between Phase I and Phase II will create defined flow paths across newly lowered floodplains with multiple connections to the main channel to improve hydraulic connectivity. Several smaller side channels will create off-channel salmonid habitat while reducing the existing slow-water habitat for aquatic predatory species. Design side channel features will be constructed by cutting into the banks and/or floodplain.

2.4.1 Area SC-1

SC-1 is a 1,830 ft^2 area at the downstream end of the site on the right bank situated at Station 11+00 between the mainstem and the large backwater alcove. The area is an existing low point on the bank that separates the mainstem and the alcove. SC-1 currently inundates at approximately 1,130 cfs and causes the alcove to function as a high flow channel. It has relatively minimal vegetation compared to the surrounding bank area, which hosts narrowleaf willow and valley oak.

The design objective for SC-1 is to construct a low-flow connector channel with an activation target of 150 cfs. Inundation of this connector channel will be controlled by the IC-3 riffle crest and will work in conjunction with the SC-2 connector channel to increase flows and velocities into the existing alcove at summer and winter baseflows. The design of SC-1 takes advantage of an existing low point in the terrain to help convert the backwater alcove into a flowing feature by cutting 200 yd^3 of material. This feature will reduce existing habitat for non-native fish species, increase geomorphic complexity, and create off-channel habitat for Chinook Salmon and *O. mykiss*.

2.4.2 Area SC-2

SC-2 is an 8,920 ft^2 area at the downstream end of the site on the right bank situated at Station 16+00 between the mainstem and the large backwater alcove. The area is an existing low point on the bank that separates the mainstem and the alcove. SC-2 currently inundates at approximately 3,000 cfs and causes the alcove to function as a high flow channel. Existing vegetation in SC-2 is a thicket of narrowleaf willow.

The design objective for SC-2 is to construct a low-flow connector channel with an activation target of 150 cfs. This connector channel will be controlled by the IC-5 riffle crest and will work in conjunction with the SC-1 connector channel to contribute increased flow and velocity into the existing alcove at low flows. The design of SC-2 takes advantage of an existing high flow channel in the terrain to help convert the backwater alcove into a flowing feature by cutting 790 yd^3 of material. The SC-2 feature is designed to reduce existing habitat for non-native fish, increase geomorphic complexity, and create high quality off-channel habitat for Chinook Salmon and *O. mykiss*. The SC-2 connector channel alignment avoids adjacent mature valley oaks.

2.4.3 Area SC-3

SC-3 is a 42,100 ft^2 area on the left bank floodplain just upstream of the Zanker Farm pump intake. The existing ground at SC-3 is a relatively flat, open area comprised of an armored matrix of sand and cobble vegetated with non-native grasses. The area inundates at flows above 1,580 cfs and drains via overland flow and some poorly-defined flow paths. Exposed Mehrten formation sandstone is present at some locations within SC-3 and the surrounding area (Figure 4).

The design objective for SC-3 to is create a side-channel complex that: (1) hydraulically connects floodplain areas FP-1, FP-2, and FP-3 with the mainstem; (2) creates off-channel habitat for Chinook Salmon and *O. mykiss*; and (3) creates a more defined drainage path for high-flow events. The side channel will have an anabranching channel configuration, connecting to the mainstem at multiple locations as well as an existing off-channel pond that has poor drainage under current conditions. The SC-3 side channel inlets will activate between IC-9 and IC-10 when the mainstem flows are 150 cfs and upstream of IC-11 for flows of 700 cfs or greater; the drainage path from the off-channel pond will activate at approximately 1,130 cfs. The side channel alignment avoids mature vegetation, including valley oaks present in this area. Approximately 3,770 yd^3 of cut will be generated from SC-3.

2.4.4 Area SC-4

SC-4 is a 4,810 ft^2 area located at Station 49+50 on the left bank adjacent to the IC-15 gravel bar cutoff channel. The area is vegetated with dense riparian species and has sand and silt substrate.

The design objective for SC-4 is to construct a side channel outlet that connects the downstream end of the SC-5 side channel to the mainstem channel via the IC-15 gravel bar cutoff channel. At flows of 750 cfs and above, SC-4 and SC-5 will function together as a flowing side channel. SC-4 is sloped toward the channel to promote drainage into the mainstem at flows lower than 750 cfs. SC-4 and SC-5 are not connected because the area between them is an existing low point in the terrain. Approximately 360 yd^3 of cut will be generated from SC-4.

2.4.5 Area SC-5

SC-5 is a side channel that branches off of low-flow side channel SC-7 and returns to the mainstem downstream of Area IC-15. The proposed side channel is an 83,660 ft^2 region near the existing slough in an upland area that is approximately 10 ft above the summer baseflow elevation and higher than the 10-year flood elevation. Area SC-5 overlaps with a former gravel processing plant and the remnant haul road fill prism. The substrate consists of a matrix of coarse gravels sorted from dredger tailings.

The design objective for SC-5 is to construct a side channel with an activation target of 750 cfs. This side channel will work in conjunction with floodplains FP-6, FP-7, FP-8, FP-9, and FP-10 to create off-channel habitat and refugia for salmonids and also promote the establishment of cottonwood, willow, and cattails to create habitat for avian species. SC-5 will serve as a defined drainage path for these three floodplain areas, which is expected to reduce the risk of fish stranding. SC-5 will work in conjunction with SC-4, which serves as the downstream connection with the mainstem; SC-4 and SC-5 are not connected because the area between them is an existing low point in the terrain. Approximately 22,000 yd^3 of cut will be generated from SC-5.

2.4.6 Area SC-6 and SC-7

SC-6 and SC-7 are 39,820 ft^2 and 107,380 ft^2 areas, respectively, which connect and repurpose the existing dredger tailing slough into a low-flow side channel. SC-6 and SC-7 function together as a single side channel spanning the length of the slough. The existing slough is a deep, stagnant pool with a silty bottom. It currently supports invasive species such as predatory bass and bullfrogs, as well as water hyacinth. The slough is split into two halves by a remnant haul road.

The design objective for SC-6 and SC-7 is to construct a low-flow side channel that activates at 300 cfs to provide year-round off-channel habitat and refugia for salmonids while simultaneously reducing existing non-native predator habitat. This will be accomplished by adding 3,930 yd^3 of fill in SC-6 and 13,890 yd^3 at SC-7 to construct riffles, bars, and benches that reduce channel width, increase velocities, and create a sinuous flow path through the existing slough. Additionally, 1,180 yd^3 of material will be cut within SC-6 to create a channel through the haul road fill prism. Existing channel depths will be preserved in pools and existing mature riparian vegetation along the banks will be preserved to the greatest extent possible. The main inlet to the side channel will be at the existing slough inlet just upstream of IC-24, which will have approximately 10% of the total flow in the mainstem enter the side channel at 300 cfs under design conditions. The SC-6 side channel will plug the existing outlet of the slough adjacent to IC-16 at Station 55+00under design conditions, so SC-6 will follow a new channel alignment and reconnect with the mainstem in a cutoff channel behind the IC-15 gravel bar. The plug at the existing slough outlet is designed so that this area will create floodplain habitat at approximately 500 cfs. Willow trenches and a large wood habitat structure will be installed to help promote deposition and keep the side channel separated from the mainstem.

2.4.7 Area SC-8

SC-8 is a 30,230 ft^2 area extending from Station 77+00 to 87+00 along the left bank near the upstream end of the Project area. The area is close to summer baseflow elevation and inundates frequently. It primarily hosts herbaceous riparian vegetation.

The design objective for SC-8 is to construct a low-flow side channel that flows at and above 300 cfs to provide year-round off-channel habitat and refugia for salmonids. This will be accomplished by excavating 4,290 yd^3 of material to create a section of channel with a riffle–pool sequence, an inlet located at the pool above IC-29, and an outlet at the pool below IC-26 (Figure 2).

2.5 Floodplain Features

Design floodplain features aim to lower surfaces to increase inundation frequency and create off-channel habitat and velocity refugia and rearing habitat for juvenile salmonids (Figure 1, Figure 2). Floodplain areas will also promote the establishment of cottonwood, willow, and cattails to create habitat for avian species (Appendix D). Floodplains will slope towards adjacent side channels to promote drainage and reduce the risk of fish stranding. Floodplains were designed to inundate between approximately 300 cfs and 5,400 cfs. Depending on the water year, all floodplains can provide both rearing habitat for juvenile salmonids and also riparian recruitment. However, due to the flow regime, lower floodplains are designed for the ecological propose of providing rearing habitat, low velocity refuge during winter and spring flows, and frequent and long-duration inundation to spur primary and secondary production and food for juvenile salmonids. Higher floodplains that inundate above a few thousand cfs will likely recruit more riparian plants, contributing shade and leaf litter to in-channel aquatic habitat and supporting a wide range of native fauna.

2.5.1 Area FP-1

FP-1 is a 3,840 ft^2 area extending from approximately Station 30+00 to 31+00 on the left bank. FP-1 is currently an open, armored surface vegetated almost exclusively with non-native grasses. The area inundates at a flow between 1,580 cfs to 3,000 cfs.

The design objective for this area is to create a lowered floodplain bench connected to the SC-3 side channel at 500 cfs by cutting 410 yd^3 of material. The FP-1 design will provide off-channel velocity refugia, juvenile rearing habitat, and create connection to shallow groundwater that will benefit natural riparian regeneration or plantings.

2.5.2 Area FP-2

FP-2 is a 12,070 ft^2 area extending from approximately Station 31+00 to 34+00 on the left bank. The area is adjacent to the SC-3 side channel. FP-2 is an open, armored surface vegetated almost exclusively with non-native grasses. Existing conditions hydraulic modeling showed that this area inundates at a flow of approximately 3,000 cfs.

The design objective for FP-2 is to lower the existing surface by cutting 830 yd^3 of material to create a sloped floodplain bench that provides variable depths when inundated between 633 cfs to 1,580 cfs and create off-channel refugia and juvenile rearing habitat for salmonids during high flows. FP-2 will add habitat complexity by connecting to the SC-3 side channel at multiple locations and elevations, creating variable flow paths and a range of hydraulic conditions. The design footprint of FP-2 will avoid nearby valley oaks.

2.5.3 Area FP-3

FP-3 is a 7,150 ft^2 area extending from approximately Station 34+00 to 35+50 on the left bank. FP-3 is an open area vegetated almost exclusively with non-native grasses. Existing conditions hydraulic modeling showed that this area inundates at approximately 3,000 cfs.

The design objective for FP-3 is to lower the floodplain by cutting 180 yd^3 of material to create a bench that inundates at a flow of approximately 1,580 cfs and create off-channel refugia and juvenile salmonid rearing habitat during high flows. FP-3 will add habitat complexity by connecting the SC-3 side channel and creating an alternate flow path at flows above 1,580 cfs. The design footprint of FP-3 avoids nearby valley oaks.

2.5.4 Area FP-4

FP-4 is a 52,810 ft^2 area extending from approximately Station 40+50 to 44+50 located on the left bank near the primary riffle control for the Phase I area. FP-4 encompasses an area of exposed gravel/cobble that is most likely an historical mainstem channel alignment. Existing vegetation is sparse, and the area is mostly open ground with some narrowleaf willow. Existing conditions hydraulic modeling showed that this area inundates at relatively low flows (approximately 500 cfs to 700 cfs).

The design objective for this area is to lower the floodplain by cutting 3,940 yd^3 of material to an inundation threshold of 300 cfs. The FP-4 design will better define the existing flow path and create connection to shallow groundwater that will benefit natural riparian regeneration or plantings.

2.5.5 Area FP-5

FP-5 is a 46,420 ft^2 areas extending from approximately Station 42+00 to 48+00 on the left bank upstream of the SC-3 side channel. The area is adjacent to an existing mainstem alcove and off-channel pond. The existing vegetation within FP-5 is predominantly narrowleaf willow, cottonwood, and emergent species. There is suspected to be Mehrten formation sandstone located within a few ft of the existing ground surface in this area.

The design objective for FP-5 is to lower the floodplain by cutting 1,650 yd^3 of material to a gradually sloped floodplain that inundates between 500 cfs to 1,000 cfs and create off-channel refugia for salmonids during high flows while improving the hydraulic connection between the mainstem and the small existing off-channel pond.

2.5.6 Area FP-6 and FP-7

FP-6 and FP-7 are 20,620 ft^2 and 36,710 ft^2 areas, respectively, in the central part of the Project area near Lake Road and the downstream extent of the SC-5 side channel complex. FP-6 and FP-7 are in an open area of non-native grasses that was once the location of a gravel processing plant. The substrate consists of a matrix of coarse gravels sorted from dredger tailings. The existing terrain in both floodplain areas is an upland area that sits about 10 ft higher than the summer baseflow elevation. Consequently, this area rarely becomes inundated since only flows above 11,500 cfs (10-year flood event) begin to reach this elevation.

The design objective for FP-6 and FP-7 is to lower the floodplains by excavating 8,460 yd^3 and 13,060 yd^3 of material, respectively, to begin to inundate at 300 cfs and create off-channel refugia for salmonids during high flows. The FP-6 and FP-7 floodplain surfaces will slope toward the SC-5 side channel to promote drainage and minimize the risk of fish stranding (Figure 2). Lowering FP-6 and FP-7 is also intended to promote the establishment of cottonwood, willow, and valley oak to create habitat for avian species.

2.5.7 Area FP-8

FP-8 is a 15,850 ft^2 area in a central part of the Project area between Lake Road and the R-3 remnant haul road. Like Areas FP-6 and FP-7, FP-8 is an open area of non-native grasses on an upland area about 10 ft higher than the summer baseflow elevation. Consequently, this area rarely becomes inundated since only flows above 11,500 cfs (10-year flood event) begin to reach this elevation.

The design objective for FP-8 is to lower the floodplain by excavating 2,970 yd^3 to create a gradually sloped floodplain that begins to inundate at 300 cfs to create off-channel refugia for salmonids during high flows. The FP-8 floodplain surface will slope toward the SC-5 high-flow side channel to promote drainage and minimize the risk of fish stranding. Lowering FP-8 is also intended to promote the establishment of cottonwood, willow, and valley oak to create habitat for avian species. Lake Road is to the south of this area and higher in elevation, and the existing road prism of Lake Road will not be affected by the project.

2.5.8 Area FP-9

FP-9 is an 8,260 ft^2 area upstream of FP-8 and near Lake Road and the R-3 remnant haul road. FP-9 is an open area of non-native grasses on an upland area about 10 ft higher than the summer baseflow elevation. Consequently, this area rarely becomes inundated since only flows above 11,500 cfs (10-year flood event) begin to reach this elevation.

The design objective for FP-9 is to lower the floodplain by excavating 1,360 yd^3 to create a gradually sloped flooplain that begins to inundate at 300 cfs to create off-channel refugia for salmonids during high flows. The FP-9 floodplain surface will slope toward the SC-5 high-flow side channel to promote drainage and minimize the risk of fish stranding. Lowering FP-9 is also intended to promote the establishment of cottonwood, willow, and valley oak to create habitat for avian species.

2.5.9 Area FP-10

FP-10 is a 31,970 ft^2 area at the upstream end of SC-5 and near Lake Road and the R-3 remnant haul road. FP-10 is an open area of non-native grasses on an upland area about 10 ft higher than the summer baseflow elevation. Consequently, this area rarely becomes inundated since only flows above 11,500 cfs (10-year flood event) begin to reach this elevation.

The design objective for FP-10 is to lower the floodplain by excavating 5,190 yd^3 to inundate between 3,000 cfs and 5,400 cfs to create off-channel refugia for salmonids during high flows. The FP-10 floodplain surface will slope toward the SC-5 high-flow side channel to promote drainage and minimize the risk of fish stranding. Lowering FP-10 is also intended to promote the establishment of cottonwood, willow, and valley oak to create habitat for avian species.

2.6 Remnant Infrastructure Removal

The remains of a decommissioned haul road bridge at approximately Station 64+00 include a concrete bridge abutment on the right bank, 23 I-beams driven vertically into the bed in the center of the channel, and an earthen fill road prism on the left bank (Figure 2). The design requires the removal and disposal of these remnant infrastructure components.

2.6.1 Area R-1

R-1 is a 4,750 ft^2 area located at Station 63+50 on the right bank at the remnant haul road location. The existing terrain is a concrete abutment left over from the decommissioning of a haul road bridge that crossed the river at this location. The abutment protrudes about 15 ft into the mainstem and is severely undercut and deteriorated by the river.

The design objective for R-1 is to remove the bridge abutment and regrade the area by emulating nearby existing ground. The intention is to eliminate risk to boaters and remove this hard point in the river, which is likely interfering with natural channel migration and evolution. The concrete rubble removed from R-1 may not be used in the construction of design features and must be properly disposed of by the contractor.

2.6.2 Area R-2

R-2 is located at Station 63+50 in between the remnant haul road bridge abutment (R-1) and road fill prism (R-3) in the center of the channel. This area is a deep section of open water in which 23 I-beams are embedded into the bottom of the channel. The vertically-oriented I-beams are roughly 2 ft wide and approximately 5 ft below summer baseflow elevation, which makes them nearly invisible to boaters and swimmers.

The design objective for R-2 is to remove the I-beams from the channel. This action will eliminate the potential hazard to river users. The removal of these I-beams is also necessary for the construction of the IC-19 gravel bar. Once removed, it is the duty of the contractor to properly dispose of the I-beams.

2.6.3 Area R-3

R-3 is an 18,900 ft^2 area extending from approximately Station 62+50 to 65+50 on the left bank at the remnant haul road. The existing terrain is a simple trapezoidal road fill prism that gradually slopes from the bank to the upland area near Lake Road. The existing vegetation is primarily open grass with some herbaceous riparian species near the water. This area separates the two halves of the existing dredger slough.

The design objective for R-3 is to lower the haul road fill prism and create an additional hydraulic connection between the mainstem and SC-6 side channel at approximately 500 cfs. Removing the haul road will facilitate construction of the channel segment connecting the upstream (SC-7) and downstream (SC-6) halves of the dredger slough into a single side channel. Excavated material from R-3 may be processed, washed, and used as fill to construct other design features.

2.7 Peaslee Creek Gravel Augmentation

The downstream end of Peaslee Creek near the confluence with the Tuolumne River (Figure 2) currently hosts a silty channel bed indicative of deposition during backwater flows from the Tuolumne River into Peaslee Creek and the lack of coarse sediment supply from Peaslee Creek itself. The mucky substrate is suitable spawning habitat for warm-water predator species such as Largemouth Bass, Smallmouth Bass, and Striped Bass. The design proposes to add 40 yd^3 of coarse sediment to this 980 ft^2 area to reduce or eliminate predatory species' spawning habitat. Any coarse sediment transported downstream and into the mainstem Tuolumne River will help improve in-channel coarse sediment resources and maintain existing alluvial features downstream.

2.8 Fish Screen

As part of the Project, the irrigation water intake for the property will be replaced with a fish-friendly intake structure that meets National Marine Fisheries Service (NMFS) approach velocity standards. Two options were considered during the design process: a conical fish screen and infiltration galleries. Burial requirements associated with infiltration galleries and near-surface bedrock at the existing irrigation intake infrastructure eliminated this option as infeasible, thus a conical fish screen was chosen. Based on expected irrigation flows, a 5.5-ft diameter ISI C66-18 cone screen was identified as suitable.

Due to the presence of salmonid fry, the proposed screen must have an approach velocity that is less than 0.33 ft/s, as outlined in *Fish Screening Criteria for Anadromous Salmonids.* (NMFS 1997). Considering a maximum irrigation flow of 5 cfs, the conical fish screen must have a total submerged surface area of 15.2 ft^2. Three scenarios were considered when analyzing the suitability of the proposed fish screen:

1. Screen placed directly on the channel bottom,
2. Screen placed on a 1-ft base, and
3. Screen placed on a 2-ft base.

Scenario 3 was selected as the proposed fish screen for the purpose of longevity and structural stability. Using the geometry of the proposed screen and surveyed channel geometry at the intake structure, a minimum water surface elevation that meets the submergence criteria was calculated for all three scenarios (Figure 17). The analysis shows that under the most restrictive conditions (Scenario 3, cone on 2-ft base), a minimum water surface elevation of 142.9 ft is required to maintain adequate screen submergence. The modeled water surface elevation for the minimum flow (80 cfs) expected through the project reach is 143.9-ft, meaning the screen should be fully submerged under all flow conditions. An ISI C66-18 conical screen has a screen surface area of 26.8 ft^2 when fully submerged and therefore will meet the approach velocity criteria.

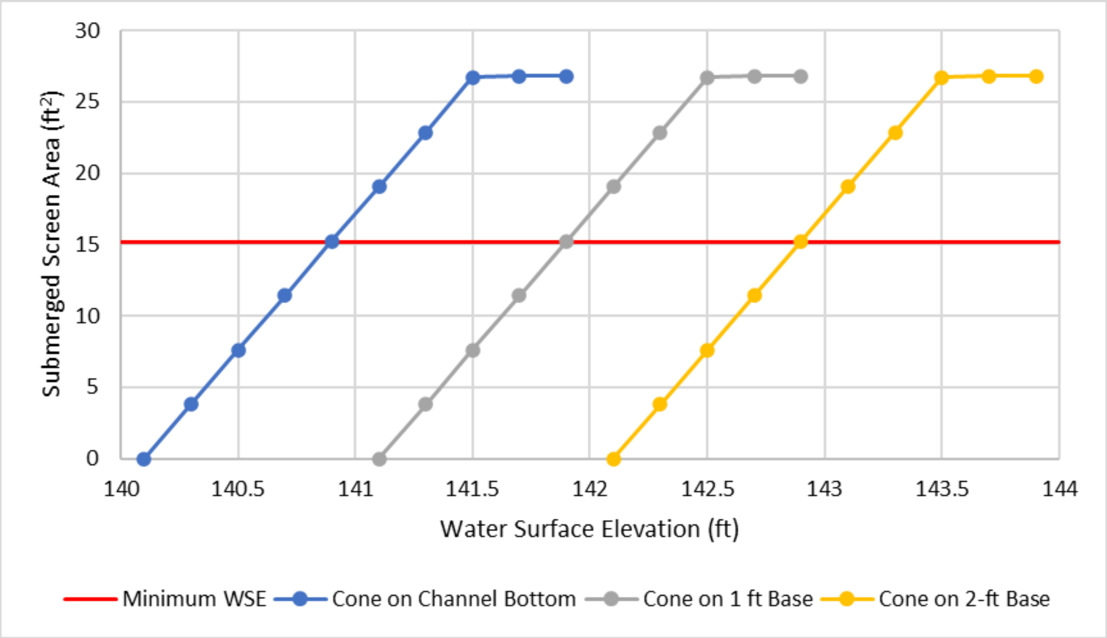

Figure 17. Submerged screen area by water surface elevation is plotted for three different cone screen elevations at the site, along with a red line showing the minimum submerged screen area required to meet approach velocity criteria. Any combination of cone base elevation and water surface elevation above the red line would meet NMFS approach velocity criteria.

2.9 Revegetation

Although the Project was designed to promote natural riparian regeneration, post-implementation revegetation may be used to provide immediate benefits to the site and guide the development of riparian vegetation toward larger floodplain species. A revegetation design was prepared from the 65% design topography and relies on a zonation approach patterned after historical and existing vegetation {Bair et al. 2021; Hoag and Landis 2001; 2002}. Proposed revegetation is intended to recreate larger patches of emergent and riparian vegetation similar, albeit smaller in area, to what was historically present at the site. Existing native vegetation within and adjacent to the Project has been preserved to the greatest extent feasible and will provide cover and a readily available seed source immediately after construction. Habitat continuity and ecotone diversity between the riparian corridor and adjacent upland areas at restoration sites is important for maintaining wildlife corridors, which function to facilitate local movement and critical proximity to and from food, cover, and water. Future cohorts of tree species are expected to voluntarily colonize some areas within the Project footprint, evidence that a self-sustaining dynamic riparian system directly linked to the functional integrity of the channel and associated floodplains has been restored.

2.9.1 Revegetation Objectives

Revegetation objectives include:

- Compensate (to the extent possible) for potential riparian habitat losses due to Project implementation.
- Increase wetland, emergent, and riparian vegetation abundance in the tree, shrub, and herb layer within the construction footprint.
- Arrange plant species in a pattern that can form the primary components of wildlife and fish habitat and the basis of allochthonous (imported) organic material that could be utilized by benthic macroinvertebrates and biofilms.
- Maintain continuous corridors of riparian vegetation with a more variable ecotone (transitional area between two biological communities) between the riparian and upland zones.
- Reduce the area and species richness of non-native plant species within the Project area.

2.9.2 Revegetation Basis of Design

Given suitable hydrology and soils, riparian vegetation generally establishes on ground surfaces within a fixed distance from (i.e., height above) the shallow groundwater table. The relationship between existing vegetation cover types and their estimated depth to groundwater served as the basis for revegetation designs. A 2021 vegetation map was combined with the existing ground terrain model and the low-flow 80 cfs water surface elevation to establish the approximate depth to groundwater for cover types in the Project area. Vegetation zones were defined by evaluating the ranked median depth to groundwater for each vegetated cover type. The depth to groundwater was then calculated for 100% design conditions using design topography and the design 80 cfs water surface elevation, and vegetation zones were applied to determine the most suitable locations for plant groups. Species selection was based on the composition of existing plant communities (i.e., cover types). A full description of the revegetation basis of design can be found in Appendix F.

2.9.3 Revegetation Design Overview

The revegetation design mimics vegetation patterns found on alluvial landforms of less disturbed regional streams and uses a zonation approach {Bair et al. 2021; Hoag and Landis 2001; 2002}. The revegetation approach varied by the design element and existing conditions within the Project area. The 100% grading plan avoids patches of existing riparian vegetation within the Project area that currently provide cover and a readily available seed source immediately after construction.

Revegetation activities may include material salvage, salvaging and installing willow clumps which are contiguous masses of willows salvaged during construction and planted nearby, installing willow trenches which are linear planting features consisting of shrubby willows that are packed tightly into trenches, preparing planting areas, laying out the planting design, planting a mixture of emergent and mesic plants, direct-seeding acorns, and applying a native seed mix. Salvaged materials like slash, wood chips, and topsoil, will be incorporated back into the site either as live material, mulch, or soil amendment. Detailed descriptions of willow clumps and willow trench installation are provided in the Revegetation Implementation Appendix F.

The revegetation design includes planting channel margins, backwaters, and low-flow channels with a combination of herbaceous and woody species to provide immediate cover and inhibit non-native invasive species such as water hyacinth. Planting emergent areas with sedges and rushes (i.e., herbaceous plants) will provide immediate aquatic cover to fishes when inundated. Floodplains within the Project area designed to provide winter rearing habitat for juvenile *O. mykiss* will be planted with a combination of woody and herbaceous plants in the low and high riparian zone. The transition zone and upland zones will be direct seeded as described in Appendix E. A seed mix composed of native grass and forb species has been designed for the Project. The seed mix should be applied to planting areas above the 3,000 cfs water surface elevation in the riparian, riparian–upland transition, and upland zones and on decommissioned access roads, disturbed upland areas, spoils piles, and staging locations.

A list of plant species for revegetation implementation within each plant zone was developed (Figure 18, Table 11). Plant materials may consist of live hardwood poles, bareroot plants, nursery container stock, acorns, and seeds (Table 11). Ideally, all plant material for the Project should be propagated from material found and collected within the lower Tuolumne River watershed. It is recommended that willows and cottonwoods are planted as live hardwood cuttings (i.e., poles); however, live hardwood cuttings must be planted so that the bottom of the cutting is in direct contact with the fall groundwater table. Un-irrigated plantings will need to be planted in low elevation locations with available groundwater for best success.

No revegetation is proposed for areas where bedrock is thought to occur within the civil design. If upon further investigation some of these areas are determined to have suitable substrate for planting, then revegetation could be included for those areas in the next design phase.

The revegetation design includes riparian plantings within the FP-6 floodplain on the south bank. However, more information is needed about the depth of substrate above bedrock in this area to ensure that it is suitable for planting. This area may also need refinement before the next design stage.

Figure 18. Proposed 100% revegetation design. See Appendix H.

2.9.4 Planting Groups

A list of plant species by planting zone was developed for the 100% revegetation design (Table 11, Appendix H). Plant materials may consist of nursery container stock, live hardwood poles, or bareroot plants. A full description of the plant zones used in the revegetation design is included in Appendix F.

Table 11. Plant zones used in the 100% revegetation design, associated plant species, and plant material size proposed for planting. Other native species appropriate to the ecosite may be used with approval. Taxonomy follows The Jepson Manual, 2nd Edition (Baldwin et al. 2012)

Zone	Common name	Scientific name	Plant material size/type
Emergent/Channel Margin	Pacific willow	*Salix lasiandra*	pole cutting
	black willow	*Salix gooddingii*	pole cutting
	buttonbush	*Cephalanthus occidentalis*	8 tree pot (818)
	common rush	*Juncus effusus*	Plug[1]
	iris-leaved rush	*Juncus xiphioides*	Plug[1]
	Mexican rush	*Juncus mexicanus*	Plug[1]
	torrent sedge	*Carex nudata*	Plug[1]
	whiteroot	*Carex barbarae*	Plug[1]
High Riparian	arroyo willow	*Salix lasiolepis*	pole cutting
	black willow	*Salix gooddingii*	pole cutting
	blue elderberry	*Sambucus nigra ssp. caerulea*	8 tree pot (818)
	cottonwood	*Populus fremontii*	pole cutting
	deer grass	*Muhlenbergia rigens*	AB34[2]
	mugwort	*Artemisia douglasiana*	AB34[2]
	Oregon ash	*Fraxinus latifolia*	8 tree pot (818)
	Pacific willow	*Salix lasiandra*	pole cutting
	white alder	*Alnus rhombifolia*	8 tree pot (818)
	whiteroot	*Carex barbarae*	Plug[1]
Low Riparian	arroyo willow	*Salix lasiolepis*	pole cutting
	mugwort	*Artemisia douglasiana*	AB34[2]
	Pacific willow	*Salix lasiandra*	pole cutting
	red willow	*Salix laevigata*	pole cutting
	whiteroot	*Carex barbarae*	AB34[2]
Riparian-Upland Transition	valley oak	*Quercus lobata*	Acorn

Upland	blue oak	*Quercus douglasii*	Acorn

[1] Plug root volume approximately 1.7–2 in^3

[2] AB34 root volume approximately 17.7 in^3

2.10 Materials and Quantities

The total volumes of cut and fill for 100% design activity areas was calculated using surface comparison tools in AutoCAD (Table 12). Fill for in-channel areas will be comprised of coarse sediment mixtures per the grainsize analysis conducted for the design (Section 2.1.2). Riffles will be comprised of either the fine or standard spawning gravel mixture (Table 5). Gravel bars will be comprised of either of the two spawning mixes or a mix of the standard spawning mix augmented with oversized (6 inch to 12 inch) rock to create an oversized mixture, with the fraction of oversized rock in each gravel bar determined on a case-by-case basis. The Peaslee Creek gravel augmentation area will use oversized rock. The exact volumes of fine spawning mix, standard spawning mix, and oversized rock needed to construct each individual design feature are included in sheets C-4 to C-9 of the 100% design civil planset (Appendix H). The total quantities of fine spawning mix, standard mix, and oversized rock are given in Table 13. Gravels for spawning mixes and oversized rock may be recovered from excavated design activity areas during construction or may be sourced from off-site. All gravels placed in the river to construct design features must be cleaned and washed of fines.

Material quantities for wood, boulder, and willow trench placements are given in Table 14. Quantities in Table 14 are not exact and are subject to a number of variables including the dimensions of rootwad logs, pin logs, and boulders; achievable embedment depths and lengths at wood placement sites; ability to source materials on site; and variability in conditions encountered in the field during construction.

Table 12. Cut and fill volumes for the 100% design broken down by activity area.

Activity Area	Area (ft^2)	Cut (yd^3)	Fill (yd^3)	Net (yd^3)	
IC-1	12,960	0	1,360	1,360	<Fill>
IC-2	31,340	130	4,910	4,780	<Fill>
IC-3	6,630	0	800	800	<Fill>
IC-4	43,100	0	6,910	6,910	<Fill>
IC-5	42,390	0	1,770	1,770	<Fill>
IC-6	21,740	0	1,730	1,730	<Fill>
IC-7	12,540	0	870	870	<Fill>
IC-8	29,650	0	2,080	2,080	<Fill>
IC-9	12,150	0	920	920	<Fill>
IC-10	17,790	0	1,210	1,210	<Fill>
IC-11	6,180	0	180	180	<Fill>
IC-12	7,860	0	320	320	<Fill>
IC-13	27,910	0	3,860	3,860	<Fill>
IC-14	11,120	0	420	420	<Fill>
IC-15	34,470	0	6,530	6,530	<Fill>
IC-16	46,450	0	6,380	6,380	<Fill>
IC-17	56,650	0	9,300	9,300	<Fill>

Activity Area	Area (ft^2)	Cut (yd^3)	Fill (yd^3)	Net (yd^3)	
IC-18	13,260	0	1,540	1,540	<Fill>
IC-19	30,400	0	4,330	4,330	<Cut>
IC-20	7,740	0	1,330	1,330	<Fill>
IC-21	16,090	0	2,560	2,560	<Fill>
IC-22	7,220	0	760	760	<Fill>
IC-23	37,510	0	6,750	6,750	<Fill>
IC-24	8,970	0	1,170	1,170	<Fill>
IC-25	42,980	0	9,260	9,260	<Fill>
IC-26	13,890	0	2,170	2,170	<Fill>
IC-27	11,800	0	1,350	1,350	<Fill>
IC-28	11,010	0	990	990	<Fill>
IC-29	5,990	0	210	210	<Fill>
IC-30	6,990	0	470	470	<Fill>
IC-31	8,300	0	510	510	<Fill>
IC-32	8,600	0	730	730	<Fill>
IC-33	7,160	0	730	730	<Fill>
SC-1	1,830	200	0	200	<Cut>
SC-2	8,920	790	0	790	<Cut>
SC-3	42,100	3,770	0	3,770	<Cut>
SC-4	4,810	360	0	360	<Cut>
SC-5	83,660	22,000	0	22,000	<Cut>
SC-6	39,820	1,180	3,930	2,750	<Fill>
SC-7	107,380	1,070	13,890	12,820	<Fill>
SC-8	30,230	4,290	0	4,290	<Cut>
FP-1	3,840	410	0	410	<Cut>
FP-2	12,070	830	0	830	<Cut>
FP-3	7,150	180	0	180	<Cut>
FP-4	52,810	3,940	0	3,940	<Cut>
FP-5	46,000	1,640	0	1,640	<Cut>
FP-6	20,620	8,460	0	8,460	<Cut>
FP-7	36,710	13,060	0	13,060	<Cut>
FP-8	15,850	2,970	0	2,970	<Cut>
FP-9	8,260	1,360	0	1,360	<Cut>
FP-10	31,280	6,990	0	6,990	<Cut>
Peaslee Creek Gravel Augmentation	980	0	40	40	<Fill>
Remove Bridge*	4,750	660	0	660	<Cut>
Total	***1,217,910***	***73,630***	***102,270***	***28,640***	***<Fill>***

*Remove Bridge cut volume consists of concrete rubble that shall not be used to construct design features and must instead be disposed of by the contractor. Remove Bridge volume is not included in Project total volume.

Table 13. Volumes of spawning gravel and oversized rock needed to construct 100% design gravel bars and riffles.

Material	Volume
Fine spawning mix	9,450
Standard spawning mix	68,970
Oversized rock (6 inch to 24 inch, most 6-12)	6,910
Total coarse sediment volume	**85,330**

Table 14. Material quantities for 100% design large wood and boulder habitat features, willow trenches, and willow clumps.

Material	Basis	Quantity	Notes
Rootwad logs	Quantity	40	Rootwad logs are tree trunks with rootwads still attached, likely imported from off-site.
Pin logs	Quantity	80	Assuming two pin logs per rootwad log. Actual quantity will depend on dimensions of rootwad logs and pin logs used and embedment that can be achieved in the field.
Willow cuttings	Quantity	240	Assuming six willow cuttings per rootwad log.
Boulders	Quantity	76	Boulders may be sourced from off-site or recovered from on-site resources.
Willow trenches	Linear Feet	360	Four-foot wide trenches.
Willow cuttings for trenches	Quantity	4,320	Assuming 12 cuttings per linear foot of trench.
Willow clumps	Quantity	6	Placed in Peaslee Creek gravel augmentation patch.

3 100% DESIGN EVALUATION

The objectives and goals of this project will be best achieved if broader riverine and ecological processes are considered. Therefore, it is important to understand how the 100% design will impact biological components in the project area. Fisheries resources, turtle populations, an extirpated frog population, and riparian recruitment were evaluated under 100% design and compared to existing conditions using a series of hydraulic and ecological models. This analysis was updated for the 100% design after minor changes to in-channel features. After analysis, the 100% design increased salmonid spawning and rearing habitat under the flows relevant to those life stages in comparison to the existing conditions, except Chinook Salmon juvenile rearing habitat. The 100% design should also reduce invasive bullfrog habitat without impacting native Western Pond Turtle habitat and increase the amount of passive riparian recruitment.

3.1 Salmonid Habitat

To evaluate and refine the proposed restoration design to benefit Central Valley fall-run Chinook Salmon and federally threatened California Central Valley *O. mykiss*, weighted usable area (WUA) of suitable habitat was calculated under existing conditions and the 100% design. Existing conditions Phase I and Phase II were combined before calculating WUA to compare to 100%

design WUA. WUA curves depict a weighted measure of habitat for target species and life history stages at different flows. WUA calculations use species- and life-stage specific habitat suitability indices (HSI) that describe the relative suitability of physical habitat attributes, such as depth, velocity, cover, and substrate. HSI values range between 0 and 1, with 0 meaning not suitable and 1 most suitable (Bovee 1986, Normandeau Associates 2014). The evaluation focused on adult spawning habitat and fry and juvenile rearing habitat for both species, and adult *O. mykiss* habitat, as they are affected by limited existing instream habitat. Percent change in WUA was calculated to evaluate the predicted change from existing conditions to the 100% design.

Data used to calculate WUA included depth and velocity results from existing conditions and 100% design 2-D hydraulic models (Section 2.1.1), substrate and cover data, and habitat suitability indices (HSI). For the existing conditions WUA analysis, field-mapped substrate and cover data were used. For 100% design (i.e., future conditions), design cover and substrate maps were developed by modifying the existing conditions cover and substrate maps based on the 100% design habitat features, proposed vegetation designs (Section 2.8), and new riffle and gravel augmentations (Appendix B). HSI for Chinook Salmon and *O. mykiss* spawning, fry and juvenile rearing developed for the Yuba River (USFWS 2010a, USFWS 2010b) were selected based on expert opinion and their use in previous habitat evaluations in the Bobcat Flat restoration area (Gard 2014, Benn and Gard 2019, MA 2020) and earlier phases of the Zanker Farm Project (McBain Associates 2021, 2022a, 2022b, 2022c). HSI used to evaluate adult resident *O. mykiss* WUA were developed for the Lower Tuolumne River (Stillwater Sciences 2013) and used in FERC relicensing studies for Don Pedro and La Grange dams.

Area under the WUA curve (AUC) was calculated to provide a flow-independent, single metric comparison of overall changes in WUA from existing conditions to the 100% design. The AUC is the area between the WUA curves and the x-axis (effectively summing all habitat available across all flows). It was generated using the AUC function in the “MASS” package in program R. The AUC function uses the definite integral and the trapezoidal rule to calculate the area between a graphed curve and the x-axis; therefore, the units for this metric are simply the product of the x and y axes (in this case, cfs × acres).

A limiting life stage analysis was conducted to estimate which life stage was the most limited by the available suitable habitat in the Project area for both existing and 100% design conditions. The limiting life stage was determined by which life stage would produce the lowest number of adult spawners given the habitat provided. For the analysis, we used habitat capacity parameters from the Clear Creek Synthesis Report (Table 15, USFWS 2015) and AUC habitat results for that life stage. Since cfs is incorporated into the AUC calculations, the results were converted into an index of adult spawners to determine which life stage was limited. The sources of information for the habitat requirement numbers in Table 15 were the average size of fall-run Chinook Salmon redds measured by the Red Bluff Fish and Wildlife Office, and fry and juvenile densities from snorkel survey data collected by the Red Bluff Fish and Wildlife Office (USFWS 2015). The parameters were applied to both Chinook Salmon and *O. mykiss,* similar to the Clear Creek Synthesis Report. It is important to note that results from the analysis presented in this report do not predict how many adults can be supported in the Project area. Similar to AUC, results provide a flow-independent, single metric to compare which life stage is the most limited.

Table 15. Habitat capacity parameters from the Clear Creek Synthesis Report (USFWS 2015) used to calculate the total number of adults spawners from total suitable habitat for each life stage. Parameters are Clear Creek specific, from U.S. Fish and Wildlife Service Red Bluff Fish and Wildlife Office.

Life stage	Habitat requirement	Adult equivalent
Spawning	100 ft^2 / redd	2.5 adults / redd
Fry (< 60 mm)	1.45 fry / ft^2	200 fry / adult
Juvenile (> 60 mm)	0.77 juveniles / ft^2	67 juveniles / adult

In this section, we summarize the results from the AUC analysis and WUA analysis as the percent change from existing conditions to the 100% design to efficiently communicate the design's effects on fish habitat and better identify where improvements to the design can be made. Planform maps of WUA were used to illustrate spatial differences and the amount and quality of WUA under different designs. Complete WUA results are in Appendix B.

3.1.1 Area Under the Curve and Limiting Life Stage Analysis

When summed across all flows, WUA increased from existing conditions to the 100% design for all life stages of *O. mykiss* and Chinook Salmon (Table 16). The greatest increase in WUA occurred for *O. mykiss* spawning, which increased by 96% due to the constructed in-channel riffles and gravel bars that extended suitable spawning habitat throughout the site across a broad range of flows (Section 3.1.2.3). The second greatest increase in WUA was for Chinook Salmon spawning, so overall, the 100% design improved salmonid spawning habitat throughout the site. The smallest increase in WUA was for Chinook Salmon fry rearing (3%), but the location of suitable habitat was close to suitable Chinook Salmon spawning habitat and will therefore be easily accessible by fry once they emerge from redds (Section 3.1.2.2).

Similar to AUC, adult salmonid abundances were increased from existing conditions to the 100% design for all life stages. Under existing conditions, the life stage most limited by available suitable habitat was Chinook Salmon spawning. While Chinook Salmon spawning was also the most limiting under 100% design, the potential number of spawning adults was increased to 0.39 compared to 0.32 under existing conditions (Table 17).

Table 16. Area under the curve values calculated from WUA curves for the target species and life stages.

Species	Life stage	Existing conditions area under the curve (cfs × acres)	100% design area under the curve (cfs × acres)	Change from existing conditions (cfs × acres)	Change from existing conditions (%)
Chinook Salmon	Fry	139,384	144,190	4,806	3%
	Juvenile	162,915	178,015	15,100	9%
	Spawning	25,310	31,158	5,848	23%
O. mykiss	Fry	200,784	213,931	13,147	7%
	Juvenile	213,211	232,281	19,070	9%
	Spawning	47,152	92,227	45,075	96%
	Adult	191,820	218,945	27,125	14%

Table 17. Indices of potential adult spawners calculated for each life stage from AUC results and the habitat capacity parameters. The life stage with the lowest index value is the limiting life stage.

Species	Life stage	Index of potential adults under existing conditions	Index of potential adults under 100% design
Chinook Salmon	Fry	0.51	0.52
	Juvenile	0.95	1.00
	Spawning	0.32	0.39
O. mykiss	Fry	0.56	0.58
	Juvenile	0.94	1.00
	Spawning	0.45	0.89

3.1.2 Weighted Usable Area

WUA for Chinook and *O. mykiss* life stages is most heavily constrained at low flows ranging from approximately 1,000 cfs and below. This is due to the limited suitable hydraulic conditions, habitat, and complexity present within the mainstem channel at these flows. At flows of approximately 3,000 cfs and above, floodplain inundation begins to occur, creating up to three times more habitat than is present at lower flows. For example, at 3,000 cfs there is 14.59 acres of habitat for Chinook Salmon fry rearing habitat under existing conditions, while there is only 4.91 acres present at 300 cfs (Table B-6, Appendix B). Therefore, the amount of habitat for Chinook and *O. mykiss* is not a limiting factor once flows are high enough for floodplain inundation to occur. For this reason, WUA results in this section are presented for flows of 3,000 cfs and below. See Appendix B for results at all modeled flows.

3.1.2.1 Chinook Salmon Spawning

Adult fall-run Chinook Salmon typically arrive in the upper Tuolumne River (mostly above Roberts Ferry Bridge) to spawn in early October (TID and MID 2007) with peak spawning occurring in November (TID and MID 2013), during fall baseflows and prior to large storm events. Therefore, flows between 150 cfs and 300 cfs were modeled to calculate the suitable spawning habitat available during the spawning period (Table 3). At these flows, suitable spawning habitat occurred in the upper and lower parts of the Project area under existing conditions but was distributed throughout the Project area for the 100% design and was associated with newly constructed riffles and gravel bars. Under 100% design conditions, the available suitable spawning habitat could support upwards of 3,882 spawning Chinook Salmon adults at 300 cfs (Appendix B).

WUA increased under the 100% design compared to existing conditions at all flows up to 3,000 cfs and increased by a maximum of 170% at 1,580 cfs (Figure 20). The increase in suitable spawning habitat occurred because hydraulic conditions in the main channel increased in suitability due to the newly constructed gravel bars (Figure 19). Flows greater than 3,000 cfs are not common during the spawning season so analysis of flows above 3,000 cfs is not presented.

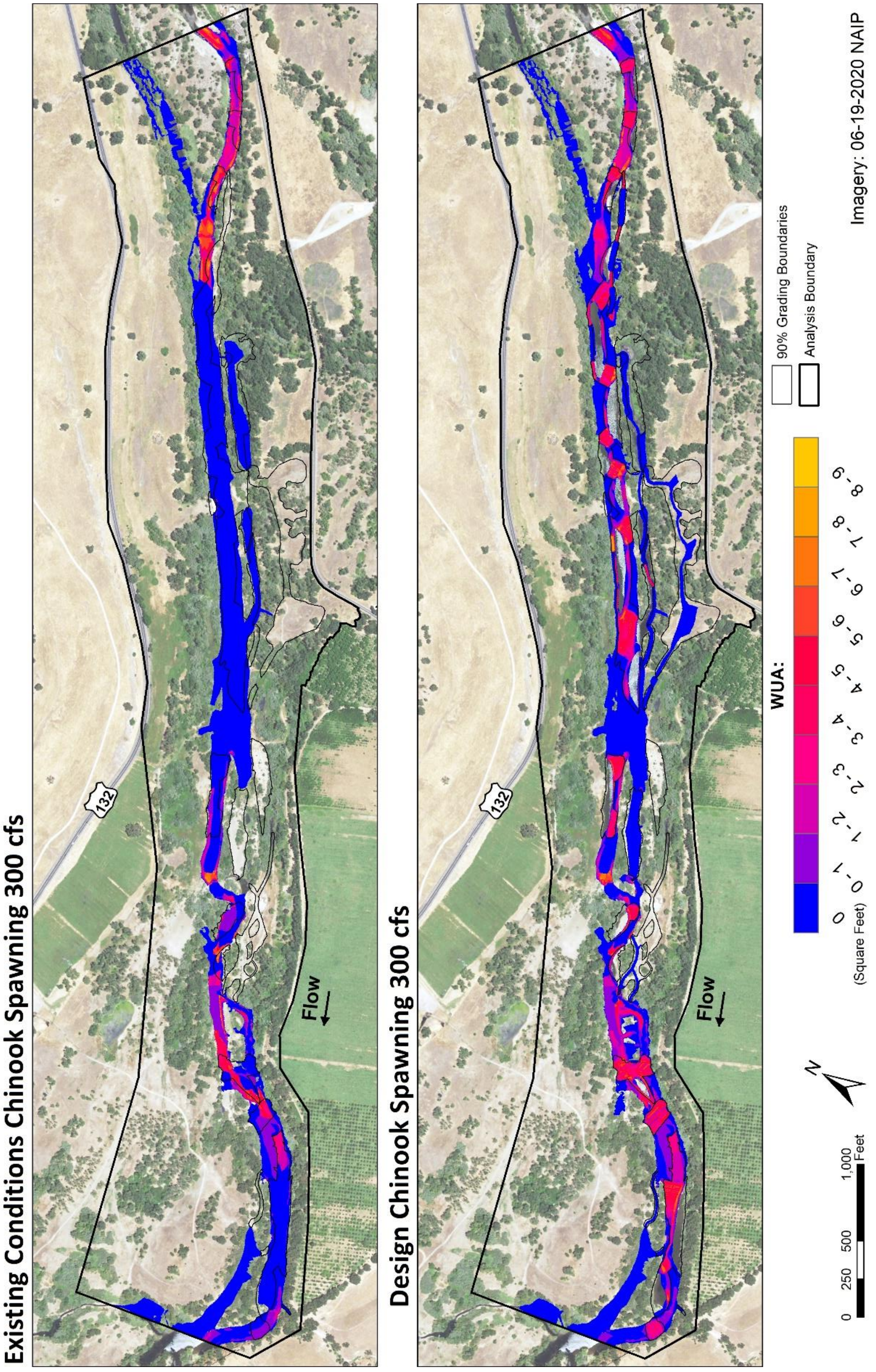

Figure 19. Planform view of Chinook Salmon spawning WUA at 300 cfs, illustrating the extent of suitable spawning habitat throughout the site under the 100% design compared to existing conditions.

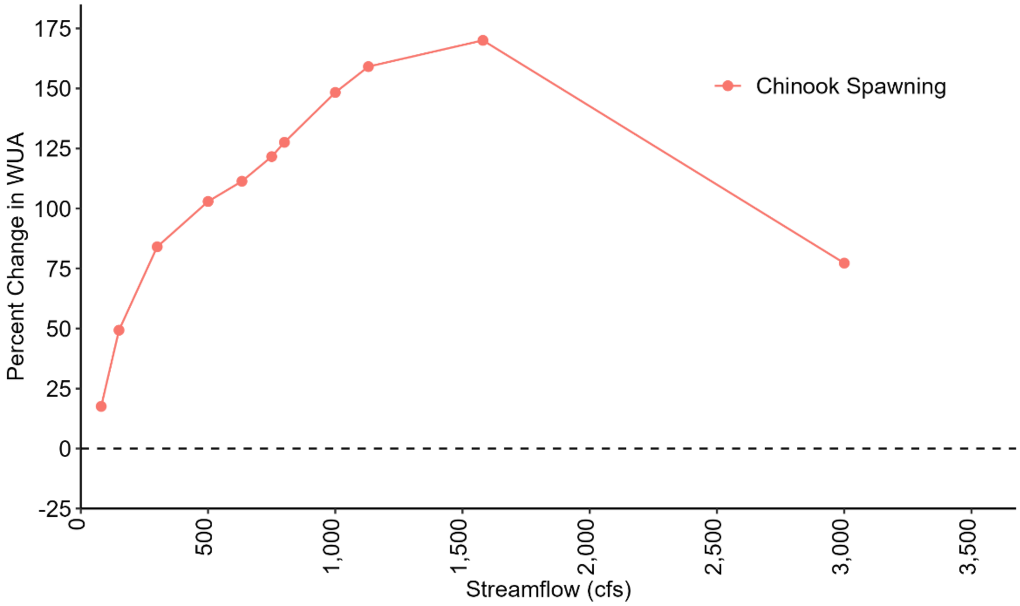

Figure 20. Percent change in WUA from existing conditions to the 100% design for Chinook Salmon spawning.

3.1.2.2 Chinook Salmon Fry and Juvenile Rearing

Chinook Salmon fry rearing WUA increased in the 100% design relative to existing conditions for all flows up to 3,000 cfs, with the greatest increase (104%) at 800 cfs (Figure 21). The increase in suitable habitat in the 100% design was due to the inundation of constructed side channels and floodplains, which increased habitat complexity and provided opportunities for off-channel salmonid rearing (Figure 23). Flows above 3,000 cfs do not occur frequently during the Chinook Salmon fry rearing period, and when they do, the increased habitat complexity in the 100% design can provide interstitial areas of high flow refugia that may not be detectable using WUA. Therefore, WUA results for flows greater than 3,000 cfs are not presented. Suitable fry rearing habitat occurred at the upper and lower end of the Project area adjacent to spawning habitat, while suitable habitat under existing conditions was confined to the wetted edge of the long-simplified channel in the upper half of the Project area. Therefore, under the 100% design, fry rearing habitat will be more accessible to emerging fry because it is closer to spawning habitat compared to fry rearing habitat under existing conditions.

WUA for Chinook Salmon juvenile rearing increased in the 100% design relative to existing conditions for all flows up to 3,000 cfs except for a nominal (1%) decrease at 300 cfs, as floodplains inundated and hydraulic conditions in the main channel increased in suitability for juvenile rearing (Figure 21). The increase in rearing habitat was the greatest at 3,000 cfs (43%) where high flow refugia opportunities in floodplain habitat were the most abundant (Figure 23). While there is a 1% decrease in Chinook Salmon juvenile rearing WUA at 300 cfs, suitable habitat was dispersed throughout the Project areas in constructed side channels and floodplains, while suitable juvenile rearing habitat under existing conditions was confined to the wetted edge of long simplified channels where habitat complexity was limited.

Fry and juvenile rearing occurs from approximately December through May of each year, when flows are between 225 cfs and several thousand cfs. Fry rearing under the design conditions will increase during this period and flow. Juvenile rearing habitat was not limited under existing conditions and is generally more substantial under the 100% design (Section 3.1.1); therefore, the small reduction in Chinook Salmon juvenile habitat at 300 cfs will likely not limit Chinook Salmon production.

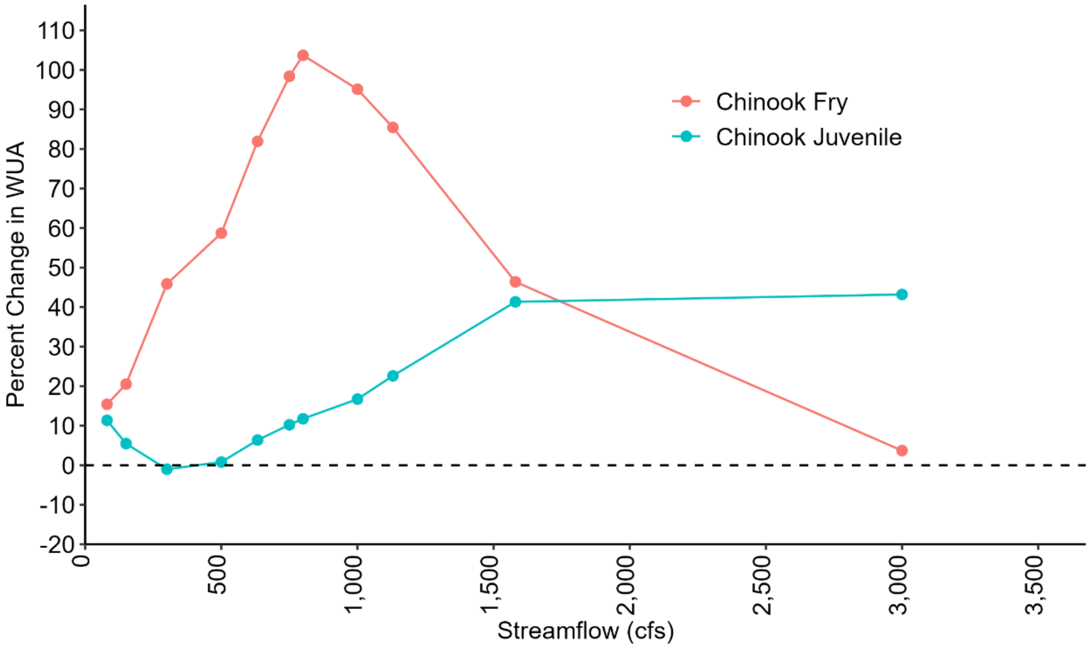

Figure 21. Percent change in WUA from existing conditions to the 100% design for Chinook Salmon fry and juvenile rearing.

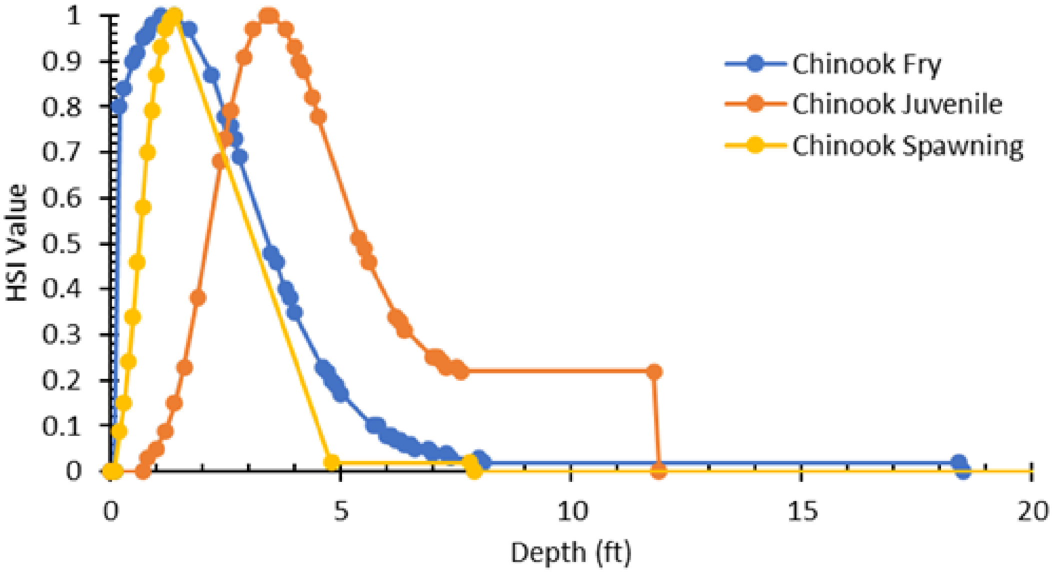

Figure 22. Habitat Suitability Index (HSI) for Chinook Salmon fry, juveniles, and spawning showing most suitable depth for juveniles around 4 ft deep.

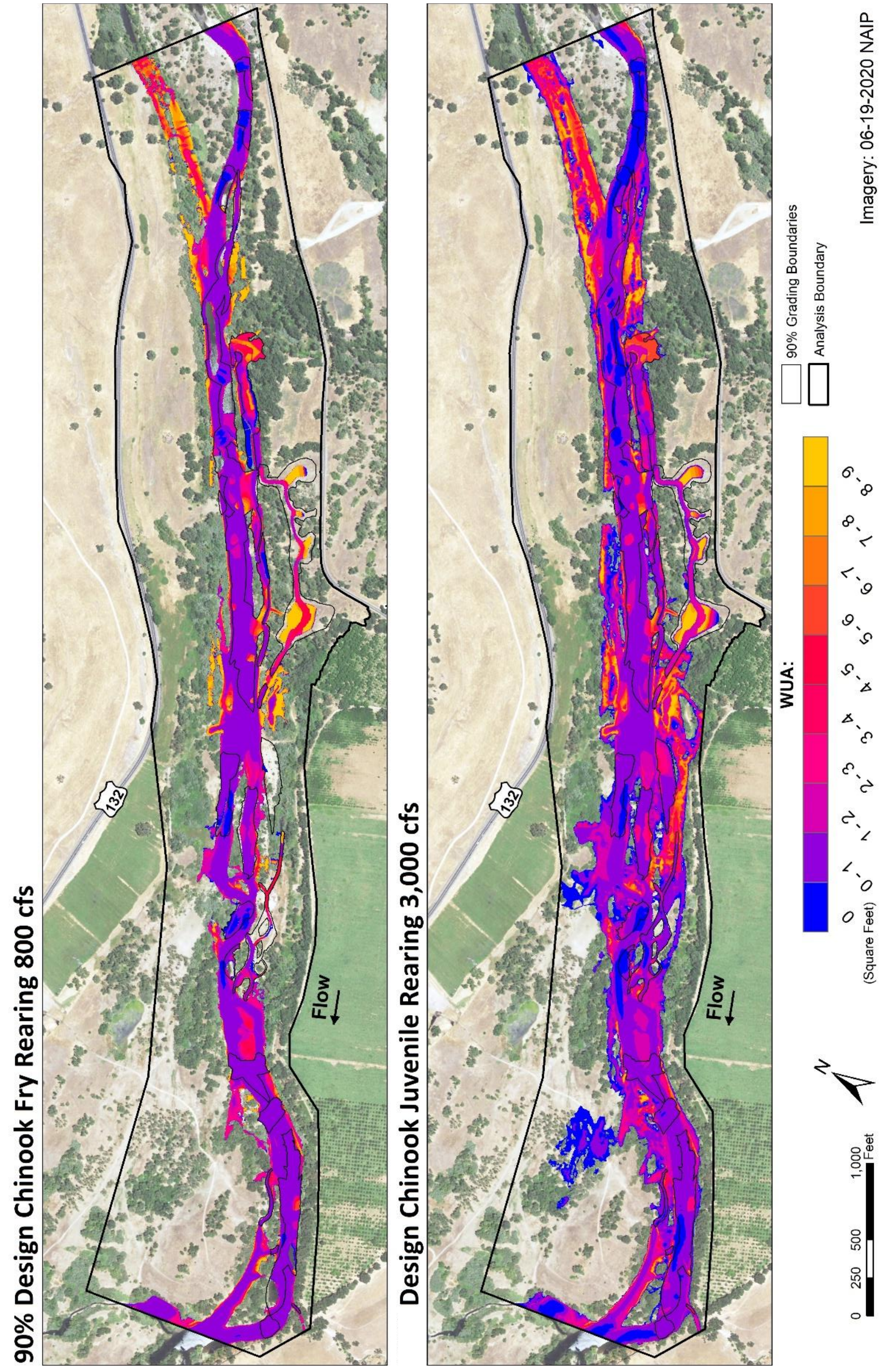

Figure 23. Planform view of WUA under the 100% design for Chinook Salmon fry rearing at 800 cfs and juvenile rearing at 3,000 cfs, illustrating how WUA increased for both life stages at these flows due to inundation of constructed side channels and floodplains, which increased habitat complexity and provided opportunities for off-channel salmonid rearing.

3.1.2.3 *O. mykiss Spawning*

O. mykiss spawning WUA increased in the 100% design compared to existing conditions at all flows (Figure 24). The increase in suitable habitat in the 100% design for these flows was due to the constructed in-channel riffles and gravel bars that extended suitable spawning habitat throughout the site, providing more dispersed *O. mykiss* spawning opportunities compared to existing conditions (Figure 25). Under existing conditions, suitable *O. mykiss* spawning habitat was primarily located in the downstream end of the Project area (Figure 25). *O. mykiss* adults typically spawn from December through April, when flows can be in the low to moderate range (300 cfs to 1,500 cfs) and the presence of abundant high-quality spawning habitat in the 100% design at moderate flows will benefit spawning adult *O. mykiss.*

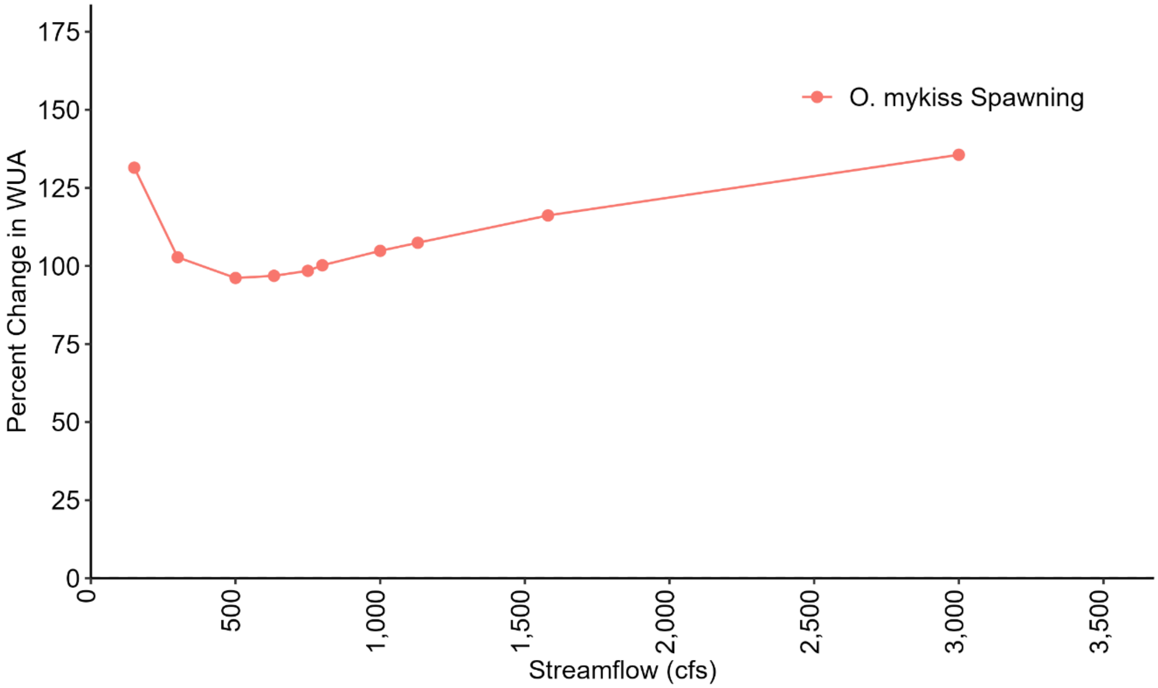

Figure 24. Percent change in WUA from existing conditions to the 100% design for O. mykiss *spawning.*

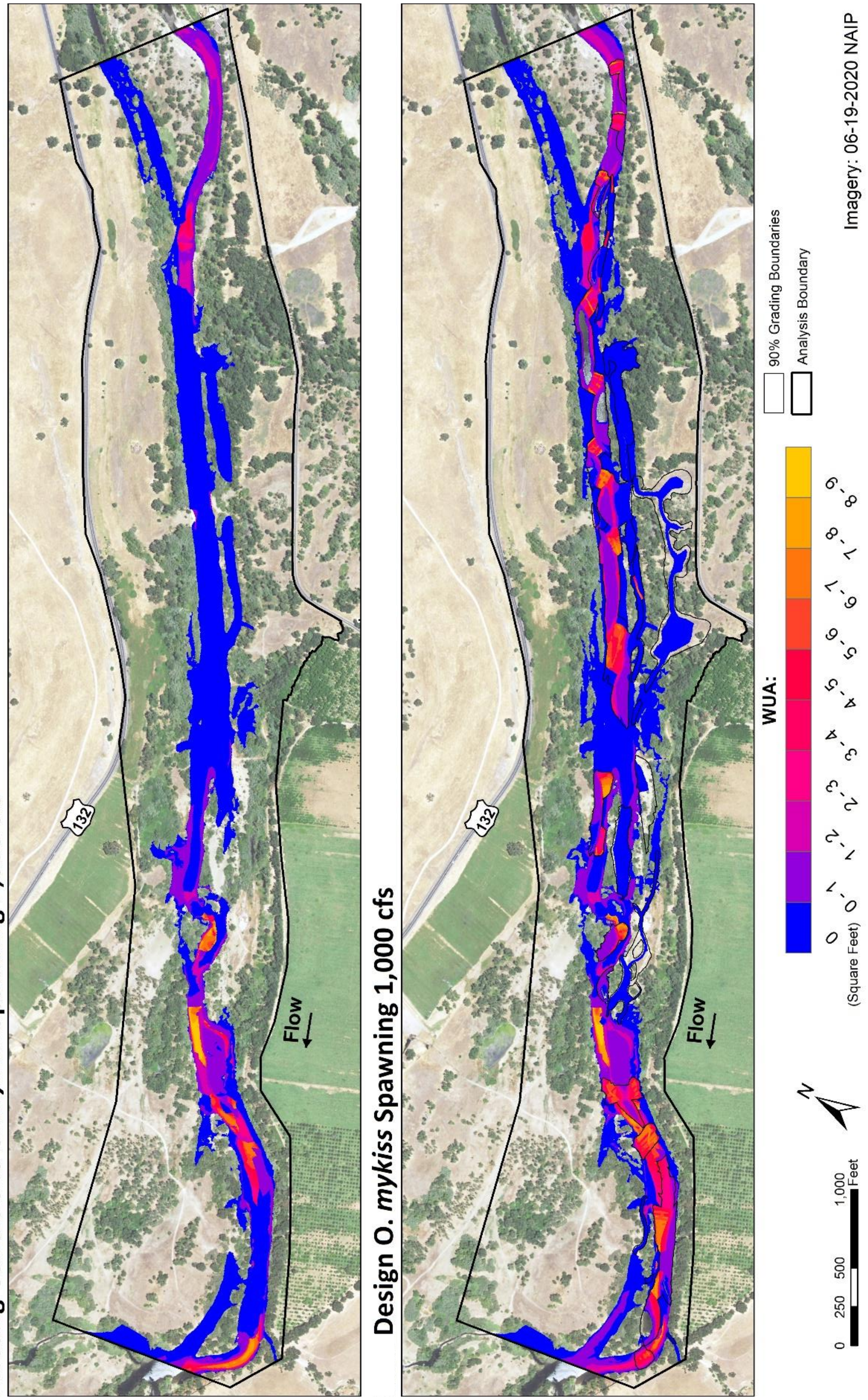

Figure 25. Planform view of O. mykiss *spawning WUA at 1,000 cfs, illustrating the extent of suitable spawning habitat throughout the site for a moderate flow under the 100% design compared to existing conditions.*

3.1.2.4 O. mykiss *Fry and Juvenile Rearing*

The quality, location, and transition of WUA as flow increased was similar for *O. mykiss* fry and juvenile life stages because they have similar HSI. For both life stages, WUA increased in the 100% design compared to existing conditions for all flows up to 3,000 cfs for fry and juveniles (Figure 26). The greatest increase in *O. mykiss* rearing WUA occurred at 1,000 cfs for fry (91%), and at 1,130 cfs for juveniles (67%). The increase in suitable habitat in the 100% design compared to existing conditions was due to the inundation of designed side channels and adjacent floodplains (e.g., SC-5 and FP-7; Figure 27). In addition, inundation of existing floodplains in the Project area will occur at lower flows in the 100% design than under existing conditions and could potentially provide floodplain rearing access for longer durations than under existing conditions. While juvenile rearing occurs year-round, fry rearing begins after emergence, which can occur one month or so after spawning, when flows are likely to be approximately 300 cfs through 2,000 cfs (Section 1.1.1). At these flows, the design increased rearing habitat. Flows greater than 3,000 cfs do not occur frequently during the fry and juvenile rearing periods, therefore WUA results for flows above 3,000 cfs are not presented.

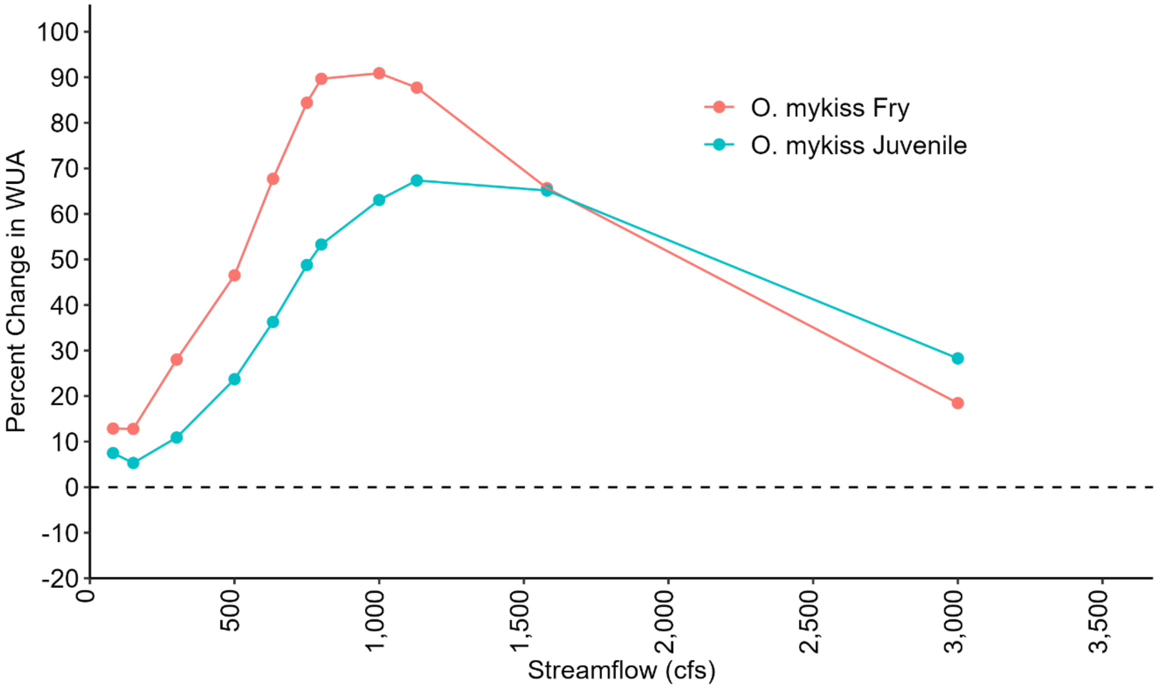

Figure 26. Percent change in WUA from existing conditions to the 100% design for O. mykiss *fry and juvenile rearing.*

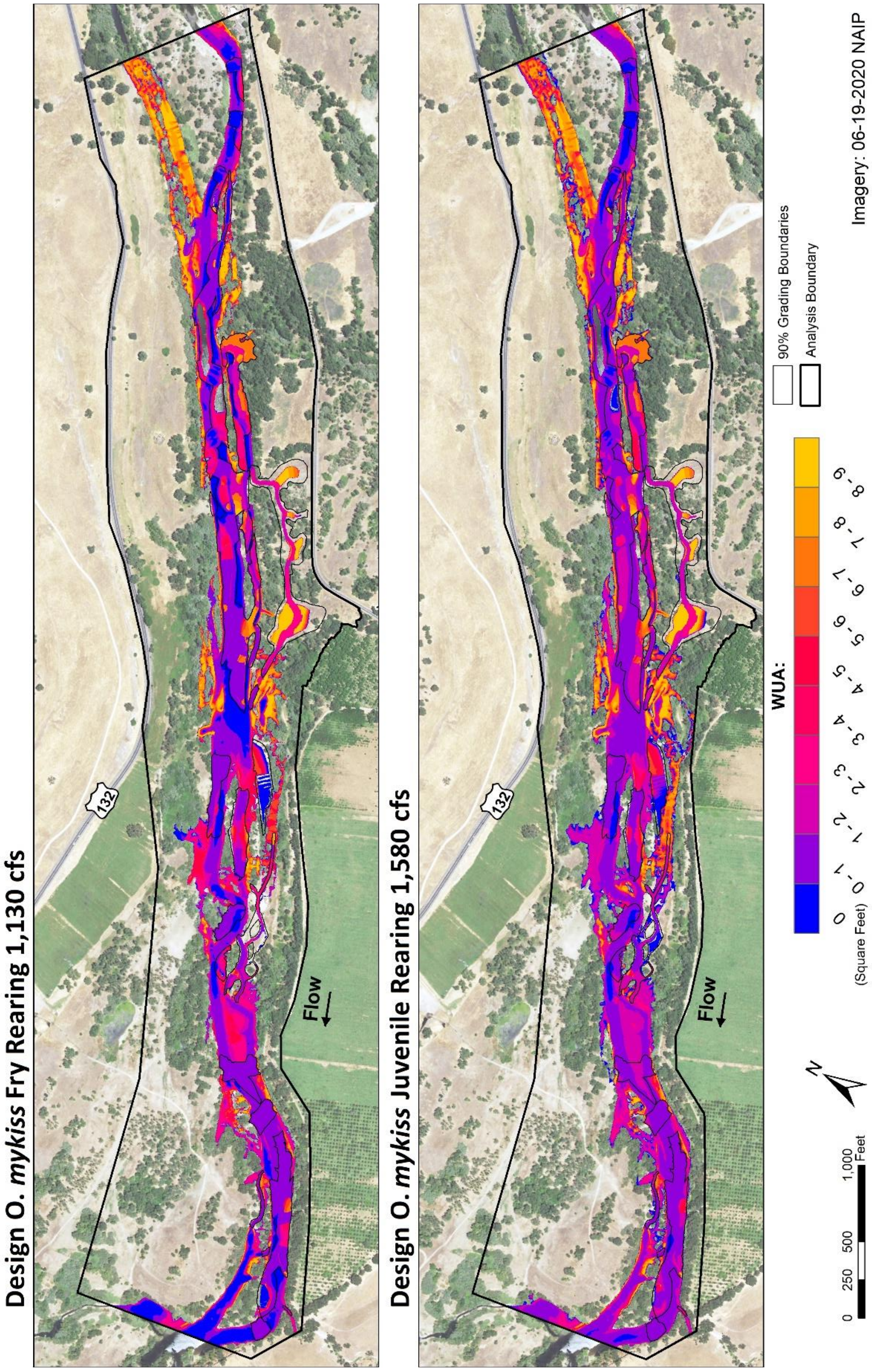

Figure 27. Planform view of O. mykiss *fry rearing WUA at 1,130 cfs, and juvenile rearing WUA at 1,580 cfs, illustrating how the increase in suitable habitat under the 100% design was due to the inundation of designed side channels and adjacent floodplains (e.g., SC-5 and FP-7).*

3.1.2.5 O. mykiss *Adult Habitat*

O. mykiss adult WUA increased under the 100% design compared to existing conditions at all flows (Figure 28). The greatest increase in WUA occurred at 3,000 cfs (44%). Under existing conditions, suitable habitat in the upstream end of the Project area was confined to the wetted edge of the long, simplified channel, while in the 100% design, suitable habitat occurred in more complex areas including side channels, floodplains, in the alternate gravel bar/riffle configuration, and in the vicinity of wood habitat features, which provide suitable cover.

The increase in WUA in the 100% design was due to the inundation of designed side channels and adjacent floodplains (e.g., SC-5 and FP-7), similar to *O. mykiss* fry and juvenile rearing (Figure 29). At 300 cfs to 500 cfs the increase in area was more modest but was due to the sinuosity created by the alternate gravel bar/riffle configuration of IC-19 though IC-27, extending *O. mykiss* adult habitat into the upstream end of the Project area. Under existing conditions, *O. mykiss* habitat is primarily located in the downstream end of the Project area.

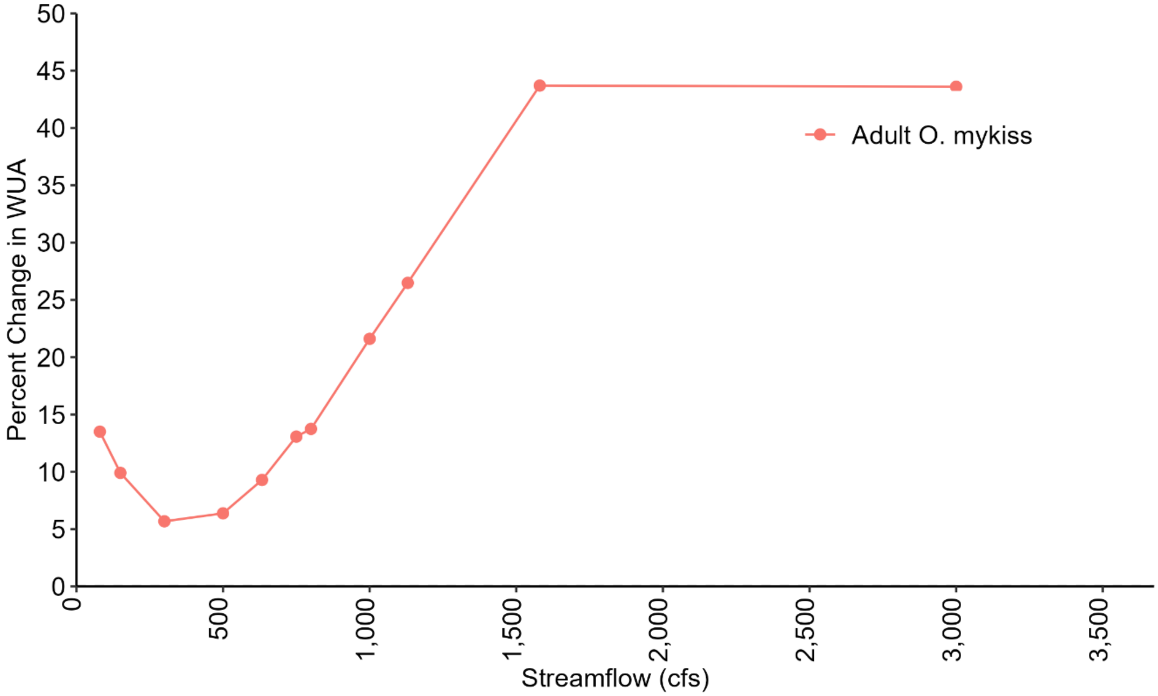

Figure 28. Percent change in WUA from existing conditions to the 100% design for adult O. mykiss *habitat.*

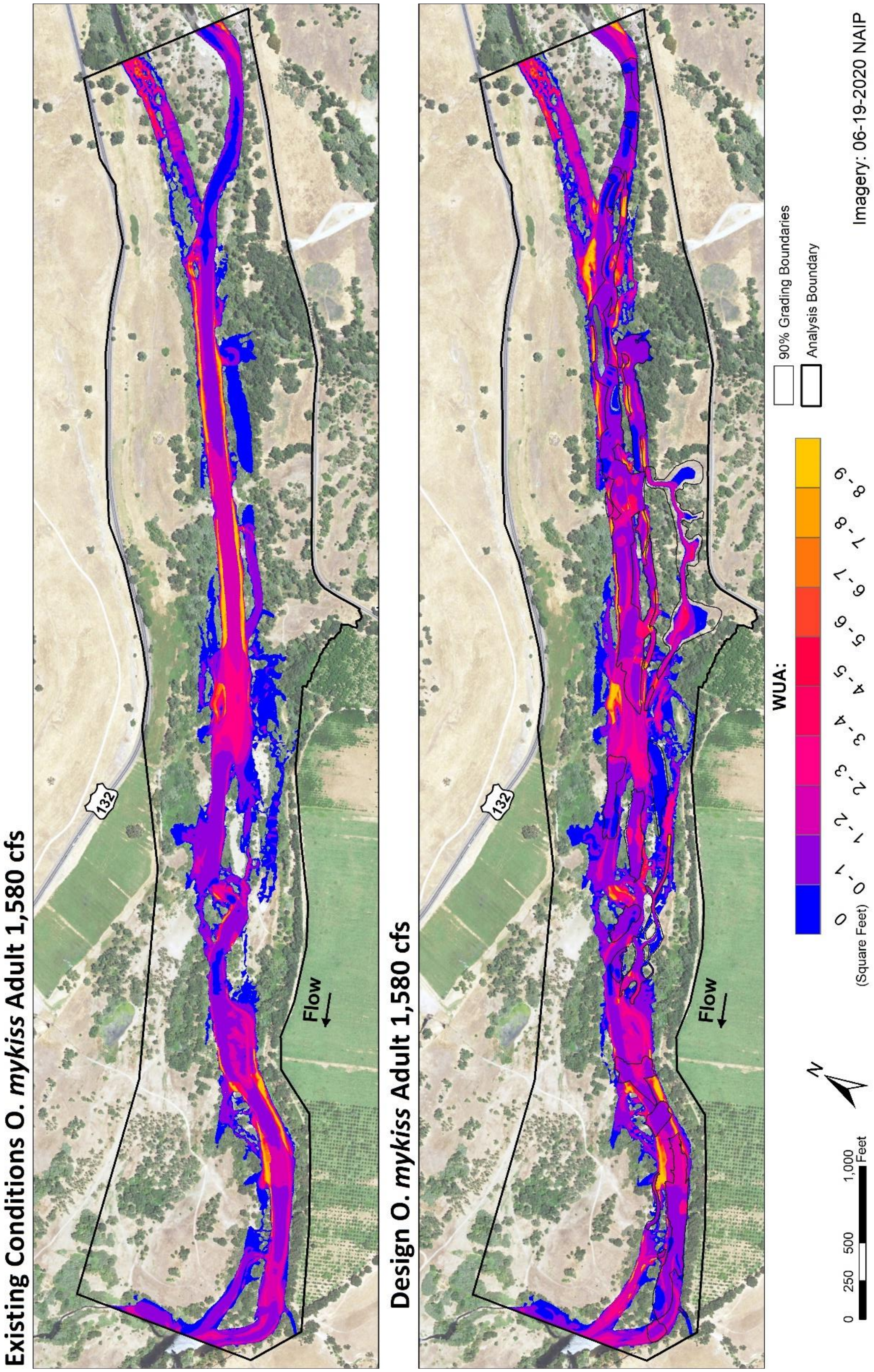

Figure 29. Planform view of adult O. mykiss *WUA at 1,580 cfs, illustrating how side channel and adjacent floodplain inundation (e.g., SC-5 and FP-7), increased suitable habitat under the 100% design compared to existing conditions, similar to* O. mykiss *fry and juvenile rearing.*

3.2 Benthic Macroinvertebrate Habitat

Benthic macroinvertebrates (BMI) are an important component of riverine ecology and associated food webs, as they are a primary food source for many organisms including rearing juvenile salmonids, amphibians and reptiles, and terrestrial animals including bats and birds (Jackson et al. 2020). High salmonid growth rates require abundant and diverse food resources, even when physical habitat and water quality conditions are favorable (Dill et al. 1981). Using BMI indices such as diversity and biomass when evaluating restoration designs can provide insight into how well designs improve habitat over existing conditions and if abundant food resources are available.

Similar to salmonid habitat (Section 3.1) BMI diversity and biomass WUA and AUC were calculated under existing conditions and the 100% design for comparison. Two metrics were selected to evaluate BMI WUA:

1. *Baitidae, Chironomidae, Hydropsychidae* (BCH) Biomass to represent food supply for salmonids.
2. Shannon-Weaver Diversity Index (Diversity) as a measurement of ecosystem health.

The HSI selected to calculate WUA curves were developed for the Sacramento River (USFWS 2006). Results are presented as the percent change from existing conditions to the 100% design. Planform maps of WUA were used to illustrate the amount and quality of WUA. Complete WUA results are in Appendix B.

3.2.1 Area Under the Curve

When summed across all flows, WUA generally increased in the 100% design compared to existing conditions for both BMI metrics (Table 18). The greatest increase in WUA occurred for BCH biomass, which increased by 19%. Both BMI metrics increased in the 100% design due to the increase in designed gravel bars and riffles that provide suitable substrate for BMI production (Section 3.2.2).

Table 18. Area under the curve values calculated from WUA curves for the benthic macroinvertebrate metrics: Baitidae, Chironomidae, Hydropsychidae *(BCH) Biomass and Shannon-Weaver Diversity Index (Diversity).*

Species	Metric	Existing conditions area under the curve (cfs × acres)	100% design area under the curve (cfs × acres)	Change from existing conditions (cfs × acres)	Change from existing conditions (%)
Benthic Macro-invertebrate	BCH Biomass	182,086	217,376	35,290	19%
	Diversity	496,125	570,574	74,449	15%

3.2.2 Weighted Usable Area

The quality, location, and transition of WUA as flow increased was similar for both BMI metrics because they have similar HSI. WUA for BCH Biomass and Diversity increased in the 100% design relative to existing conditions at flows greater than 150 cfs, with the greatest increase in WUA at 1,580 cfs (Figure 30). The magnitude of increase was greater for BCH Biomass (149%) than for Diversity (67%, Figure 30). The increase in WUA for both metrics was due to the increase in designed gravel bars and riffles that provide suitable substrate for BMI production, where under existing conditions there is a long, simplified pool with a finer grain substrate. BCH Biomass and Diversity WUA decreased at low flows (80 cfs and 150 cfs) in the 100% design, because flow was shared among the main channel and side channels, creating hydraulic conditions lower in suitability compared to existing conditions. However, WUA was relatively high at these lower modeled flows under 100% design (e.g., 2.8 acres at 80 cfs for BCH Biomass and 17.1 acres at 80 cfs for Diversity, Appendix B); therefore, there was still abundant suitable habitat for BMI production under 100% designs despite predicted decreases at low flows.

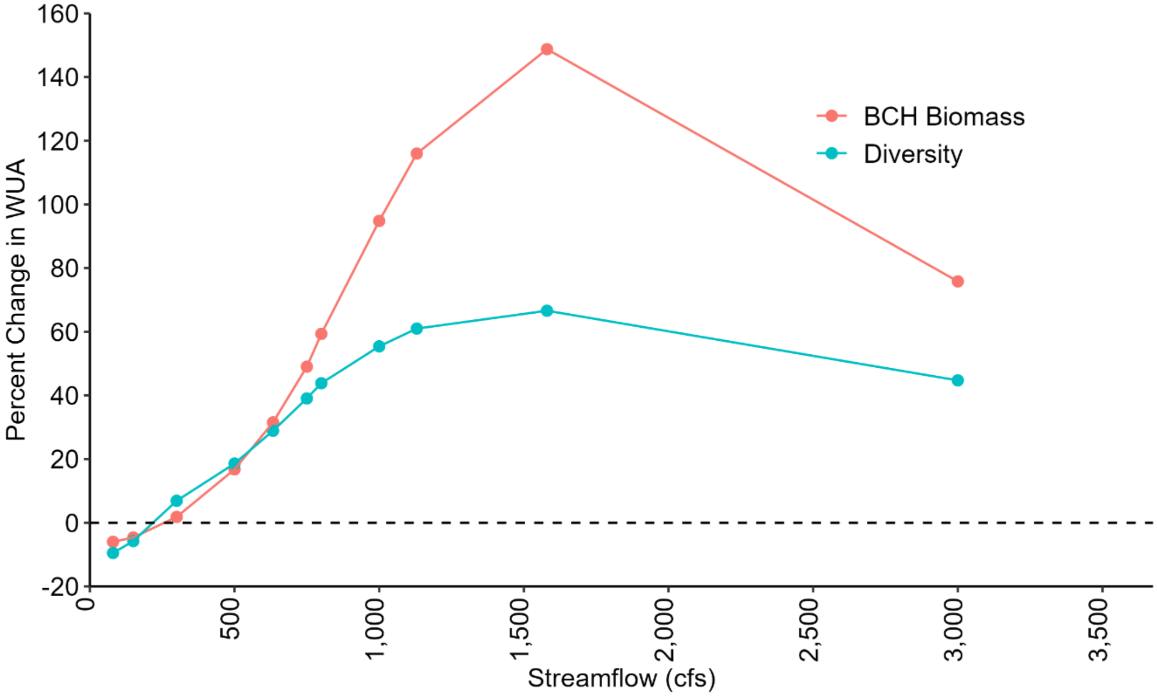

Figure 30. Percent change in WUA from existing conditions to the 100% design for the benthic macroinvertebrate metrics: Baitidae, Chironomidae, Hydropsychidae *(BCH) Biomass and Shannon-Weaver Diversity Index (Diversity).*

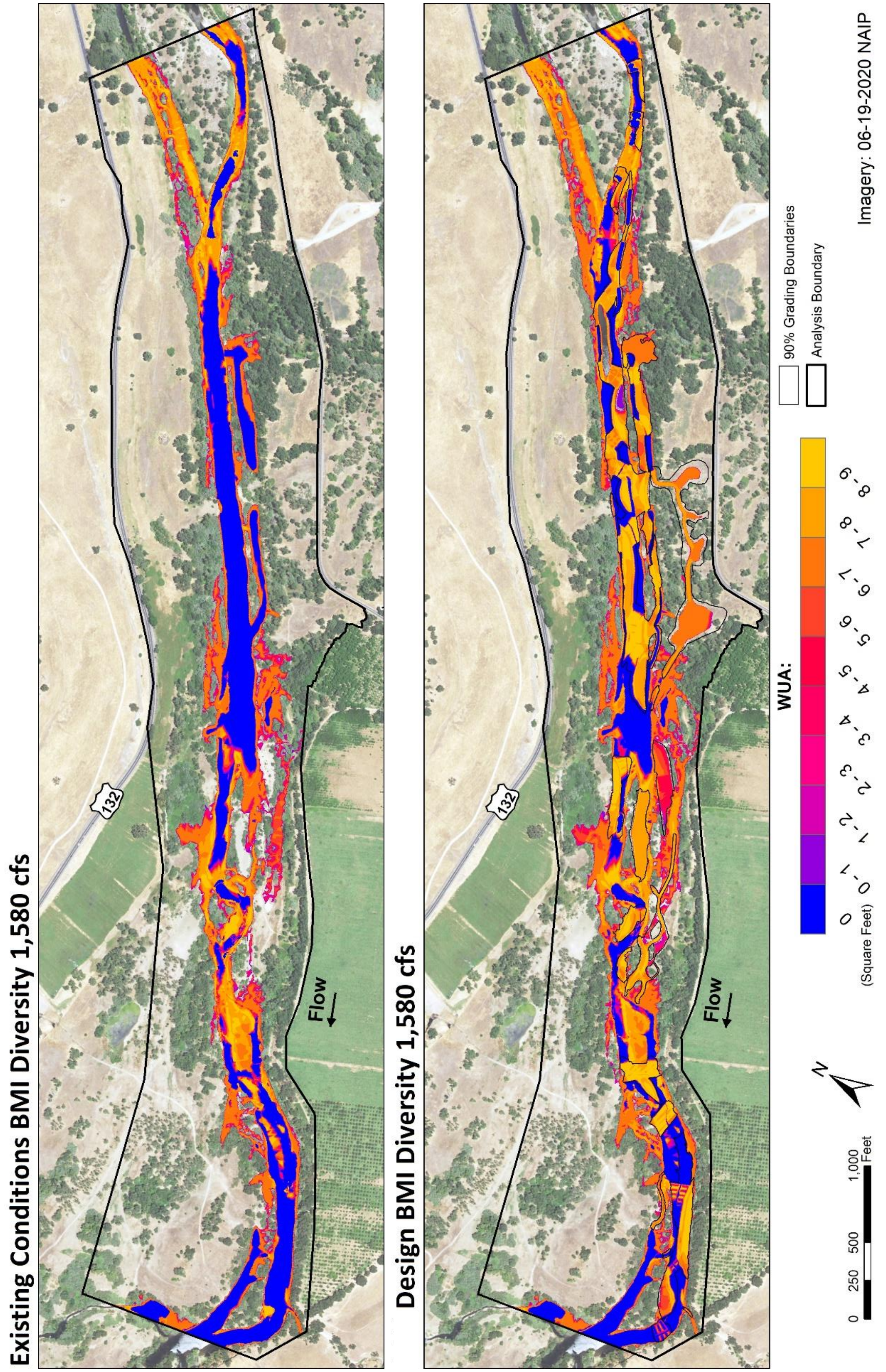

Figure 31. Planform view BMI Diversity WUA at 1,580 cfs, illustrating the extent of productive BMI habitat throughout the site under the 100% design compared to existing conditions.

3.3 Turtle Habitat

Two species of turtles are known to be present in the Zanker Farm Project area: the native Northwestern Pond Turtle (*Actinemys marmorata*), and the invasive Red-eared Slider, (*Trachemys scripta elegans*). Observations in summer 2022 and reports from the landowner indicate the invasive Red-eared Slider is well established and appears to be more abundant in the area than the native Northwestern Pond Turtle.

Both turtle species are considered habitat generalists and they share overlapping habitat requirements. They compete for resources, including food, basking sites, refugia, and suitable nest sites. Compared to the Northwestern Pond Turtle, Red-eared Sliders grow faster, reach larger adult sizes, and have greater reproductive output, including more eggs per nest and more nests per year. The Red-eared Slider evolved in competition with up to half a dozen other species of freshwater turtles within its native range, whereas the Northwestern Pond Turtle is the only native freshwater turtle throughout most of its range. Thus, the Red-eared Slider often has the advantage in competitive interactions between the species, exhibiting more aggressive behavior, often displacing the native turtle. The invasive turtle also serves as a vector for disease and parasites to which the native turtle is susceptible.

It is challenging to design habitat features to promote native turtle conservation without also benefiting the invasive turtle, although there are subtle differences in behavior and habitat use that may allow for habitat restoration designs favoring the native turtle. Red-eared Sliders tend to be slightly more aquatic and show a greater affinity to calm waters compared to Northwestern Pond Turtles, which more readily inhabit flowing waters. Red-eared Sliders are considered opportunistic omnivores consuming a wide variety of invertebrate and vertebrate prey although aquatic vegetation is often a large component of the diet of adults. Northwestern Pond Turtles are primarily carnivorous. Although some vegetation and algae are consumed, plant material is rarely a significant component of the diet.

Habitat restoration features in the 100% design for the Zanker Farm Project area may reduce the amount of habitat preferred by Red-eared Sliders while keeping habitat for Northwestern Pond Turtles. These restoration features include reduction of large deep pools in the main channel, development of riffle and gravel bar habitats, and increasing flow in side channels. Returning functional alluvial river elements via the extensive design side channels on the left bank may reduce the overall amount of turtle habitat, but negative impacts are likely to have a greater effect on the invasive Red-eared Slider population than on native Northwestern Pond Turtles. Increased alluvial function includes increasing flow in side-channels to scour aquatic vegetation and fine substrates, decreased depth of large pools, and improved sediment routing to promote rockier aquatic substrates. Scouring flows in winter can reduce proliferation of aquatic vegetation, particularly non-native vegetation, reducing habitat suitability for Red-eared Sliders. Furthermore, Red-eared Sliders are far more likely to remain active through the winter or to overwinter in the water compared to the Northwestern Pond Turtle. In river environments, the Northwestern Pond Turtle tends to overwinter on land. Thus, an increase in scouring flows during the winter is more likely to impact the invasive turtle without jeopardizing native turtles overwintering in the upland. Due to the extensive wetlands beyond the extent of the Project area, it may not be possible to eliminate invasive Red-eared Sliders at the Zanker Farm, but returning functional alluvial river elements may give a competitive advantage to the Northwestern Pond Turtle. Under the existing condition, without restoration, it is likely that over time, the Red-eared Slider will displace and ultimately replace the Northwestern Pond Turtle.

3.4 Foothill Yellow-legged Frog Habitat

The Foothill Yellow-legged Frog (FYLF; *Rana boylii*) was once widespread across California, but it has experienced significant declines across its range, including extirpation from many localities in the Central Valley, and appears to be extirpated from the Zanker Project area. FYLF has long been recognized as a Species of Special Concern in California (Jennings and Hayes 1994, Thomson et al. 2016). In December 2019, FYLF was listed under the California Endangered Species Act (CESA 1970), receiving endangered status for the East/Southern Sierra Clade. The species is also currently in review for federal listing under the Endangered Species Act (ESA 1973), with an endangered status listing for the South Sierra Distinct Population Segment expected from USFWS in 2023 (Federal Register Vol. 86, No.246, December 2021). Primary threats to the species include alteration of flow and thermal regimes and other habitat degradations associated with dam operations, as well as changes in land use, invasive species pressure, and disease (Kupferberg et al. 2012, Adams et al. 2017). FYLF historically occurred in the Zanker Farm Project area and does still occur in the Tuolumne River upstream of Don Pedro Reservoir. The California Natural Diversity Database (CNDDB) managed by CDFW includes recent observations within a few miles of the Project area (reported from the Chinese Creek USGS 7.5 × 7.5 quad map), suggesting potential for recolonization or reintroduction with improved habitat conditions. Appendix C provides more details on the FYLF analysis.

The FYLF has evolved strategies to time reproduction with hydrograph cycles to minimize scour and desiccation risks to eggs while maximizing development time for offspring. Breeding typically occurs along stream margins in spring (March to June), depending on water year type, hydrograph timing, and water temperature. Individual frogs decide when to initiate breeding based on a suite of environmental cues (Wheeler and Welsh 2008). Downstream of dams, components of the hydrograph may be decoupled from natural environmental cues, hampering the frog's ability to make the best choice of when and where to lay eggs (Lind et al. 1996, Lind et al. 2016). In snowmelt-driven rivers of California, seasonal patterns are somewhat predictable, but the annual variability in hydrograph shape, magnitude and timing can lead to failure of the cohort.

Channel rehabilitation can reverse degradation downstream of dams, improving conditions for breeding and rearing FYLF. A combination of mechanical manipulation and ecologically based flow management is often most effective for improving reproductive success of FYLF in flow-regulated rivers. Reduced flood magnitude and frequency downstream of dams allows encroachment of riparian vegetation, formation of berms, and downcutting of the channel, leading to a loss of shallow edge water habitats used for breeding by FYLF (Kupferberg et al. 2012, Yarnell et al. 2012). Grading vegetated banks, berms, and down cut channel beds to recreate gravel bars, side channels and other shallow waters along the river margin provides habitat used for breeding and rearing. Coupling channel rehabilitation with flow management that considers seasonal timing of FYLF reproductive cycle promotes population recovery and maintenance of this endangered river-breeding frog.

The Foothill Yellow-legged Frog Assessment Model (FYFAM; Railsback et al. 2016, 2021a) is an individual-based simulation model that provides a way to assess reproductive success of FYLF at a site. FYFAM uses ground topography, streamflows, and water temperature to predict reproductive success based on survival of key life stages: egg mass, tadpole, and metamorphosis to froglet stage. Results include predictions of timing of life history stages, risk of mortality due to scour and desiccation, and froglet production, allowing for numerical comparisons of reproductive success for proposed site designs and/or flow regimes.

3.4.1 Methods

FYFAM V2.1.3 A (FYFAM; Railsback et al. 2021) was used to evaluate and compare potential reproductive success for FYLF in the Project area for existing conditions (EC) and the 65% design (65). As only minor changes to floodplain surfaces were made at 90% and 100%, FYFAM was not revised based on the 90% or 100% design. This set of simulations used the same parameter settings and flow and temperature scenarios representing three water year types (dry, moderate, wet) as were used for evaluating Zanker Phase I and Phase II (McBain Associates 2022a, McBain Associates 2022b). Water temperature influences oviposition timing, which commonly begins when water temperature reaches 10–12 °C. Oviposition prior to spring peak flows increases flow-related mortality risks to eggs and tadpoles. Oviposition later in the spring or summer decreases time available for development and growth before winter. Since no site-specific, empirical data on water temperature triggering FYLF breeding were available for the lower Tuolumne River, these evaluations assessed three breeding threshold temperatures, 10, 11, and 12 °C.

To account for probabilistic and stochastic functions in the model, 10 replicate simulations were run for each combination of topography (existing condition and 65% design), water year type (dry moderate, and wet), and breeding threshold temperature (10, 11, and 12 °C). The "most typical" replicate of each set of 10 simulations, which was closest to the mean values for froglet production and median date of metamorphosis, was used for interpretation of model results.

3.4.2 Results and Conclusions

Overall, there were minimal differences between model predictions of froglet production between the existing condition and 65% design. Model predictions of froglet production and timing of metamorphosis were similar for the existing condition and 65% design for the dry and moderate water year types at all breeding threshold temperatures (Figure 32). In the dry water year example, for the 65% design, FYFAM predicted slightly higher froglet production than what was predicted for existing conditions. Median date of metamorphosis in late July gave froglets plenty of time to forage and grow before winter and improved their probability of overwinter survival. This pattern held across all three breeding threshold temperatures evaluated. Drier water years are most conducive to reproductive success for FYLF in mainstem rivers due to metamorphosis occurring earlier in the season, allowing more time for froglets to feed and grow prior to overwintering and thus increasing their chance of overwinter survival. Additionally, increases in froglet production in an already high-production year results in a greater chance of satiating predators and therefore a higher number of froglets that survive predation. For these reasons, even the modest increase in froglet production predicted for design conditions can contribute to population growth (i.e., growth of the reproductive population that ultimately survive to produce a future cohort).

In the moderate water year example, the flow peaks began a couple weeks later than in the dry water year type and the series of peaks continued for about a month, leading to high scour mortality of egg masses and low froglet production. Metamorphosis occurred in August and embryos that metamorphosed to froglets would be expected to have high overwinter survival. Differences between the existing condition and 65% design were minor, but the existing condition produced slightly more froglets than the 65% design. This pattern held true across all three of the breeding threshold temperatures evaluated. Due to low reproductive success in the moderate water year, differences in froglet production are not likely to produce a population level effect. Different water year types have different levels of reproductive success and therefore different sensitivity to changes in froglet production. While these minor differences did exist, overall froglet production was similar between existing conditions and 65% design except for in one case described below.

In the wet water year type, froglet production was higher for existing conditions than the 65% design at the 12 °C breeding threshold temperature (Figure 32). The additional flow peak in August resulted in considerable tadpole scour mortality in the 65% design topography, which was not as apparent for the existing condition, leading to higher froglet production for the existing condition. Overall, froglet production in the wet water year type was low, similar to the moderate water year example. However, froglet production was higher for the 12 °C breeding threshold temperature because breeding started after spring peak flows subsided. For all simulations in the wet water year type, metamorphosis occurred too late to expect froglets to survive their first winter, so differences between the existing condition and 65% design are not expected to affect population growth.

It is important to note that while FYLF is likely to have occurred historically in the lower Tuolumne River, there are no recent records of this species within the Project boundary. It is possible that recolonization or reintroduction could occur with improved habitat conditions, including increased riffle and gravel bar habitat, although other factors may suppress opportunities for this species to re-occupy the Project area. Side channels can support earlier breeding while providing some protection from scouring spring flows. The Zanker Farm 65% design provides many of these features (side channels, riffles, and gravel bars) and would improve conditions for reintroduction or recolonization of FYLF.

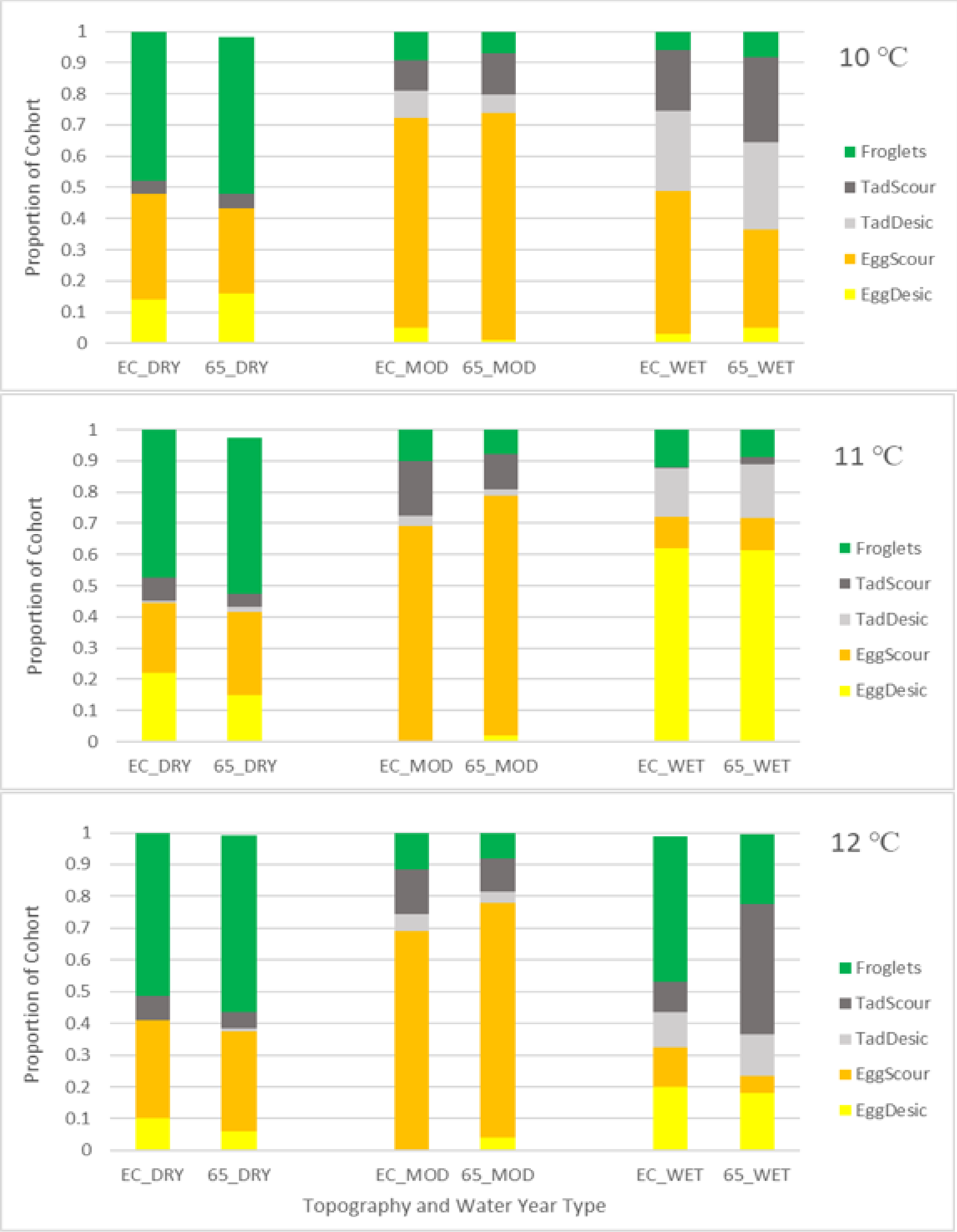

Figure 32. Stacked bar graphs depicting predicted mortality risk for eggs and tadpoles, and embryos surviving to metamorphose into froglets. Evaluations are shown for three breeding threshold temperatures (10, 11, and 12 ℃) and three representative water year types (Dry, Moderate, and Wet). The dry water year type produced the most froglets regardless of temperature, with slightly higher froglet production for the 65% design topography. Froglet production was lowest for the moderate water year type, with slightly lower froglet production for the 65% design. Froglets produced in the wet water year type reached metamorphosis too late to be considered successful.

3.5 Vegetation Zonation

The same methods used to conduct the existing conditions depth to estimated groundwater analysis were used to conduct a depth to estimated groundwater analysis that incorporated the 100% design surface terrain. The 100% design terrain DEM and the modeled 100% design 80 cfs water surface elevation were used to create a 100% design relative elevation model. Vegetation zone boundaries defined using existing vegetation (Appendix F and McBain Associates 2021, 2022a, 2022b) were applied to the 100% depth to groundwater to evaluate how the proposed design topography would change existing vegetation zonation patterns in terms of depth to groundwater (Bair et al. 2021). Based on comments received on the existing conditions vegetation zonation analysis, the riparian zone was separated into a low and high riparian zone as described in Appendix F. The area of individual vegetation zones within the 100% design surface was tabulated and used to quantify the effects that proposed restoration actions would have on vegetation zone area compared to existing conditions.

The design for the Zanker Farm Project will convert drier vegetation zones to wetter vegetation zones (Table 19). The proposed physical designs result in a slight decrease of 0.7 acres in the water zone but increases emergent/channel margin and riparian zones by 20.6 acres at 80 cfs (Table 19). Within the Project area, 0.7 acres of water, 10.8 acres of the riparian–upland transition zone, and 9.1 acres of upland zone will be converted to 13.5 acres of emergent/channel margin zone, 3.8 acres of low riparian zone, and 3.4 acres of high riparian zone.

Table 19. The Zanker Farm Project area vegetation zone area comparison under existing conditions and design.

Vegetation zone	Existing conditions (acres)	100% Design (acres)	Difference (acres)
Water	30.79	30.08	–0.71
Emergent/Channel Margin	9.85	23.31	+13.46
Low Riparian	34.18	37.91	+3.79
High Riparian	65.20	68.59	+3.39
Riparian-Upland Transition	48.42	37.62	–10.80
Upland	38.33	29.20	–9.13
Total	226.77	226.77	

3.6 Riparian Recruitment

The potential of design surfaces (e.g., floodplains, gravel bars, and side channels) to support natural riparian recruitment was evaluated using TARGETS-2D, an updated recruitment model based in part on the Mahoney and Rood (1998) box recruitment model. TARGETS-2D incorporates streamflow magnitude, timing, duration, and rate of change in combination with site topography, stage–discharge relationships, root growth rates, and seed dispersal periods to forecast seedling survival during the modeled time period. Inundation, desiccation, and scour are mortality agents that directly result in biologic responses (i.e., seedling death) to changing hydrologic and physical conditions. Appendix D provides more details about the TARGETS-2D analysis.

Two riparian hardwood species and five streamflow scenarios were modeled (Table 20). Fremont cottonwood and narrowleaf willow were chosen because they each represent a dominant riparian hardwood strategy; Fremont cottonwood is a long-lived, large riparian forest tree that forms stands on floodplains following episodic flooding events, whereas narrowleaf willow is a thicket-forming shrub species with high reproductive success that frequently exploits low-water channel margins. The streamflow scenarios spanned two water years, from May 1 to June 30 of the following year, when surviving seedlings reached 1 year old. Therefore, each streamflow scenario represented one water year type (Wet, Above Normal, Below Normal, Dry, and Critically Dry) during the year of seed germination and establishment, and another water year type during the first growing season, when low fall baseflows could cause seedling desiccation and high winter flows could potentially scour or drown seedlings.

The 65% design was used to compare to existing conditions for TARGETS modeling. As only minor changes to floodplain surfaces were made at 90% and 100%, TARGETS was not revised based on the 90% or 100% design. TARGETS modeling showed that the 65% design surfaces will be low enough to support early life stages for willows and cottonwoods. The design increased seedling survival across all modeled water year types for both species (Table 20). The design boosted passive recruitment opportunities in wetter years when passive recruitment is typically low. The smallest increases in seedling quantity over existing conditions occurred in Below Normal and drier years that would normally produce a high number of seedlings. Overall, the 65% design produced 3–85% more cottonwood seedlings and 2–317% more narrowleaf willow seedlings than existing conditions.

Desiccation and inundation were the most significant mortality agents in all water year types for both cottonwood and narrowleaf willow seedlings. Desiccation caused 80–85% mortality in drier years and 43-62% in wetter years. Inundation caused 30–50% of cottonwood seedling mortality in Above Normal and Wet years and only 15% mortality in drier years. In the 65% design, there was a 5% increase in inundation mortality in Wet years, presumably because lower floodplain benches will be inundated longer, increasing inundation mortality over existing conditions. Even though there was an increase in inundation mortality in Wet years, the number of seedlings that established during this period was still much higher than under existing conditions (Table 20).

Scour mortality was mostly insignificant, an unexpected outcome, especially for the Dry to Wet water year scenario (2016–2017). Reduced flows in Dry water years cause seedlings to become established on lower surfaces that are closer to the groundwater. When Dry years are followed by higher flows in Wet years, many seedlings growing on lower surfaces are either scoured during high flows or drowned during prolonged inundation. Scour did not account for more than 0.5% mortality in any of the scenarios modeled. Full TARGETS modeling results are presented in Appendix D.

Dense revegetation with a diverse plant palette will help manage invasive species, create habitat in the short term, and lead to long term vegetation structural success. The Project area will recruit willows and cottonwoods in the future, leading to the development of a multi-age stand and potentially self-sustaining woody riparian habitat.

Table 20. The number of surviving seedlings on June 30 modeled by TARGETS by species and water year type for existing conditions and the 65% design.

Species and water year type	Existing conditions	65% Design conditions
Fremont cottonwood		
2010–2011 (Above Normal to Wet)	511	2,892
2016–2017 (Dry to Wet)	1,788	6,291
2017–2018 (Wet to Below Normal)	27	2,294
2018–2019 (Below Normal to Wet)	668	3,178
2021–2022 (Critically Dry–Critically Dry)	21,329	58,176
Narrowleaf willow		
2010–2011 (Above Normal to Wet)	48	2,154
2016–2017 (Dry to Wet)	3,972	8,340
2017–2018 (Wet to Below Normal)	6	1,902
2018–2019 (Below Normal to Wet)	3,600	8,772
2021–2022 (Critically Dry–Critically Dry)	32,796	68,088

3.7 Preliminary Cost Estimate

The 100% cost estimate includes detailed quantity calculations for the design elements followed by equipment and labor calculations for each construction stage. The cost estimate assumes:

- 18,000 cy of suitable coarse sediment is expected to be obtained from floodplain excavation on site. Floodplain excavation totals 73,630 cy and it is assumed that 18,000 cy of this will be suitable.
- Any excess spoil material (i.e. fines) will be transported to the Zanker mining site.
- 60,420 cy of suitable coarse sediment will be purchased at $25 / cy. The grant manager will purchase clean, sorted gravel from the Zanker mining site across Lake Road and the contractor will transport it to the Project in-channel areas.
- 6,910 cy of oversized 6-12 inch material will need to be purchased, at an assumed cost of $25 per cubic yard.
- Civil construction will take place over a two-year period and riparian implementation will occur after the second year of civil construction.
- Higher density planting is the only invasive plant management tool currently projected for this Project. Revegetation costs for wetland areas are higher than riparian areas due to higher density plantings. Lower density plantings are designed in riparian areas and direct seeding is proposed for the transition and upland areas.
- The costs to install willow clumps, collect materials, and install willow trenches are included in the revegetation cost. Also included is the cost for a native seed mix, mulch, and labor to spread seed and mulch.
- A cost estimate to spray star thistle with herbicide on all areas of disturbance including access roads has been included with a 10% contingency.
- A 15% administrative overhead fee for contract handling is included in the revegetation cost.

- A 10% contingency is included to account for potential inflation and continued design development. A 20% contingency is included in the revegetation estimate to account for uncertainty in planting material costs.

Table 21. Cost estimate for 100% design grading, excavation, habitat features, revegetation, and monitoring costs.

Item	Quantity	Total
Placing gravel and excavating coarse sediment	85,330 cubic yards of specified gravel mixes, 16,940 cubic yards of unsorted fill placement, and 73,630 cubic yards of excavation, sorting, and cleaning	$10,977,043
Habitat feature materials and construction, and remnant haul road removal	40 rootwad logs, 80 pin logs, 71 boulders, and associated willow stakes, plus removal of 23 I-beams, 150 cubic yards of concrete, and 450 linear feet of sheetpile	$459,682
Fish Screen	C66-21EA Cone Screen	$217,604
Revegetation	10 acres planted	$1,249, 975
Monitoring, oversight, environmental compliance	2 years	$1,217,766
Chemical treatment of star thistle	2 years	$66,942
GRAND TOTAL		**$14, 189, 012**

4 PROJECT PHASING AND TIMELINE

This Project would likely be constructed over two years, to allow in-water work to fit within the June to October in-water work window. Plant acquisition needs to begin 1–2 years before the year the revegetation plan is implemented.

Please see Appendix E, revegetation implementation process, for more details on revegetation material collection, handling, and implementation.

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Appendix A: Hydraulic Modeling

APPENDIX A. ZANKER FARM SALMONID HABITAT RESTORATION PROJECT 100% DESIGN 2-DIMENSIONAL HYDRAULIC MODELING REPORT

1 INTRODUCTION

Hydraulic modeling was performed to evaluate the 90% design. The hydraulic model was not updated from the 90% design stage to the 100% design stage because no changes were made to the design features at these stages. Depth, velocity, and shear stress results from the hydraulic model were used as the basis for other design analyses including substrate sizing, large wood stability, revegetation design, and habitat assessments for various species.

2 MODEL DEVELOPMENT

The 90% hydraulic model was developed and calibrated using Hydrological Engineering Center–River Analysis System (HEC-RAS) v.6.0.0, the U.S. Army Corps of Engineers (USACE) multi-dimensional hydraulic modeling program. It was based on the 65% design model, which was in turn developed from the calibrated existing conditions hydraulic model of the Zanker Farm project. A full description of the existing conditions hydraulic model can be found in the *Existing Conditions Report* (McBain Associates Applied River Sciences 2021).

To evaluate the 90% design, the model terrain was updated from the 65% design stage to include modifications made to design features. In CAD, surfaces of updated design features were created and combined with the existing conditions surface and recent survey data to produce a single surface with the 90% design overlaid on existing conditions. The final 90% design surface was imported to HEC-RAS for use as the modeling terrain.

The extent of the 90% design hydraulic model domain was set to the upstream and downstream extent of the DTM (Figure 1). This was done to eliminate any potential impacts of boundary conditions on the results, and to allow the topography to control the hydraulics within the project area. The lateral extent of the model domain was set to ensure confinement of the 100-year flood (i.e., the active flow area during a 100-year flood simulation will not come in contact with the model domain boundary). The model mesh was refined to use a 5-foot square mesh in the channel, a 10-foot mesh on the floodplains, and a 40-foot mesh in upland areas that only inundate during high flow events. This was done to improve the spatial resolution and accuracy of the model over the uniform 10-foot mesh that was used for existing conditions modeling while still providing reasonable run times for high flow simulations. A six-second computation interval was found to be suitable for this mesh configuration.

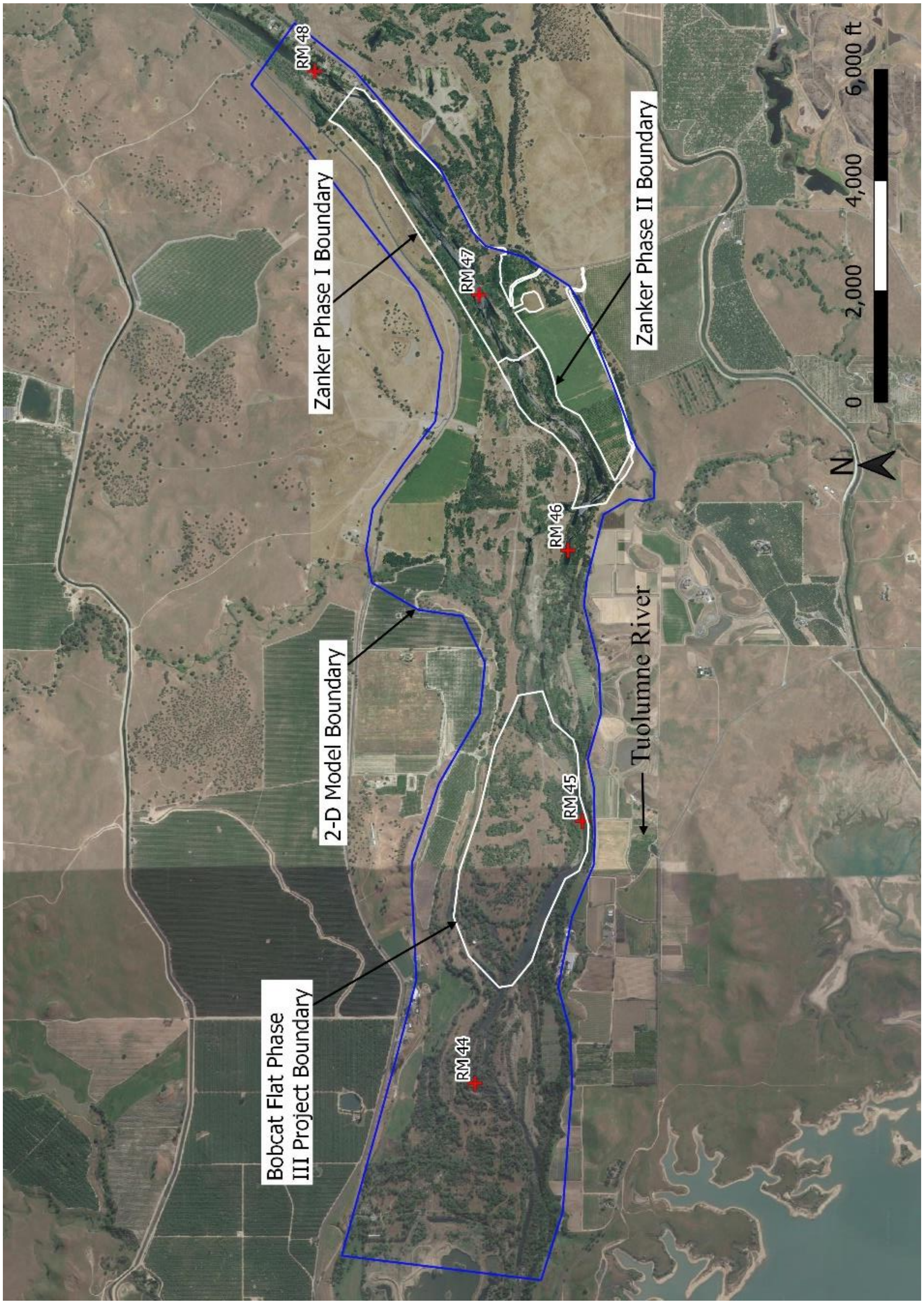

Figure 1. 2-D model domain with respect to Zanker Farm Phase I and Phase II project boundaries and Bobcat Flat Phase III project boundary. Tuolumne River mile markers are displayed. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

The model requires upstream boundary conditions that control flow input at the upstream end of the model reach, and downstream boundary conditions that control the downstream WSE during modeling. Flow was modeled as steady state, so the magnitude of flow remained constant for the entire duration of a given model run until the simulation arrived at equilibrium (i.e., flow into and out of the model domain are equal). A flow hydrograph type boundary condition was used for the upstream boundary, with a constant flow input used for the entire simulation time. A normal depth type boundary condition was used as the downstream boundary condition with a friction slope of 0.002, which was based on the bed slope at the downstream boundary. The normal depth boundary was used because the downstream boundary of the model is situated so far away from the Zanker Farm project area that any potential impacts due to the downstream boundary conditions can not affect model results in areas undergoing analyses (i.e., the project area).

Detailed Manning's *n* polygons were generated in GIS and used to assign roughness values based on land cover type (Figure 2 and Table 1). The polygon shapefile used to assign roughness throughout the model domain was derived from vegetation and substrate mapping conducted by Stillwater Sciences in 2012 and McBain Associates in 2021 and 2022. The 2012 data included the entire model domain while the 2021 and 2022 data were specific to the Zanker Phase II and Zanker Phase I Project areas. Vegetation and substrate polygons from the two data sources were combined with polygons for design features (riffles, gravel bars, side channels, and floodplains) into a single shapefile covering the entire model domain and imported to HEC-RAS. Each roughness polygon was assigned one of the categories listed in Table 1 depending on vegetation type or D_{84} in the case of substrate mapping. Manning's *n* values from the calibrated existing conditions model were used for undisturbed areas and reasonable Manning's *n* values were assumed for design areas.

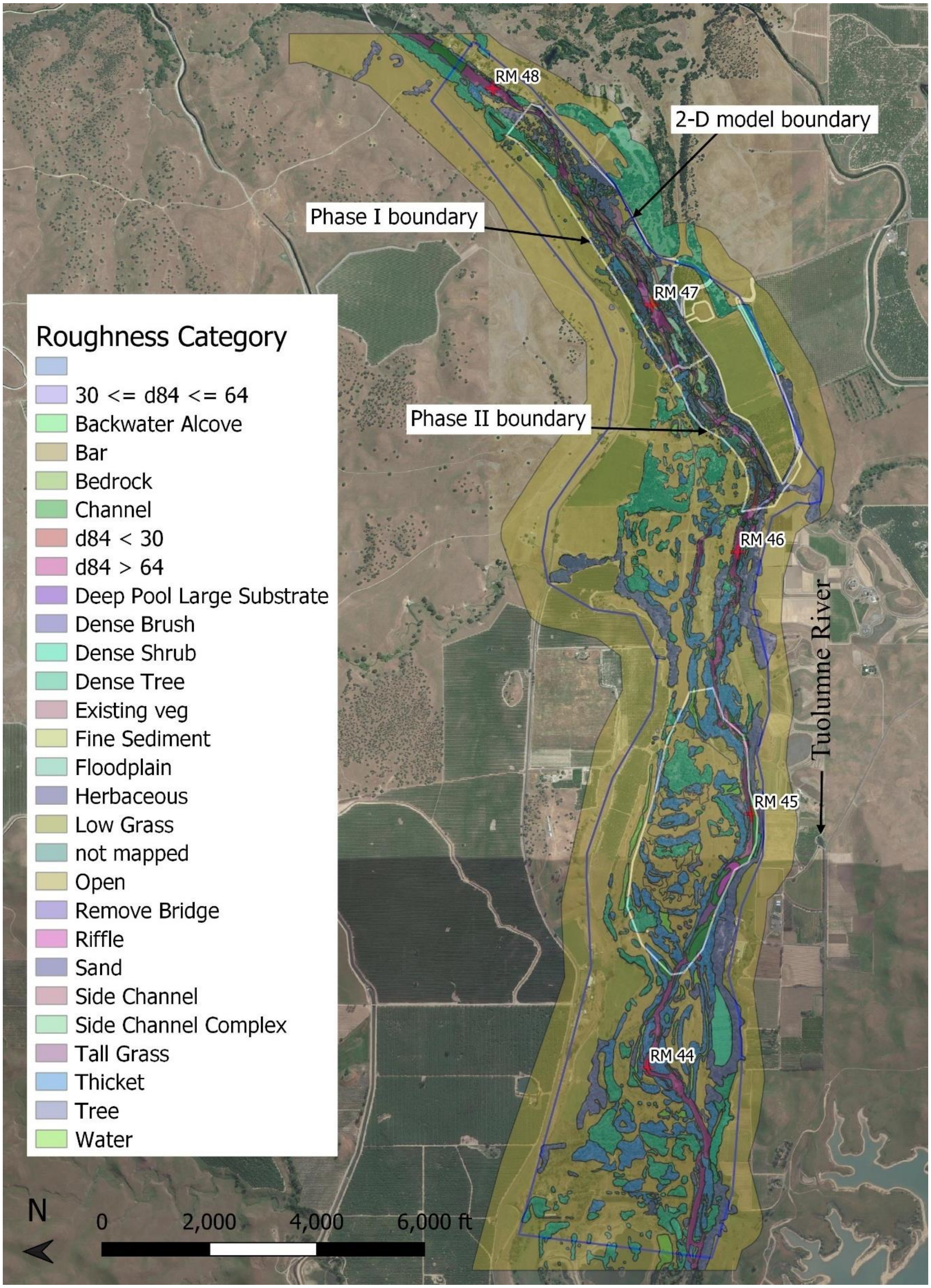

Figure 2. Manning's n roughness polygons used in 90% design hydraulic model with categories assigned based on design area and vegetation and substrate mapping. Tuolumne River mile markers are displayed. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

Table 1. Manning's n roughness factors assigned based on land cover category. The values below are the final roughness factors resulting from the existing conditions model calibration process and the assumed roughness factors for design areas.

Category	**Manning's *n***
Default/Not Mapped	0.035
$30 \leq D_{84} \leq 64$	0.035
$D_{84} < 30$	0.033
$D_{84} > 64$	0.035
Backwater Alcove	0.045
Bar (Design)	0.034
Sandstone (Bedrock)	0.030
Channel/Water	0.035
Deep Pool Large Substrate	0.042
Dense Brush	0.060
Dense Shrub	0.070
Dense Tree	0.100
Existing Veg	0.050
Fine Sediment	0.031
Floodplain (Design)	0.033
Herbaceous	0.036
Low Grass	0.035
Open	0.040
Remove Bridge (Design)	0.035
Riffle (Design)	0.034
Sand	0.032
Side Channel (Design)	0.032
Side Channel Complex (Design)	0.033
Tall Grass	0.040
Thicket	0.090
Tree	0.080

3 MODEL RESULTS

Model runs were performed to simulate flow distribution, depth, WSE, velocity, and shear stress. Table 2 lists all flows that were simulated for the 90% design model and briefly describes their relevance to these analyses. Depth and velocity model outputs for the flows in Table 2 are shown in Figure 3 to Figure 16 as examples of typical 90% design hydraulic model outputs. The model results for depth, velocity, shear stress, and water surface elevation were used as the basis for the grain size analysis, large wood stability analysis, zonal vegetation analysis, salmonid habitat analysis, and Foothill Yellow-legged Frog (FYLF) analysis (see main report).

Table 2. List of flows run in the hydraulic model. Descriptions of each flow selected, and sources used to arrive at these flow magnitudes are included.

Flow (cfs)	Description	Source/analysis/citation
80	Approx September low flow period min under existing conditions $Q_{1.5}$ 30-day duration, growing season	Hydrograph component analysis conducted for riparian planting Minimum flows used to determine depth to groundwater as described in Bair et al. (2021)
110	Calibration flow	Flow during MA calibration data collection
150	Low range of Chinook Salmon spawning flows under existing conditions (Dry and Critically Dry Water Year types) Q_2 21-day duration during seed dispersal period	Table 2, main report Flow duration analysis (McBain Associates 2021)
300	High range of Chinook Salmon spawning flows under existing conditions (wetter water year types) Roughly $Q_{2.5}$ 21-day duration during juvenile salmonid rearing period	Table 1, main report Flow duration analysis (McBain Associates 2021)
500	Index flow for habitat analyses	Selected to improve shape of habitat curve (McBain Associates 2021)
633	Roughly Q_4 21-day duration during juvenile salmonid rearing period	Flow duration analysis (McBain Associates 2021)
750	Index flow for habitat analyses	Selected to improve shape of habitat curve (McBain Associates 2021)
800	Index flow for habitat analyses	Selected to improve shape of habitat curve (McBain Associates 2021)
1,130	Q_5 30-day duration for juvenile salmonid rearing period Approximate existing floodplain inundation threshold	Flow duration analysis (McBain Associates 2021) *Lower Tuolumne Instream Flow Study* (Stillwater Sciences 2013)
1,580	Q_5 21-day duration for juvenile salmonid rearing period	Flow duration analysis (McBain Associates 2021)
3,000	Low threshold for bed mobility Low magnitude pulse flow	*Coarse Sediment Management Plan for Lower Tuolumne River* Figure 21 (M&T 2004) *Restoration Plan* Section 3.2.2 (M&T 2000)
5,400	Channel forming flow Moderate magnitude winter power generation flow	*Restoration Plan* Section 3.2.2 (M&T 2000)
7,050	Waters of US/state based on current ACOE assessment Close to high threshold for bed mobility (6,880 cfs)	Clean Water Act Section 401 Water Quality Certification for Tuolumne River (M&T 2000)
9,600	Index habitat flow	Selected to improve shape of habitat curve (McBain Associates 2021)
11,500	Q_{10} instantaneous peak flow	Flood frequency analysis Bulletin 17C (England et al. 2019)

Flow (cfs)	Description	Source/analysis/citation
44,000	Q_{100} peak flow	Central Valley Flood Protection Board (https://gis.bam.water.ca.gov/bam/)

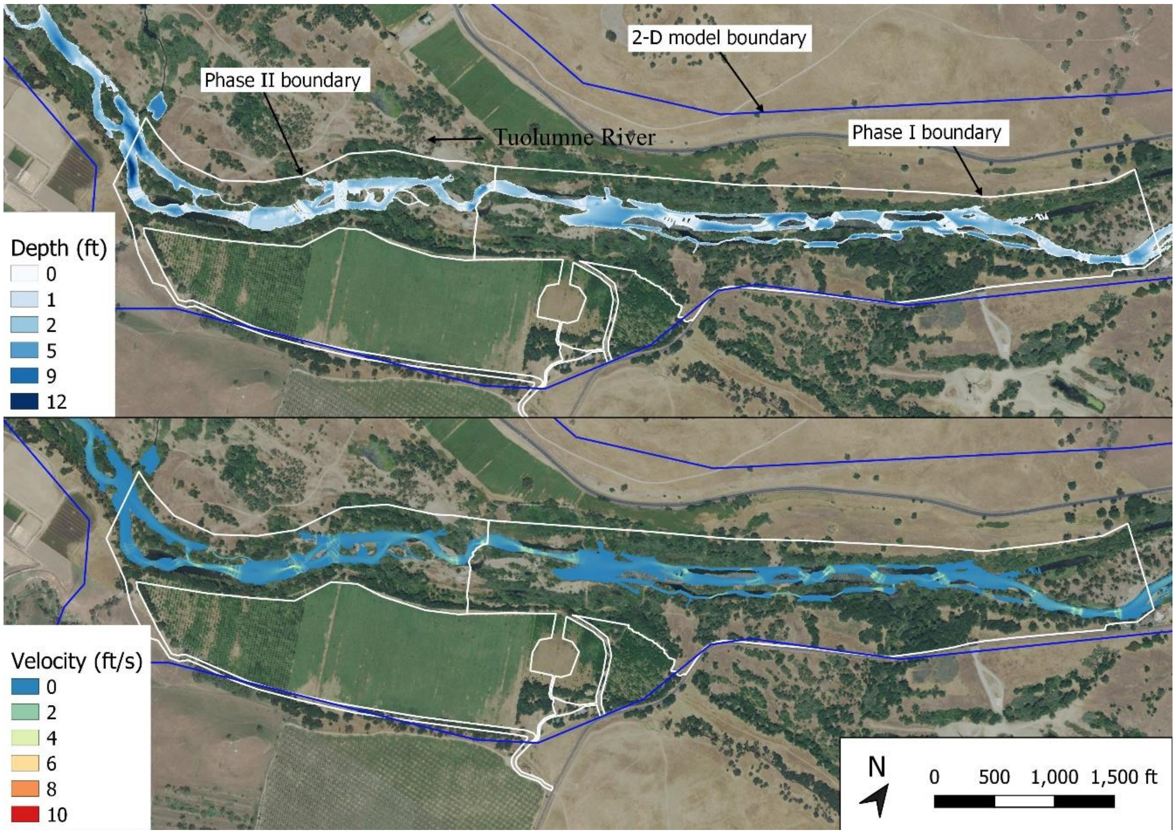

Figure 3. Hydraulic modeling depth and velocity results for 80 cfs, approximate September-November low flow period minimum. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

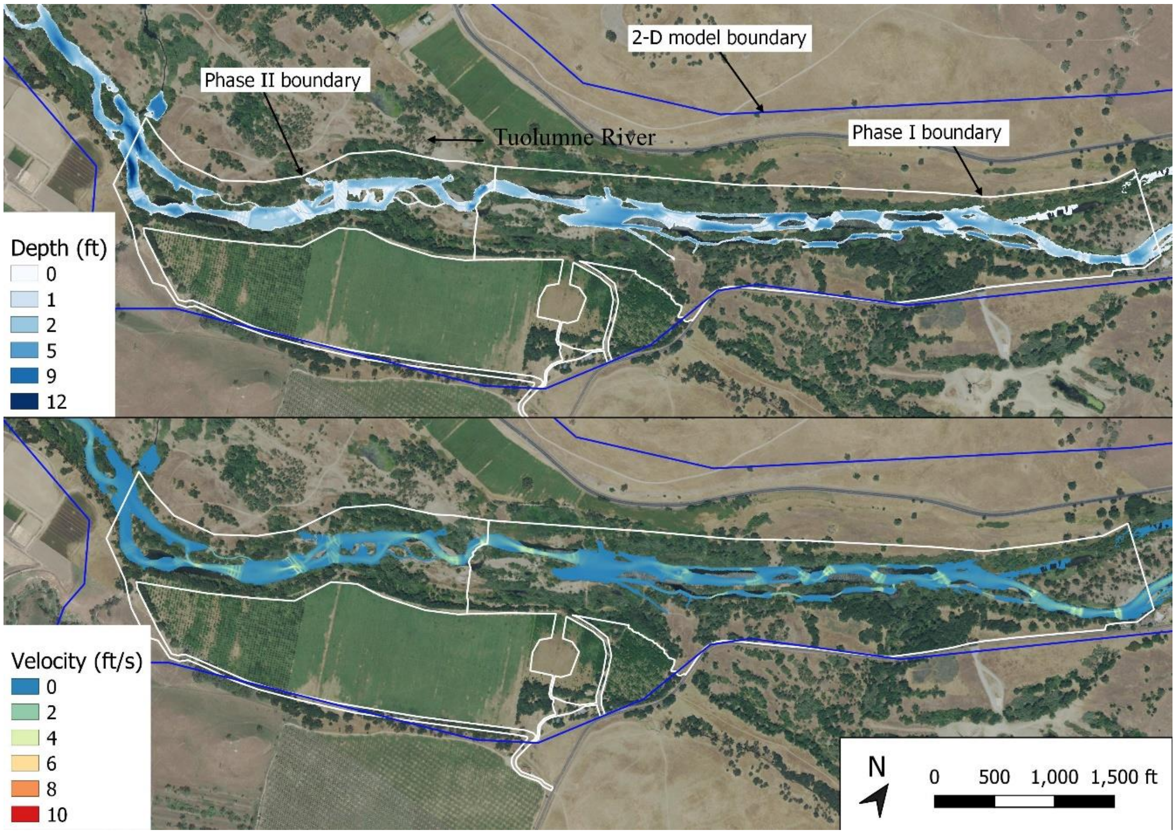

Figure 4. Hydraulic modeling depth and velocity results for 150 cfs, the low range of spawning flows. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

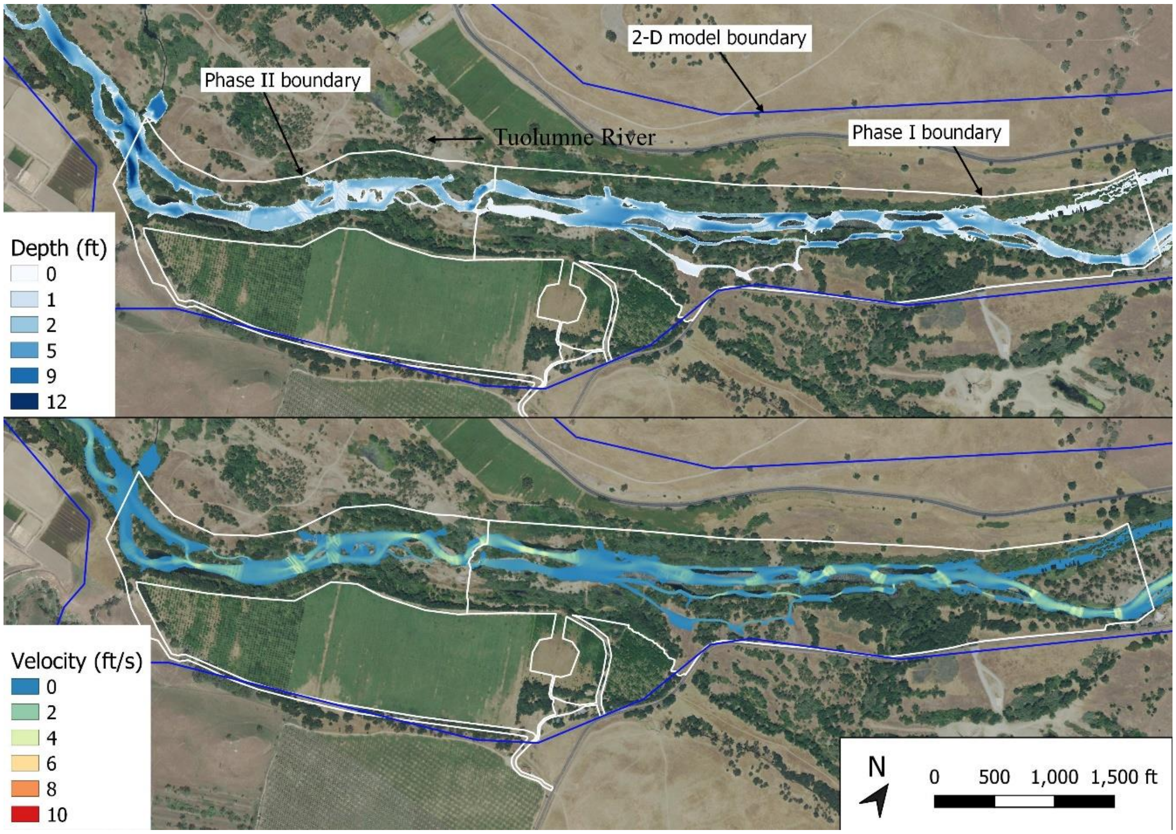

Figure 5. Hydraulic modeling depth and velocity results for 300 cfs, the high range of spawning flows. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

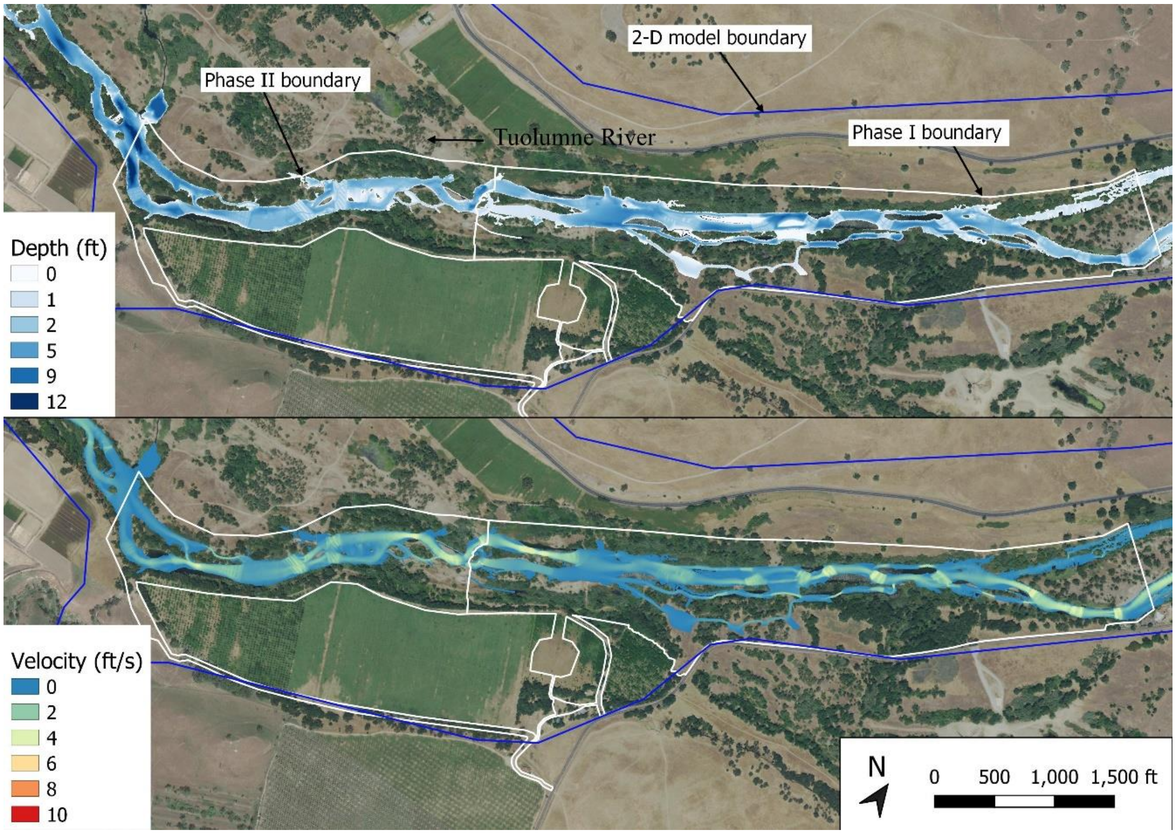

Figure 6. Hydraulic modeling depth and velocity results for 500 cfs, an index flow for habitat analyses. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

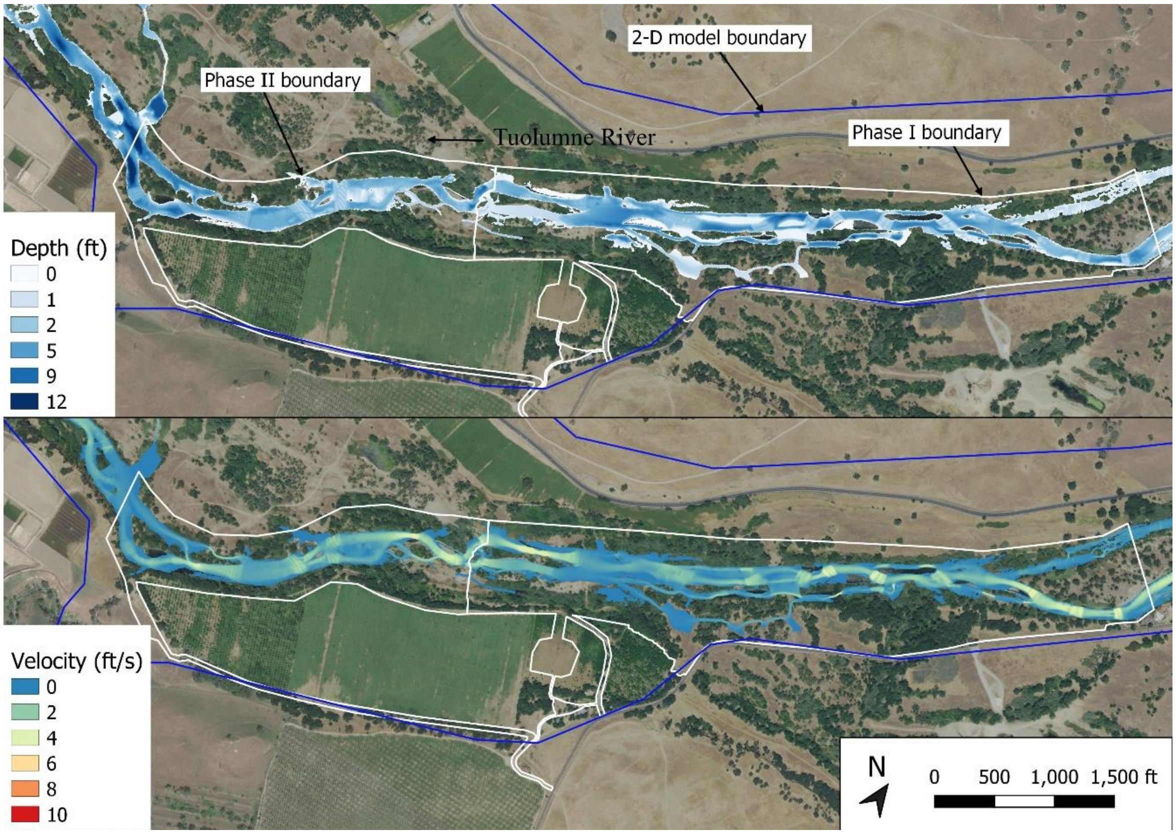

Figure 7. Hydraulic modeling depth and velocity results for 633 cfs, approximate Q_4 21-day duration flow during juvenile salmonid rearing period. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

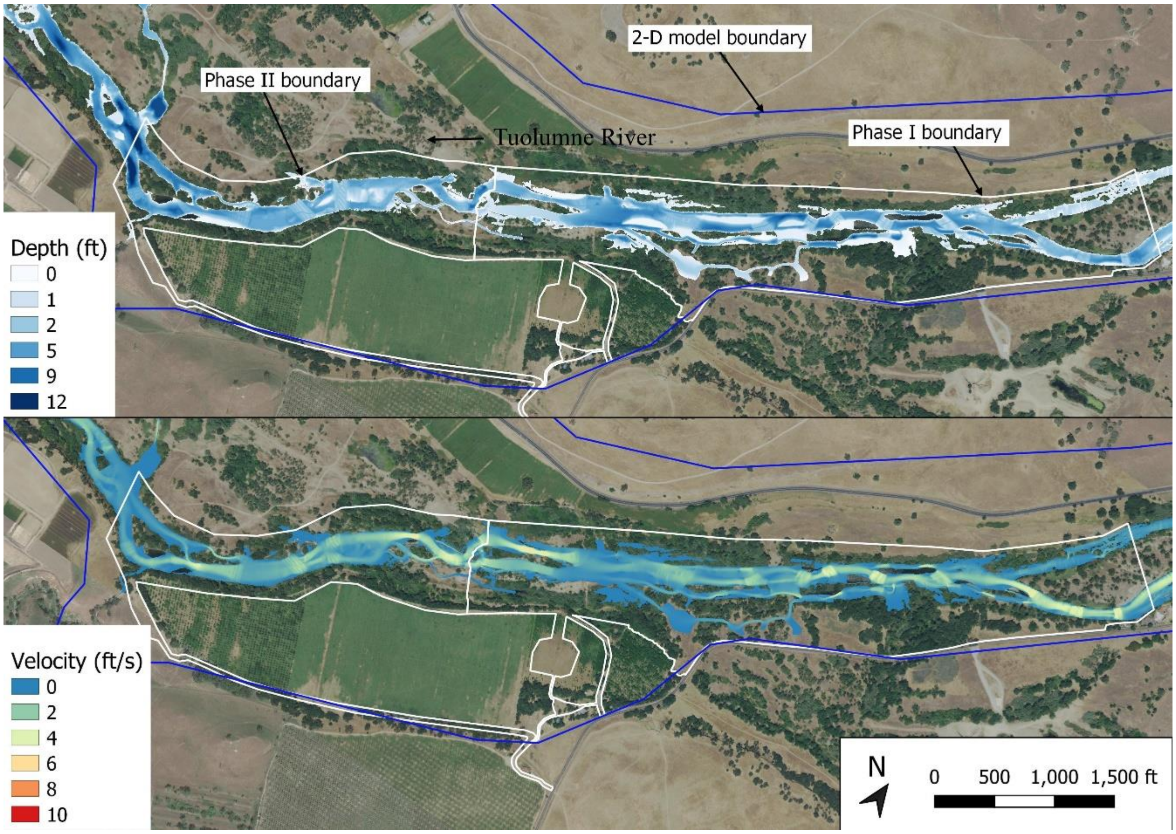

Figure 8. Hydraulic modeling depth and velocity results for 750 cfs, an index flow for habitat analyses. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

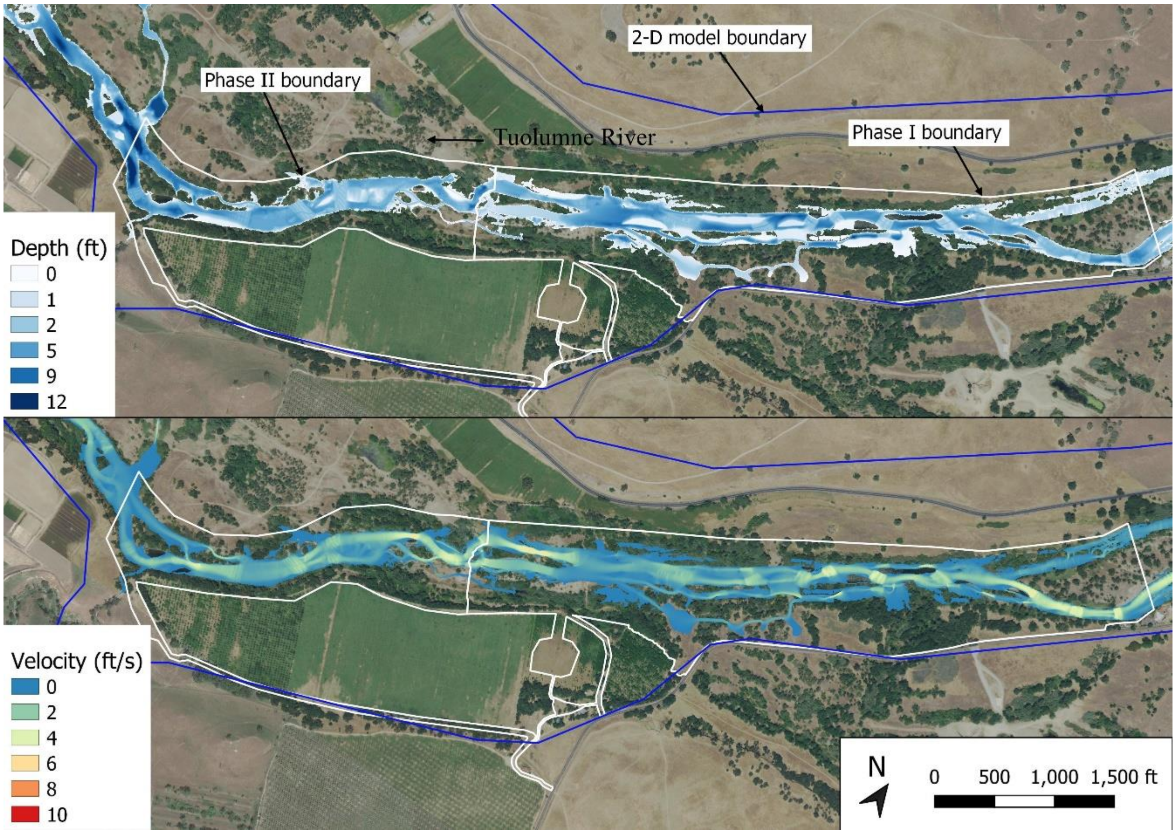

Figure 9. Hydraulic modeling depth and velocity results for 800 cfs, an index flow for habitat analyses. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

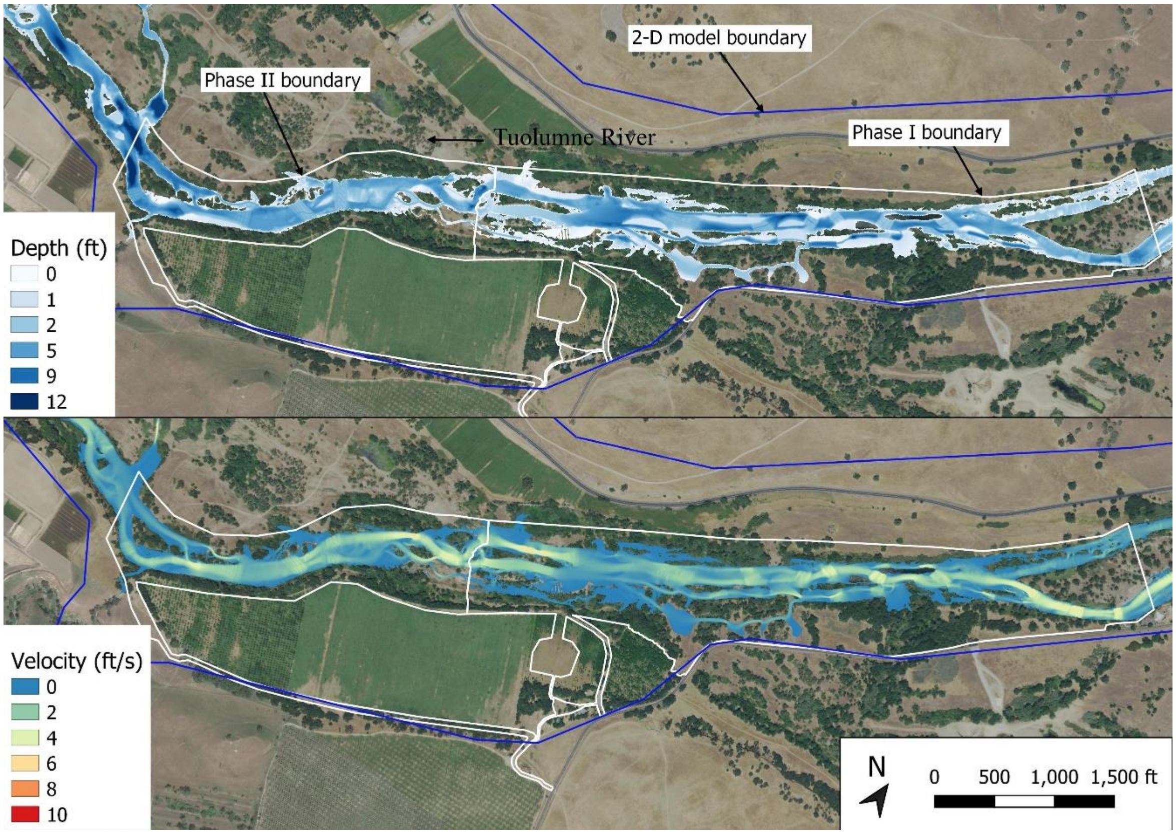

Figure 10. Hydraulic modeling depth and velocity results for 1,130 cfs, the approximate floodplain inundation threshold and the Q_5 *30-day duration flow for juvenile salmonid rearing period. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.*

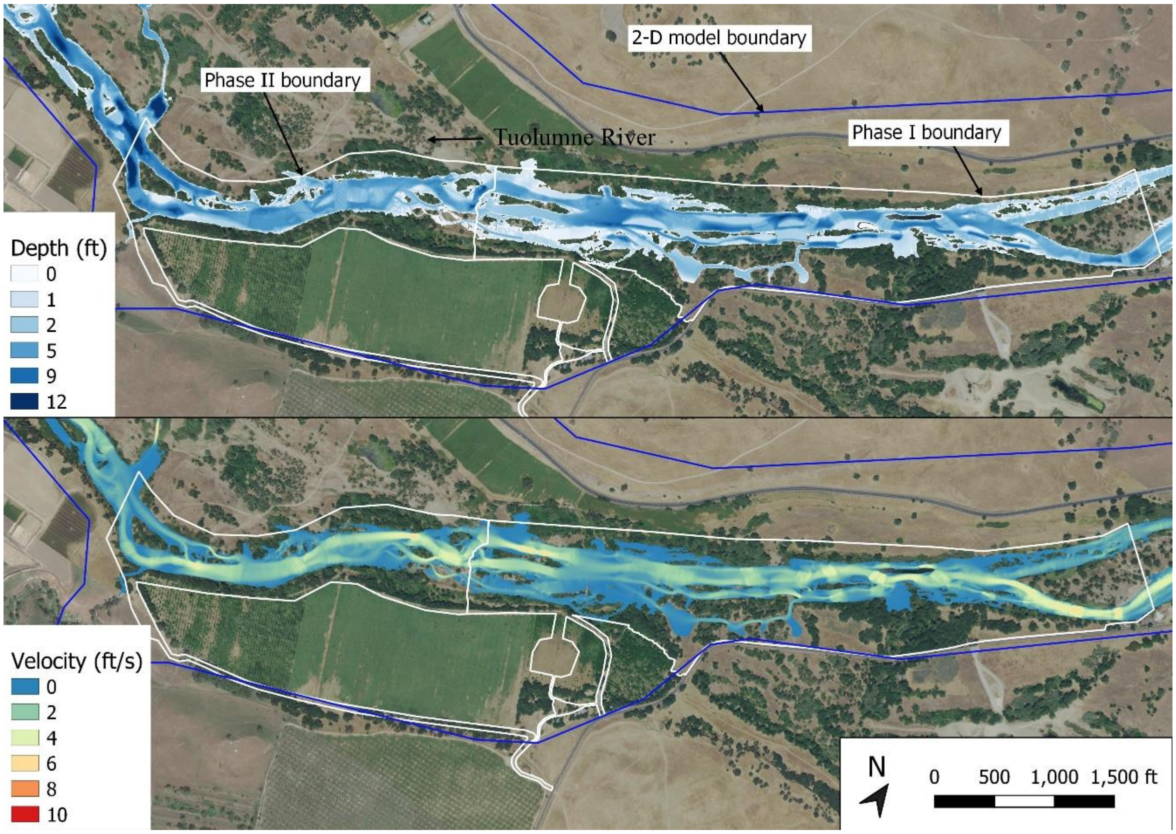

Figure 11. Hydraulic modeling depth and velocity results for 1,580 cfs, a design flow and the Q_5 21-day duration flow for juvenile salmonid rearing period. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

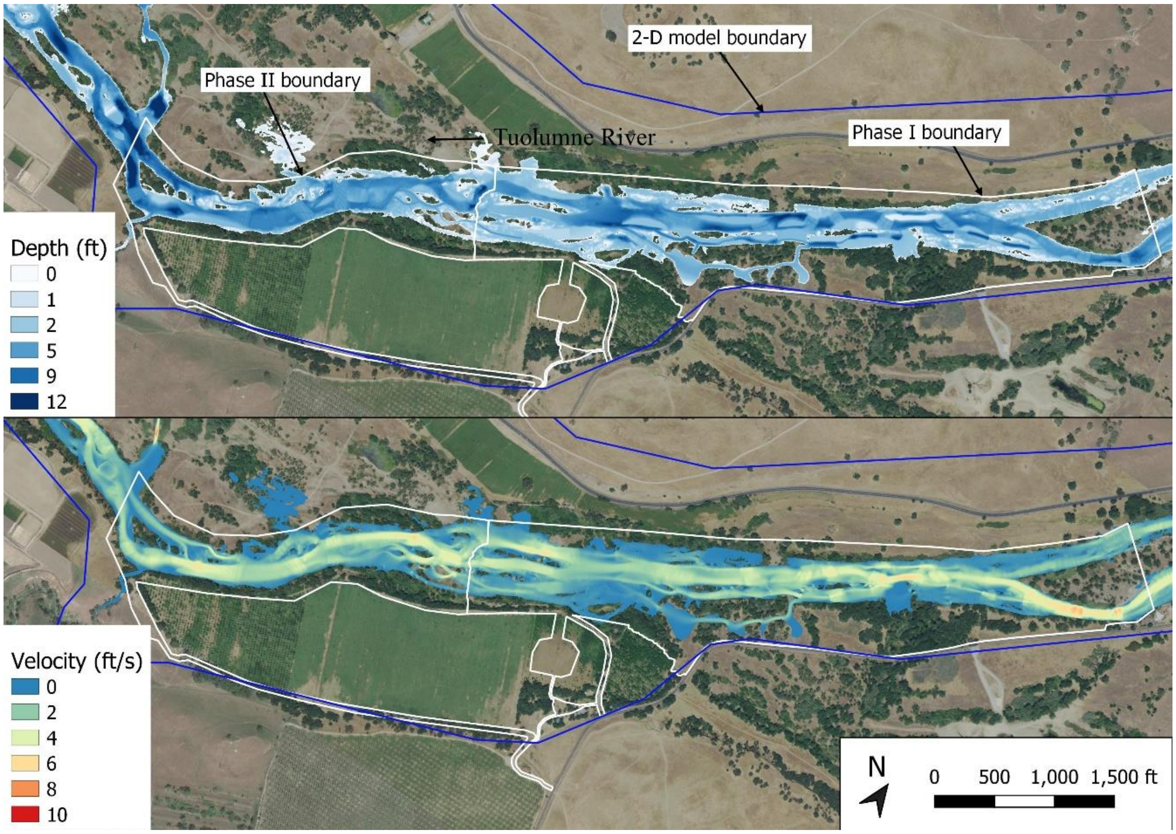

Figure 12. Hydraulic modeling depth and velocity results for 3,000 cfs, the low threshold for bed mobility and low magnitude pulse flow. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

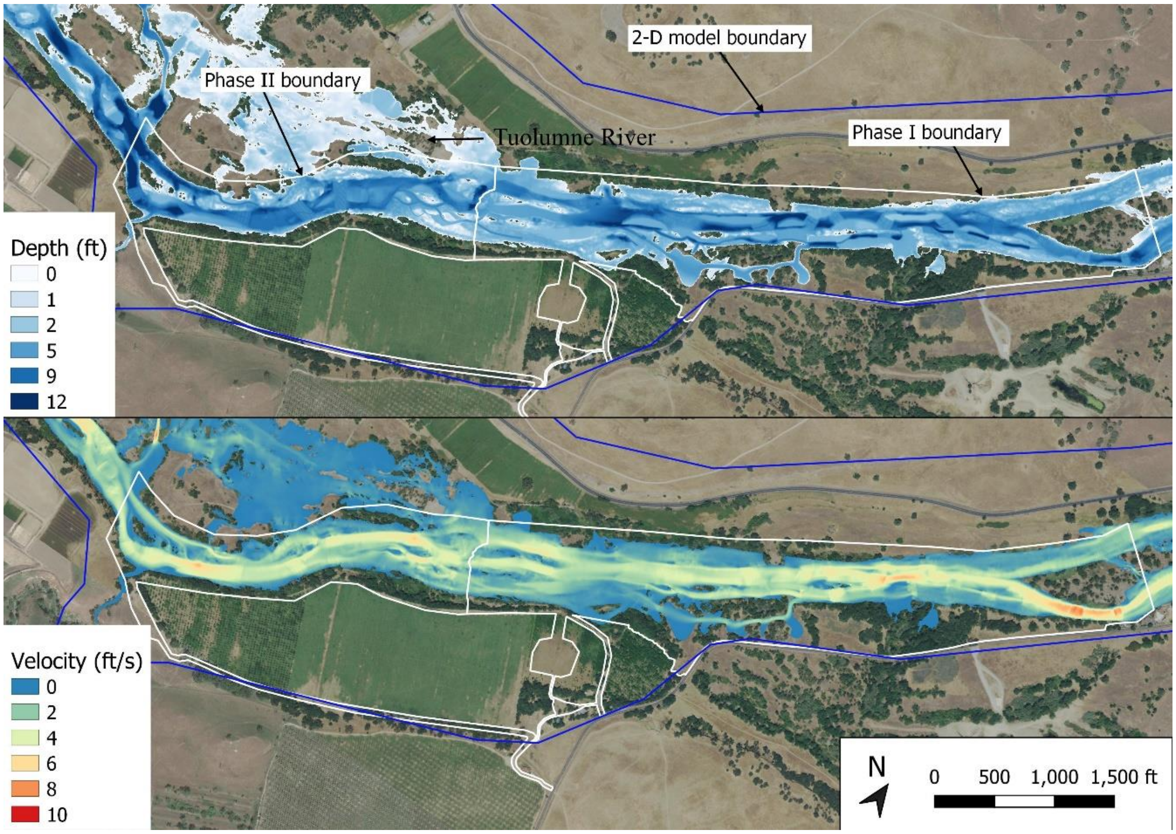

Figure 13. Hydraulic modeling depth and velocity results for 5,400 cfs, the approximate channel forming flow. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

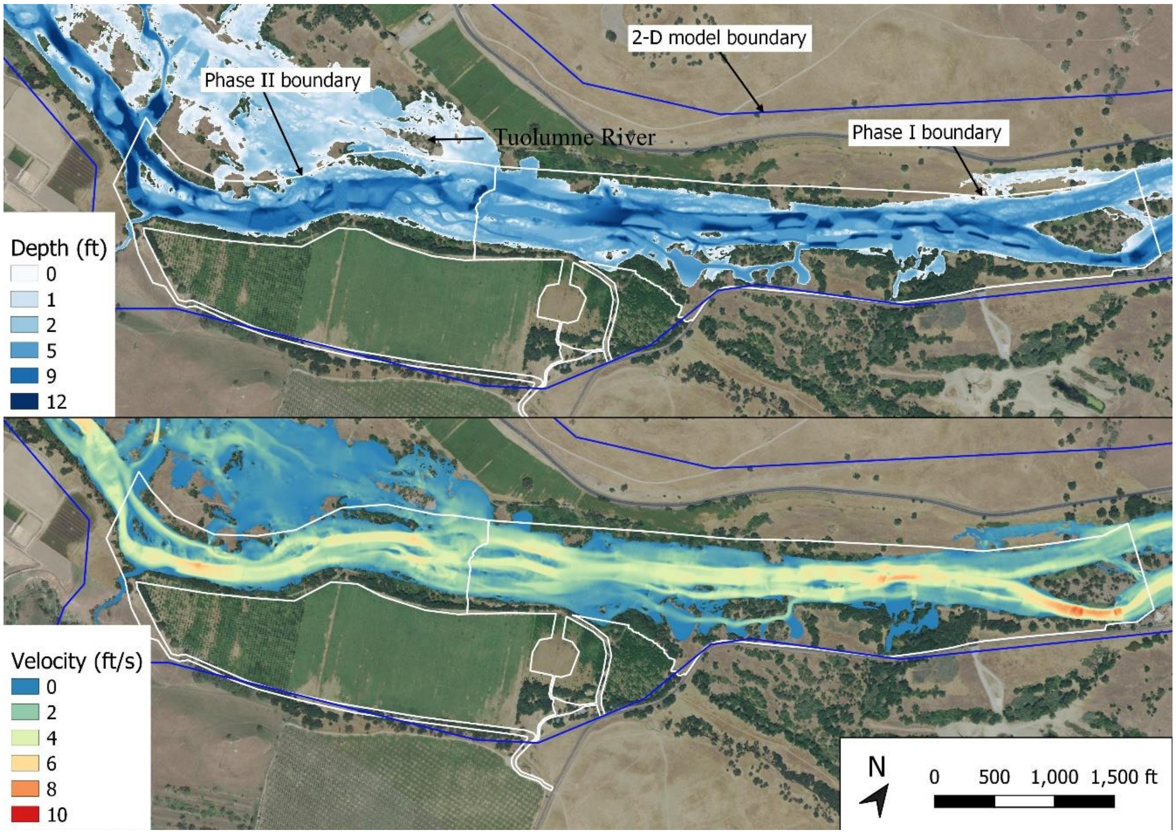

Figure 14. Hydraulic modeling depth and velocity results for 7,050 cfs, the flow defining waters of the US. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

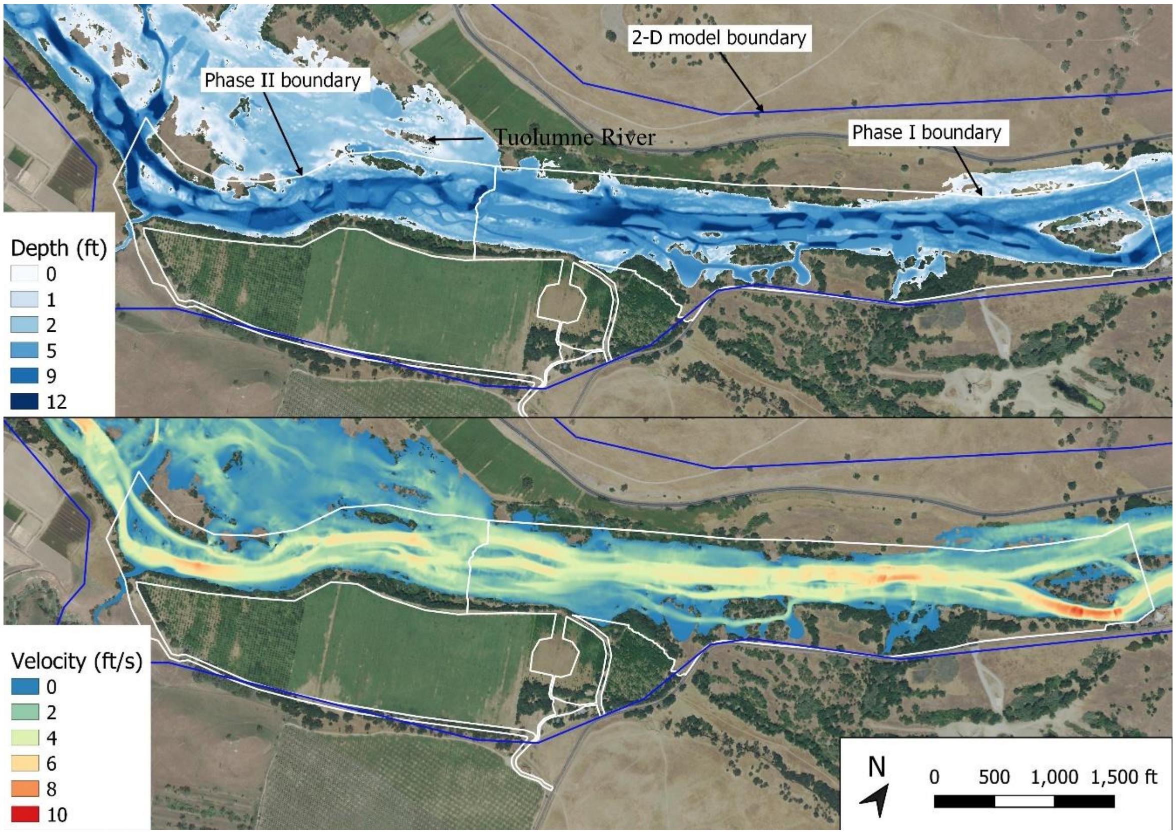

Figure 15. Hydraulic modeling depth and velocity results for 9,600 cfs, an index flow for habitat analyses. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

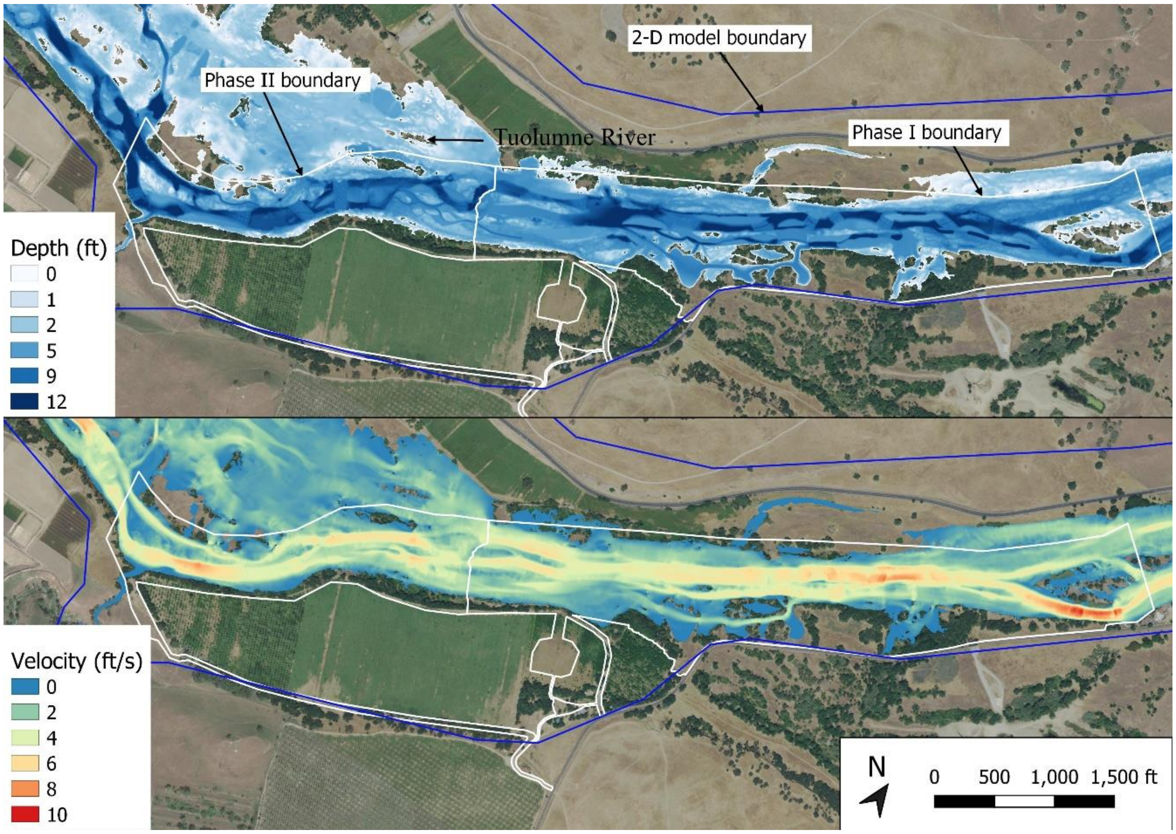

Figure 16. Hydraulic modeling depth and velocity results for 11,500 cfs, the 10-year recurrence interval peak flow. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

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Appendix B: Salmonid Habitat Suitability Evaluation

APPENDIX B. WUA ANALYSIS FOR ZANKER FARM PROJECT PHASE I AND PHASE II EXISTING CONDITIONS AND 100% DESIGN

Suitable habitat for the Zanker Farm Project, was compared between existing conditions and the 90% design to allow the designer and reviewer to gauge if restoration objectives (see main report) are being met. The analysis was not updated from the 90% design stage to the 100% design stage because no changes were made to design features and therefore the results of the habitat analysis will be the same. Existing conditions for Phase I and Phase II of the Project were combined to calculate WUA and compare to 90% design conditions WUA. WUA results are presented separately for each life history and species (Section 1 through Section 3). Habitat suitability used to calculate WUA is included to aid in interpreting results. Percent change in WUA was calculated to evaluate the predicted change from existing conditions to the 90% design (Section 4). While WUA was calculated for all modeled flows, WUA charts were truncated to 6,000 cfs to allow for better viewing of results at flows typically present during the time periods life stages are present. WUA results for all flows, including those above 6,000 cfs, are presented in WUA result tables below.

1 CHINOOK SALMON

1.1 Habitat Suitability

Table B-1. Data and habitat suitability index sources used for each Chinook Salmon life history stage.

Life Stage	Hydraulic (Depth and Velocity)	Cover	Substrate
Fry	USFWS (2010a)	USFWS (2010a)	N/A
Juvenile	USFWS (2010a)	USFWS (2010a)	N/A
Spawning	USFWS (2010a)	N/A	USFWS (2010b)

N/A = Not applicable.

Table B-2. Velocity HSI for Chinook Salmon from USFWS (2010a and 2010b).

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Velocity (ft/s)	**HSI**	**Velocity (ft/s)**	**HSI**	**Velocity (ft/s)**	**HSI**
0	1	0	1	0	0
0.1	0.99	0.1	1	0.22	0
0.2	0.95	0.2	0.99	0.23	0.09
0.3	0.89	0.3	0.98	0.3	0.13
0.4	0.81	0.4	0.97	0.4	0.21
0.6	0.65	0.5	0.96	0.5	0.3
0.7	0.56	0.6	0.94	0.8	0.63
0.8	0.49	0.7	0.92	1	0.81
0.9	0.42	0.8	0.89	1.1	0.87
1.1	0.3	0.9	0.87	1.2	0.92
1.3	0.22	1	0.84	1.3	0.96
1.4	0.19	1.1	0.81	1.5	1
1.7	0.13	1.2	0.78	1.7	1
2	0.1	1.3	0.74	1.8	0.99
2.1	0.1	1.4	0.71	1.9	0.97

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Velocity (ft/s)	HSI	Velocity (ft/s)	HSI	Velocity (ft/s)	HSI
2.2	0.09	1.5	0.67	2	0.96
2.7	0.09	1.6	0.63	2.6	0.84
2.8	0.1	1.7	0.6	2.7	0.83
2.9	0.1	1.8	0.56	2.8	0.81
3	0.11	1.9	0.52	3.1	0.78
3.1	0.11	2	0.48	3.2	0.78
3.2	0.12	2.1	0.45	3.3	0.77
3.4	0.12	2.2	0.41	3.4	0.77
3.5	0.13	2.3	0.38	3.5	0.76
3.62	0.13	2.4	0.34	3.6	0.76
3.63	0	2.5	0.31	3.8	0.74
100	0	2.55	0.3	3.9	0.72
		3.98	0.3	4	0.71
		3.99	0	4.2	0.65
		100	0	4.3	0.61
				4.4	0.56
				4.5	0.51
				4.6	0.45
				4.7	0.38
				4.8	0.31
				4.9	0.24
				5.1	0.12
				5.2	0.08
				5.3	0.05
				5.31	0.05
				5.32	0
				100	0

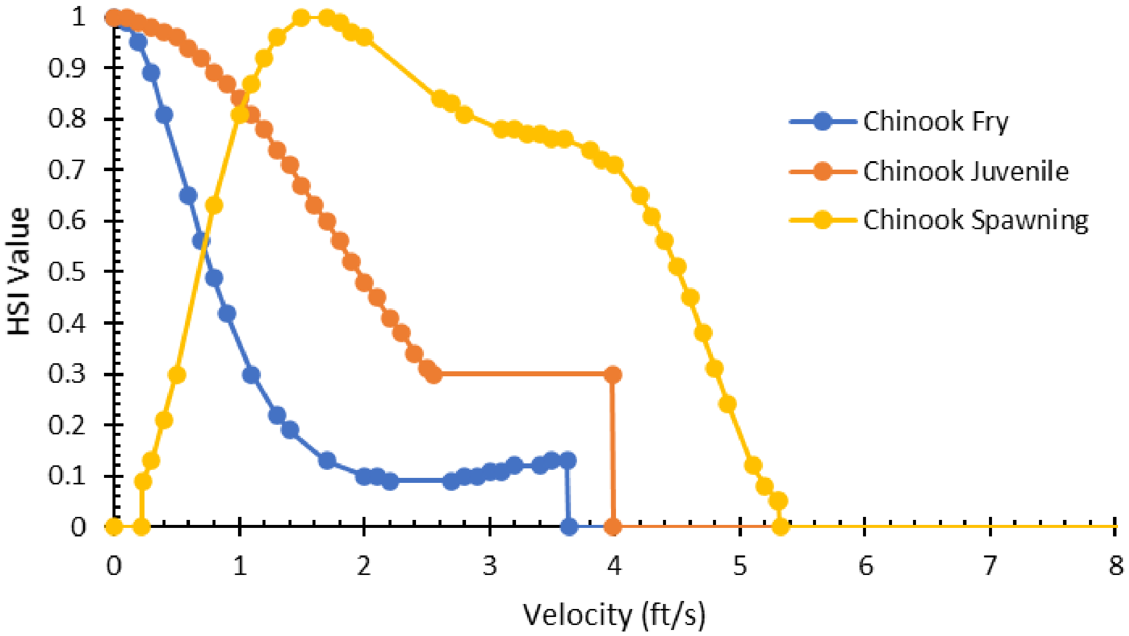


Figure B-1. Velocity HSI curves for Chinook Salmon from USFWS (2010a and 2010b).

Table B-3. Depth HSI for Chinook Salmon from USFWS (2010a and 2010b).

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Depth (ft)	**HSI**	**Depth (ft)**	**HSI**	**Depth (ft)**	**HSI**
0	0	0	0	0	0
0.1	0	0.7	0	0.1	0
0.2	0.8	0.8	0.03	0.2	0.09
0.3	0.84	1	0.05	0.3	0.15
0.5	0.9	1.2	0.09	0.4	0.24
0.6	0.92	1.4	0.15	0.5	0.34
0.7	0.95	1.6	0.23	0.6	0.46
0.8	0.96	1.9	0.38	0.7	0.58
0.9	0.98	2.4	0.68	0.8	0.7
1.1	1	2.5	0.73	0.9	0.79
1.4	1	2.6	0.79	1	0.87
1.7	0.97	2.9	0.91	1.1	0.93
2.2	0.87	3.1	0.97	1.2	0.97
2.5	0.78	3.4	1	1.3	0.99
2.6	0.76	3.5	1	1.4	1
2.7	0.73	3.8	0.97	4.8	0.02
2.8	0.69	4	0.93	7.8	0.02
3.5	0.48	4.1	0.9	7.9	0

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Depth (ft)	**HSI**	**Depth (ft)**	**HSI**	**Depth (ft)**	**HSI**
3.6	0.46	4.2	0.88	100	0
3.8	0.4	4.4	0.82		
3.9	0.38	4.5	0.78		
4	0.35	5.4	0.51		
4.6	0.23	5.5	0.49		
4.7	0.22	5.6	0.46		
4.8	0.2	6.2	0.34		
4.9	0.19	6.3	0.33		
5	0.17	6.4	0.31		
5.7	0.1	7	0.25		
5.8	0.1	7.1	0.25		
6	0.08	7.2	0.24		
6.1	0.08	7.3	0.23		
6.2	0.07	7.5	0.23		
6.3	0.07	7.6	0.22		
6.4	0.06	11.8	0.22		
6.5	0.06	11.9	0		
6.6	0.05	100	0		
6.9	0.05				
7	0.04				
7.3	0.04				
7.4	0.03				
8	0.03				
8.1	0.02				
18.4	0.02				
18.5	0				
100	0				

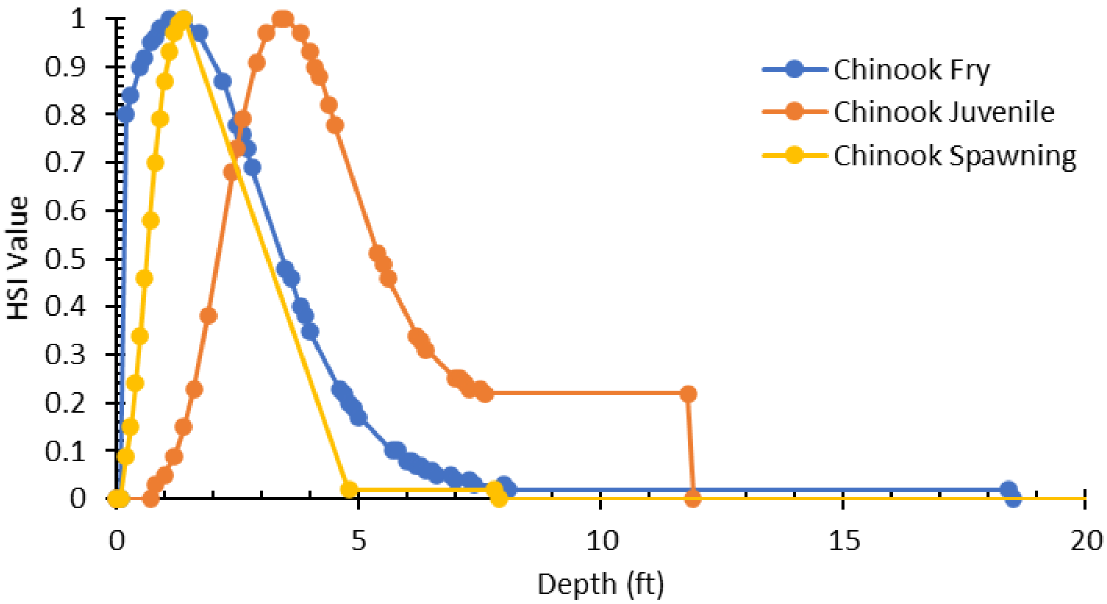


Figure B-2. Depth HSI curves for Chinook Salmon from USFWS (2010a and 2010b).

Table B-4. Cover and substrate codes from USFWS (2010a, b) and their corresponding descriptions.

Cover		Substrate	
Code	**Description**	**Code**	**Description**
0	No cover	0.1	Sand or silt/sand (< 0.1 inches)
1	Cobble	1	Small gravel (0.1–1 inches)
2	Boulder	1.2	Medium gravel (1–2 inches)
3	Fine woody vegetation (< 1 inch diameter)	1.3	Medium/large gravel (1–3 inches)
3.7	Fine woody vegetation + overhead	2.3	Large gravel (2–3 inches)
4	Branches	2.4	Gravel/cobble (2–4 inches)
4.7	Branches + overhead	3.4	Small cobble (3–4 inches)
5	Log (> 1 inch diameter)	3.5	Small cobble (3–5 inches)
5.7	Log + overhead	4.6	Medium cobble (4–6 inches)
7	Overhead cover (> 2 ft above substrate)	6.8	Large cobble (6–8 inches)
8	Undercut bank	8	Large cobble (8–10 inches)
9	Aquatic vegetation	9	Boulder/ bedrock (> 12 inches)
9.7	Aquatic vegetation + overhead	10	Large cobble (10–12 inches)
10	Rip-rap		

Table B-5. Cover HSI for Chinook Salmon fry and juveniles (USFWS 2010a) and substrate HSI for Chinook Salmon spawning (USFWS 2010b).

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Cover Code	**HSI**	**Cover Code**	**HSI**	**Substrate Code**	**HSI**
0	0.1	0	0.24	0.1	0
1	0.25	1	0.24	1	0
2	0.1	2	0.24	1.2	0.05
3	0.54	3	0.24	1.3	0.58
3.7	1	3.7	1	2.4	1
4	1	4	1	3.5	0.65
4.7	1	4.7	1	4.6	0.29
5	1	5	1	6.8	0.01
5.7	1	5.7	1	8	0
7	0.25	7	0.24		
8	1	8	1		
9	0.25	9	0.24		
9.7	0.1	9.7	0.24		
10	0.54	10	0.24		

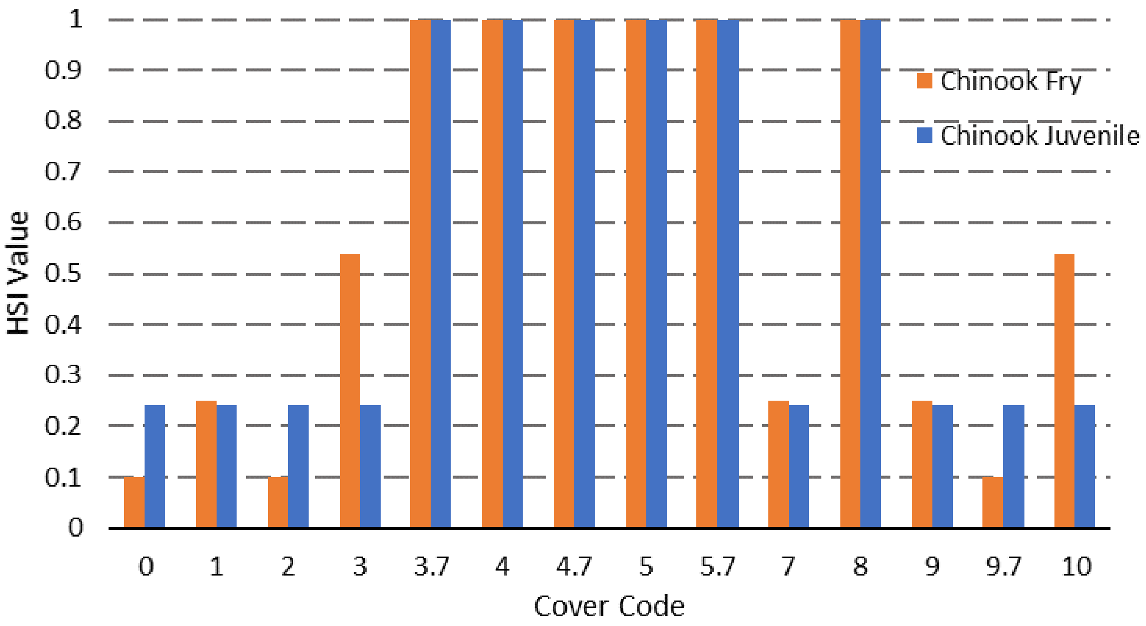


Figure B-3. Cover HSI for Chinook Salmon fry and juveniles from USFWS (2010a and 2010b).

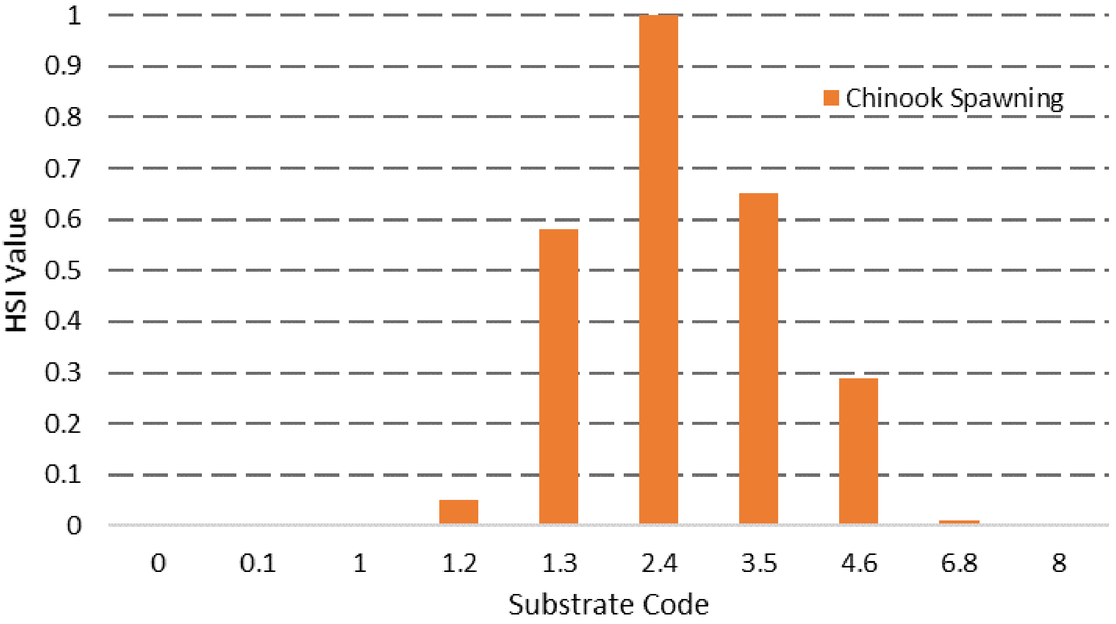


Figure B-4. Substrate HSI for Chinook Salmon spawning from USFWS (2010a and 2010b).

1.2 Existing Conditions

Table B-6. Existing conditions WUA for Chinook Salmon (using depth, velocity, and substrate HSI), fry and juvenile rearing (using depth, velocity, and cover HSI).

Modeled Flow (cfs)	**Chinook Salmon Spawning**	**Chinook Salmon Fry Rearing**	**Chinook Salmon Juvenile Rearing**
	WUA (Acres)		
80	1.10	5.01	4.24
150	1.58	4.79	4.88
300	1.94	4.91	5.75
500	1.98	4.94	6.04
633	1.92	4.99	6.07
750	1.87	5.12	6.02
800	1.84	5.24	6.02
1,000	1.79	6.25	6.08
1,130	1.78	7.04	6.01
1,580	1.83	10.19	6.10
3,000	2.40	14.59	9.85
5,400	2.91	14.21	16.63
7,050	2.67	13.05	18.27
9,600	1.79	12.06	18.58
11,500	1.28	12.46	18.48

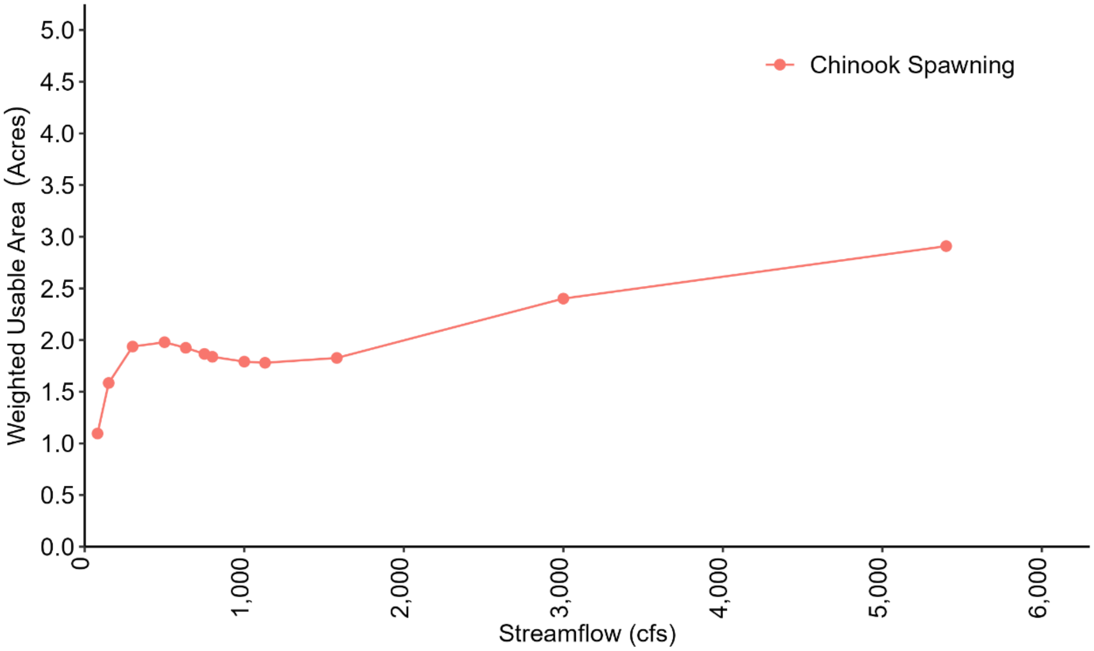


Figure B-5. Existing conditions WUA (using depth, velocity, and substrate HSI) for Chinook Salmon spawning.

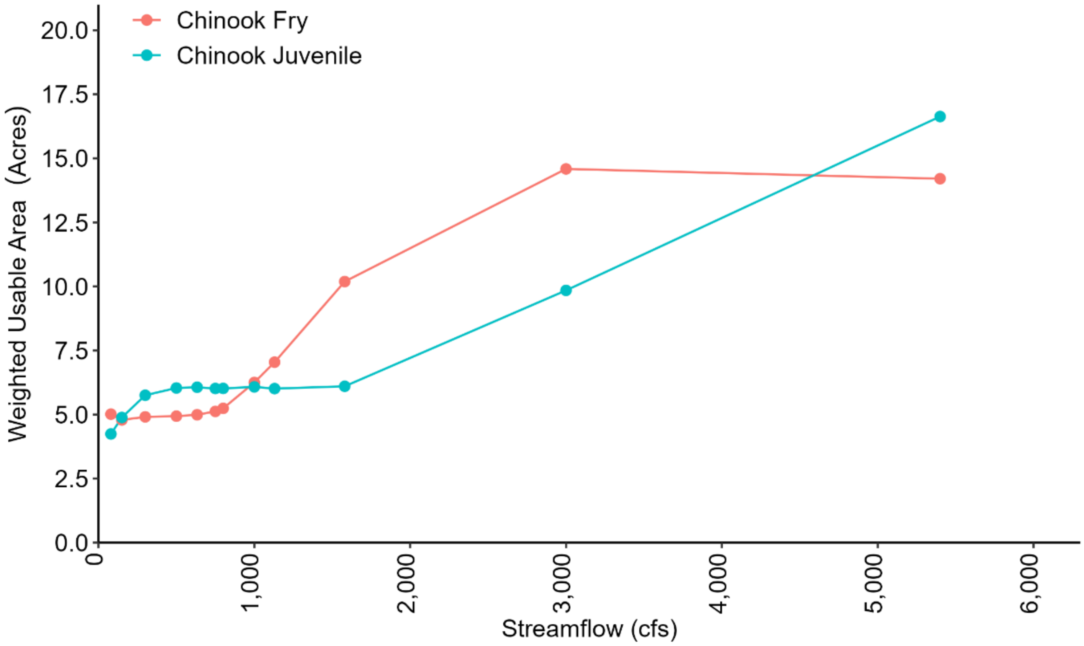


Figure B-6. Existing conditions WUA (using depth, velocity, and cover HSI) for Chinook Salmon fry and juvenile rearing.

1.3 90% Design

Table B-7. 90% design WUA for Chinook Salmon (using depth, velocity, and substrate HSI), fry and juvenile rearing (using depth, velocity, and cover HSI).

Modeled Flow (cfs)	Chinook Salmon Spawning	Chinook Salmon Fry Rearing	Chinook Salmon Juvenile Rearing
	WUA (Acres)		
80	1.29	5.79	4.72
150	2.37	5.77	5.15
300	3.56	7.16	5.69
500	4.02	7.84	6.09
633	4.07	9.08	6.45
750	4.13	10.16	6.63
800	4.18	10.67	6.73
1,000	4.45	12.20	7.10
1,130	4.61	13.06	7.37
1,580	4.93	14.92	8.62
3,000	4.26	15.13	14.10
5,400	2.75	13.28	18.92
7,050	2.03	12.37	19.06
9,600	1.22	11.05	17.84
11,500	0.87	11.98	17.62

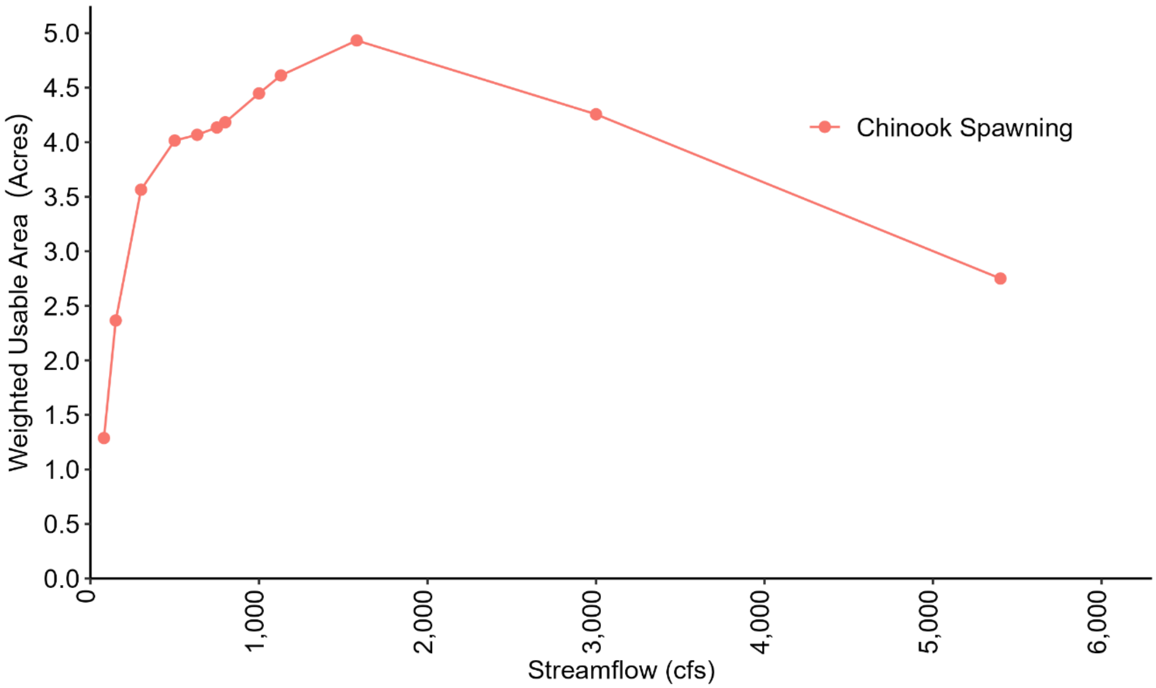


Figure B-7. 90% design WUA (using depth, velocity, and substrate HSI) for Chinook Salmon spawning.

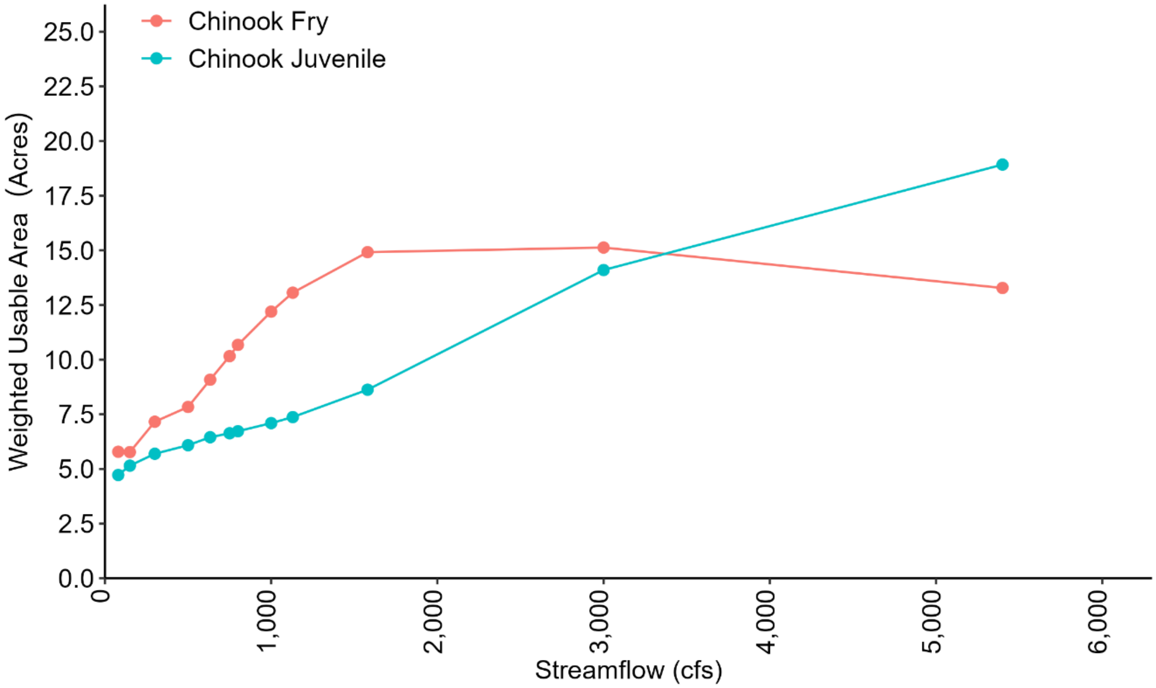


Figure B-8. 90% design WUA (using depth, velocity, and cover HSI) for Chinook Salmon fry and juvenile rearing.

2 ***O. MYKISS***

2.1 Habitat Suitability

Table B-8. Data and habitat suitability index sources used for O. mykiss *life history stages.*

Life Stage	Hydraulic (Depth and Velocity)	Cover	Substrate
Fry	USFWS (2010a)	USFWS (2010a)	N/A
Juvenile	USFWS (2010a)	USFWS (2010a)	N/A
Adult	Stillwater (2013)	USFWS*(2010a)	N/A
Spawning	USFWS (2010b)	N/A	USFWS (2010b)

* No cover criteria were included in the Adult spawning HSI. Therefore, the juvenile cover HSI from USFWS (2010a) were used when evaluating adult *O. mykiss* WUA.

N/A = Not applicable.

Table B-9. Velocity HSI for O. mykiss *from USFWS (2010a and 2010b).*

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Velocity (ft/s)	**HSI**	**Velocity (ft/s)**	**HSI**	**Velocity (ft/s)**	**HSI**
0	1	0	1	0	0
0.1	1	0.1	1	0.08	0
0.2	0.99	0.2	0.99	0.09	0.02
0.3	0.98	0.3	0.98	0.2	0.02
0.4	0.97	0.4	0.97	0.3	0.03
0.5	0.96	0.5	0.96	0.4	0.05
0.6	0.94	0.6	0.94	0.5	0.07
0.7	0.92	0.7	0.92	0.6	0.09
0.8	0.89	0.8	0.89	0.7	0.12
0.9	0.87	0.9	0.87	0.8	0.15
1	0.84	1	0.84	0.9	0.2
1.1	0.81	1.1	0.81	1	0.24
1.2	0.78	1.2	0.78	1.1	0.3
1.3	0.74	1.3	0.74	1.2	0.35
1.4	0.71	1.4	0.71	1.3	0.41
1.5	0.67	1.5	0.67	1.4	0.48
1.6	0.63	1.6	0.63	1.5	0.54
1.7	0.6	1.7	0.6	1.6	0.6
1.8	0.56	1.8	0.56	1.7	0.67
1.9	0.52	1.9	0.52	1.8	0.72
2	0.48	2	0.48	1.9	0.78
2.1	0.45	2.1	0.45	2	0.83
2.2	0.41	2.2	0.41	2.1	0.87
2.3	0.38	2.3	0.38	2.2	0.91

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Velocity (ft/s)	**HSI**	**Velocity (ft/s)**	**HSI**	**Velocity (ft/s)**	**HSI**
2.4	0.34	2.4	0.34	2.4	0.96
2.5	0.31	2.5	0.31	2.6	1
2.6	0.28	2.55	0.3	2.9	1
2.7	0.25	3.98	0.3	3.3	0.94
2.8	0.23	3.99	0	3.4	0.91
2.9	0.2	100	0	3.5	0.88
3	0.18			3.8	0.79
3.1	0.16			4.1	0.68
3.2	0.14			4.2	0.65
3.3	0.12			4.3	0.61
3.4	0.11			4.4	0.58
3.5	0.09			4.6	0.51
3.6	0.08			5.1	0.38
3.66	0.07			5.2	0.36
3.67	0			5.3	0.34
100	0			6.1	0.27
				6.2	0.26
				6.3	0.27
				6.8	0.3
				6.9	0.32
				6.92	0.33
				6.93	0
				100	0

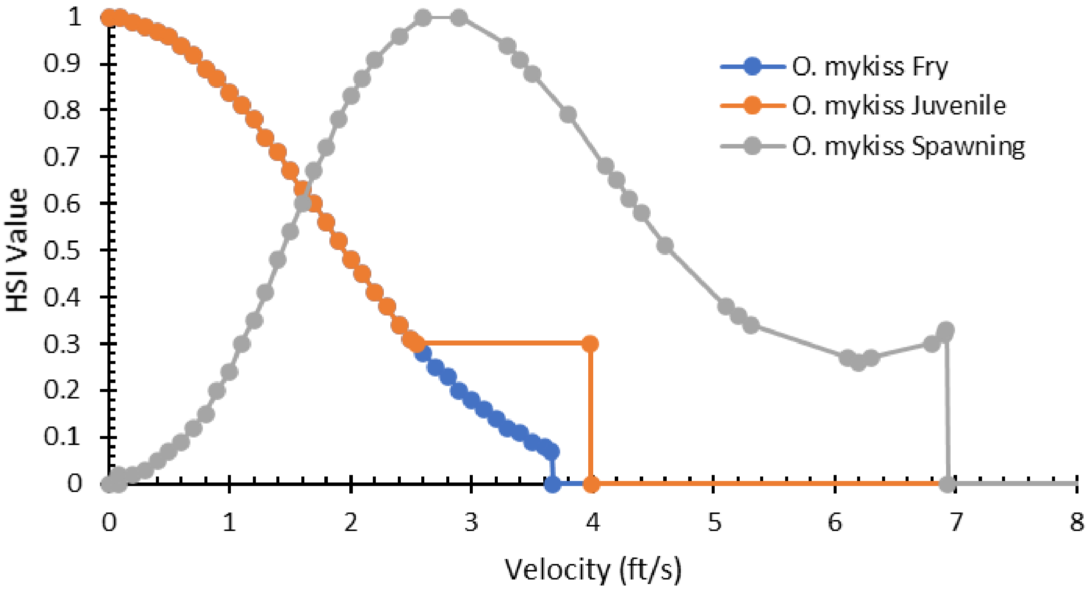


Figure B-9. Velocity HSI curves for O. mykiss *from USFWS (2010a and 2010b).*

Table B-10. Depth HSI for O. mykiss *from USFWS (2010a and 2010b).*

Fry (USFWS 2010a)		**Juvenile (USFWS 2010a)**		**Spawning (USFWS 2010b)**	
Depth (ft)	**HSI**	**Depth (ft)**	**HSI**	**Depth (ft)**	**HSI**
0	0	0	0	0	0
0.1	0	0.4	0	0.3	0
0.2	0.47	0.5	0.45	0.4	0.01
0.4	0.57	1.6	0.9	0.5	0.01
0.5	0.63	2	0.98	0.6	0.01
0.6	0.67	2.2	1	0.7	0.01
0.7	0.72	2.5	1	0.8	0.02
0.8	0.77	3	0.94	0.9	0.02
1	0.85	3.5	0.84	1	0.03
1.1	0.88	5.5	0.32	1.1	0.04
1.2	0.91	6.5	0.17	1.2	0.06
1.3	0.94	8	0.07	1.3	0.08
1.5	0.98	9.5	0.04	1.4	0.1
1.7	1	10.5	0.03	1.5	0.14
1.9	1	13.5	0.03	1.6	0.18
2.2	0.97	15	0.04	1.7	0.23
2.4	0.93	15.1	0	1.8	0.29
2.5	0.9	100	0	1.9	0.36
2.9	0.78			2	0.43
3	0.75			2.1	0.51
3.1	0.71			2.2	0.58
3.2	0.67			2.3	0.64
3.3	0.64			2.4	0.7
3.4	0.6			2.5	0.74

Fry (USFWS 2010a)		Juvenile (USFWS 2010a)		Spawning (USFWS 2010b)	
Depth (ft)	**HSI**	**Depth (ft)**	**HSI**	**Depth (ft)**	**HSI**
3.5	0.57			2.6	0.78
3.6	0.53			2.7	0.82
3.7	0.5			2.8	0.84
3.8	0.46			2.9	0.86
4.2	0.34			3	0.88
4.3	0.32			3.1	0.89
4.4	0.29			3.2	0.9
4.5	0.27			3.3	0.91
4.6	0.24			3.4	0.92
4.8	0.2			3.5	0.92
4.9	0.19			3.6	0.92
5	0.17			3.7	0.92
5.1	0.16			3.8	0.92
5.2	0.14			6.5	0.94
5.9	0.07			6.6	0.96
6	0.07			6.7	0.97
6.1	0.06			6.8	0.98
6.2	0.06			6.9	0.99
6.3	0.05			7	1
6.4	0			19.9	1
100	0			100	0

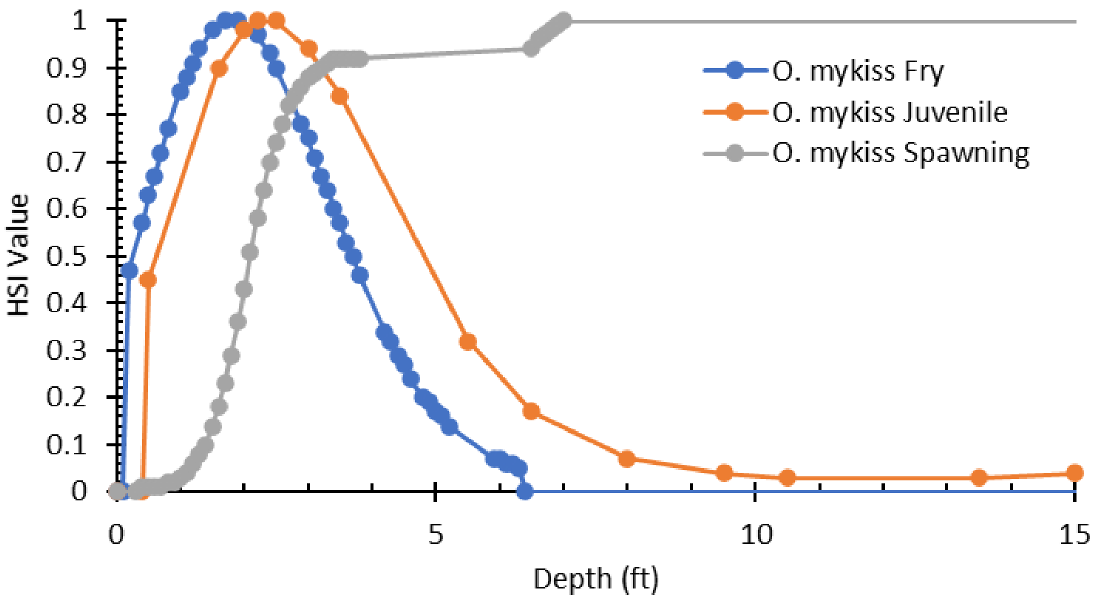


Figure B-10. Depth HSI curves for O. mykiss *from USFWS (2010a and 2010b).*

Table B-11. Cover HSI for O. mykiss *fry, juveniles and adults (USFWS 2010a), and substrate HSI for O. mykiss spawning (USFWS 2010b).*

Fry (USFWS 2010a)		Juvenile and Adult (USFWS 2010a)		Spawning (USFWS 2010b)	
Cover Code	**HSI**	**Cover Code**	**HSI**	**Substrate Code**	**HSI**
0	0.12	0	0.24	0	0
1	0.57	1	0.24	0.1	0
2	0.28	2	0.24	1	0.13
3	0.28	3	0.24	1.2	1
3.7	1	3.7	1	1.3	0.85
4	0.57	4	1	2.4	0.28
4.7	1	4.7	1	3.5	0.16
5	1	5	1	4.6	0.05
5.7	1	5.7	1	6.8	0
7	0.28	7	0.24		
8	1	8	1		
9	0.12	9	0.24		
9.7	0.12	9.7	0.24		
10	1	10	0.24		

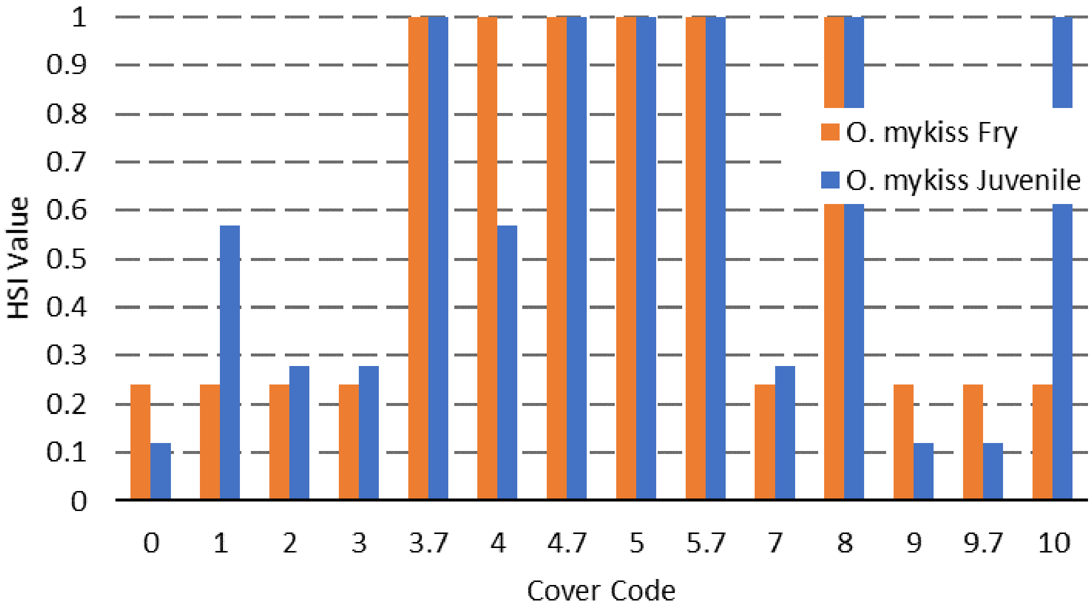


Figure B-11. Cover HSI for O. mykiss *fry and juveniles from USFWS (2010a and 2010b).*

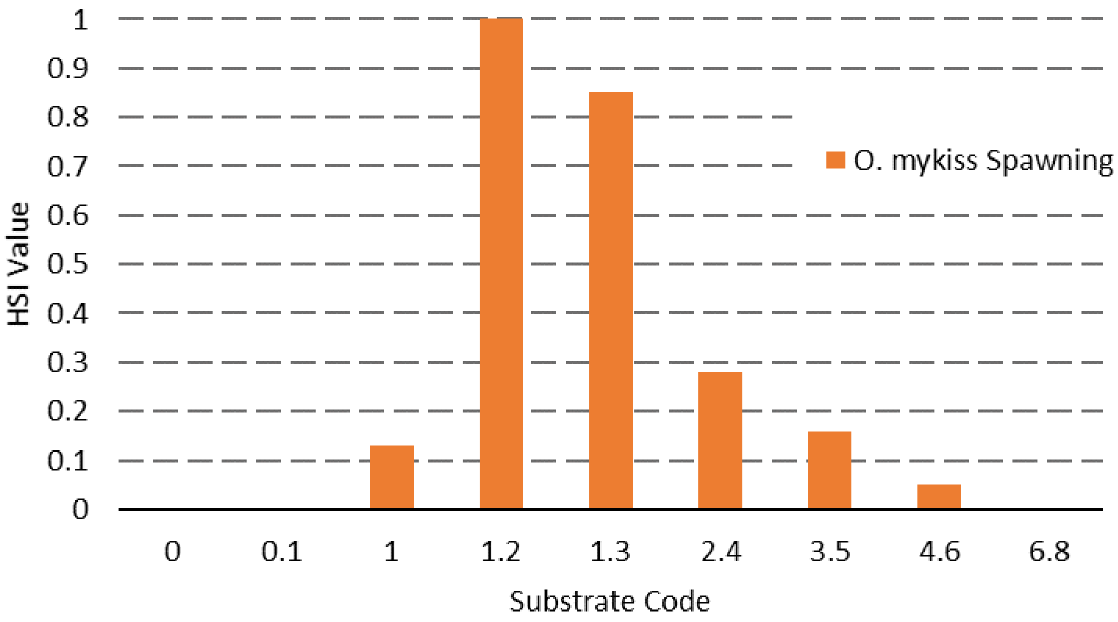


Figure B-12. Substrate HSI for O. Mykiss *spawning from USFWS (2010a and 2010b).*

Table B-12. Velocity and depth HSI for adult O. mykiss from Stillwater Sciences (2013).

Adult (Stillwater 2013)			
Velocity (ft/sec)	**HSI**	**Depth (ft)**	**HSI**
0.03	0	0.8	0
0.04	0.19	0.9	0.12
0.1	0.23	1	0.15
0.2	0.3	1.25	0.23
0.3	0.38	1.5	0.34
0.4	0.48	1.75	0.45
0.5	0.57	2	0.57
0.6	0.67	2.25	0.69
0.7	0.77	2.5	0.79
0.8	0.85	2.75	0.87
0.9	0.92	3	0.93
1	0.97	3.25	0.97
1.1	1	3.5	1
1.2	1	3.75	1
1.3	0.98	4	0.99
1.4	0.94	15.5	0.87
1.5	0.88	15.75	0.87
1.6	0.81	16	0.85
1.7	0.74	16.25	0.82
1.8	0.65	16.5	0.77

Adult (Stillwater 2013)			
Velocity (ft/sec)	**HSI**	**Depth (ft)**	**HSI**
1.9	0.57	16.75	0.7
2	0.49	17	0.61
2.09	0.42	17.25	0.51
2.15	0.41	17.5	0.41
4.25	0	17.75	0.31
100	0	18	0.22
		18.25	0.14
		18.5	0.09
		18.75	0.05
		19	0.02
		19.5	0
		100	0

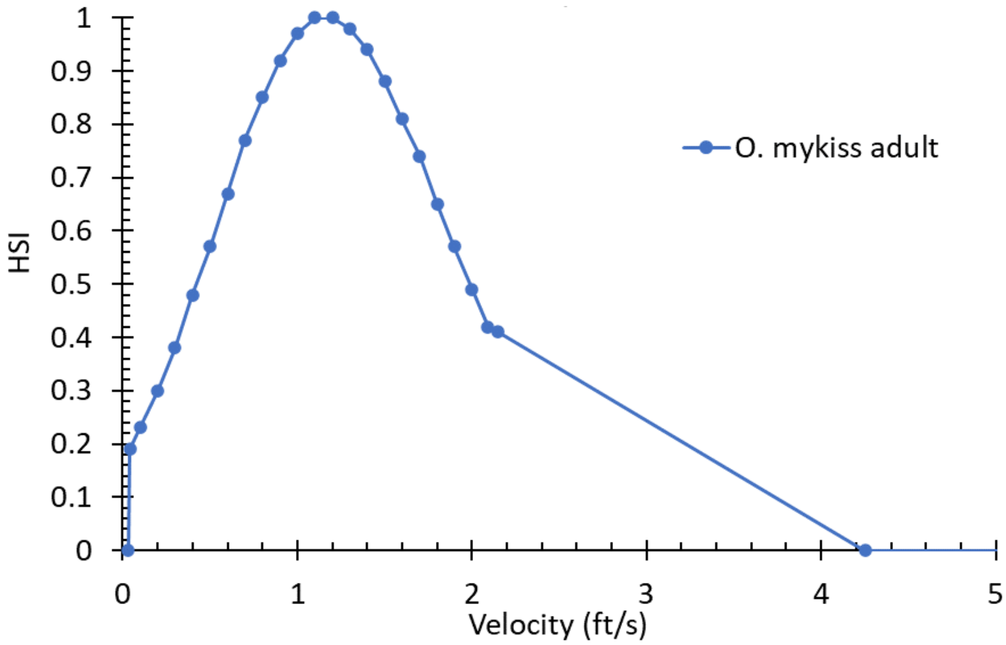


Figure B-13. Velocity HSI curves for adult O. mykiss *from Stillwater Sciences (2013).*

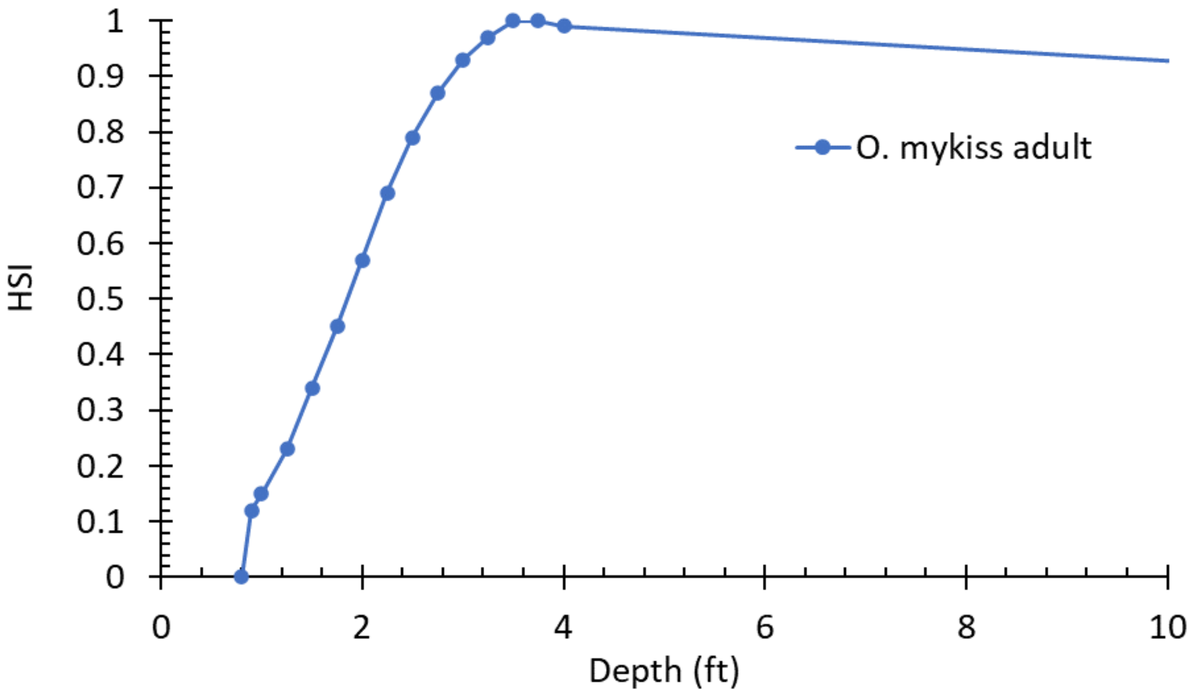


Figure B-14. Depth HSI curves for adult O. mykiss *from Stillwater Sciences (2013).*

2.2 Existing Conditions

Table B-13. Existing conditions WUA for O. mykiss *spawning (using depth, velocity, and substrate HSI), adult habitat, and fry and juvenile rearing (using depth, velocity, and cover HSI).*

Modeled Flow (cfs)	***O. mykiss* Spawning**	***O. mykiss* Fry Rearing**	***O. mykiss* Juvenile Rearing**	***O. mykiss* Adult Habitat**
	WUA (Acres)			
80	0.05	6.43	6.68	1.56
150	0.17	6.61	7.08	2.48
300	0.58	6.62	7.31	3.97
500	1.23	6.48	7.28	5.14
633	1.61	6.45	7.24	5.66
750	1.91	6.52	7.21	5.98
800	2.01	6.63	7.24	6.15
1,000	2.38	7.55	7.68	6.47
1,130	2.57	8.25	7.99	6.64
1,580	3.04	11.25	9.92	7.08
3,000	3.74	18.45	16.84	10.60
5,400	4.46	21.47	22.13	17.88
7,050	4.73	20.50	22.60	21.24
9,600	5.05	18.80	22.06	24.03
11,500	5.16	18.60	22.01	25.07

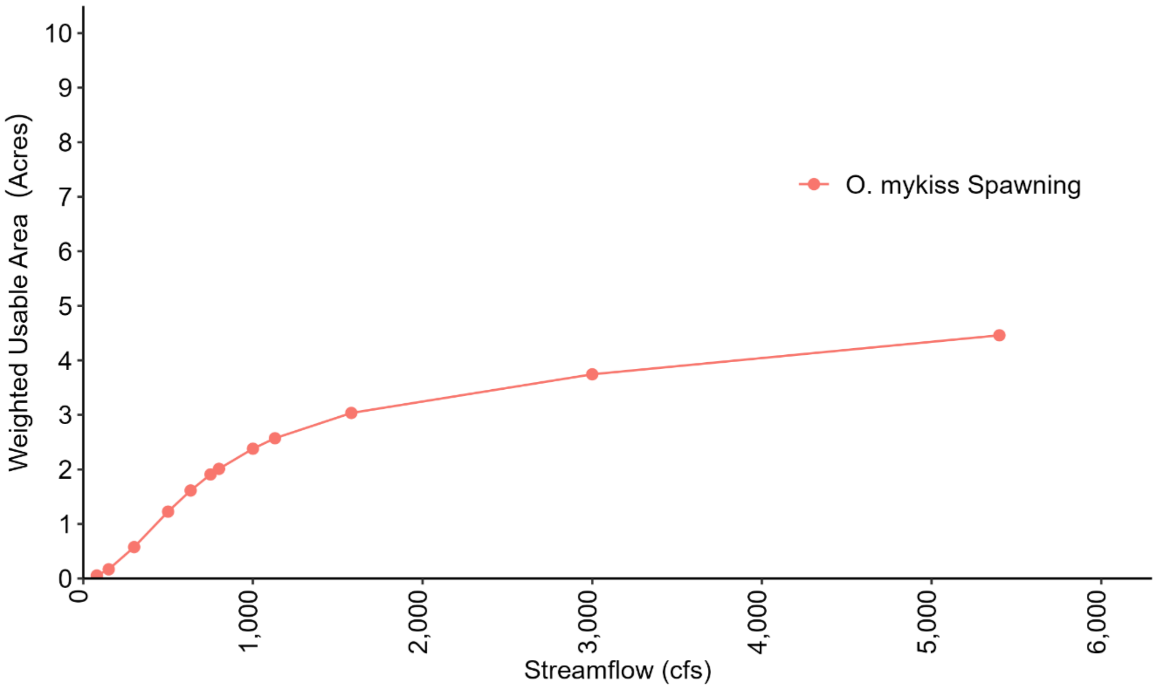


Figure B-15. Existing conditions WUA (using depth, velocity, and substrate HSI) for O. mykiss *spawning.*

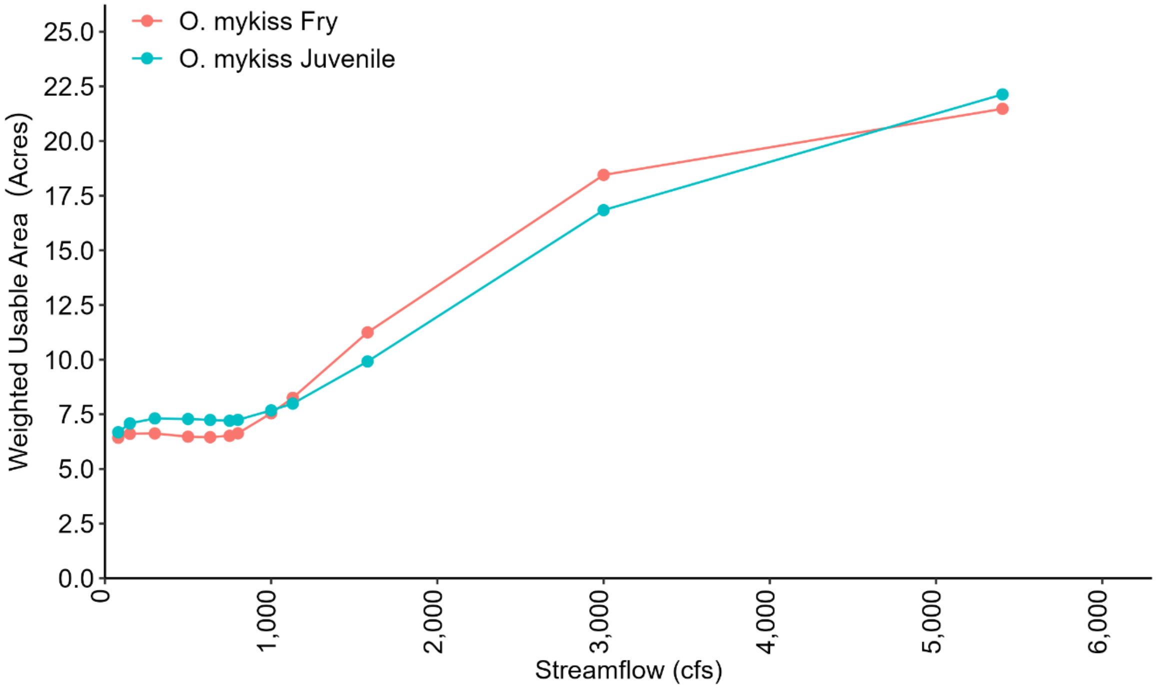


Figure B-16. Existing conditions WUA (using depth, velocity, and cover HSI) for O. mykiss *fry and juvenile rearing.*

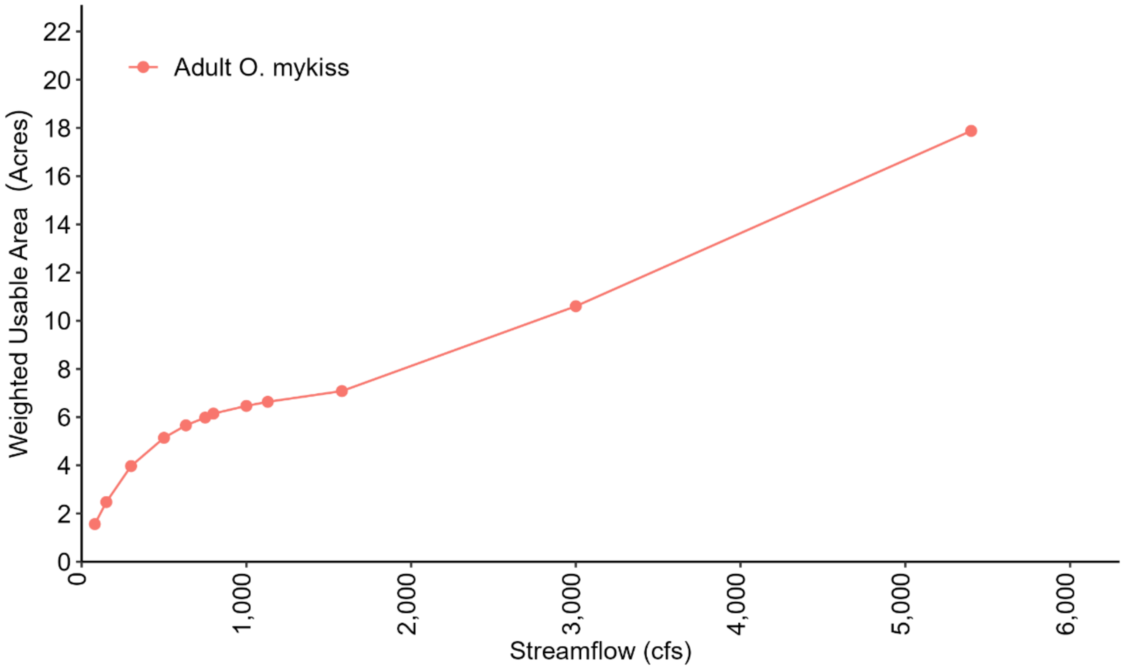


Figure B-17. Existing conditions WUA (using depth, velocity, and cover HSI) for O. mykiss *adults.*

2.3 90% Design

Table B-14. 90% design WUA for O. mykiss *spawning (using depth, velocity, and substrate HSI), adult habitat, and fry and juvenile rearing (using depth, velocity, and cover HSI).*

Modeled Flow (cfs)	***O. mykiss* Spawning**	***O. mykiss* Fry Rearing**	***O. mykiss* Juvenile Rearing**	***O. mykiss* Adult Habitat**
	WUA (Acres)			
80	0.15	7.26	7.18	1.77
150	0.39	7.45	7.46	2.72
300	1.17	8.48	8.11	4.20
500	2.41	9.49	9.01	5.47
633	3.18	10.82	9.87	6.19
750	3.79	12.02	10.72	6.77
800	4.03	12.57	11.10	6.99
1,000	4.88	14.40	12.52	7.87
1,130	5.33	15.49	13.37	8.39
1,580	6.56	18.63	16.38	10.18
3,000	8.82	21.85	21.60	15.23
5,400	9.49	20.91	23.18	21.39
7,050	9.16	19.55	22.70	23.49
9,600	8.49	17.67	21.27	24.95
11,500	8.08	18.02	21.38	25.52

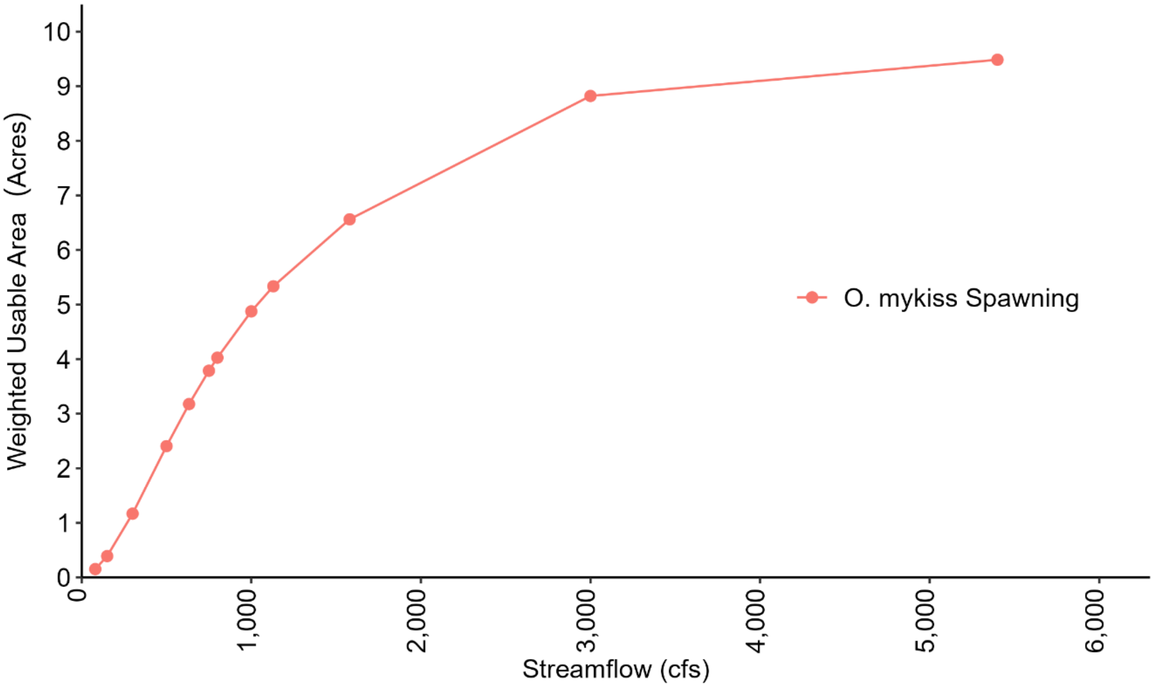


Figure B-18. 90% design WUA (using depth, velocity, and substrate HSI) for O. mykiss *spawning.*

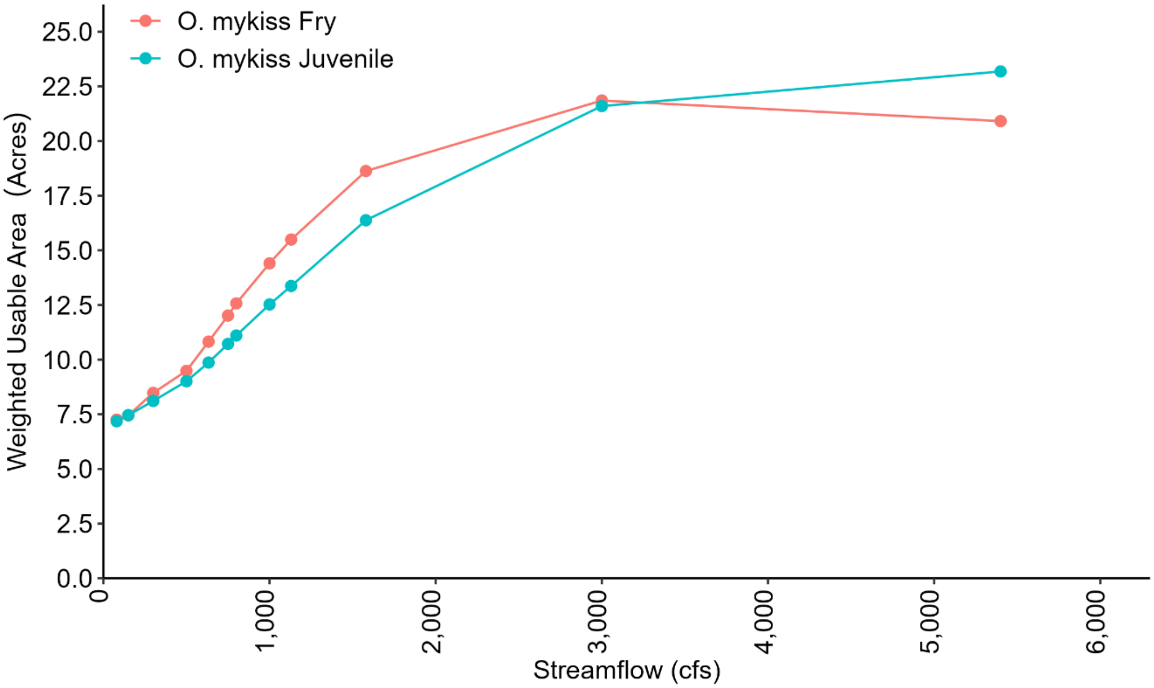


Figure B-19. 90% design WUA (using depth, velocity, and cover HSI) for O. mykiss *fry and juvenile rearing.*

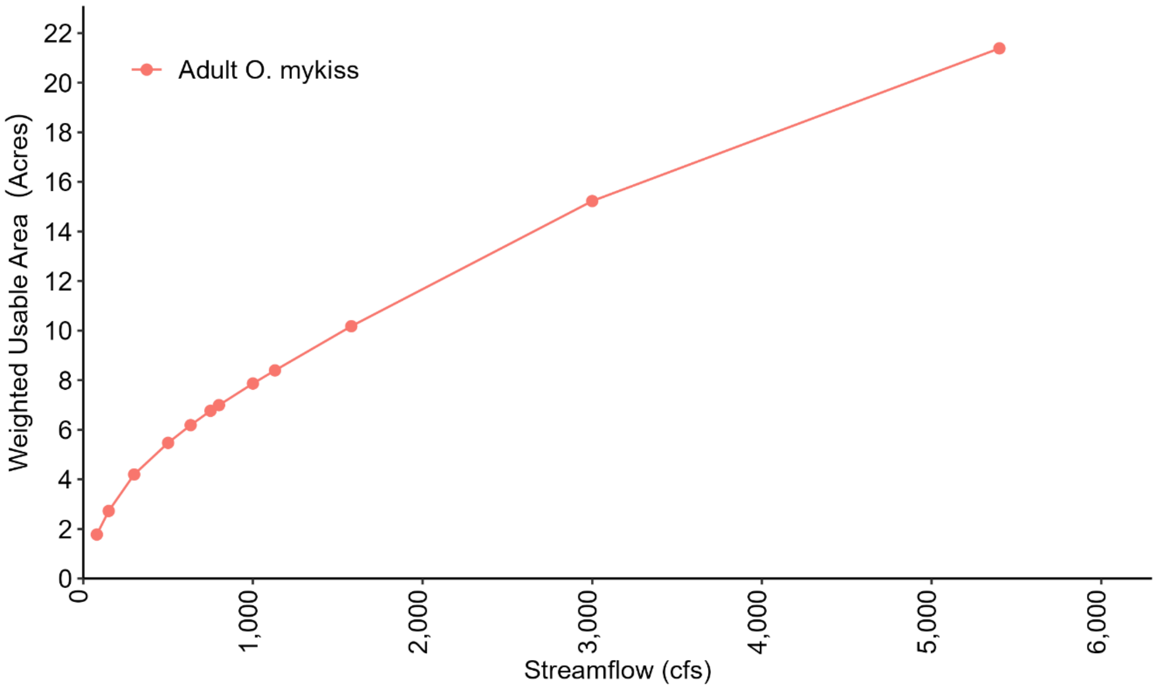


Figure B-20. Adult O. mykiss 90% design WUA.

3 BENTHIC MACROINVERTEBRATES

3.1 Habitat Suitability

Table 1. Data and habitat suitability index sources used for each BMI metric: Baitidae, Chironomidae, Hydropsychidae *(BCH) Biomass and Shannon-Weaver Diversity Index (Diversity).*

Table B-15.

BMI Metric	Hydraulic (Depth and Velocity)	Substrate
BCH Biomass	USFWS (2006)	USFWS (2006)
Diversity	USFWS (2006)	USFWS (2006)

Table B-16. Velocity HSI for BMI metrics from USFWS (2006).

BCH Biomass		Diversity	
Velocity (ft/s)	**HSI**	**Velocity (ft/s)**	**HSI**
0	0	0	0.78
0.1	0.08	0.2	0.78
0.2	0.15	0.5	0.81
0.3	0.23	0.6	0.83
0.4	0.29	0.7	0.84
0.5	0.36	0.8	0.86
0.6	0.42	0.9	0.87
0.7	0.48	1	0.89
0.8	0.54	1.1	0.91
0.9	0.59	1.3	0.93
1	0.64	1.4	0.95
1.1	0.69	1.8	0.99
1.2	0.73	1.9	0.99
1.3	0.77	2	1
1.4	0.81	2.4	1
1.5	0.84	2.5	0.99
1.6	0.87	2.6	0.98
1.7	0.9	2.7	0.98
2	0.96	3	0.95
2.1	0.97	3.1	0.93
2.2	0.99	3.4	0.9
2.3	0.99	3.5	0.88
2.4	1	3.8	0.85
2.6	1	3.9	0.85
2.7	0.99	4	0.84
2.8	0.99	4.2	0.84

BCH Biomass		Diversity	
Velocity (ft/s)	**HSI**	**Velocity (ft/s)**	**HSI**
2.9	0.97	4.4	0.86
3	0.96	4.7	0.92
3.1	0.94	4.8	0.96
3.3	0.9	4.86	0.98
3.7	0.77	4.87	0
3.8	0.73		
3.9	0.69		
4	0.64		
4.1	0.59		
4.2	0.54		
4.3	0.48		
4.4	0.43		
4.5	0.36		
4.6	0.3		
4.7	0.23		
4.8	0.16		
5	0		

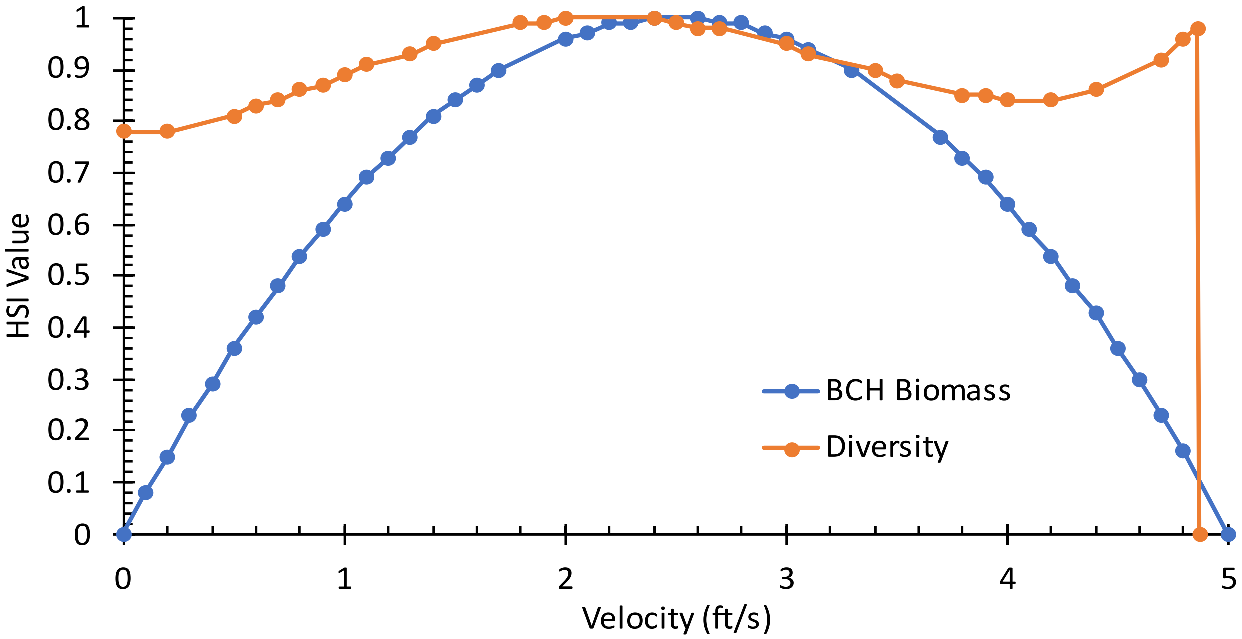


Figure B-21. Velocity HSI curves for BMI metrics: Baitidae, Chironomidae, Hydropsychidae *(BCH) Biomass and Shannon-Weaver Diversity Index (Diversity) from USFWS (2006).*

Table B-17. Depth HSI for BMI metrics from USFWS (2006).

BCH Biomass		**Diversity**	
Depth (ft)	**HSI**	**Depth (ft)**	**HSI**
0	0	0	0
0.1	0	0.1	0.18
0.2	0.02	0.2	0.34
0.3	0.03	0.3	0.47
0.4	0.06	0.4	0.59
0.5	0.09	0.5	0.68
0.6	0.12	0.6	0.76
0.7	0.16	0.7	0.82
0.8	0.21	0.8	0.86
0.9	0.26	0.9	0.9
1	0.31	1	0.92
1.1	0.36	1.2	0.95
1.2	0.41	1.5	0.95
1.3	0.47	1.6	0.94
1.4	0.52	2.2	0.88
1.5	0.58	2.3	0.88
1.6	0.63	2.4	0.87
1.7	0.68	2.6	0.87
1.8	0.74	2.7	0.88
1.9	0.78	2.8	0.89
2	0.83	2.9	0.89
2.1	0.87	3	0.91
2.2	0.91	3.2	0.93
2.3	0.94	3.3	0.95
2.4	0.96	3.5	0.97
2.5	0.98	3.6	0.99
2.6	0.99	3.7	0.99
2.7	1	3.8	1
2.8	1	3.9	1
2.9	0.99	4.1	0.98
3	0.97	4.2	0.96
3.1	0.93	4.3	0.93
3.2	0.89	4.4	0.88
3.3	0.84	4.5	0.82
3.4	0.78	4.6	0.75
3.5	0.7	4.7	0.66
3.6	0.61	4.8	0.55
3.7	0.51	4.9	0.41

BCH Biomass		Diversity	
Depth (ft)	HSI	Depth (ft)	HSI
3.8	0.4	5	0.26
3.9	0.27	5.1	0.08
4	0.12	5.2	0
4.1	0		

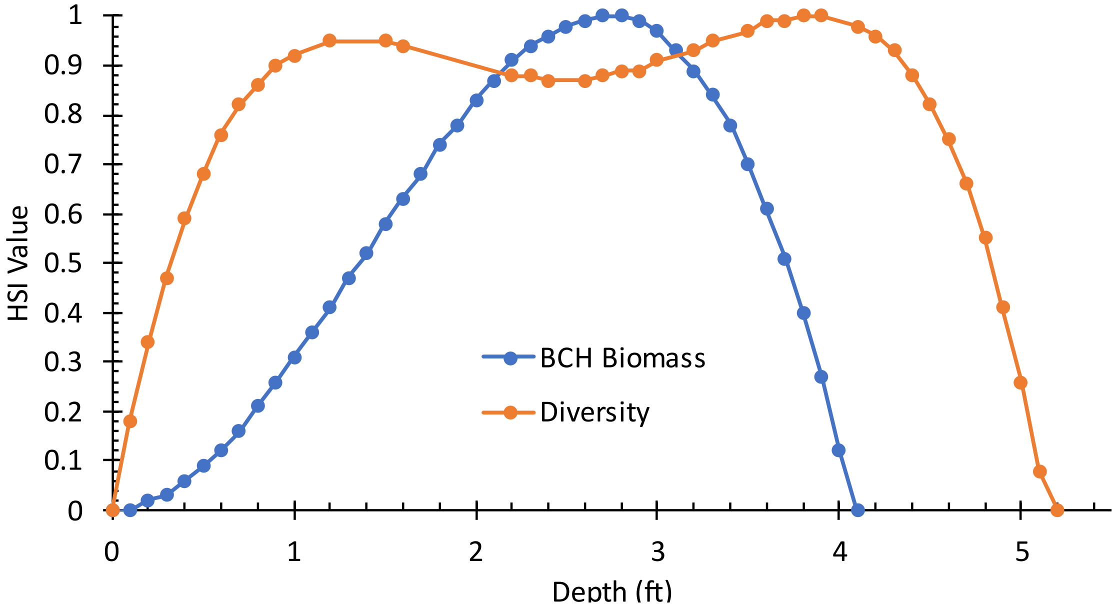


Figure B-22. Depth HSI curves for BMI metrics from USFWS (2006).

Table B-18. Substrate codes and HSI for BMI metrics from USFWS (2006).

Subsrate		HSI	
Substrate	**Description**	**BCH Biomass**	**Diversity**
0.1	Sand or silt/sand (< 0.1 inches)	1	1
1	Small gravel (0.1–1 inches)	1	1
1.2	Medium gravel (1–2 inches)	1	1
1.3	Medium/large gravel (1–3 inches)	1	1
2.3	Large gravel (2–3 inches)	1	1
2.4	Gravel/cobble (2–4 inches)	1	1
3.4	Small cobble (3–4 inches)	1	1
3.5	Small cobble (3–5 inches)	1	1
4.6	Medium cobble (4–6 inches)	1	1
6.8	Large cobble (6–8 inches)	1	1
8	Large cobble (8–10 inches)	1	1
9	Boulder/ bedrock (> 12 inches)	1	1
10	Large cobble (10–12 inches)	1	1

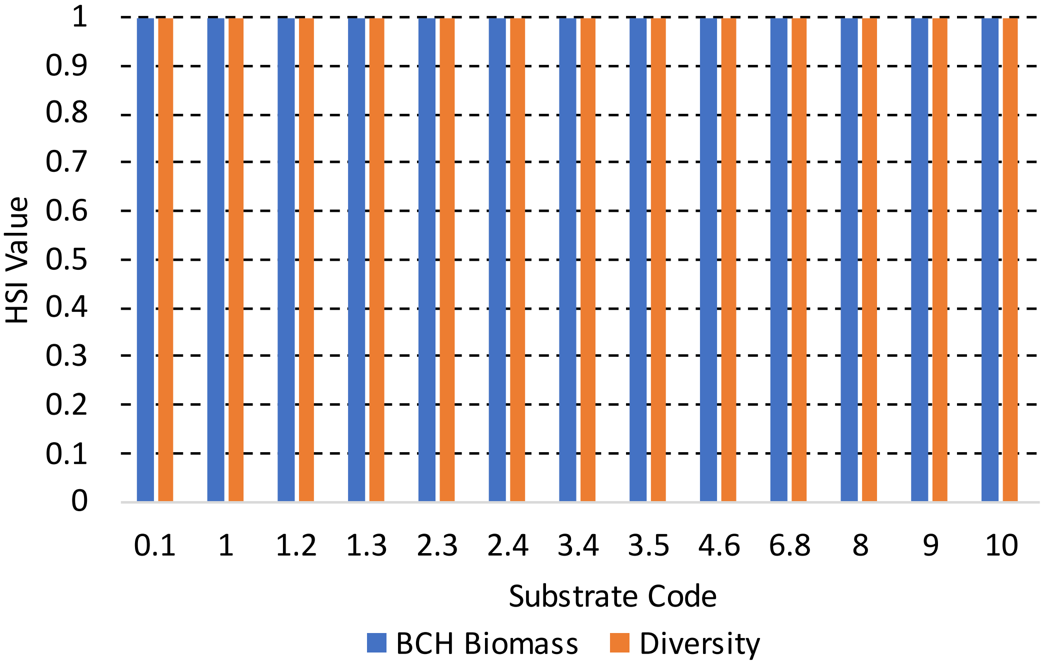


Figure B-23. Substrate HSI for BMI metrics from USFWS (2006).

3.2 Existing Conditions

Table B-20. Existing conditions WUA for BMI metrics (using depth, velocity, and substrate HSI.

Modeled Flow (cfs)	BCH Biomass	Diversity
	WUA (Acres)	
80	2.97	18.88
150	4.80	19.86
300	6.98	20.65
500	7.57	21.01
633	7.06	20.98
750	6.43	20.84
800	6.13	20.72
1,000	5.43	20.84
1,130	5.17	20.93
1,580	5.35	22.37
3,000	10.53	30.11
5,400	16.19	48.28
7,050	19.13	53.81
9,600	23.22	56.34
11,500	25.94	58.06

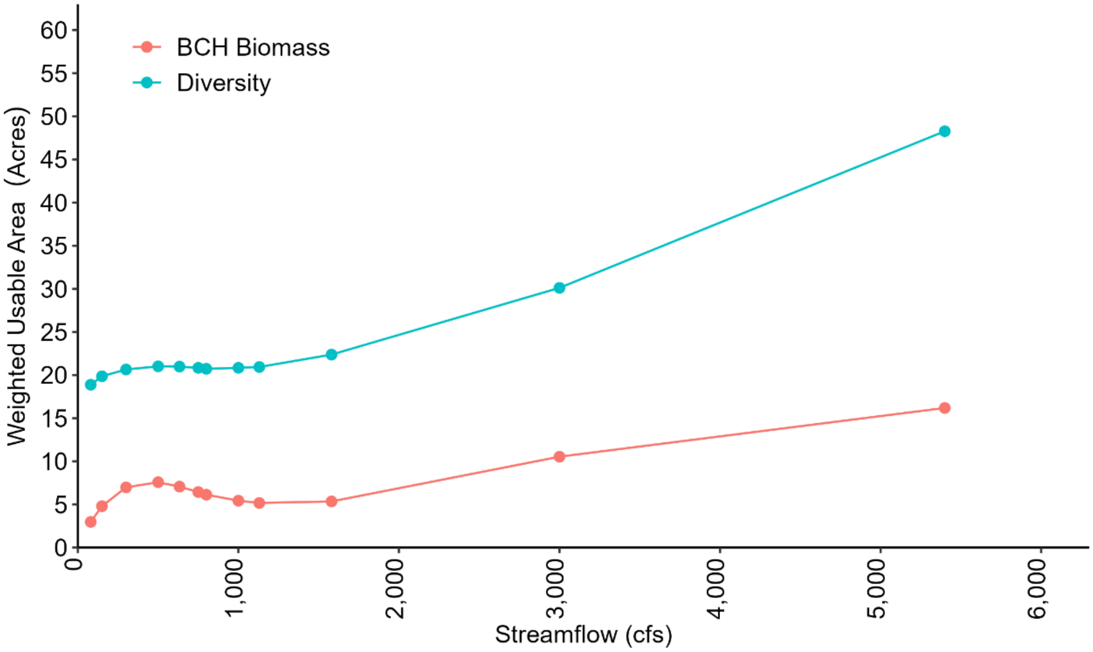


Figure B-24. Existing conditions WUA (using depth, velocity, and substrate HSI) for BMI metrics.

3.3 90% Design

Table B-21. 90% design WUA for BMI metrics (using depth, velocity, and substrate HSI).

Modeled Flow (cfs)	BCH Biomass	Diversity
	WUA (Acres)	
80	2.80	17.08
150	4.58	18.72
300	7.11	22.07
500	8.84	24.92
633	9.29	27.04
750	9.59	28.98
800	9.76	29.80
1,000	10.59	32.39
1,130	11.17	33.70
1,580	13.30	37.28
3,000	18.52	43.58
5,400	18.44	56.20
7,050	19.34	57.82
9,600	24.22	56.58
11,500	27.62	59.00

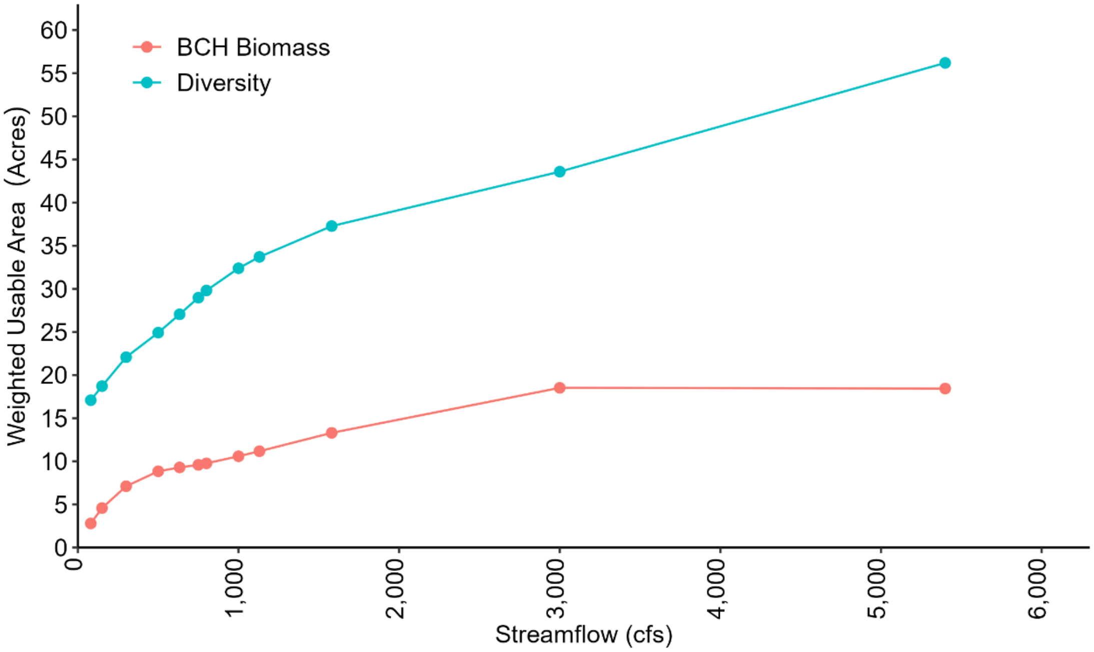


Figure B-25. 90% design WUA (using depth, velocity, and substrate HSI) for BMI metrics.

4 COMPARISON OF EXISTING CONDITIONS TO 90% DESIGN

4.1 Chinook Salmon

Table B-22. Percent change in WUA from existing conditions to 90% design for Chinook Salmon spawning (using depth, velocity, and substrate HSI), fry and juvenile rearing (using depth, velocity, and cover HSI).

Modeled Flow (cfs)	Chinook Salmon Spawning	Chinook Salmon Fry Rearing	Chinook Salmon Juvenile Rearing
	Percent Change in WUA		
80	18%	15%	11%
150	49%	21%	5%
300	84%	46%	-1%
500	103%	59%	1%
633	111%	82%	6%
750	122%	98%	10%
800	128%	104%	12%
1,000	148%	95%	17%
1,130	159%	85%	23%
1,580	170%	46%	41%
3,000	77%	4%	43%
5,400	-5%	-7%	14%
7,050	-24%	-5%	4%
9,600	-32%	-8%	-4%
11,500	-32%	-4%	-5%

Table B-23. The difference in WUA (acres) from existing conditions to 90% design for Chinook Salmon spawning, fry and juvenile rearing.

Modeled Flow (cfs)	Chinook Salmon Spawning	Chinook Salmon Fry Rearing	Chinook Salmon Juvenile Rearing
	Change in WUA (Acres)		
80	0.19	0.77	0.48
150	0.78	0.98	0.27
300	1.63	2.25	-0.06
500	2.04	2.90	0.05
633	2.14	4.09	0.39
750	2.27	5.04	0.62
800	2.34	5.43	0.71
1,000	2.66	5.94	1.02
1,130	2.83	6.02	1.36
1,580	3.11	4.73	2.52
3,000	1.85	0.54	4.25
5,400	-0.16	-0.93	2.29
7,050	-0.64	-0.68	0.79
9,600	-0.57	-1.00	-0.74
11,500	-0.42	-0.48	-0.87

4.2 O. Mykiss

Table B-24. Percent change in WUA from existing conditions to 90% design for O. mykiss *spawning (using depth, velocity, and substrate HSI), and fry and juvenile rearing and adult habitat (using depth, velocity, and cover HSI).*

Modeled Flow (cfs)	***O. mykiss*** **Spawning**	***O. mykiss*** **Fry Rearing**	***O. mykiss*** **Juvenile Rearing**	***O. mykiss*** **Adult Habitat**
	Percent Change in WUA			
80	179%	13%	7%	14%
150	131%	13%	5%	10%
300	103%	28%	11%	6%
500	96%	47%	24%	6%
633	97%	68%	36%	9%
750	98%	84%	49%	13%
800	100%	90%	53%	14%
1,000	105%	91%	63%	22%
1,130	107%	88%	67%	26%
1,580	116%	66%	65%	44%
3,000	136%	18%	28%	44%
5,400	113%	-3%	5%	20%
7,050	94%	-5%	0%	11%
9,600	68%	-6%	-4%	4%
11,500	56%	-3%	-3%	2%

Table B-25. The difference in WUA (acres) from existing conditions to 90% design for O. mykiss *spawning, fry and juvenile rearing, and adult habitat.*

Modeled Flow (cfs)	***O. mykiss* Spawning**	***O. mykiss* Fry Rearing**	***O. mykiss* Juvenile Rearing**	**O. mykiss Adult Habitat**
	Change in WUA (Acres)			
80	0.10	0.83	0.50	0.21
150	0.22	0.85	0.38	0.25
300	0.59	1.86	0.80	0.23
500	1.18	3.01	1.73	0.33
633	1.56	4.37	2.63	0.53
750	1.88	5.50	3.51	0.78
800	2.02	5.94	3.86	0.85
1,000	2.50	6.86	4.84	1.40
1,130	2.76	7.24	5.38	1.76
1,580	3.53	7.38	6.46	3.09
3,000	5.08	3.40	4.76	4.62
5,400	5.03	-0.56	1.05	3.51
7,050	4.44	-0.95	0.10	2.25
9,600	3.45	-1.13	-0.78	0.92
11,500	2.91	-0.57	-0.63	0.45

4.4 Benthic Macroinvertebrates

Table B-26. Percent change in WUA from existing conditions to 90% design for BMI metrics (using depth, velocity, and substrate HSI).

Modeled Flow (cfs)	BCH Biomass	Diversity
	Percent Change in WUA	
80	-6%	-10%
150	-5%	-6%
300	2%	7%
500	17%	19%
633	32%	29%
750	49%	39%
800	59%	44%
1,000	95%	55%
1,130	116%	61%
1,580	149%	67%
3,000	76%	45%
5,400	14%	16%
7,050	1%	7%
9,600	4%	0%
11,500	6%	2%

Table B-27. The difference in WUA (acres) from existing conditions to 90% design for BMI metrics.

Modeled Flow (cfs)	BCH Biomass	Diversity
	Change in WUA (Acres)	
80	-0.18	-1.79
150	-0.22	-1.14
300	0.13	1.43
500	1.27	3.91
633	2.23	6.06
750	3.15	8.14
800	3.64	9.08
1,000	5.15	11.55
1,130	6.00	12.77
1,580	7.95	14.90
3,000	7.98	13.47
5,400	2.25	7.92
7,050	0.21	4.01
9,600	1.00	0.25
11,500	1.68	0.94

5 LIMITING LIFE STAGE ANALYSIS

5.1 Chinook Salmon

5.1.1 Existing Conditions

Table B-28. Flow specific adult capacity estimates for all Chinook Salmon life stages calculated using existing conditions WUA results and habitat capacity parameters from the Clear Creek Synthesis Report (USFWS 2015).

Modeled Flow (cfs)	Chinook Salmon Spawning	Chinook Salmon Fry Rearing	Chinook Salmon Juvenile Rearing
	Total Adults		
80	1,193	1,584	2,123
150	1,725	1,513	2,445
300	2,109	1,550	2,880
500	2,155	1,559	3,022
633	2,096	1,576	3,037
750	2,032	1,618	3,012
800	2,002	1,655	3,013
1,000	1,950	1,974	3,043
1,130	1,938	2,225	3,010
1,580	1,989	3,218	3,055
3,000	2,615	4,607	4,929
5,400	3,168	4,486	8,326
7,050	2,909	4,121	9,146
9,600	1,947	3,808	9,302
11,500	1,397	3,935	9,254

5.1.2 90% Design

Table B-29. Flow specific adult capacity estimates for all Chinook Salmon life stages calculated using 90% design WUA results and habitat capacity parameters from the Clear Creek Synthesis Report (USFWS 2015).

Modeled Flow (cfs)	Chinook Salmon Spawning	Chinook Salmon Fry Rearing	Chinook Salmon Juvenile Rearing
	Total Adults		
80	1,402	1,828	2,364
150	2,576	1,823	2,579
300	3,882	2,261	2,850
500	4,373	2,475	3,047
633	4,430	2,868	3,230
750	4,503	3,209	3,320
800	4,555	3,371	3,367
1,000	4,843	3,852	3,552

Modeled Flow (cfs)	**Chinook Salmon Spawning**	**Chinook Salmon Fry Rearing**	**Chinook Salmon Juvenile Rearing**
	Total Adults		
1,130	5,022	4,125	3,690
1,580	5,372	4,711	4,318
3,000	4,635	4,777	7,058
5,400	2,995	4,193	9,473
7,050	2,216	3,906	9,541
9,600	1,323	3,490	8,931
11,500	945	3,784	8,820

5.2 O. mykiss

5.2.1 Existing Conditions

Table B-30. Flow specific adult capacity estimates for O. mykiss *spawning, fry and juvenile rearing life stages calculated using existing conditions WUA results and habitat capacity parameters from the Clear Creek Synthesis Report (USFWS 2015).*

Modeled Flow (cfs)	***O. mykiss*** **Spawning**	***O. mykiss*** **Fry Rearing**	***O. mykiss*** **Juvenile Rearing**
	Total Adults		
80	60	2,030	3,345
150	184	2,087	3,547
300	627	2,092	3,661
500	1,336	2,045	3,647
633	1,757	2,038	3,624
750	2,078	2,058	3,607
800	2,190	2,094	3,627
1,000	2,592	2,383	3,845
1,130	2,801	2,607	3,999
1,580	3,306	3,551	4,965
3,000	4,078	5,826	8,430
5,400	4,856	6,782	11,080
7,050	5,146	6,475	11,314
9,600	5,496	5,936	11,043
11,500	5,621	5,873	11,021

5.2.2 90% Design

Table B-31. Flow specific adult capacity estimates for O. mykiss *spawning and fry and juvenile rearing life stages calculated using 90% Design WUA results and habitat capacity parameters from the Clear Creek Synthesis Report (USFWS 2015).*

Modeled Flow (cfs)	***O. mykiss* Spawning**	***O. mykiss* Fry Rearing**	***O. mykiss* Juvenile Rearing**
	Total Adults		
80	166	2,292	3,595
150	425	2,354	3,735
300	1,272	2,678	4,060
500	2,620	2,996	4,511
633	3,459	3,418	4,939
750	4,124	3,795	5,366
800	4,385	3,971	5,559
1,000	5,309	4,549	6,270
1,130	5,810	4,893	6,693
1,580	7,146	5,883	8,198
3,000	9,607	6,901	10,813
5,400	10,330	6,604	11,605
7,050	9,978	6,175	11,365
9,600	9,251	5,580	10,650
11,500	8,794	5,692	10,703

Appendix C: Foothill Yellow-Legged Frog Modeling

APPENDIX C. ZANKER FARM SALMONID HABITAT RESTORATION PROJECT 100% DESIGN FOOTHILL YELLOW-LEGGED FROG MODELING

1 BACKGROUND

The modeling methods and results presented in this appendix were conducted at the 65% design stage. As only minor changes to floodplain surfaces were made at the 90% and 100% design stages, FYFAM was not revised based on the 90% or 100% design. Therefore, mentions of the 65% design stage and analysis in this document are directly applicable to the 90% and 100% designs.

The Foothill Yellow-legged Frog (FYLF; *Rana boylii*) was once widespread across California, but it has experienced significant declines across the species' range, including extirpation from many localities in the Central Valley, and appears to be extirpated from the project area. FYLF has long been recognized as a Species of Special Concern in California (Jennings and Hayes 1994, Thomson et al. 2016) and in December 2019 FYLF was listed under the California Endangered Species Act (CESA 1970), receiving endangered status for the South Sierra Distinct Population Segment. The species is also currently in review for federal listing under the Endangered Species Act (ESA 1973), with an endangered status listing expected in 2023. Primary threats to the species include alteration of flow and thermal regimes and other habitat degradations associated with dam operations, as well as changes in land use, invasive species pressure, and disease (Kupferberg et al. 2012, Adams et al. 2017). Breeding typically occurs along stream margins in spring (March to June), depending on water year type, hydrograph timing and water temperature. The FYLF has evolved strategies to time reproduction with hydrograph cycles to minimize scour and desiccation risks to eggs while maximizing development time for offspring. Individual frogs decide when to initiate breeding based on a suite of environmental cues (Wheeler and Welsh 2008). Downstream of dams components of the hydrograph may be decoupled from natural environmental cues, hampering the frog's ability to make the best choice of when and where to lay eggs (Lind et al. 1996, Lind et al. 2016). Water temperature, water quality, primary productivity, and predation pressure also influence success of the cohort.

FYLF historically occurred in the Zanker Farm project area and does still occur in the Tuolumne River upstream of Don Pedro Reservoir. California Natural Diversity Database (CNDDB) includes recent observations within a few miles of the project area (reported from the Chinese Creek USGS 7.5x7.5 quad map), suggesting potential for recolonization with improved habitat conditions.

In snowmelt driven rivers of California, seasonal patterns are somewhat predictable, but the annual variability in hydrograph shape, magnitude and timing can lead to failure of the cohort. Reduced flood magnitude and frequency downstream of dams allows encroachment of riparian vegetation, formation of berms, and downcutting of the channel, leading to a loss of shallow edge water habitats used for breeding by FYLF (Kupferberg et al. 2012, Yarnell et al. 2012). Channel rehabilitation can reverse degradation downstream of dams, improving conditions for breeding and rearing FYLF. A combination of mechanical manipulation and ecologically based flow management is often most effective for improving reproductive success of FYLF in flow-regulated rivers. Grading vegetated banks, berms, and down cut channel beds to recreate gravel bars, side channels and other shallow waters along the river margin provides habitat used for breeding and rearing. Coupling channel rehabilitation with flow management that considers seasonal timing of FYLF reproductive cycle promotes population recovery and maintenance of this endangered river-breeding frog (Figure 1).

Figure 1. Foothill Yellow-legged Frog egg mass, tadpole, and adult frog.

2 METHODS FOR EVALUATION OF THE 100% DESIGN

An individual-based simulation model has been developed to assess reproductive success of FYLF at a site based on channel geometry, flow, and water temperature. The Foothill Yellow-legged Frog Assessment Model (FYFAM; Railsback et al. 2016, 2021) provides a way to evaluate and compare various hydrographs and site designs. Results include predictions of timing of life history stages, risk of mortality due to scour and desiccation, recruitment of new froglets, and location for each life stage transition and mortality event allowing for numerical comparisons of reproductive success for proposed site designs and/or flow regimes. FYFAM version V2.1.3 A (Railsback et al. 2021a) was used to evaluate and compare potential reproductive success for FYLF within the Zanker Phase I and II combined project area for the existing ground condition (EC) and 65% restoration design (65%).

2.1 Inputs and parameter settings

FYFAM uses ground topography, streamflows, and water temperature to predict froglet production based on survival of key life stages: egg mass, tadpole, and metamorphosis to froglet stage. This set of simulations used the same flow and temperature scenarios as used for evaluating Zanker Phase I and Phase II (McBain Associates 2021), and represent three water year types (dry, moderate, wet). Simulation was initiated with 100 breeders, each capable of producing one egg mass containing 1,000 embryos, for a maximum potential cohort size of 100,000. Breeding frogs were allowed 60 days from the onset of oviposition to find a suitable location to deposit their egg mass, with breeder movement distance set at 30-m per day. The 30-m per day breeder movement distance was used to maintain comparability with previous evaluations of Zanker Phase I and Phase II. Due to the large size of the combined Phase I and II site and complexity of the 65% design topography, a few breeders did not deposit their egg mass in some of the replicates within a set of simulations. In the dry water year type for the 65% design, one to three of the 100 breeders were not able to reach suitable habitat for oviposition within specified time and movement distance. This also occurred in the wet water year at the 12 ℃ breeding threshold temperature for one breeder for each of the topographies.

The model's predicted froglet production numbers are based on scour and desiccation risk to eggs and tadpoles. Eggs not lost to scour or desiccation hatch into tadpoles, and tadpoles not lost to scour or desiccation reach metamorphosis to emerge as froglets, with the timing of metamorphosis providing an indication of potential overwinter survival; no other mortality factors are modeled.

Timing of oviposition is a major factor in risk exposure to eggs and tadpoles, and thus has a strong effect on froglet production (number produced and timing of metamorphosis). Water temperature influences oviposition timing, which commonly begins when water temperature reaches 10–12 ℃. Oviposition prior to spring peak flows increases exposure of eggs and tadpoles to flow-related mortality. Oviposition later in the spring or summer decreases time available for development of eggs and tadpoles before winter. Since no site-specific, empirical data on water temperature triggering FYLF breeding were available for the Lower Tuolumne River, these FYFAM evaluations assessed three breeding threshold temperatures, 10, 11, and 12 °C.

Timing of metamorphosis is an important outcome metric in FYFAM assessments. Early metamorphosis allows froglets to forage and grow before winter, presumably improving overwinter survival. Late metamorphosis dates reduce time available for froglets to forage and grow, which could reduce overwinter survival of first year frogs (Catenazzi and Kupferberg 2013, Wheeler et al. 2014). To help with consideration of potential survival of froglets over their first winter, a thrive cut-off date was added to the results graphs. For these simulations, the thrive cut-off was set at the Autumnal Equinox (September 21), after which overwinter survival of froglets is expected to decrease dramatically.

For each combination of ground condition, flow/temperature scenario, and breeding threshold temperature, 10 replicate simulations were performed (a total of 180 simulations). Replicate simulations accounted for stochasticity in model results that arise from probabilistic and stochastic functions in various sub models within FYFAM. The “most typical” replicate of each set of replicates was that which was closest to the mean value for froglets and mean of the median date of metamorphosis, equally weighted. In the event of a tie, biological significance guided selection of the most typical replicate. Each replicate was graphed to display timing of life history events in relation to streamflow and temperature and the graph for the most typical replicate for set of simulations was selected.

3 RESULTS

3.1 Froglet production

Water year type had the greatest influence on predicted froglet production for FYLF, with the dry water year type producing the most froglets (Figure 2). Breeding threshold temperature had relatively little influence, except for the 12 °C breeding threshold temperature in the wet water year type. The higher breeding threshold temperature delayed breeding enough so eggs were deposited after peak flows reducing mortality risk to egg masses, although tadpoles were exposed to increased risk of scour under the 65% design topography.

The 65% design was predicted to produce slightly more froglets in the dry water year type. In larger rivers, dry water years tend to favor FYLF by decreasing scour risk and allowing for earlier oviposition dates, leading to earlier metamorphosis dates and likely higher survival of froglets in their first winter. Therefore, even modest increases in froglet production in drier water years can contribute to population growth.

The increased froglet production predicted for the wet water year type at the 12 °C breeding threshold temperature, with the existing condition producing more froglets than the 65% design, may not actually result in a biologically meaningful difference due to later metamorphosis dates lowering overwinter survival of froglets (further discussed below).

For the 65% design topography at all three breeding threshold temperatures evaluated, the total proportion of the cohort is slightly less than 1.0, meaning not all breeders were able to find a suitable location in the allotted time. This is an artifact of the random placement of breeders at model initiation, the large area of the site, and the selected breeder-habitat-radius of 30-m. At a higher breeder-habitat-radius of 75-m, all breeders were able to find suitable breeding and proportions total to 1.0 (results not shown here). The 30-m breeder-habitat-radius was used for these simulations to be consistent with previous simulations conducted for the Zanker Phase I and Phase II project evaluations (McBain 2021, 2022).

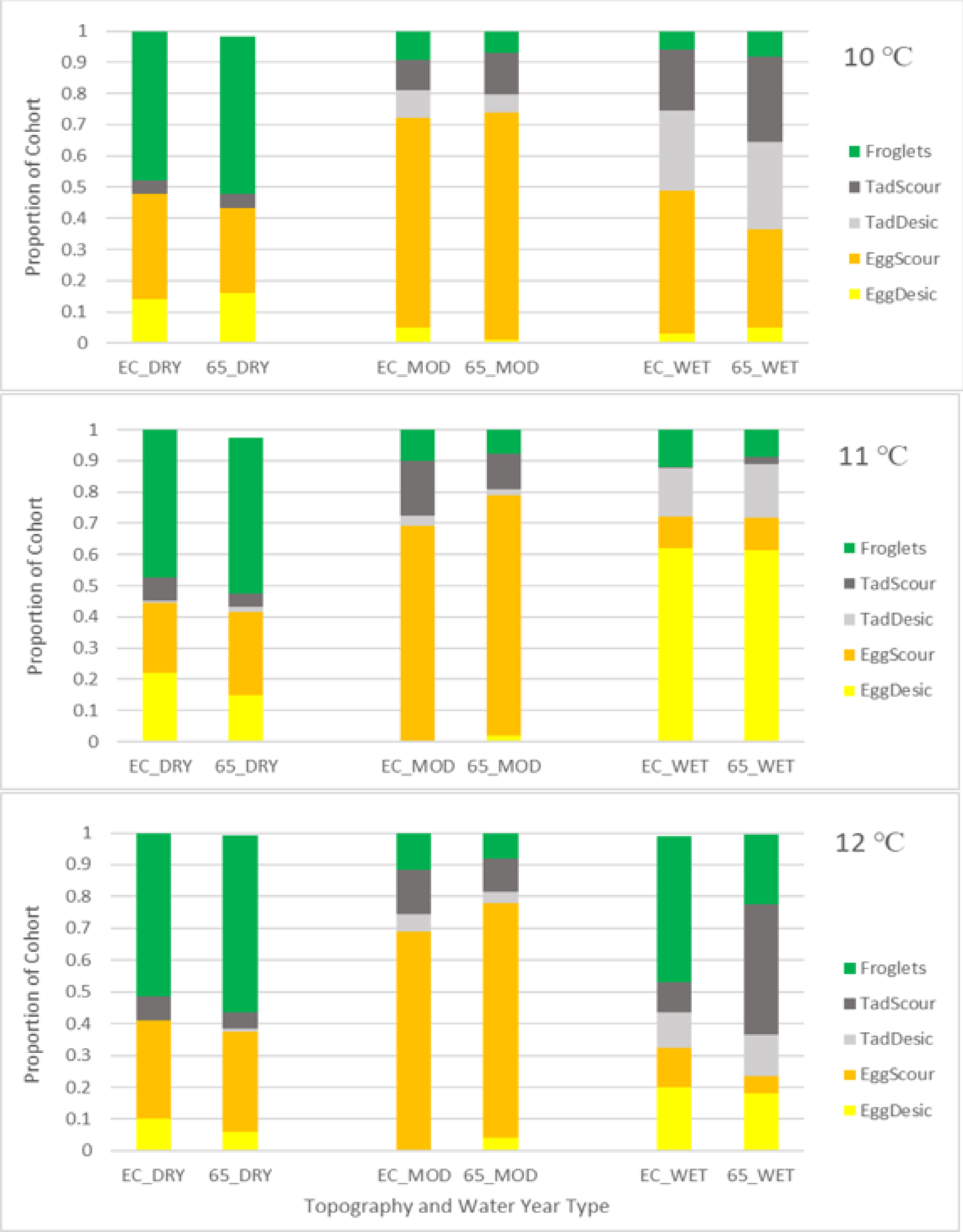


Figure 2. Stacked bar graphs depicting predicted mortality risk for eggs, tadpoles, and embryo surviving to metamorphose into froglets. Existing condition (EC) and the 65% design (65) are compared for three representative water year types (Dry, Moderate, and Wet). Evaluations are shown for three breeding threshold temperatures (10, 11, and 12 °C). The dry water year type produced the most froglets, with slightly higher froglet production for the 65% design topography. Froglet production was lowest for the moderate water year type, with slightly lower froglet production for the 65% design. Froglets produced in the wet water year type reached metamorphosis too late to be considered successful.

3.2 Timing of metamorphosis

In addition to froglet production, another important model outcome is the timing of metamorphosis. Graphs of mortality risks and froglet production along with the annual hydrograph and thermograph illustrate how flow and water temperature effect reproductive success (Figure 3 through Figure 11). The timing of oviposition is influenced by both water temperature and stability of river stage. Breeding can begin once water temperature reaches the breeding threshold temperature (10, 11, or 12 °C in these simulations) and the change in water depth at a particular breeder's selection oviposition location is relatively stable (< 0.03 m per day for these simulations). In the dry and moderate water year examples, oviposition begins in late March, leading to metamorphosis dates in August and extending into early September. In the wet water year example, breeding begins much later, with considerable variation depending on the specified breeding threshold temperature. This results in much later dates of metamorphosis, with median date of metamorphosis in October (for 10 °C), November (for 11 °C), or December (for 12 °C). Median date of metamorphosis is past the selected "thrive cut-off date" of September 21 for all three breeding threshold temperature evaluated here. This does not mean no recruitment occurred, but the probability of survival for froglets over their first winter diminishes as the season progress beyond the Autumnal Equinox. And so, while the existing condition shows much higher froglet production compared to the 65% design in wet water year at 12 °C breeding threshold temperature, the froglets emerging in December have low probability of overwinter survival and differences between the existing condition and 65% design may not translate to intrinsic population growth.

3.3 Discussion and Conclusion

Model predictions of froglet production and timing of metamorphosis were similar for the existing condition and 65% design. In the dry water year example, the 65% design, FYFAM predicted slightly higher froglet production. This pattern held across all three breeding threshold temperatures evaluated. Because drier water years are most conducive to reproductive success for FYLF in mainstem rivers, even modest increases in froglet production can contribute to population growth. In the moderate water year example, the flow peaks began a couple weeks later and a series of peaks continued for about a month leading to high scour mortality of egg masses and low froglet production. Metamorphosis occurred in August and embryos surviving to reach metamorphosis to froglets would be expected to have high overwinter survival. Differences between the existing condition and 65% design were minor, but the existing condition produced slightly more froglets than the 65% design. This pattern held true across all three of the breeding threshold temperatures evaluated. Due to low reproductive success in the moderate water year, differences in froglet production are not likely to produce a population level effect. In the wet water year type, froglet production was low, similar to that of the moderate water year example, but metamorphosis dates were far too late to expect overwinter survival of the few froglets produced. This pattern was seen at the 10 °C and 11 °C breeding threshold temperatures, but froglet production was higher for the 12 °C breeding threshold temperature because breeding started after spring peak flows subsided. The additional flow peak in August resulted in considerable tadpole scour mortality in the 65% design topography which was not as apparent in the existing condition, leading to higher froglet production for the existing condition in the wet water year type, relative to the 65% design. Metamorphosis occurred too late in the wet water year to expect many of the froglets to survive their winter, so differences between the existing condition and 65% design are not expected to contribute to population growth.

It is important to note that while FYLF is likely to have occurred historically in the Lower Tuolumne River, there are no recent records of this species in the project area. It is possible recolonization or reintroduction could occur with improved habitat conditions, including increased area of riffle and gravel bar habitat, although other factors may suppress opportunities for this species to re-occupy the project area. Side-channels can provide conditions conducive to earlier breeding while providing some protection from scouring spring flows. This can lead to earlier metamorphosis and higher over-winter survival of the cohort, relative to the main channel.

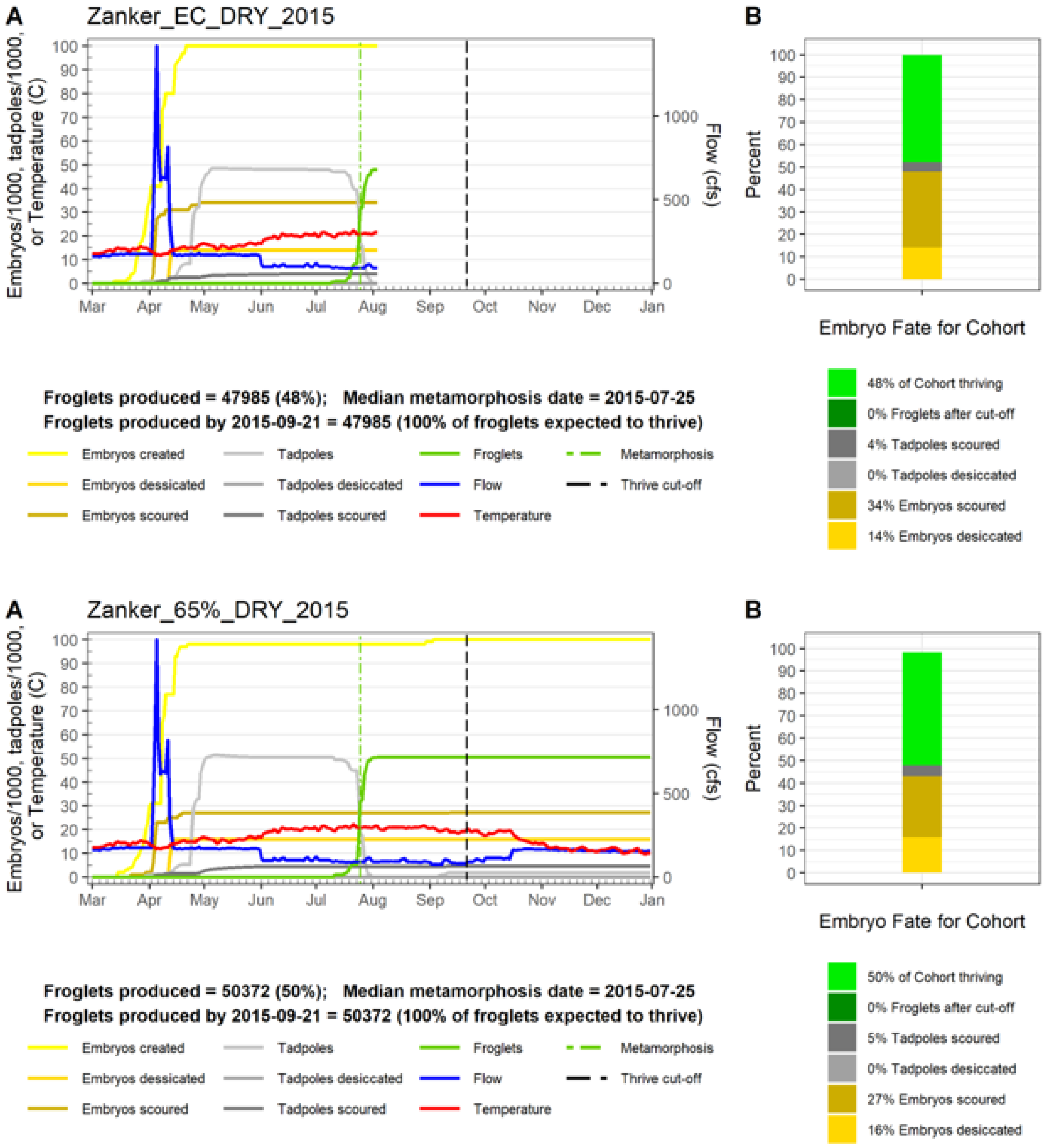
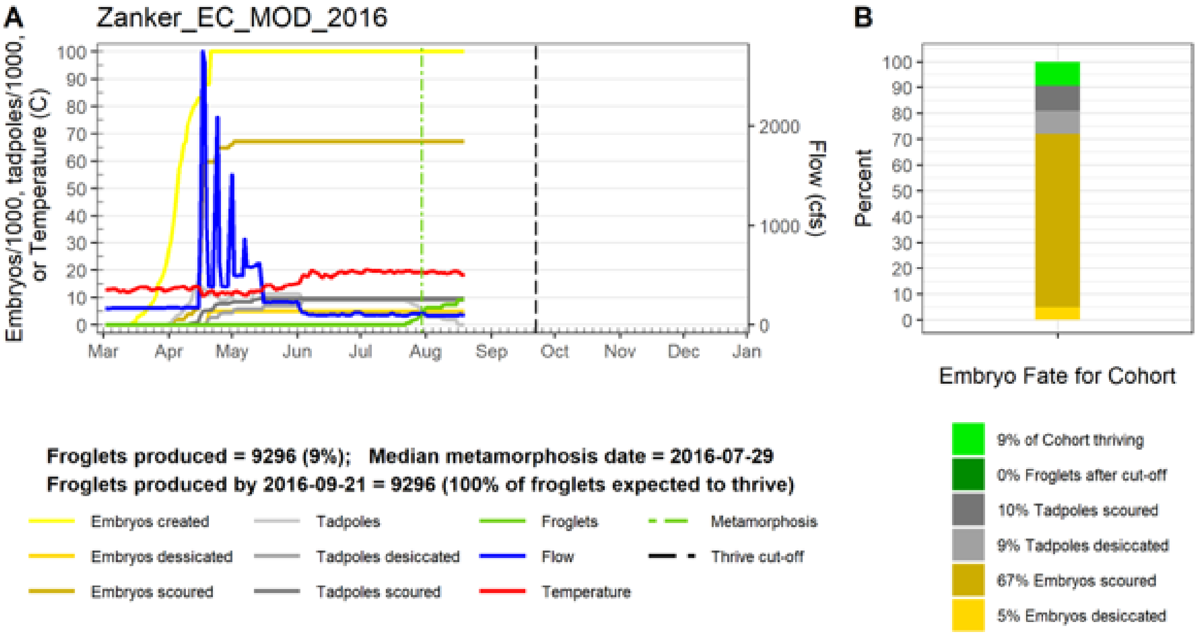


Figure 3. Dry water year type with breeding threshold temperature set at 10 °C. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Stable flows and warming water in late March triggered breeding to begin prior to the onset of peak flows at the beginning of April. Twenty to 30 percent of the egg masses were scoured during the flow peaks. Some egg masses were deposited during the lull between the primary and secondary peaks, leading to additional scour mortality as well as some desiccation mortality as flow rapidly receded in mid-April. Tadpole mortality was low and about half the cohort reached metamorphosis by the beginning of August. The 65% design topography produced slightly more froglets even though two of the breeders were not able to find a suitable location for oviposition within the specified breeding window of 60 days and allotted breeder movement distance of 30-m per day, so the model continued to run until the end of the time series on December 31st.



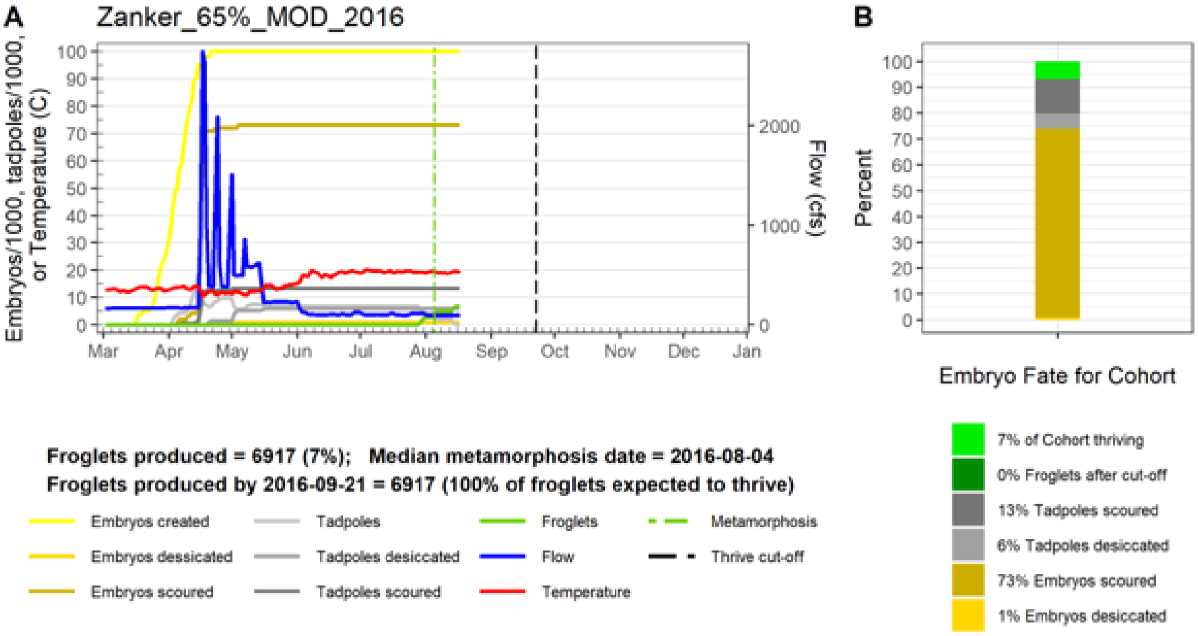


Figure 4. Moderate water year type with breeding threshold temperature set at 10 ℃. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Breeding occurred prior to peak flows in mid-April resulting in high scour mortality of egg masses with additional loss of tadpoles to scour and desiccation. Less than 10% of embryos survived to metamorphosis with only slight differences in froglet production between the existing condition and 65% design topography. Remaining tadpoles reached metamorphosis by early August, giving emerging froglets sufficient time to forage and grow before winter.

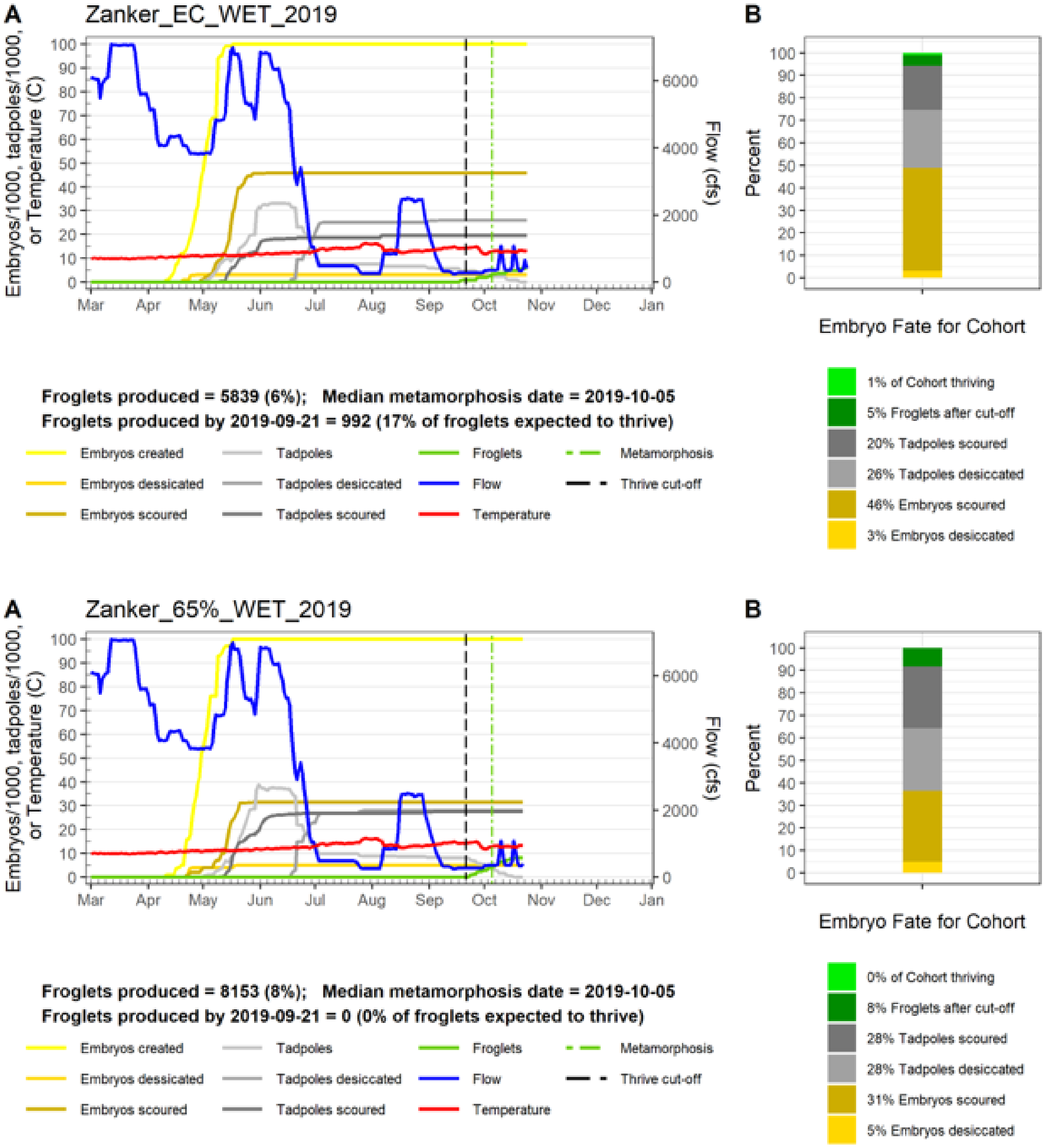


Figure 5. Wet water year type with breeding threshold temperature set at 10 ℃. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Breeding began mid-April and continued through the prolonged flow peak in May. Scour mortality of egg masses and tadpoles and desiccation of tadpoles as flow receded lead to low froglet production. Embryos that survived to metamorphosis into froglets occurred in early Autumn, reducing their probability of overwinter survival. While slightly more froglets were produced in the 65% design, this difference is not likely to be biologically relevant due to the later metamorphosis dates.

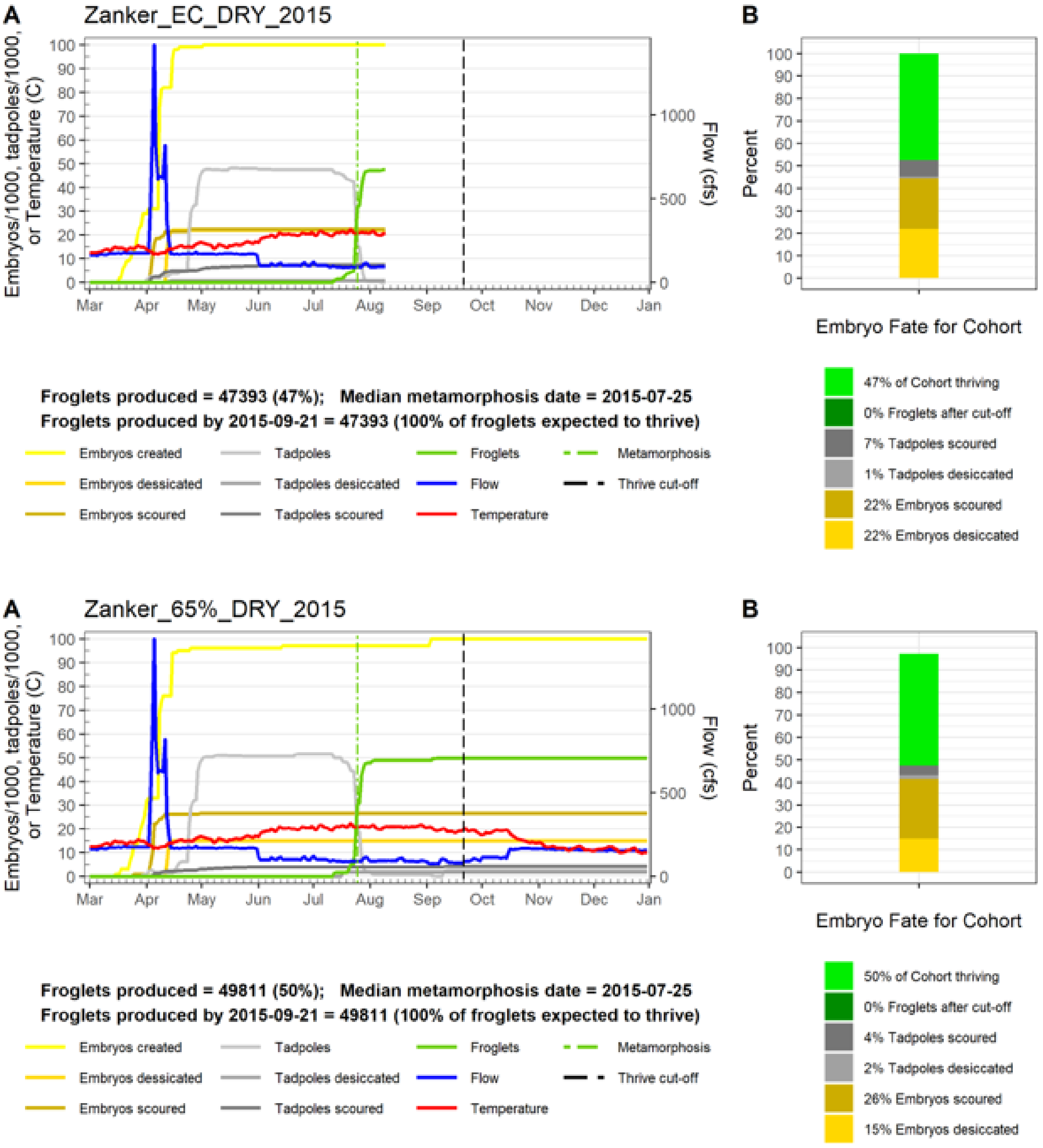
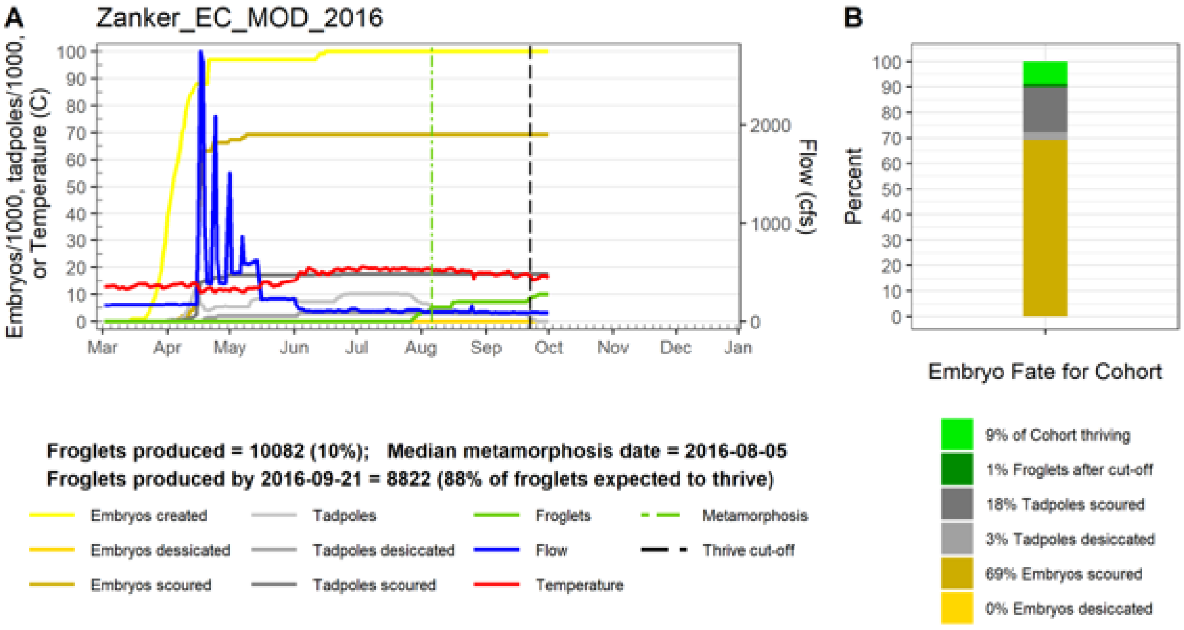


Figure 6. Dry water year type with breeding threshold temperature set at 11 °C. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. The onset of breeding occurred prior to peak flows but most of the oviposition occurred after the primary peak so scour mortality of egg masses was much lower than was predicted at the 10 °C breeding threshold temperature. Desiccation of egg masses occurred on the descending limb of the peak, but tadpole mortality was relatively low and survival to metamorphosis was similar to that seen at the 10 °C breeding threshold temperature. For the 65% design, three of the breeders were not able to find a suitable location for oviposition within the 60-day breeding window and specified movement distance of 30-m per day, so the model continued to run until the end of the time series on December 31st.



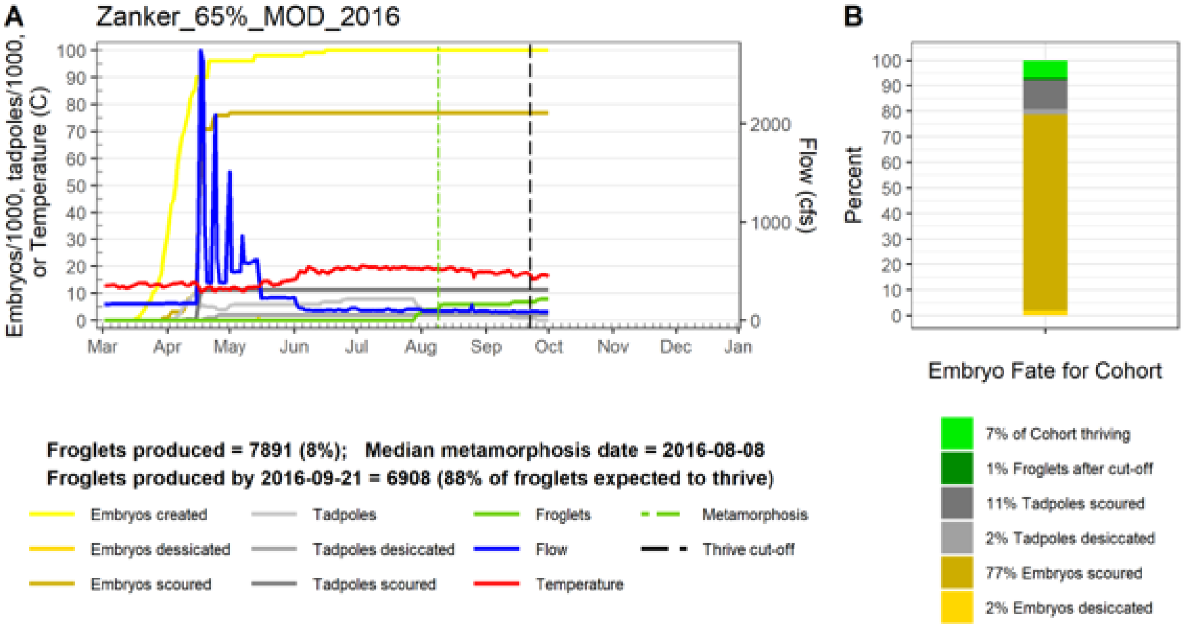


Figure 7. Moderate water year type with breeding threshold temperature set at 11 °C. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Nearly all of the oviposition occurred prior to the primary flow peak leading to high scour mortality of egg masses for both topographies. Tadpole mortality was relatively low and embryos that survived to reach metamorphosis emerged with ample time to forage and grow before winter, giving them a high probability of overwinter survival. The existing condition produced slightly more froglets, but overall production was low and differences between the topographies are not likely to have a population-level impact.

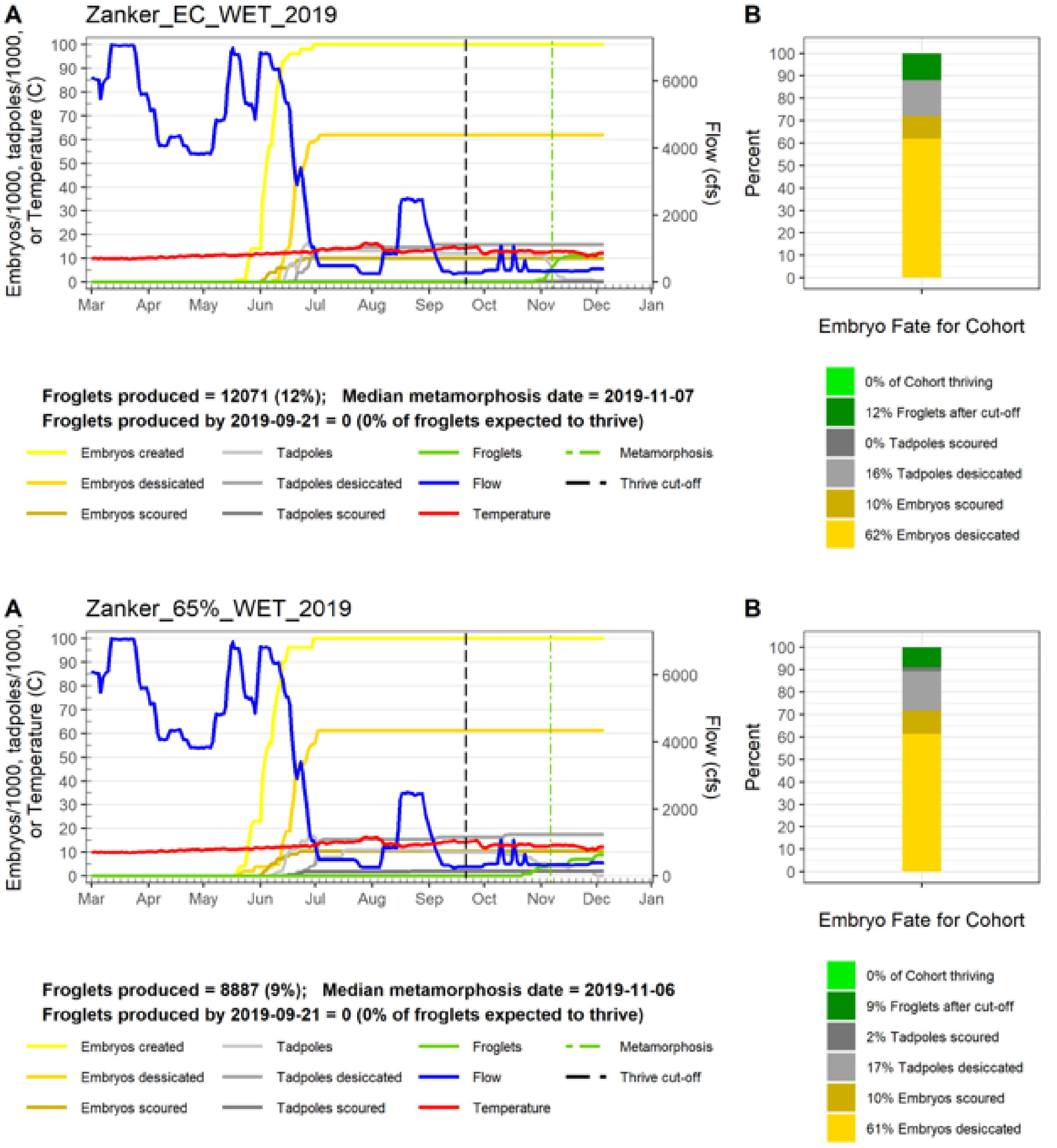


Figure 8. Wet water year type with breeding threshold temperature set at 11 ℃. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Breeding began on the descending limb of the spring hydrograph peak, resulting in high desiccation risk to egg masses for both topographies. While the existing condition produced slightly more froglets than the 65% design, metamorphosis dates were too late in the season for froglets to forage and grow before winter, lowering their probability of survival.

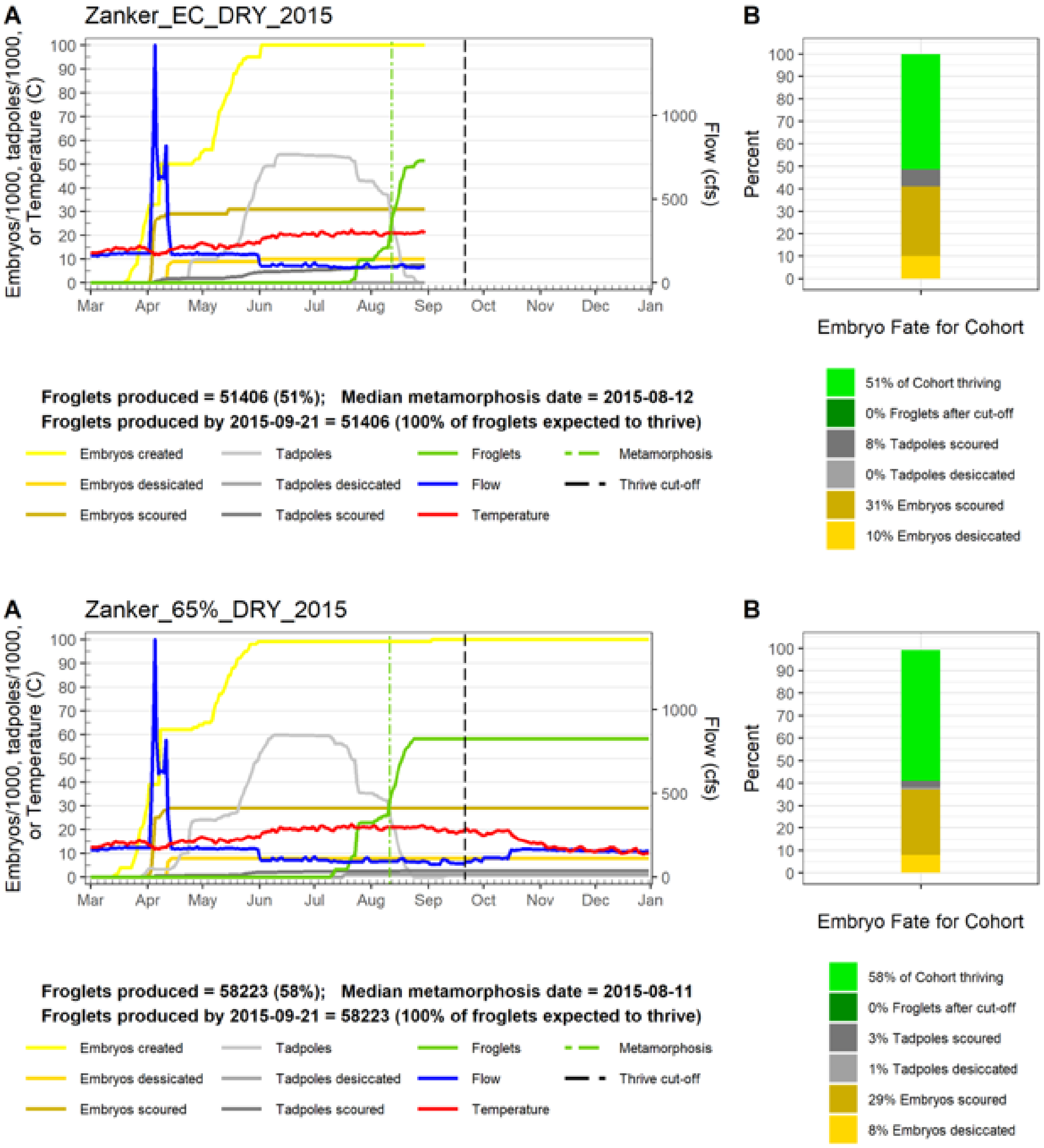


Figure 9. Dry water year type with breeding threshold temperature set at 12 °C. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Breeding began prior to peak flows but most of the oviposition occurred after the flow peak leading to low mortality of egg masses and tadpoles. Early metamorphosis dates provided ample time for froglets to forage and grow prior to winter, giving them a high probability of overwinter survival. The 65% design topography produced slightly more froglets, even though one of the breeders was not able to find a suitable oviposition location within the allotted time and movement distance.

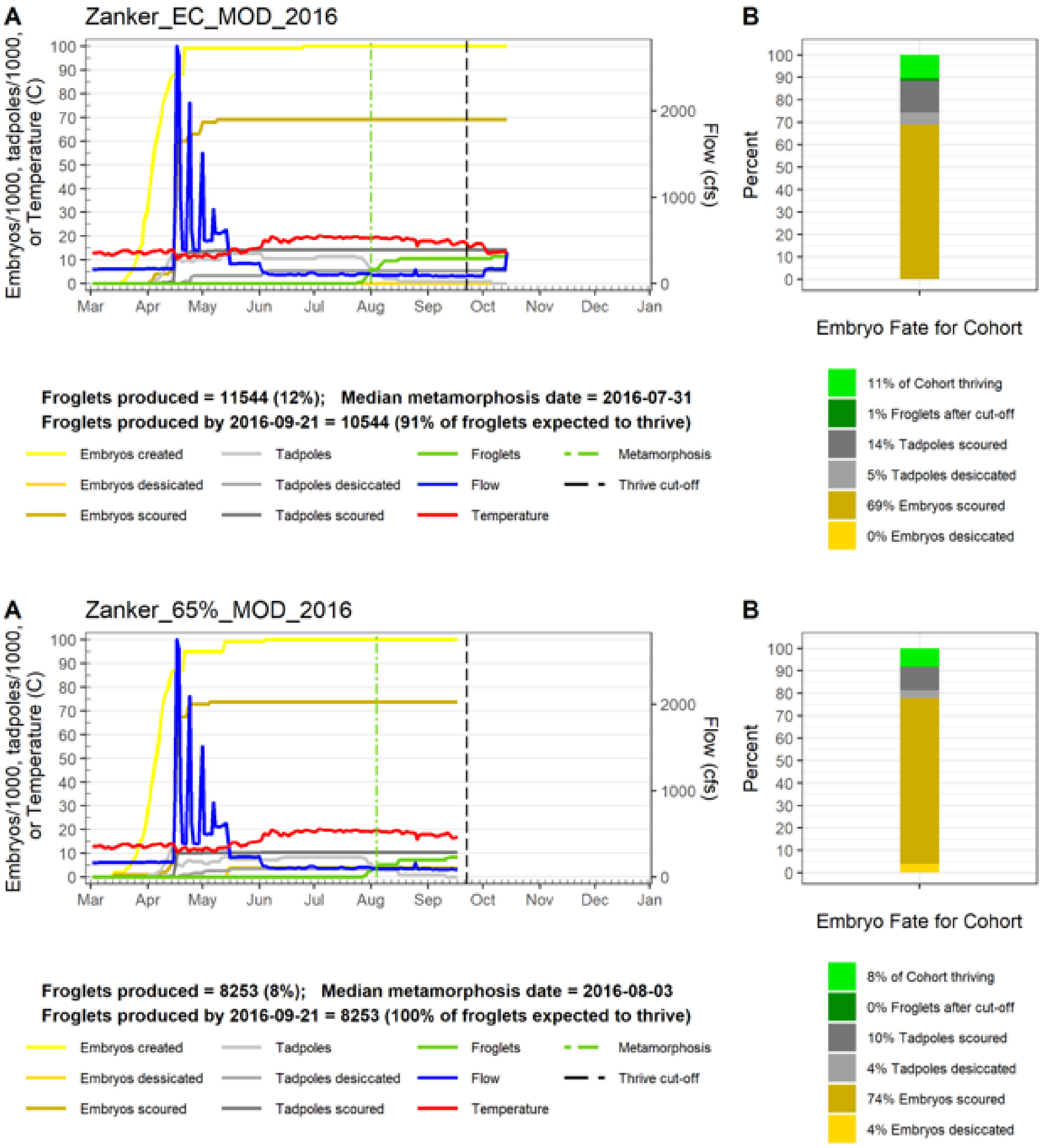


Figure 10. Moderate water year type with breeding threshold temperature set at 12 ℃. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Most of the breeding occurs prior the peak flows and scour mortality of egg masses is high. Tadpoles that hatched prior the flow peaks are also exposed to risk of scour during the multiple peaks in May. Egg masses deposited after the first two flow peaks hatched successfully and warmer waters in summer promoted rapid growth of tadpoles with median date of metamorphosis for the cohort in early August. These froglets have ample opportunity to forage and grow prior to winter and their probability of overwinter survival is presumed to be high. For the existing condition, mortality risk for egg masses was lower than seen for the 65% design but tadpole

mortality was slightly higher. Overall froglet production was slightly higher for the existing condition than for the 65% design.

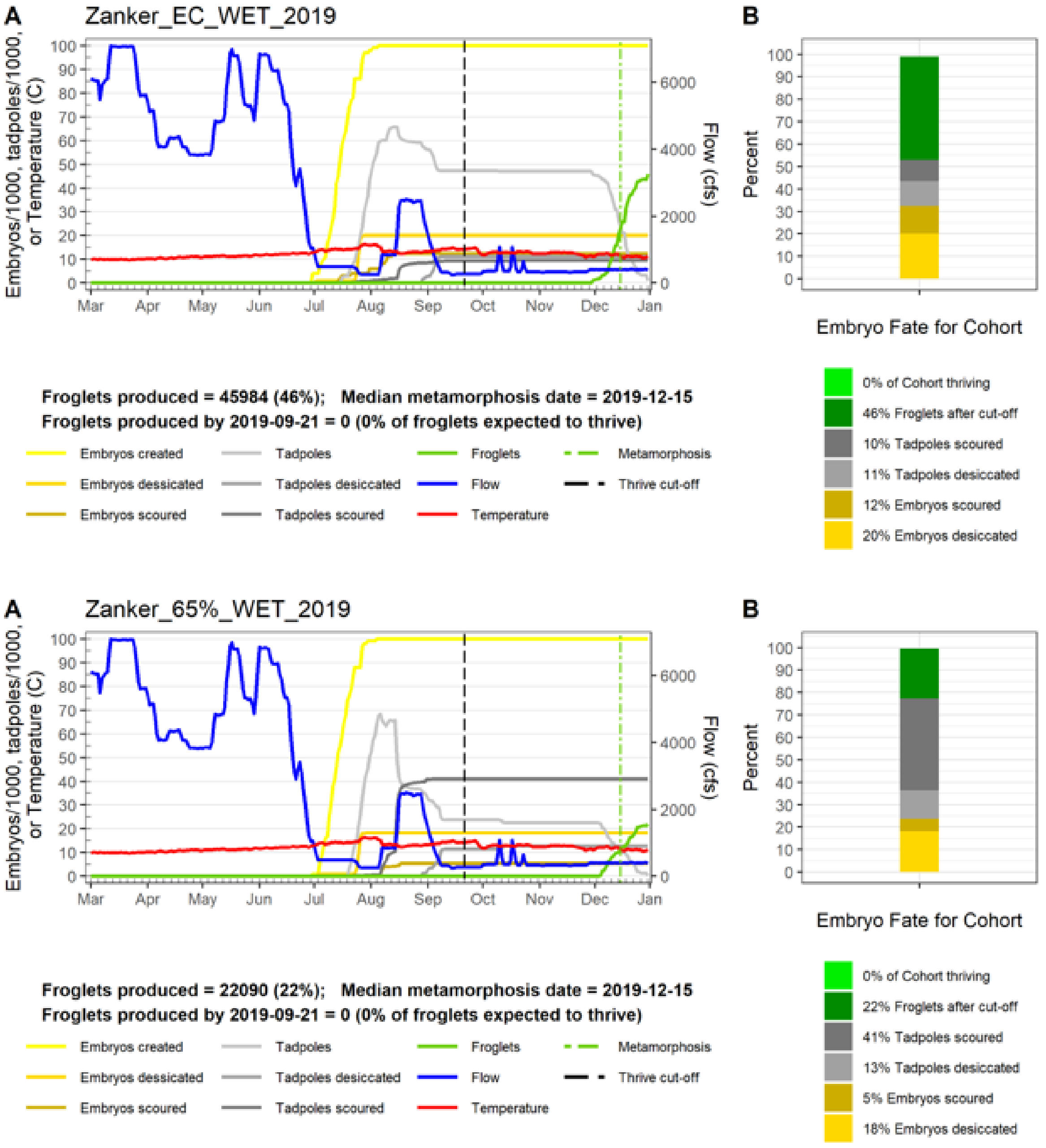


Figure 11. Wet water year type with breeding threshold temperature set at 12 ℃. Panel A displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph in Panel B displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. In the wet year example, water temperature remains below the 12 ℃ breeding threshold temperature until July, delaying oviposition. This leads to metamorphosis dates in December when food resources are scarce and ambient temperatures are not conducive to digestion and assimilation. Froglets emerging this late in the season have a low probability of surviving their first winter. So, while the model predicted twice as many froglets produced for the existing condition, this is not likely to contribute to population growth.

3.4 Invasive Species Impacts on FYLF Recovery

Invasive aquatic predators present a significant threat to reestablishment and recovery of FYLF at Zanker Family Farm. The assemblage of non-native fishes in the river leaves little opportunity for successful development of eggs and larvae in the main channel (Hayes and Jennings 1986). Shallow side channels and isolated pools may provide some refuge away from larger predatory fishes but provide habitat for other invasive predators (Holgerson et al. 2022). American Bullfrog (*Lithobates catesbeianus*) is native to the eastern United States and was introduced to California as a food source over a century ago (Jennings and Hayes 1985). This large voracious predator consumes a wide variety of vertebrate and invertebrate prey, competing with and preying upon the native amphibians. Bullfrog tadpoles grow faster and significantly larger than any native tadpoles making them less susceptible to fish predation. Red Swamp Crayfish (*Procambarus clarkii*), native to the southern United States, also poses a threat to FYLF recovery by consumption of eggmasses. Measures to limit predation pressure by invasive aquatic predators of FYLF through habitat manipulation may help support recovery of FYLF but there is overlap in habitat preferences so there’s not a simple prescription. Restoration of natural riverine processes may be most successful at limiting invasive aquatic predators and promote native amphibians. Native predators, such as the North American River Otter (*Lontra canadensis*) readily consume bullfrogs and crayfish, helping control invasive predator populations and may support FYLF recovery.

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Appendix D: Riparian Recruitment Modeling – TARGETS 2-D

APPENDIX D. ZANKER FARM SALMONID HABITAT RESTORATION PROJECT 100% DESIGN REPORT TARGETS-2D DESIGN EVALUATION

The Tool for Achieving Riparian Germination and Establishment of Target Species (TARGETS) was developed to evaluate and quantify the effects of physical topography, shallow groundwater, and annual hydrology on riparian hardwood quantity and distribution. TARGETS can be used to evaluate the effect of instream flows or to evaluate how much and where proposed channel designs improve passive recruitment opportunities. The TARGETS-2D model was used to evaluate the effects of the 65% physical restoration designs on cottonwood and narrowleaf willow passive recruitment. As only minor changes to floodplain surfaces were made at the 90% and 100% design stages, TARGETS was not revised based on the 90% and 100% designs.

1.1 Introduction

Passive recruitment is the process of plant reproduction without direct human intervention. Passive recruitment can be from sexual (i.e., seeds) or asexual reproduction (i.e., stems or root fragments). Riparian hardwood seedlings respond opportunistically to exposed sediment, moist seedbeds, rate of flow recession, and interannual bed scour. Seedlings at ground surface elevations above the low-flow channel margin are vulnerable to desiccation, but less vulnerable to scour from winter high flows. Seedlings lower in bank elevation, especially along the low-water margin, are more vulnerable to scour, but less vulnerable to desiccation. If a seedling survives desiccation in the first growing season, seedling roots are likely to grow to constantly available soil moisture thereby reducing desiccation mortality. Channel bed scour is the most probable mortality agent to kill seedlings after the first growing season is complete. The balance between desiccation and scour defines a window of riparian hardwood recruitment opportunity along the riverbank (Wilcock et al. 1995).

1.1.1 TARGETS Model Overview

TARGETS models passive riparian hardwood recruitment from seeds. The original TARGETS model was developed in 2004 (Alexander 2004) and updated in 2018 (Poulsen et al. 2019). The original TARGETS model was a cross section-based one-dimensional model that predicted the bank location where Fremont cottonwood (*Populus fremontii*) seed germination and survival through the first growing season (i.e., initiation) could occur in response to annual streamflows. The original TARGETS could only predict location, not the density of hardwoods initiated. The cross section-based TARGETS model was updated to create TARGETS-2D (Railsback and Bair 2023).

TARGETS-2D is based in part on the Mahoney and Rood (1998) box recruitment model, which was also the basis for previous versions of TARGETS. TARGETS-2D incorporates streamflow magnitude, timing, duration, and rate of change in combination with site topography, stage–discharge relationships, root growth rates, and seed dispersal periods to forecast seedling survival during the modeled period. Inundation, desiccation, and scour are mortality agents that cause young seedlings to perish and are the direct result of biologic responses to changing hydrologic and physical conditions.

1.1.2 TARGETS Updates

The updated TARGETS-2D model design was strongly influenced by experience with previous model versions and the shortcomings related to common management questions. Many of the non-biological components of TARGETS-2D are reused from previous two-dimension river management models, especially the InSTREAM 7 trout model (Railsback et al. 2021a) and FYFAM, a frog breeding model (Railsback et al. 2016, Railsback et al. 2021b). Sub-models within TARGETS-2D continue to be refined based on model parameter sensitivity analyses (Railsback and Bair 2023).

The updated TARGETS-2D model uses the same basic methods for modeling seed establishment and survival as partially described by Poulsen et al. (2019). However, the updated model is terrain-based, not cross section-based, and uses two-dimensional hydraulic model output. TARGETS-2D models seed dispersal, seed, sprout, seedling, and dormant seedling developmental stages (Figure 1) and uses a terrain-based cell or mesh-based ground surface and hydraulic model output to model seedling establishment. Similar to previous versions of TARGETS, seedling desiccation and inundation mortality are modeled (Figure 1). However, scour mortality, and seed source location and dispersal characteristics have been added to the TARGETS-2D model. Fremont cottonwood and narrowleaf willow (*Salix exigua*) initiation were modeled as a function of the project’s annual hydrology and the proposed 65% design surfaces.

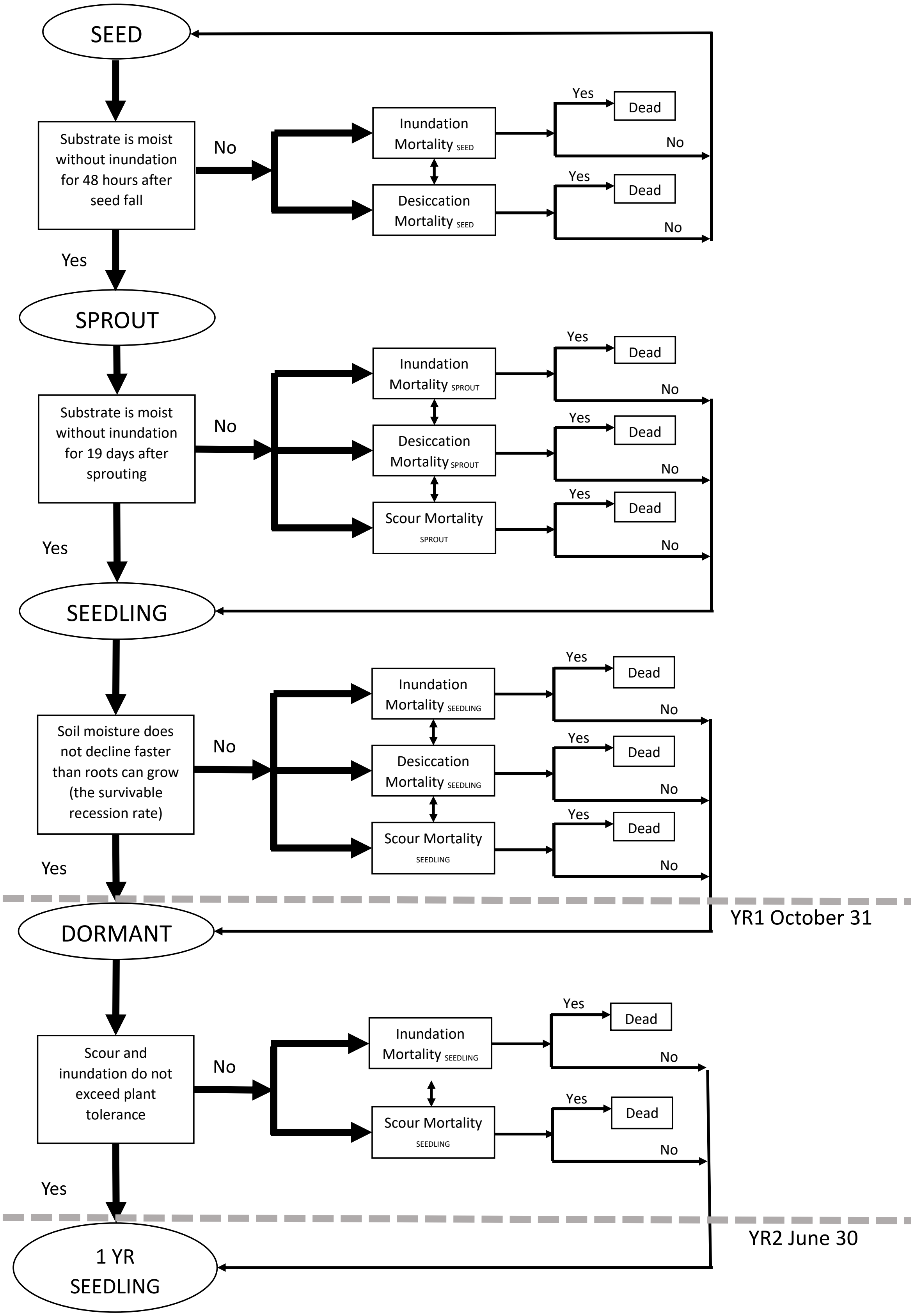

Figure 1. Schematic showing TARGETS-2D model decisions.

1.1.3 Sensitivity Analyses

A sensitivity analysis was conducted using TARGETS-2D and a set of simulation experiments that examined how strongly individual parameters affect the primary results of TARGETS-2D (Railsback and Bair 2023). A very simple approach was applied where one parameter was analyzed at a time, running the model once for each parameter value over a range of feasible values. All other parameters were kept at their standard value. Results were presented graphically, as plots of model results (number of seedlings alive at the end of a simulation) vs. parameter value. The slopes of these plots are the primary measures of sensitivity: the higher the slope, the stronger the effect of the parameter. Higher coefficients of correlation R^2 also indicate a stronger (relative to the model's stochasticity) or more linear parameter effect.

Parameter sensitivity can vary among simulated sites and hydrographs; for example, parameters for scour mortality can have no effect in simulations with no floods but have a larger effect when floods occur. Simulations were run for a 13-month period, starting on May 1, to include the seed dispersal period through most of the following winter–spring high flow season. Results from the sensitivity trials are not presented in this report, but are included in Railsback and Bair 2022 (https://ecomodel.humboldt.edu/targets-2d-riparian-seed-establishment-model).

1.2 Goals and Objectives

The TARGETS-2D modeling goal was to forecast the passive riparian hardwood recruitment response to proposed 65% design surface topography and compare it to existing conditions. Accordingly, the TARGETS modeling objectives were:

- Evaluate passive recruitment trends for Fremont cottonwood and narrowleaf willow.
- Evaluate the predicted seedling quantities and bank locations for existing and 65% ground surfaces.
- Evaluate the relationship between water year type and passive recruitment for each species.
- Identify specific improvements in the design grading that could improve natural riparian recruitment.

Key conclusions of the TARGETS analysis detailed in the following sections are:

- The 65% design increases passive recruitment compared to existing conditions.
- The highest quantities of seedlings for both species occur in the driest water year types.
- There is a strong possibility of vegetation encroachment along newly constructed channels.

1.3 Methods

1.3.1 Physical

TARGETS-2D used a high-resolution ground surface topography developed from a combination of bare earth LiDAR, surveyed channel bathymetry, and supplemental ground surface surveys. The bathymetry and supplemental ground surface points were surveyed in 2021–22. The ground surface used in the model did not include vegetation.

TARGETS-2D used relationships between physical topography and discharge modeled in HEC-RAS. A 2-dimensional hydraulic model was developed for existing and 65% design conditions (McBain Associates 2021, 2022a, McBain Associates 2022b). The HEC-RAS model simulated existing and design conditions at a range of streamflows and produced depth, water surface elevation, and shear stress results. A detailed description of the 65% design hydraulic model development and results can be found in Appendix A of the Zanker Farm Salmonid Habitat Restoration Project 65% Design Report.

Substrate capillarity, or the height that water is “wicked up” by substrate (i.e., the capillary fringe), acts as a natural buffer against diurnal fluctuations and moderate drops in water surface elevation on potentially vegetated surfaces. Soil capillarity was estimated to be 0.2 m across the entire project area, which is representative of medium sand (Reid et al. 1987). Medium sand was used as a general substrate descriptor because there is coarse to finer sand in the interstitial matrix between cobbles and gravels.

1.3.2 Hydrologic

Fremont cottonwood and narrowleaf willow recruitment were modeled as a function of five streamflow scenarios (Table 1, Figure 2) that were selected from the 2010 to 2022 streamflow period of record at the USGS gage near La Grange. Each scenario started on May 1 and ended on June 30 of the following year. Each scenario was developed so that a different water year type was modeled in the first year. A portion of a second water year was included to assess the role of winter and spring streamflows on establishing seedlings. Scenarios were developed to include one of five water types with a following year with flood flows, or contrast to the first year. For example, scenario 4 (Dry year followed by a Wet year) provides more contrast to Scenario 5 (Critically Dry year followed by Critically Dry year) than the 2020–21 (Dry followed by Critically Dry) period would have. Water year types were determined using the San Joaquin Valley 60-20-20 index reported on the California Department of Water Resources’ website, https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST.

Table 1. Five hydrologic scenarios modeled to assess water year type trends.

Scenario	**First year after May 1**		**Peak Q after May 1 (cfs)**	**Second year through June 30**		**Peak Q before June 30 (cfs)**
1	Wet	2017	9,161	2018	Below Normal	4,586
2	Above Normal	2010	5,520	2011	Wet	8,380
3	Below Normal	2018	4,041	2019	Wet	7,097
4	Dry	2016	860	2017	Wet	14,277
5	Critically Dry	2021	179	2022	Critically Dry	1,950

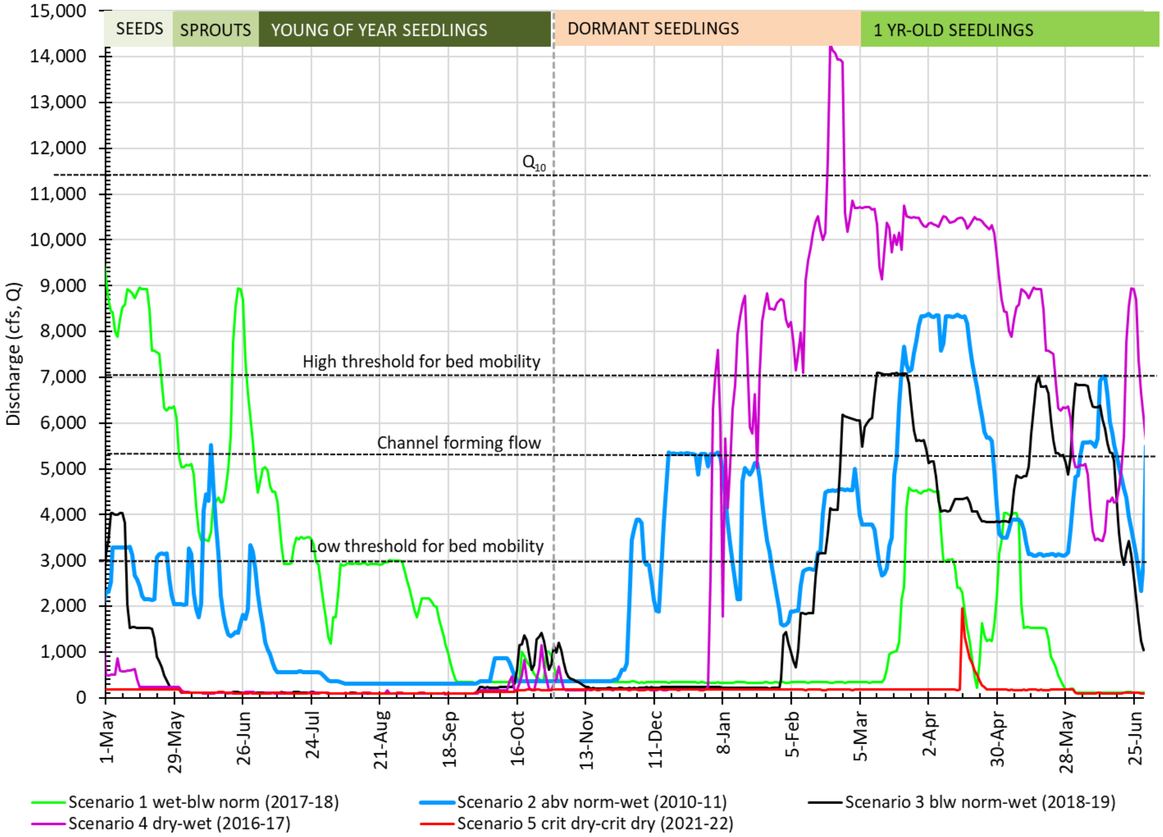

Figure 2. Five TARGETS 2-D modeled water year scenarios.

The general bank locations where seedlings established at the end of the first year and through June 30 of the following year were assessed using inundation classes. Physically, hydrologically, or biologically important streamflows (Table 2) were used to define eight inundation classes: <150 cfs, 150–300 cfs, 300–1,130 cfs, 1,130–3,000 cfs, 3,000–5,400 cfs, 5,400–7,050 cfs, and 7,050–11,500 cfs. Two assumptions are that channel encroachment risk may be highest in inundation classes associated with the lowest streamflows below 300 cfs, and that inundation classes between 300 and 3,000 may best illustrate whether designed floodplains are promoting passive seedling recruitment over 65% design conditions.

Table 2. Streamflows used to define eight inundation classes.

Streamflow (cfs)	Notes/Justification
150	Q_2 21-day inundation duration during seed dispersal Low range of spawning flows
300	Late summer/early fall average baseflows High range of spawning flows
1,130	Streamflow recurrence interval ~1.11 yr Approximate floodplain inundation threshold (Stillwater Sciences 2013)
3,000	Approximate post-NDPP 1.5-yr streamflow recurrence interval (McBain & Trush 2000) Low threshold for bed mobility (McBain & Trush 2004)
5,400	Flood control bench/winter maximum power generation Channel-forming flow (McBain & Trush 2000)
7,050	Streamflow recurrence interval 5 yr Close to high threshold for bed mobility (McBain & Trush 2000)
11,500	Streamflow recurrence interval ~10 yr (England et al. 2019)

1.3.3 Biological

Two riparian hardwood species, Fremont cottonwood and narrowleaf willow were selected for modeling. Fremont cottonwood grows into a large tree and may reach heights of 150 ft or more. Fremont cottonwood is an important contributor of large wood and enhances the vertical structure of riparian vegetation on upper bar and floodplain surfaces. Beyond older Fremont cottonwood trees, few Fremont cottonwood seedlings and sapling were observed during late May 2021 fieldwork, suggesting that passive Fremont cottonwood recruitment in the Project area is infrequent under existing conditions. Narrowleaf willows may form dense thickets up to 25 ft in height in undisturbed locations. Narrowleaf willow seed dispersal overlaps with other willows, however, its flowering and seed dispersal period extends father into the summer than other willows. Narrowleaf willow is unusual among willows in that it may form more than one iteration of catkins per growing season (i.e., it can flower and seed more than once), which may extend seed dispersal over a couple of months well into summer low-flow months.

Fremont cottonwood and narrowleaf willow were chosen as target species for modeling because their seed dispersal periods bracket the seed dispersal periods for many other riparian hardwood species along the lower Tuolumne River. The potential initiation response of other riparian hardwood species can be inferred through forecasting the initiation success of Fremont cottonwood and narrowleaf willow. The seed dispersal of Fremont cottonwood begins before other species, except for arroyo willow, and narrowleaf willow seed dispersal is the last willow or cottonwood species to disperse seeds during summer months in the Project area. The seed dispersal periods quantified over three years on the Tuolumne and San Joaquin rivers by Stella and Battles (2010) were used the Zanker Project TARGETS-2D modeling (Table 3).

Table 3. Fremont cottonwood and narrowleaf willow seed dispersal used in the Zanker Project Area TARGETS-2D model, from Stella and Battles (2010).

Species	Begin	Peak	End	Total Days
Fremont cottonwood	8-May	24-May	4-Jun	27 days
narrowleaf willow	1-Jun	21-Jun	11-Jul	40 days

1.3.3.1 Seed Life Stage

The seed life stage for TARGETS modeling was defined as the initial condition and lasted until the seed began to grow its primary root to become a sprout. Cottonwood and willow seeds are small and seed viability decreases with seed age. Stella et al. (2010) found germination decreased to 50% after 54 days for Fremont cottonwood seeds and 44 days for narrowleaf willow. Generalizing the seed viability longevity information in Stella et al. (2010), Fremont cottonwood has ~60% gemination (Figure 3) and narrowleaf willow has ~70% gemination (Figure 4) at 30 days. Narrowleaf willow seed viability reaches close to zero at 65 days (Figure 4) and 90% of Fremont cottonwood seeds were dead by 90 days (Figure 3). In addition to reduced germination, older seeds took longer to germinate; 60 day-old took eight days for 50% to germinate. The seeds still require saturated soil surface to germinate, it just takes longer for germination to occur. Stella et al. did not explore the role of temperature on seed viability. In the TARGETS-2D model all seeds were dead at the onset of dormancy (Oct 31).

Cottonwoods and willows are often assumed to be prolific seeders, but female tree location within the Project site was unknown. Therefore, TARGETS-2D model runs used three million seeds for each species uniformly dispersed across the modeled area. Each location (mesh cell) in the model had an equal probability of receiving a seed.

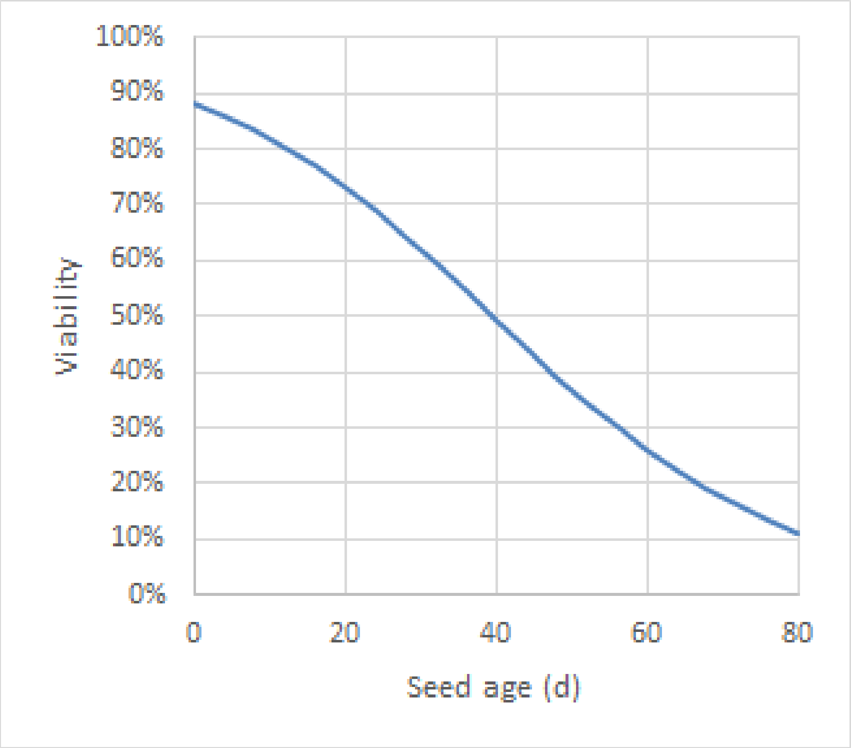

Figure 3. Fremont cottonwood seed viability longevity function used in TARGETS-2D, adapted from Stella et al. (2010).

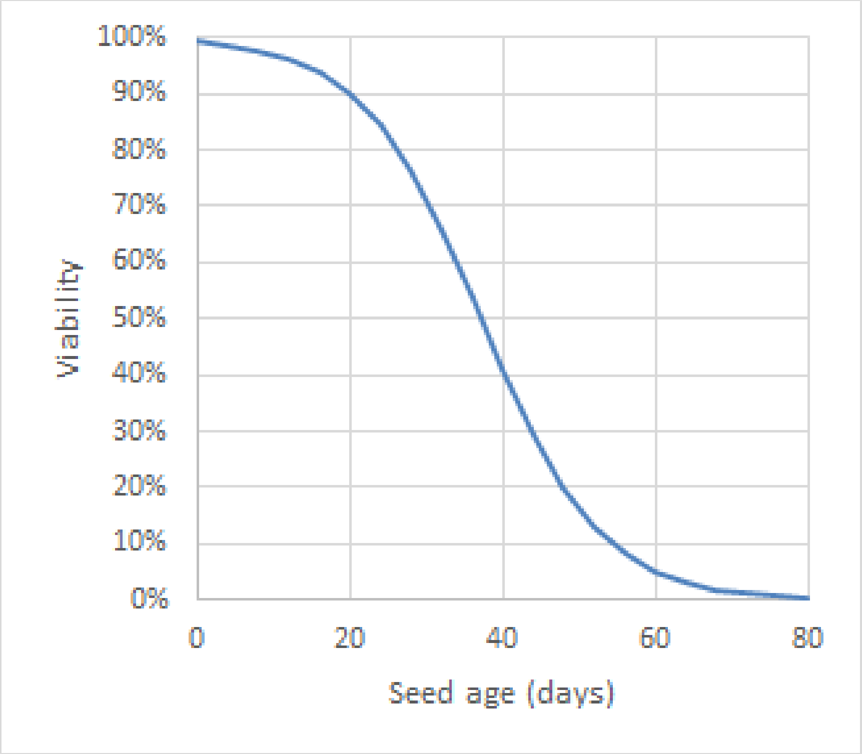

Figure 4. Narrowleaf willow seed viability longevity function used in TARGETS-2D adapted from Stella et al. (2010).

1.3.3.2 Sprout Life Stage

A seed may germinate and become a sprout if the appropriate conditions exist. The time it takes a seed to land, imbibe enough water to germinate, and form a tap root is a minimum of 72 to 120 hours (Schreiner 1974, Young and Young 1992, Pregitzer and Friend 1996, Hoopa Valley Tribe and McBain & Trush 2007). The ability for a seed to directly contact moist soil may limit germination if the soil on which a seed lands does not remain moist. Once seeds land on moist, fine-textured substrate, germination may occur rapidly. A few cottonwood seeds may germinate within 36 hours of being sown on fine sand, though most seeds germinate within 48 hours of landing on substrate and begin to form cotyledons and a tap root immediately (Hoopa Valley Tribe and McBain & Trush 2007). The length of time that a seed was in the sprout stage (Figure 1) is a user-defined model parameter and was 72 hours for both cottonwood and narrowleaf willow in the Zanker Project Area TARGETS model.

1.3.3.3 Seedling Life Stage

The seedling life stage begins 72 hours up to 120 hours after germination (Figure 1). A sprout becomes a seedling when it can grow roots fast enough to follow declining water levels. Willow roots grow at about 1 to 2.75 cm per day and cottonwood roots at 2 to 2.5 cm per day (Segelquist et al. 1993, Mahoney and Rood 1998, Amlin and Rood 2002, Stella et al. 2010). One TARGETS-2D model assumption is that roots stop growing once low-water conditions have been reached. Surviving seedlings roots are assumed to be in contact with perennial water sources at the end of the first growing season when the seedling becomes dormant and can no longer be killed by rapid flow recession. The root growth rate is a user-defined model parameter and was 2.5 cm per day for Fremont cottonwood and 1 cm per day for narrowleaf willow roots in the Zanker Project area TARGETS model.

1.3.3.4 Dormant Seedling Life Stage

A seedling becomes a dormant seedling at the end of the first growing season (Figure 1). The time when seedlings become dormant may vary from year to year based on seasonal growing conditions. The onset of dormancy is a user-defined model parameter and was defined as October 31 for both cottonwoods and willows in the Zanker Project area TARGETS model. A dormant seedling is physiologically prepared to be frozen and/or inundated for long periods. At the onset of dormancy, a seedling may be subject to a variety of stressors before the second growing season begins. The primary mortality agents that dormant seedling face during this time are inundation or flood scour.

1.3.3.5 1-Year Old Seedling Life Stage

A dormant seedling becomes a 1 yr-old seedling when the model ends on June 30. Growth characteristics in the second year and the beginning of the second growing season have not been included in the current version of the TARGETS-2D model.

1.3.4 Mortality Agents

TARGETS-2D models three mortality agents: desiccation, inundation, and scour, which are modeled as a function of a survival probability. Survival is simulated by first calculating a daily survival probability S that depends on the plant life stage and its location. Whether the plant survives or dies is determined stochastically, as a Bernoulli trial, with S as the probability of survival.

1.3.4.1 Desiccation Mortality

Desiccation in the first growing season is assumed to be a primary cause of mortality (Figure 1). If seeds do not land on moist soil or the soil dries, they perish. Desiccation mortality may also result when a seedling’s growing roots cannot keep up with receding groundwater and soil moisture. Rapidly growing roots must maintain contact with water or soil moisture in the capillary fringe for seedlings to survive. If growing roots are not in contact with soil moisture, they perish from desiccation (Figure 1). The estimated probability value of a growing seedling surviving desiccation is a user-defined model parameter and was defined as 0.5 in the Zanker Project area TARGETS model.

1.3.4.2 Inundation Mortality

Inundation in the first growing season may be uncommon on some regulated rivers but may be a significant cause of mortality in unregulated rivers (Figure 1). Inundation is assumed completely fatal for seeds and sprouts because they may be dispersed directly into the water or are easily detached from the substrate and washed away. Seed and sprout inundation mortality is assumed to occur on any day the water depth is greater than zero where they are located.

Seedlings that are partially or fully submerged may perish due to prolonged periods of inundation. Auchincloss et al. (2012) assessed the vulnerability of Fremont cottonwood seedlings to inundation mortality. The study found that seedling roots that were inundated for long periods to the ground surface but not the above ground had similar survival to plants that were not inundated, and that inundation mortality was most significant when some portion of the above ground stem was inundated. In the TARGETS model, a plant is considered inundated when the water depth equals or exceeds the plant’s root depth, a simple approximation of when depth is sufficient to impair gas and light transfer in the stem and leaves. Growing seedlings are more prone to inundation mortality than dormant seedlings because they depend on light and respiration, which inundation interrupts. The estimated probability value of a growing seedling surviving inundation is a user-defined model parameter and was defined as 0.96 in the Zanker Project area TARGETS model. A probability value of 0.96 provides similar mortality results to the Fremont cottonwood mortality observations from Auchincloss et al. (2012) of 22%, 50%, and 71% at 1, 2, and 4 weeks submergence, respectively (Figure 5). An estimated probability value of 0.96 causes 98% seedling mortality after 100 days of inundation.

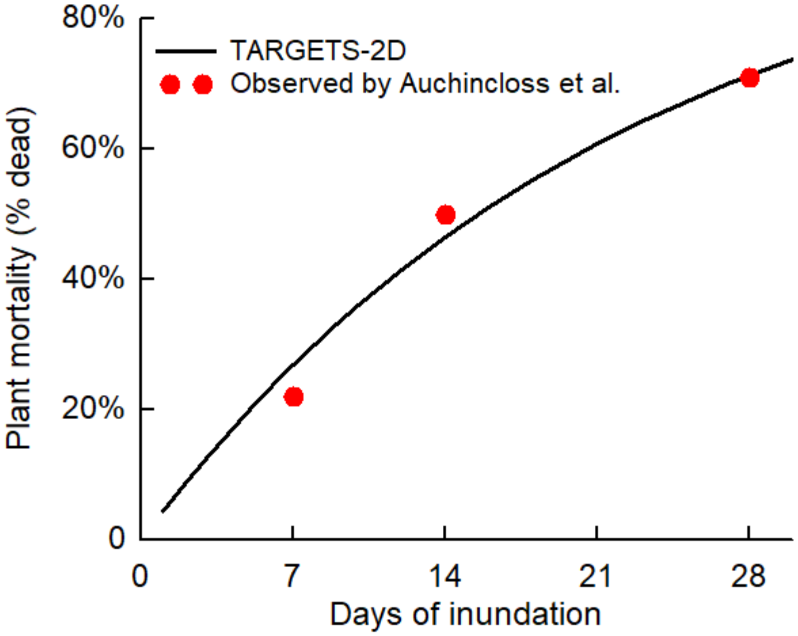

Figure 5. Estimated daily seedling survival probability value of 0.96 used in the TARGETS-2D model (black line) and Fremont cottonwood observed mortalities of 22%, 50%, and 71% at 1-, 2-, and 4-weeks submergence, respectively (Auchincloss et al. 2012).

Dormant seedlings are less dependent on light because they lack leaves and respire less and are therefore less susceptible to inundation mortality while dormant. Dormant seedlings have a higher probability of daily survival if inundated. The estimated probability value of a dormant seedling surviving inundation is a user-defined model parameter and was defined as 0.99 in the Zanker Project Area TARGETS model. An estimated probability value of 0.99 for dormant seedlings assumes that dormant seedling mortality is 1/3 the values observed by Auchincloss et al. (2012) and causes 63% dormant seedling mortality after being inundated for 100 days.

1.3.4.3 Scour Mortality

Root depths vary between seedlings and bank locations where they grow. As flood water recedes, higher elevation bank locations are exposed first and are where older seedlings within a cohort are located (Bair 2001)001). Seedlings growing at higher elevation bank locations have significantly longer roots than at those growing lower on the channel-bank (Bair 2001). Root growth rate is a user-defined model parameter in the TARGETS-2D model (Section 1.3.3.3); Fremont cottonwood root growth was set at 2.5 cm per day and narrowleaf willow at 1 cm a day until summer low-water elevations are reached. Seedlings at lower bank positions not only have shorter roots but they also may experience higher shear stresses during floods than those farther up the channel-bank.

Scour mortality is the outcome of water velocity and shear stress effects on seedlings and dormant seedlings. Due to their young age and very small size, seeds and sprouts would be killed by inundation before suffering from scour (Section 1.3.4.2). Scour mortality represents multiple actual processes, including plants being pulled out by the force of water on their stems and leaves, scouring of the sediment in which plants are rooted, and impact damage to stems and leaves from debris in the water. Riparian plant scour has been studied and modeled in detail, e.g., by Pollen and Simon (2005) and Bankhead et al. (2017). TARGETS-2D uses a highly simplified approach that avoids the need for complex assumptions and inputs while still making scour survival depend on the magnitude and timing of high-flow events.

Scour mortality is assumed to be a function of both hydraulic shear stress, which reflects the force of water on both plants and sediment, and seedling root depth, with longer roots offering higher resistance to scour. The root breaking strength relationship that TARGETS-2D uses was developed based on field measured stem diameter and root depth data collected by McBain Associates staff (Bair 2001, Hoopa Valley Tribe and McBain Associates 2018) and root breaking relationships developed by Bankhead et al. (2017). The root breaking strength relationship assumes scour mortality occurs whenever the ratio of shear to root depth is above a threshold. A value of 2.46 lbs/ft^2 shear per foot of root length (385 pascals/meter) is a reasonable threshold based in part on Bankhead et al. (2017) and field data analyses.

1.3.1 TARGETS-2D Passive Recruitment Forecast Evaluations

It is reasonable to expect that the 65% design will improve passive recruitment over existing conditions. However, the magnitude of difference between design and existing conditions is unknown. It is also unknown whether there will be a greater difference in passive recruitment associated in some water year types and not others between 65% design and existing conditions.

1.3.1.1 65% Design Comparison to Existing Conditions

The 65% design forecasts were compared to existing condition forecasts. Passive recruitment trends for Fremont cottonwood and narrowleaf willow were evaluated separately. The total 1-yr old seedling quantity was compared for existing and 65% design conditions to evaluate differences in passive recruitment response magnitude. Seedling demographic changes were evaluated and compared between existing and 65% design conditions. The proportion of seeds that sprouted, sprouts that became seedlings, seedlings that went dormant, and dormant seedlings that survived to become 1 yr-old seedlings was calculated, summarized, and compared between existing and 65% design conditions. The proportion of seeds that became sprouts, seeds that became seedlings, seeds that became dormant seedlings, and seeds that became 1-yr old seedlings was calculated, summarized, and compared between existing and 65% design conditions.

Established 1-yr old seedling channel bank-locations and channel-bank heights under existing and 65% design conditions were evaluated to address the question of whether floodplain designs increased passive recruitment over existing conditions in channel bank positions and whether the designed floodplains were likely to perform as designed. One-year old seedlings were sorted into eight inundation classes (Section 1.3.2, Table 2) based on the channel bank elevation where they established. Histograms showing the number of 1 yr-old seedlings within each inundation class were developed for each hydrologic scenario, and existing and 65% design conditions. Histograms for existing conditions were visually compared to 65% design conditions to assess differences and design performance.

1.3.1.2 Assessing Water Year Type Influence on Passive Recruitment

Fremont cottonwood and narrowleaf willow seedling quantities associated with each hydrologic scenario were compared between existing and 65% design conditions. Generally, if one water type had more predicted seedlings than others, then it is reasonable to expect that seedling initiation events for a given species are favored by that water year type. However, years that are associated with high passive recruitment, often have large quantities of seedlings in both existing and design conditions, with the design performing only modestly better than existing conditions. In water year types when recruitment overall is lower, there can often be a larger magnitude of difference between existing and 65% design conditions, with design conditions establishing a substantially greater number of seedlings over existing conditions. Seedling quantity for each species and hydrologic scenario were compared between existing and 65% design conditions to assess the role of water year type on passive recruitment.

1.4 Results

Successful initiation of many riparian hardwoods relies on the annual cycle of spring floods, the timing and rate of receding water, and areas of open moist ground near the wetted channel (Bradley and Smith 1986, Scott et al. 1993). Seed germination can lead to successful establishment if flows recede gradually enough to provide favorable soil moisture conditions to growing seedling roots. The TARGETS-2D predicted that the 65% design will significantly increase willow and cottonwood passive recruitment after Project construction. The model results are summarized by species, water year scenario, and life stages.

1.4.1 65% Design Comparison to Existing Conditions

In all hydrologic scenarios Fremont cottonwood and narrowleaf willow had higher quantities of 1-yr old seedlings under 65% design conditions when compared to existing conditions (Table 5 through Table 13 and Figure 6 through Figure 15). Overall, the highest 1-yr old cottonwood and narrowleaf willow seedling quantities occurred Scenario 5 (a Critically Dry year followed by a Critically Dry year; Table 8, Table 13, Figure 10, and Figure 15).

Modeled seedling quantities were summed across Scenario 4 (2016–17), Scenario 1 (2017–18), and Scenario 3 (2018–19), a three-year establishment period to show the number of Fremont cottonwood and narrowleaf willow seedlings that would have established during the three-year period. The water year scenarios corresponding to these years were Dry, Wet, and Below Normal. During the three-year period, 2,483 1-yr old cottonwood seedlings established under existing conditions, compared to 11,763 1-yr old seedlings in the 65% design. During the same period, 7,002 1-yr old narrowleaf willow seedlings established under existing conditions, compared to 13,320 1-yr old narrowleaf seedlings established under 65% conditions. There was a 658% increase in cottonwood seedling production and a 250% increase in narrowleaf seedling production during the 2016 to 2019 period under 65% design conditions when compared to existing conditions.

Fremont cottonwoods disperse seeds in May, which leads to seedlings establishing at higher bank elevations than narrowleaf willow. Fremont cottonwood annually established seedlings above 1,130 cfs in all scenarios except for Scenario 5 (Critically Dry year followed by a Critically Dry year; Table 5 through Table 8, Figure 6 through Figure 10). In Scenario 1 through Scenario 4, Fremont cottonwood established at higher bank elevations in the 65% design when compared to existing conditions. The highest elevation Fremont cottonwood bank establishment was between 7,050 and 11,500 cfs associated with Scenario 1 (2017–2018 Wet–Below Normal, Figure 6) and Scenario 2 (2010–2011 Above Normal–Wet, Figure 7). Scenario 1 (2017–2018 Wet–Below Normal) had the greatest and highest elevation range of established cottonwood and narrowleaf willow seedlings of any modeled year (Figure 6, Figure 11). Increases in Fremont cottonwood 1-yr old seedlings in the 1,130 to 3,000 inundation class over existing condition were due to increased floodplain area in the 65% design, suggesting that 65% design floodplain benches in the 1,130 to 3,000 cfs range will perform as intended (Figure 16).

Narrowleaf willow seedlings typically established at lower bank elevations due to their later seed dispersal periods. In all scenarios, some narrowleaf willow seedlings established below 300 cfs annually (Figure 12 through Figure 15). The highest bank elevation bank of 1-yr old narrowleaf willow establishment was associated with Scenario 1 (a Wet year followed by a Below Normal year, Figure 12) and Scenario 2 (an Above Normal year followed by a Wet year, Figure 12), with Scenario 2 having the greatest elevation range of established narrowleaf willow seedlings of any modeled year. Overall, 1-yr old narrowleaf willow seedlings established at lower bank elevations than cottonwood.

The Scenario 1 (Wet–Below Normal, Figure 11) and Scenario 2 (Above Normal–Wet, Figure 12) narrowleaf willow results indicated that under existing conditions, there were few opportunities for narrowleaf willow 1-yr old willow establishment, but under the 65% design conditions, not only was 1-yr old seedling establishment increased, the elevation range for narrowleaf willow seedlings was expanded. The increase in 1-yr old narrowleaf willow seedlings associated with the 65% design in Scenario 5 was the result of increased ground surface area at a range of streamflows and an increase in overall ground surface variability.

Fremont cottonwood had fewer seedlings than narrowleaf willow under existing conditions in all scenarios except Scenario 5 (2021–2022, Critically Dry–Critically Dry). However, under 65% design conditions, cottonwood passive recruitment increased 2.7 times over existing conditions (Table 8) and exceeded narrowleaf willow seedling. The 65% design and Scenario 5 model results were the only instance in the model forecasts where cottonwood exceeded narrowleaf willow 1-yr old seedling establishment in drier years.

Table 4. Scenario 1, Fremont cottonwood 2017 Wet water year to 2018 Below Normal water year modeled seedling demographic results.

Life stage	**Existing conditions**	**65% design conditions**
Seeds	3,000,000	
Seeds that sprouted	4.6%	5.5%
Seeds that became seedlings	0.2%	0.4%
Seeds that survived to dormancy October 31	0.0%	0.1%
Seeds that survived winter and spring floods to June 30 of next year	0.0%	0.1%
Sprouts became seedlings	5.1%	7.8%
Seedlings went dormant on October 31	0.4%	17.9%
Dormant seedlings survived the winter and spring floods	100.0%	100.0%
Inundation mortality	51.6%	56.7%
Desiccation mortality	48.4%	43.2%
Scour mortality	0.002%	0.003%
Number of surviving seedlings June 30	27	2,294

Table 5. Scenario 2, Fremont cottonwood 2010 Above Normal water year to 2011 Wet water year type modeled seedling demographic results.

Life stage	**Existing conditions**	**65% design conditions**
Seeds	3,000,000	
Seeds that sprouted	13.6%	14.1%
Seeds that became seedlings	0.2%	0.3%
Seeds that survived to dormancy October 31	0.02%	0.1%
Seeds that survived winter and spring floods to June 30 of next year	0.02%	0.1%
Sprouts became seedlings	1.3%	1.9%
Seedlings went dormant on October 31	9.7%	36.7%
Dormant seedlings survived the winter and spring floods	98.3%	97.9%
Inundation mortality	37.8%	44.0%
Desiccation mortality	62.2%	56.0%
Scour mortality	0.003%	0.003%
Number of surviving seedlings June 30	511	2,892

Table 6. Scenario 3, Fremont cottonwood 2018 Below Normal water year to 2019 Wet water year modeled seedling demographic results.

Life stage	**Existing conditions**	**65% design conditions**
Seeds	3,000,000	
Seeds that sprouted	1.7%	3.3%
Seeds that became seedlings	0.2%	0.6%
Seeds that survived to dormancy October 31	0.1%	0.4%
Seeds that survived winter and spring floods to June 30 of the year	0.0%	0.1%
Sprouts became seedlings	11.4%	19.7%
Seedlings went dormant on October 31	56.1%	68.0%
Dormant seedlings survived the winter and spring floods	20.9%	24.1%
Inundation mortality	19.4%	23.8%
Desiccation mortality	80.6%	76.1%
Scour mortality	0.001%	0.025%
Number of surviving seedlings June 30	668	3,178

Table 7. Scenario 4. Fremont cottonwood 2016 Dry water year to 2017 Wet water year modeled seedling demographic results.

Life stage	Existing conditions	65% design conditions
Seeds	3,000,000	
Seeds that sprouted	1.5%	4.1%
Seeds that became seedlings	0.5%	1.6%
Seeds that survived to dormancy October 31	0.4%	1.4%
Seeds that survived winter and spring floods to June 30 of next year	0.1%	0.2%
Sprouts became seedlings	30.5%	39.2%
Seedlings went dormant on October 31	79.8%	85.6%
Dormant seedlings survived the winter and spring floods	15.9%	15.1%
Inundation mortality	14.7%	16.8%
Desiccation mortality	85.3%	82.8%
Scour mortality	0.007%	0.163%
Number of surviving seedlings June 30	1,788	6,291

Table 8. Scenario 5, Fremont cottonwood 2021 Critically Dry water year to 2022 Critically Dry water year modeled seedling demographic results.

Life stage	Existing conditions	65% design conditions
Seeds	3,000,000	
Seeds that sprouted	1.5%	3.8%
Seeds that became seedlings	0.8%	2.1%
Seeds that survived to dormancy October 31	0.8%	2.1%
Seeds that survived winter and spring floods to June 30 of next year	0.7%	1.9%
Sprouts became seedlings	50.5%	55.2%
Seedlings went dormant on October 31	98.8%	98.8%
Dormant seedlings survived the winter and spring floods	93.2%	93.1%
Inundation mortality	13.8%	14.8%
Desiccation mortality	85.5%	83.3%
Scour mortality	0.001%	0.040%
Number of surviving seedlings June 30	21,329	58,176

Table 9. Scenario 1, 2017 narrowleaf willow Wet water year to 2018 Below Normal water year type modeled seedling demographic results.

Life stage	Existing conditions	65% design conditions
Seeds	3,000,000	
Seeds that sprouted	9.9%	10.4%
Seeds that became seedlings	0.2%	0.4%
Seeds that survived to dormancy October 31	0.0%	0.1%
Seeds that survived winter and spring floods to June 30 of next year	0.0%	0.1%
Sprouts became seedlings	1.8%	3.7%
Seedlings went dormant on October 31	0.1%	16.7%
Dormant seedlings survived the winter and spring floods	100.0%	100.0%
Inundation mortality	51.8%	56.9%
Desiccation mortality	48.2%	43.0%
Scour mortality	0.000%	0.000%
Number of surviving seedlings June 30	6	1,296

Table 10. Scenario 2, narrowleaf willow 2010 Above Normal water year to 2011 Wet water year type modeled seedling demographic results.

Life stage	Existing conditions	65% design conditions
Seeds	3,000,000	
Seeds that sprouted	10.6%	11.4%
Seeds that became seedlings	0.0%	0.2%
Seeds that survived to dormancy October 31	0.0%	0.1%
Seeds that survived winter and spring floods to June 30 of next year	0.0%	0.1%
Sprouts became seedlings	0.3%	1.5%
Seedlings went dormant on October 31	30.6%	69.4%
Dormant seedlings survived the winter and spring floods	14.0%	61.2%
Inundation mortality	36.8%	43.0%
Desiccation mortality	63.2%	57.0%
Scour mortality	0.000%	0.003%
Number of surviving seedlings June 30	42	840

Table 11. Scenario 3, narrowleaf willow 2018 Below Normal water year to 2019 Wet water year type modeled seedling demographic results.

Life stage	Existing conditions	65% design conditions
Seeds	3,000,000	
Seeds that sprouted	1.6%	3.4%
Seeds that became seedlings	1.3%	2.8%
Seeds that survived to dormancy October 31	0.7%	1.5%
Seeds that survived winter and spring floods to June 30 of next year	0.1%	0.3%
Sprouts became seedlings	83.1%	83.1%
Seedlings went dormant on October 31	50.4%	54.1%
Dormant seedlings survived the winter and spring floods	18.1%	19.2%
Inundation mortality	14.1%	15.8%
Desiccation mortality	85.7%	83.8%
Scour mortality	0.035%	0.220%
Number of surviving seedlings June 30	3,024	4,326

Table 12. Scenario 4, narrowleaf willow 2016 Dry water year to 2017 Wet water year type modeled seedling demographic results.

Life stage	Existing conditions	65% design conditions
Seeds	3,000,000	
Seeds that sprouted	1.6%	3.3%
Seeds that became seedlings	1.3%	2.8%
Seeds that survived to dormancy October 31	0.9%	2.1%
Seeds that survived winter and spring floods to June 30 of next year	0.1%	0.3%
Sprouts became seedlings	82.8%	83.3%
Seedlings went dormant on October 31	67.7%	74.3%
Dormant seedlings survived the winter and spring floods	14.8%	13.5%
Inundation mortality	14.1%	15.5%
Desiccation mortality	85.7%	83.8%
Scour mortality	0.077%	0.426%
Number of surviving seedlings June 30	3,972	7,698

Table 13. Scenario 5, narrowleaf willow 2021 Critically Dry water year to 2022 Critically Dry water year type modeled seedling demographic results.

Life stage	**Existing conditions**	**65% design conditions**
Seeds	3,000,000	
Seeds that sprouted	1.6%	3.3%
Seeds that became seedlings	1.3%	2.7%
Seeds that survived to dormancy October 31	1.3%	2.6%
Seeds that survived winter and spring floods to June 30 of next year	1.1%	2.3%
Sprouts became seedlings	79.5%	82.3%
Seedlings went dormant on October 31	96.6%	97.4%
Dormant seedlings survived the winter and spring floods	87.4%	86.2%
Inundation mortality	13.1%	13.7%
Desiccation mortality	86.0%	84.7%
Scour mortality	0.024%	0.170%
Number of surviving seedlings June 30	32,796	43,002

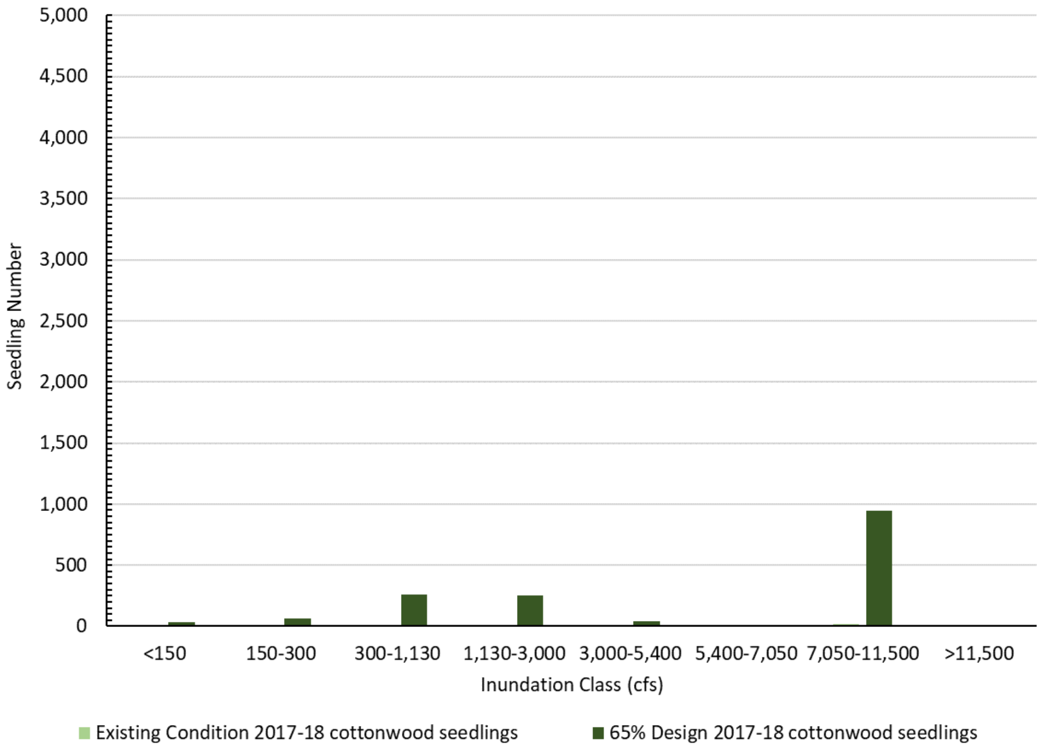

Figure 6. Scenario 1, Fremont cottonwood 2017 Wet water year to 2018 Below Normal water year type modeled seedling quantities within eight inundation classes.

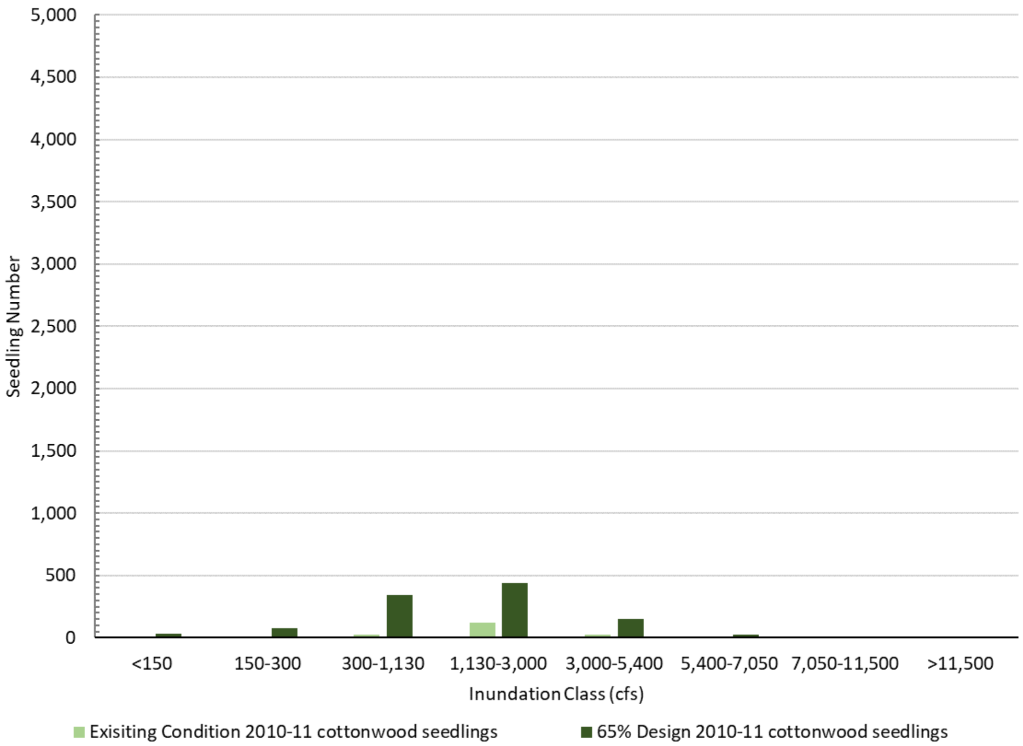

Figure 7. Scenario 2, 2010 Fremont cottonwood Above Normal water year to 2011 Wet water year type modeled seedling quantities within eight inundation classes.

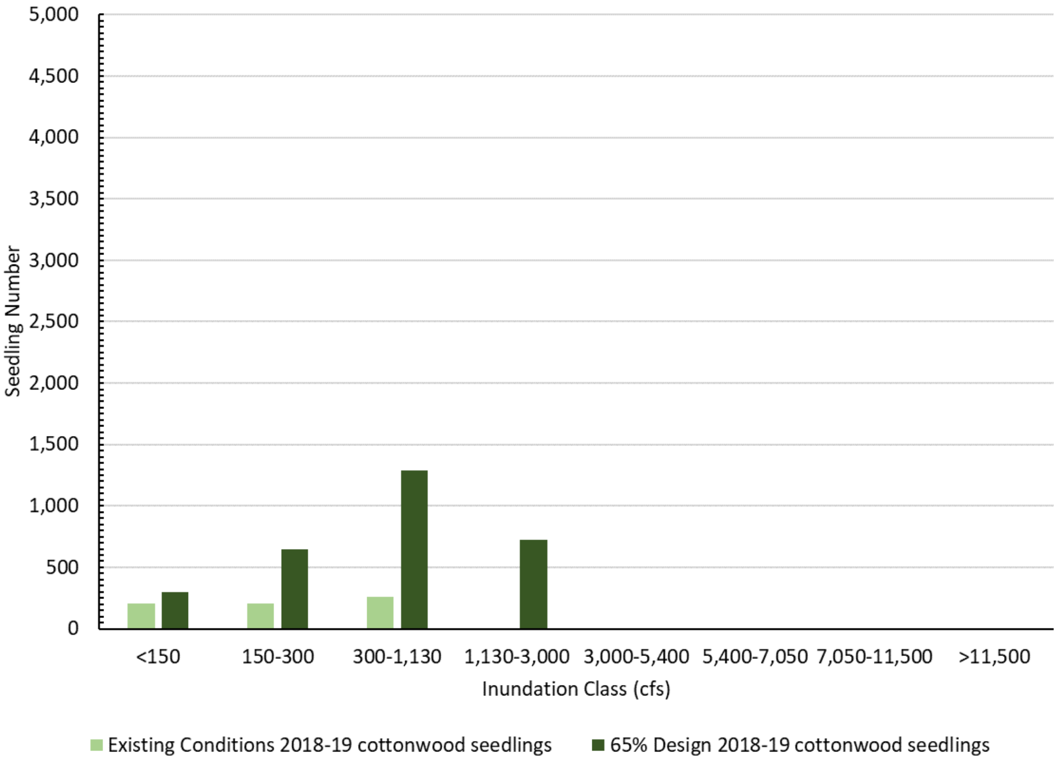

Figure 8. Scenario 3, Fremont cottonwood 2018 Below Normal water year to 2019 Wet water year type modeled seedling quantities within eight inundation classes.

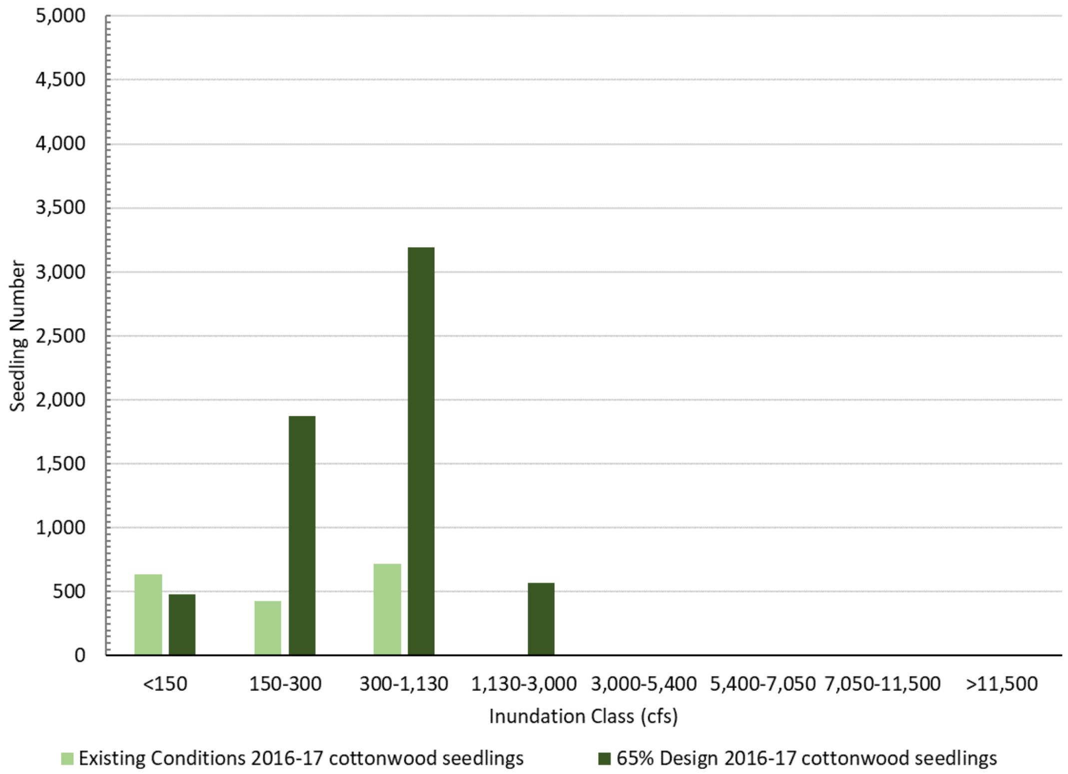

Figure 9. Scenario 4, Fremont cottonwood 2016 Dry water year to 2017 Wet water year type modeled seedling quantities within eight inundation classes.

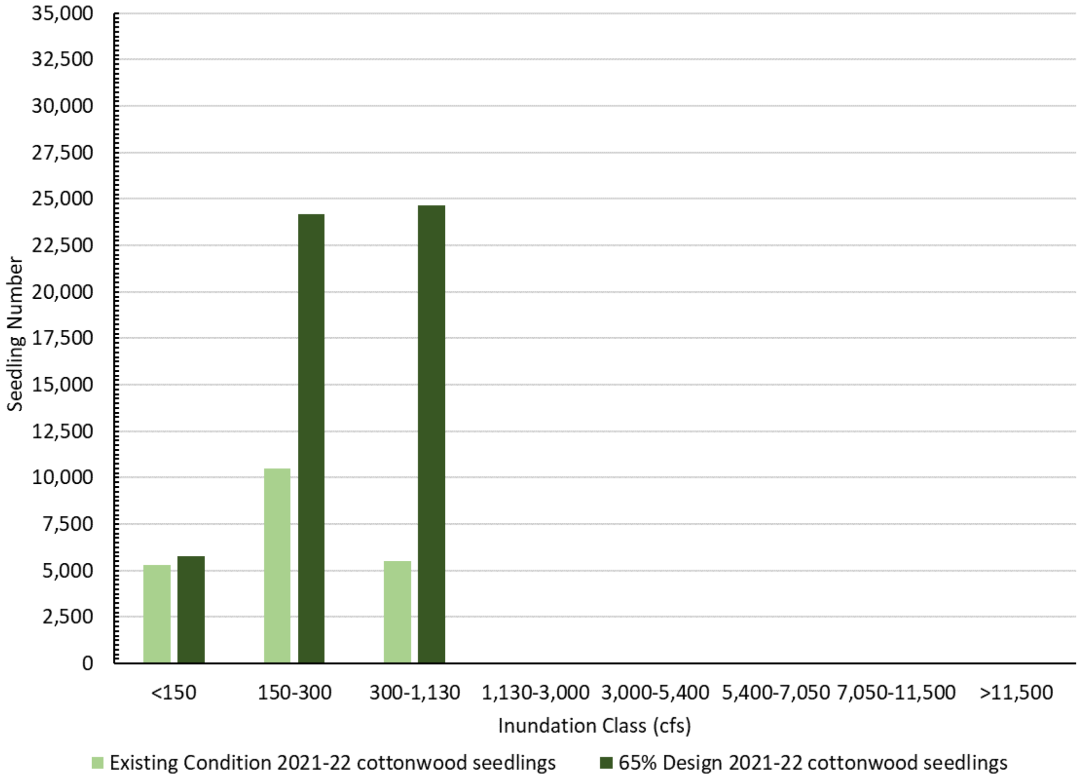

Figure 10. Scenario 5, Fremont cottonwood 2021 Critically Dry water year to 2022 Critically Dry water year type modeled seedling quantities within eight inundation classes.

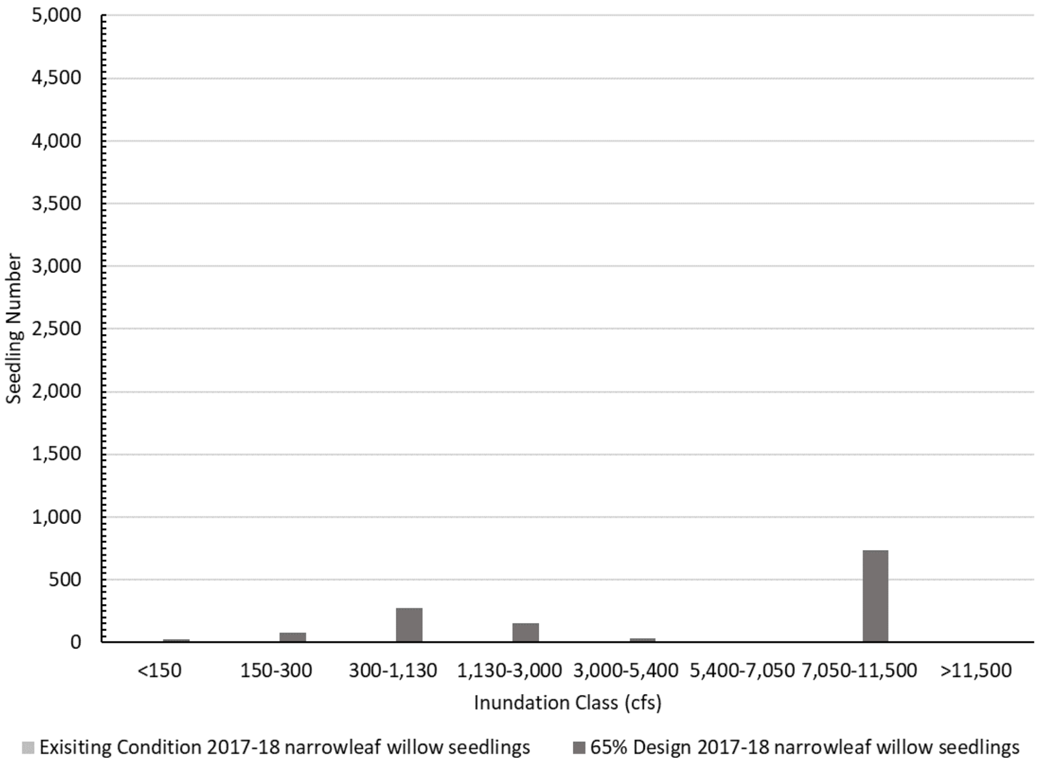

Figure 11. Scenario 1, narrowleaf willow 2017 Wet water year to 2018 Below Normal water year type modeled seedling quantities within eight inundation classes.

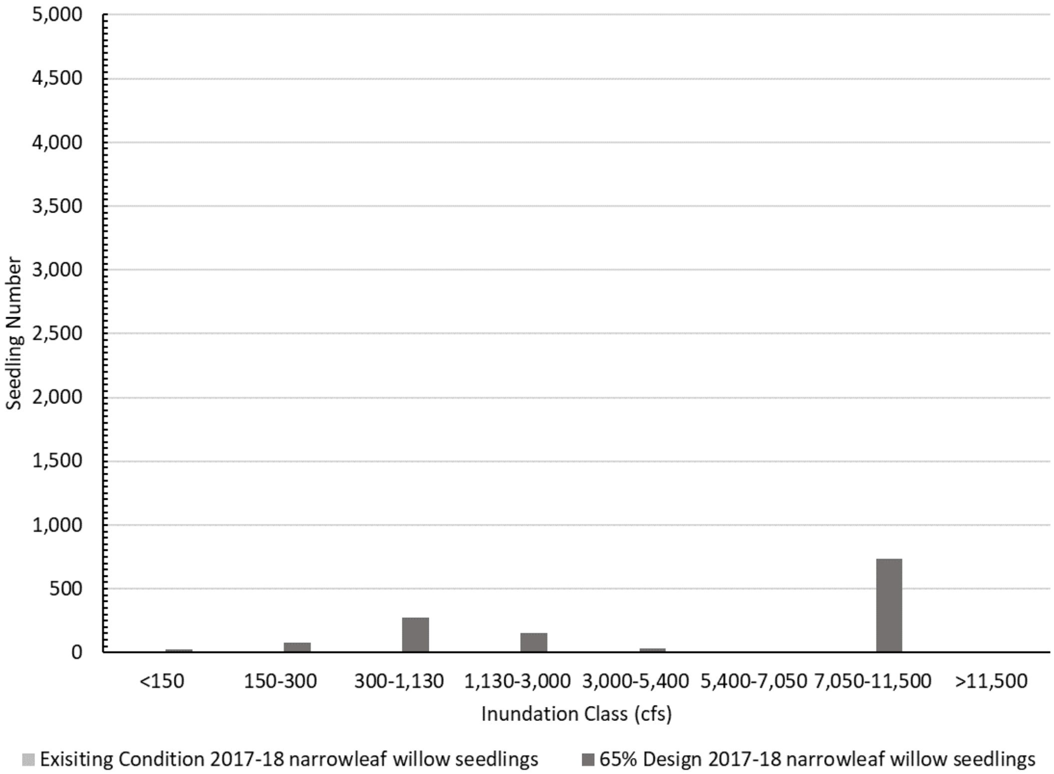

Figure 12. Scenario 2, narrowleaf willow 2010 Above Normal water year to 2011 Wet water year type modeled seedling quantities within eight inundation classes.

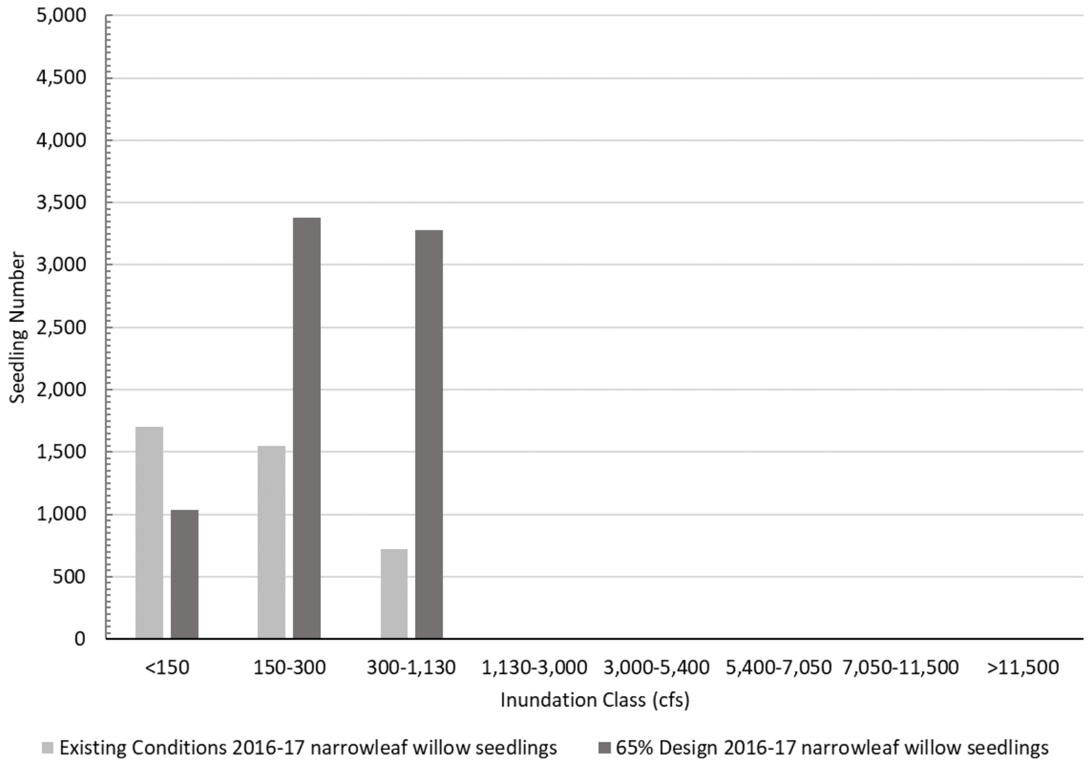

Figure 13. Scenario 3, narrowleaf willow 2018 Below Normal water year to 2019 Wet water year type modeled seedling quantities within eight inundation classes.

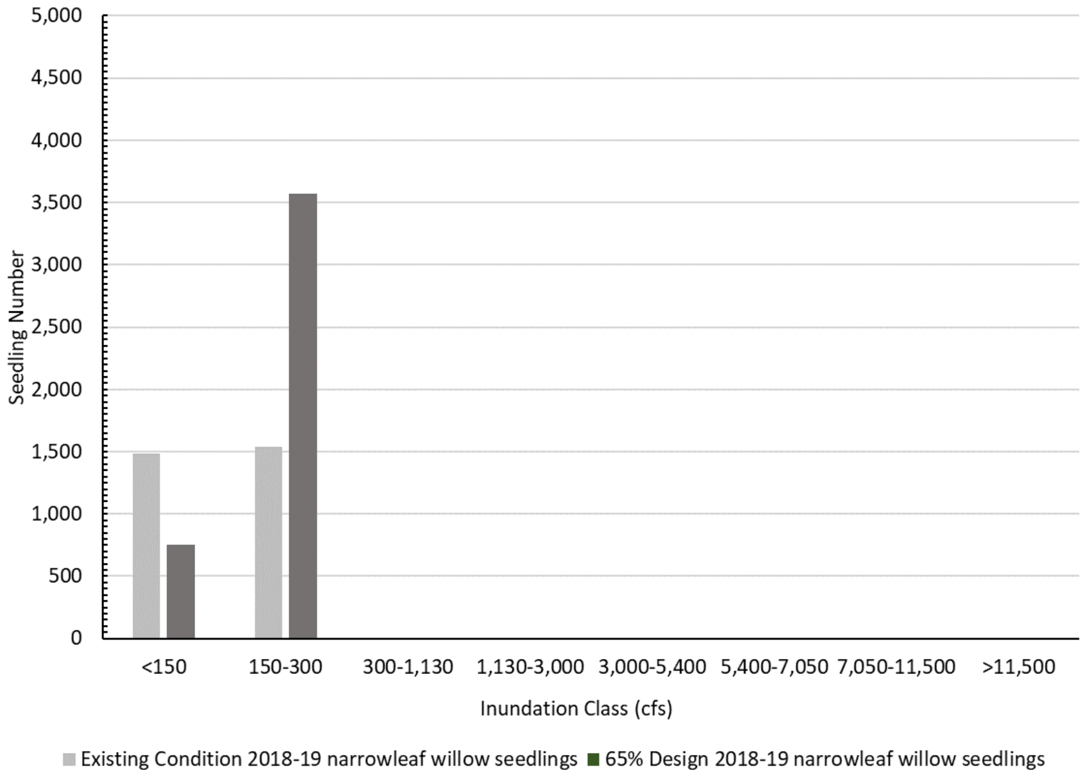

Figure 14. Scenario 4, narrowleaf willow 2016 Dry water year to 2017 Wet water year type modeled seedling quantities within eight inundation classes.

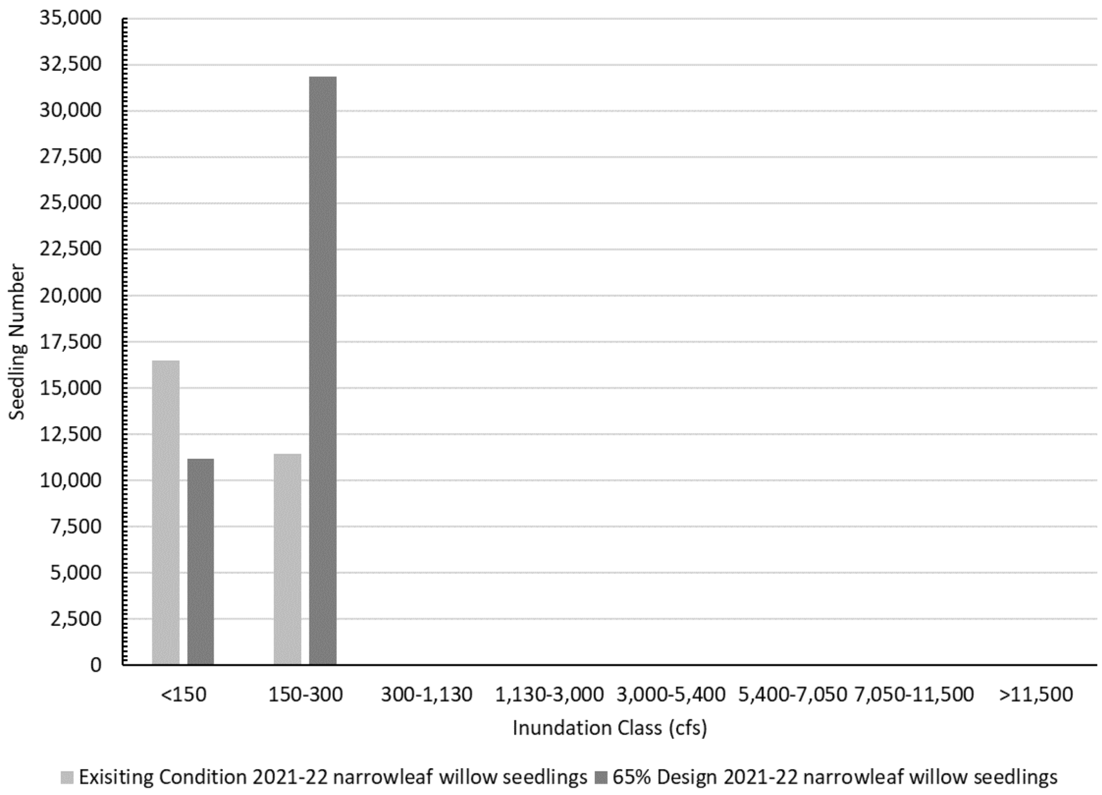

Figure 15. Scenario 5, 2021 narrowleaf willow Critically Dry water year to 2022 Critically Dry water year type modeled seedling quantities within eight inundation classes.

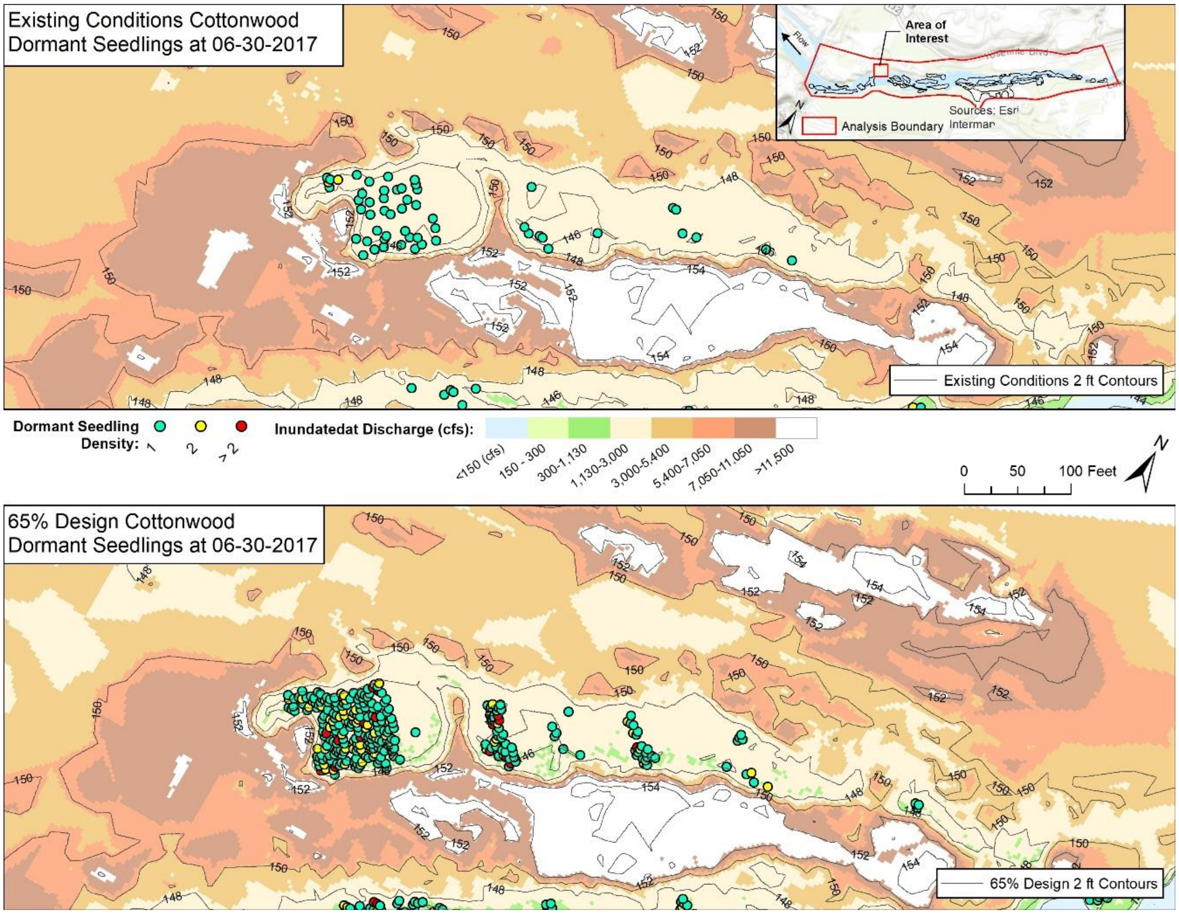

Figure 16. Planform view of a location within the Zanker Project showing inundation class areas and topography under existing conditions in the upper panel and 65% design in the lower panel where 1,130 to 3,000 cfs floodplain designs increased 1-yr old Fremont cottonwood seedlings establishment in Scenario 4 (Dry–Wet).

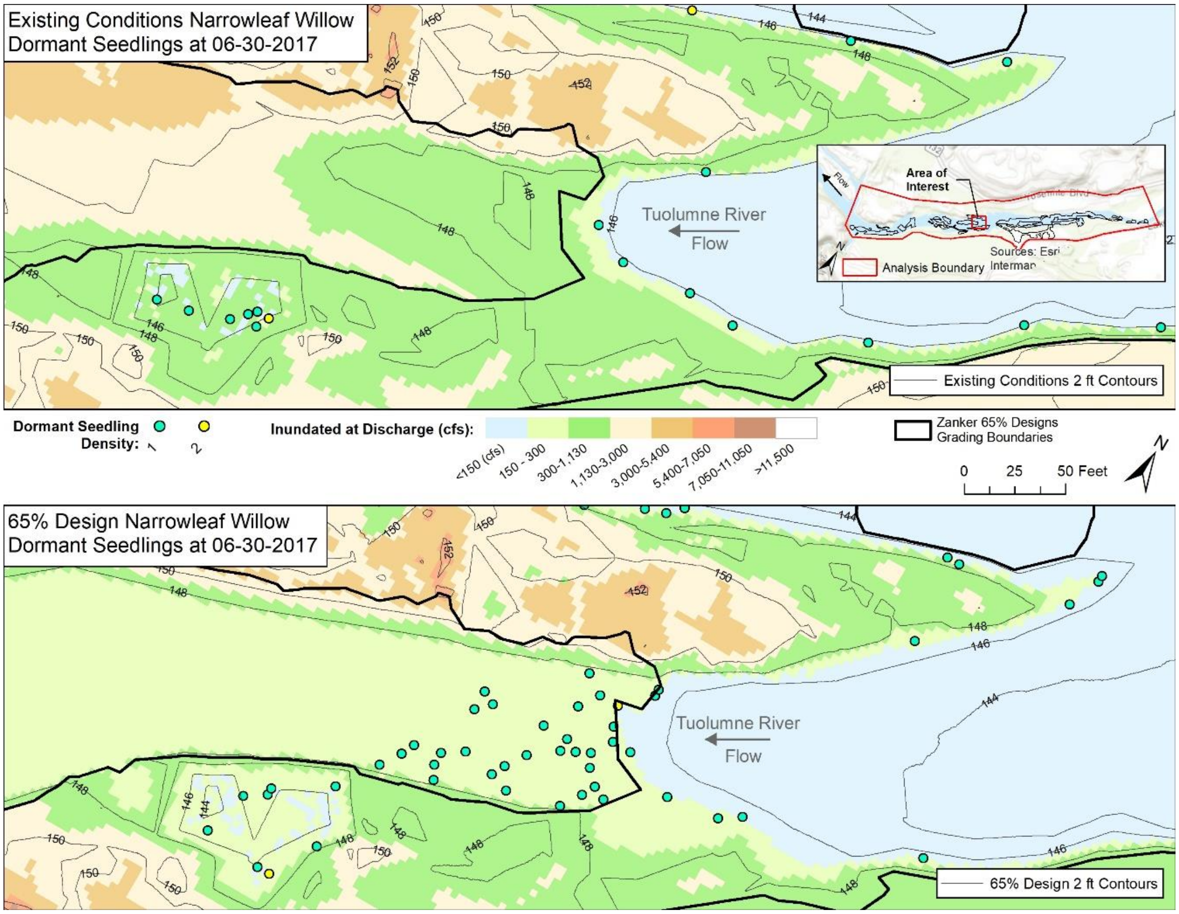

Figure 17. Planform view of a location within the Zanker Project showing inundation class areas and topography under existing conditions in the upper panel and 65% design in the lower panel where narrowleaf willow seedling establishment increased in the 150 to300 cfs low-flow areas in Scenario 4 (Dry–Wet).

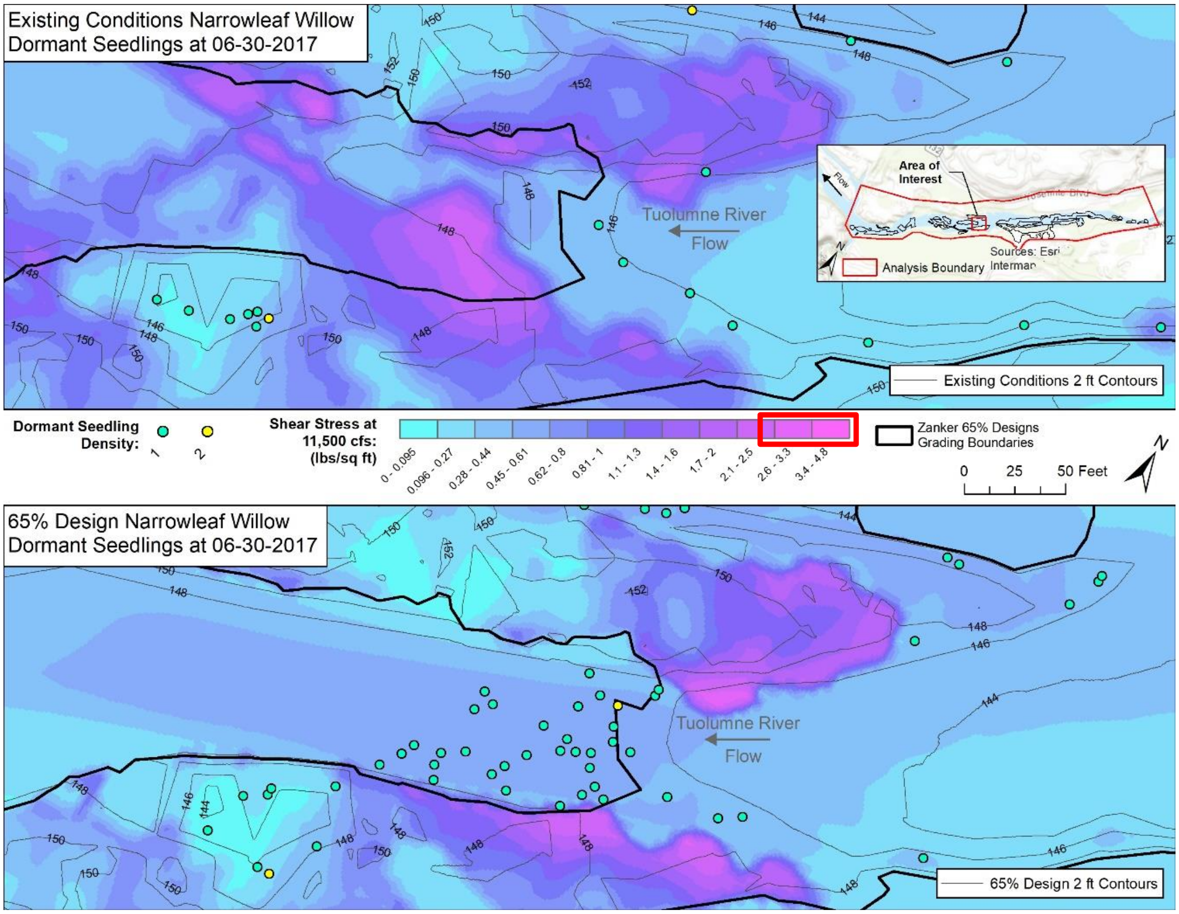

Figure 18. Planform isopach of a location within the Zanker Project where 1-yr old narrowleaf willow seedling establishment increased in the 150–300 cfs cfs inundation class and shear stress under existing conditions in the upper panel and 65% design in the lower panel. Seedlings with 1- to 1.75-ft long roots (305–457mm) require 2.28-3.70 lbs/ ft^2 to be scoured (108.6–176.2 pascals; red rectangle).

1.4.2 Water Year Type Influence

Wetter years generally have more cottonwood establishment than narrowleaf willow and drier years generally have higher quantities of narrowleaf willow seedling establishment than cottonwood. More cottonwood 1 yr-old seedlings established than narrowleaf willow in Scenario 1 (Wet–Below Normal), and Scenario 2 (Above Normal–Wet) under both existing and 65% design conditions (Table 4, Table 5, Figure 6, and Figure 7). More narrowleaf seedlings established than cottonwood in Scenario 3 (Below Normal–Wet year), and Scenario 4 (Dry–Wet year) under both existing and 65% design conditions (Table 11, Table 12, Figure 13, Figure 14).

High streamflows through the spring in Scenario 1 (Wet–Below Normal) led to 1-yr old Fremont cottonwood and narrowleaf willow seedling establishment at the highest bank positions of any modeled hydrologic scenario (Figure 6, Figure 11). In Critically Dry years (i.e., Scenario 5), cottonwood establishment was restricted to lower bank elevations and may only establish on the channel margin and lower floodplains up to 1,130 cfs (Figure 10). In Below Normal and Critically Dry years, 1-yr old narrowleaf willow establishment was restricted to lower bank elevations and may only establish on the channel margin up to 300 cfs (Figure 13, Figure 15). The bank locations where Fremont cottonwoods and narrowleaf willow established in drier years were similar (Figure 9, Figure 10).

Higher flows during the first year of establishment can increase the bank elevations where seedlings establish, even in drier years. In Scenario 3 (Below Normal–Wet) and Scenario 5 (Critically Dry–Critically Dry), narrowleaf willow seedlings did not establish above 300 cfs (Figure 13, Figure 15). However, in Scenario 4 (Dry–Wet), narrowleaf willow seedlings established in the 300–1,130 cfs range (Figure 14). In Scenario 5 (Critically Dry–Critically Dry), more than seven times the number of narrowleaf seedlings were established than in any other year (Table 13, Figure 15). The next greatest number of established seedlings occurred in 2018, a Below Normal year (Table 11, Figure 13) and the third greatest number was in 2016, a Dry water year (Table 12, Figure 9).

1.4.3 Mortality Agents

Desiccation and inundation mortality were the primary cause of death in all scenarios. Fremont cottonwood and narrowleaf willow had similar patterns and causes of mortality within each modeled scenario. Desiccation was greatest in drier years (Table 6, Table 7, Table 8, Table 11, Table 12, Table 13) and caused greatest amounts of mortality in all scenarios except Scenario 1 (Wet–Below Normal). Inundation mortality was higher in wet years (Table 4, Table 5, Table 9, and Table 10), and only exceeded desiccation as the primary cause of mortality in Scenario 1 (Wet–Below Normal; Table 4, Table 9).

Scour caused less than 1% mortality in all scenarios, even in wet years with flood peaks exceeding 14,000 cfs. Scour-induced seedling mortality was always higher in the 65% design compared to existing conditions (Table 5 through Table 13). The highest amounts of Fremont cottonwood scour mortality were associated with Scenario 4 (Dry–Wet) and the highest amounts of narrowleaf willow scour mortality were associated with Scenario 3 (Below Normal–Wet) and Scenario 5 (Critically Dry–Critically Dry).

Only one year, 2017, had flows higher than 11,500, and there were three years with flows higher than 7,050 cfs (2011, 2017, and 2019, Table 1). A peak flow of 11,5000 cfs had a maximum shear stress of 4.85 lbs/ft^2 (231.1 pascals), which could scour seedlings with 1.97-ft (60.1-cm) long roots. It takes 24 days for Fremont cottonwood seedling roots to reach 1.97 ft long and 60 days for narrowleaf willows to reach this root length. A peak flow of 7,050 cfs had a maximum shear stress of 3.99 lbs/ft^2 (190.1 pascals) and could scour seedlings with 1.62-ft (49.4-cm) long roots, which cottonwood seedlings grow in 20 days, and narrowleaf willows grow in 50 days. Fremont cottonwood and narrowleaf willow seedling scour were highest in the winter of 2017, when flows peaked at 14,277 cfs (Table 7, Table 12).

1.5 Discussion

1.5.1 65% Design Comparison to Existing Conditions

TARGETS-2D modeling showed that the 65% design surfaces will be low enough to support Fremont cottonwood and narrowleaf willow establishment. Dense revegetation with a diverse plant palette will help manage invasive species, create habitat in the short term, and lead to long-term vegetation structural success. After construction, willows and cottonwoods will rapidly establish on constructed surfaces, leading to the development of a multi-age stand and potentially self-sustaining woody riparian habitat.

The 65% design boosted passive recruitment opportunities in wetter years. Fremont cottonwood showed a much bigger increase in 1-yr old seedling quantity in the 65% design conditions when compared to narrowleaf willow. The smallest increases in seedling quantity over existing conditions occurred in Below Normal and drier years that would normally produce a high number of seedlings. Overall, the 65% design produced 3 to 85% more cottonwood seedlings and 2 to 317% more narrowleaf willow seedlings than existing conditions. The greatest increase in Fremont cottonwood and narrowleaf willow seedling quantities when compared to existing conditions occurred during Above Normal and Wet years (Table 5, Figure 7, Table 10, Figure 11).

In the 65% design there was a 5% increase in inundation mortality in Wet years, presumably because lower floodplain benches were inundated longer, increasing inundation mortality over existing conditions (Table 4, Table 9). Even though there was an increase in inundation mortality in Wet years, the number of seedlings that established during this period was still much higher than under existing conditions and over a broader elevation range (Table 4, Table 9, Figure 6, and Figure 11).

There is a possibility of vegetation encroachment on constructed gravel bars and channel margins along newly constructed surfaces. In both existing conditions and the 65% design conditions, high shear stress values and associated scour mortality were localized. The Project area is flat and has a low channel gradient (slope). Due to the low slope, most of the site has low shear stress values (<50 pascals) on the floodplain and channel banks across all modeled flows. Low shear stress at higher flows means that scour mortality was limited to those areas where higher shear stress could be achieved. One-year old narrowleaf willow establishment patterns on 65% design floodplain benches in the 150 to 300 cfs inundation class should be evaluated relative to design feature objectives. Narrowleaf willow establishment in the 150 to 300 cfs inundation area could lead to unwanted fine sediment deposition and/or could cut off flow paths. In locations where narrowleaf willow establishment is a concern, the 65% design may need to be modified to inhibit seedling establishment, if feasible.

Currently scour mortality is low under existing conditions and only slightly increases under 65% design conditions. It is unlikely that the slight increases in scour mortality under design conditions will be enough to fend off encroaching seedlings, since there is little to no reduction in existing channel width, and shear stress on design surfaces does not increase enough to control seedling establishment that could lead to encroachment. Vegetation encroachment would, over time, disconnect the channels from surrounding low velocity habitat and could prevent the development of floodplains. Narrowleaf willow is likely to be the primary species to encroach the channel, and depending on streamflow hydrographs, will establish in the lowest bank positions. To help reduce encroachment, rushes and sedges could be densely planted at 18-inch spacing along the channel margins to fill the space where narrowleaf willow could densely establish. Planting rushes and sedges will fill the space and help avoid a narrowleaf willow monoculture forming a dense band along the channel. The planting would have space for woody recruitment and planted emergent plants would allow the channel to adjust while providing good winter rearing habitat in the short term.

1.5.2 Water Year Type Influence

1.5.2.1 Fremont Cottonwood Establishment

Two general patterns of cottonwood establishment were observed depending on water year type in a seedling’s first year. Cottonwood establishment patterns in drier years were similar; Scenario 4 (Dry–Wet) had more seedlings than Scenario 3 (Below Normal–Wet), but seedlings established at similar bank elevations, suggesting that the effects of drier years could affect the number of seedlings but were unlikely to affect the bank locations where predicted passive recruitment could occur (Figure 8, Figure 9). Fremont cottonwood establishment patterns and seedling quantities were similar in wetter years (Table 4, Table 5, Figure 6, and Figure 7). More seedlings established at higher bank elevations in Scenario 1 (Wet–Below Normal) than in Scenario 2 (Above Normal–Wet). In Scenario 2, the greatest number of 1-yr old cottonwood seedlings established in the 1,130 to 3,000 cfs streamflow class (Figure 7).

Generally, in wetter years:

- More cottonwood seedlings establish than narrowleaf willow in the same period.
- There are fewer cottonwood seedlings established when compared to cottonwood establishment in other years, but cottonwoods establish in more inundation classes and higher in elevation than in drier years.

1.5.2.2 Narrowleaf Willow Establishment

One general narrowleaf willow establishment pattern was associated with wetter years and another with drier years. Narrowleaf willow had similar water-year related establishment patterns as cottonwood; however, narrowleaf willow tended to have more seedlings in drier years than Fremont cottonwood and 1-yr old narrowleaf willow seedlings established at lower bank elevations than cottonwood.

Drier year years produce more 1-yr old narrowleaf willow seedlings in lower bank positions than wetter years. Scenario 4 (Dry–Wet) and Scenario 3 (Below Normal–Wet) 1-yr old narrowleaf willow establishment patterns were similar, with the highest amounts of seedlings establishing in the 150 to 300 cfs inundation class. Scenario 3 had less seedlings than Scenario 5 (Critically Dry–Critically Dry) however, 1-yr old narrowleaf willow seedlings did not establish higher than 300 cfs in either scenario (Figure 13, Figure 15).

Above Normal and Wet years had the broadest narrowleaf willow establishment elevation ranges when compared to other years, just as for cottonwoods (Figure 11, Figure 12). Scenario 2 (Above Normal–Wet) and Scenario 1 (Wet–Below Normal) 1-yr old narrowleaf willow establishment patterns and quantities were similar, with Scenario 2 producing slightly more seedlings overall than Scenario 1 (Table 9, Table 10) In Scenario 2, more seedlings established at higher bank elevations than in Scenario 1, but Scenario 1 established 1-yr old narrowleaf seedlings in the 7,050 to 11,500 cfs streamflow class, the highest bank position of all model scenarios (Figure 11).

Generally, in drier years:

- More narrowleaf willow seedlings establish than cottonwoods in the same period.
- There are higher amounts of narrowleaf willow seedlings established when compared to narrowleaf willow establishment in other years, but narrowleaf establish in fewer inundation classes and lower in elevation than in wetter years.

1.5.3 Mortality Agents

Desiccation and inundation were the most significant mortality agents in all water year types for both Fremont cottonwood and narrowleaf willow. Desiccation was the biggest cause of mortality, accounting for 80–85% of Fremont cottonwood mortality in drier years (Table 7, Table 8), and 43–62% in wetter years (Table 4, Table 5). Desiccation had a similar effect on narrowleaf willow, accounting for 83–86% mortality in drier years (Table 11, Table 12, Table 13) and 43–63% in wetter years (Table 9, Table 10).

Inundation mortality accounted for 30 to 50% of cottonwood seedling mortality in Above Normal and Wet years and only 15% mortality in drier years (Table 5 through Table 8). Inundation mortality accounted for more than 50% of narrowleaf seedling mortality in Wet years and 35–45% in Above Normal years (Table 9, Table 10).

Scour did not kill a high number of cottonwood seedlings and accounted for less than 0.163% of seedling mortality in Scenario 1 (Wet–Below Normal) when the highest rates of scour mortality were modeled (Table 4). Scour killed 10 times more narrowleaf willow seedlings than cottonwoods, but still only accounted for less than 0.5% of seedling mortality in spring of 2017 when the highest rates of scour mortality were modeled (Table 12).

1.5.4 Uncertainty

The TARGETS model results over-estimate passive recruitment. The factors contributing to overestimation of passive recruitment include:

- The terrain used in the model was unvegetated, so every location on the terrain could potentially grow a seed. Much of the river margin is actually vegetated and unlikely to support seed germination and establishment.
- The model does not explicitly consider bedrock areas where seedlings might begin to grow but would quickly perish due a lack of shallow groundwater.
- Nor does the model consider hydrochory (water dispersal) or inter /intra specific competition.
- The user defined model parameter for root growth rate used in the TARGETS-2D model trials and derived from literature is conservative, as it is based on controlled greenhouse experiments in a porous medium without capillary fringe or soil moisture. It is reasonable to expect that actual root growth rates and desiccation vulnerability may be higher than the conservative literature values where substrate capillarity and soil moisture were derived.

TARGETS-2D results could be made more conservative by using a vegetation and bedrock map overlay and only including areas in the model that could potentially grow seedlings.

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Appendix E: Existing Conditions Vegetation and Revegetation Basis of Design

APPENDIX E. ZANKER FARM SALMONID HABITAT RESTORATION PROJECT 100% DESIGN EXISTING CONDITIONS VEGETATION AND REVEGETATION BASIS OF DESIGN

Vegetation within the Zanker Farm Project area is characteristic of Central Valley rivers. There are agricultural lands interspersed with undeveloped areas of oak savannahs and woodlands and vast expanses of foothill annual grasslands. The riparian corridor consists of a mix of cottonwoods, tree willows, shrub willows, and various understory species. While the general character could be evaluated from aerial photos, the specific composition of vegetation communities within the Zanker Farm Project area could not be determined without field sampling.

Mapping was used to describe vegetation types within the Project area. Vegetation mapping created a high-resolution map of existing mesic and xeric vegetation currently within the Project area to serve as a baseline against which to compare future conditions. The vegetation map was used to quantify existing vegetation types and their relative abundance, evaluate the vegetation patterns as a function of the ground surface height above the lower Tuolumne River water surface elevation and used for developing revegetation design concepts (Bair et al. 2021). The vegetation map may also be used during the Project permitting to estimate restoration-related impacts to riparian vegetation. The vegetation map could be used in the future for documenting post-construction riparian vegetation recovery.

1 VEGETATION MAPPING

Mapping was conducted for the entire Zanker Farm property as well as surrounding areas. The Project area boundary used to describe existing conditions was 226.8 acres. After the Zanker Farm Existing Conditions Report was written (MA 2021), two restoration phases were defined within the 226.8-acre Project area (Figure 1, Figure 2). The two separate phases were then combined at the 65% design stage. Figures and acreages have been updated to show both phases.

The vegetation map was developed and combined with existing ground surface topography to evaluate the interrelationship of vegetation growing within the Project area and the physical and hydrologic environments that support it. The relationships between existing vegetation and ground surface height above the river water surface elevations were developed to: (1) explain existing vegetation patterns, (2) provide design criteria that would facilitate wetland and riparian vegetation types, and (3) inform the development of physical designs that promote the growth of revegetated plants and increase recruitment of a higher number of mesic plant species.

Vegetated and unvegetated areas in the Project area were mapped on June 3 and June 4, 2021 (Figure 1, Figure 2). The mapping goal was to map all vegetated and unvegetated areas within the Project area and assign a cover type name to mapped polygons. Specific objectives were to:

- Map all vegetated and unvegetated areas in the field within the Project area using 2020 NAIP images;
- Prepare an ArcGIS-compatible 2021 vegetation layer from the field maps; and
- Quantify acreages of mapped vegetated and unvegetated areas within the Project area.

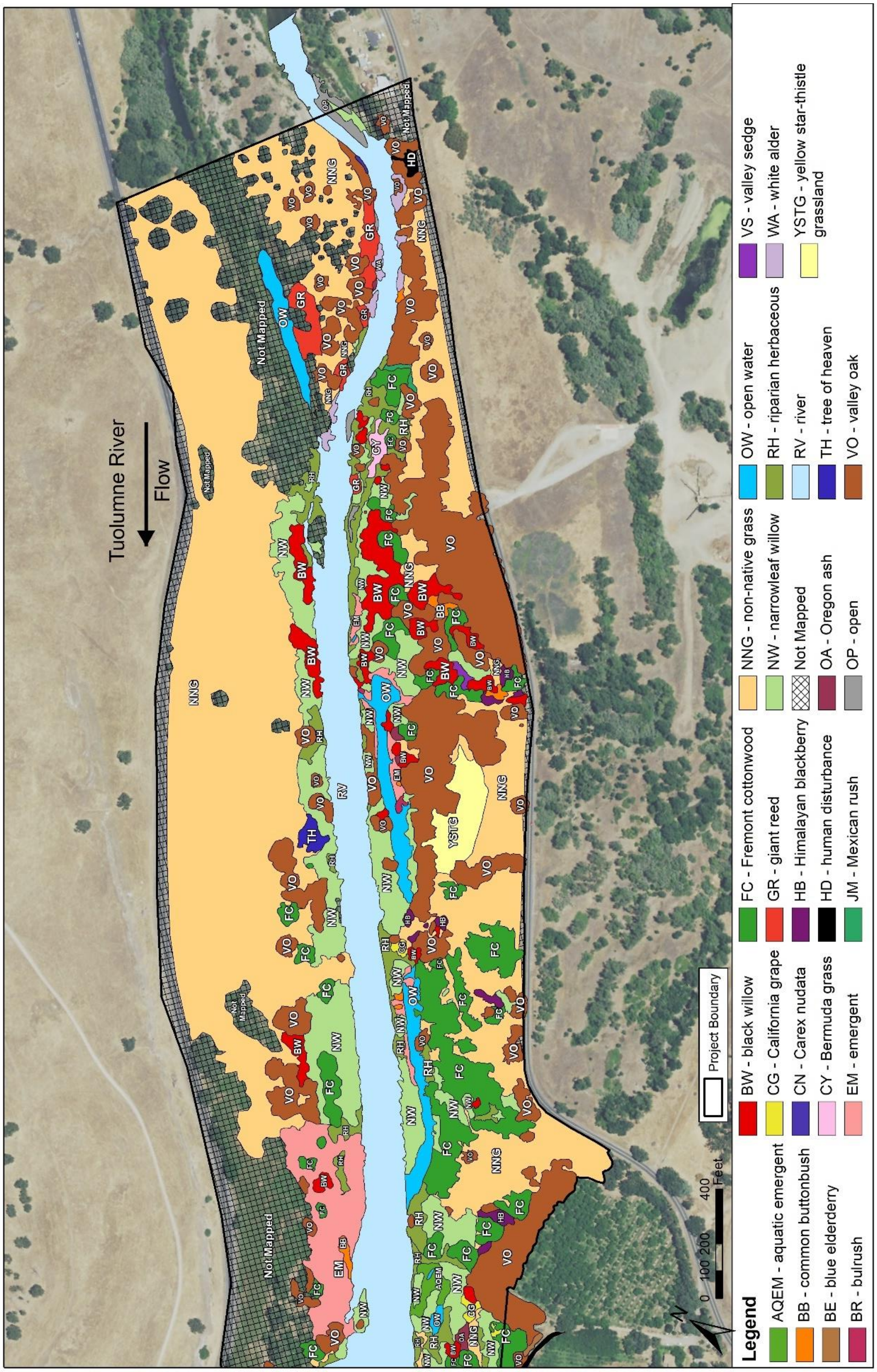

Figure 1. Existing vegetated and unvegetated cover types mapped in 2021 in the Zanker Farm Project area.

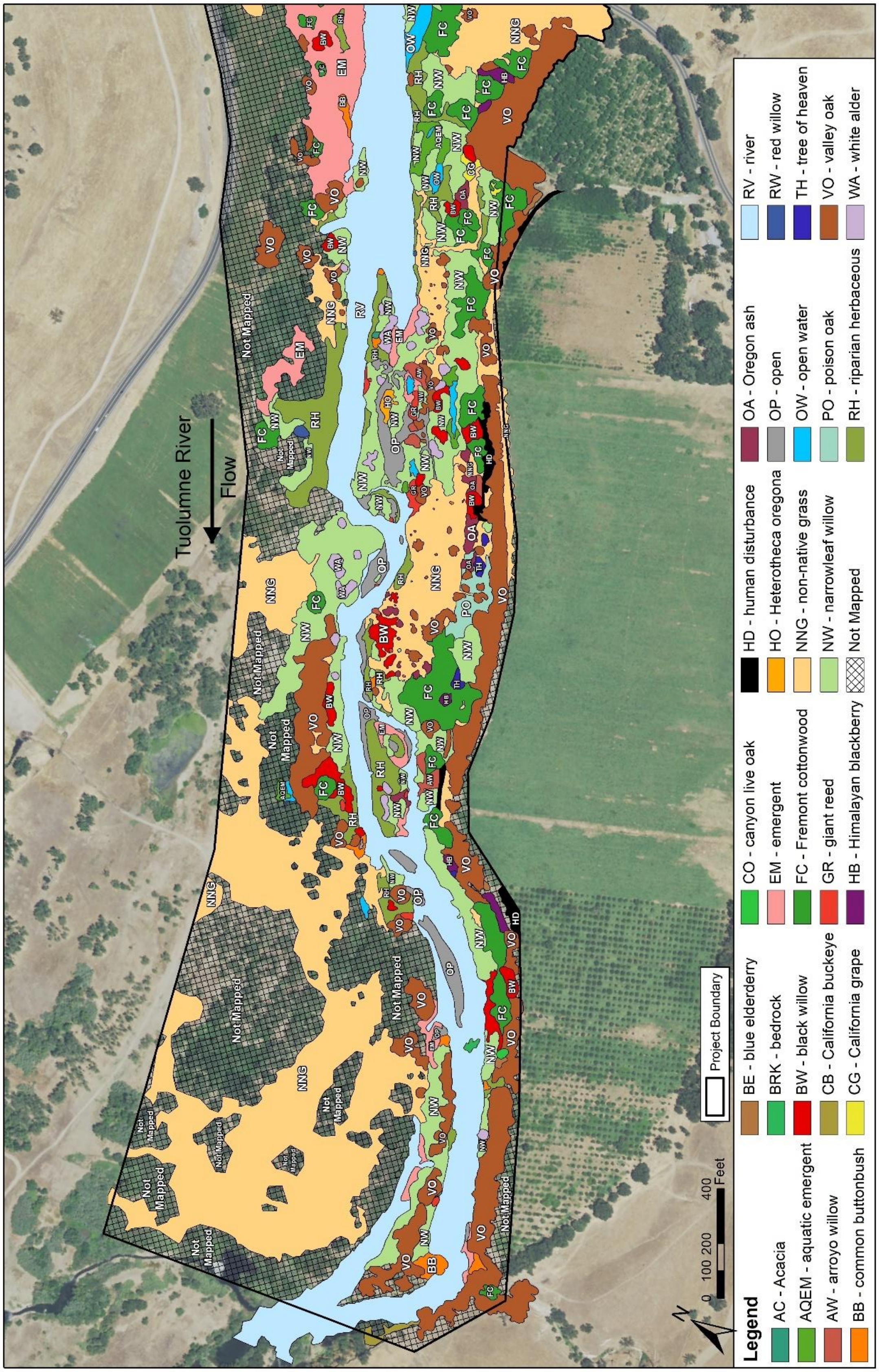

Figure 2. Existing vegetated and unvegetated cover types mapped in 2021 in the Zanker Farm Project area property.

1.1 Methods

Base maps used for vegetation mapping were plotted at 1:1,200 scale using 2020 NAIP imagery. Polygons were drawn on the base maps in the field and attributed with a cover type. When possible, field mapping extended beyond the defined Project boundary to assure inclusion of current and future anticipated restoration activities.

1.1.1 Vegetation Mapping and Classification

Polygons were drawn to delineate boundaries around areas of homogenous composition on aerial photo base maps and classified with a land cover type attribute following similar protocols used in other riparian vegetation inventories (HVT and MA 2015, HVT and MA 2021). Delineated polygons were typically greater than 10 ft × 10 ft in area (M&T 2004, NSR 2009). Unvegetated polygons were assigned a land cover type based on visible substrate and level of human disturbance. Vegetated polygons were assigned land cover type attributes based on the dominant plant species in the canopy, which is similar to the plant alliance classification developed by Sawyer et al. (2009).

1.1.1.1 Mapping Boundary

Vegetation within the entire Project area was mapped as possible, with a focus on the southern side of the river. Since access was not granted on the north side, vegetation in that part of the Project was mapped using a combination of aerial photo interpretation and opportunistic viewing from across the river. Mapping sometimes extended beyond the current Project area to anticipate potential future actions or where a stand of vegetation continued beyond the boundary. Within the Project area, 179 acres were mapped, and 48 acres could not be mapped. Vegetation analyses in this technical memorandum were conducted using all mapped vegetation (181 acres), including two acres that were outside of the Project area (Figure 1, Figure 2).

1.1.2 Field Map Digitization

Field maps were scanned, and field-mapped polygons digitized in a GIS-compatible software using the California State Plane NAD83, Zone III (ft) coordinate system. The California State Plane coordinate system map was converted to a UTM coordinate system. A vegetation layer was prepared and checked for attribution accuracy and polygon completion. Attribute data were compiled and joined to each of the vegetated cover types. Attributes created for each cover type included the corresponding vegetation alliance per the Manual of California Vegetation (Sawyer et al. 2009); the State Rank (rarity) for the vegetation alliance; the native, non-native, or invasive status of the dominant species within the cover type; a roughness value for use in the 2-D hydraulic model; the plant functional group; the California Invasive Plant Council Rank; the wetland indicator status for the dominant species in each cover type utilizing the USACE 2018 Wetland Plant List for the arid west (USACE 2018); and the expected vegetation zonal type based on professional judgement. The GIS database was queried, and the aerial extent of different cover types was evaluated.

1.1.2.1 Data Quality Assurance and Quality Control (QA/QC)

The vegetation mapping data were checked for completeness to ensure that the defined Project area was covered. Data were checked to ensure that attributes assigned to polygons met the requirements for the land cover type assigned. Topology of the data was also checked to confirm the connectivity of elements from which polygons were constructed. Additional QA/QC efforts included a formal systemwide visual inspection of the vegetation map at a fixed scale of 1=6,000. This visual inspection was conducted with the vegetation layer symbolized by cover type. A random selection of polygons was also visually inspected and compared to the field maps to ensure that the transfer of attributes into the GIS layer from the field maps was correct.

1.1.2.2 Uncertainty and Estimation of Error

There are several sources of potential variability that may affect the accuracy of areas quantified by mapping. Mapping accuracy varies, and the effect is difficult to estimate. Human error could potentially affect how a polygon was drawn, as well as how the cover type was assigned. Results were presented in as *precise* a manner as the data allowed; however, map *accuracy* is variable depending on several factors such that the effects of how different vegetation ecologists map vegetation, base map quality, software technology, and other factors may influence the results of map comparisons in the future.

Currently there is no quantitative estimate of the amount of error associated with polygon areas. Given the inherent errors with field mapping and aerial photo interpretation, polygon areas were estimated to be 95% accurate based on professional experience (HVT and MA 2015). If future vegetation cover monitoring occurs, the estimated differences between years should be greater than 5% in area to be considered a real change.

1.1.3 Detrended Ground Surface Digital Elevation Model

The groundwater within the lower Tuolumne River riparian corridor is seasonally variable, and ground surface topography also varies within the Project area. When shallow groundwater is lower than the stream water surface elevation, a stream is losing water into the adjacent groundwater; when shallow groundwater is higher than the stream water surface elevation, the stream is gaining water from the adjacent hillsides. Riparian and wetland vegetation persists in locations where groundwater is shallow, whether created by more drainage from the valley wall, or due to lower elevation ground surfaces.

Given suitable hydrology and soils, riparian vegetation generally establishes within a fixed distance (i.e., height) from the shallow groundwater table. In many river systems with coarse substrates, groundwater can be approximated by the stream water surface, and the height above the water surface elevation can be used as a surrogate for the height above the groundwater table. A topographic map showing the ground surface height above the groundwater is a valuable tool for:

- Evaluating the elevation distribution of existing individual vegetation cover types above the groundwater to define vegetation zones, and
- Evaluating the extent of and location where proposed physical designs modify ground surface elevations and the vegetation types that the proposed design may support or inhibit.

Updates were made to the existing conditions terrain data and modeled 80 cfs water surface after the depth to estimated groundwater analysis was originally performed on existing conditions for the Phase I project (MA 2021). Within the Zanker property boundaries, the existing ground surface layer is a combination of 2017 LiDAR data and bathymetric and terrestrial topographic surveys conducted in summer 2021. The depth to groundwater analysis presented in this report reflects all updates that were made to existing conditions terrain and hydraulic modeling results as presented in the 65% Basis of Design report.

A Detrended Digital Elevation Model (dtDEM) was developed using the Zanker Farm existing condition terrain and a HEC-RAS modeled 80 cfs water surface elevation (WSE). In the Project area, the 80 cfs flow is the $Q_{1.5}$ 30-day duration flow during the riparian growing season and thus representative of groundwater conditions that riparian plants will experience (Bair et al. 2021). Within the Zanker property boundaries, the existing ground surface layer is a combination of 2017 LiDAR data and bathymetric and terrestrial topographic surveys conducted in summer 2021.

Creating the dtDEM required differencing the existing ground surface and a planar projection of the 80 cfs water surface. Since 80 cfs modeled water surface elevation data points were constrained to the low flow water edge, the data had to be extrapolated to areas outside of the river channel and then interpolated between upstream and downstream locations to create a planar projection of the water surface. To do this, WSE points were offset from the channel towards the valley walls. Once WSE points were established across the valley, data were then interpolated across all data points to create a planar WSE that extended upstream to downstream and outwards across the valley walls. Data interpolation used the ArcGIS tool called "natural neighbor" (Sibson 1981). Once the extended WSE planar surface was created, it was then differenced from the existing ground surface to create the final dtDEM (i.e., height above river) surface layer.

To be truly representative of a depth to groundwater, groundwater elevations that correspond to the streamflow water surface elevation should be included in the WSE planar surface. The dtDEM that was constructed for the Zanker Farm Project area did not use groundwater data because none were available, and thus a simple planar projection of the 80 cfs water surface elevation was used. The relationship between vegetation and the ground height above 80 cfs water surface elevation oversimplifies the relationship of shallow groundwater because the simple flat planar projection of the stream's wetted edge at 80 cfs water may not portray the actual groundwater conditions at a given location; the groundwater within the Project area may be lower (deeper) than the streamflow water surface elevation with distance from the river channel. However, the dtDEM surface was a reasonable approximation of groundwater conditions that allowed for data-driven revegetation design (Bair et al. 2021).

1.1.4 Analysis

The relationships between vegetated and unvegetated cover types and the 80 cfs dtDEM were evaluated. Cover types mapped in June 2021 were overlaid on the 80 cfs dtDEM. An analysis was conducted to identify the minimum, maximum, 25th and 75th percentiles, and median height above river elevations associated with the range of dtDEM pixel values linked to each cover type (Bair et al. 2021). These summary statistics were used to construct a box whisker chart, where an evaluation of the median height above the 80 cfs water surface was used to assign each cover type a vegetation zone. Cover types were ranked from smallest median value (lowest elevation) to largest median value (highest elevation), and vegetation zones were qualitatively assigned in increments loosely based on asymptotes in ascending medians (Bair et al. 2021).

1.2 Results

The riparian corridor within the Project area includes areas that are close to groundwater and areas that are high above it. Mapped vegetation types dominated by wetland and riparian species tended to grow lower in ground elevation above the 80 cfs streamflow elevation. Five vegetation zones and one water zone were initially defined for the project: channel margin, mesic, mesic–xeric transition, xeric, and water. In response to comments that were received on the 30% design an additional vegetation zone was defined for the Zanker Farm Project. The mesic zone was split into two zones a low riparian zone and a high riparian zone. The depth to estimated groundwater analysis has been updated in this report to reflect the new zonal break.

1.2.1 Vegetation Mapping and Classification

Vegetation mapping within the Zanker Farm Project area included mesic vegetation along the lower Tuolumne River and upland xeric vegetation. Twenty-nine vegetated and five unvegetated cover types were mapped in the 226.8-acre Project area in 2021 (Figure 1, Figure 2, Table 1). Non-native grassland was the most abundant cover type within the Project area, covering 65.6 acres. The next six most abundant vegetated cover types included: 27.6 acres of valley oak (*Quercus lobata*), 19.6 acres of narrowleaf willow (*Salix exigua*), 10.5 acres of Fremont cottonwood (*Populus fremontii*), 6.5 acres of riparian herbaceous (multiple species), 4.8 acres of emergent (multiple species), and 4.5 acres of black willow (*Salix gooddingii*). The remaining 22 vegetated cover types each covered 1.5 acres or less.

Table 1. Area of vegetated and unvegetated cover types within the Project area. Cover types in red are dominated by non-native species.

Cover type	**Vegetation alliance**	**CDFW Global/ State Rank**	**Phase I area (ac)**	**Phase II area (ac)**	**Combined area (ac)**
Acacia sp.	no corresponding alliance	No/None	0.01	0.0	0.01
Aquatic emergent	Numerous aquatic emergent alliances may apply within this group.	N/A	0.44	0.07	0.51
Arroyo willow	*Salix lasiolepis* Shrubland Alliance Arroyo willow thickets	G4/S4	0.19	0.16	0.35
Common buttonbush	*Cephalanthus occidentalis* Shrubland Alliance Button willow thickets	G5/S2	0.34	0.34	0.68
Blue elderberry	no corresponding alliance	No/None	0.0	0.04	0.04
Bulrush	*Schoenoplectus (acutus, californicus)* Herbaceous Alliance Hardstem and California bulrush marshes	GNR/S3S4	0.04	0.0	0.04
Bedrock	N/A	N/A	0	0.04	0.04
Black willow	*Salix gooddingii–Salix laevigata* Forest and Woodland Alliance Goodding’s willow–red willow riparian woodland and forest	G4/S3	3.53	1.0	4.53
California buckeye	*Aesculus californica* Forest and Woodland Alliance California buckeye groves	G3/S3	0.0	0.08	0.08
California grape	*Vitis arizonica–Vitis girdiana* Shrubland Alliance Wild grape shrubland	G3/S3	0.17	0.0	0.17
Channel	N/A	N/A	16.7	9.4	26.14
Carex nudata	*Carex nudata* Herbaceous Alliance Torrent sedge patches	G3/S3	0.02	0.0	0.02
Canyon live oak	*Quercus chrysolepis* (tree) Forest and Woodland Alliance Canyon live oak forest and woodland	G5/S5	0.0	0.03	0.03
Bermuda grass	Mediterranean California Naturalized Annual and Perennial Grassland Group (several corresponding alliances)	N/A	0.18	0.0	0.18
Emergent	Numerous alliances may apply within this group	N/A	4.22	0.57	4.79
Fremont cottonwood	*Populus fremontii–Fraxinus velutina–Salix gooddingii* Forest and Woodland Alliance Fremont cottonwood forest and woodland	G4/S3	8.28	2.26	10.54
Giant reed	*Phragmites australis–Arundo donax* Herbaceous Semi-Natural Alliance Common and giant reed marshes	GNR/SNR	1.14	0.07	1.21

Cover type	**Vegetation alliance**	**CDFW Global/ State Rank**	**Phase I area (ac)**	**Phase II area (ac)**	**Combined area (ac)**
Himalayan blackberry	*Rubus armeniacus–Sesbania punicea–Ficus carica* Shrubland Semi-Natural Alliance Himalayan blackberry–rattlebox–edible fig riparian scrub	GNR/SNR	0.44	0.19	0.63
Human disturbance	N/A	N/A	0.33	0.20	0.53
Heterotheca oregona	*Heterotheca (oregona, sessiliflora)* Herbaceous Alliance Goldenaster patches	G3/S3	0.10	0.0	0.10
Non-native grass	Mediterranean California Naturalized Annual and Perennial Grassland Group (several corresponding alliances)	N/A	43.8	21.8	65.6
Not mapped	N/A	N/A	24.83	23.2	48.03
Narrowleaf willow	*Salix exigua* Shrubland Alliance Sandbar willow thickets	G5/S4	13.47	6.16	19.63
Oregon ash	*Fraxinus latifolia* Forest and Woodland Alliance Oregon ash groves	G4/S3	0.24	0.30	0.54
Open	N/A	N/A	1.03	1.13	2.16
Open water	N/A	N/A	2.72	0.07	2.79
Mexican rush	*Juncus arcticus* (var. *balticus, mexicanus*) Herbaceous Alliance Baltic and Mexican rush marshes	G5/S4	0.07	0.0	0.07
Poison oak	*Toxicodendron diversilobum* Shrubland Alliance Poison oak scrub	G4/S4	0.0	0.47	0.47
Riparian herbaceous	Numerous alliances may apply within this group	N/A	4.79	1.66	6.45
Red willow	*Salix gooddingii–Salix laevigata* Forest and Woodland Alliance Goodding's willow–red willow riparian woodland and forest	G4/S3	0.05	0.0	0.05
Tree of heaven	*Eucalyptus* spp.*–Ailanthus altissima–Robinia pseudoacacia* Woodland Semi-Natural Alliance Eucalyptus–tree of heaven–black locust groves	GNA/SNA	0.20	0.13	0.33
Valley oak	*Quercus lobata* Forest and Woodland Alliance Valley oak woodland and forest	G3/S3	19.3	8.3	27.6
Valley sedge	*Carex barbarae* Herbaceous Alliance White-root beds	G2?/S2?	0.07	0.0	0.07

Cover type	Vegetation alliance	CDFW Global/ State Rank	Phase I area (ac)	Phase II area (ac)	Combined area (ac)
White alder	*Alnus rhombifolia* Forest and Woodland Alliance White alder groves	G4/S4	0.80	0.34	1.14
Yellow star-thistle grassland	*Brassica nigra–Centaurea (solstitialis, melitensis)* Herbaceous Semi-Natural Alliance Upland mustard or star-thistle fields	GNA/SNA	1.23	0.0	1.23
Totals			148.7	78.1	226.8

1.2.1.1 Sensitive Natural Communities

Natural Communities are described at the alliance or association level for vegetation types in California (MCV, Sawyer et al. 2009). CDFW maintains a list and provides oversight of habitats (i.e., plant communities) listed as Sensitive on the California Sensitive natural communities List (CDFW 2021). Natural Communities are listed based on global and state rarity rankings (Table 2). CDFW considers Natural Communities with state ranks of S1–S3 to be Sensitive natural communities (CDFW 2020). Not all associations have been assigned global and state ranking determinations at the time of the latest updated list (August 18, 2021) of Sensitive natural communities (CDFW 2021).

Table 2. Global and state rarity rankings for Sensitive natural communities in California.

Global Ranks
G1 = Fewer than 6 viable occurrences of the vegetation type worldwide and/or < 2,000 acres
G2 = 6–20 viable occurrences of the vegetation type worldwide and/or > 2,000–10,000 acres
G3 = 21–100 viable occurrences of the vegetation type worldwide and/or > 10,000–50,000 acres
G4 = Greater than 100 viable occurrences of the vegetation type worldwide and/or > 50,000 acres
G5 = Vegetation type is demonstrably secure due to worldwide abundance
GNR = Global rank not yet assessed
GNA = Global rank not applicable
State Ranks
S1 = Fewer than 6 viable occurrences of the vegetation type statewide and/or < 2,000 acres
S2 = 6–20 viable occurrences of the vegetation type statewide and/or > 2,000–10,000 acres
S3 = 21–100 viable occurrences of the vegetation type statewide and/or > 10,000–50,000 acres
S4 = Greater than 100 viable occurrences of the vegetation type statewide and/or > 50,000 acres
S5 = Vegetation type is demonstrably secure due to statewide abundance
SNR= State rank not yet assessed
SNA= State rank not applicable
A question mark (?) denotes an inexact rank due to insufficient samples

Mapped vegetated cover types have been cross-walked to vegetation alliances as defined by the MCV (Sawyer et al. 2009; Table 1). Not all vegetated cover types could be cross-walked to an alliance, and for some mapped cover types such as aquatic emergent, emergent, and riparian herbaceous cover types, multiple alliances may fit into each of these broader groups.

1.2.2 Detrended Digital Elevation Model

As expected, ground surfaces closest to the estimated groundwater occurred directly adjacent to the channel, while surfaces farther from the channel were also farther from the estimated groundwater (Figure 3). Four percent of the existing ground dtDEM within the 226.8-acre Project area was between 0 and 2 ft above the 80 cfs Tuolumne River water surface elevation; 15% occurred between 2 and 5 ft; 29% occurred between 5 and 9 ft; 21% occurred between 9 and 14 ft; and 17% occurred on ground surfaces that were greater than 14 ft (Figure 3, Table 4).

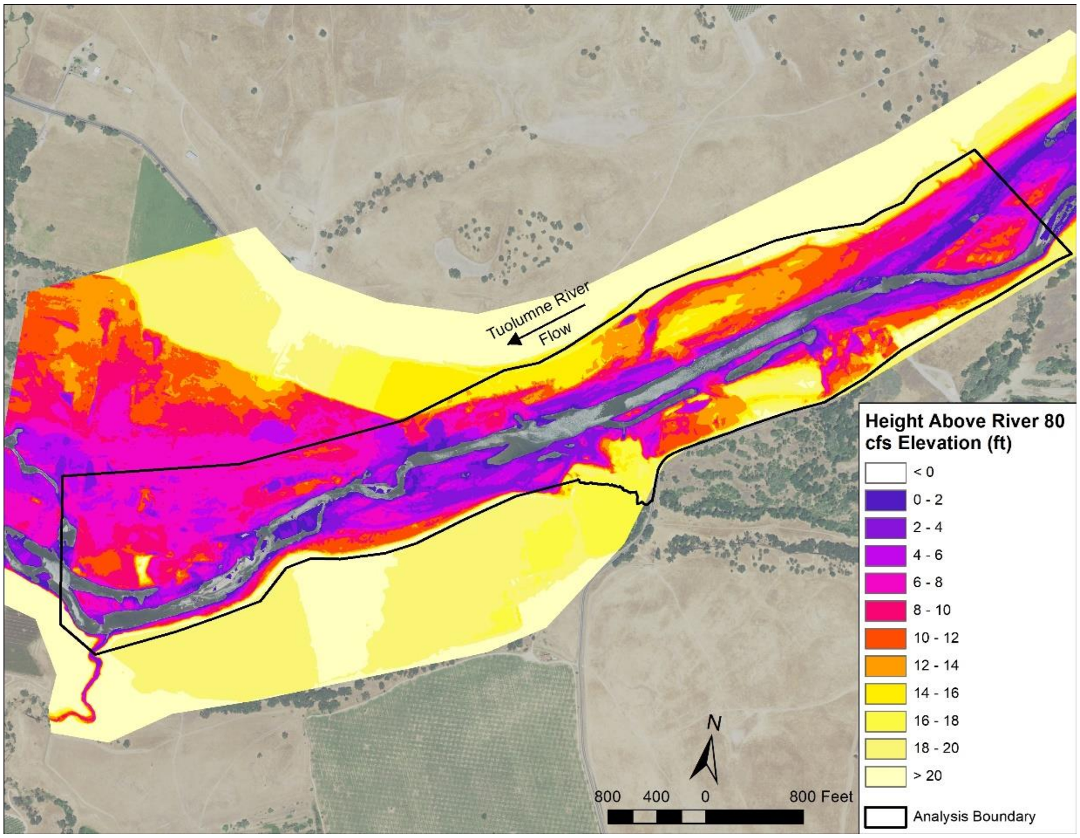

Figure 3. Detrended Digital Elevation Model (dtDEM) of the Project area.

1.2.3 Existing Vegetation Zonation

The riparian corridor has been defined as the zone of direct interaction between the terrestrial and aquatic system(s) or by the dominant plant species present (Gregory et al. 1991). A riparian corridor is an area where the gradient from 100% aquatic habitat to 100% upland habitat occurs. Many definitions of riparian areas (or corridors) consider the present channel location, and adjacent land where the stream sustains a higher, off-channel groundwater table. But the riparian corridor should also include those areas the channel once occupied and might occupy in the future. Often a riparian corridor is bounded by adjacent valley walls or high terraces.

The California State Water Resources Control Board (SWRCB) has developed a working definition for riparian areas (SFEI and ASC 2012):

> *Riparian areas are areas through which surface and subsurface hydrology interconnect aquatic areas and connect them with their adjacent uplands (Brinson et al. 2002). They are distinguished by gradients in biophysical conditions, ecological processes, and biota. They can include wetlands, aquatic support areas, and portions of uplands that significantly influence the conditions or processes of aquatic areas.*

Physical and hydrologic gradients within the riparian corridor exert a strong influence on vegetation patterns adjacent to streams and water bodies. Closer to the water, hydrophytic and emergent plants may thrive, whereas riparian plants may dominate vegetation a little further and higher from the water (Figure 4). Vegetation zonation created by hydrologic and physical gradients has been used in the past as a basis of revegetation design (Hoag and Landis 2001, 2002, Bair et al. 2003, Sullivan and Bair 2004, HVT et al. 2006, HVT and M&T 2015, Bair et al. 2021).

After comments on the 30% Basis of Design Report were received, five vegetation zones and one aquatic zone were qualitatively assigned in increments loosely based on asymptotes in ascending medians (Bair et al. 2021), (Figure 4, Table 3, Figure 5). Each zone is defined as an elevation above the 80 cfs water surface elevation. The areas for each vegetation zone vary in size and location (Table 4, Figure 6).

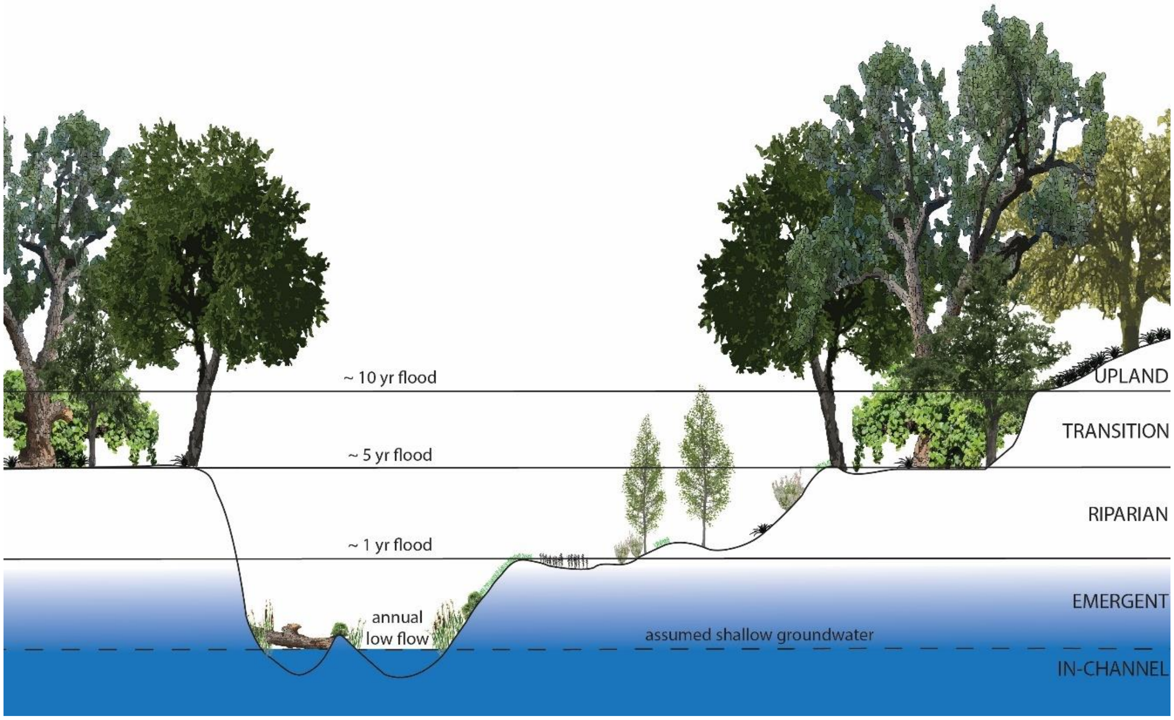

Figure 4. Vegetation zones used as a basis for revegetation design.

Table 3. Five vegetation zones and one water zone defined using the height above 80 cfs water surface analysis.

Vegetation zone	Height above 80 cfs water surface	Annual inundation duration	Description
Water	< 0 ft	All year	This zone is inundated constantly and is one source of shallow groundwater throughout the year
Emergent/Channel Margin	0–2 ft	All year to multiple months	This zone is in constant contact with the shallow groundwater through capillarity or direct inundation
Low Riparian	2 to 5 ft	Many weeks to days	This zone is in frequent contact with the shallow groundwater through capillarity or direct inundation
High Riparian	5 to 9 ft	Many weeks to days	This zone is in frequent contact with the shallow groundwater through capillarity or direct inundation
Riparian–Upland Transition	9 to 14 ft	Days to hours	This zone is infrequently in contact with the shallow groundwater through capillarity or direct inundation
Upland	> 14 ft	Hours to never	This zone is rarely in contact with the shallow groundwater through capillarity or direct inundation

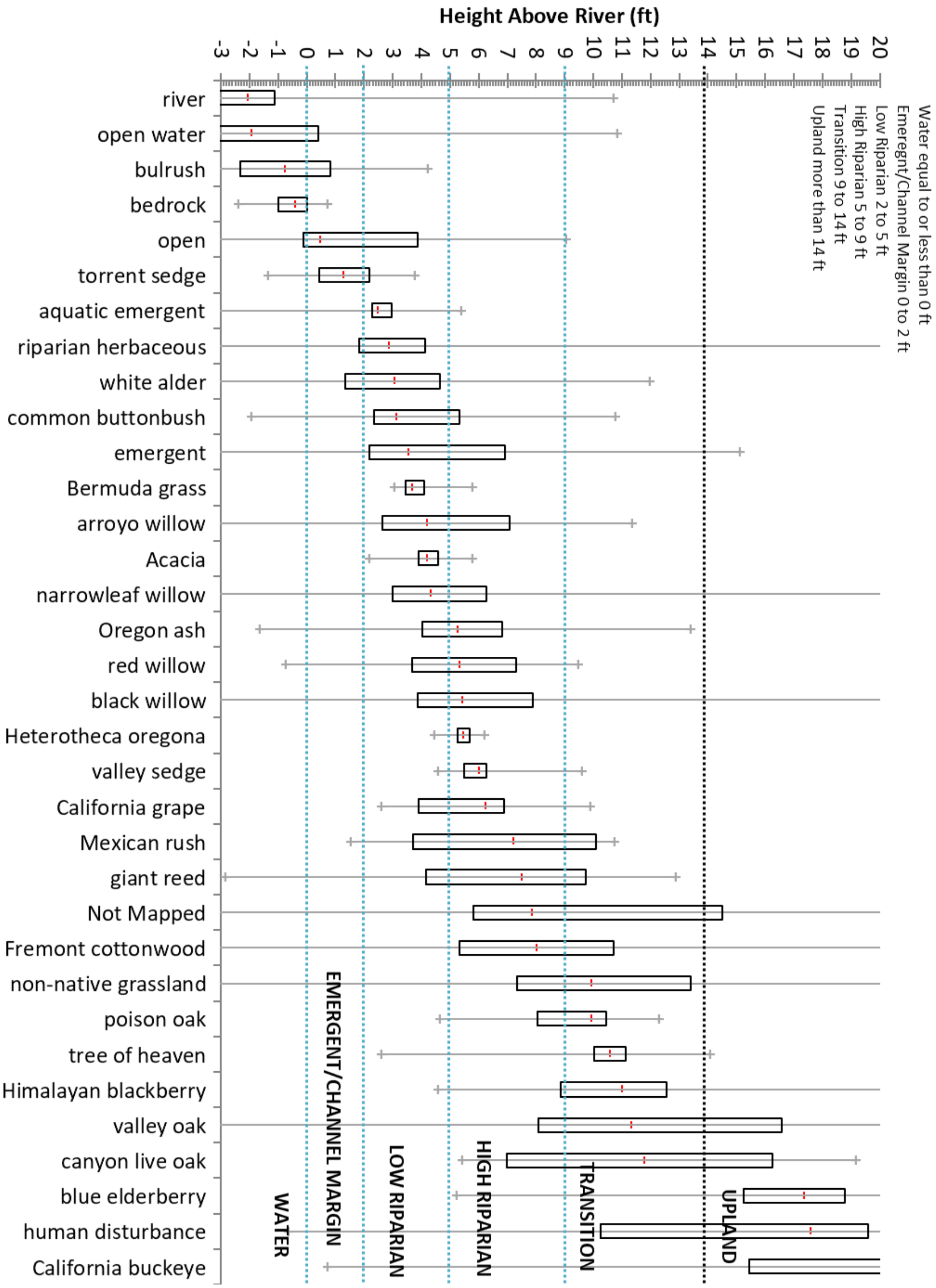

Figure 5. Box plots illustrating the median height and range of heights above the 80 cfs water surface elevation for mapped cover types. The red dash is the median elevation of the cover type. The box is defined by the 25th and 75th percentiles, and the grey lines show the range in data between minimum and maximum height. The height in the chart is truncated to 20 ft.

Table 4. Percent area of existing vegetation zones within the Project area.

Zone	Percent of Project area
Water	14%
Emergent / Channel Margin	4%
Low Riparian	15%
High Riparian	29%
Riparian–Upland Transition	21%
Upland	17%
Total	**100%**

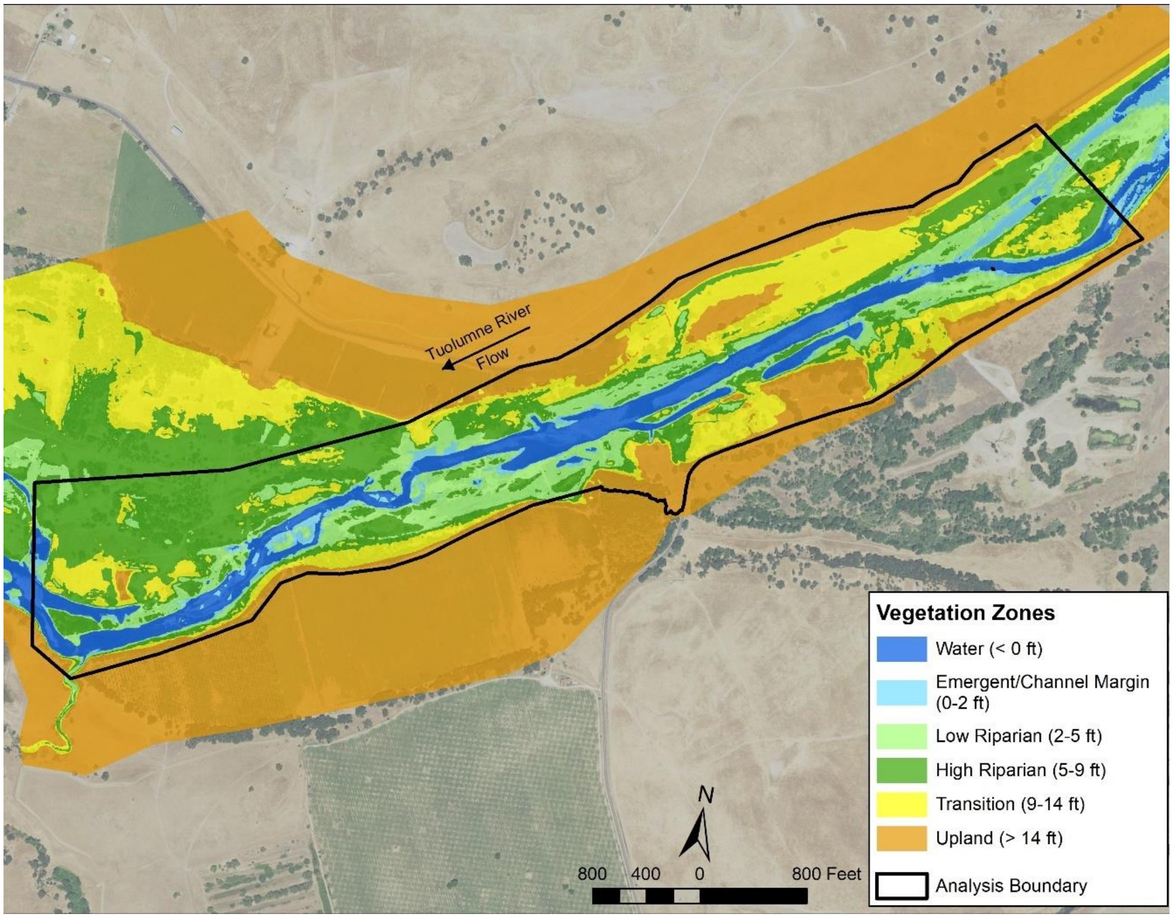

Figure 6. Existing vegetation zonation within the Zanker Farm.

1.2.4 Cover Types and Sensitive Natural Communities Within Vegetation Zones

Vegetated cover types that are associated with CDFW Sensitive natural communities occur within the water, channel margin, low riparian, high riparian, mesic–xeric transition, and xeric zones in the Project area. The high riparian zone had the highest number of Sensitive natural communities. Vegetation and Sensitive natural communities within each zone are described in more detail below.

1.2.4.1 Water

Four cover types were mapped within the zone defined as water (Figure 5). These cover types occurred at elevations that were lower than or equal to the 80 cfs water surface (Figure 5) and included river, bedrock, open water, and bulrush (*Schoenoplectus* sp.). Areas mapped as open water were typically pond areas with very little vegetation. The mapped bulrush cover type corresponds to the hardstem and California bulrush marshes (*Schoenoplectus* (*acutus*, *californicus*) Herbaceous Alliance) and covered 0.04 acre within the Project area. The association within the Alliance was not determined. However, all associations except for *Schoenoplectus acutus*–common reed (*Phragmites australis*) are considered Sensitive. No common reed was observed within the site, so the bulrush cover type did not correspond to that association. Therefore, we assumed the hardstem and California bulrush marshes are considered Sensitive.

1.2.4.2 Emergent/Channel Margin

The emergent or channel margin zone occurs between 0 and 2 ft above the fall water surface (Figure 5). Cover types occurring within the channel margin zone included open areas that lacked vegetation, and torrent sedge patches (*Carex nudata* Herbaceous Alliance) which are considered Sensitive natural communities. Torrent sedge patches covered 0.02 acre in the Project area.

1.2.4.3 Low Riparian Zone

Nine cover types were mapped within the low riparian zone between 2 and 5 ft above the 80 cfs water surface (Figure 5). Three broad cover types within the low riparian zone were composed of groups of herbaceous species. The three broad groups included aquatic emergent, emergent, and riparian herbaceous cover types. These broad cover classes were used to describe groups of species that generally occurred together and were found in similar habitat types. Species dominance shifted within the groups throughout the Project area, and the broad groups do not correspond to more detailed vegetation alliances.

The aquatic emergent cover type was mapped in areas with ponded or standing water where aquatic vegetation was dominant. Commonly associated species within this cover type included: native bulrush (*Schoenoplectus* sp.), cattail (*Typha* sp.), and whorled marsh pennywort (*Hydrocotyle verticillata*). The non-native invasive species water hyacinth (*Eichhornia crassipes*), parrot’s feather (*Myriophyllum aquaticum*), and crisp-leaved pondweed (*Potamogeton crispus*) also occurred within this cover type.

The emergent cover type occurred in areas with saturated soil that were not in standing water. This cover type occurred adjacent to ponds or the river channel. Associated species in this cover type included the invasive non-native species marsh purslane (*Ludwigia peploides*), and the native species nutsedge (*Cyperus eragrostis*), and spikerush (*Eleocharis macrostachya*). Field mint (*Mentha arvensis*), a non-native species that is considered naturalized, also occurred in this cover type (Baldwin et al. 2012).

The riparian herbaceous cover type occurred throughout the low riparian zone, typically in locations closer to the river. Commonly associated species in this group included: the native species Mexican rush (*Juncus mexicanus*), horseweed (*Erigeron canadensis*), beardless wild rye (*Elymus triticoides*), common scouring rush (*Equisetum hyemale*), valley sedge (*Carex barbarae*), mugwort (*Artemisia douglasiana*), and the non-native species Kentucky blue grass (*Poa pratensis* ssp. *pratensis*).

Two cover types mapped in the low riparian zone corresponded to Sensitive natural communities: button willow thickets (*Cephalanthus occidentalis* Shrubland Alliance); and arroyo willow thickets (*Salix lasiolepis* Shrubland Alliance). Arroyo willow thickets are not considered Sensitive at the alliance level, but the alliance contains some associations that are considered Sensitive. The mapped arroyo willow cover type corresponded to the arroyo willow association (*Salix lasiolepis*) which is considered Sensitive. This association is described in *Vegetation Alliances and Associations of the Great Valley Ecoregion* (Buck-Diaz et al. 2012).

Two native riparian cover types occur within the low riparian zone that did not correspond to Sensitive natural communities, the narrowleaf willow and white alder (*Alnus rhombifolia*) cover types. Two non-native cover types occur in the low riparian zone, Bermuda grass (*Cynodon dactylon*), and Acacia (*Acacia* sp.).

1.2.4.4 High Riparian Zone

Ten cover types were mapped within the high riparian zone between 5 and 9 ft above the 80 cfs water surface (Figure 5). Several cover types mapped in the high riparian zone correspond to Sensitive natural communities: Oregon ash groves (*Fraxinus latifolia* Forest and Woodland Alliance); wild grape shrubland (*Vitis arizonica–Vitis girdiana* Shrubland Alliance); Fremont cottonwood forest and woodland (*Populus fremontii–Fraxinus velutina–Salix gooddingii* Forest and Woodland Alliance); white root beds (*Carex barbarae* Herbaceous Alliance); goldenaster patches (*Heterotheca* (*oregona*, *sessiliflora*) Herbaceous Alliance); black willow–red willow riparian woodland and forest (*Salix gooddingii–Salix laevigata* Forest and Woodland Alliance). One native cover type, Mexican rush (*Juncus mexicana*) does not correspond to a Sensitive Natural Community. The non-native giant reed (*Arundo donax*) cover type also occurs within the high riparian zone.

1.2.4.5 Riparian-Upland Transition Zone

Six cover types were mapped within the mesic–xeric transition zone between 9 to 14 ft above the 80 cfs water surface (Figure 5). One Sensitive Natural Community occurred within the mesic–xeric transition zone, valley oak woodland and forest (*Quercus lobata* Forest and Woodland Alliance). Two other native cover types occurred in this zone that are not considered Sensitive natural communities, the canyon live oak (*Quercus chrysolepis*) cover type and the poison oak (*Toxicodendron diversilobum*) cover type. Non-native cover types in this zone included non-native grassland, Himalayan blackberry (*Rubus armeniacus*), and tree of heaven (*Ailanthus altissima*).

1.2.4.6 Upland Zone

Four cover types were mapped within the upland zone which occurs at elevations greater than 14 ft above the 80 cfs water surface (Figure 5). One Sensitive Natural Community occurred within the upland zone, California buckeye groves (*Aesculus californica* Forest and Woodland Alliance). The location of the California buckeye groves in shown in (Figure 7). The blue elderberry cover type also occurred in the upland zone but does not crosswalk to a defined Vegetation Alliance per the Manual of California Vegetation (Sawyer et al. 2009). However, this species requires special consideration due to its ecological role as a host plant for the Federally threatened Valley Elderberry Longhorn Beetle (VELB; *Desmocerus californicus dimorphus*, Section 1.4). One non-native cover type, yellow star-thistle grassland, occurred in the upland zone. The human disturbance cover type, which generally has sparse to no vegetation, also occurred in this zone.

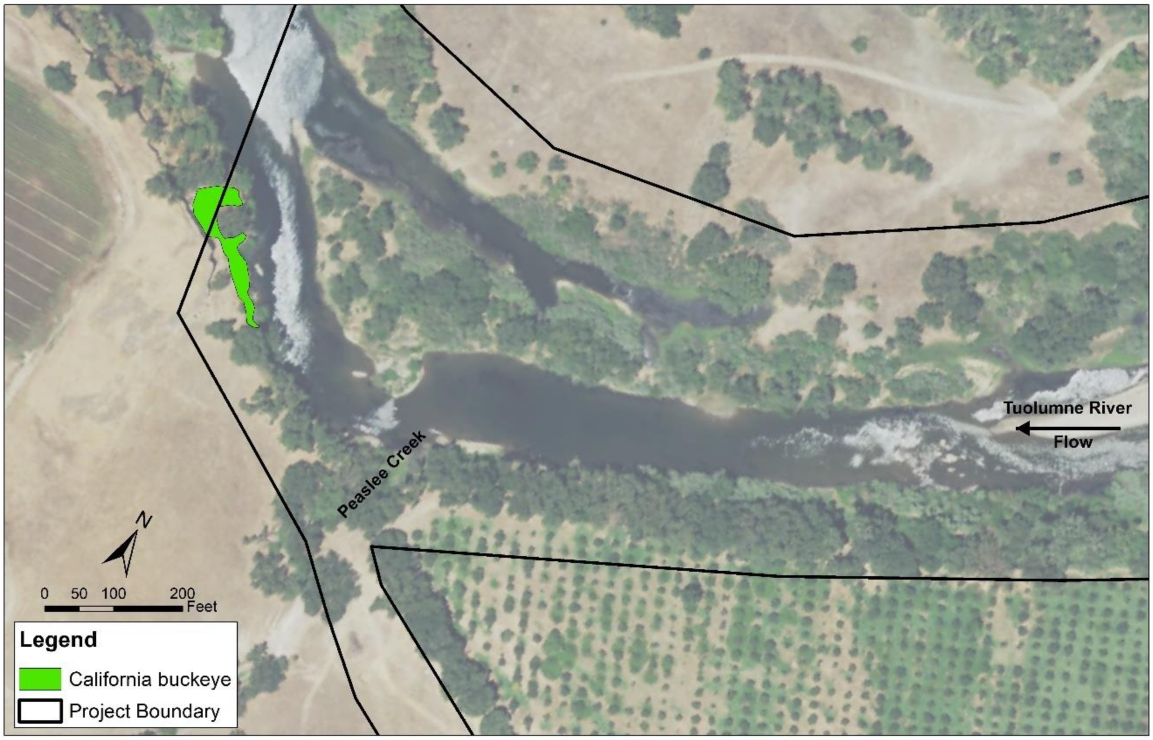

Figure 7. California buckeye grove is the only sensitive natural community that occurs in the upland zone within the Zanker Farm project boundary. California buckeye groves occur elsewhere on the lower Tuolumne River including upstream of old La Grange bridge.

1.3 Non-native Invasive Plants

Several non-native invasive plant species occurred within the Project area and six non-native invasive cover types were mapped (Figure 8). Mapped cover types included: Acacia (*Acacia* sp.), giant reed grass, Himalayan blackberry, tree of heaven, common fig (*Ficus carica*), and yellow star-thistle (*Centaurea solstitialis*) grassland. Only large patches of non-native invasive plant species were mapped during vegetation mapping. Individual non-native invasive trees were mapped when possible, but mapping of invasive non-native species was not comprehensive. Several non-native invasive plant species were observed during vegetation mapping that did not occur in large enough patches to be mapped as a cover type, or the species occurred within another cover type. Non-native invasive plant species observed within the site are listed in Table 5 along with non-native invasive plants that have been observed by McBain Associates on the lower Tuolumne River previously (M&T 2000).

Aquatic non-native invasive plants were observed that may be especially problematic to restoration efforts. Non-native invasive aquatic species observed within the Project area include water hyacinth, parrot’s feather, crispate-leaved pondweed, yellow flag iris (*Iris pseudacorus*), and floating primrose. During construction, efforts should be taken to clean equipment and prevent the spread of propagules from locations with aquatic invasive species to locations where they do not occur.

Terrestrial non-native invasive species should be removed with equipment during construction whenever feasible and disposed of, or buried, in an appropriate manner to prevent propagule spread. Non-native invasive trees and shrubs observed within the Project area included: tree of heaven, common fig, Acacia sp., tree tobacco (*Nicotiana glauca*), and Himalayan blackberry. Non-native invasive terrestrial herbaceous species included: giant reed, Bermuda grass, yellow star-thistle, and mullein (*Verbascum thapsus*). McBain Associates has previously observed tamarisk

(*Tamarix* sp.), black locust (*Robinia pseudoacacia*), and Eucalyptus (*Eucalyptus* sp.) on the lower Tuolumne River as mentioned in the *Restoration Plan* (M&T 2000). If these species are observed within the Project area, they should also be removed when feasible.

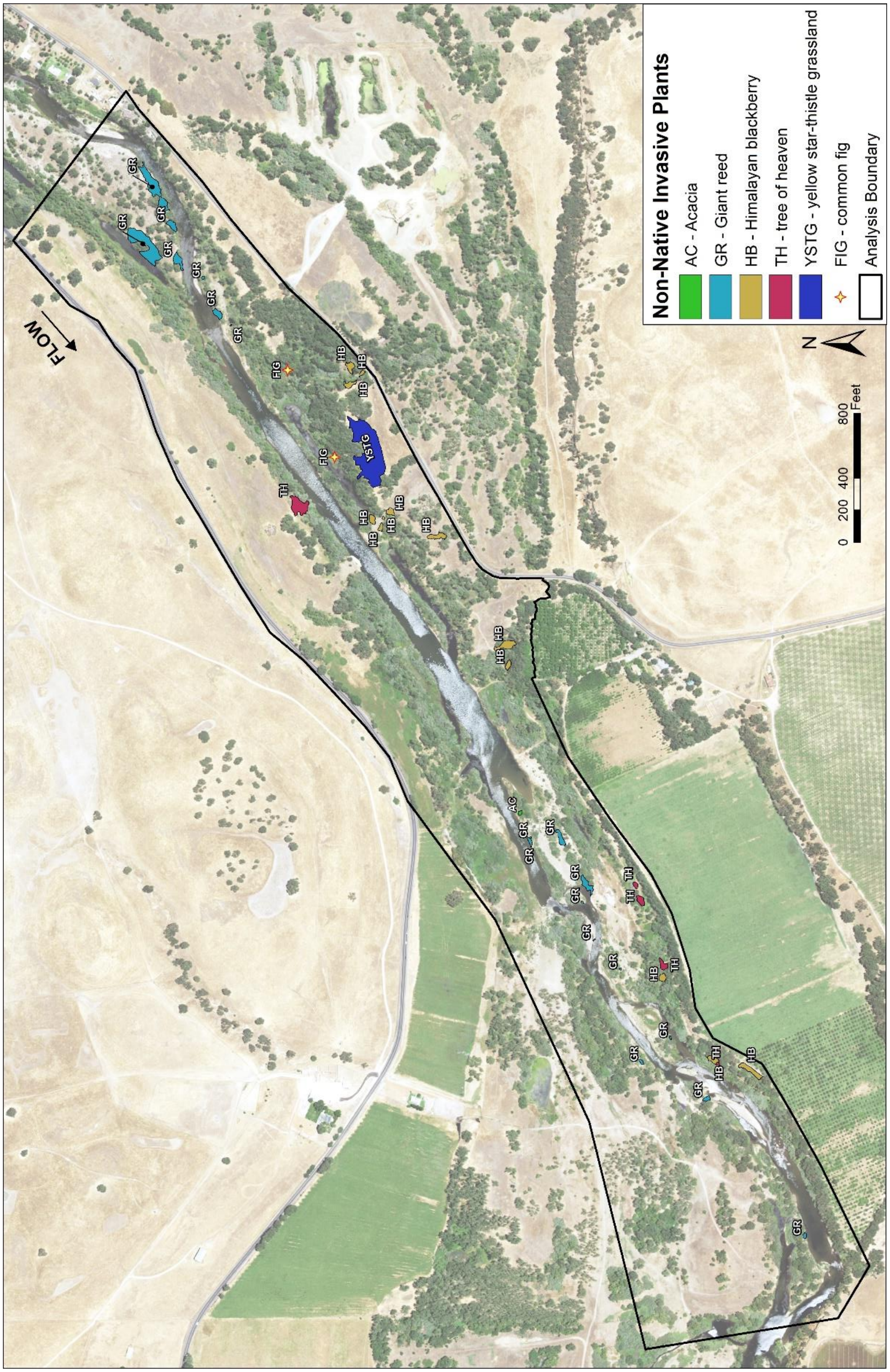

Figure 8. Cover types dominated by invasive plant species mapped in July 2021. Generally, only large patches of invasive plant species were mapped. Individual trees were occasionally mapped but mapping for invasive species is not comprehensive.

Table 5. Invasive plants of concern that were observed within the Project area or that were identified in the Habitat Restoration Plan for the Lower Tuolumne River Corridor (M&T 2000) are listed below along with their Cal-IPC Inventory Rank.

Common name	Scientific name	Cal-IPC Inventory threat rank	Occurrence summary
Giant reed	*Arundo donax*	High	Observed in field
Tree of heaven	*Ailanthus altissima*	Moderate	Observed in field
Common fig	*Ficus carica*	Moderate	Observed in field
Acacia sp.	*Acacia* sp.	Variable by species (Watch to Moderate)	Observed in field
Bermuda grass	*Cynodon dactylon*	Moderate	Observed in field
Himalayan blackberry	*Rubus armeniacus*	High	Observed in field
Tamarisk	*Tamarix* sp.	Varies by species (most are High)	*Restoration Plan*
Eucalyptus sp.	*Eucalyptus* sp.	Variable by species (Limited to Watch)	*Restoration Plan*
Yellow star-thistle	*Centaurea solstitialis*	High	Observed in field
Mullein	*Verbascum thapsus*	Limited	Observed in field
Water hyacinth	*Eichhornia crassipes*	High	Observed in field
Crispate-leaved pondweed	*Potamogeton crispus*	Moderate	Observed in field
Parrot’s feather	*Myriophyllum aquaticum*	High	Observed in field
Poison hemlock	*Conium maculatum*	Moderate	Observed in field
Tree tobacco	*Nicotiana glauca*	Moderate	Observed in field
Black locust	*Robinia pseudoacacia*	Limited	*Restoration Plan*
Yellow flag iris	*Iris pseudacorus*	Limited	Observed in field
Floating water primrose	*Ludwigia peploides*	High	Observed in field

1.4 Valley Elderberry Longhorn Beetle

Elderberry shrubs (*Sambucus* spp.) are the obligate larval host plant for the Federally threatened Valley Elderberry Longhorn Beetle (VELB; *Desmocerus californicus dimorphus*). Potential project effects on VELB must be evaluated as part of the project’s permitting process. Guidelines to assess potential effects to VELB are presented in the USFWS *Framework for Assessing Impacts to the Valley Elderberry Longhorn Beetle* (USFWS 2017). VELB are rarely observed, and their presence is evaluated by assessing elderberry shrubs to determine stem size and the presence of VELB activity (i.e., bore holes). If an elderberry plant has stems greater than 1 inch, the plant is considered a potential host and VELB presence is assumed. Indications of VELB occupancy do not need to be observed to assume presence.

Locations of individual blue elderberry (*Sambucus nigra* ssp. *caerulea*) plants and patches were assessed within the upstream end of the Zanker Farm Project area on June 2, 2021. Initially, locations of elderberry patches were drawn on the map in the field then digitized into GIS compatible software (Table 6, Figure 9), and data for individual blue elderberry shrubs were collected. Seven blue elderberry shrubs were documented near the upstream end of Zanker Farm, and GPS data, stem size, and presence of bore holes were collected for five of the elderberry plants (Table 6, Figure 9). Due to the number of blue elderberry that were observed throughout the

Project area, a decision was made not to evaluate the individual shrubs and patches until a later date. Due to the dense overstory canopy, the accuracy of the GPS unit was limited. When further mapping is conducted, the shrub center point should be mapped with high accuracy survey equipment, and data collected on stem number, crown diameter and presence or absence of bore holes (USFWS 2017). Conservation and mitigation measures for Valley Elderberry Longhorn Beetle must be followed for the project and are discussed in Section 1.3 in Appendix F.

Table 6. Data collected for seven blue elderberry shrubs occurring within the upstream reach of the Zanker Farm Project area. Current blue elderberry location data are incomplete given the frequency of blue elderberry within the Project area.

Point	Riparian or upland	Number of stems ≥ 1 Inch	Crown diameter	Bore holes
1	Upland (close to riparian)	1	7 ft	Yes
2	Upland (close to riparian)	1	6 ft	Yes
3	Upland (close to riparian)	1	5 ft	No
4	Riparian (at change in slope)	3	13 ft	Yes
5	Upland	0	8 in	No
Location drawn on aerial image	Upland	13	10 ft	Yes, on dead stems
Location drawn on aerial image	Upland	16	22 ft	Yes, on dead stems

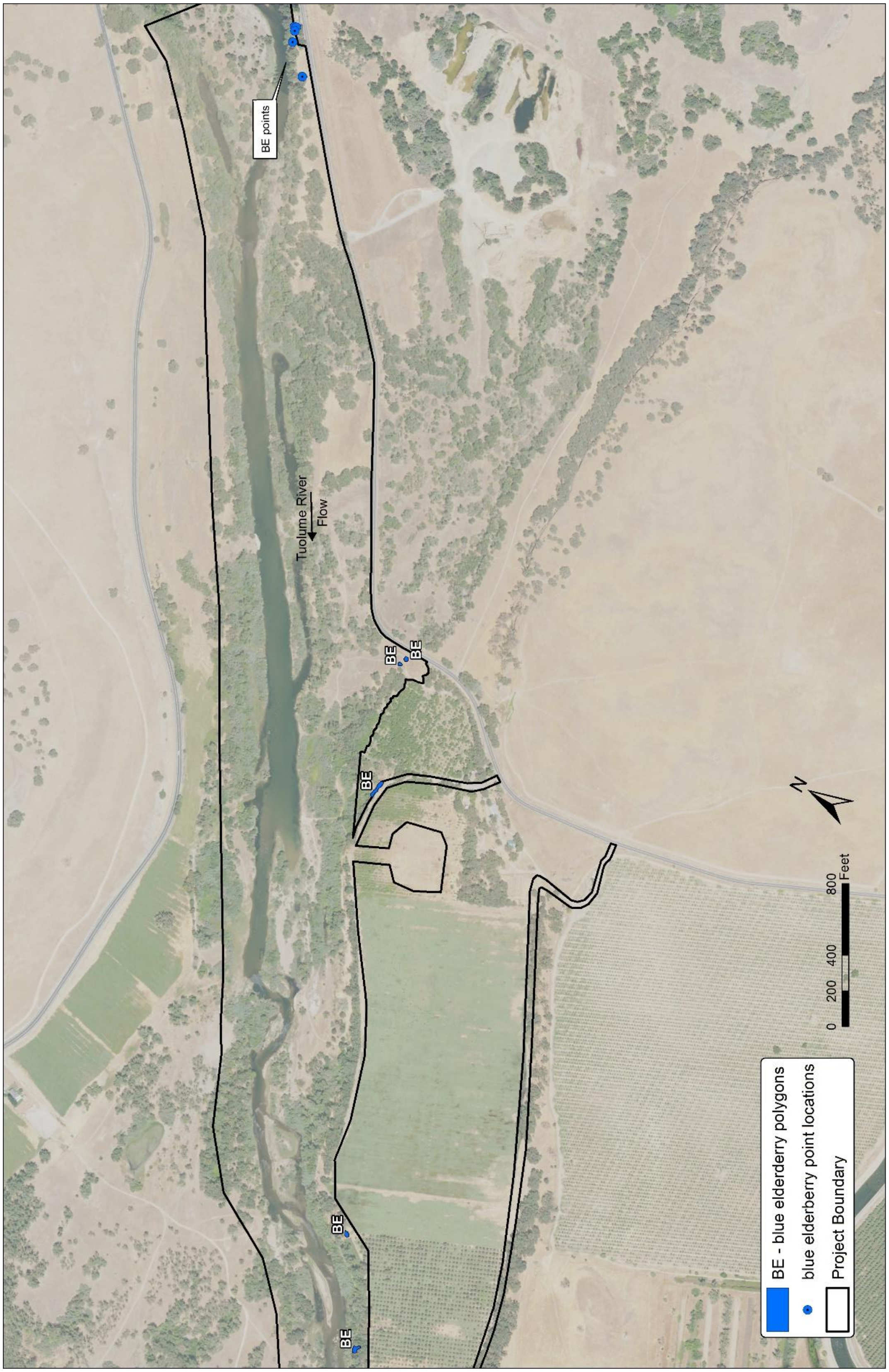

Figure 9. Individual blue elderberry locations near the upstream end of the project where data were initially collected. Due to the frequency of blue elderberry observed throughout the Zanker Farm Project area, the survey was postponed until further into the design process.

2 REVEGETATION DESIGN

2.1 Revegetation Goals and Objectives

The proposed revegetation approach is intended to recreate larger patches of vertically heterogenous riparian vegetation while leaving some ground surfaces exposed for natural plant recruitment from seed, thereby creating a complex, diverse, and self-sustaining dynamic riparian system that is directly linked to the functional integrity of channel and floodplain dynamics. Design concepts should selectively convert xeric (upland) zones into emergent/channel margin, riparian, or riparian-upland transition zones. An overall increase in emergent/channel margin vegetation is expected despite local vegetation removal needed to implement the Project. Additionally, it is expected that future cohorts of tree and herbaceous species will voluntarily colonize some areas within the Project footprint. Where proposed construction will create a ground disturbance that could favor the establishment of disturbance-dependent, non-native invasive plant species, planting recommendations will attempt to reduce the impact that non-native invasive plant species could have after the Project is completed. Diverse riparian vegetation should be maintained and rehabilitated via:

- Preserving as much of the existing riparian vegetation as possible and minimizing ground disturbance;
- Constructing topographic surfaces/benches at hydrologically suitable elevations to encourage natural riparian woody plant regeneration;
- Removing invasive non-native plants during construction; and
- Planting a variety of species in a simple arrangement based on vegetation associations found within the Project area (Section 1.2.1).

The long-term revegetation goal is to create, maintain, enhance, or restore the structural and functional integrity of aquatic, riparian, and associated upland systems needed to perpetually support populations of native fish and wildlife at both Project area and landscape levels. Floods will disturb and transform revegetated areas into more complex riparian vegetation with a diverse range of age classes, structural variation, and increased riparian plant and animal diversity. Revegetation designs reflect vegetation patterns that are indicative of other less disturbed portions of regional watersheds. The revegetation strategy relies on the combination of active (planting) and passive (natural plant regeneration) techniques to restore vegetation. Revegetation efforts should not conflict with design elements that are intended to restore a dynamic stream channel.

Revegetation objectives include:

- Compensate (to the extent possible) for potential riparian habitat losses due to Project implementation;
- Increase wetland, emergent, and riparian vegetation abundance in the tree, shrub, and herb layer within the construction footprint;
- Maintain continuous corridors of riparian vegetation with a more variable ecotone (transitional area between two biological communities) between the riparian and upland zones; and
- Reduce the area and species richness of non-native plant species within the Project area.

The relationship between vegetation and height above the 80 cfs water surface elevation described in Section 1.2.3 (Figure 5, Table 3, Figure 6) served as a basis for the Zanker Farm revegetation designs.

2.2 Predicted Vegetation Zone Response to Future Site Conditions

The work area has been designed to include variable ground surface elevations that will be seasonally inundated at different streamflows for varying lengths of time. Plantings are proposed within the Project footprint to establish the primary components of wildlife and fish habitat and cover disturbed ground surfaces. Areas designated for planting would be planted with appropriate species depending on proximity to the main channel and intended hydrologic function.

The same methods used to conduct the existing conditions height above river analysis were used to create a 90% design dtDEM product. The 90% design terrain DEM and a modeled 80 cfs water surface elevation using the 90% design DEM were used to create a separate 90% design dtDEM. Vegetation zone boundaries defined using existing vegetation (Table 4) were applied to the 90% dtDEM to evaluate how proposed design topography would change existing zonation patterns (Bair et al. 2021). The revegetation analysis and design were not updated between the 90% design stage and 100% designs stage because no modifications were made to design features between these two stages.

The 90% design for the Zanker Farm Project converts drier vegetation zones to wetter vegetation zones (Table 7). The proposed physical designs result in a slight decrease of 0.7 acres in the water zone, but increased emergent/channel margin and riparian zones by 20.6 acres at 80 cfs (Table 7). Within the Project area, 0.7 acres of water, 10.8 acres of the riparian-upland transition zone, and 9.1 acres of upland zone will be converted to 13.5 acres of emergent / channel margin zone, 3.8 acres of low riparian zone, and 3.4 acres of high riparian zone.

Table 7. The Zanker Farm Project area vegetation zone area comparison under existing conditions and with the proposed 90% revegetation design.

Vegetation zone	**Existing conditions (acres)**	**90% Design (acres)**	**Difference (acres)**
Water	30.79	30.07	–0.72
Emergent / Channel Margin	9.85	23.31	+13.46
Low Riparian	34.18	37.97	+3.79
High Riparian	65.20	68.59	+3.39
Riparian–Upland Transition	48.42	37.62	–10.80
Upland	38.33	29.20	–9.13
Total	226.7	226.7	

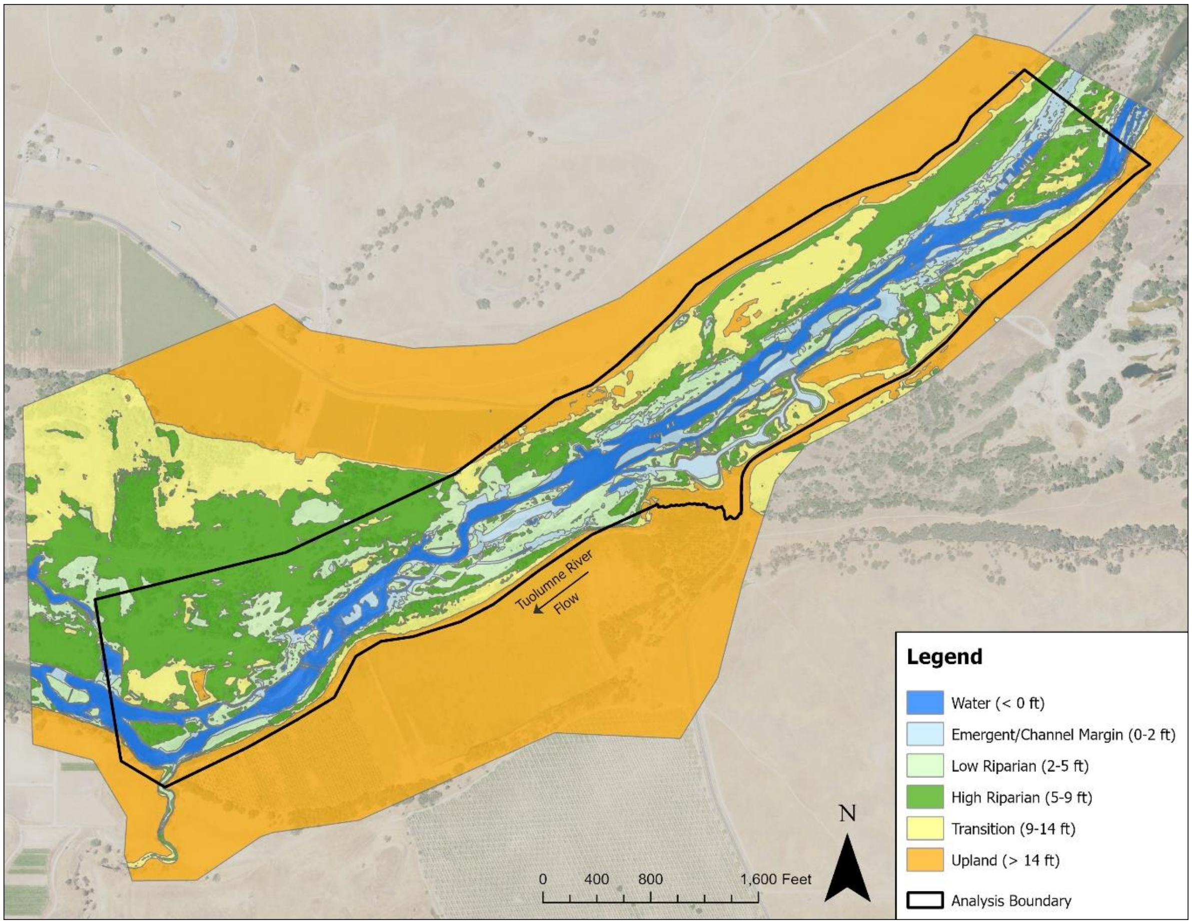

Figure 10. Vegetation zones defined by the 90% design height above the 80 cfs water surface.

2.3 Revegetation Design Overview

The revegetation design mimics vegetation patterns found on alluvial landforms of less disturbed regional streams and uses a zonation approach (Hoag and Landis 2001, 2002). Revegetation habitat zones were patterned after historical and existing vegetation patterns. The revegetation approach varies by the type of design element constructed and existing conditions within the Project area (Figure 11). The grading plan avoids removing patches of existing riparian vegetation within the project area that currently provide cover and a readily available seed source immediately after construction.

Revegetation activities may include material salvage, salvaging and installing willow clumps, installing willow trenches, preparing planting areas, laying out the planting design, planting a mixture of emergent and mesic plants, direct seeding acorns, and applying a native seed mix. Salvaged materials will be incorporated back into the site either as live material, mulch, or soil amendment. The revegetation design includes planting channel margin, backwaters, and low flow channels with a combination of herbaceous and woody species to aid in immediate cover and inhibit non-native invasive species such as water hyacinth from growing on these surfaces. Planting emergent areas with sedges and rushes (i.e., herbaceous plants) will provide aquatic cover to fishes when inundated. Floodplains within the Project area designed to provide winter rearing habitat for juvenile salmonids will be planted with a combination of woody and herbaceous plants in the low and high riparian zones. Habitat continuity and ecotone diversity between the riparian corridor and adjacent upland areas at restoration sites is important for maintaining wildlife corridors, which function to facilitate local movement and critical proximity to and from food, cover, and water. The transition zone and upland zones will be direct seeded as described in Section 5.2. A seed mix composed of native grass and forb species has been designed for the project. The seed mix should be applied to planting areas above the 3,000 cfs water surface elevation in the riparian, riparian-upland transition, and upland zones and on access roads, disturbed upland areas, spoils piles, and staging locations.

Plant species that may be planted in each vegetation zone are presented in (Table 8). Plant materials may consist of live hardwood poles, bareroot plants, nursery container stock, acorns and seeds (Table 8). Ideally, all plant material required for the Project should be propagated from material found and collected within the lower Tuolumne River watershed. It is recommended that willows and cottonwoods are planted as live hardwood cuttings (i.e., poles); however, live hardwood cuttings must be planted so that the bottom of the cutting is in direct contact with the fall groundwater table. No revegetation is proposed for areas where bedrock is thought to occur within the civil design. If upon further investigation some of these areas are determined to have suitable substrate for planting, then revegetation could be included for those areas in the next design phase.

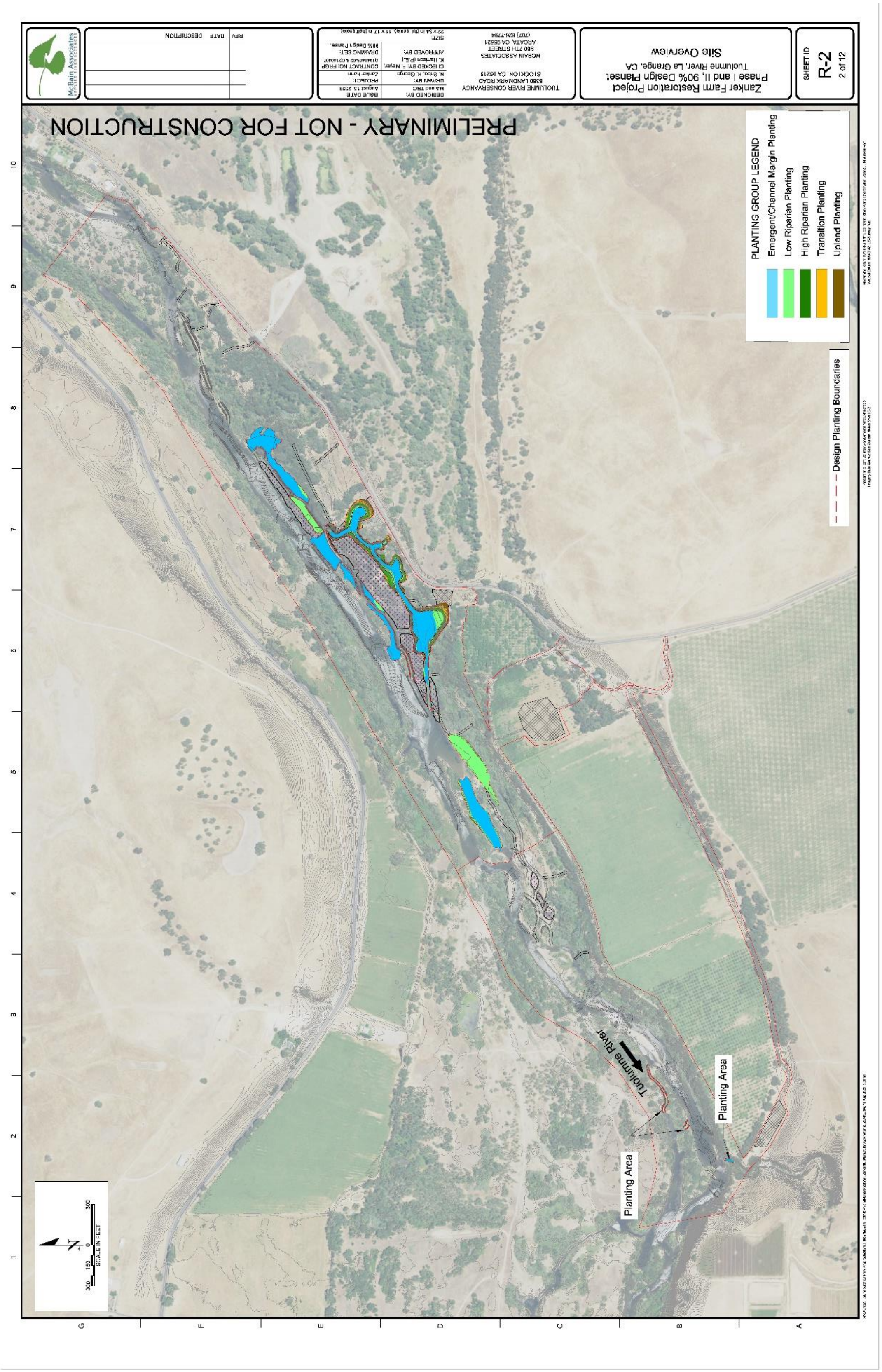

Figure 11. Proposed 90% revegetation design. See sheet Appendix H.

2.4 Proposed Planting Groups and Species

Revegetation zones should be planted with different combinations of herbaceous, shrub, and tree species to maximize habitat structure (Table 8). Species were selected to provide a variety of structural characteristics that form the basis of wildlife habitat. Plant groups in the riparian category are split into groups for the high riparian zone or the low riparian zone.

Table 8. Vegetation zones used in the 90% revegetation design, proposed plant groups, species, and growth forms. Taxonomy follows The Jepson Manual, 2nd Edition (Baldwin et al. 2012).

Zone	Common name	Scientific name	Plant material size/type
Emergent/Channel Margin	Pacific willow	Salix lasiandra	pole cutting
	black willow	Salix gooddingii	pole cutting
	buttonbush	Cephalanthus occidentalis	8 tree pot (818)
	common rush	Juncus effusus	Plug[1]
	iris-leaved rush	Juncus xiphioides	Plug[1]
	Mexican rush	Juncus mexicanus	Plug[1]
	torrent sedge	Carex nudata	Plug[1]
	whiteroot	Carex barbarae	Plug[1]
High Riparian	arroyo willow	Salix lasiolepis	pole cutting
	black willow	Salix gooddingii	pole cutting
	blue elderberry	Sambucus nigra ssp. caerulea	8 tree pot (818)
	cottonwood	Populus fremontii	pole cutting
	deer grass	Muhlenbergia rigens	AB34[2]
	mugwort	Artemisia douglasiana	AB34[2]
	Oregon ash	Fraxinus latifolia	8 tree pot (818)
	Pacific willow	Salix lasiandra	pole cutting
	white alder	Alnus rhombifolia	8 tree pot (818)
	whiteroot	Carex barbarae	Plug[1]
Low Riparian	arroyo willow	Salix lasiolepis	pole cutting
	mugwort	Artemisia douglasiana	AB34[2]
	Pacific willow	Salix lasiandra	pole cutting
	red willow	Salix laevigata	pole cutting
	whiteroot	Carex barbarae	AB34[2]
Transition	valley oak	Quercus lobata	Acorn
Upland	blue oak	Quercus douglasii	Acorn

Plant spacing may vary by revegetation zone. The water zone is composed of the Lower Tuolumne River low-flow channel and ponded areas. No revegetation is currently proposed for the water zone with the exception of planting mature willow shrubs and trees that will be salvaged where feasible and planted in low velocity areas.

2.4.1 Vegetation Zones

The emergent/channel margin zone includes channel margins, seasonal wetlands and channels, and low-lying floodplains that will be frequently inundated during the winter and spring and may be utilized by rearing steelhead, Chinook Salmon, and/or Rainbow Trout. The emergent/channel margin zone occupies the ecotone between the aquatic environment and the woody riparian zone and consists of semi-open substrate, herbaceous plants, inundation tolerant shrubs, and establishing woody plants. Bed scour is frequent in this zone. The short stature and herbaceous nature of rushes and sedges ensures that sunlight will be able to reach the water during winter months. Sedges and rushes will lie down at higher discharges (reducing channel roughness), while still providing bank strength through a dense network of fibrous roots. Many projects choose not to plant within the emergent zone because the channel will adjust after the project is constructed and plantings within the emergent zone can inhibit short term channel adjustment and potentially limit the extent to which the channel can be dynamic in the future. However, planting the emergent zone can also accelerate cover and vegetative benefits to seasonally inundated aquatic habitat used by rearing fish and limits the amount of area that disturbance-dependent non-native invasive species can colonize. The emergent/channel margin zone is designed for planting on 1.5 ft centers at a density of 22,356 plants per acre.

The riparian zone will be inundated annually to semi-annually during the winter and early spring. Tree and shrub species should be planted together and near each other to create a heterogeneous canopy structure beneficial to neotropical birds (RHJV 2004). The revegetation design includes planting different species in the low riparian and high riparian zone (Table 8). The low and high riparian zone may be planted at a density of 654 plants per acre which includes trees at a density of 109 trees per acre on approximately 20 ft centers.

The transition zone is infrequently in contact with the shallow groundwater table through capillary or direct inundation. Direct seeding of valley oak acorns is proposed for the transition zone. Containerized stock has not been recommended for planting in the transition or upland zone as no permanent irrigation system is being proposed.

The upland zone is rarely if ever inundated and is composed of mostly upland plant species. Direct seeding of blue oak is proposed in the upland zone. Northern California black walnut (*Juglans hindsii*) seeds may be used as a substitute for blue oak in upland locations.

Twenty-seven plant species have been proposed for revegetation planting (Table 8) and for the project seed mix which is described in Section 2.4.2 below. The revegetation designs may be implemented using pole cuttings, seeds, bareroot plants, nursery-grown container stock, or some combination. Plant material should be installed in the locations shown in the plan set and should be planted following the details. Willows and cottonwoods may be planted as live hardwood cuttings (i.e., poles); however, if live hardwood cuttings are used, then poles must be planted so that the bottom of the cutting is in direct contact with the fall groundwater table.

2.4.2 Planting

Plants species are affiliated with each zone (i.e., emergent/channel margin, low and high riparian, riparian/upland transition, and upland zones Table 8). The water zone is composed of the Tuolumne River low-flow channel and no revegetation is proposed within the water zone. Plant spacing varies by vegetation zone, with herbaceous plantings more closely spaced than woody shrub and tree plantings. Planting layouts were developed to ensure that species get planted in the appropriate locations for their life history requirements and that plants are not planted randomly in locations where they will not establish and thrive. Selected plants are arranged with other species with similar life history strategies to achieve revegetation objectives in the fastest time possible, while reducing cost and mortality. Willow trenches are linear planting features consisting of shrubby willows packed densely into a trench and placed at key locations in the emergent/channel margin zone to provide stability to side channels included in this design (Appendix H, Sheet C-27). Willow trenches should provide cover to fish when inundated. Shrubby willows such as arroyo willow (*Salix lasiolepis*) pole cuttings should be packed densely into a trench so that 3 – 6 ft of the pole sticks above the ground surface. Hardwood poles must be planted into the winter groundwater table to survive. The portion of the hardwood pole that remains above ground should not be cut back to the ground and provides channel roughness, cover, and shade immediately after planting. Willow trenches should be installed during civil construction.

Willow clumps are contiguous masses of above ground and below ground portions of willows salvaged opportunistically during channel construction and replanted in appropriate locations nearby. Willow clumps are proposed within the emergent/channel margin zone at the mouth of Peaslee Creek and in four other locations (Appendix H). Additional willow clumps may be installed during channel construction if material is available. The benefits of willow clumps and methods for acquisition, handling, and planting are described in Section 3 of Appendix F.

The application of the seed mix and mulch is described in Section 5.1 of Appendix F. Native forb species included in the seed mix are: yarrow (*Achillea millefolium*), Spanish lotus (*Acmispon americanus* var. *americanus*), miniature lupine (*Lupinus bicolor*), gum plant (*Grindelia camporum*), and narrowleaf milk weed (*Asclepias fascicularis*). Native grass species in the seed mix are California brome (*Bromus carinatus*), blue wildrye (*Elymus glaucus*), and three-week fescue (*Festuca microstachys*). Quantities for each species in the seed mix are provided in the revegetation designs in Appendix H.

Appendix F: Revegetation Implementation Process

APPENDIX F. ZANKER FARM SALMONID HABITAT RESTORATION PROJECT 100% DESIGN REVEGETATION IMPLEMENTATION PROCESS

The revegetation schedule is contingent on design, permitting, and construction tasks being accomplished within an estimated time frame. Construction is expected to occur between June and October, with the instream work limited to the July, August, September, and early October period. Construction phasing is still to be determined and the revegetation schedule will need to be developed as more information becomes available.

Donor stock for seeds and cuttings should be identified through reconnaissance and mapping during the summer or spring two or three years before implementation. Identifying donor stock well in advance of collection makes the implementation process run smoother, as the timing of revegetation is critical for success. Many nursery-grown trees and shrubs are more successful if planted as two-year-old plants. Seeds or cuttings for the specified trees and shrubs need to be collected with enough time to grow two-year-old plants.

Revegetation implementation in many areas is not limited to the channel construction period and often may occur after September 30 as long as access is available. Nursery-grown containerized plants commonly used in revegetation may require irrigation. Herbaceous bareroot material and hardwood poles should be used and planting delayed until November. Some portion of revegetation may rely on pole cuttings. Hardwood pole cutting planting should be done after November and completed by the following March.

1 EXISTING VEGETATION STRUCTURE AND HABITAT VALUE PRESERVATION

Restoration activities should avoid existing riparian vegetation to the extent possible, with emphasis on avoiding areas of mapped native woody vegetation. Vegetation to avoid and preserve during restoration within the Zanker Farm Project work area should be identified and protected prior to construction. Trees and plants that are designated for removal should be clearly marked.

1.1 Wetland Protection Zones

Wetlands occurring within the Project area will be delineated prior to project implementation to inform project activities and project permits. If wetlands occur near grading boundaries or contractor use areas, wetlands to be protected will be identified with temporary fencing or flagging and will be avoided during construction.

1.2 Tree Protection Zones

Vegetation that is not going to be removed should be protected from injury or damage during project implementation (Figure 12). Trees may be cut and pruned as required to accommodate construction; however, soil and roots within the tree protection zone should not be disturbed (Figure 12). Tree protection zones will be defined around areas that will be avoided during construction using temporary fencing or flagging.

Only trees and plants that are designated or marked for removal should be removed. No trees greater than 8 inches diameter at breast height should be cut or felled unless previously identified for removal. Permitting agencies may require additional tree protection.

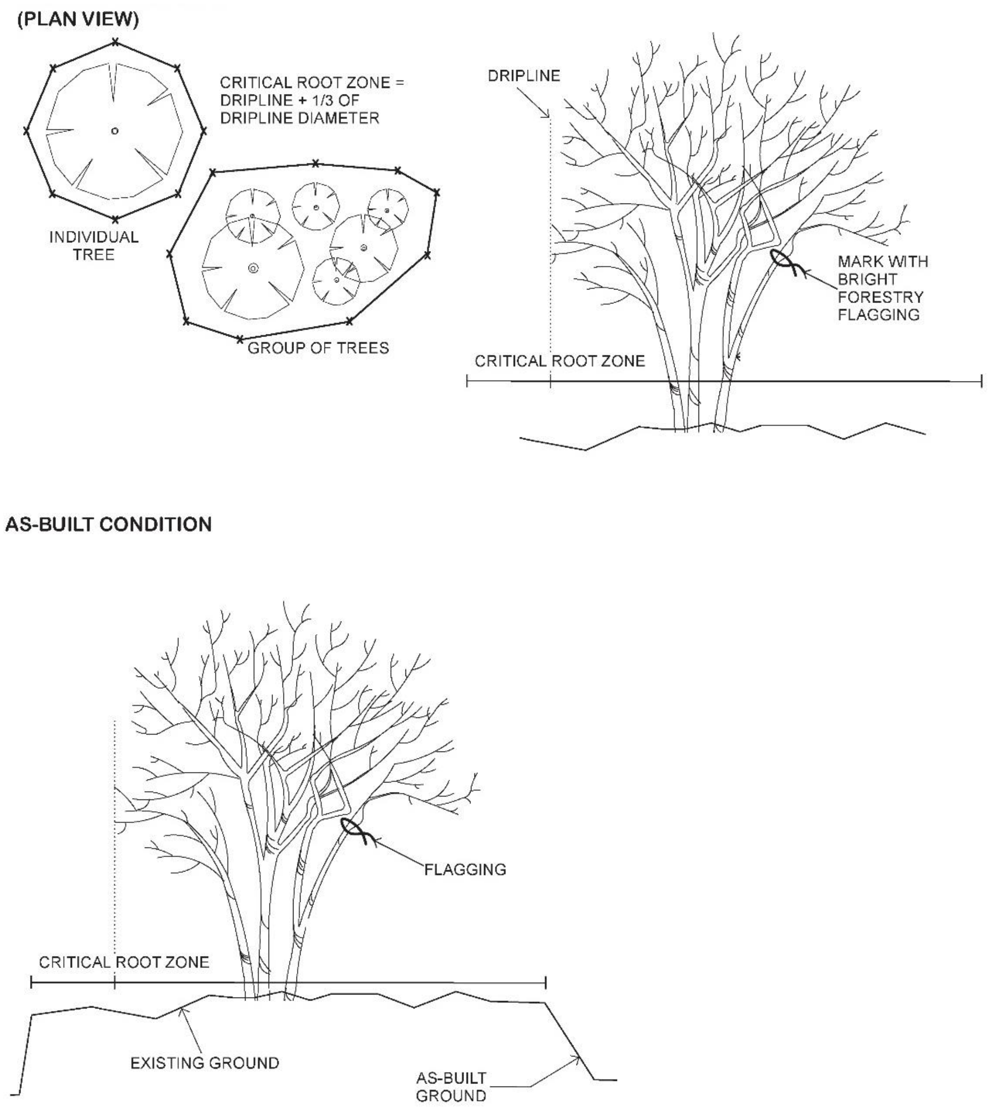

Figure 12. Recommended tree protection and critical root zones.

Individual trees that do not occur within a tree protection zone but are intended to be preserved should be clearly identified with flagging in the field, and construction activities should avoid the critical root zone around the tree. The critical root zone is the tree dripline plus ⅓ of the dripline diameter and the area around trees where vital root growth is assumed to exist (Figure 12). The critical root zone area represents the minimum area to be protected from compaction, grading, and other disturbance during construction. Cottonwoods and oaks are particularly sensitive to construction activities within the critical root zone; alders are less so.

The following actions should not be allowed within tree protection zones or the critical root zones:

- Parking or storage of automobiles or other vehicles;

- Stockpiling of building material, refuse, or excavated materials;
- Skinning or bruising of bark;
- Use of trees as support posts, power poles or signposts; anchorage or similar functions for ropes, guy wires, or power lines;
- Dumping of toxic materials on or around trees and roots, including but not limited to paint, petroleum products, contaminated water, or other deleterious materials;
- Damage to trunk, limbs, or foliage caused by maneuvering vehicles or stacking material or equipment too close to the tree;
- Compaction of the root area by movement of trucks or grading machines, or storage of equipment, gravel, earth fill, or construction supplies;
- Excessive water or heat from equipment, utility line construction, or burning of trash under or near trees;
- Damage to root system from flooding, erosion, and excessive wetting and drying resulting from dewatering and other operations;
- Alteration of existing sub-reach surface drainage patterns within protective fence zones and tree canopies unless indicated otherwise on the drawings;
- Alteration of the existing water table under tree canopies; and
- Grading within canopies of trees to be protected unless otherwise shown on the drawings.

1.3 Elderberry Fencing

Conservation and mitigation measures listed in Section 2.3.9.9 – *Valley Elderberry Longhorn Beetle Conservation* (USFWS 2017) will be implemented during project construction to avoid and minimize potential effects and mitigate for effects to elderberry shrubs and Valley Elderberry Longhorn Beetle (VELB; *Desmocerus californicus dimorphus*). Potential effects to VELB will be reduced by avoiding elderberry shrubs within 20 ft of activities by installing fencing or flags around the shrubs as a buffer between activities, and training workers on VELB to avoid these areas. Adult or larvae VELB could be harmed or killed if these shrubs were accidentally impacted by construction activities. The closest shrubs may be to proposed activities without being directly affected is approximately 15 ft away. Direct effects to these shrubs will be avoided or reduced either by creating at least a 20-ft buffer from the dripline of the shrub with fencing or flags, or only allowing use of hand tools within 5–10 ft to avoid affecting the shrubs’ roots. If it is not possible to avoid the blue elderberry during construction, appropriate mitigation will be proposed following the USFWS guidance (USFWS 2017). Permitting agencies may have other specific protection requirements.

2 MATERIALS SALVAGED DURING CONSTRUCTION

Plants, soil, and logs may be salvaged during construction and used for different purposes. Salvage may include large wood salvage, willow clumps, plant materials for maceration, cobble, gravel, boulders, and soil. Willows and cottonwoods within the construction footprint that cannot be avoided during construction should be salvaged as willow clumps, hardwood poles, or large woody debris. Woody plants greater than 8 inches at the largest cut end are considered large wood and should be salvaged and stockpiled for later placement. Woody plants less than 8 inches at the largest cut end are considered plant material and should be salvaged and stockpiled for maceration. Salvaged materials must be stockpiled separately and may have different storage requirements. Macerated plant materials and salvaged soil should be placed close to designated planting areas and on top of constructed surfaces before decompaction so that they can be incorporated into the constructed surface when it is ripped (decompacted).

2.1 Plant Material Salvage for Maceration

The goal of maceration is to reduce plant material to a generally homogenous size and to place this homogenous organic material in planting areas and constructed surfaces as an amendment along with fine sediment, or to be used as mulch around revegetation plantings. Proper maceration salvage requires that invasive non-native plant material (i.e., Himalayan blackberry) is separated from other plant materials and stockpiled in separate piles. Macerated plant material should contain no more than 5% invasive plant materials. Stockpiled non-invasive plant material should be macerated, ground, chipped, or otherwise reduced in size into 4- inch × 4- inch × 4- inch maximum size pieces (length, width, and height). After maceration, plant material should be stockpiled for future placement within planting areas.

2.2 Fine Sediment Salvage

Fine sediments should be salvaged and stockpiled whenever practical for redistribution. Fine sediments less than 2 mm within the excavation footprint that are uncontaminated by invasive plants should be salvaged and stockpiled. Areas where fine sediment could be salvaged should be assessed during implementation, but before disturbance. If fine sediment can be salvaged and used as fill in planting areas and/or ripped into planting areas during decompaction when the work is done, the chances of a successful re-establishment of vegetative cover are increased. Salvaged fine sediment should be able to sustain healthy plant life. If fine sediment needs to be stockpiled for a period exceeding six months, the stockpile should be seeded with a mix of native and sterile grasses. This will protect the soil from erosion and will maintain the existing microorganisms and other soil constituents through natural nutrient cycling processes.

Salvaged fine sediment typically consists of reclaimed fine-textured material that underlies removed vegetation. Salvaged fine sediment should contain no more than 15% (by volume) refuse, roots, heavy or stiff clay, sticks, brush, litter, or other deleterious substances. Organic material macerated or chipped into pieces no greater than 1 inch that is added to the soil should be no more than 5% by volume. Ideally, salvaged fine sediment should contain no more than 20% clay fraction and have more than a 40% sand fraction. The overall soil texture should be a fine sand. Drainage should exceed 2 inches per hour but not exceed 16 inches per hour. However, soil for planting may be limited on-site. Sand and sediment derived from screening rock for gravel infusion will be retained by the Zanker mine.

3 WILLOW CLUMP ACQUISITION, HANDLING, AND PLANTING

Willow clumps are planted to rapidly create cover, shade, and provide organic materials. Willow clumps increase the area and size of material that can be successfully planted, thereby increasing the diversity of habitat and benefits immediately after revegetation. Willow clumps are salvaged opportunistically during channel construction and replanted nearby. Ideally, willow clumps are salvaged and replanted as quickly as possible after excavation, preferably within the same day. If willow clumps must be stored, special measures must be taken to keep the willow clump alive. Willow clumps salvaged during construction should be replanted at the locations indicated following the details provided on the revegetation design sheets during the earthworks implementation. The actual number of willow clumps that can be salvaged during construction is unknown. Willow clump material sources will be identified before and during implementation. Willows selected for salvage should be healthy, vigorous plants.

Willow clumps should be salvaged and planted as indicated in the revegetation design details. A salvaged willow consists of a contiguous mass of above-ground and below-ground portions of multiple or single-stemmed willows. Soil retained and bound by roots is considered a valuable component of the salvaged willow; therefore, care must be taken to minimize the loss of soil around the roots of the salvaged willow. A salvaged willow should have stems or trunks that are at least 12–20 inches tall from the top of the root crown and have a minimum of two viable axillary buds per stem. The length of stems sticking out of the ground must be high enough so that sediment deposition will not cover lopped tops at the end of planting.

When harvesting with a backhoe or excavator, care should be exercised in excavating as much of the root mass as possible with minimal damage to the root system. Ideally, about 70–75% of the root mass should be taken with each salvaged clump. Work should progress in such a manner as to minimize the disturbance of the soil bound by the root mass. Transplants should be wrapped in a single layer of wetted burlap immediately after harvest to prevent desiccation of roots.

Willow clumps should be promptly moved to the temporary storage location or planted. There may be a number of salvage willow clumps initially that require storage before planting. However, salvaging a willow clump and then directly installing the clump is better for the health and vigor of the salvaged clumps. If salvaged willow clumps are moved to storage, they should be watered before placing in the storage area. Willow clumps should be stored and maintained for as short a period of time as possible, ideally not to exceed 72 hours. At the designated storage areas, salvaged willow clumps should be placed root side down with edges snugly adjoining adjacent clumps. Willow clumps should not be stacked. The civil contractor is responsible for maintaining adequate soil moisture within salvaged willow root masses during the storage period. Clump plantings should be planted as quickly as feasible after removal from the designated storage site.

To plant willow clumps, a hole approximately the size of the rootwad should be excavated along the low flow channel slope or surface. Any competing vegetation within a 2-ft radius of the planting hole should be removed. The side of the planting hole should be vertical, lightly scarified, and the bottom should be loosened to a minimum depth of 6 inches. Planting holes should be filled with water at least 1 hour but not more than 2 hours before planting the transplant.

One clump planting should be placed in the excavated hole, burying ½ to ⅔ of the willow clump with ¼ to ½ of the root mass into the groundwater. The planting hole should be backfilled ⅔-full with the soil excavated from the planting hole. The planting hole should be filled with water to eliminate air pockets around roots. After the hole has drained, more soil and water should be added until saturated backfill material covers the top of the root crown to a minimum depth of 2 inches. Make sure that branches are sticking out of the ground after installing the willow clump deep enough for the roots to reach the water table. The stems or trunks should be lopped off after planting. After planting, salvaged willow clumps should be thoroughly watered.

4 POST-GRADING GROUND SURFACE PREPARATION BEFORE REVEGETATION

Constructed surfaces may need to be prepared for revegetation after construction (Figure 13). Preparing constructed surfaces for revegetation may include placement of stockpiled soil, placement of macerated plant material, and surface decompaction. Areas that will receive stockpiled fine sediment and macerated plant materials should be identified before decompaction.

Macerated plant material and soil that will not be used as a backfill amendment should be spread evenly over the constructed surfaces before they are decompacted (Figure 13). Soil replacement can minimize the need for soil amendments associated with plantings. Seeds should be placed in the best possible soil medium for germination and establishment. Macerated plant material should be spread as evenly as possible in a layer no more than 4 inches thick over the previously spread soil before constructed surfaces are decompacted.

Staging areas and excavated areas should be decompacted, if necessary, after final grading (Figure 13). Decompaction is not required on permanent access roads, undisturbed surfaces, and spoils sites. Decompaction mixes sub-grade with applied materials to a minimum depth of 16 inches through ripping or other methods, after stockpiled materials are spread. Decompaction should homogenously mix applied materials and the subsoil material. The intent is to accommodate seeding to proper depth, to provide sufficient infiltration of precipitation for soil storage of moisture, and to decrease runoff and erosion. On slopes, ripping parallel to contours should be done to slow runoff and promote infiltration. Depth of ripping should be at least 16 inches where possible and should be set to maximize intermixing of the soil layer and the underlying subsoil or spoil material. If methods used to decompact surfaces result in furrows, furrow height should be no more than 4 inches tall. Decompaction should not occur in areas where tree roots would be disturbed.

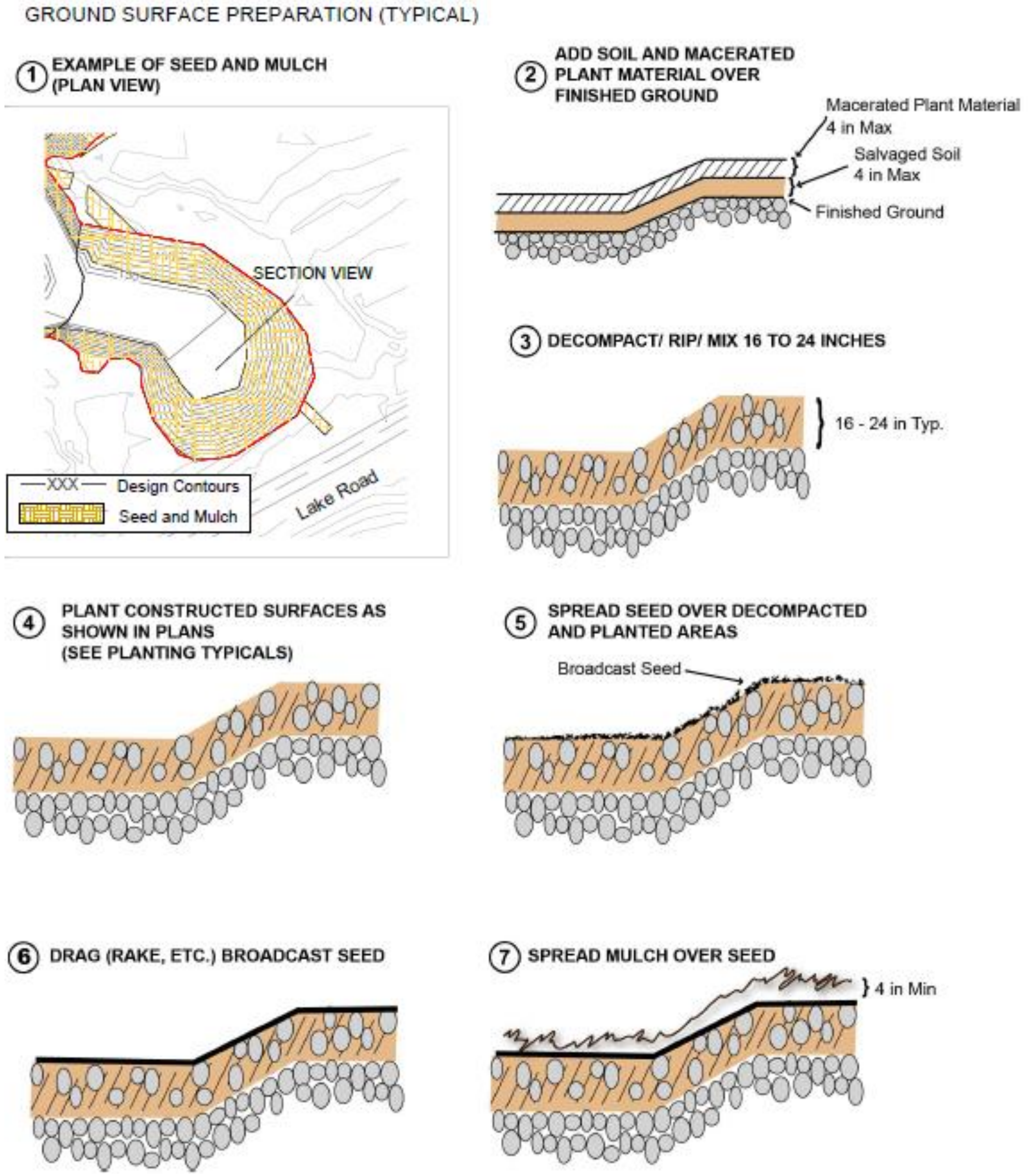

Figure 13. Recommended decompaction, broadcast seeding, and mulch application to post-construction ground surfaces.

5 SEEDING

5.1 Seed Mix

A seed mix composed of native grasses and forbs has been designed for the project to be used in planting areas above 3,000 cfs within the riparian, riparian-upland transition, and upland zones. Seed should be weed-free, and free from disease, insect pests, other non-specified seeds, stones, and other harmful or deleterious matter. Native seed should be purchased in quantities that achieve the application rate specified per acre on seeded surfaces.

5.2 Seed Application

All areas disturbed during earthworks and revegetation implementation, including construction staging areas, stockpile locations, decommissioned roads, and excavated material spoiling areas should be seeded if above the 3,000 cfs water surface elevation. Seed must make good soil contact and can only successfully germinate when daytime soil temperatures are above 60 °F. Seeds must be placed at the appropriate depth and in direct contact with the soil to optimize germination. In general, seeds should be planted ¼- to ½-inch deep in the soil.

Seed may be either applied by hand or mechanically in a dry condition, or with hydro-seeding equipment. Drill seeding is normally considered to be the most efficient and effective seeding procedure. Seed should be drilled to a depth of ¼- to ½-inch deep. Drill seeding is very effective and economical on large, relatively flat areas (up to 3:1 slope). Hand or mechanical broadcast seeding can be very effective with proper technique and is more practical and economical for small and/or hard to reach areas. After broadcasting the seed, the seedbed should be lightly harrowed or chain-dragged to fully incorporate the seed with the soil and ensure proper seed–soil contact (Figure 13). Hydro-seeding can be an efficient means of applying seed to steep areas (> 3:1), though hydro-seeding has the disadvantage of being a less effective means of achieving proper soil to seed contact. Hydro-seeding should be done as a separate operation from hydro-mulching, although it is acceptable to add a small amount of mulch in the seed slurry to bind to the soil and allow visible evidence of covered areas. Seeding rates for hydro-seeding should be double the recommended drill-seeding rate. If the site is hydro-seeded, a minimum of 500 pounds of fiber per acre should be mixed and applied with the seed. Fertilizer may also be mixed with the seed and fiber and applied in the hydro-seeding operation. The hydro-mulch fiber should be in addition to incorporating straw when an application of straw is specified. Seeding should be done after the second rain in November or December.

6 MULCHING

The application of mulch deters erosion during vegetation establishment, conserves moisture, and reduces surface compaction and crusting. When seeding is completed at the end of revegetation, all seeded areas including construction staging areas, stockpile locations, decommissioned roads, and excavated material spoiling areas should have weed free straw mulch applied to the soil surface as shown in Figure 13. Mulch should be weed free and derived from native grass hay, cereal grain straw, or an approved alternate. The hay or straw should be applied at a minimum rate of 4,000 pounds per acre. Slopes exceeding 5:1 or areas where windy conditions are likely should be mulched at 6,000 pounds per acre. After mulch is applied over the seeded areas, the mulch should be crimped in place with a mechanical crimper made for such purposes or using a farm-type disc plow set straight with adequate weight to crimp the material to a depth of approximately 4 inches. Mulch must be stored in a dry location. If rain is expected during construction, the mulch will require cover. All twine associated with straw/hay mulch should be biodegradable, and if not, then it should be collected and properly disposed of.

Appendix G: Photo Atlas

APPENDIX G: ZANKER SALMONID HABITAT RESTORATION PROJECT 65% DESIGN REPORT PHOTO ATLAS

In May 2021 for Zanker Phase I and July 2022 for Zanker Phase II, MA and TRC staff established sixteen photopoints spread throughout the project area and took photographs to document the existing site conditions and as a monitoring tool for the design, implementation, and post-construction phases of the project (0 through Figure 4). Photopoints (PPs) were chosen to capture locations and features in the project area that are expected to change as a result of project implementation. Therefore, the PPs capture a wide range of existing features, including riffles, gravel bars, haul road remnants, dredger sloughs, Peaslee Creek, gravel bars, the side channel, the lake–cascade morphology of the main channel, and exposed bedrock.

Table 1. Matrix of Zanker Farm photo points. Photo point number, file name, date of photo, northing and easting, and direction of photo.

PP No.	File Name (*.jpg)	Photo Date	Location		Facing
			Northing (Y)	Easting (X)	
PP-1	Zanker_PP2	5/21/2021	20544443.812	6560662.789	WNW
PP-2	Zanker_PP2	5/21/2021	2054278.858	6560050.371	WNW
PP-3	Zanker_PP3	5/21/2021	2053297.910	6559059.210	NW
PP-4	Zanker_PP4	5/21/2021	2053319.874	6558872.986	NE
PP-5	Zanker_PP5	5/21/2021	2053391.534	6558762.827	NW
PP-6	Zanker_PP6	5/21/2021	2052823.964	6558035.996	NE
PP-7	Zanker_PP7	5/21/2021	2053324.796	6559621.943	NW
PP-8	Zanker_PP8	5/21/2021	2052172.700	6556511.550	NW
PP 1	PP1_20220712	7/12/2022	2050426.473	6554341.440	N
PP 2	PP2_20220712	7/12/2022	2051234.784	6555443.690	N
PP 3	PP3_20220712	7/12/2022	2051428.782	6555636.231	N
PP 4	PP4_20220712	7/12/2022	2051646.309	6555856.534	N
PP 5	PP5_20220712	7/12/2022	2051924.963	6556430.318	N
PP 6	PP6_20220712	7/12/2022	2051984.603	6556488.666	N
PP 7	PP7_20220712	7/12/2022	2051009.765	6555157.542	SW
PP 8	PP8_20220921	7/12/2022	2050713.144	6554673.853	S

Figure 1. Overview of photopoint locations of the Zanker Farm Project Area overlaid on NAIP 2020 aerial imagery.

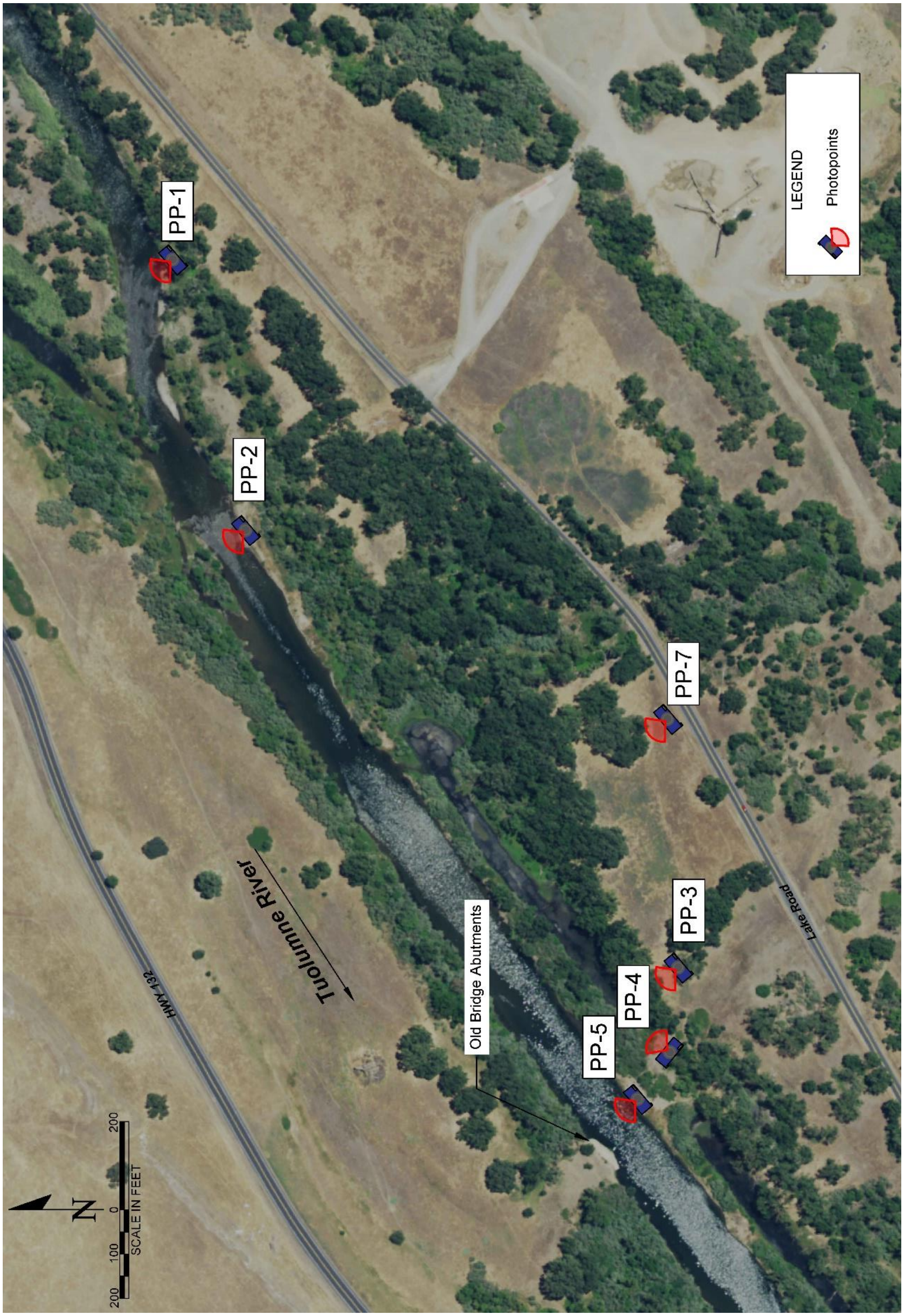

Figure 2. Photopoint locations in the upstream section of the Zanker Farm Project Area overlaid on NAIP 2020 aerial imagery.

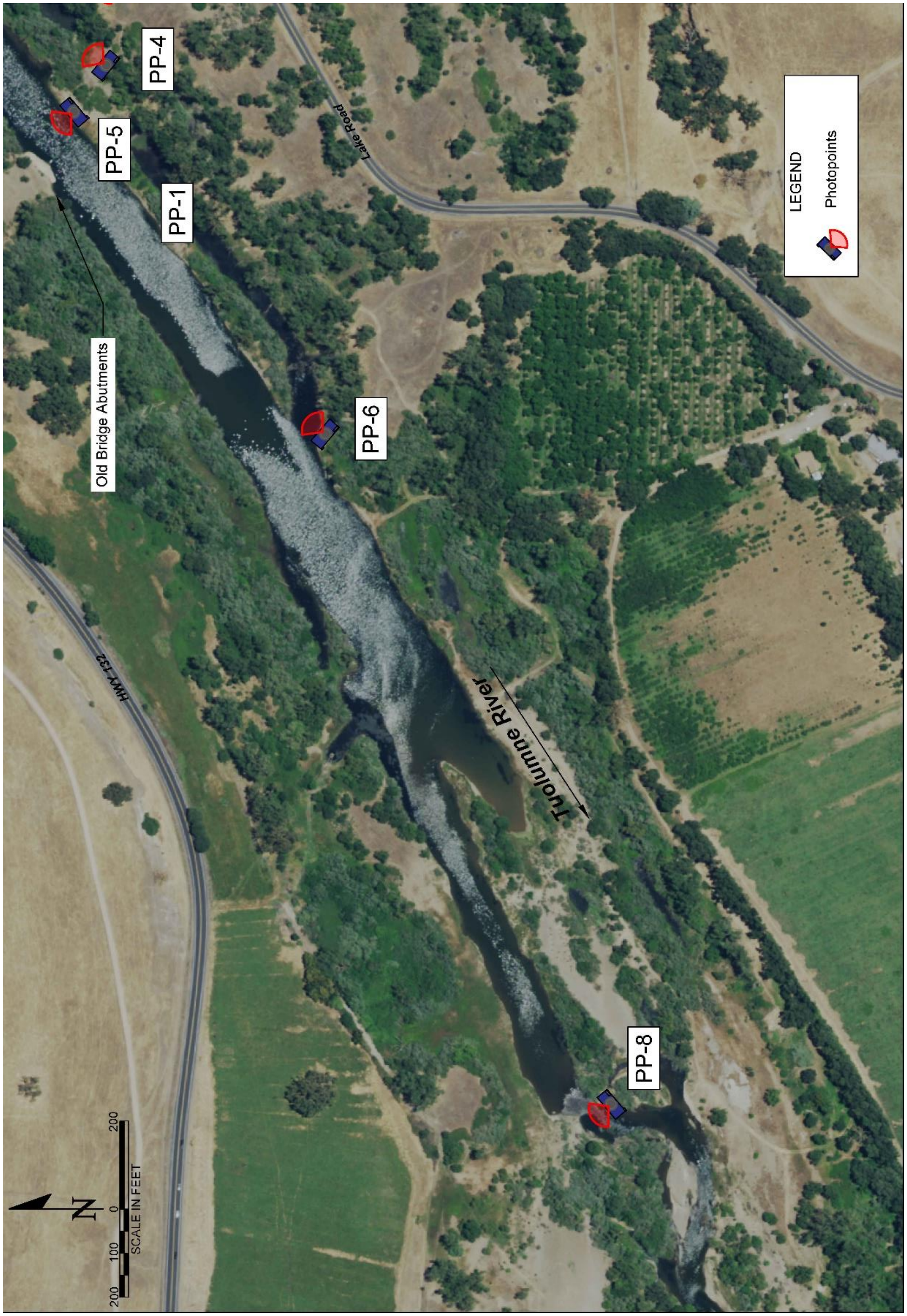

Figure 3. Photopoint locations in the downstream section of the Zanker Farm Project Area overlaid on NAIP 2020 aerial imagery.

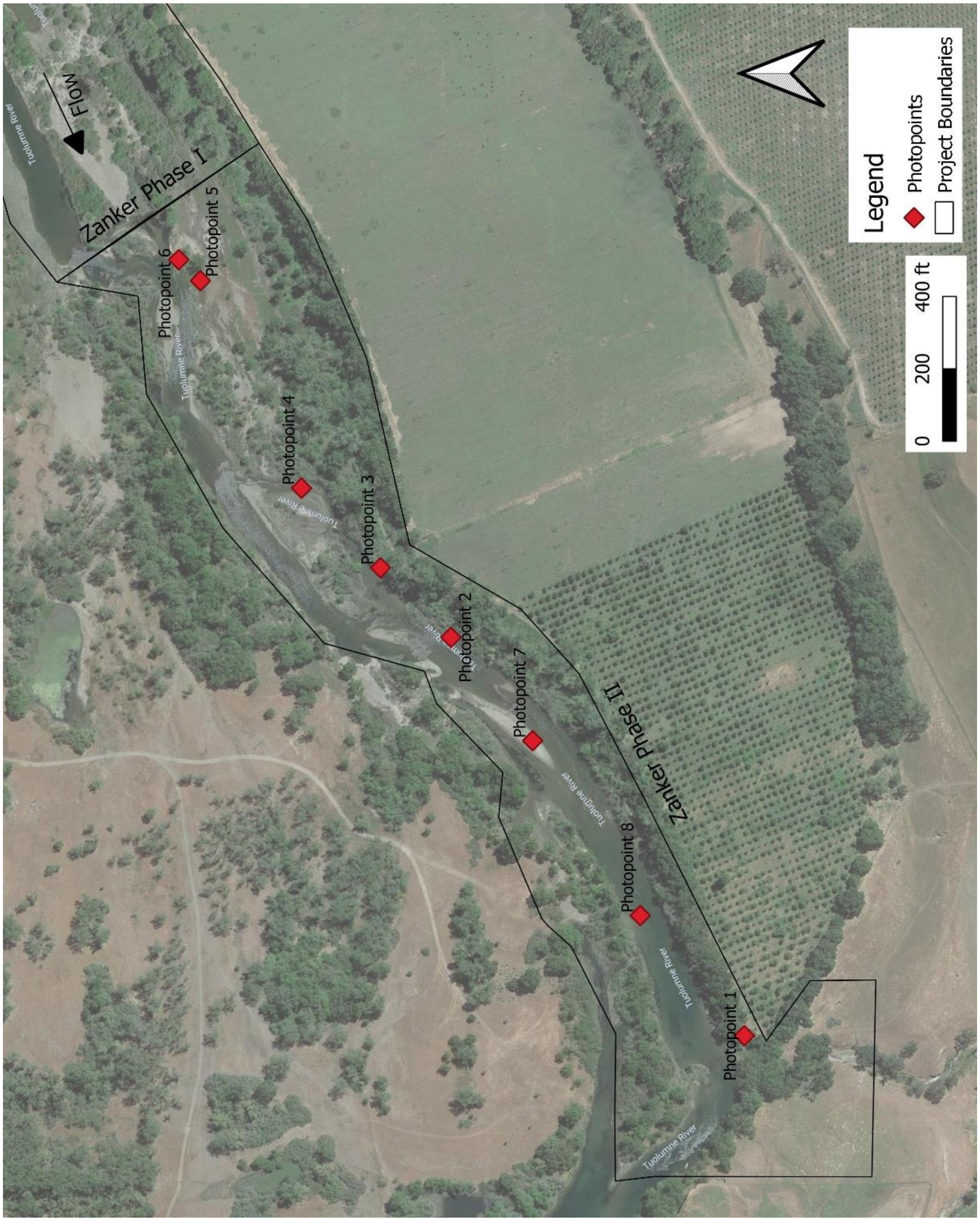

Figure 4. Map of Zanker Phase II photo monitoring locations

PHOTOPOINT 1

Figure 5. Photopoint 1. PP-1 faces north overlooking the river and is located at the top of the Zanker Farm project site.

PHOTOPOINT 2

Figure 6. Photopoint 2. PP-2 faces north across the river and is located at the second most upstream riffle. Photo captures a panorama showing the channel and riffle.

PHOTOPOINT 3

Figure 7. Photopoint 3. PP-3 faces north towards the river. Photopoint is located on the left bank under a large cottonwood tree.

PHOTOPOINT 4

Figure 8. Photopoint 4. PP-4 faces north overlooking the river and left bank. Photopoint is located on the road looking over the river near the old bridge abutment and the upstream portion of the old side channel that is obscured by vegetation in this photo.

PHOTOPOINT 5

Figure 9. Photopoint 5a. PPT 5 faces northwest and is located on the left bank at the old bridge abutment. Photo shows the bridge abutment and portion of river where submerged I-beams are located.

Figure 10. Photopoint 5b. PPT 5 faces northwest and is located on the left bank at the old bridge abutment. Photo shows the river just upstream of the bridge abutment and portion of river where submerged I-beams are located.

PHOTOPOINT 6

Figure 11. Photopoint 6. PP-6 is located on the left bank and faces upstream at the downstream section of the alcove formed by the old haul road.

PHOTOPOINT 7

Figure 12. Photopoint 7. PP-7 looks across the left-bank floodplain.

PHOTOPOINT 8

Figure 13. Photopoint 8a. PP-8 is located on the left bank at downstream boundary of the Zanker Farm Project Area. Photo shows the most downstream primary control riffle in the Project.

Figure 14. Photopoint 8b. PP-8 is located on the left bank at downstream boundary of the Zanker Farm Project Area. Photo shows stretch of river below the downstream primary control riffle in the Project.

Figure 15. PP 1: Peaslee Creek (left) and the lower end of the Zanker Phase II Project Area

Figure 16. PP 1: Lower end of the Zanker Phase II Project Area

Figure 17. PP 2 – Gravel bar and Arundo donax (Giant reed, invasive species) visible across the river

Figure 18. PP 3 – Taken from the Zanker River pump. Wood features visible in shallow silty side channel

Figure 19. PP 4 – Side channel. Shallow riffle that connects to the mainstem Tuolumne River is to the right where MA staff is crossing

Figure 20. PP 5 – Former spawning area, now bedrock riffle to the left, main control riffle to the right

Figure 21. Near PP 5 – Bedrock exposed in the bedrock riffle

Figure 22. PP 6 – Exposed bedrock in foreground, primary control riffle and upstream of Project Area

Figure 23. PP 7 – Looking downstream from gravel bar towards bedrock outcrops

Figure 24. PP 8 – Bedrock exposed in pool in downstream half of Zanker Phase II Project Area