ZANKER FARM SALMONID HABITAT RESTORATION PROJECT

EXISTING CONDITIONS REPORT

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Abbreviations

cfs	cubic feet per Second
d	diameter
ft	feet
ft/ft	feet per foot
ft^2	square foot
in	inches
lb	pound
lb/ft^2	pound per square foot
yd^3	cubic yards

Acronyms

2-D	Two Dimensional
A	Access Roads
ADCP	Acoustic Doppler Current Profiler
ASTM	A370 Standard Test Methods
BOB	Bobcat Flat Phase III
C	Contractor Use and Staging Areas
CALFED	Collaboration Among State and Federal Agencies to Improve California's Water Supply Also, California Bay-Delta Authority
CDFW	California Department of Fish and Wildlife
CVFPB	Central Valley Flood Protection Board
DEM	Digital Elevation Model
dtDEM	Detrended Digital Elevation Model
DTM	Digital Terrain Model
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FP	Floodplain Bench
GCP	Ground Control Points
GM	Silty Gravel
GMA	Graham Mathews 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
HSIi	Weighted HSI Value
HVT	Hoopa Valley Tribe
HWM	High-Water Mark
IC	In-Channel Feature
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
SC	Side Channel
SRP	Special Run Pool
SW	Well Graded Sand
TIN	Triangular Irregular Network
TP	Test Pit
TRC	Tuolumne River Conservancy
U	Upland Areas
UAS	Unmanned Aircraft System
USACE	United States Army Corp of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
W	Wetland
WSE	Water Surface Elevation
WUA	Weighted Usable Area

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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 Project (Project Area) encompasses the upper 1-mile section between RM 45.7 and 46.7. The Project Area is approximately 3.5 RM west of the community of La Grange, and approximately 28 miles east of Modesto (Figure 1). The Project is situated in the Dominant Salmon Spawning Reach of the Tuolumne River (Figure 2), 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 is identified as high priority in the *Restoration Plan* due to degraded channel and habitat conditions following gold mining and streamflow regulation.

Restoration at Zanker Farm began in 2021 with a grant from California Department of Fish and Wildlife (CDFW) to prepare a site investigation plan, which was submitted and reviewed by CDFW in May 2021, collect existing site data, develop conceptual design alternatives, and advance a preferred design alternative from a preliminary 30% design stage to the 100% design stage, along with supporting analyses and documentation. Field data collection at the Zanker Farm Project Area began with an effort conducted by staff from the Tuolumne River Conservancy (TRC), O'Dell Engineering, and McBain Associates (MA) in May and June 2021. Data collection included establishment of site control, topographic and bathymetric surveys, surface geology, remnant haul road debris mapping, photo documentation, water surface elevations, existing vegetation, and existing salmonid habitat mapping. Supplemental field data were collected by MA staff in July 2021 to further refine existing topography and bathymetry.

For the Zanker Farm Project, this report compiles background information and historic data in addition to data collected this year and describes existing site conditions within the project boundary. The description of existing conditions includes physical descriptions of the site, local geology, geomorphology, hydrology, vegetation mapping, salmonid and herpetological habitat analysis, and 2-D hydraulic modeling. Establishing a baseline in these areas provides a reference point from which to analyze habitat restoration designs for the project and metrics for how designs will improve habitat and ecological function.

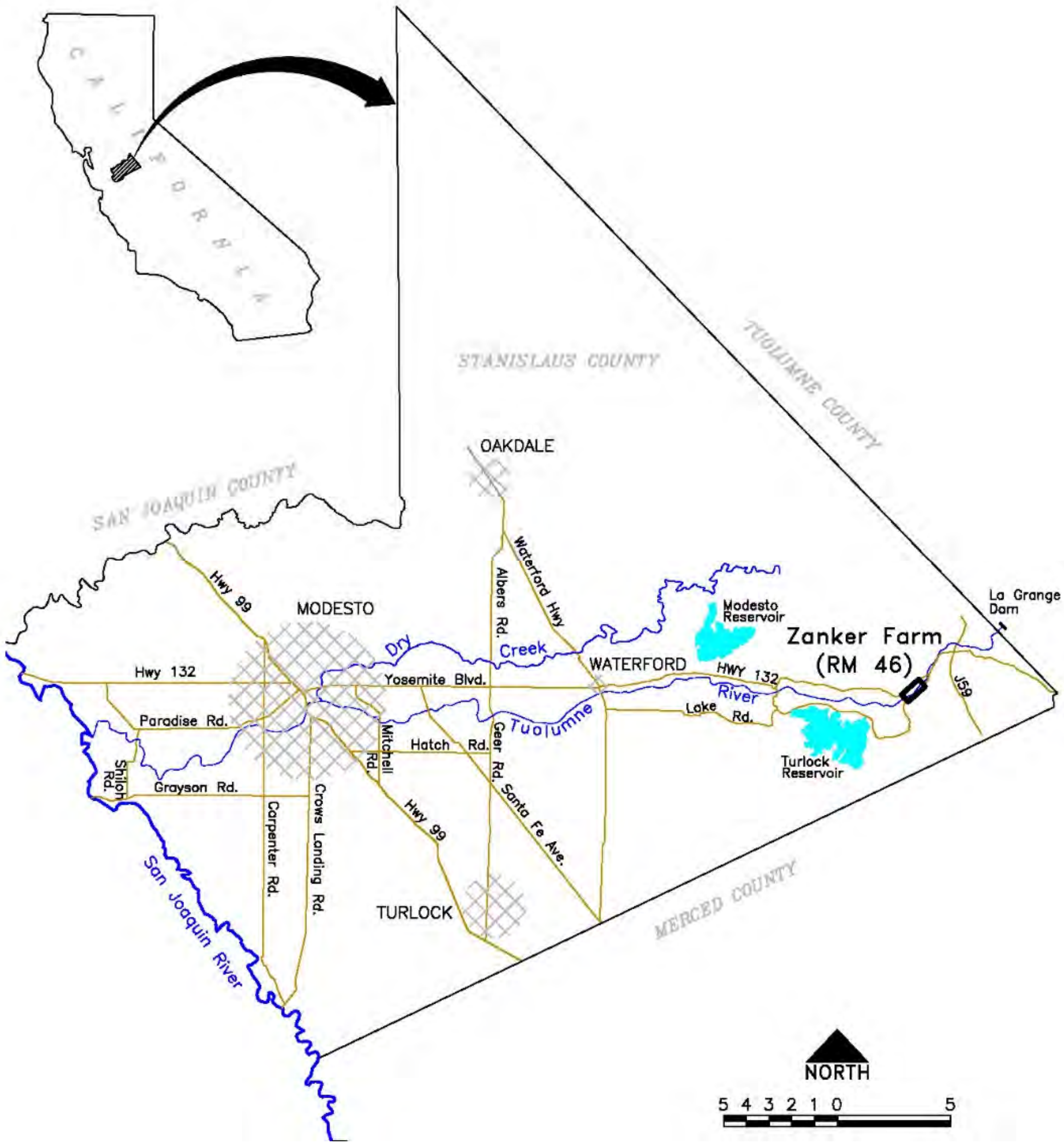


Figure 1. Zanker Farm (RM 45.2 to RM 46.7) location map showing nearby cities of Waterford and Modesto, and close proximity to Turlock Reservoir and La Grange Dam.

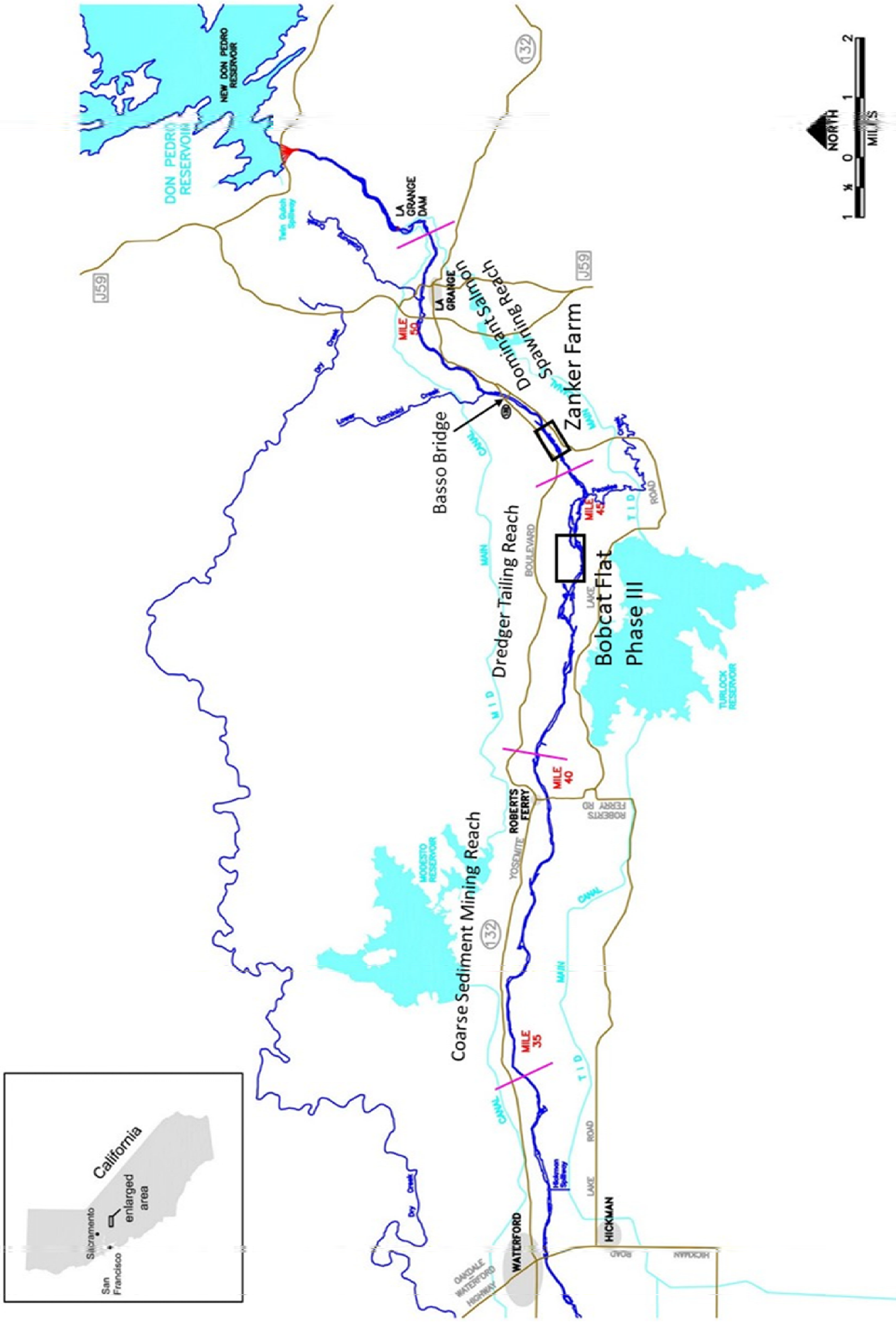


Figure 2. Detailed view of Zanker Farm Project (RM 45.2 to RM 46.7) location map showing nearby cities of Waterford and La Grange, and close proximity to Basso Bridge, the Bobcat Flat Phase III restoration site, Turlock Reservoir, and La Grange Dam. Also shown are the Coarse Sediment Mining Reach, Dredger Tailing Reach, and Dominant Salmon Spawning Reach as described in M&T (2000).

1.1 Background

The Tuolumne River is one of three major tributaries to the San Joaquin River that drain the west slopes of the Sierra Nevada. It has an extensive history of gold and aggregate mining, water supply storage, power generation, agriculture, and recreation. Beginning with the Gold Rush in 1848, the Tuolumne River has been extensively modified by land use practices (agriculture, ranching, and urbanization) and resource extraction (water for irrigation and municipal use, gold mining, and aggregate mining). Streamflow regulation began with construction of Wheaton Dam (1871) and La Grange Dam (1893), intensified in the 1920s with the construction of several large reservoirs in the basin, and culminated in 1971 with construction of the New Don Pedro (NDP) Project, which more than tripled the storage capacity of the basin.

During the first half of the 1900s, the Tuolumne River channel and floodplain around RM 43 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 that replaced the alluvial deposits and floodplain soils (Figure 3). By the end of the gold mining era, the majority of the area's floodplains, including this Project Area, had been converted to dredger tailings. In the 1960s, many of the tailings were excavated to provide construction material for NDP Dam. These areas remain largely barren, unproductive surfaces with exposed coarse sediment/cobble and little or no soil layer.

Following the removal of the gold dredge tailings, Davis-Grunsky Act funds were used in the early 1970s to reconstruct a defined channel through the multiple channels that remained as a result of the gold mining and subsequent removal of the tailings for construction of NDP dam. Unfortunately, only the reach upstream of Basso Bridge (RM 47.5) was completed, leaving downstream areas, including the Zanker Farm Project (RM 45.7–46.7), unchanged in a severely impaired condition.

Figure 3. Example of the lower Tuolumne River Coarse Sediment Mining Reach in 1950, post-gold dredger mining near La Grange, California.

The current condition contributes little salmonid habitat for the lower Tuolumne River relative to historic conditions. Once healthy salmonid habitat now receives considerably less spawning use than upstream riffles within the Dredger Tailing Reach (Figure 2). This problem was caused by dredge mining converting the channel morphology from a natural pool–riffle sequence to a "lake–cascade" morphology, which is characterized by a series of deeper/longer pools and steep riffles (Figure 4). This conversion removed the numerous low-gradient riffles highly conducive to Chinook Salmon (*Oncorhynchus tshawytscha*) spawning and rearing habitat to a smaller number of high-gradient riffles that were separated by long pools. Many of these high-gradient riffles are greater than 1% slope during spawning flows (< 300 cubic ft per second [cfs]), creating velocities larger than those preferred by spawning salmonids over much of the riffle surface. The conversion to steep riffles by dredge mining resulted in a dramatic decrease in Chinook Salmon and *Oncorhynchus mykiss* (which includes Central Valley steelhead and residential Rainbow Trout) spawning habitat due to higher gradient, higher velocities, and reduced number of riffles. The lack of coarse sediment recruitment below the dam, combined with the reduction of high flows to mobilize sediment and help restore channel morphology, prevents recovery of the natural channel morphology.

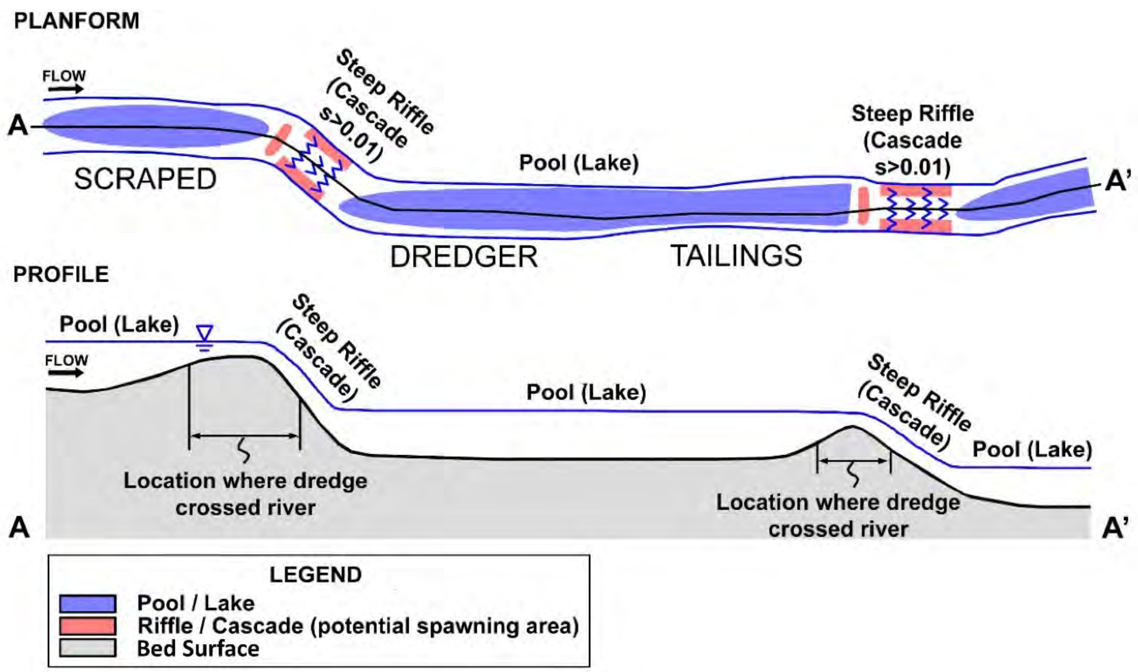


Figure 4. Post-gold dredge mining planform and longitudinal profile conceptual model showing the impacts of mining on the channel through the disruption of natural pool–riffle segments and creation of long pools separated by over-steepened riffles.

The Bobcat Flat Restoration Project (RM 44) is an example of a successful restoration effort in proximity to the Zanker Farm Project Area. Restoration of Bobcat Flat was initiated in 2003 as a multi-phase project to restore morphologic function and habitat for target species within the Dredger Tailing Reach. To date, three restoration projects within the Bobcat Flat West property have been designed, permitted, and constructed: Phase I in 2005 (M&T 2006), Phase II in 2011 (M&T 2011), and Duck Slough in 2016 (MA 2018). Combined, these three projects have restored approximately 18 acres of remnant scraped dredger tailing surfaces to functional riparian floodplains, restored geomorphic function and salmonid habitat by sorting and placing approximately 28,500 cubic yards (yd^3) of ¼-inch to 6-inch diameter coarse sediment into 0.6 miles of the Tuolumne River mainstem channel, and constructed approximately 0.4 miles of high quality low-flow side channel salmonid spawning and rearing habitat by placing 9,000 yd^3 of coarse sediment in an existing slough created by historic gold dredging. Additionally, a third phase of the Bobcat Flat project has been designed and permitted and funded by CDFW, with initial construction to begin in 2022. The Bobcat Flat Restoration Project provides information relevant to Zanker Farm, including an extensive two-dimensional hydraulic model and design criteria that performed successfully in a similar setting approximately 1.2 miles downstream of the Zanker Farm Project Area.

1.2 Zanker Farm Site Description

The majority of the mainstem Tuolumne River within the Zanker Farm Project Area consists of a straight section of channel having little topographic complexity (Figure 5), with channel depths ranging from 4–15 feet. The channel through the site is essentially a single deep pool with very low velocity during summer baseflows, is straight (no sinuosity), and is hydraulically controlled in the middle by remnants of a historic haul road bridge and at the downstream end of the site by a steep riffle. The channel bottom is clay hardpan overlayed with pockets of coarse sediment (sand, gravel, and cobble).

Although the site can be described as a single pool, smaller topographic and hydraulic features are nested within the project reach that create some geomorphic variability. For example, deep areas of the channel and areas that are shielded from velocity at high flows have substantial silt deposits on the bed. Bars comprised of coarse sediment occur near the downstream control riffle, indicating a former channel location prior to channel migration into its current alignment during peak flows in 1997 and 2017 (described in Section 0). A shallow alcove exists just above the coarse sediment deposits, which is likely a remnant of the old mainstem that has filled in with sediment. Another alcove feature is located at the upstream end of the site on the right bank, which functions as a backwater alcove at low flows and as a side channel at high flows. Overbank flow within this reach does not occur until flow exceeds 1,130 cfs, which is approximately a 1.1-year recurrence interval flow (Section 3.2).

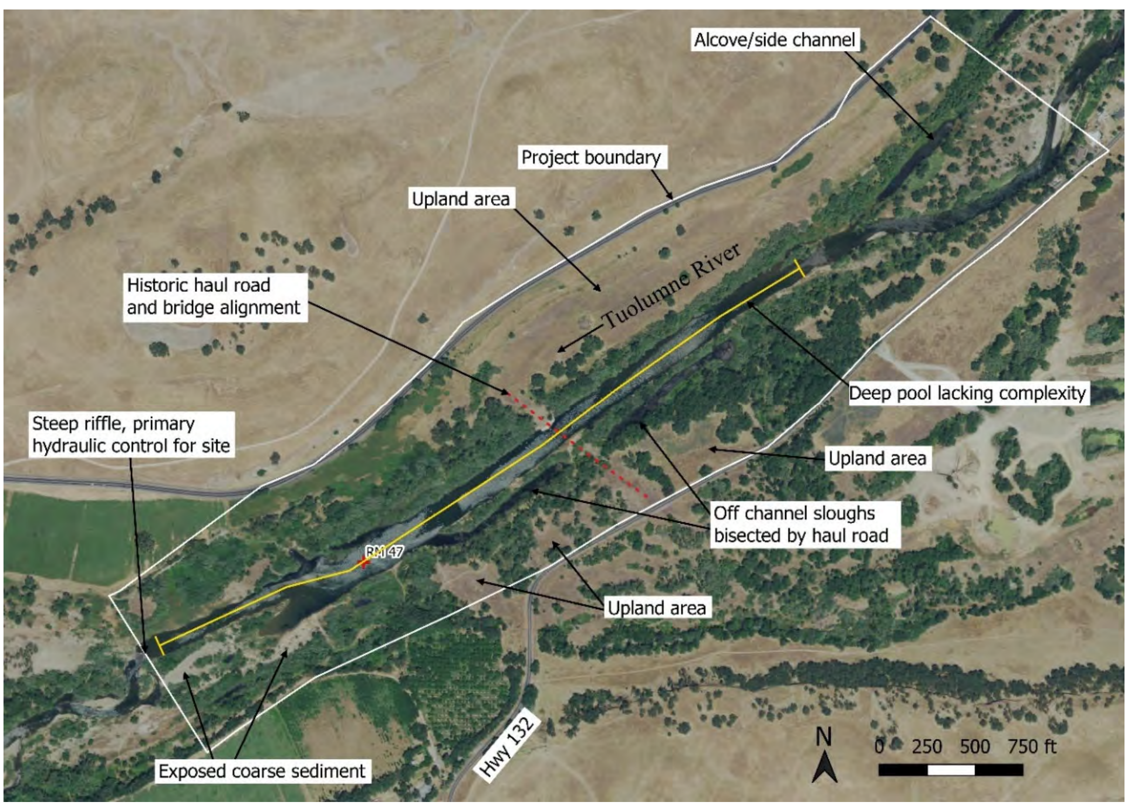


Figure 5. Zanker Farm Project Area existing conditions site map describing major area of focus for rehabilitation. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

Both banks are intermittently vegetated with riparian trees and shrubs including white alder (*Alnus rhombifolia*), Oregon ash (*Fraxinus latifolia*), valley oak (*Quercus lobata*), black willow (*Salix gooddingii*), Fremont cottonwood (*Populus fremontii*), and narrowleaf willow (*Salix exigua*). The right bank upland area above the riparian zone is primarily a large, armored surface vegetated with non-native grasses. Along the downstream 0.4 miles of the right bank, riparian herbaceous and emergent species are prevalent. The left bank upland area is heavily populated with valley oak and Fremont cottonwood in addition to armored surfaces with non-native grasses. Further discussion and analysis of existing vegetation is presented in Section 6.

Remnants of historic gravel mining at the site include a haul road and parts of a bridge in the middle of the site (Figure 5). Currently, these elements constrain and constrict the mainstem channel, preventing natural channel migration laterally and increasing velocities during flood events, which promotes coarse sediment scour. The haul road was built during the construction of NDP 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. 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 likely a side channel or former mainstem alignment, 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 fish species such as Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), and Striped Bass (*Morone saxatilis)*, all of which prey on salmonids, as well as invasive plant species such as water hyacinth (*Eichhornia crassipes*).

1.3 Constraints and Opportunities

Property ownership in the Project Area presents both opportunities and constraints. The Zanker Family are key partners in this Project and have been supporters of Tuolumne River restoration projects for decades, including participation in the 2000 Restoration Plan. The Zanker family own both parcels of land on the left bank within the 144-acre project area (Figure 6) and have signed a landowner access agreement prepared for this Project and will work to monitor the evolution of the site for any future maintenance actions if needed. The primary constraint for the project is associated with the property on the right (north) bank of the Tuolumne River, which is not owned by the Zanker Family. Landowner permission has not been granted for the property on the right bank. While the right bank is included in the ESL, no earthwork may be conducted on that floodplain. Additionally, an irrigation pump intake located in an alcove on the right bank must be protected in place to ensure water delivery to the pump is unaffected by any project activities (Figure 7).

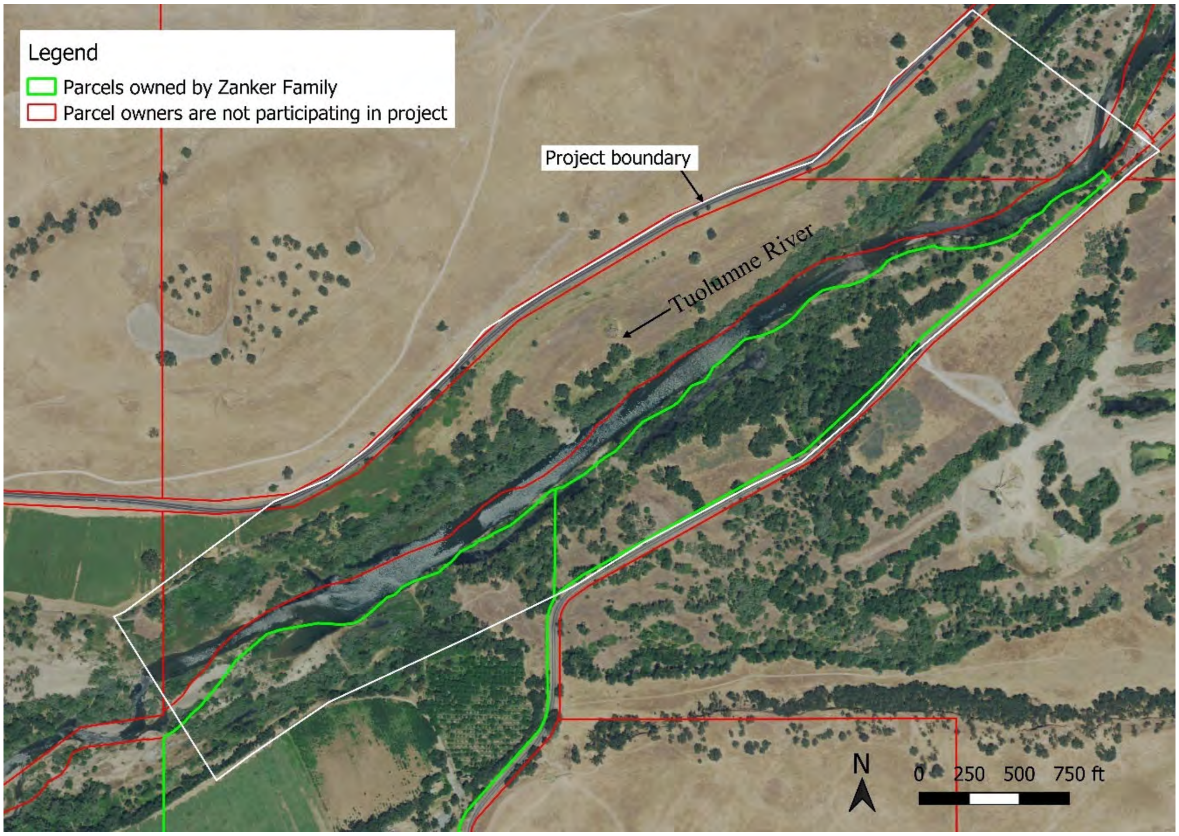


Figure 6. Assessor's parcel map showing property owned by Zanker Family and other Stanislaus County parcel boundaries.

An additional constraint is that the project must not raise the 100-year flood elevation. To evaluate this constraint, a 2-D hydraulic model of the site was used to establish the 100-year flood elevation under existing conditions to provide a baseline for comparison with design conditions which will be developed in future stages of the project (Section 5).

In addition to habitat restoration opportunities, a major opportunity within the Zanker Farm Project Area is to eliminate the remains of a historic haul road and bridge infrastructure (Figure 7 through Figure 9). The concrete abutment is approximately 2,250 ft^2 in planform area and 10 ft thick vertically with corrugated metal sheeting lining the exterior sides (Figure 9). It is severely undercut, indicating that the river will eventually undermine the structure, causing it to fall into the channel and effectively become rubble. The 23 I-beams are roughly 2-ft in width and are submerged between 2–5 ft below summer baseflow water surface elevations, presenting a hazard to boaters and swimmers (Figure 8). Removal of the road prism and connection of the two alcoves would convert these features into a side channel with colder flow from the mainstem, eliminating predator habitat. Additionally, the road prism material likely contains coarse gravel that can be sorted, cleaned, and placed in the river to help restore coarse sediment balance. In summary, removal of the bridge and haul road remnant infrastructure represents an opportunity to eliminate hazards within the mainstem, reduce predatory fish habitat, and restore geomorphic function in the Tuolumne River.

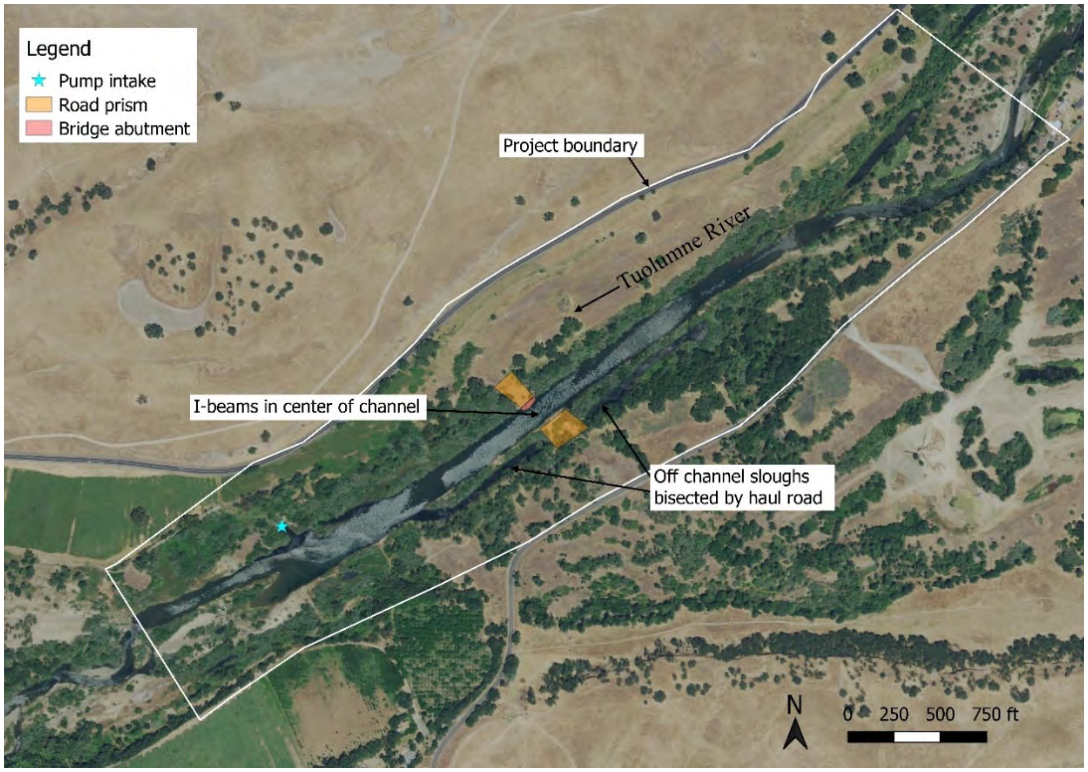


Figure 7. Overview map of the Zanker Farm Project Area, showing irrigation pump intake and historic haul road and bridge remnants. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

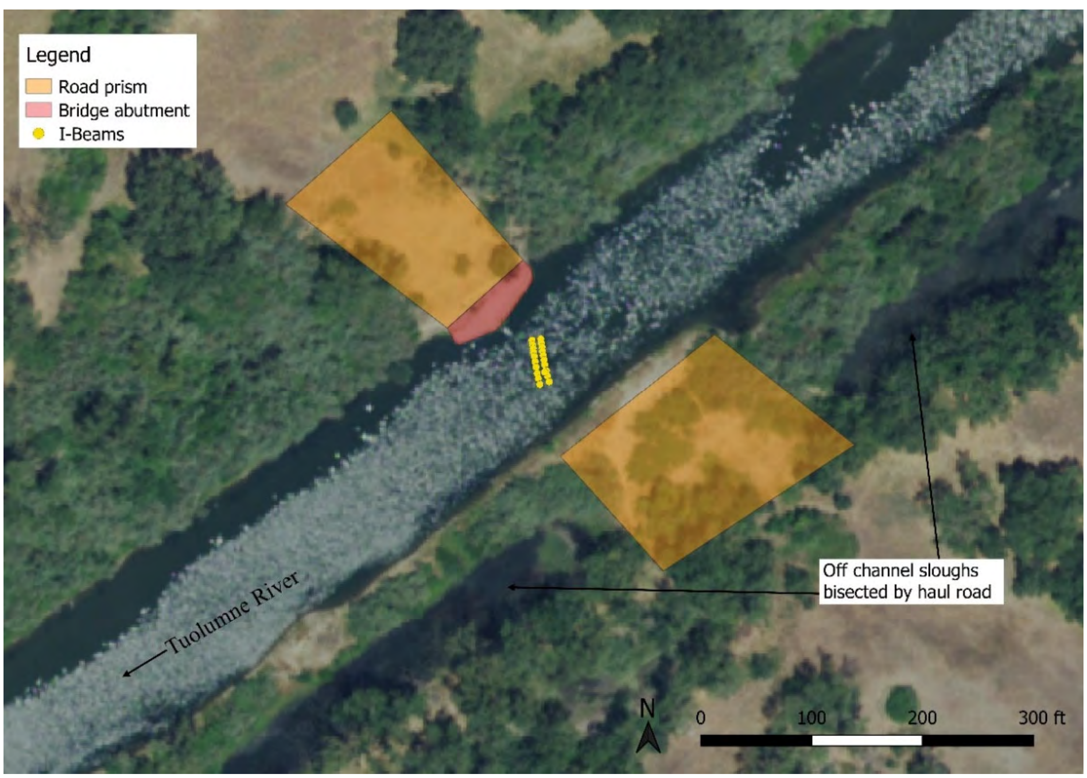


Figure 8. Detail view of historic haul road and bridge remnants. Points indicate I-beam approximate location and orientation only, not scale. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

Figure 9. Photo showing the remnant haul road bridge abutment on the right bank. I-beams are submerged in the middle of the channel and not visible from this vantage. Photo taken from the left bank facing north, flow is right to left and is approximately 110 cfs.

1.4 Goals and Objectives

The focus of salmonid restoration on the Tuolumne River has been to rebuild a naturally reproducing population of fall-run Chinook Salmon and *O. mykiss* similar to numbers seen in past decades and of adequate amount to maintain a viable population during low escapement years. The restoration objectives have an ecological and geomorphic perspective that is focused on readjusting the river to function normally under contemporary flow and sediment regimes.

The Zanker Farm Project is focused on creating a dynamic system where ecological and geomorphic aspects evolve together. 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 4) to be a more natural pool–riffle morphology (Figure 10);
3. Reduce aquatic non-native predator habitat; and
4. Increase off-channel rearing habitat for fry and juvenile salmonids via construction of low-flow side channels and annually inundated floodplain benches.

These four primary actions will have a lasting impact on aquatic, terrestrial, and riparian species by improving existing degraded habitat and providing additional new habitat.

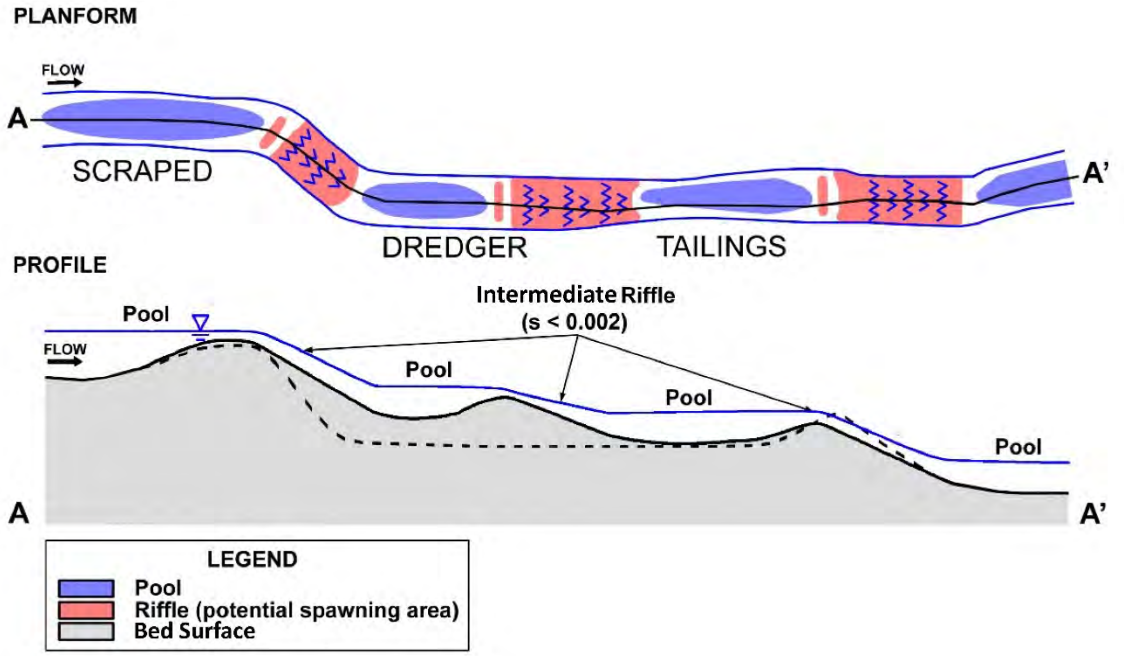


Figure 10. Example of riffle slope redistribution from steep riffles associated with existing lake–cascade channel morphology by constructing intermediate riffles and bars that backwater into the steep upstream riffle (compare to dashed line representing the bed surface from Figure 4).

The primary objectives will be accomplished by excavating the armored surfaces of the floodplain down to inundation thresholds that will reconnect the river during specified flows scaled to the post-dam flow regime. The coarse sediment harvested from floodplain lowering will be used to reconstruct features in the main channel, such as point bars, medial bars, pools, and riffles. This in turn will provide spawning habitat for adult salmonids as well as increase invertebrate production for rearing salmonids. Lowering the floodplains will also provide opportunities for natural recruitment and/or plantings of riparian species by giving them access to groundwater and allowing them to recolonize the now barren, armored surfaces. The addition of side channels and wetland marsh areas will provide off-channel rearing habitat for salmonid fry and juveniles, as well as Northwestern Pond Turtles. This includes improving connections to existing wetlands, increasing groundwater distribution throughout the site and providing additional areas of velocity refugia and cover. Remnant dredger channels and/or instream coarse sediment pits will be partially filled and contoured to convert them into useful habitat for the species of interest while reducing predatory species habitat.

The following sections describe existing conditions at the Zanker Farm that will be used to inform the development of conceptual designs and evaluate the performance of design alternatives. A combination of existing reports, professional experience in the Project Area, and additional data collection was used to describe the existing physical and biological characteristics of the Zanker Farm Project Area.

2 REGIONAL AND LOCAL GEOLOGY

The Tuolumne River originates near 11,000 ft elevation in the Sierra Nevada range and flows southwesterly to its confluence with the San Joaquin River, between the Merced River watershed to the south and the Stanislaus River watershed to the north. The watershed spans two of California's 11 geomorphic provinces, the Sierra Nevada and the Great Valley, which have vastly different geologic and geomorphic characteristics and whose boundary separates the Tuolumne River into upper and lower regions (respectively). The upper Tuolumne River flows from its headwaters down the west slope of the Sierra Nevada and the Sierra Nevada foothills before becoming impounded by NDP Dam. The upper Tuolumne River is generally characterized by its steep gradient and confined channel that passes through exposed bedrock, including granitic rocks of the Sierra Nevada batholith (Cretaceous) and metamorphic rocks of the Sierra Nevada foothills (Paleozoic–Jurassic). Downstream of NDP Dam to its confluence with the San Joaquin River, the lower Tuolumne River flows through the Great Valley province and is characterized by a much lower gradient and alluvial channel, with bed and banks composed of varying age deposits of sand, gravel, and cobble (Quaternary) confined within steep bluffs of the valley walls as far as Modesto. A generalized geologic map of the watershed is shown in Figure 11.

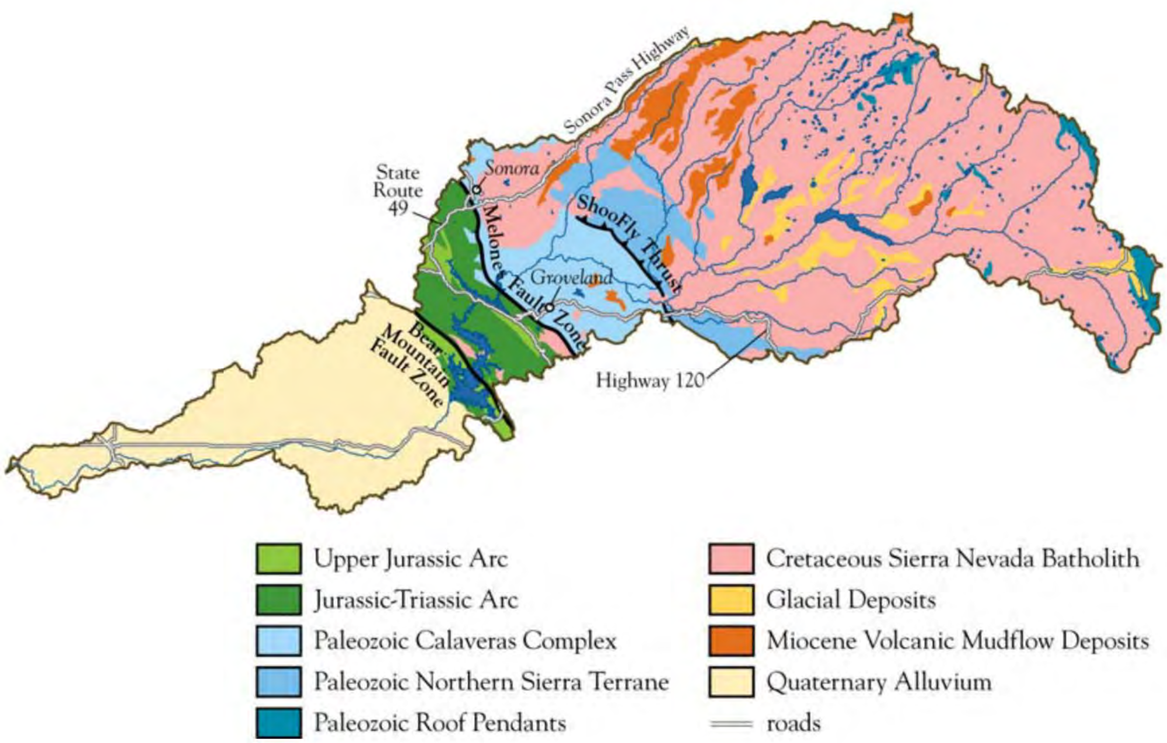


Figure 11. Generalized geologic map of the Tuolumne River watershed (from Mount and Purdy 2010). Primary bedrock types in the upper Tuolumne River (upstream of New Don Pedro Dam) include the granitic Sierra Nevada batholith (pink) and metamorphic Sierra Nevada foothills (green and blue). In contrast, the lower Tuolumne River flows through Quaternary alluvium (tan) chiefly composed of sand, gravel, and cobble that originated higher in the watershed and has been transported down to and deposited on the valley floor.

The Zanker Farm Project Area sits along the lower Tuolumne River approximately eight miles downstream of LaGrange Dam. The river corridor is bound by high bluffs of the Modesto formation (late Pleistocene) and Turlock Lake formation (early Pleistocene), both of which are composed primarily of sand and gravel glacial outwash as far down as Modesto (Marchand and Allwardt 1981). A series of lower elevation inset alluvial terraces and the contemporary lower Tuolumne River floodplain lies between the bluffs. The terraces generally decrease in age with decreasing elevation and proximity to the active channel. Geologic mapping from 1981 in the project vicinity (Marchand et al. 1981) identified two separate post-Modesto formation alluvial terrace units within the Zanker Farm Project Area (map units pm2 and pm3, Holocene), plus recent channel deposits (pm4), and dredge tailings ((t), Figure 12).

In addition to the published mapping, claypan exposures were observed during 2021 data collection (Section 5.1) in the wetted channel and on adjacent banks, primarily on the south bank at the downstream end of the project reach. The claypan is assumed laterally extensive but additional investigation is needed to confirm its presence and thickness in other portions of the Project Area.

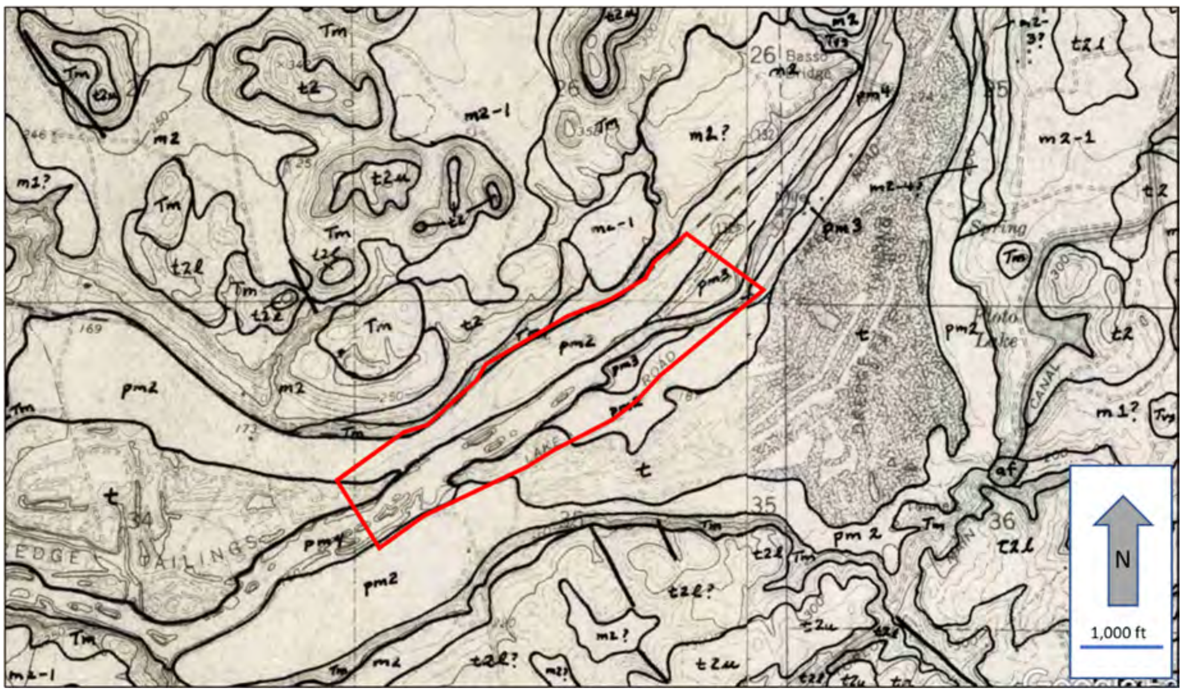


Figure 12. Geologic map of the Zanker Farm Project Area (red polygon) and vicinity (Marchand et al. 1981). Mapped units, from oldest to youngest, include late Holocene alluvial terraces (pm2 and pm3), recent alluvial deposits (pm4), and modern dredge tailings (t).

2.1 Subsurface Investigation

In October 2003, MA staff excavated 55 test pits throughout the Domecq Wilderness Area and Zanker family property to evaluate coarse sediment availability (gravel and cobble) for potential use in future restoration efforts. Test pits were excavated immediately adjacent to (east of) the current project boundary (Figure 13) on surfaces identified as dredge tailings and late Holocene alluvial terraces (units t and pm2 on Figure 12). The excavation depth and thickness of coarse sediment were recorded for each test pit. Bulk sediment samples were collected in most of the test pits, analyzed to determine the grain size distribution at each test pit location, and were summarized in the context of gravel content between 8 mm and 128 mm (Appendix A).

While all but one of the 2003 test pits are located outside of the Zanker Farm Project Area, some are within close enough proximity that their results can be used to assume similar sediment composition within the project area (e.g., 03ZD35–37). We assume conditions from 2003 remain representative of present-day conditions because the test pit locations sit higher than common contemporary flood elevations and are assumed to have not undergone any appreciable geomorphic change since the 2003 test pit investigation.

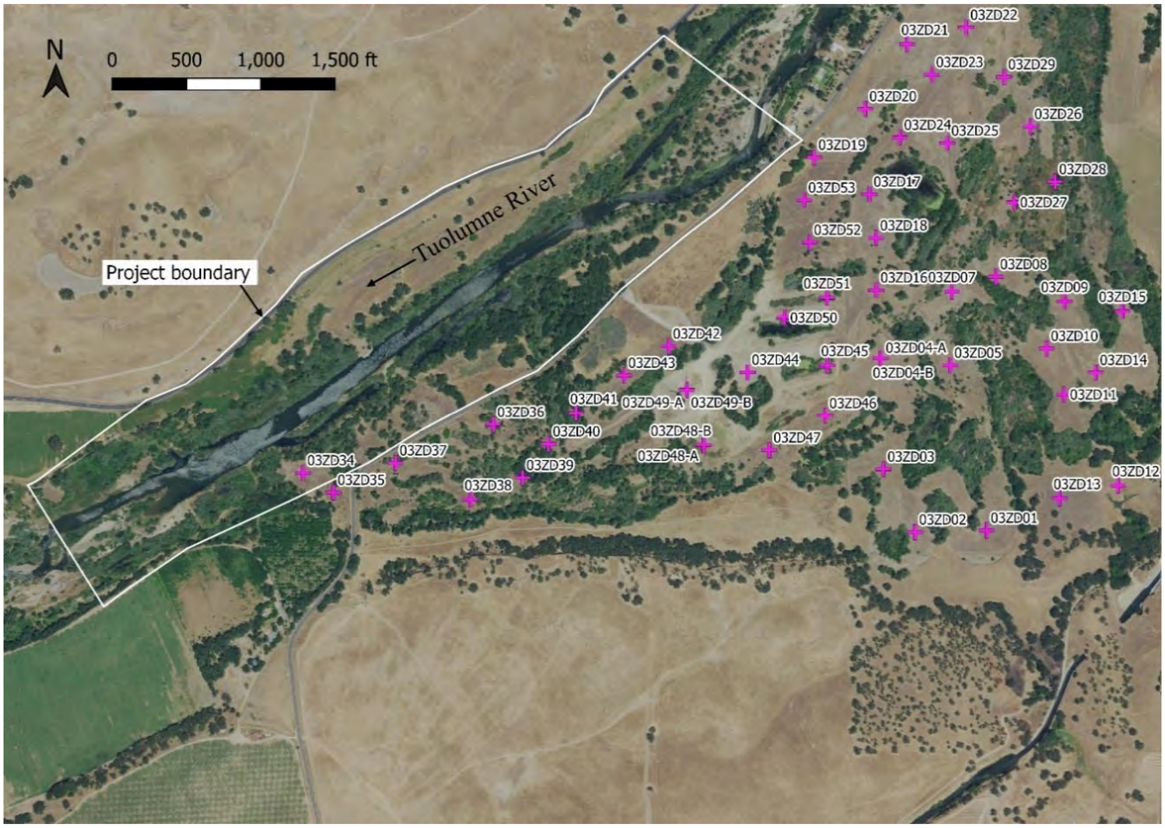


Figure 13. Test pit locations from 2003 with respect to the Zanker Farm Project Area boundary (white polygon). National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

3 HYDROLOGY

The Tuolumne River watershed is a 1,960-square mile (5,080-square kilometer) drainage on the western slope of the Sierra Nevada Range and flows approximately 130 miles westward to its confluence with the San Joaquin River. The Tuolumne River is the largest of three tributaries of the San Joaquin River system that flows northward and drains into the Sacramento–San Joaquin Delta. The lower Tuolumne River begins below Don Pedro Reservoir and flows 2.3 miles to La Grange Dam, where water is diverted into two canals owned and operated by the Turlock Irrigation District (TID) and Modesto Irrigation District (MID). The remaining water flows from below La Grange Dam, through the Sierra Nevada foothills to the San Joaquin Valley where land is primarily used for irrigated agriculture. Below La Grange Dam, the river can be divided into two geomorphic reaches that are defined by channel slope and bed composition. The gravel-bedded reach extends from La Grange Dam (RM 52) to RM 24.0. The sand-bedded reach extends from RM 24.0 to the confluence with the San Joaquin River (RM 0, (TID and MID 2005). The Zanker Farm Project Area is situated in the gravel-bedded reach.

Snowmelt and rainfall are the primary source of streamflow in the Tuolumne River. Snowmelt runoff occurs primarily in the upper basin between April and July, while rainfall is the main source of runoff in the Sierra foothills and the San Joaquin Valley primarily between December and March. Streamflow was relatively unimpaired in the lower Tuolumne River until the 1860s when water was diverted for use in agriculture. La Grange Dam was constructed by TID and MID in 1893 to replace Wheaton Dam, which was constructed to divert water into irrigation canals (TID and MID 2005). The original Don Pedro Reservoir was completed in 1923, and TID and MID completed the new Don Pedro Reservoir, two miles downstream of the original Don Pedro Reservoir, in 1971 (TID and MID 2005). Since completion of New Don Pedro Reservoir, peak flows in the lower Tuolumne River have been greatly reduced compared to historical flows. The impaired two-year return-period flood since construction of La Grange Dam is 3,507 cfs, while the unimpaired two-year return period flood was 21,000 cfs. The impaired 25-year return-period flood flow is 18,030 cfs, while the 20-year return-period flood flow was 59,000 cfs (FERC 1996).

According to the 1996 FERC Order, minimum instream flows are required for Chinook Salmon below Don Pedro Reservoir. Minimum required releases are 100 to 300 cfs from October 1 to 15, 150 to 300 cfs from October 16 to May 31, and 50 to 250 cfs from June 1 to September 30, depending on hydrologic conditions. Additional pulse releases under all but critically dry conditions are to be made to assist upstream migrating adult Chinook Salmon and downstream migrating juveniles. Minimum annual releases from La Grange Dam vary from 94,000 acre-feet in critically dry years to approximately 300,923 acre-feet in above normal and wet years (FERC 1996, TID and MID 2005).

Hydrologic analyses were conducted for the Tuolumne River to provide up-to-date information for the selection of flows to run in the Zanker Farm hydraulic model and to identify flows that are significant with respect to riparian vegetation (seeding, growth), and to salmonids (e.g., juvenile rearing). Site hydrology informs aspects of the conceptual design process such as elevation targets for floodplain inundation or side channel activation. Flow duration and flood frequency analyses were performed, and both analyses used data published by the USGS for the Tuolumne River below La Grange Dam gaging station (USGS gage #11-289650). Both analyses were performed for the post-NDP Dam flow regime (i.e., 1971 to present).

3.1 Flow Duration

Flow duration curves identify flows that are equal to or exceeded during specific time intervals (duration in days). The flow duration curves created for this project were used to identify flows that inundate design surfaces at different recurrence intervals and represented important thresholds for various physical and ecological processes. We identified return flows for a full water year (Figure 14, Table 1) and for three additional ecological periods relevant to design objectives: (1)

cottonwood and tree willow seed dispersal (May 15 through May 31, Figure 15, Table 2), (2) riparian vegetation growth (March 15 through October 31, Figure 16, Table 3), and (3) juvenile Chinook Salmon rearing (January 1 through May 15, Figure 17, Table 4). Since juvenile *O. mykiss* rear year-round, results from the full water year flow duration curve analysis can be used for habitat designs that target juvenile *O. mykiss*.

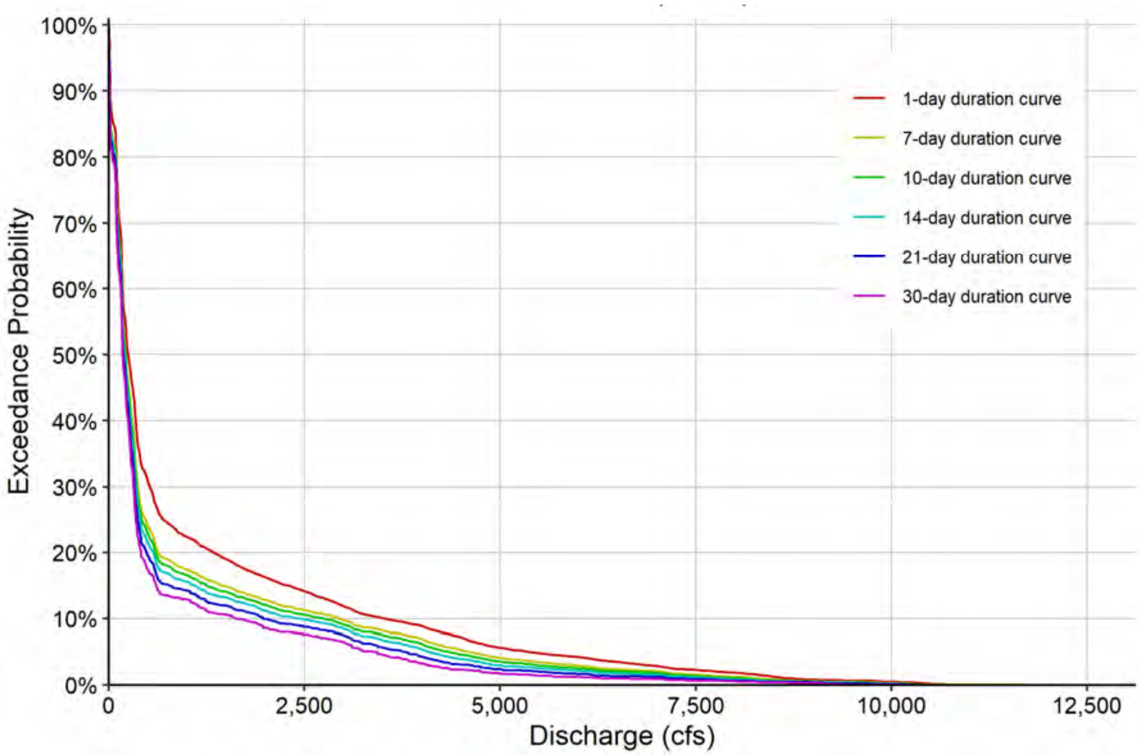


Figure 14. Flow duration curves calculated for the entire water year for six duration periods.

Table 1. Return flows calculated for the entire water year. The return flow is the minimum flow that occurred for the specified duration period (in days) for each recurrence interval (in years).

Recurrence Interval (years)	Exceedance Probability (percent)	1-day Duration (cfs)	7-day Duration (cfs)	10-day Duration (cfs)	14-day Duration (cfs)	21-day Duration (cfs)	30-day Duration (cfs)
Q_1	100	50*	50*	50*	50*	50*	50*
$Q_{1.5}$	66.6	162	146	138	128	118	111
Q_2	50	249	219	213	205	184	174
Q_3	33.3	421	345	336	327	313	295
Q_4	25	697	471	417	396	364	344
Q_5	20	1,345	632	599	569	482	409
Q_{10}	10	3,520	2,950	2,760	2,430	1,970	1,630
Q_{100}	1	8,720	8,310	8,150	7,810	7,380	6,560

*Minimum flow per existing FERC license.

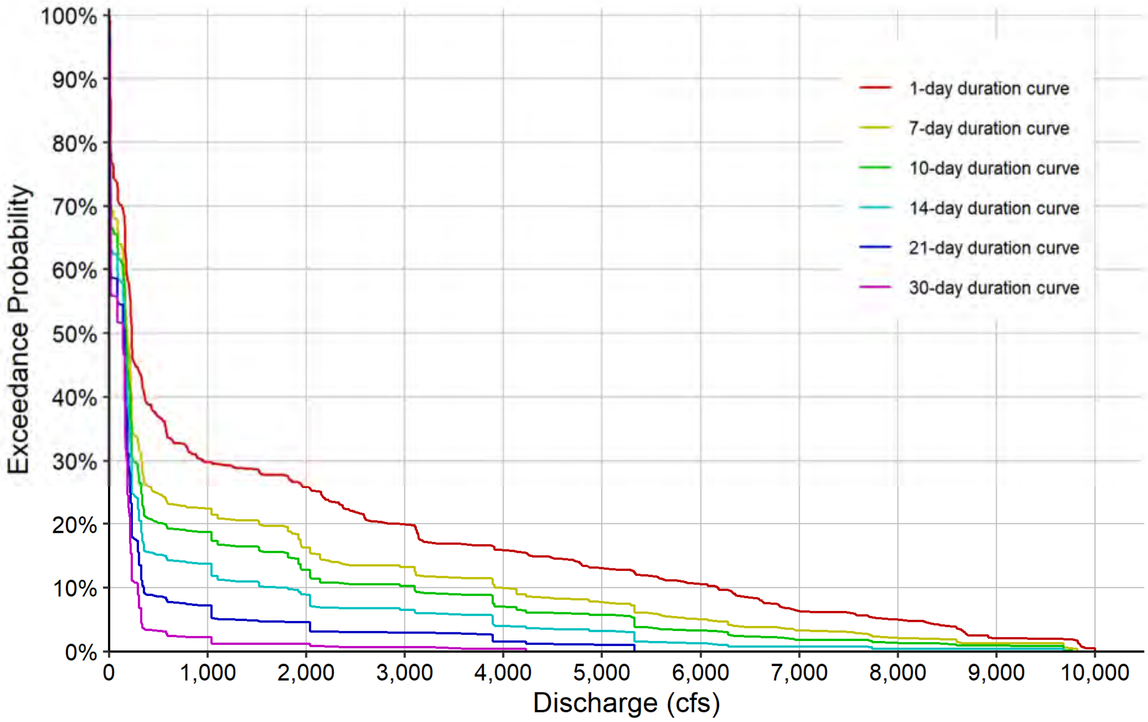


Figure 15. Flow duration curves calculated for the seed dispersal period (May 15–May 31) for six duration periods.

Table 2. Return flows calculated for the seed dispersal period (May 15–May 31). The return flow is the minimum flow that occurred for the specified duration period (in days) for each recurrence interval (in years).

Recurrence Interval (years)	Exceedance Probability (percent)	1-day Duration (cfs)	7-day Duration (cfs)	10-day Duration (cfs)	14-day Duration (cfs)	21-day Duration (cfs)	30-day Duration (cfs)
Q_1	100	50*	50*	50*	50*	50*	50*
$Q_{1.5}$	66.6	159	88	50*	50*	50*	50*
Q_2	50	229	182	167	158	158	138
Q_3	33.3	650	293	229	213	184	167
Q_4	25	2,150	474	323	229	210	184
Q_5	20	3,005	1,520	579	322	229	210
Q_{10}	10	6,175	4,060	3,100	1,810	353	293
Q_{100}	1	9,855	9,680	9,140	6,280	5,330	2,040

*Minimum flow per existing FERC license.

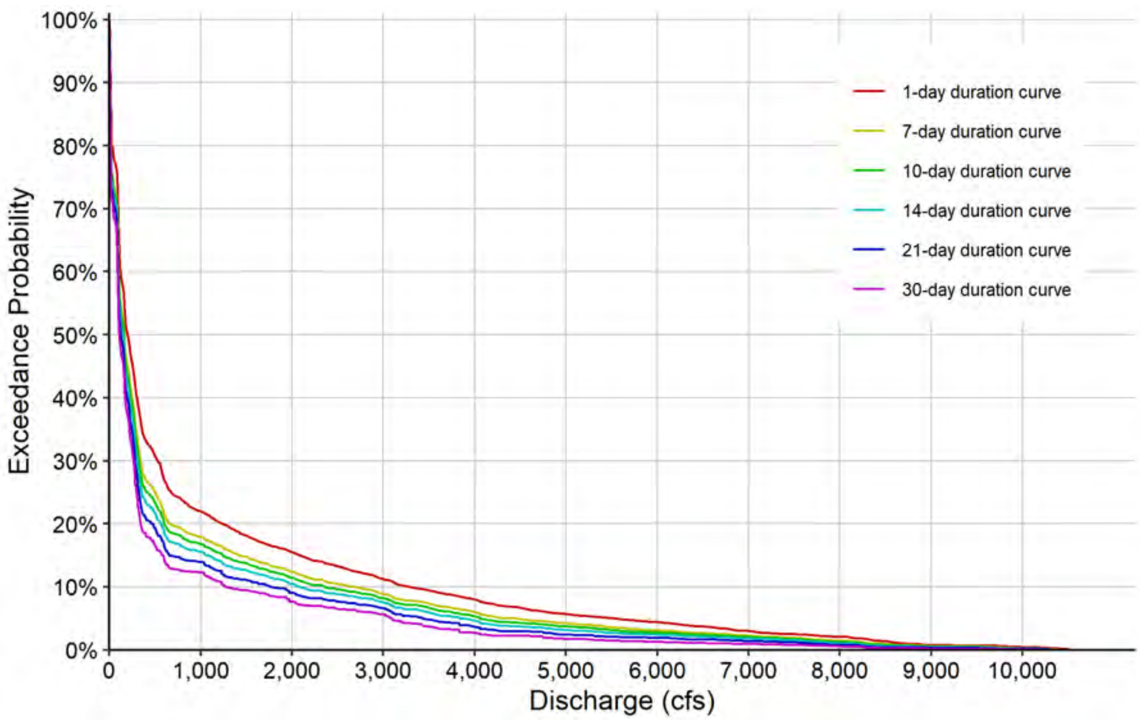


Figure 16. Flow duration curves calculated for the riparian vegetation growing period (March 15–October 31) for six duration periods.

Table 3. Return flows calculated for the riparian vegetation growing period (March 15–October 31). The return flow is the minimum flow that occurred for the specified duration period (in days) for each recurrence interval (in years).

Recurrence Interval (years)	Exceedance Probability (percent)	1-day Duration (cfs)	7-day Duration (cfs)	10-day Duration (cfs)	14-day Duration (cfs)	21-day Duration (cfs)	30-day Duration (cfs)
Q_1	100	50*	50*	50*	50*	50*	50*
$Q_{1.5}$	66.6	106	94	92	91	87	80
Q_2	50	202	167	161	156	127	110
Q_3	33.3	409	311	297	281	265	242
Q_4	25	680	505	407	357	326	301
Q_5	20	1,240	665	605	569	482	344
Q_{10}	10	3,295	2,705	2,370	2,090	1,780	1,270
Q_{100}	1	8,830	8,490	8,280	8,200	7,740	6,905

*Minimum flow per existing FERC license.

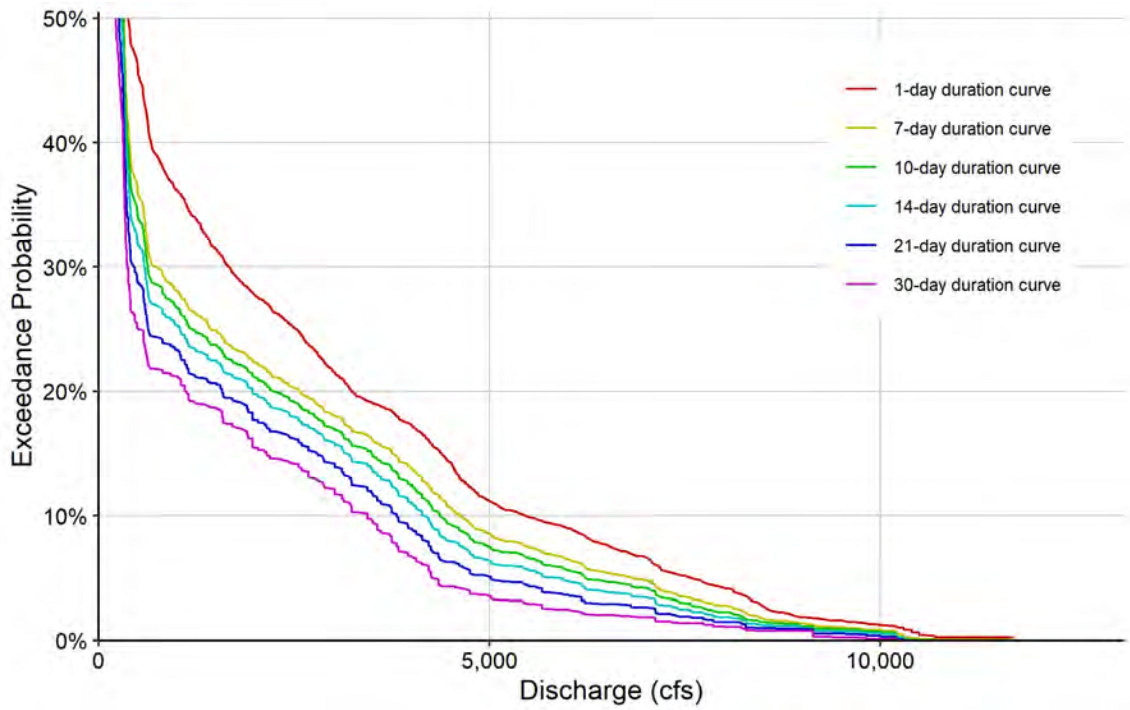


Figure 17. Flow duration curves calculated for the Chinook Salmon rearing period (Jan 1–May 15) for six duration periods.

Table 4. Return flows calculated for the Chinook Salmon rearing period (Jan 1–May 15). The return flow is the minimum flow that occurred for the specified duration period (in days) for each recurrence interval (in years).

Recurrence Interval (years)	Exceedance Probability (percent)	1-day Duration (cfs)	7-day Duration (cfs)	10-day Duration (cfs)	14-day Duration (cfs)	21-day Duration (cfs)	30-day Duration (cfs)
Q_1	100	50*	50*	50*	50*	50*	50*
$Q_{1.5}$	66.6	222	180	174	172	168	166
Q_2	50	378	322	314	287	258	222
Q_3	33.3	1,330	604	571	462	381	343
Q_4	25	2,540	1,440	1,220	1,040	633	554
Q_5	20	3,240	2,580	2,275	1,970	1,580	1,130
Q_{10}	10	5,470	4,630	4,370	4,180	3,810	3,440
Q_{100}	1	10,300	9,730	9,210	9,140	8,960	8,280

*Minimum flow per existing FERC license.

The flow duration curve analysis used daily average streamflow from the USGS Tuolumne River below La Grange Dam gage for water years 1971 through 2020 to reflect contemporary flows since the completion of NDP Dam in 1971. The entire year was used to calculate the full water year duration curves, while only the specified dates from each year were used to calculate the duration curves for the seed dispersal, riparian growth, and Chinook Salmon rearing periods.

Flows were evaluated for six duration periods, 1-day, 7-day, 10-day, 14-day, 21-day, and 30-day. For each duration period, the daily moving minimum flow values were sorted from lowest to highest and divided by the maximum flow to calculate flow-specific exceedance probabilities. The daily moving minimum flows and exceedance probabilities were plotted to create the flow duration curves. Return flows used for consideration in habitat designs were flows within each duration period that had an exceedance probability associated with target recurrence intervals (exceedance probability that is equal to 1/recurrence interval).

3.2 Flood Frequency

A flood frequency analysis was performed using USGS annual instantaneous peak flow data for the post-NDP Dam period of record (1971–2021). The analysis was performed using the USGS PeakFQ v7.3 software package (https://water.usgs.gov/software/PeakFQ) and USGS Bulletin 17C method (England et al. 2018). Results are shown in Figure 18 and Table 5.

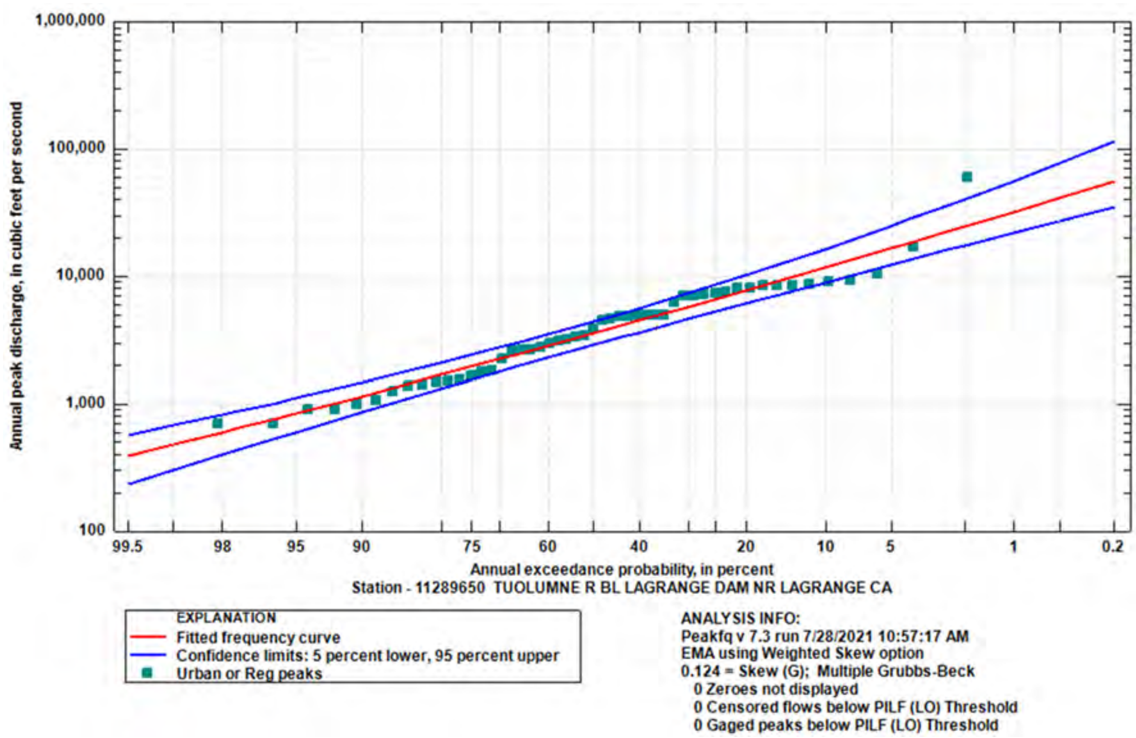


Figure 18. Plot of Bulletin 17C (England et al. 2018) flood frequency analysis results showing peak flow data used as inputs, fitted frequency curve, and confidence intervals.

Table 5. Results of Bulletin 17C (England et al. 2018) flood frequency analysis.

Recurrence Interval (years)	Annual Exceedance Probability	Discharge (cfs) with Regional Skew	5% Lower Confidence Limit (cfs)	95% Upper Confidence Limit (cfs)
1.01	0.990	475	299	671
1.05	0.950	836	591	1,100
1.11	0.900	1,137	845	1,455
1.25	0.800	1,663	1,292	2,076
1.50	0.667	2,386	1,906	2,947
2.00	0.500	3,507	2,838	4,355
2.33	0.429	4,122	3,337	5,158
5.0	0.200	7,595	6,023	10,070
10.0	0.100	11,500	8,842	16,230
25.0	0.040	18,030	13,250	27,730
50.0	0.020	24,230	17,180	39,780
100	0.010	31,700	21,670	55,540

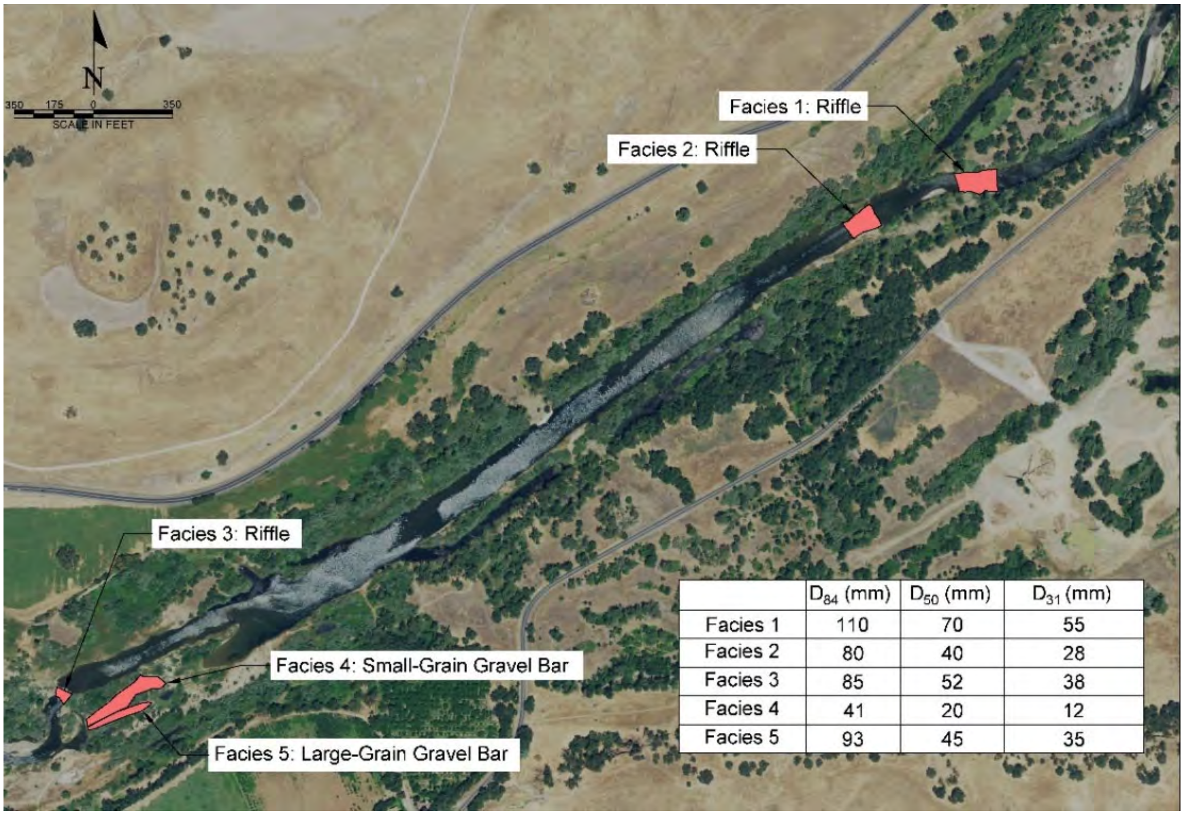
4 CHANNEL MORPHOLOGY

The *Habitat Restoration Plan for the Lower Tuolumne River Corridor* (M&T 2000) identified seven geomorphic subreaches for the lower Tuolumne River. The Zanker Farm Project Area begins at the Reach 6/7 transition and extends upstream into Reach 7. Called the Dominant Salmon Spawning Reach, Reach 7 is described in the Habitat Restoration Plan as:

> *…disproportionately high salmon spawning use, agricultural land use (grazing), low valley confinement during high flows, moderate slope (0.0010 to 0.0015), and a gravel-bedded channel. Construction of the NDPP in 1970 removed the extensive dredger tailings throughout the reach for use as construction materials for the New Don Pedro Project. This activity and subsequent channel reconstruction resulted in a single-thread meandering low water channel with low bankfull confinement. The quality and availability of spawning habitat in this reach surpasses that of all other reaches.*

The Project Area has been impacted by the loss of coarse sediment supply that historically provided essential sediment for the formation of alternate bar features and in-channel and floodplain habitat structure. This lost coarse sediment supply, combined with the dramatic reduction in high flows, has prevented regenerative fluvial processes from promoting river recovery.

As of summer 2021, there has been very little change in planform geometry within the Zanker Farm Project Area since 1998, based on aerial imagery analysis. Seventy percent of the channel length consists of a single large pool, which is mostly confined by heavily vegetated lateral berms (Appendix B, Section B-B', Section C-C', and Section D-D'). Even during extremely high flow events, this type of "bowling alley" channel geometry does not tend to change. This long pool is bounded at both ends by gravel riffles (Appendix B, Long Profile). Both riffles (and the next riffle upstream) offer high quality spawning habitat with median grain sizes ranging from 40 to 70 mm based on surface facies mapping and pebble count data collected by MA in 2021 (Figure 19). These riffle areas also host more channel complexity (e.g., side channels, more active channel margins) than the long pool.



	D_{84} (mm)	D_{50} (mm)	D_{31} (mm)
Facies 1	110	70	55
Facies 2	80	40	28
Facies 3	85	52	38
Facies 4	41	20	12
Facies 5	93	45	35

Figure 19. Substrate facies mapping conducted by MA in 2021. National Agriculture Imagery Program (NAIP) 2020 aerial image.

Unlike the reach above, the riffle–island complex that comprises the primary riffle control at the downstream end of the site (Appendix B, Long Profile, approximate station 4+50) has changed recently in response to 2017 high flows (17,000 cfs, approximate 23-year return interval). Even though most of this feature lies outside the project boundary, it is important to note that it influences the water surface elevation of the entire reach above, and an examination of its recent evolution is warranted. Figure 20 illustrates the riffle–island complex evolution from 2013 to 2021: (1) channel migration into the vegetated bank on the north side of the river, (2) the development of a large scour hole at the toe of the control riffle, (3) proportionally more flow in the north channel coupled with partial plugging of the south channel entrance, (4) channel migration to the south resulting in additional exposure of assumed claypan, and (5) formation of a gravel bar and side channel across the river from the southern channel migration. The claypan feature is more resistant than the surrounding alluvial deposits and contributes to island–riffle complex instability by inhibiting lateral migration to the south and concentrating scouring hydraulic forces into the island–riffle complex (Figure 20, Figure 21). The apparent instability in this area suggests that the downstream riffle crest (Appendix B, Section A-A') could be outflanked or eroded, which would lower the water surface elevation through the entire upstream pool.

4.1 Off-channel Hydrologic Features

There are several off-channel features in the Zanker Farm Project Area. A remnant channel along the south bank is bisected by a historic haul road, creating two distinct sloughs (Figure 8, Figure 5). The downstream slough is strongly connected by a deep confluence to the river and forms an alcove, while the upstream slough has a weak connection via a sandy, shallow plug that is currently maintained at low summer flow (~145 cfs) by a beaver trail. Both sloughs are filled with a complex variety of woody debris and numerous large trees that remain perched above the water, soon to be recruited. Two off-channel wetlands/wet meadows along the south side of the river may present stranding issues for juvenile salmonids. A third side channel occurs at the upstream end of the project on the north side and was not directly evaluated in 2021. The downstream end of this side channel appears to function as an alcove at low flows and the upstream end, outside the project boundary, appears to have a high flow connection; it is separated from the main channel by a large gravel bar.

Figure 20. Google Earth imagery in 2013 (top) and 2021 (bottom) illustrating changes associated with the 2017 peak flow event. While the flow in the 2021 photo is higher (172 cfs vs 92 cfs in 2013), proportionally more of the total flow appears to be in the north channel. Field observations in July 2021 confirmed virtually zero flow into the south channel.

Figure 21. Oblique upstream photo taken from a UAV on May 20, 2021 (176 cfs at USGS 11289650), illustrating the suite of geomorphic features and associated processes that together indicate local channel instability with potential hydraulic consequences (lowering of water surface elevation) for the project area upstream.

5 HYDRAULIC 2-D MODELING

Hydraulics of the Zanker Farm Project existing conditions were evaluated using Hydrological Engineering Center–River Analysis System (HEC-RAS) v.6.0.0, the U.S. Army Corps of Engineers (USACE) multi-dimensional hydrodynamic modeling program. Modeling was performed to estimate flow distribution, depth, WSE, and velocities. HEC-RAS uses physical input data to solve the two-dimensional Saint-Venant equations to determine flow depth and velocity across each computational grid face. Topographic data were collected to generate a detailed digital terrain map of the Tuolumne River and its floodplains, which was used in the 2-D hydraulic model and as the basis for other subsequent analyses.

5.1 Data Collection and Analyses

A variety of physical data were collected to document existing conditions and provide requisite information to proceed with the design process. These data include an aerial photo of the site, topography and bathymetry, water surface elevations (WSE) from staff plates, substrate size and quantity estimates, and photographic documentation. A two-dimensional (2-D) hydraulic model of existing conditions was developed and calibrated to existing water surface data to predict hydraulic variables such as depth, velocity, and inundation thresholds that would serve as a baseline for the design process, as well as inform initial biological and physical evaluations.

5.1.1 Survey Control Network

A survey control network was established by a professional land surveyor (PLS) with O'Dell Engineering on May 20, 2021 (Table 6). The control network is referenced to the California State Plane Zone III NAD83 (2011) US Feet coordinate system. The project benchmark is a National Geodetic Survey benchmark located near Cooperstown Road, north of the town of La Grange.

Using this benchmark, the PLS set a new benchmark (BM3) within the Zanker Farm Project Area comprised of an aluminum disc on a concrete footing, as well as three control points. McBain Associates staff used a Trimble R10 GNSS system for RTK survey work on the Zanker Farm Project Area and used benchmark BM3 as the base station control point. In addition, O'Dell Engineering surveyed topographic and bathymetric points used to check the existing 2012 LiDAR and 2005 bathymetric data. This check showed that the 2012 LiDAR topographic data were useable, but the 2005 bathymetric data would need to be updated.

Table 6. Zanker Farm Project Area control network established by O'Dell Engineering.

Point Number	Northing	Easting	Elevation (ft)	Point Description	Notes
25001	2070502.728	6570503.909	408.000	BM 7RS 406	NGS benchmark, Cooperstown Road. Brass disc set in rock outcrop.
103	2053319.957	6558864.775	156.312	BM3 ALUM DISC	O'Dell benchmark on Zanker property. Aluminum disc in concrete footing.
15005	2053392.083	6558761.757	150.101	CP 5	O'Dell control point on Zanker property.
15006	2052729.963	6558219.561	161.708	CP 6	O'Dell control point on Zanker property.
15007	2052738.108	6558061.333	156.835	CP 7	O'Dell control point on Zanker property.

5.1.2 Topography, Bathymetry, and Water Surface Elevation Surveys

Detailed topographic and bathymetric surveys were conducted at the site by MA staff in June and July of 2021 using the control network established by the PLS (Table 6). Prior to this date, the most recent bathymetry data available within this reach was from a 2005 survey conducted by Graham Mathews and Associates (GMA) Hydrology. Peak flows exceeding bed mobility thresholds have occurred since 2005, prompting the need for updated bathymetry.

A Trimble R10 GNSS system was used to perform RTK surveys both by wading with a survey rod and with an integrated depth sounder mounted on a boat. This equipment was used to collect bathymetry within the mainstem Tuolumne River, topographic breaklines along the tops and toes of the banks, topography on floodplain benches, and bathymetry of off-channel ponds and sloughs on the left bank (south) side of the river. The survey data extends from the upstream (eastern) end of the project area to approximately 500 ft downstream of the primary riffle control for the site at the downstream (western) end of the project area.

The boat-mounted depth sounder connected to the GNSS system was used to map deep pools and alcoves in the mainstem Tuolumne River that could not be surveyed via wading. This boat-mounted system was not used to survey the off-channel ponds and sloughs due to the density of vegetation, which impeded the boat and interfered with the sonic return of the depth sounder unit. In areas where the system was feasible, the boat was paddled across the channel, surveying cross sections in these deep areas, with an approximate spacing of 30–50 feet between cross sections. Each survey point collected by the depth sounder system consisted of a water surface elevation and depth value, from which the channel bed elevation was calculated. Survey points were spaced on average 5–10 ft apart.

Shallow areas, riffles, and topographic breaklines along the tops and toes of the banks were surveyed on foot and by wading using the R10 rover head mounted on a 6.5-ft survey rod. This was done to capture bathymetry in areas that could not be reached by the depth sounder, create breaklines to better define the channel and provide detail when generating a digital terrain model (DTM) of the surface, and to overlap the RTK survey with the LiDAR data that would be used to generate the terrain model. The off-channel ponds and slough were surveyed by wading or by boat using the R10 rover mounted on an extendable 14-ft rod to get deep areas where the depth sounder could not get a reliable sonic return.

The area just downstream of the primary riffle control was mapped by wading with a survey rod to capture changes to the channel alignment and geometry that occurred since the 2005 bathymetric survey (Section 0, Figure 10, and Figure 22). Geomorphic changes in this region include shifting of the mainstem alignment towards the left bank; development of gravel bar on the right bank; development of cut-off channels following alignment of old, abandoned mainstem alignment; and development of deep scour pools. It was infeasible to survey the two deep pools, so these features were instead generated within Civil 3D based on field observations of depth and planform layout.

A long profile of water surface elevation points was surveyed within the Zanker Farm Project Area to provide data needed to calibrate the hydraulic model of the site using Manning's *n* roughness estimates. The points were measured with the RTK and survey rod both by wading and by boat. A total of 59 water surface elevation measurements were collected.

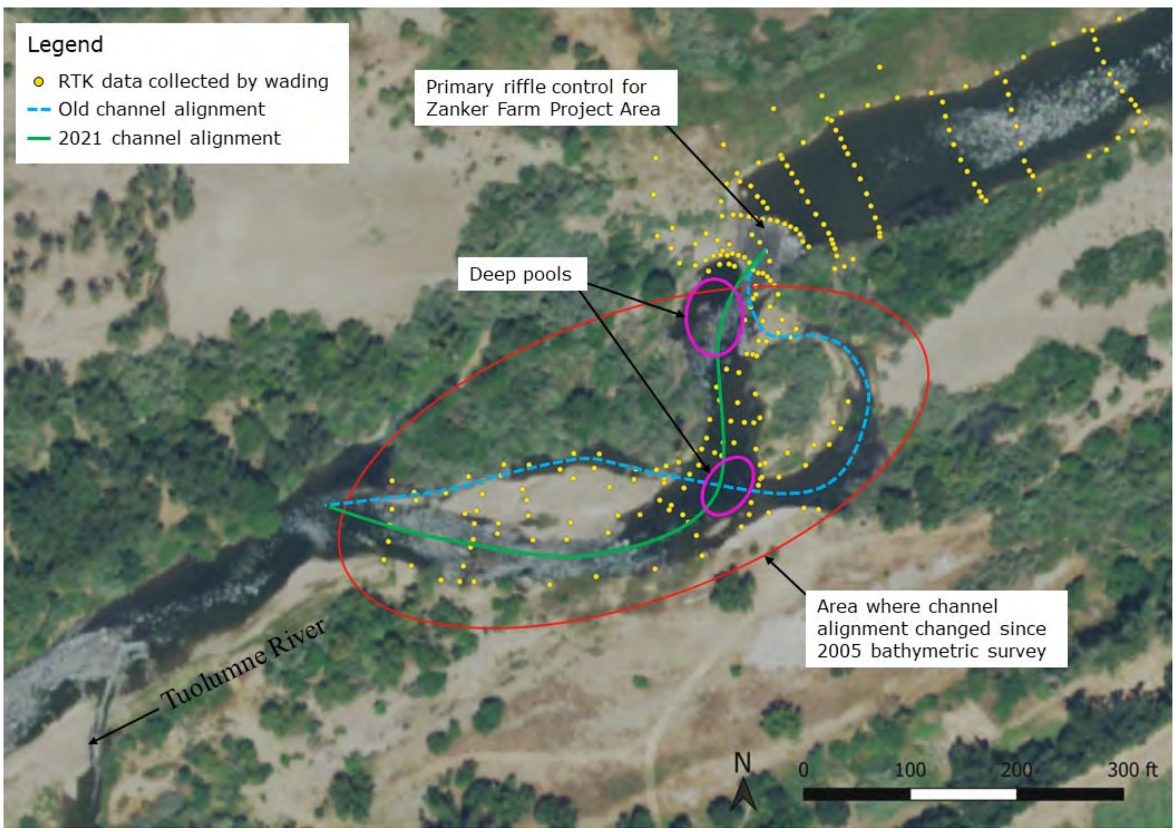


Figure 22. Section of channel downstream of the primary riffle control for the project area that was surveyed to capture changes to channel alignment and geometry that occurred since the 2005 bathymetric survey. 2020 National Agriculture Imagery Program (NAIP) aerial image reflects present-day conditions, such as the right bank gravel bar that developed where the old mainstem alignment once flowed.

5.1.3 Existing Conditions Terrain

A digital terrain model (DTM) of existing conditions at Zanker Farm was created in AutoCAD Civil 3D for use in hydraulic modeling, analysis of existing conditions, and development of civil designs. The terrain was generated using a combination of the topographic and bathymetric data collected within the Zanker Farm Project Area in 2021 and the existing conditions terrain used for Bobcat Flat Phase III (MA 2020). The Bobcat Flat terrain was used as the basis for the Zanker Farm terrain because it contains an assortment of the most up-to-date topographic and bathymetric data available and covers the entirety of the 2-D hydraulic model domain, which extends from RM 43.6 to RM 48.2 Situating the terrain and model domain in this manner allowed the 2-D hydraulic model boundaries to be located sufficiently far upstream and downstream to negate any potential influence of boundary conditions on hydraulics within the project area and allowed the topography to be the primary driver of hydraulics within the majority of the model domain.

The Bobcat Flat DTM of existing topography and bathymetry was generated using a combination of recent surveys and previously collected terrain data. The data sources comprising the Bobcat Flat Phase III existing conditions terrain include Light Detection and Ranging (LiDAR) topographic data from a flight in 2012, bathymetry data collected in 2005, and bathymetry and topographic data collected in 2017 and 2020 (Table 7). The final Bobcat Flat DTM of existing topography was generated by pasting the 2017 and 2020 surveys into the combined 2012 LiDAR/2005 bathymetric surface (MA 2020). This finalized DTM was used as the basis for the Zanker Farm existing conditions terrain.

Table 7. Topographic datasets comprising the existing conditions terrain used in the Zanker Farm Project Area digital terrain model, which was based on the Bobcat Flat Phase III terrain model.

Dataset	Date of Collection	Collected By	Description
LiDAR	March 2012	Photo Science Inc.	LiDAR data covering floodplains, upland areas, and exposed banks.
Bathymetry	Spring 2005	GMA Hydrology	Mainstem bathymetry for areas outside of Bobcat Phase III and Zanker Farm Project Areas.
Detailed Bathymetry (Bobcat Flat Phase III)	October/November 2017	U.S. Fish and Wildlife Service	ADCP and RTK survey of mainstem bathymetry collected at 440 cfs within Bobcat Phase III project area.
Supplemental Survey (Bobcat Flat Phase III)	October 2017, July 2020	McBain Associates	Total station survey of irrigation channel, slough, disconnected dredger ponds, shallow overland flow paths out of slough, and fill-in points in mainstem.
Detailed Bathymetry (Zanker Farm)	June + July 2021	McBain Associates	Depth sounder and RTK survey of mainstem bathymetry, bank breaklines, and off-channel ponds and sloughs.

The Zanker Farm 2021 survey data (Section 5.1.2) were combined with the Bobcat Flat Phase III existing conditions terrain to create the Zanker Farm existing conditions terrain (Table 7). In Civil 3D, a terrain was created comprised of the Zanker Farm 2021 depth sounder and RTK survey data. Breaklines were drawn along tops and toes of slopes and added to the terrain surface to improve interpolation of the triangular irregular network (TIN) surface. The surface boundary was drawn by connecting points along the outer edge of the survey extent. In some locations, 3-D polylines were added to the surface as contours to define features that were infeasible to survey directly in the field (e.g., deep scour pools downstream of the primary riffle control at the downstream end of the Zanker Farm Project Area, Figure 22) or to provide better definition of channel geometry where survey data were less dense. The planform layout and elevation of these contours were assumed based on field observations.

The 2021 survey data include the area just downstream of the primary riffle control (Figure 22, Table 7) because the channel alignment in this location has shifted since the 2005 bathymetry survey conducted by GMA. Using the 2021 survey data here was necessary to define the contemporary channel alignment, elevation, and geometry, and to ensure that the use of older data from 2005 does not incorrectly characterize the hydraulics upstream of the riffle control and within the Zanker Farm Project Area. Just downstream, the 2021 data tie into the 2005 bathymetry at a location where the 2005 bathymetry is still considered representative of the current channel alignment.

The 2021 Zanker bathymetry and topography terrain was pasted into the Bobcat Flat existing conditions terrain to create the Zanker existing conditions terrain (Figure 23, Figure 24). After internal review by the Engineer of Record and other McBain Associates engineering staff, the terrain was exported from Civil 3D as a .tif file to be used in 2-D hydraulic modeling.

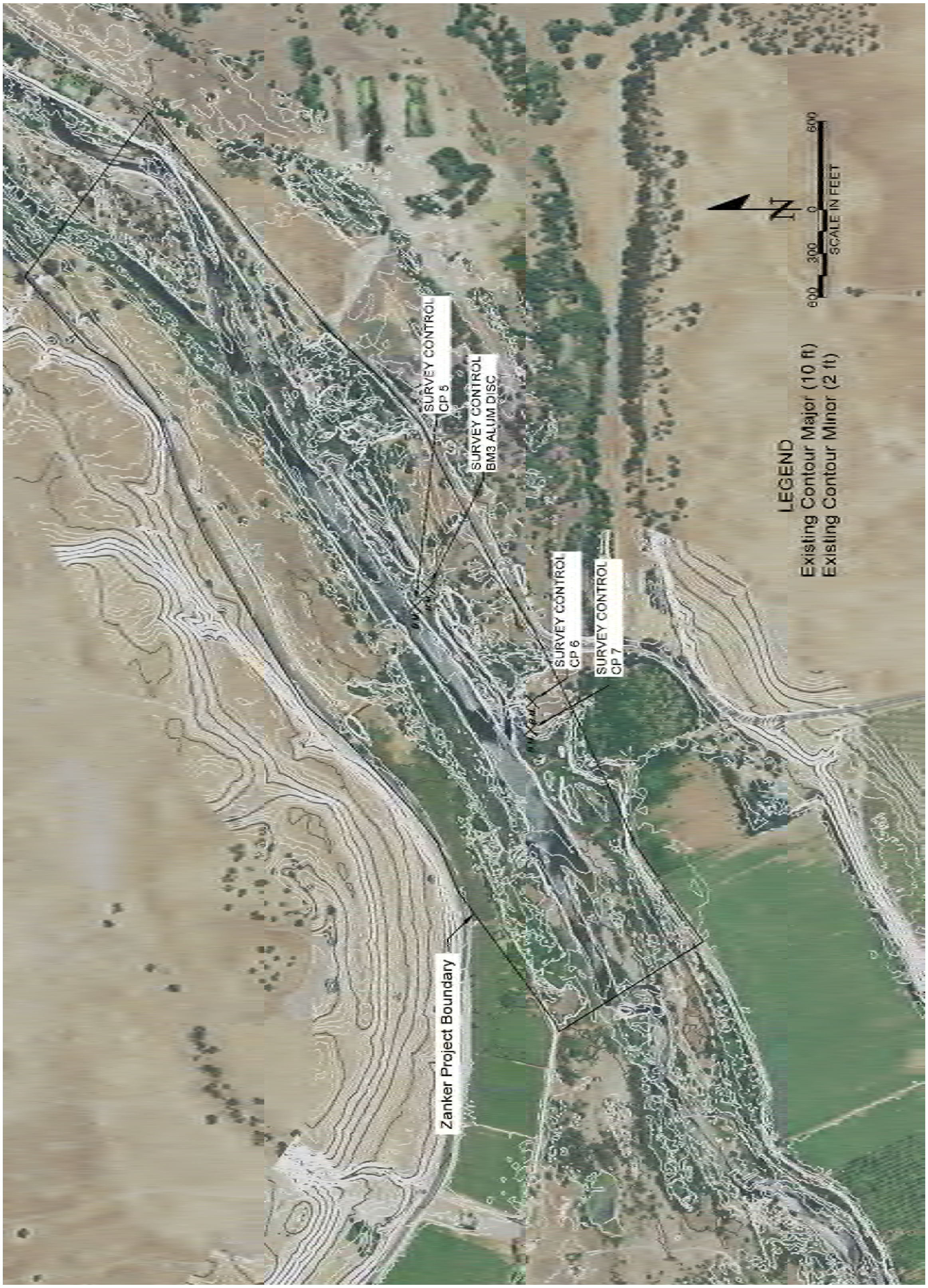


Figure 23. Existing conditions topography map for Zanker Farm, showing the locations of the control points. The surface extends from upstream of Zanker Farm to downstream of Bobcat Flat (not pictured) using a combination of data sources (Table 7). National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

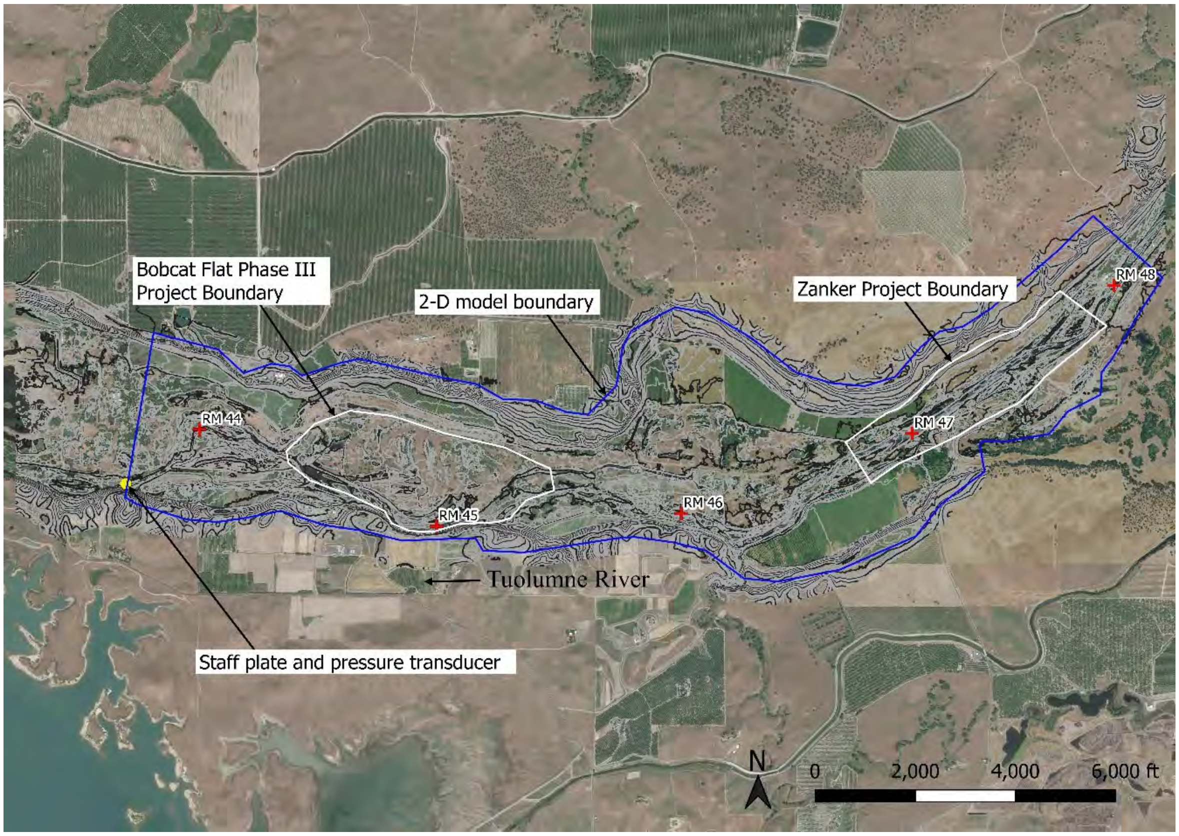


Figure 24. Map showing full extent of existing conditions terrain with respect to the Zanker Farm and Bobcat Flat Phase III project boundaries, 2-D model boundary, and staff plate and pressure transducer. River miles and two-ft elevation contours are displayed. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

5.1.4 Streamflow Measurement

Streamflow was measured by MA staff on June 6, 2021, to determine the flow at which existing conditions hydraulic model calibration data (i.e., water surface elevation measurements described in Section 5.1.5) were collected. The streamflow was measured by wading the river using a FlowTracker2 handheld acoustic doppler velocimeter (ADV) system. A measurement cross section was selected roughly 0.85 mi upstream of the Zanker Farm Project Area based on its suitability for an accurate flow measurement (e.g., uniform flow direction, near-laminar flow conditions, simple cross-sectional geometry, minimal vegetation, and adequate depths and velocities for the ADV probe). No flow accretion or loss is assumed between the measurement cross section and the Zanker Farm Project Area.

A flow of 110 cfs was measured following USGS streamflow measurement protocols (Rantz 1982). A staff plate near the streamflow measurement cross section was used to determine if Tuolumne River streamflow was constant during the collection of WSE calibration data. Stage at the staff plate was unchanged from the start and end times of calibration data collection, so no additional flow measurements were needed.

5.1.5 Stage Monitoring

Water surface elevation (or "stage") data are necessary for providing downstream boundary conditions for the hydraulic model. On June 3, 2021, MA began monitoring stage in a gaging pool at the downstream end of the hydraulic model boundary by installing a staff plate and continuously-recording submerged pressure transducer (Figure 24**Error! Reference source not found.**). The staff plate and pressure transducer were attached to an 8-ft length of channel iron driven vertically into the channel near the right bank. Because the submerged pressure transducer was not vented, its data had to be corrected for changes in barometric pressure. To do this, a second pressure transducer to record barometric pressure was installed above potential flood elevations in a shed on the Zanker Family property. The elevation of the staff plate and submerged pressure transducer were surveyed with an RTK tied into the Zanker Farm control network. Stage data collected at the time of staff plate installation were used to develop the downstream boundary condition for hydraulic model calibration (Table 8). As of this writing, the pressure transducers have not been downloaded, as no high flow events have occurred since installation. Once the pressure transducer has been active over the course of one or more complete water years, the recorded data will be used to develop a rating curve to provide more accurate downstream boundary conditions for the hydraulic model.

Table 8. Staff plate metadata, location, initial reading, and calculated water surface elevation at the time of installation. Streamflow was measured by MA staff at a cross section approximately 0.85 mi. upstream of the Zanker Farm Project Area boundary.

Zanker Farm Downstream Model Boundary Staff Plate	
Installation Date	June 3, 2021
Pressure Transducer Serial No.	20945598
Pressure Transducer Recording Interval (min)	30
Easting	6541990.163
Northing	2051746.642
Location	In river near right bank
Flow at Time of Installation (cfs)	110
Base of Staff Plate Elevation (ft)	127.388
Staff Plate Reading (ft)	1.120
Water Surface Elevation (ft)	128.588

5.1.6 Photopoint Establishment

In May 2021, MA and TRC staff established eight photopoints (PPs) 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 (Figure 25, Figure 26). 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 the barren and disconnected floodplain surface, the lake–cascade morphology of the main channel, the overgrown and stagnant ponds, and the slow-moving, deep, off-channel slough. The PPs are documented and described in Appendix C.

Figure 25. Example of existing conditions at PP 2. Panoramic photo shows the channel and riffle at the second upstream-most riffle. Photo is taken on the left (south) bank facing north, flow is from right to left and is approximately 110 cfs.

Figure 26. Aerial photograph showing an overview of photopoint locations for the Zanker Farm Project Area. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial imagery.

5.2 Model Setup

There are three primary geometry inputs needed for the hydraulic model: site terrain, computational mesh, and Manning's *n* roughness values. The existing conditions topography developed in AutoCAD Civil 3D from the combination of the topographic, bathymetric, and LiDAR data provided the existing conditions site terrain for the 2-D hydraulic model (Figure 24**Error! Reference source not found.**). A DTM of the combined existing ground datasets was prepared by MA staff as described in Section 5.1.3. The DTM was imported to HEC-RAS and the extent of the hydraulic model domain was set to the upstream and downstream extent of the DTM. 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).

Detailed Manning's *n* polygons were generated and used to assign roughness values based on land cover type. 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. The 2012 data cover the entire model domain while the 2021 data cover the Zanker Farm Project Area. Vegetation and substrate polygons from the two data sources were combined into a single shapefile covering the entire model domain and imported to HEC-RAS (Figure 27, Figure 28). Each roughness polygon was assigned one of the categories listed in Table 9 depending on vegetation type or D_{84} in the case of substrate mapping. Manning's *n* values were assigned by category and iteratively adjusted throughout the model calibration process to find the most appropriate values that achieve the closest calibration.

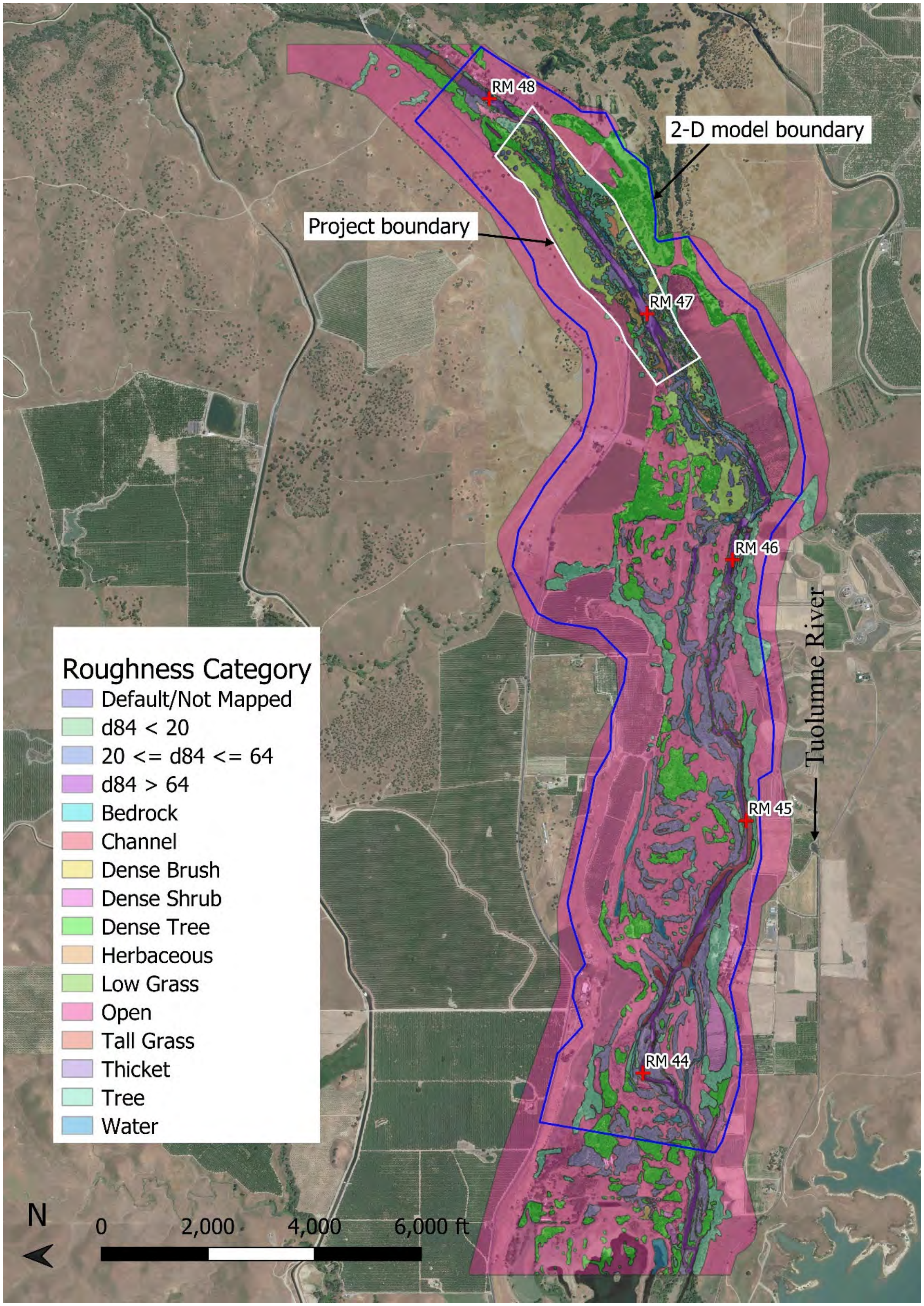


Figure 27. Manning's n roughness polygons with categories assigned from vegetation and substrate mapping used in the hydraulic model. Full 2-D model domain and river miles are shown. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

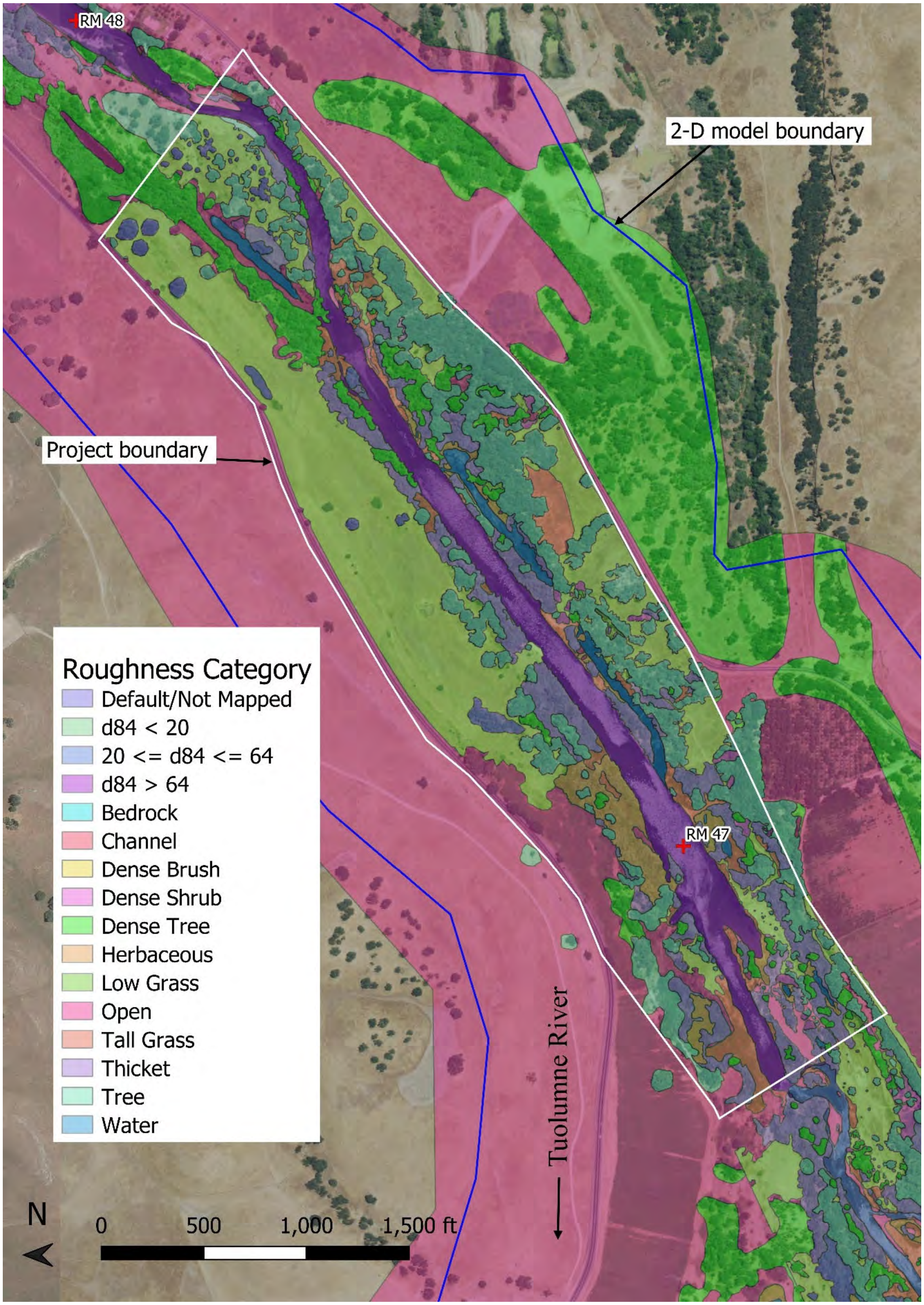


Figure 28. Manning's n roughness polygons with categories assigned from vegetation and substrate mapping used in the hydraulic model. Zanker Farm Project Area and river miles are shown. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

Table 9. Manning's n roughness factors assigned based on land cover category. Values below are the final roughness factors resulting from the model calibration process.

Category	**Manning's *n***
Default/Not Mapped	0.035
$20 \le D_{84} \le 64$	0.035
$D_{84} < 20$	0.033
$D_{84} > 64$	0.035
Bedrock	0.032
Channel	0.035
Dense Brush	0.060
Dense Shrub	0.070
Dense Tree	0.100
Herbaceous	0.036
Low Grass	0.035
Open	0.040
Tall Grass	0.040
Thicket	0.090
Tree	0.080
Water	0.035

The computational mesh was comprised of 10-ft square cells. This cell size was selected to capture the existing channel geometry with sufficient detail while maintaining manageable run times. Breaklines were added as needed to better define the model mesh along breaks in slope. The full momentum equation set was used to achieve the most accurate results possible.

An important model parameter related to mesh cell size is the computation interval, which defines the size of each iterative time-step. The relationship between computation interval, cell size, and velocity is defined by the Courant condition (Equation 1). For the Zanker Farm model, a computation interval of 6 sec to 10 sec was used, depending on the flow being run, in order to satisfy the Courant condition, with a 10 sec interval used for the calibration flow of 110 cfs. The model domain, mesh size, and roughness factors were kept consistent between the calibration flow and subsequent analysis flows.

Equation 1. Courant condition equation:

$$C = \frac{V\Delta T}{\Delta X} \le 1.0 \ (with\ a \max C = 3.0)$$

Or

$$\Delta T \le \frac{\Delta X}{V} \ (With\ C = 1.0)$$

Where: C = Courant Number

V = Flood wave velocity, or wave celerity (ft/sec)

ΔT = Computational time-step(s)

ΔX = Average cell size (ft)

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, meaning that 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. For the calibration flow of 110 cfs, a stage hydrograph type boundary condition was used at the downstream boundary with a constant stage of 128.588 ft applied, which was the WSE measured at the downstream boundary staff plate at the time calibration data were collected (Table 8). Since a rating curve has not been developed for the gaging pool at the downstream boundary, a normal depth type boundary condition was used for all flow simulations other than the calibration flow.

5.3 Calibration

Calibration criteria from *Standards for Physical Habitat Simulation Studies* (USFWS 2011) were used to provide confidence that hydraulic parameters predicted by the model are reasonably accurate. This document is the best resource available for 2-D hydraulic model setup, calibration, and validation criteria. The pertinent criterion from USFWS (2011) for model calibration is as follows:

> *Calibration is considered to have been achieved when the water surface elevation levels (WSEs) predicted by the 2-D hydraulic model at the upstream transect are within 0.1 ft of the WSE predicted by PHABSIM for the highest simulated flow (or observed at the highest measured flow).*

Calibration as defined above is considered to have been achieved when the water surface elevation predicted by the 2-D hydraulic model at the upstream boundary transect is within 0.1 ft of the water surface elevation predicted by the hydraulic modeling software PHABSIM for the highest predicted flow (or observed at the highest measured flow). This is a reasonable starting point for calibration criterion; however, using one model to calibrate another model is not ideal. Rather, calibration of 2-D hydraulic models should use observed water surface elevations. A minimum of 50 spatially-distributed data points provides a reasonable target. Therefore, the calibration process for the Zanker Farm hydraulic model was modified to provide a higher degree of rigor by using measured rather than modeled water surface elevations. The model-predicted water surface elevation for a known streamflow should be within 0.1 ft of the corresponding observed water surface elevation at the upstream end of the modeled site. In addition, for all measured water surface elevation points, the root mean square error (RMSE) value between measured and predicted should be 0.5 or lower. The RMSE statistic is used as it a measure of the error between two data sets, with lower values indicating less error

The existing conditions model was calibrated using WSE data collected by MA at a flow of 110 cfs. The 59 calibration points were spatially distributed throughout the Zanker Farm Project Area (Figure 29), the area in which hydraulic model results must be most accurate for use in other analyses (e.g., weighted usable area habitat assessment, Section 7.4). These points were imported to HEC-RAS and the observed values were compared to the WSE predicted by the model at each point location. The WSE residuals (predicted value minus observed value) were calculated for each calibration point and the RMSE was calculated for the set of points. To achieve the best possible calibration (i.e., lowest residuals and RMSE), Manning's *n* roughness factors were adjusted to raise or lower predicted WSE as needed (Table 9). Adjustment of roughness factors was done iteratively over a series of calibration flow simulations until the lowest residual values were obtained. Residuals from the final calibration run are plotted in Figure 29.

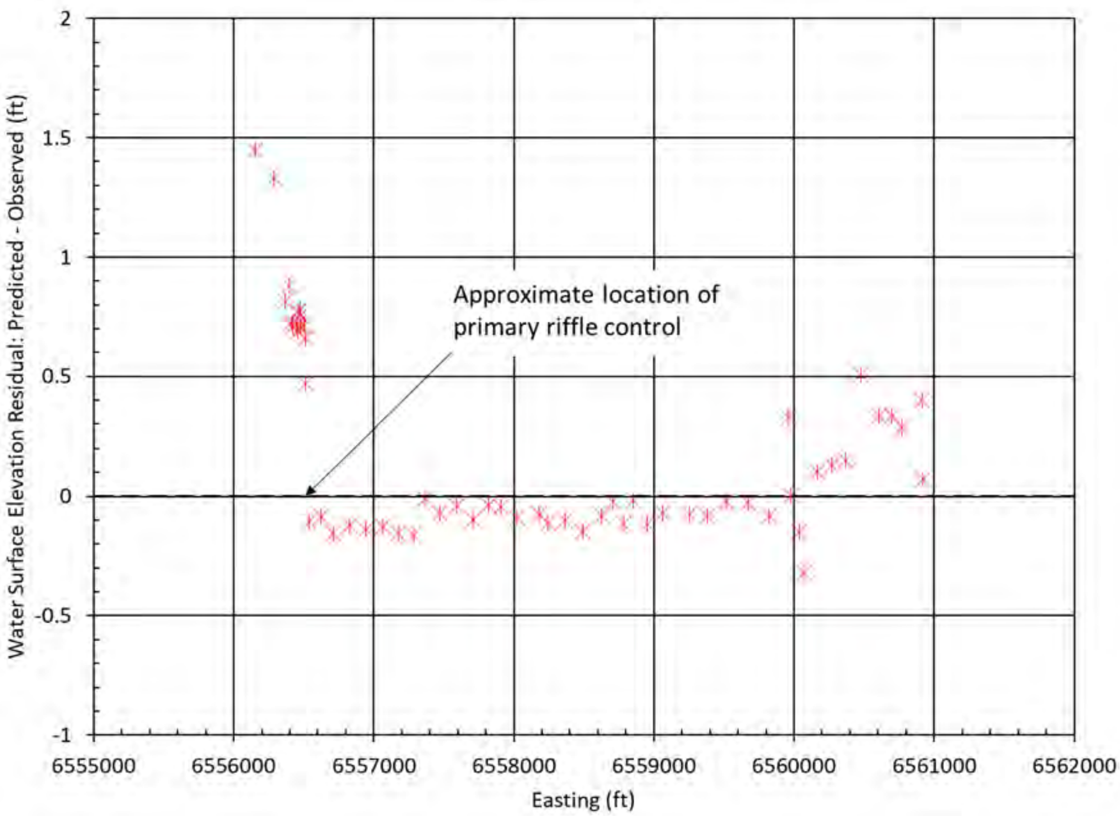


Figure 29. Longitudinal distribution of calibration points plotted by Easting coordinate, showing residual error between predicted and observed water surface elevations from downstream (left) to upstream (right).

The residual of the upstream-most calibration point is 0.072 ft, which satisfies the calibration criterion of 0.1 ft or less. However, calibration points were only collected within the Zanker Farm Project Area and not all the way to the upstream boundary of the hydraulic model. Therefore, this is not the strongest indicator of model calibration, and RMSE is likely a better indicator of calibration.

The RMSE of the set of 59 calibration points is 0.456 ft, which satisfies the calibration criterion of 0.5 or lower. While this is satisfactory, RMSE is improved if only the points within the project area are included in calculation of this statistic. The 15 calibration points at the downstream (left) end have noticeably higher residuals, on the order of 0.5 ft to almost 1.5 ft (Figure 29). These points are downstream of the primary riffle control for the project area (Figure 22). This riffle control was surveyed in detail in 2021, meaning that both modeled hydraulics upstream and observed WSE points upstream of the riffle are representative of present-day conditions. Below the riffle, modeled hydraulics are controlled by the next hydraulic control downstream, which falls outside of the 2021 bathymetry survey extent. Therefore, the WSE in this section of river is controlled by 2005 bathymetry data, which is not as representative of present-day conditions, as channel features and elevations have likely evolved since the 2005 survey. This explains high WSE residuals below the Zanker Farm primary riffle control. Using only the 44 calibration points upstream of the riffle control results in a RMSE of 0.185 ft, indicating a much closer calibration within the project area.

5.4 Modeling Results

The calibrated hydraulic model was used to simulate additional flows and generate depth, velocity, and WSE results for use in a salmonid habitat analysis (Section 7.4), zonal vegetation analysis (Section 6.2.3), and 100-year flood analysis of existing conditions (Section 5.5). The magnitude, recurrence, and duration of flows were selected based on their relevance to these analyses (Table 10). Example hydraulic depth and shear stress model results from select flows in Table 10 are shown in Figure 30 through Figure 32.

Table 10. List of hydraulic model flows used for habitat, vegetation, and 100-year flood 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	Sep–Nov low flow period min $Q_{1.5}$ 21-day duration, growing season	Hydrograph component analysis conducted for riparian planting The need for defining minimum flows is described in Bair et al. (2021)
110	Calibration flow	Flow during MA calibration data collection
150	Low range of spawning flows Q_2 21-day duration, seed dispersal period	Restoration Plan Table 2-5 (M&T 2000); Flow duration analysis
300	High range of spawning flows Sep–Nov low flow period "avg" Roughly $Q_{2.5}$ 21-day duration during juvenile rearing period Proposed minimum flow under new FERC license	Flow duration analysis Hydrograph component analysis conducted for riparian planting Restoration Plan Table 2-5(M&T 2000); FERC relicensing document
633	Roughly Q_4 21-day duration during juvenile rearing period Provides reasonable target for design benches	Flow duration analysis
800	Index habitat flow	Selected to improve shape of habitat curve
1,130	Q_5 30-day duration for juvenile rearing period Approximate floodplain inundation threshold Provides reasonable target for design benches	Flow duration analysis Lower Tuolumne Instream Flow Study (Stillwater Sciences 2013a)
1,580	Q_5 21-day duration for juvenile rearing period Provides reasonable target for design benches	Flow duration analysis
3,000	Low threshold for bed mobility Low magnitude pulse flow Approximate $Q_{1.5}$ post-NDPP	Coarse Sediment Management Plan for Lower Tuolumne River Figure 21 (M&T 2004b) Restoration Plan Section 3.2.2 (M&T 2000)
5,400	Flood control release bench Channel forming flow Moderate magnitude winter power generation flow	Restoration Plan Section 3.2.2 (M&T 2000)

Flow (cfs)	Description	Source/Analysis/Citation
7,050	Waters of US/state based on current ACOE assessment Close to high threshold for bed mobility (6,880 cfs (M&T 2000))	Clean Water Act Section 401 Water Quality Certification for Tuolumne River
9,600	Index habitat flow	Selected to improve shape of habitat curve
11,500	Q_{10}	Flood frequency analysis Bulletin 17C (England et al. 2018)
44,000	Q_{100}	Central Valley Flood Protection Board (https://gis.bam.water.ca.gov/bam/)

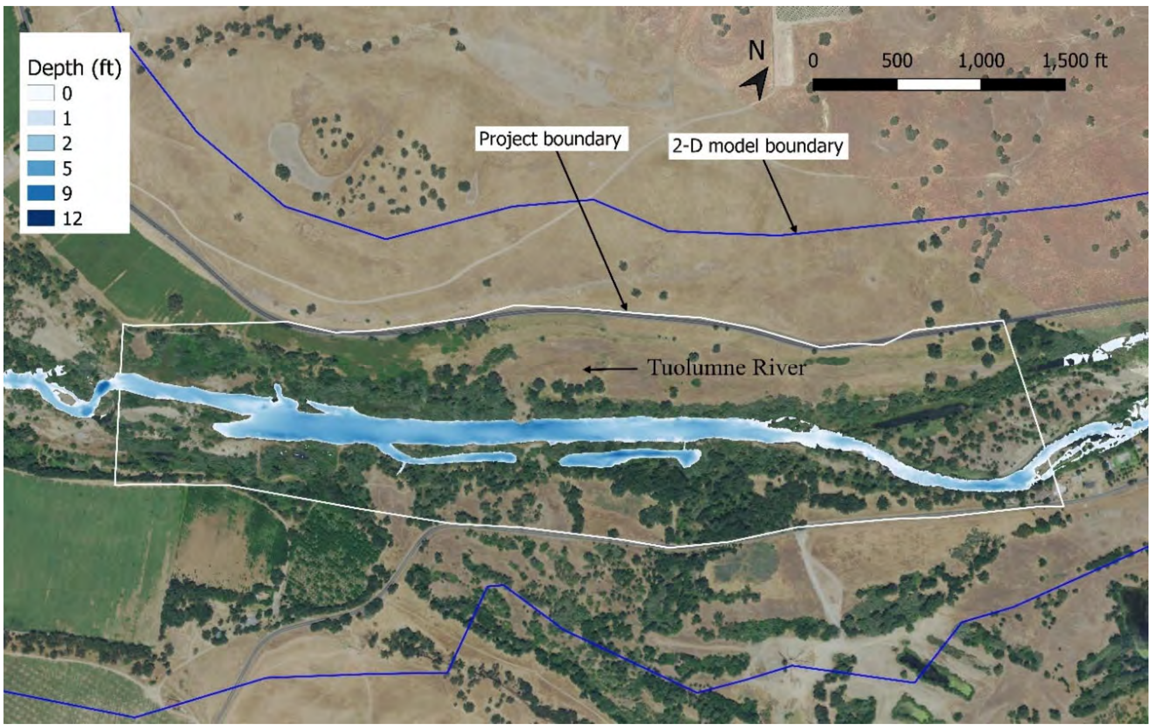


Figure 30. Hydraulic model results for depth at the calibration flow of 110 cfs. The dredger tailing sloughs on the south side of the river are active at this flow. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

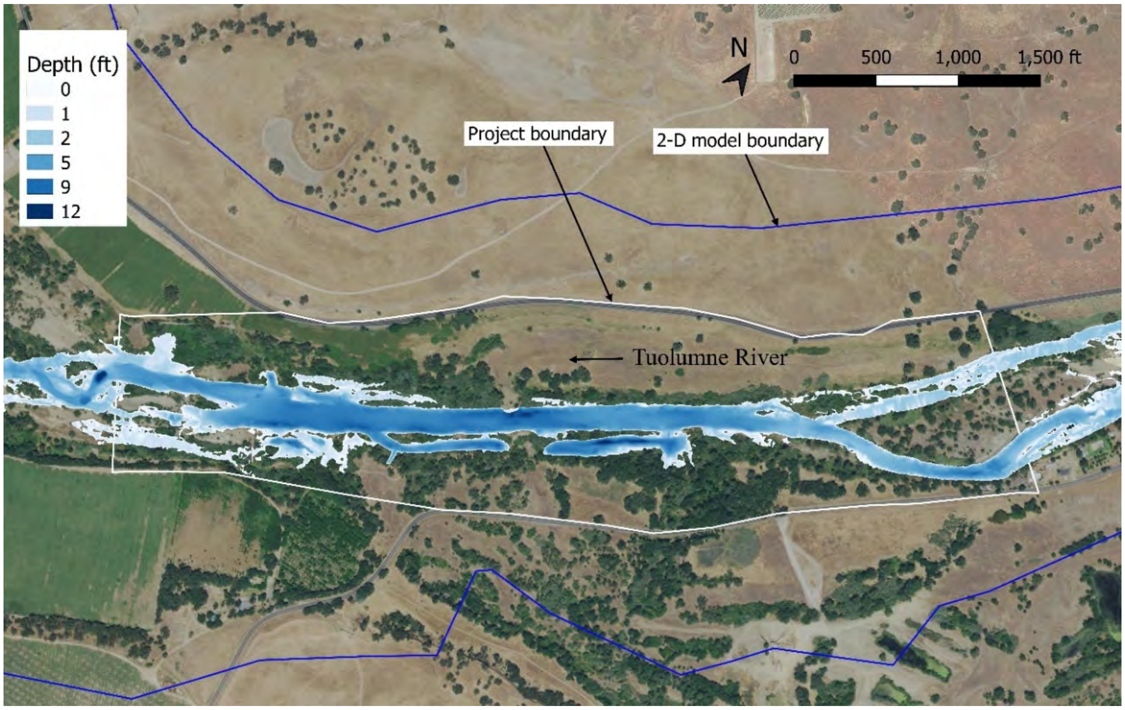


Figure 31. Hydraulic model results for depth at a flow of 1,130 cfs. This flow is the Q_5 30-day duration flow for the juvenile salmonid rearing period and the approximate floodplain inundation threshold. Initial floodplain inundation can be seen in the model results at the downstream end of the Zanker Farm Project Area. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

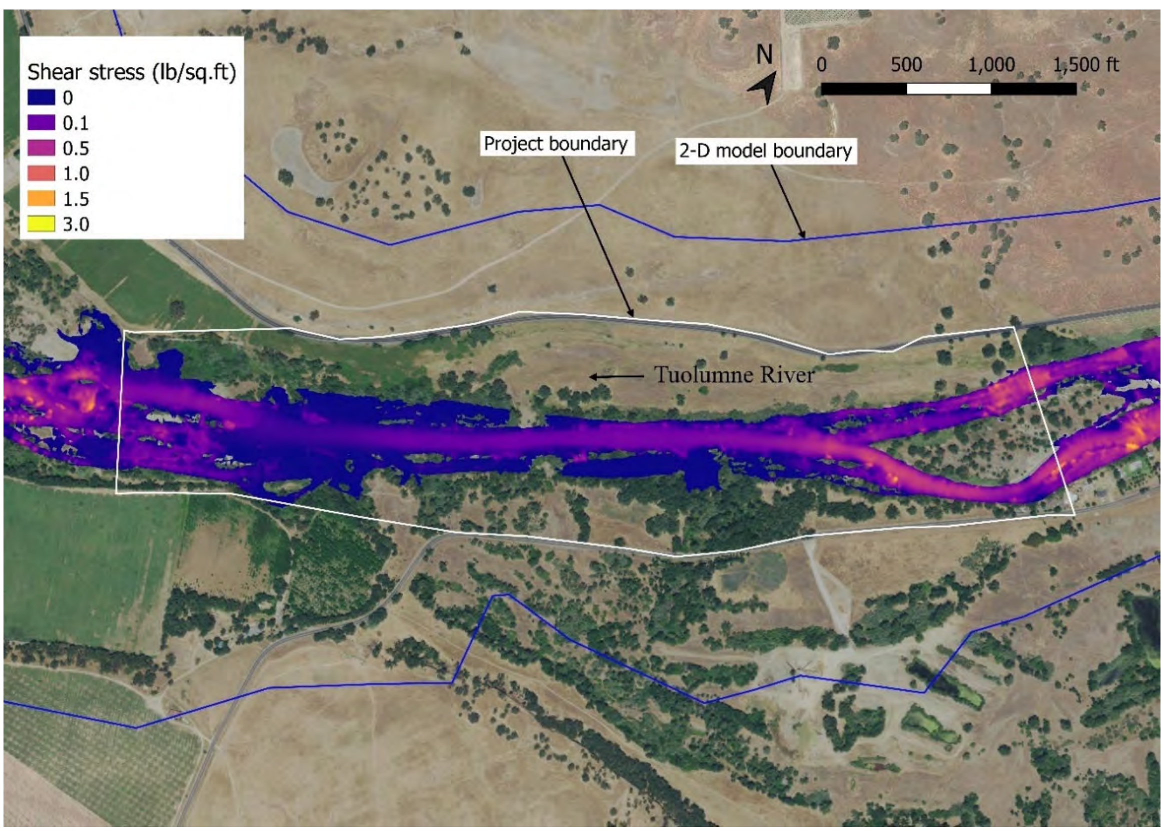


Figure 32. Hydraulic model results for shear stress at a flow of 3,000 cfs. This flow is the low threshold for bed mobility. National Agriculture Imagery Program (NAIP) 2020 and Google Satellite aerial images.

5.5 Floodway Impacts Evaluation

The proposed project area falls within the 100-year floodplain Zone A for the Tuolumne River. This section presents a preliminary floodway analysis for the existing site conditions. Hydraulic modeling was used to establish a baseline of existing site hydraulics under 100-year flood conditions.

The calibrated hydraulic model for the Zanker Farm Project Area was used as the basis for floodway modeling and was modified to simulate the 100-year flood with appropriate detail while maintaining reasonable run times. The cell size for the 2-D model area was increased from 10-ft cells to 20-ft cells. This was done to reduce the computational demands of running the 100-year flood simulation, since the level of detail afforded by a 10-ft grid is not necessary in a floodway evaluation. The computation interval was increased to 10-sec to account for this change to the grid size with respect to the Courant condition. The model mesh was refined by the addition of breaklines on the south side of the Tuolumne River to better define the berms along Lake Road. Manning's *n* roughness values were assigned by land cover type and boundary conditions for the model were applied as described in Section 5.2. Hydrologic input data for the model were based on the 100-year peak streamflow for the Tuolumne River in the Project Area (44,000 cfs) as referenced by the Central Valley Flood Protection Board.

Existing conditions depth results were plotted with a polygon shapefile of the Federal Emergency Management Agency (FEMA) 100-year floodplain map (Figure 33) to compare the floodway areas of the two data sources. The 2-D hydraulic modeling results indicate that at a flow of 44,000 cfs (the peak 100-year flow), the model provides a close representation of the 100-year flood extents as shown in the FEMA flood map for the Project Area. There are, however, some discrepancies that should be noted between the two floodway extents that are called out in Figure 33. On the left bank towards the upstream end of the project area, the FEMA map shows inundation outside of the project boundary and into the Joe Domecq Wilderness Area. In the middle of the site on the left bank at the remnant haul road, the hydraulic model predicts that the floodway will reach Highway 132 while the FEMA map does not extend quite that far. Lastly, the cultivated fields on either side of the river at the downstream end of the project are shown as part of the floodway in the FEMA map, while the hydraulic model does not predict high enough WSE to inundate these areas.

The FEMA map was published in 2008, so the discrepancies with the Zanker Farm hydraulic model are most likely due to differences in topography and modeling techniques. Since the hydraulic model uses 2012 LiDAR and 2021 bathymetry within the Zanker Farm Project Area, the conditions represented in the modeling terrain are more up-to-date and reflective of any potential changes to the channel or floodplains that may have occurred since 2008. Additionally, the FEMA map was generated using a 1-D hydraulic modeling approach. It is possible that cross-section spacing, roughness factors, or other model parameters may be responsible for the difference in floodway area from the 2-D modeling results. Since the 2-D model for Zanker Farm is intended to provide a baseline of the 100-year flood for future comparative analysis and not to re-establish floodway insurance rate maps, flood zone designation, or similar analyses, the discrepancies with the FEMA map are acceptable in this case.

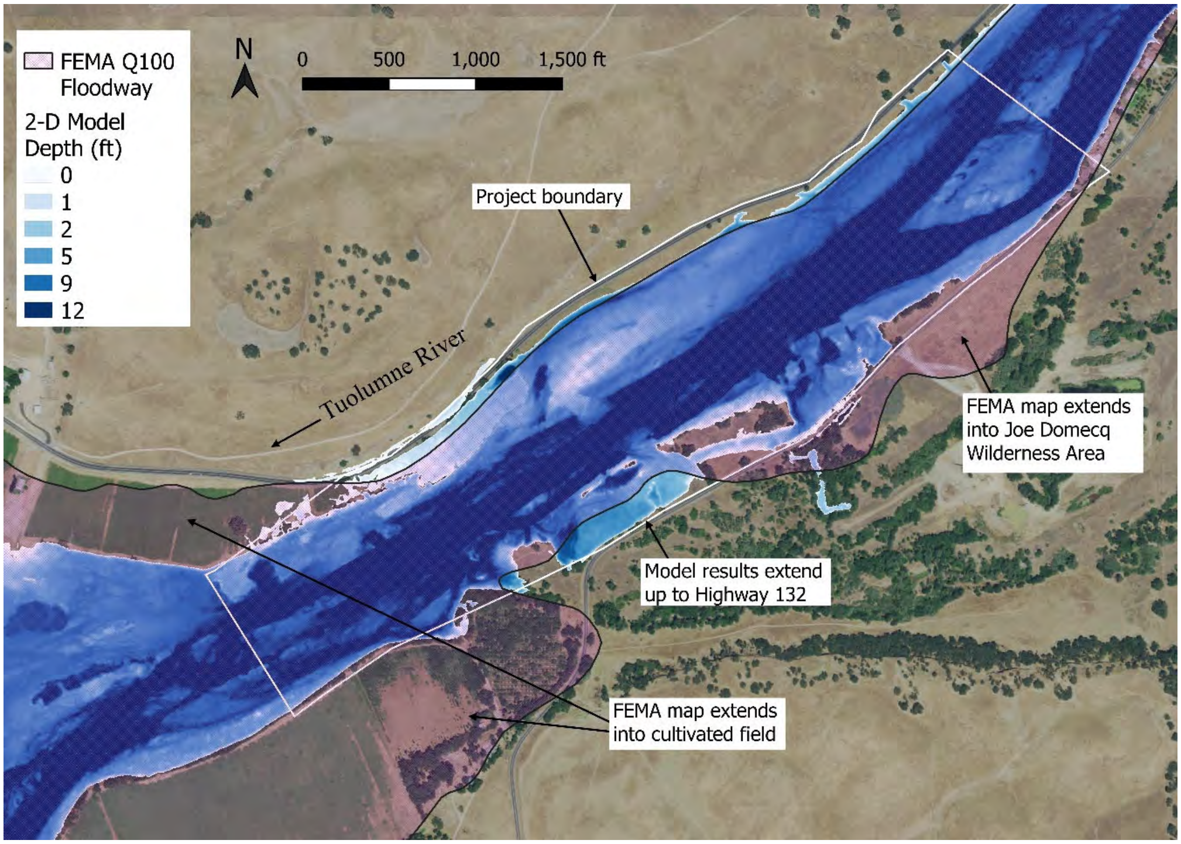


Figure 33. FEMA 100-Year floodplain map overlaid with two-dimensional hydraulic modeling results for flow depth within the project reach under existing conditions for a flow of 44,000 cfs.

6 VEGETATION

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.

Vegetation mapping was used to describe the vegetation communities in the Project Area. Vegetation mapping created a high-resolution map of existing mesic and adjacent xeric vegetation currently within the project boundary and serves as a baseline against which to compare future conditions. The vegetation map served as the basis for quantifying existing vegetation patch size, mapped cover type area, and overall corridor diversity within the Zanker Farm Project Area. The vegetation map was used to describe 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 will be used in the future 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.

A 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 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 34, Figure 35). 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.

6.1 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.

6.1.1 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 2005, 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).

6.1.1.1 Mapping Boundary

The project boundary area is 224.1 acres. Vegetation within the project boundary 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 boundary to anticipate potential future actions or where a stand of vegetation continued beyond the boundary. Within the project boundary, 176 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 five acres that were outside of the project boundary (Figure 34, Figure 35).

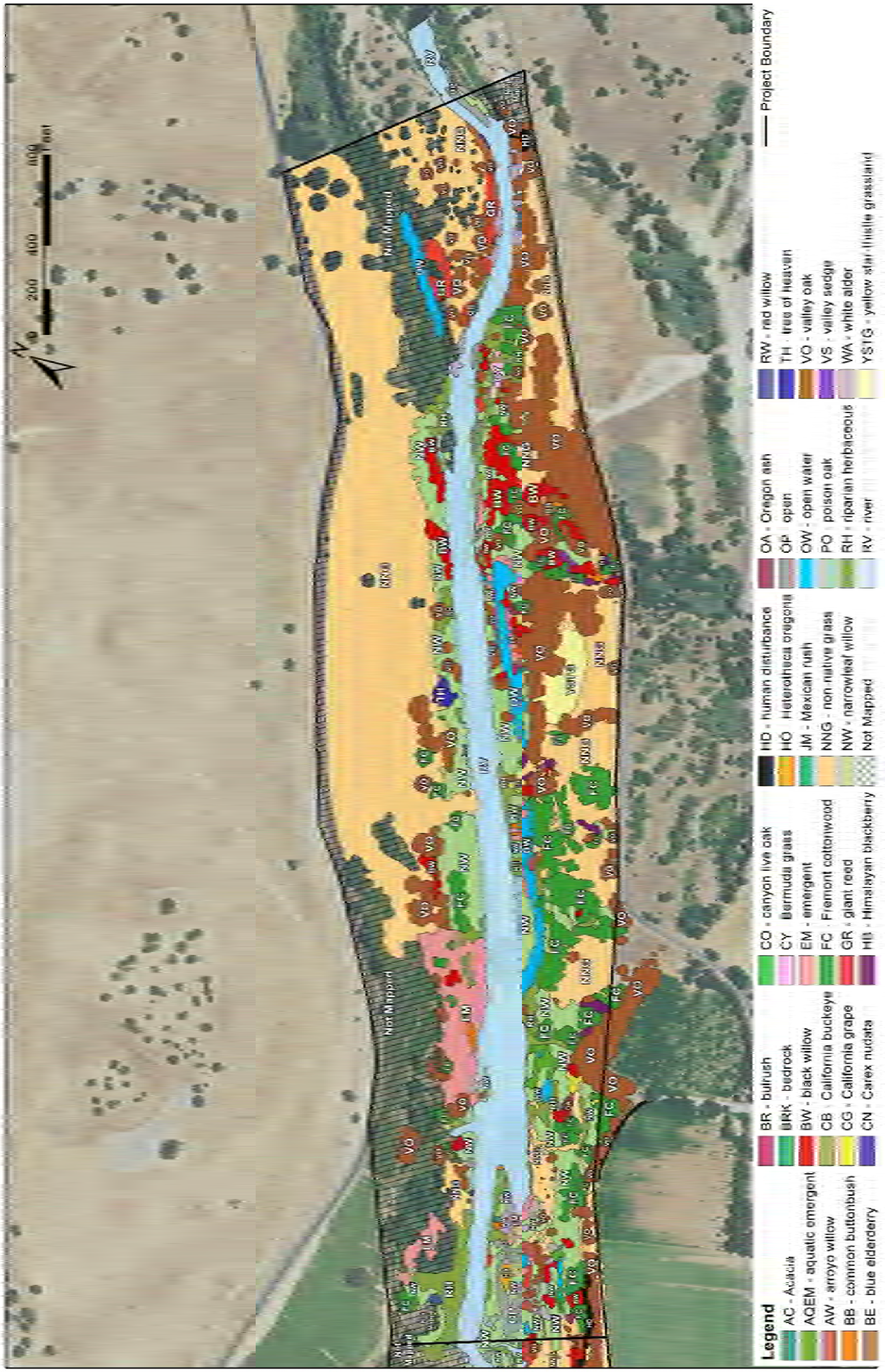


Figure 34. Existing vegetated and unvegetated cover types mapped in 2021 in the Zanker Farm Project Area.

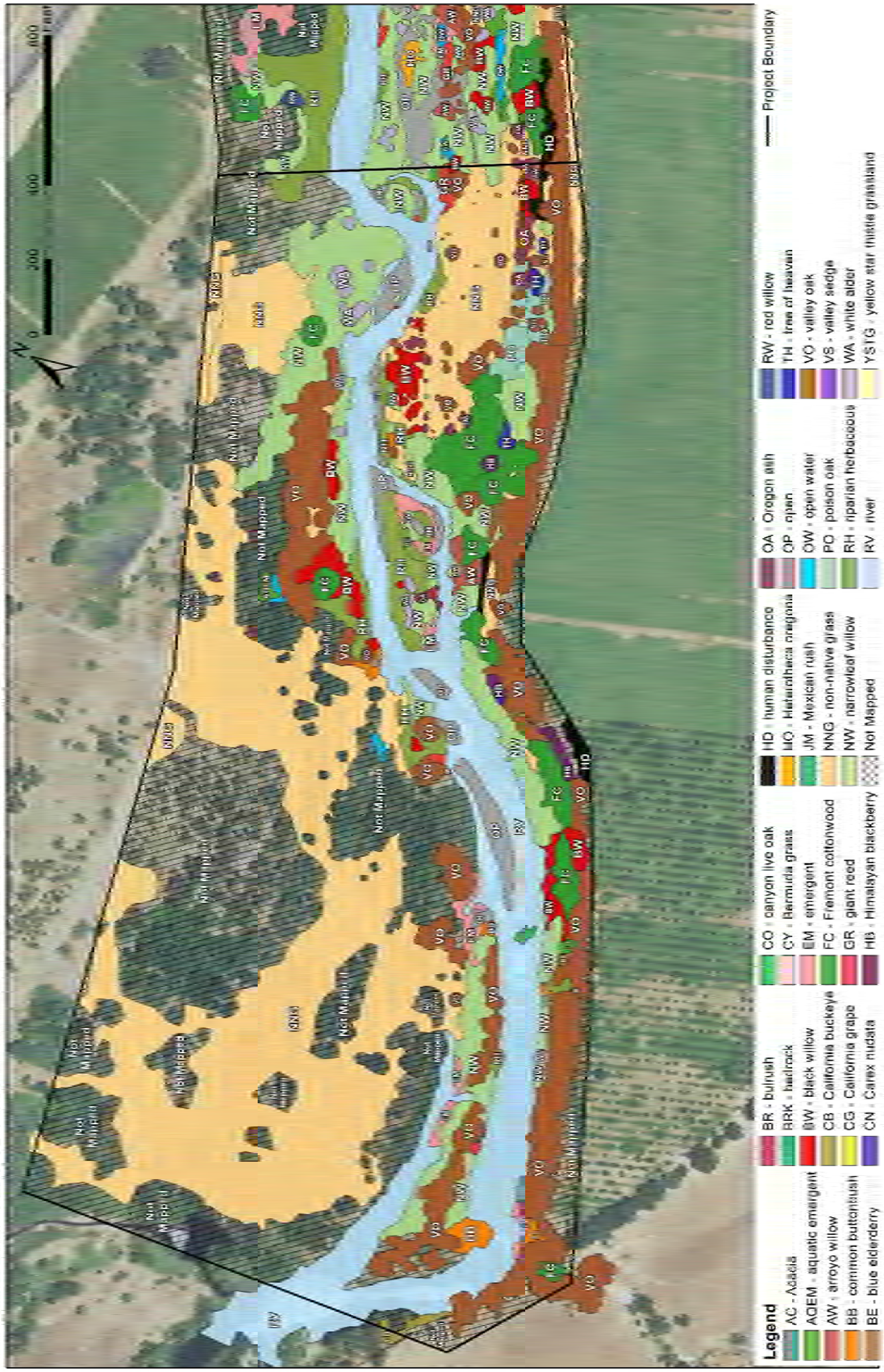


Figure 35. Existing vegetated and unvegetated cover types mapped in 2021 just downstream of the Zanker Farm Project Area, extending to the downstream boundary of the Zanker Farm.

6.1.1.2 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 zonal type based on professional judgement. The GIS database was queried, and the aerial extent of different cover types was evaluated.

6.1.1.3 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 system-wide 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.

6.1.1.4 Uncertainty and Estimation of Error

There are several sources of potential variability that may affect the accuracy of areas quantified by mapping. The accuracy of a polygon and the associated attributes were determined by many factors in the field. Human error could potentially affect how a polygon was drawn, as well as how the cover type was assigned. Mapping accuracy varies, and the effect is difficult to estimate. 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.

6.1.2 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 persist 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.

A Detrended Digital Elevation Model (dtDEM) was developed using the Zanker Farm existing condition terrain (Section 5.1.3) and a HEC-RAS modeled 80 cfs water surface elevation (WSE). The 80 cfs flow is considered to be in the range of the lowest seasonal flows in drier years. 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, cross sections were placed at hydraulic control locations where noticeable changes in water surface slope occurred (Figure 36). Cross sections run perpendicular to the channel centerline, then once beyond the channel, run perpendicular to the valley. The mean WSE value at each cross section was calculated by averaging the modeled WSE points between the left bank and right bank (i.e., the low flow wetted channel). Points were then placed on each cross-section line at intervals of 500 ft and the mean WSE value assigned to these points, thereby extrapolating the low flow channel water surface elevation to locations along the cross section away from the low flow channel. Using an ARC-GIS tool called "natural neighbor," the elevations for locations between points were interpolated to create a surface of WSE points that extends from upstream to downstream and outwards across the valley (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.

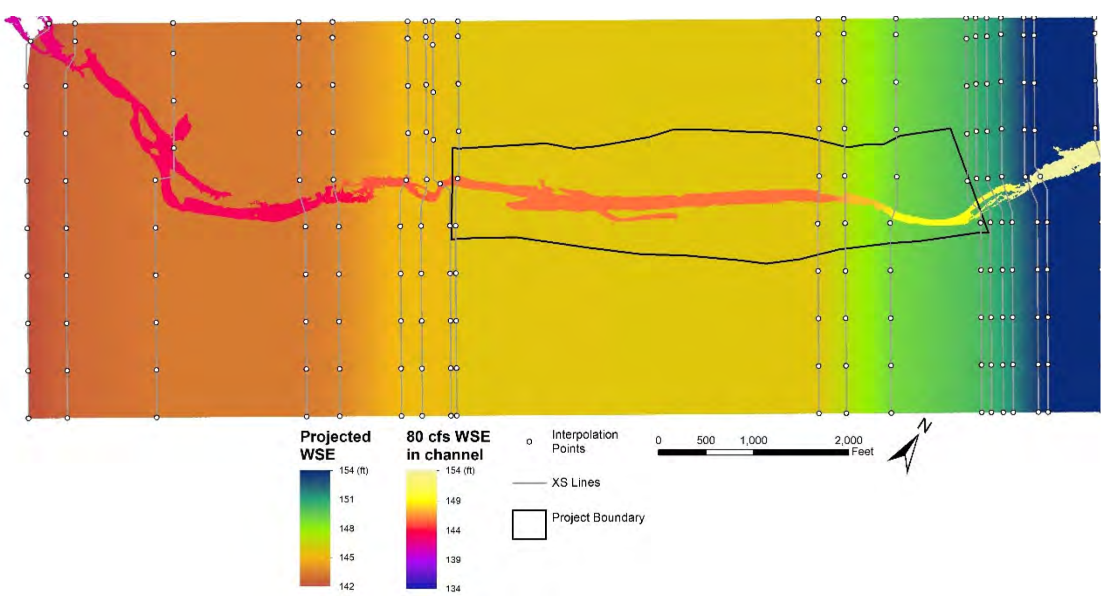


Figure 36. Interpolation of in-channel WSE data across valley bottom.

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.

6.1.3 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. 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).

6.2 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. Four vegetation zones and one water zone were defined: channel margin, mesic, mesic–xeric transition, xeric, and water.

6.2.1 Vegetation Mapping and Classification

Vegetation mapping within the project boundary included mesic vegetation along the lower Tuolumne River and upland xeric vegetation. Twenty-nine vegetated and five unvegetated cover types were mapped in the 224.1-acre project area in 2021 (Figure 34, Figure 35, Table 11). Non-native grassland was the most abundant cover type within the project area, covering 64 acres. The next six most abundant vegetated cover types included: 26.4 acres of valley oak (*Quercus lobata*), 19.6 acres of narrowleaf willow (*Salix exigua*), 10.4 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.

6.2.1.1 Sensitive Natural Communities

Natural Communities are described at the alliance or association level for vegetation types in California (MCV, Sawyer et al. 2009). The California Department of Fish and Wildlife (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 12). 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).

Mapped vegetated cover types have been crosswalked to vegetation alliances as defined by the MCV (Sawyer et al. 2009; Table 11). Not all vegetated cover types could be crosswalked 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.

Table 11. Area of vegetated and unvegetated cover types within the project boundary. Cover types in red are dominated by non-native species.

Cover Type	Vegetation Alliance	CDFW Global/ State Rank	Area (Ac)
Acacia sp.	no corresponding alliance	No/None	0.01
Aquatic emergent	Numerous aquatic emergent alliances may apply within this group.	N/A	0.51
Arroyo willow	*Salix lasiolepis* Shrubland Alliance Arroyo willow thickets	G4/S4	0.35
Common buttonbush	*Cephalanthus occidentalis* Shrubland Alliance Button willow thickets	G5/S2	0.68
Blue elderberry	no corresponding alliance	No/None	0.04
Bulrush	*Schoenoplectus* (*acutus*, *californicus*) Herbaceous Alliance Hardstem and California bulrush marshes	GNR/S3S4	0.04
Bedrock	N/A	N/A	0.04
Black willow	*Salix gooddingii–Salix laevigata* Forest and Woodland Alliance Goodding's willow–red willow riparian woodland and forest	G4/S3	4.53
California buckeye	*Aesculus californica* Forest and Woodland Alliance California buckeye groves	G3/S3	0.08
California grape	*Vitis arizonica–Vitis girdiana* Shrubland Alliance Wild grape shrubland	G3/S3	0.17
Channel	N/A	N/A	26.14
Carex nudata	*Carex nudata* Herbaceous Alliance Torrent sedge patches	G3/S3	0.02
Canyon live oak	*Quercus chrysolepis* (tree) Forest and Woodland Alliance Canyon live oak forest and woodland	G5/S5	0.03
Bermuda grass	Mediterranean California Naturalized Annual and Perennial Grassland Group (several corresponding alliances)	N/A	0.18
Emergent	Numerous alliances may apply within this group	N/A	4.79
Fremont cottonwood	*Populus fremontii–Fraxinus velutina–Salix gooddingii* Forest and Woodland Alliance Fremont cottonwood forest and woodland	G4/S3	10.38
Giant reed	*Phragmites australis–Arundo donax* Herbaceous Semi-Natural Alliance Common and giant reed marshes	GNR/SNR	1.21
Himalayan blackberry	*Rubus armeniacus–Sesbania punicea–Ficus carica* Shrubland Semi-Natural Alliance Himalayan blackberry–rattlebox–edible fig riparian scrub	GNR/SNR	0.63
Human disturbance	N/A	N/A	0.53

Cover Type	Vegetation Alliance	CDFW Global/ State Rank	Area (Ac)
Heterotheca oregona	*Heterotheca* (*oregona*, *sessiliflora*) Herbaceous Alliance Goldenaster patches	G3/S3	0.10
Non-native grass	Mediterranean California Naturalized Annual and Perennial Grassland Group (several corresponding alliances)	N/A	64.31
Not mapped	N/A	N/A	47.98
Narrowleaf willow	*Salix exigua* Shrubland Alliance Sandbar willow thickets	G5/S4	19.63
Oregon ash	*Fraxinus latifolia* Forest and Woodland Alliance Oregon ash groves	G4/S3	0.54
Open	N/A	N/A	2.16
Open water	N/A	N/A	2.79
Mexican rush	*Juncus arcticus* (var. *balticus*, *mexicanus*) Herbaceous Alliance Baltic and Mexican rush marshes	G5/S4	0.07
Poison oak	*Toxicodendron diversilobum* Shrubland Alliance Poison oak scrub	G4/S4	0.47
Riparian herbaceous	Numerous alliances may apply within this group	N/A	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
Tree of heaven	*Eucalyptus* spp.–*Ailanthus altissima–Robinia pseudoacacia* Woodland Semi-Natural Alliance Eucalyptus–tree of heaven–black locust groves	GNA/SNA	0.33
Valley oak	*Quercus lobata* Forest and Woodland Alliance Valley oak woodland and forest	G3/S3	26.45
Valley sedge	*Carex barbarae* Herbaceous Alliance White-root beds	G2?/S2?	0.07
White alder	*Alnus rhombifolia* Forest and Woodland Alliance White alder groves	G4/S4	1.15
Yellow star-thistle grassland	*Brassica nigra–Centaurea* (*solstitialis, melitensis*) Herbaceous Semi-Natural Alliance Upland mustard or star-thistle fields	GNA/SNA	1.23
		Total	224.14

Table 12. 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

6.2.2 Detrended Digital Elevation Model

Five percent of the existing ground dtDEM within the 224.1-acre project boundary was less than 1.5 ft above the 80 cfs Tuolumne River water surface elevation; 40% occurred between 1.5 and 7.5 ft; 19% occurred between 7.5 and 12 ft; and 22% occurred on ground surfaces that were greater than 12 ft (Figure 37).

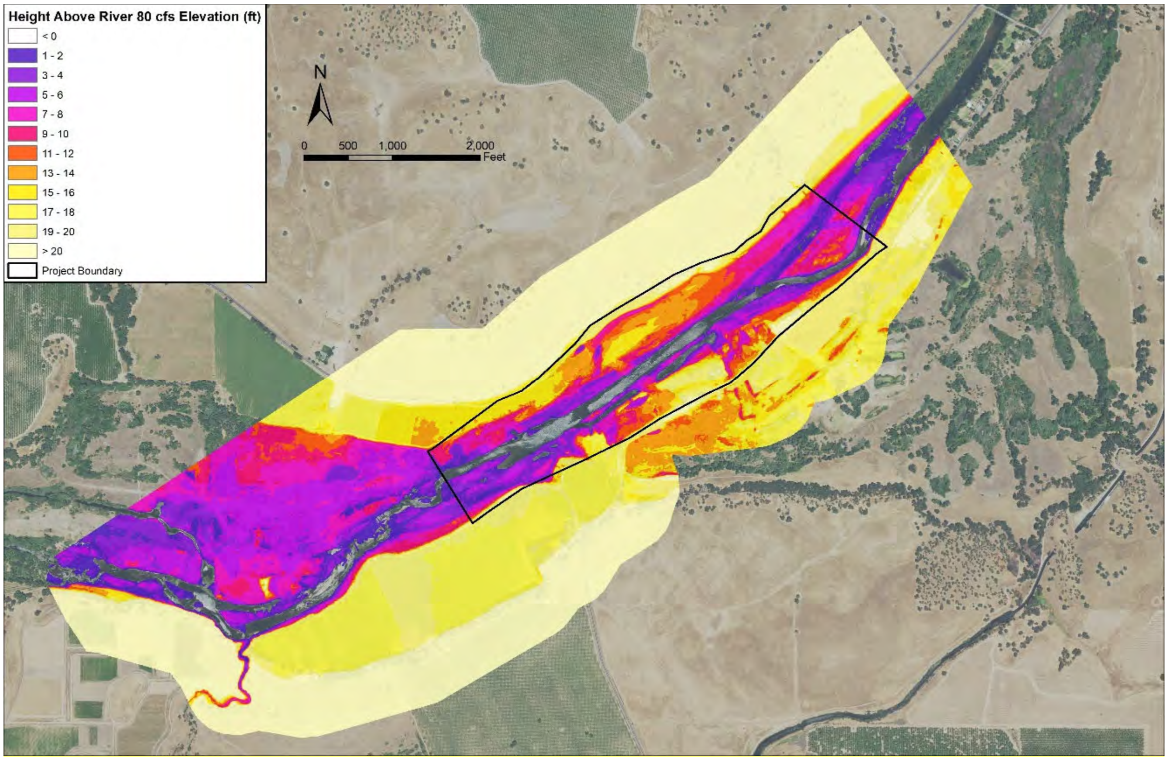


Figure 37. Detrended Digital Elevation Model (dtDEM) of the project area.

6.2.3 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 38). 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).

Four vegetation zones and one aquatic zone were defined based on the median elevations of different cover types (Figure 38, Table 13, Figure 39). Zonal boundaries were based on the interpretation of the box plot data (Figure 39). 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 14, Figure 40).

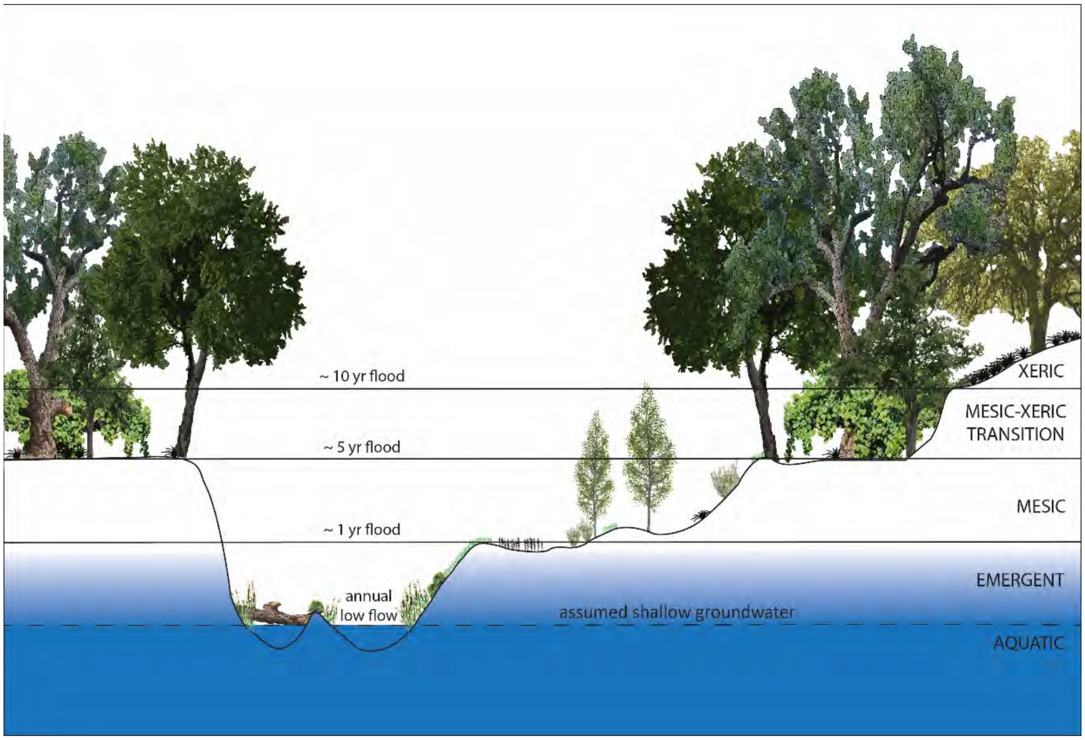


Figure 38. Vegetation zones used as a basis for revegetation design.

Table 13. Four 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
Channel Margin	0–1.5 ft	All year to multiple months	This zone is in constant contact with the shallow groundwater through capillarity or direct inundation
Mesic	1.5 to 7.5 ft	Many weeks to days	This zone is in frequent contact with the shallow groundwater through capillarity or direct inundation
Mesic–Xeric Transition	7.5 to 12 ft	Days to hours	This zone is infrequently in contact with the shallow groundwater through capillarity or direct inundation
Xeric	> 12 ft	Hours to never	This zone is rarely in contact with the shallow groundwater through capillarity or direct inundation

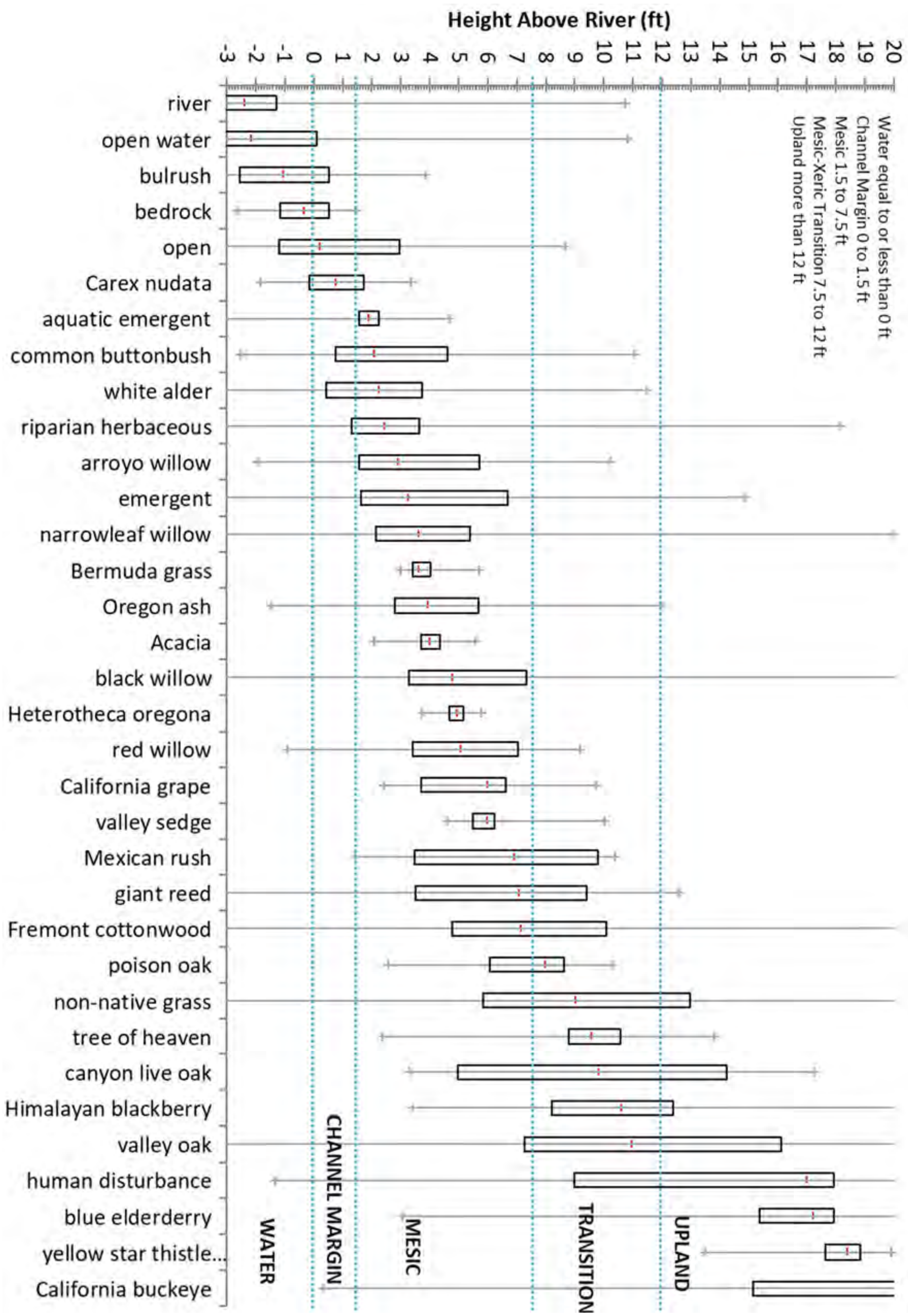


Figure 39. Box plots illustrating the median height and range of heights above the 80 cfs water surface elevation for mapped cover types. The red dash is the median elevation of the cover type. The box is defined by the 25th and 75th quartiles, and the grey lines show the range in data between minimum and maximum height. The height in the chart is truncated to 20 ft.

Table 14. Percent area of existing vegetation zones within the project boundary.

Zone	Acres	Percent of Project Area
Water	31.5	14.0%
Channel Margin	11.1	4.9%
Mesic	89.3	39.8%
Mesic–Xeric Transition	43.4	19.4%
Xeric	48.9	21.8%
Total	**224.1**	**100%**

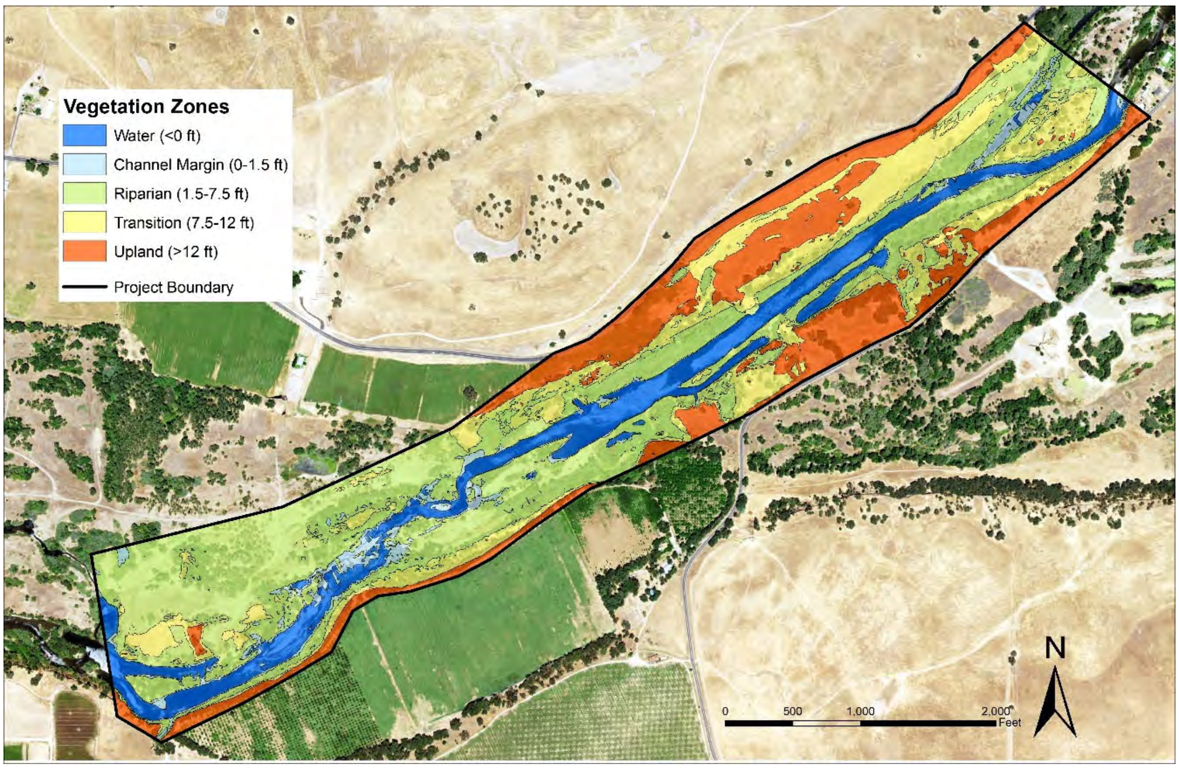


Figure 40. Existing vegetation zonation within the Zanker Farm.

6.2.4 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, mesic, mesic–xeric transition, and xeric zones in the project area. Vegetation and sensitive natural communities within each zone are described in more detail below.

6.2.4.1 Water

Four cover types were mapped within the zone defined as water (Figure 39). These cover types occurred at elevations that were lower than or equal to the 80 cfs water surface (Figure 39) and included river, bedrock, open water, and bulrush (*Schoenoplectus* sp.). Areas mapped as open water were typically associated with pond areas with very little vegetation. The mapped bulrush cover type corresponds to the hardstem and California bulrush marshes (*Schoenoplectus* (*acutus, californicus*) Herbaceous Alliance). The association within the Alliance was not determined. However, all associations except for *Schoenoplectus acutus*–common reed (*Phragmites australis*) are considered Sensitive. No giant reed was observed within the site, and the bulrush cover type does not correspond to that association. Therefore, we assume the hardstem and California bulrush marshes are considered Sensitive.

6.2.4.2 Channel Margin

The channel margin zone occurs between 0 and 1.5 ft above the fall water surface (Figure 39). 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. The channel margin covered 4.9% of the project area (Figure 34, Figure 35, Table 14).

6.2.4.3 Mesic Zone

Eighteen cover types were mapped within the mesic zone between 1.5 and 7.5 feet above the 80 cfs water surface (Figure 39). The mesic riparian zone covered 39.8% of the project area (Table 14). Three broad cover types within the mesic zone were composed of groups of herbaceous species. The three broad groups include 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 native species: nutsedge (*Cyperus eragrostis*), field mint (*Mentha arvensis*), and spikerush (*Eleocharis macrostachya*).

The riparian herbaceous cover type occurred throughout the mesic 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*).

Several cover types mapped in the mesic zone corresponded to Sensitive Natural Communities: button willow thickets (*Cephalanthus occidentalis* Shrubland Alliance); 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); 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 mesic riparian zone that did not correspond to Sensitive Natural Communities, the narrowleaf willow and white alder (*Alnus rhombifolia*) cover types. Three non-native cover types occur in the mesic riparian zone including giant reed (*Arundo donax*), Bermuda grass (*Cynodon dactylon*), and Acacia (*Acacia* sp.).

6.2.4.4 Mesic–Xeric Transition Zone

Six cover types were mapped within the mesic–xeric transition zone between 7.5 to 12 ft above the 80 cfs water surface (Figure 39). The mesic–xeric transition zone covered 19.4% of the project area (Table 14). 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*)

6.2.4.5 Xeric Zone

Four cover types were mapped within the upland zone which occurs at elevations greater than 12 ft above the 80 cfs water surface (Figure 39). The upland zone covered 21.8% of the project area (Table 14). One Sensitive Natural Community occurs within the upland zone, California buckeye groves (*Aesculus californica* Forest and Woodland Alliance). The blue elderberry cover type also occurs 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 10). One non-native cover type, yellow star-thistle grassland, occurs in the upland zone. The human disturbance cover type, which generally has sparse to no vegetation, also occurs in this zone.

6.3 Non-native Invasive Plants

Several non-native invasive plant species occur within the project area and six non-native invasive cover types were mapped (Figure 41). Mapped cover types included: Acacia (*Acacia* sp.), giant reed grass, Himalayan blackberry, tree of heaven, common fig (*Ficus carica*), and yellow star-thistle 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 15 along with non-native invasive plants that have been observed by McBain Associates on the lower Tuolumne River previously (M&T 2000).

Several 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, 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 *Lower Tuolumne River Restoration Plan* (M&T 2000). If these species are observed within the project area, they should also be removed when feasible.

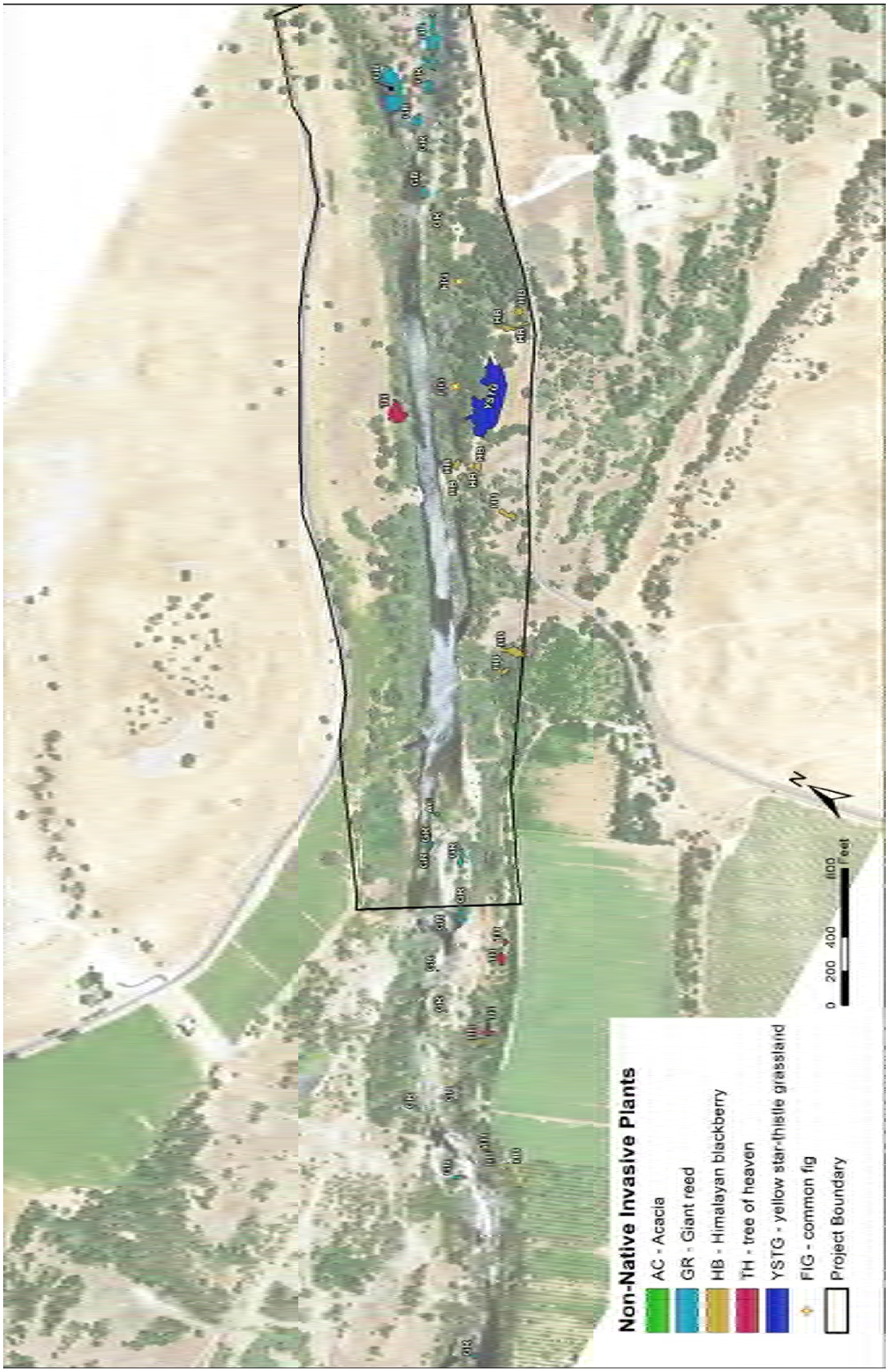


Figure 41. Cover types dominated by invasive plant species were mapped in July 2021. Generally, only large patches of invasive plant species were mapped. Individual trees were occasionally mapped but mapping for invasive species is not comprehensive.

Table 15. 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 are listed below along with their Cal-IPC Inventory Rank.

Common Name	**Scientific Name**	**Cal-IPC Inventory 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)	LTR Restoration Plan
Eucalyptus sp.	*Eucalyptus* sp.	Variable by species (Limited to Watch)	LTR 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	LTR Restoration Plan
Yellow flag iris	*Iris pseudacorus*	Limited	Observed in field
Floating water primrose	*Ludwigia peploides*	High	Observed in field

7 FISHERIES

Salmonid restoration through improvement of spawning and rearing habitat, and reduction of the non-native predator population, is a key objective of the Zanker Farm restoration project. The Tuolumne River is host to many native fish species, including resident (Rainbow Trout) and anadromous (Central Valley steelhead) forms of *Oncorhynchus mykiss*, Central Valley fall-run Chinook Salmon (*Oncorhynchus tshawytscha),* Hardhead (*Mylopharodon conocephalus*), Hitch (*Lavinia exilicauda*), Sacramento Pikeminnow (*Ptychocheilus grandis*), Sacramento Sucker (*Catostomus occidentalis*), and Sculpin (*Cottidae*). Chinook Salmon and steelhead are both federally threatened under the state and federal Endangered Species Acts. The resident form of *O. mykiss* is not federally or state listed under Endangered Species Acts but are a species of interest for restoration and conservation. Non-native species consist of Striped Bass (*Morone saxatilis),* Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Bluegill (*Lepomis macrochirus*), Western Mosquitofish (*Gambusia affinis*), and catfish (*Ictaluridae*).

Large-scale anthropogenic activities in the lower Tuolumne River corridor since the California Gold Rush have fundamentally changed the river's habitat and ecological function. Native fish, especially salmonids, have been heavily impacted by anthropogenic changes to the river. The most notable factors were gold mining, dam construction and gravel mining. Gold mining commenced in the 1850s and ended in 1894 when it was banned (Lufkin 1991, NMFS 2014), but the dredged river lacked habitat and spawning gravel (M&T 2000, 2004b). The construction of La Grange and Don Pedro Dams blocked upstream fish passage, reduced natural flows, and limited gravel supply (M&T 2000, M&T 2004b, Stillwater Sciences 2013b). Gravel pit mining also resulted in deep unnatural pools that facilitated the invasion by non-native species, which can outcompete and consume native species (TID and MID 1992, M&T 2000, M&T 2004b).

7.1 Central Valley Fall-run Chinook Salmon

Both spring-run and fall-run Chinook Salmon were historically present in California's Central Valley (Yoshiyama et al. 1996). Spring-run Chinook Salmon were extirpated from the San Joaquin drainage by the late 1940s but are currently being restored by the San Joaquin River Restoration Project. In 2020, 57 adult spring-run Chinook were captured and trucked upstream (Sutphin and Root 2021). In the San Joaquin River system, fall-run Chinook Salmon have declined by more than 90% (Ridgway 2004). Current San Joaquin River system Chinook Salmon populations are supplemented with hatchery-reared fish, and it is estimated that 90% of returning adults are of hatchery origin (TID and MID 2013b). In the Tuolumne River, spring-run Chinook Salmon have been extirpated, but fall-run Chinook persist.

In the Tuolumne River, adult fall-run Chinook Salmon arrive in the upper river near (mostly above Roberts Ferry Bridge) to spawn in early October (TID and MID 2007) ,and peak spawning occurs in November (TID and MID 2013b). Fry emerge from redds once their yolk sacks are absorbed. A large percentage of fry will immediately outmigrate to seek profitable rearing areas further downstream near the mouth or in the San Francisco Bay Delta, while others will remain in the river and rear until they smolt and outmigrate to the ocean. In-river juvenile rearing is estimated to occur from January 1 through mid-May when most of the outmigrating juveniles are detected at either the Waterford (RM 29.5) or Grayson (RM 5.2) rotary screw traps (TID and MID 2005). Juvenile Chinook Salmon in the lower Tuolumne River typically smolt and outmigrate within a year after emergence. However, low numbers of Chinook Salmon may emigrate as yearlings in some years after spending the year in freshwater and smolting the following year (TID and MID 2005).

In the Tuolumne River, adult Chinook Salmon escapement has fluctuated over time, ranging from 40,322 in 1985 to 77 in 1991, but has been on a downward trend since the 1960s (Figure 42). In 2020, only 1,028 returning adult Chinook Salmon were counted (TID and MID 2005, TID and MID 2021). There are numerous factors that have contributed to the decline of Tuolumne River Chinook Salmon, including changes to streamflow, blocked fish passage from La Grange and New

Don Pedro dams, habitat loss from dredging and gravel mining (M&T 2000), hatchery straying (Sturrock et al. 2020), climate change, declining ocean and delta conditions, blocked fluvial geomorphology for sediment transport, and the increased population size of warmwater predators directly consuming juvenile Chinook Salmon (TID and MID 2013b, Michel et al. 2020).

Historically, Chinook Salmon adult escapement numbers were related to spring flows of the year they outmigrated as juveniles (Figure 42), similar to other tributaries in the Central Valley (Sturrock et al. 2020). The relationship between escapement and flow has eroded since the 1960s and there is no longer a clear relationship to spring flow at time of outmigration (Figure 43). The degradation of that relationship suggests that a multipronged approach to restoration is needed to restore Chinook Salmon populations inclusive of spawning and juvenile rearing habitat restoration (Sommer et al. 2020), reduction of warmwater/non-native predator habitat (Michel et al. 2020), flow restoration, and restoration of the river geomorphic process with gravel augmentation (M&T 2000). Unfortunately, many of the Chinook Salmon that return today are likely hatchery strays rather than individuals which reared in the river as juveniles (Sturrock et al. 2020).

Habitat needed by Chinook Salmon includes spawning riffles, which are characterized by cobble sized substrate (16–78 mm) with moderate water depths (0.7–2.7 ft) and velocities (1.0–3.7 ft/s, Kondolf and Wolman 1993, Stillwater Sciences 2013b). Within the Zanker Farm Project Area, there are two existing spawning areas (Figure 44) that are used by Chinook Salmon, the downstream area is beyond the Phase 1 project boundary.

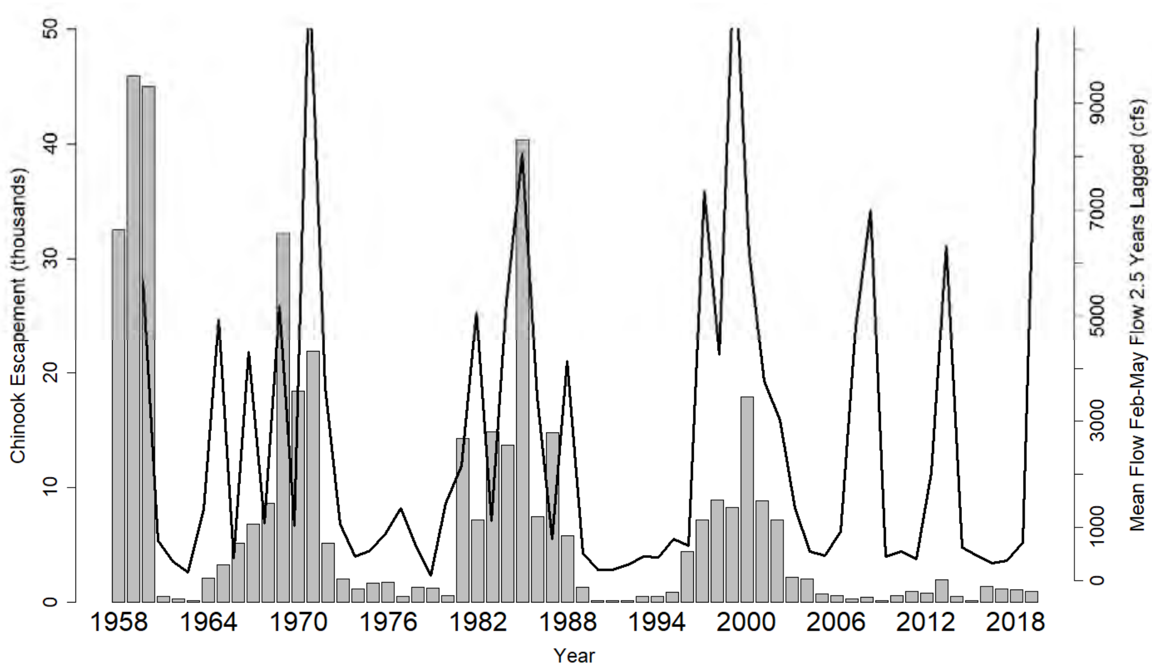


Figure 42. Trend of Tuolumne River fall-run Chinook Salmon population and relationship to flow 2.5 years prior.

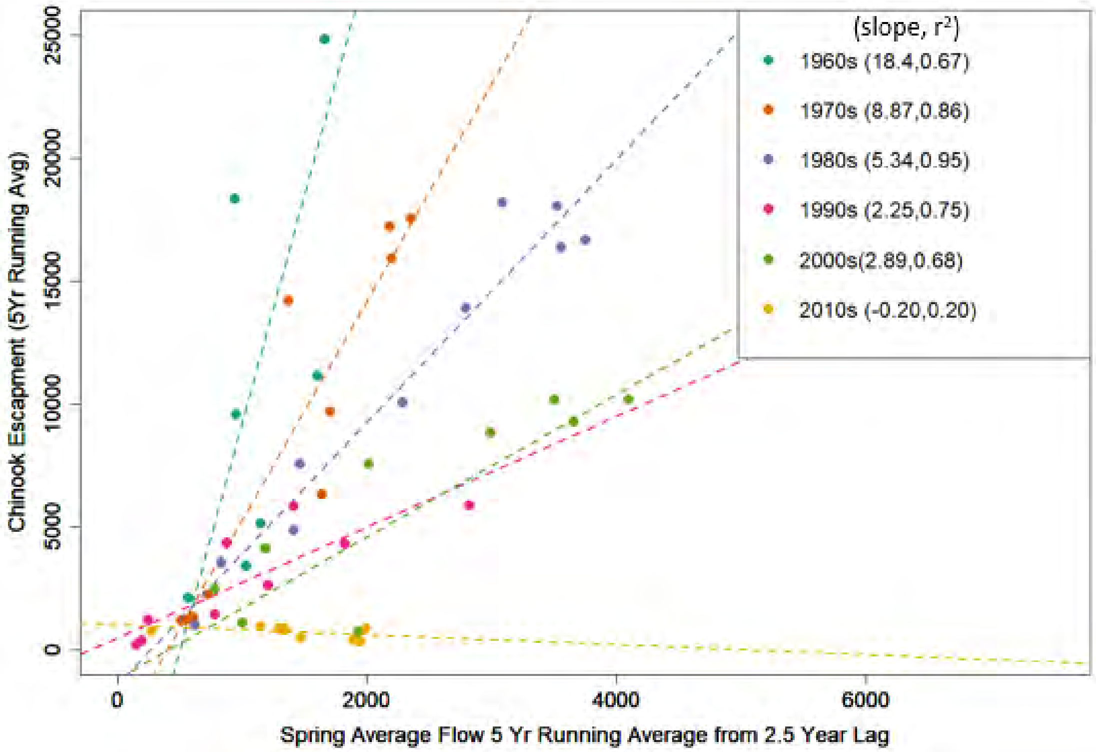


Figure 43. Decadal relationship between the 5-year running average of Chinook Salmon escapement to 5 year running average of spring flows during adult outmigration (2.5 years lagged from escapement year). Slope and r^2 values have gradually declined since the 1960s. Data used are from Huber and Carlson (2015) and Sturrock et al. (2020).

Figure 44. Observed salmonid redds in the Zanker Farm Project area from 2010–2019.

Juvenile Chinook Salmon that rear in the river seek out profitable energetic foraging positions that reduce their exposure to predation and maximize their feeding potential (Quinn 2018). Floodplain habitats in the Zanker Farm Project Area would support such feeding areas when they are inundated (Grosholz and Gallo 2006, Sommer et al. 2020). Similarly, the complex habitat at the western end of the site near the primary riffle control and downstream end of it also supports high quality in-river habitat for rearing at lower flows. The large pool in the middle of the Zanker Farm Project Area (Figure 7) is considered habitat for non-native predators, and it lacks any complexity and likely supports minimal food production.

7.2 Oncorhynchus mykiss

Oncorhynchus mykiss exhibit two life history strategies, resident (Rainbow Trout) and anadromous (steelhead). Central Valley steelhead were thought to be extirpated from the San Joaquin River system, until monitoring detected small populations of *O. mykiss* (McEwan 2000). Resident forms of *O. mykiss* remain in many Central Valley tributaries. While some incidental steelhead have been reported in the Tuolumne River (Good et al. 2005), there is uncertainty whether the present *O. mykiss* are predominantly resident or anadromous. Zimmerman et al. (2008) found that resident Rainbow Trout can produce anadromous smolts in the Central Valley, but that the proportion of resident Rainbow Trout to anadromous steelhead in the Central Valley is largely in favor of the resident form. We use *O. mykiss* throughout the report to include both life history strategies of this species.

O. mykiss adults typically spawn from December through April, with peaks from January through March. Depending on water temperature, eggs may incubate in redds for over one month before hatching. Once their yolk sacks are absorbed, fry emerge and begin actively feeding. Regardless of life history strategy, juvenile *O. mykiss* rear year round, and for the first year or two are found in cool, clear, fast-flowing water with abundant cover where they can forage profitably (Moyle 2002, Weber et al. 2014). *O. mykiss* have been observed in the lower Tuolumne River in the 10–15 miles below La Grange Dam, with most detected in riffles and the pools and runs below riffles. Resident adults were mainly detected within pool heads and riffles (TID and MID 2009).

O. mykiss rearing is similar to juvenile Chinook Salmon rearing habitat, where individuals seek profitable foraging positions with high food availability and low risk of predation (Weber et al. 2014, Quinn 2018). *O. mykiss* juveniles also utilize floodplains and side channels where food availability and cover is abundant (Grosholz and Gallo 2006, Sommer et al. 2020). Several areas were identified as high-quality resident *O. mykiss* habitat in the Zanker Farm Project Area during 2021 field surveys (Figure 45), and from previous work (M&T 2000). Most of these areas exist just downstream of the primary riffle control at the downstream end of the project boundary and consist of riffle–pool sequences, high channel complexity, and woody debris (Figure 45, Figure 46). Juvenile *O. mykiss* were observed in the first pool below the primary riffle control during summer 2021 (T. Caldwell, pers. obs.). Upstream of that within the Zanker Farm Project Area, which is channelized, slow moving, and lacking cover and complexity, there is very little usable habitat for any life history stage of *O. mykiss*. Large non-native predators are regularly observed in the long pool in the main Zanker Farm Project Area, further minimizing its potential use by *O. mykiss.*

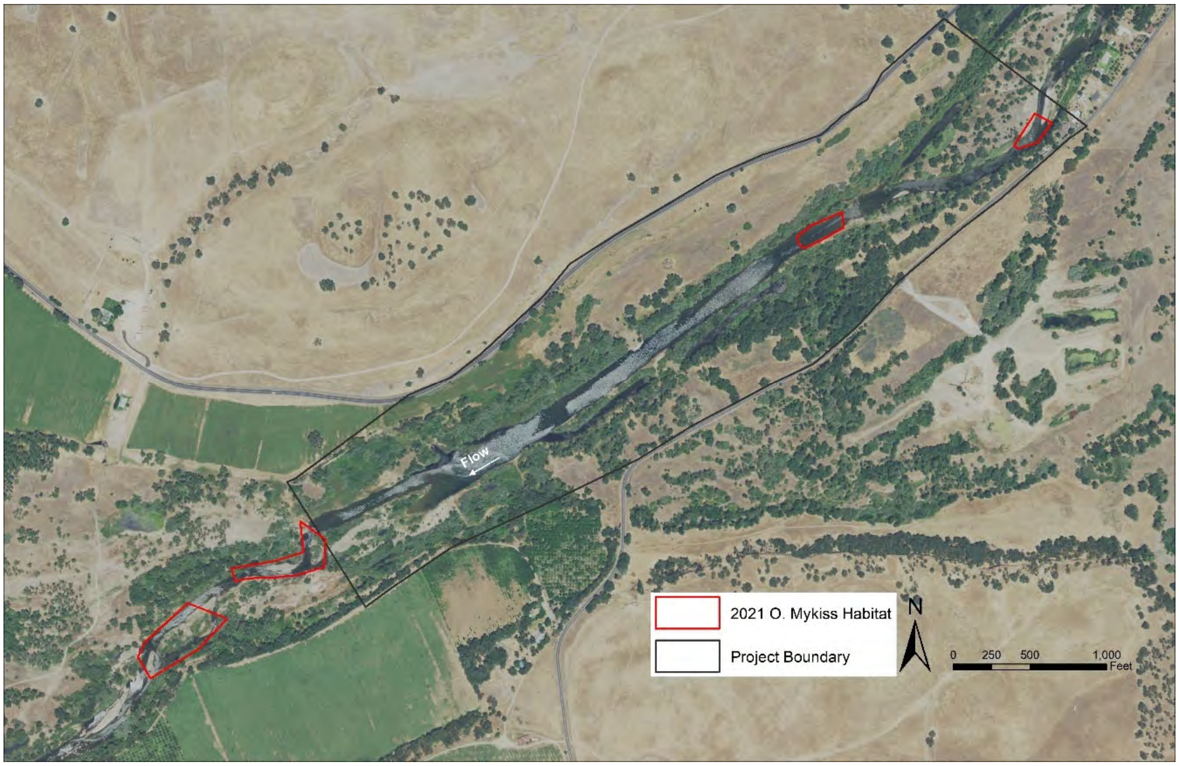
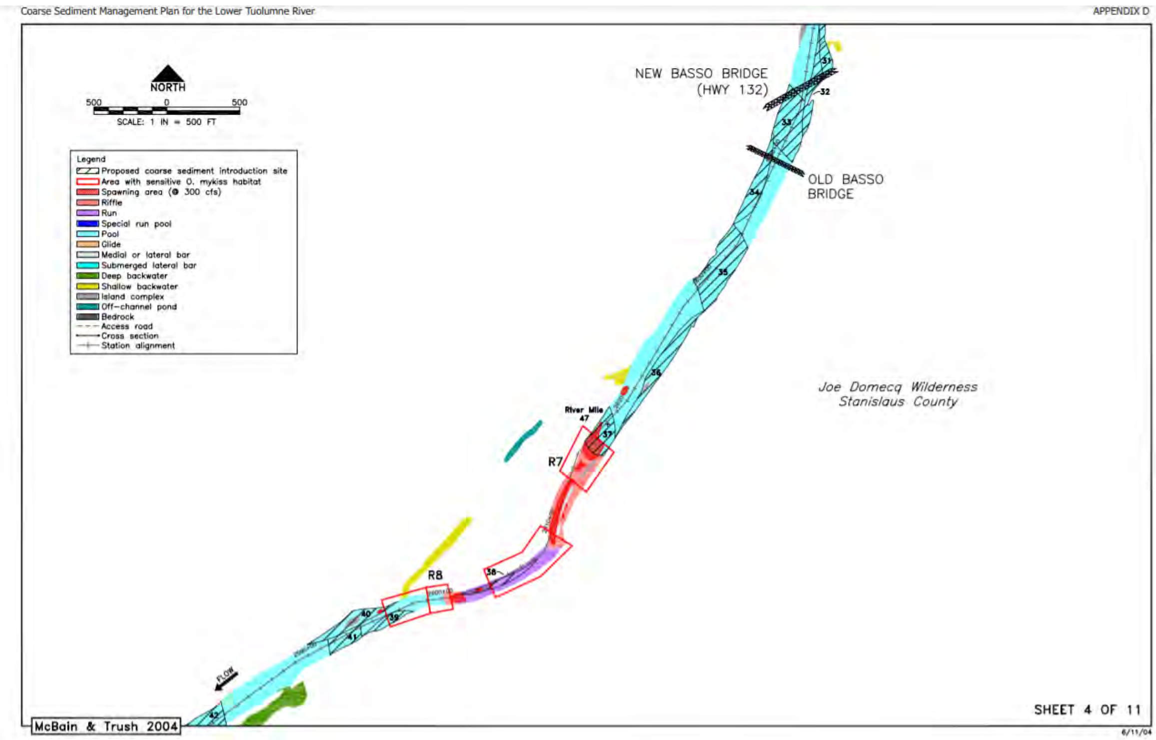


Figure 45. Identified O. mykiss *habitat (outlined in red) in the Zanker Farm Project Area. Majority of the habitat exists outside of the Project Area.*



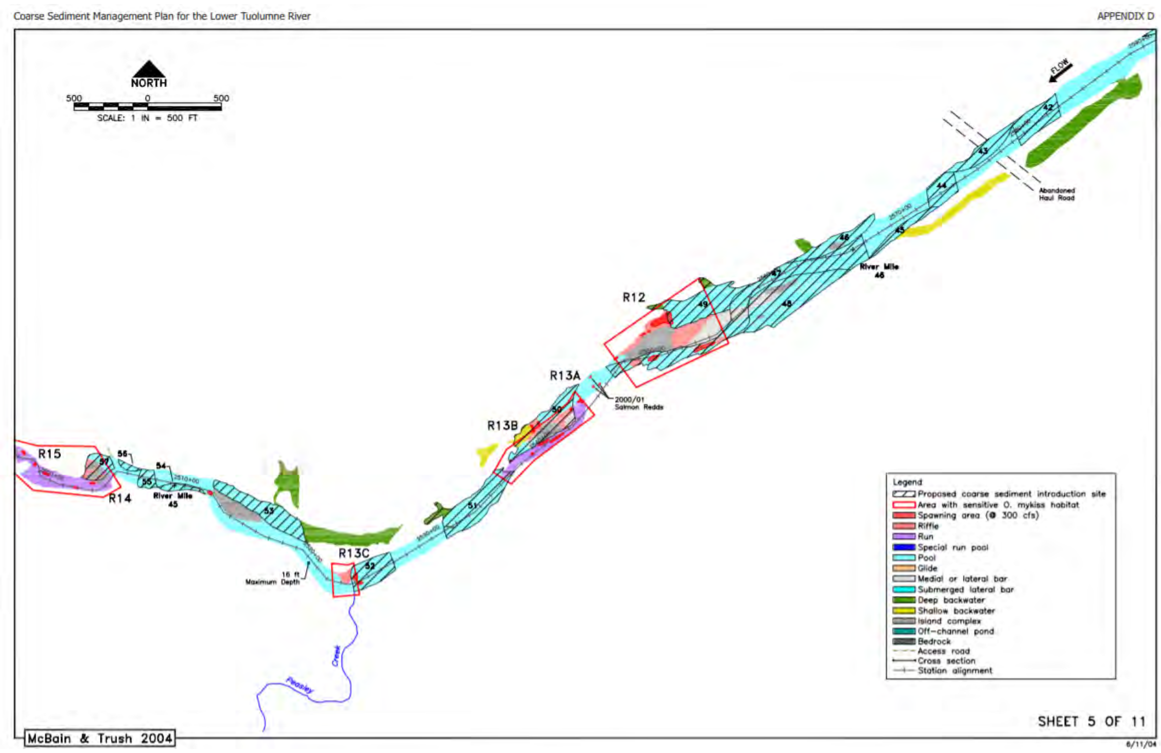


Figure 46. Identified O. mykiss *habitat (outlined in red) in the Zanker Farm Project Area, from the 2004 Coarse Sediment Management Plan (M&T 2004b). These maps include other habitat delineations as well, but the focus here is* O. mykiss *habitat.*

7.3 Non-native Predators

Predation by non-native piscivorous fish species has been identified as a threat to Chinook Salmon and *O. mykiss* in the Central Valley, and specifically the Tuolumne River. Predation by species such as Striped Bass, Smallmouth Bass, and Largemouth Bass is a significant factor affecting Chinook Salmon smolt survival in the Tuolumne River (TID and MID 1992, Demko et al. 1998). Efforts to reduce predatory bass abundance have been conducted with little success. TID/MID conducted predator isolation projects as required under Federal ESA Section 12(b) to reduce predatory fish abundances, and monitoring results suggest the projects may not have been successful in reducing Largemouth Bass linear density, and that Largemouth and Smallmouth Bass abundance had increased due to low spring and summer flows providing temperatures and flow velocities suitable to spawning. An experiment to assess the success of predator removal programs found no effect on the survival and predation rates on juvenile Chinook Salmon in the San Joaquin River after predatory fish removal efforts (Michel et al. 2020).

Smallmouth Bass, Largemouth Bass, and Striped Bass have been documented throughout the lower Tuolumne River but are observed in the highest density downstream of RM 24. The lower Tuolumne River from RM 24 to RM 52 is characterized as higher gradient, faster velocity, and gravel-bedded, while the river below RM 24 is characterized as lower gradient, lower velocity and sand-bedded with relatively higher water temperatures (Stillwater Sciences 2017). River conditions in the lower reaches favor predatory fish species. The most recent predator survey in 2020 found only a few black bass species (including Largemouth Bass and Smallmouth Bass) upstream of RM 38, while Striped Bass were observed at three locations upstream of RM 43, including a count of five large fish (500–600 mm) in pool habitat at RM 42.9 in Bobcat Flat (TID and MID 2021). While there are fewer predatory fish detected in the Zanker Farm Project Area than lower in the river, the main concern in the project area lies in the potential for habitat overlap of salmonids and predatory bass, especially in the large deep pool in the main channel, areas near the old haul road, and relics of gravel mining operations (NMFS 2014). A two-dimensional acoustic tracking study used to evaluate the role of flow in segregating potential predators from outmigrating Chinook Salmon within the run–pool habitats found overlap between Chinook Salmon and predatory bass regardless of flow. Striped Bass were found to have the greatest overlap in habitat use with Chinook Salmon, ranging from 18.4% to 46.3%, followed by Largemouth Bass ranging from 5.8% to 30.5%, and Smallmouth Bass ranging from 0.2% to 38.2% (TID and MID 2013a).

The American Bullfrog (*Lithobates catesbeianus*) occurs along the lower Tuolumne River inhabiting off-channel ponds and wetlands, as well as connected side-channels and alcoves or other calm waters of the river. This voracious predator was intentionally introduced to the west from the eastern United States over 100 years ago as a food crop and is now widespread and well-established across the western states where water is present (Dodd and Jennings 2021). Usually found in or near water, this highly aquatic frog is capable of long overland journeys during wet or cool weather, facilitating dispersal to isolated waters. Dispersal of overwintering aquatic larvae regularly occurs during winter flows. Bullfrogs threaten native amphibian species through predation, competition, and transmission of pathogens and can consume large quantities of salmonid fry and juveniles. Population control is best achieved by promoting habitats that reduce bullfrog reproductive success combined with removal of breeding adults and egg masses (Kamoroff et al. 2020).

7.4 Salmonid Habitat Evaluation

To better understand the quality and amount of available habitat for Chinook Salmon and *O. mykiss* under existing conditions, weighted usable area (WUA) curves were calculated using modeled and mapped habitat data in the Zanker Farm Project Area (Figure 5). WUA curves depict a weighted measure of habitat for targeted 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, where 0 is not suitable and 1 is the most suitable (Bovee 1986, Normandeau Associates 2014). The evaluation focused on adult spawning habitat, adult *O. mykiss* habitat, and fry and juvenile rearing habitat, as these life stages are disproportionately affected by limited instream habitat. The results from this analysis not only provide insight into habitat availability under existing conditions but can also be compared with WUA under design conditions to evaluate the performance of proposed restoration designs.

7.4.1 Methods

Data used to calculate WUA included modeled depth and velocity data, mapped substrate and cover data, and HSI relevant to the project area. Data used to calculate WUA differed among life stages based on habitat needs. In addition to depth and velocity, substrate data were used for Chinook Salmon and *O. mykiss* spawning since suitable substrate is a key component for creating redds and egg incubation success. Cover data were used along with depth and velocity data for Chinook Salmon and *O. mykiss* juvenile rearing and adult habitat because cover is important for predator avoidance (Figure 5). The 2-D hydraulic model (Section 5) was used to develop modeled depth and velocity data for a wide range of physically and ecologically important streamflows. Substrate and cover were mapped in the field and categorized by codes that were used during WUA calculations to assign suitability values based on species and life stage-specific HSI values (Figure 5, Figure 47, Figure 48, Table 16). 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 study area (Gard 2014, Benn and Gard 2019, MA 2020). We evaluated two HSI sources for adult resident *O. mykiss* habitat, one used for the Lower Tuolumne River FERC process (Stillwater Sciences 2013a), where the adult age class was defined as lengths greater than 15 cm, and one for the Middle Fork American River (PCWA 2008), where the adult age class was defined as lengths between 15 cm and 40 cm. Stillwater (2013a) criteria were agreed upon by FERC stakeholders and used in FERC relicensing studies for the Don Pedro and La Grange Relicensing studies, assumes adult *O. mykiss* depths are highly suitable up to 17–18 ft; however, Tuolumne River *O. mykiss* were observed at a maximum of 11 ft during snorkel surveys conducted during development of criteria. Placer County Water Agency (PCWA) curves were developed by combining several HSI sources including the Stanislaus and American Rivers (PCWA 2008); these curves presented habitat suitability for adult resident *O. mykiss* at depths within the ranges of depths that adult resident *O. mykiss* were observed at in the Tuolumne River. Neither HSI source developed or used cover HSI in their habitat evaluations because adding cover did not have a notable effect on habitat availability (Stillwater Sciences 2013a), or because cover was ubiquitous and not considered an important factor in modifying the habitat use of adult *O. mykiss* (PCWA 2008). For this analysis, we chose to use the cover HSI criteria that was used for *O. mykiss* juvenile rearing because cover is an important component of habitat in the project area and omitting it could mis-represent adult *O. mykiss* habitat WUA when compared to the other species and life stages that included cover and substate HSI variables. WUA curves were calculated using program R (R Core Team 2019). Adult *O. mykiss* habitat was mapped in the field and overlaid with the predicted habitat from the WUA analysis. This allowed for a cross evaluation of the two habitat methods.

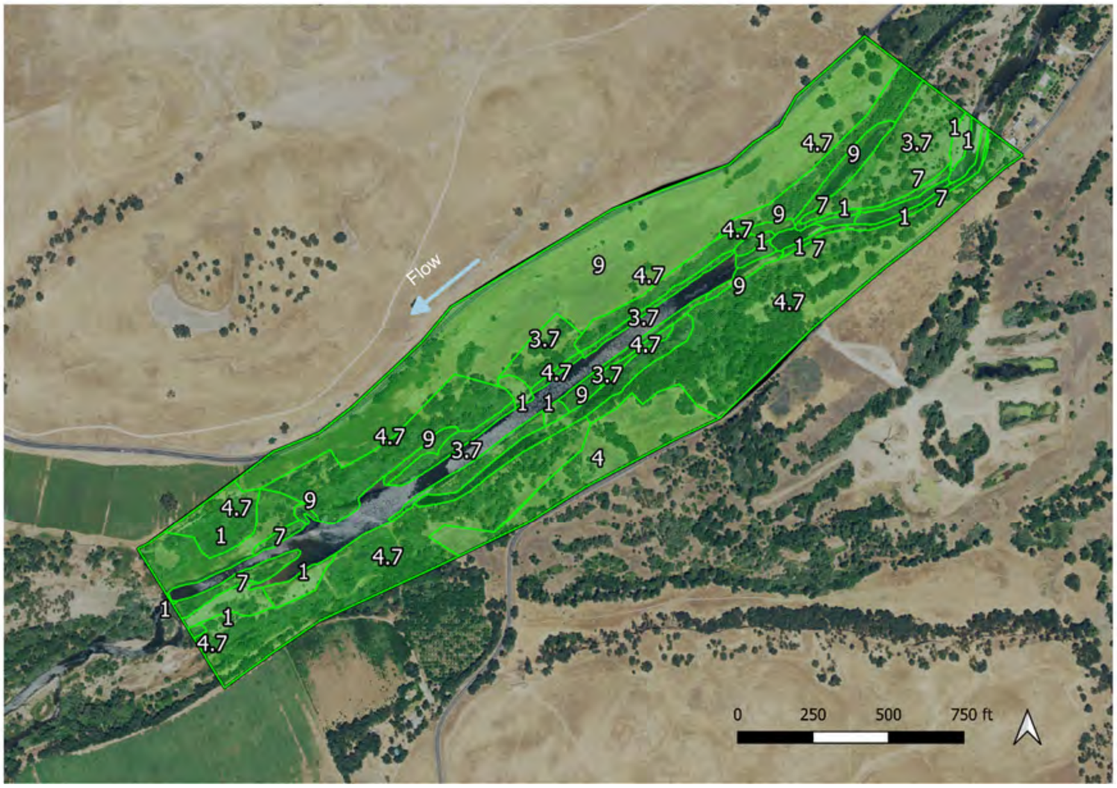


Figure 47. Mapped cover area in the project boundary. Cover types were identified with categorical codes from USFWS (2010a, b). Areas without a cover code were mapped to have no existing cover for salmonids Cover descriptions associated with codes can be found in Table 16.

Figure 48. Mapped substrate area in the project boundary. Substrate types were identified with categorical codes from USFWS (USFWS 2010a). Substrate descriptions associated with codes can be found in Table 16.

Table 16. Cover and substrate codes from USFWS (2010a, b) and their corresponding descriptions.

Cover		Substrate	
Code	**Description**	**Code**	**Description**
1	Cobble	0.1	Sand or silt/ sand (< 0.1 inches)
3.7	Fine woody vegetation + overhead	1	Small gravel (0.1-1 inches)
4	Branches	1.2	Medium gravel (1–2 inches)
4.7	Branches + overhead	2.3	Large gravel (2–3 inches)
5.7	Log + overhead	3.4	Small cobble (3–4 inches)
7	Overhead cover (> 2 ft above substrate)	4.6	Medium cobble (4–6 inches)
9	Aquatic vegetation		

WUA were calculated by multiplying the HSI values from the modeled depth and velocity data, and the mapped substrate or cover values for each hydraulic modeling mesh point (Section 5.2), producing a weighted HSI value (HSI_i) for each point:

$$HSI_i = HSI_D \times HSI_V \times HSI_{S/C}$$

HSI_i values were then multiplied by the point's corresponding polygon cell area (A_i) to calculate a WUA value for that cell. All cell-specific WUA values in the project area were then summed to return a single WUA value for each modeled flow:

$$WUA = \sum_{i=1}^{n} A_i HSI_i$$

WUA was plotted as a function of flow to create WUA curves for each target species and life stage.

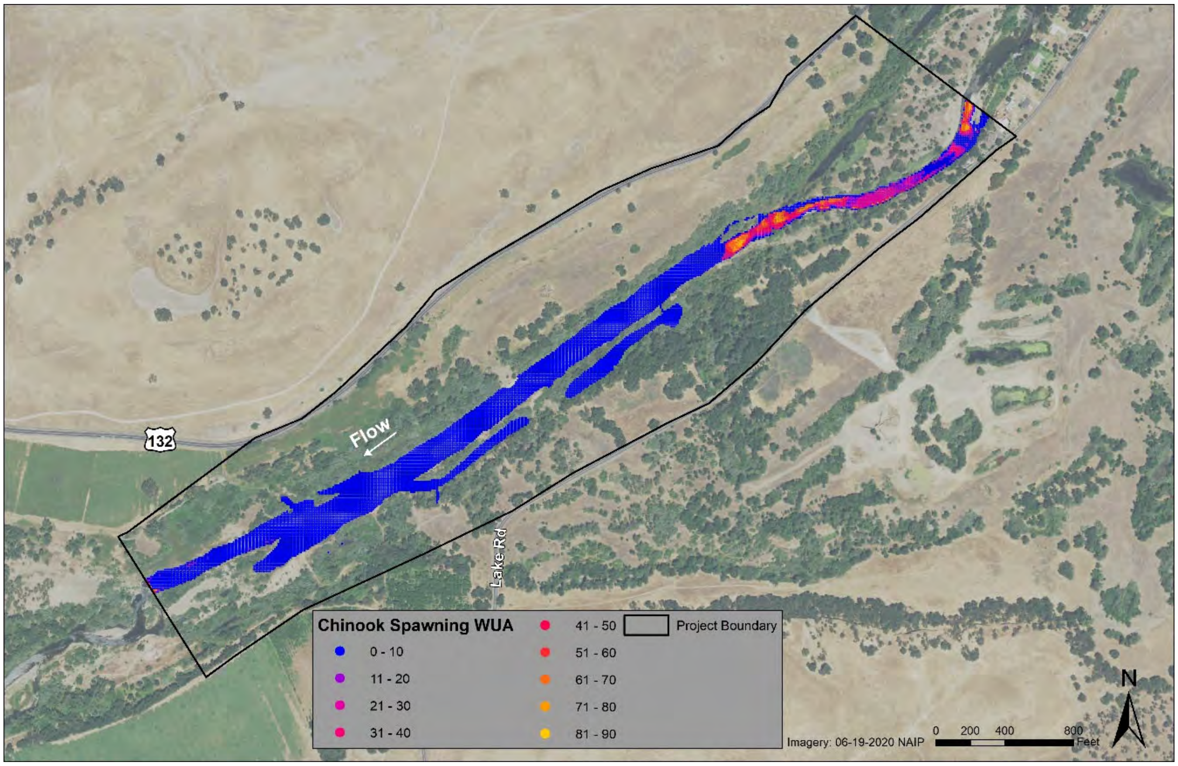
The area under the curve (AUC) for each WUA curve was calculated for each target species and life stage to condense WUA curves into a single metric to better compare habitat availability among species and life stages. The AUC is the area between the WUA curves and the x-axis, and was generated using 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. While the AUC value is derived from the available WUA in the Project Area for all modeled streamflows, it is intended to be used as a reference for comparison of habitat availability and does not represent WUA at the site at a given flow or at a snapshot in time.

7.4.2 Results

Chinook Salmon and *O. mykiss* spawning had the lowest resulting WUA for existing conditions compared to fry and juvenile rearing due to the poor spawning conditions in the project area and lack of suitable spawning substrate (Table 17, Figure 49Figure 49). Chinook Salmon spawning WUA was higher than *O. mykiss* spawning (8,667 acres vs. 6,991 acres, Table 17) and peaked at 1.2 acres at 500 cfs (Figure 50, Table 18). *O. mykiss* spawning WUA increased as streamflow increased but never reached 1 acre of WUA for the range of modeled streamflows (Figure 50). Both Chinook Salmon and *O. mykiss* spawning habitat are concentrated at the upstream end of the site where riffle habitat combined with appropriately sized gravel exists (Figure 49).

Table 17. Area under the curve values calculated from WUA curves for the target species and life stage.

Species	Life Stage	Area Under the Curve
Chinook Salmon	Fry	105,890
	Juvenile	125,759
	Spawning	8,667
O. mykiss	Fry	158,460
	Juvenile	146,731
	Spawning	6,991
	Adult (PCWA 2008)	129,753
	Adult (Stillwater Sciences 2013a)	146,925



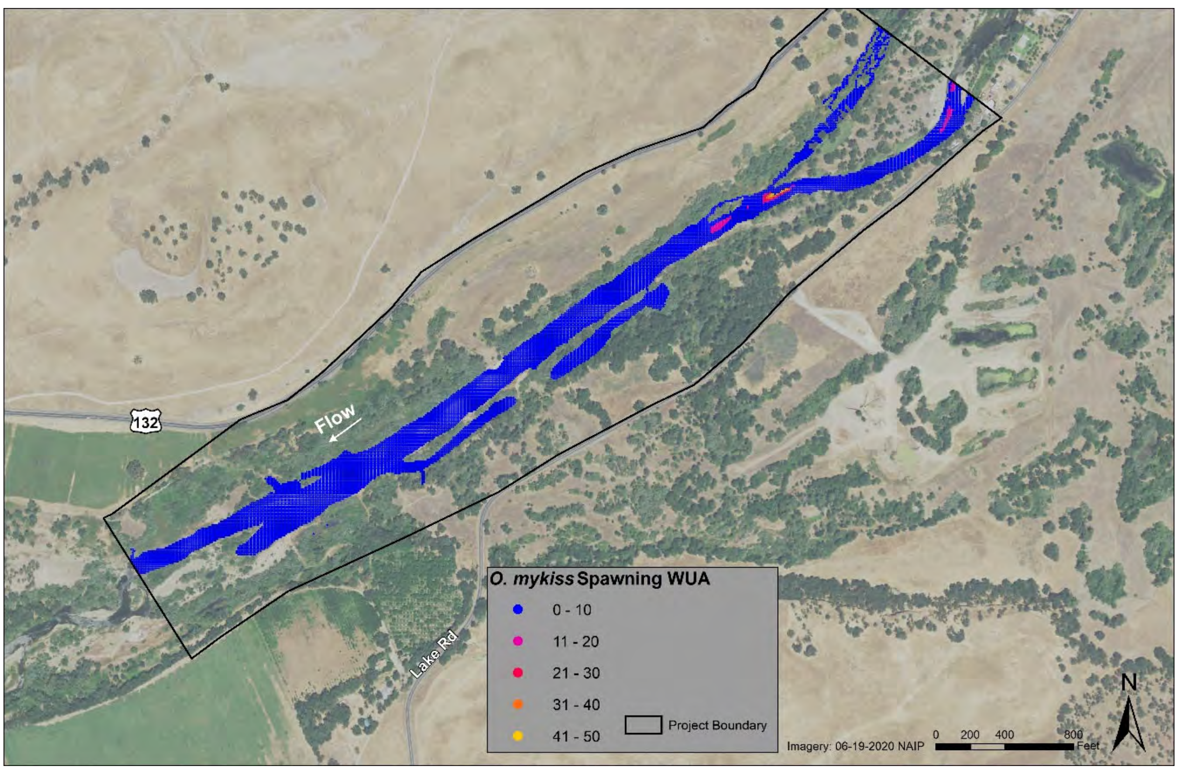


Figure 49. Planform view of available suitable spawning habitat for adult Chinook Salmon (top) and O. mykiss (bottom) *in the Zanker Farm Project Area. Suitability ranges from 0 to 100, where 0 is not suitable and 100 is the most suitable. Available suitable spawning habitat is shown at 150 cfs for Chinook Salmon and 300 cfs for* O. mykiss.

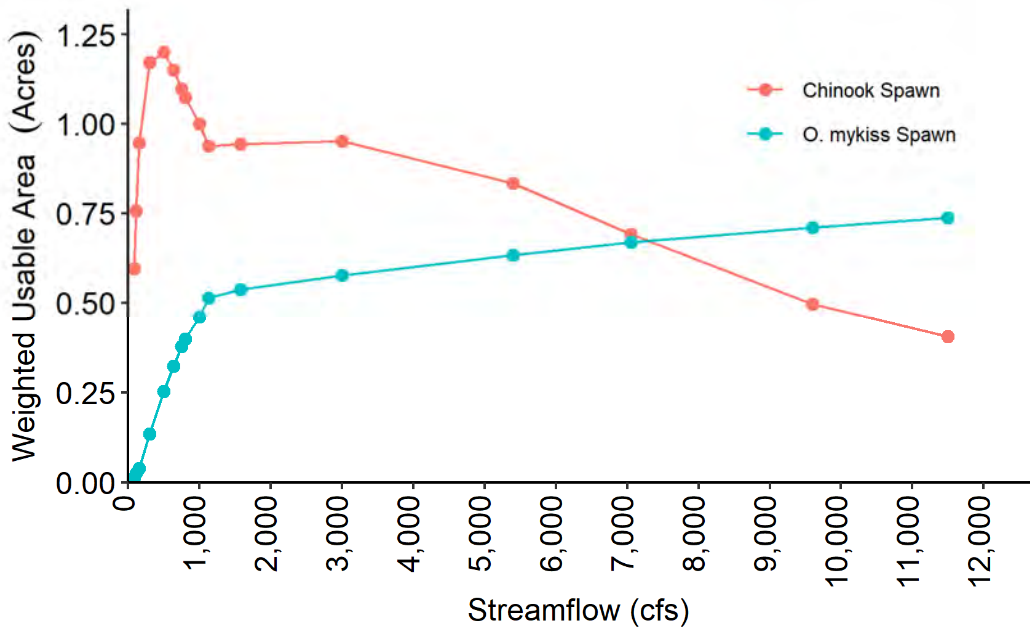


Figure 50. Existing conditions WUA (using depth, velocity, and substrate HSI) for Chinook Salmon and O. mykiss *spawning in the Zanker Farm Project Area.*

Table 18. Existing conditions WUA for Chinook Salmon and O. mykiss *spawning (using depth, velocity, and substrate HSI), fry and juvenile rearing (using depth, velocity, and cover HSI), and* O. mykiss *adult habitat (using depth and velocity HSI) in the Zanker Farm Project Area.*

Modeled Flow (cfs)	Chinook Salmon Spawning	Chinook Salmon Fry Rearing	Chinook Salmon Juvenile Rearing	*O. mykiss* Spawning	*O. mykiss* Fry Rearing	*O. mykiss* Juvenile Rearing	*O. mykiss* Adult Habitat[1]	*O. mykiss* Adult Habitat[2]
	WUA (Acres)							
80	0.60	2.45	1.38	0.01	2.38	2.97	0.60	1.04
110	0.76	2.72	1.71	0.03	2.77	3.23	0.76	1.26
150	0.95	2.59	1.74	0.04	2.77	3.16	0.96	1.55
300	1.17	2.96	2.22	0.13	3.15	3.39	1.39	1.89
500	1.20	3.28	2.52	0.25	3.53	3.69	1.81	2.15
633	1.15	3.45	2.64	0.32	3.79	3.94	2.07	2.31
750	1.10	3.99	2.85	0.38	4.19	4.55	2.28	2.47
800	1.07	4.32	2.96	0.40	4.41	4.86	2.37	2.53
1,000	1.00	5.96	3.10	0.46	5.31	6.32	2.73	2.80
1,130	0.94	7.92	3.46	0.51	6.95	8.42	3.35	3.42
1,580	0.94	9.34	3.95	0.54	8.42	10.16	4.00	4.25
3,000	0.95	12.12	8.52	0.58	14.50	15.67	8.20	9.90
5,400	0.83	9.59	13.82	0.63	16.70	15.15	14.74	15.45
7,050	0.69	8.95	14.53	0.67	16.20	13.80	17.26	15.08
9,600	0.50	9.15	13.98	0.71	15.50	12.84	18.36	12.98
11,500	0.40	9.90	13.34	0.74	15.55	13.11	18.68	12.51

[1] Stillwater Sciences (2013a), [2] PCWA (2008)

Fry and juvenile rearing WUA was greater for *O. mykiss* than for Chinook Salmon (Table 17). *O. mykiss* fry and juveniles prefer higher velocities than Chinook Salmon fry and juveniles, which is reflected in the HSI. Juvenile *O. mykiss* have a wider range of tolerance to increases in depths and velocities that occur in the project area driven by the channelization, downcutting, and lack of habitat complexity in the main channel.

At low flows minimal habitat was predicted for juvenile and fry salmonids, this is likely driven by a lack of complexity and cover in the majority of the Project Area. WUA peaked for all rearing life stages at 3,000 cfs or 5,400 cfs except for Chinook Salmon juvenile rearing, which peaked at 7,050 cfs (Figure 51). At flows greater than 3,000 cfs and 5,400 cfs (and 7,050 cfs for Chinook Salmon juvenile rearing), WUA values “leveled” with minimal increases and decreases (Table 18, Figure 51).

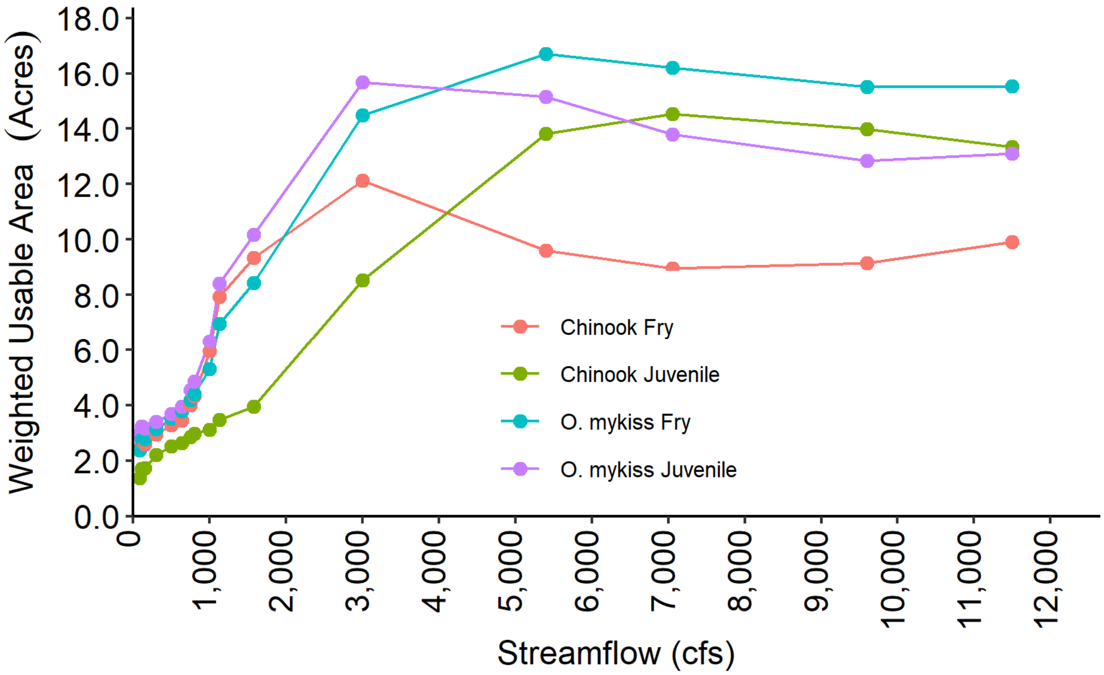


Figure 51. Existing conditions WUA (using depth, velocity, and cover HSI) for Chinook Salmon and O. mykiss *fry and juvenile rearing in the Zanker Farm Project Area.*

O. mykiss adult habitat WUA results were greater when using the Stillwater Sciences (2013a) HSI than when using the PCWA (2008) HSI (Table 17), due to the Stillwater HSI assuming high habitat suitability at depths up to 17–18 ft while PCWA HSI assumes habitat becomes less suitable at depths > 5 ft. WUA calculated using Stillwater HSI increased steadily as flows increased, and plateaued at 9,600 cfs, while WUA calculated using PCWA HSI peaked at 5,400 cfs due to depths increasing above the corresponding HSI suitability range (Table 18, Figure 52). Suitable *O. mykiss* habitat was low in the main channel under low flows regardless of HSI source, as flow increased and transitioned out of the main channel onto floodplains habitat where habitat is much more suitable (Figure 53). The universal absence of rearing habitat in the main channel at high flows is again due to a lack of habitat complexity that can cause velocities to rise in the main channel above the suitable range for adult *O. mykiss* rearing regardless of depths.

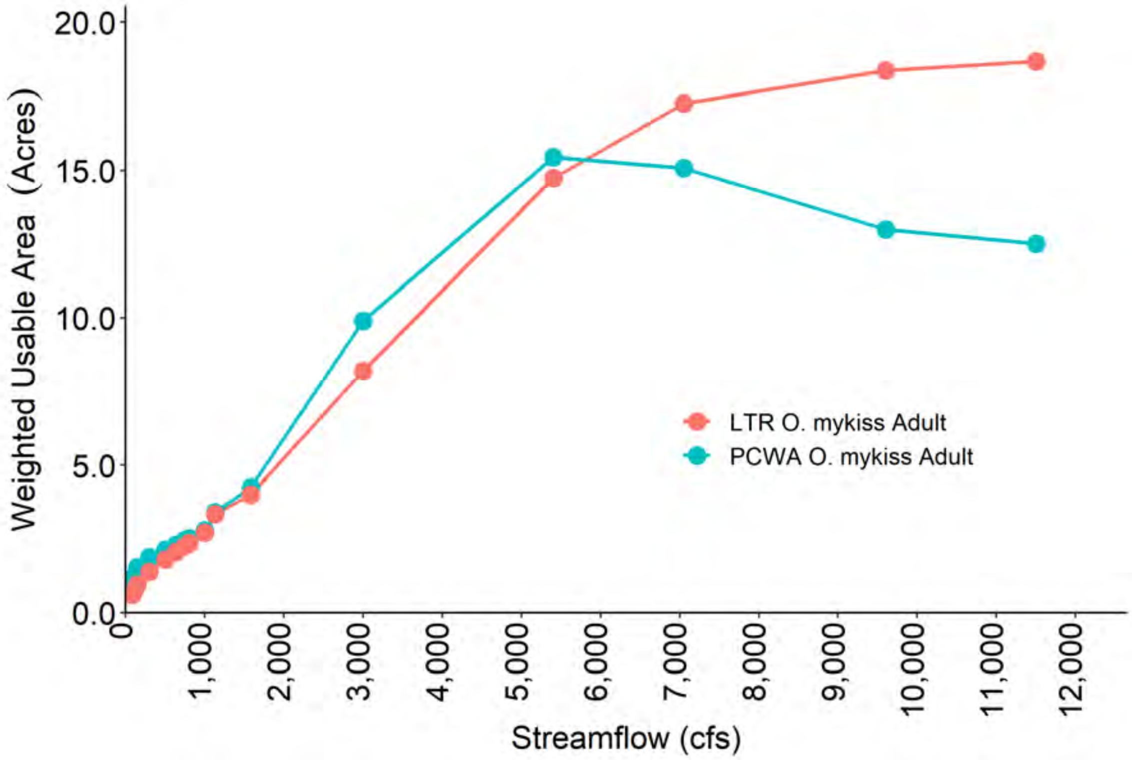


Figure 52. Existing conditions WUA (using depth and velocity HSI) for adult O. mykiss *habitat in the Zanker Farm Project Area. We evaluated WUA using two HSI sources: Stillwater Sciences (LTR, 2013a) and PCWA (2008).*

Mapped adult *O. mykiss* habitat overlapped with predicted habitat at low flows indicated that at low flows, both methods are suitable for evaluating rearing habitat. It was not possible to map rearing habitat on the floodplain because they were not inundated, however this indicates that (based on hydraulic and habitat modeling) that floodplain surfaces which are rich in cover and complexity would be useful habitat for rearing salmonids.

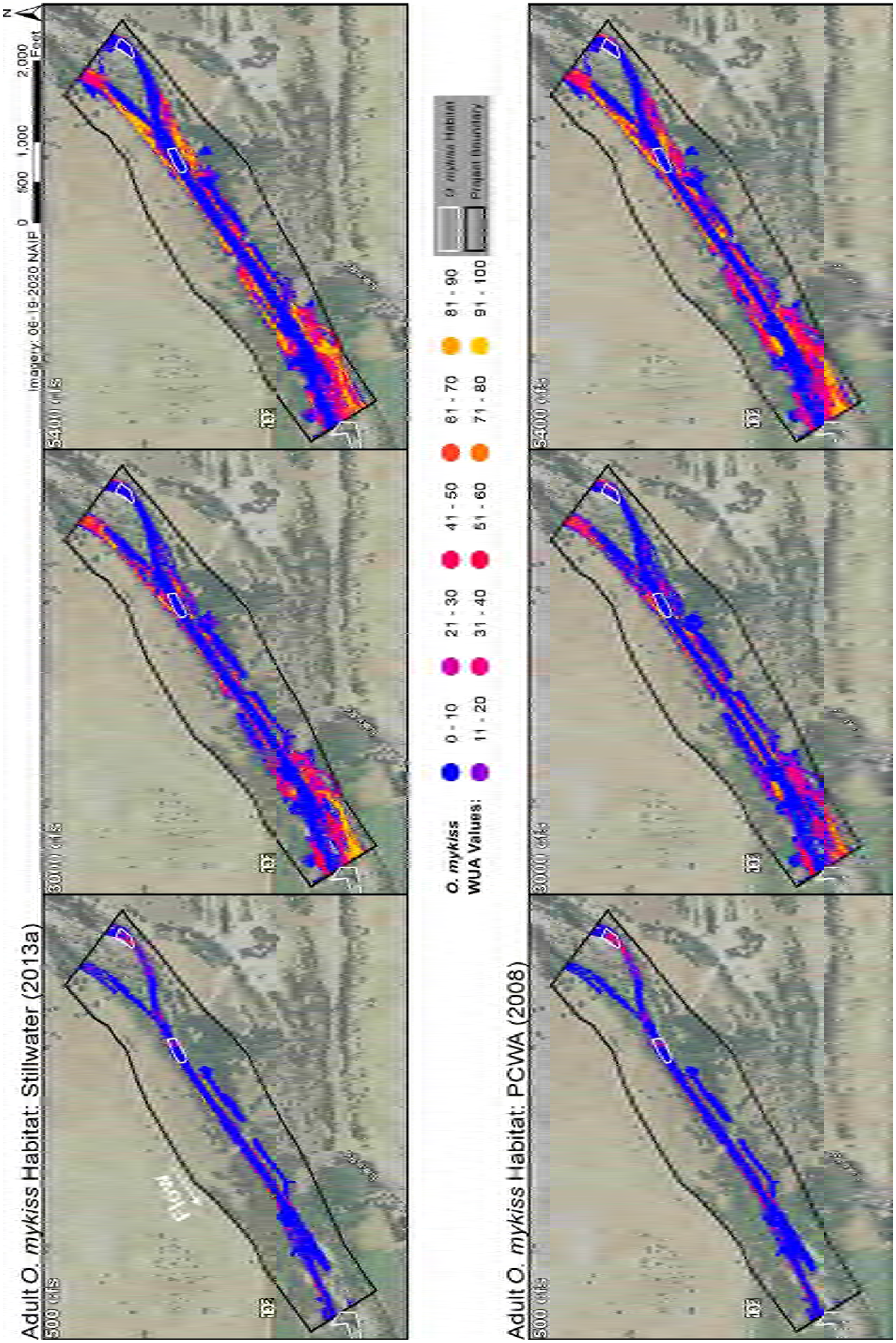


Figure 53. Planform view of adult O. mykiss *WUA under existing conditions (using depth and velocity HSI) in the Zanker Farm Project Area at various flows, illustrating how suitable habitat transitioned out of the main channel and onto high flow surfaces. We evaluated WUA using two HSI sources: Stillwater Sciences (2013a) and PCWA (2008).*

8 TURTLES AND AMPHIBIANS

Five herpetofauna species with some degree of protected status have the potential to occur in the Zanker Farm Project Area, based on a nine-quad search of California Natural Biodiversity Database (CNDDB) records. These are the Northwestern Pond Turtle, Foothill Yellow-legged Frog, California Red-legged Frog, Western Spadefoot Toad, and California Tiger Salamander. The pond turtle and yellow-legged frog will use the river and side channels, whereas the red-legged frog, spadefoot toad, and tiger salamander are primarily terrestrial as adults and tend to favor ponds and temporary pools for reproduction. Here we provide a summary of existing conditions and a brief background on these herpetofauna in relation to the Zanker Farm Project Area. The existing conditions report focuses on the two species associated with flowing waters, but all five species have potential to occur at or near the proposed Zanker Farm Project.

8.1 Northwestern Pond Turtle

The Northwestern Pond Turtle (NWPT, *Actinemys* [*Emys*] *marmorata*) is a California Species of Special Concern (Thomson et al. 2016) and is currently in review for federal status under the Endangered Species Act (ESA 1973). It is listed as a sensitive species by the U.S. Forest Service (USFS) and Bureau of Land Management (BLM). This species has been observed near the Zanker Farm Project at Bobcat Flat, less than one mile downstream, and is presumed to be active here, although CNDDB records lack reports from the Project Area.

NWPT are considered habitat generalists. While these turtles can occupy a wide variety of landscapes, they do have specific habitat requirements that shift with season and life stage. For a population to persist at a site, specific aquatic and terrestrial features, along with connectivity, must be present in order to meet life history requirements (Holland 1994, Bury et al. 2012). Although survival is low for eggs and hatchlings, adult survivorship can be quite high (> 0.95) and females may produce eggs for many decades with some individuals reproducing at ages in excess of 60 years in the wild (Bury et al. 2012).

These long-lived residents rely on knowledge of the local surroundings to locate resources needed for specific life-history functions. Bury (Bury 1979) reported a mean home range of 1,138 ft for males, 476 ft for females, and 469 ft for juveniles in a northern California Creek over a three-year period. A study spanning two decades revealed high site fidelity with 80% of recaptures occurring within 820 ft of a previous location (Ashton et al., unpublished manuscript).

Adult and juvenile turtles spend their active season in aquatic habitats. Foraging, courtship, and mating occur exclusively in aquatic habitats; this is where they accumulate resources for growth, reproduction, and lipid storage (Ashton et al. 2015). Localized distribution tends be clustered and low velocity waters with adequate depth and access to emergent basking structures and underwater refugia are mostly likely to be occupied. Waters can be permanent or temporary, flowing or still, but turtle populations with access to a variety of aquatic habitat types throughout the year tend to be the most resilient. Turtles employ heliothermic behaviors to achieve functional metabolic temperatures, promote shell health, and control ectoparasites. Emergent basking structures that are detached from land and with quick access to deeper water with underwater cover afford the most protection from terrestrial predators. Or turtles may seek sun-warmed aquatic microhabitats, such as surface waters in algae mats, for thermoregulation. Seasonal shifts in basking behavior and locations are common as environmental conditions change.

Hatchlings seek shallow waters with abundant cover, such as aquatic or emergent vegetation, soft substrates, or organic debris. Hatchlings are small (carapace length 1 in, weight 0.2 ounce) and the shell is soft, making them vulnerable to a wide array of aquatic and terrestrial predators that adult turtles are generally protected from by their size and hard shell. Providing adequate substrate and vegetative cover can improve survival and growth of hatchlings and young turtles. Hatchlings spend less time engaged in aerial basking, and they use smaller structures when they do. Their small size makes them vulnerable to predation when exposed and they heat rapidly due to their small surface to volume ratio. Seasonally inundated floodplains have fewer aquatic predators than permanent waters and can host abundant small invertebrates, enhancing opportunities for hatchling growth and survival if adequate cover is available.

Eggs are deposited in shallow nests excavated in upland areas with sparse vegetation and low slope angle and solar exposure (Bury et al. 2012). Females target areas with suitable soil perceived to be above the high floodplain to minimize risk of nest inundation during peak flows; and there could be a site fidelity component, with individuals returning to the same area in successive years (Reese 1996). Nesting occurs in late spring or early summer, and eggs develop and hatch by the fall. Hatchlings tend to overwinter in the nest chamber, emerging in the spring, often with spring rains, although in regions with mild winter climate, hatchlings may emerge from the nest chamber with the onset of fall rains. Hatchlings may spend a few weeks or more on land near the nest site before moving to aquatic habitats (Rosenberg and Swift 2013).

Periods of dormancy, from a few weeks to over six months, occur seasonally. Turtles can overwinter in mud substrates of pond bottoms, in refugia of pond banks or riverbanks, or move upland above the floodplain, where they seek shrubs or woodland to nestle into the duff layer to escape winter high flows. During periods of drought, turtles often move upland or hide in soft soils or mammal burrows near the watercourse until waters return (aestivation). Turtles may travel hundreds of feet from their aquatic activity area to reach upland overwintering or aestivation sites (Reese and Welsh 1997, Pilliod et al. 2013). A variety of overwintering strategies might be used at a complex site, and individual turtles may switch overwintering strategies in different years (Holland 1994, Reese 1996). Hatchlings often spend their first winter in the nest chamber. In regions with mild winters, they may emerge from the nest chamber in the fall and overwinter on the surface (Bury et al. 2012).

8.1.1 Northwestern Pond Turtle Habitat Evaluation

The Zanker Farm Project Area has suitable habitat features in and adjacent to the river channel with sufficient connectivity to support NWPT. Existing side channel, backwater and alcove habitat features provide velocity shelters and potential for warmer aquatic refugia. Emergent basking structures appear to be present, although limited in some portions of the site. Off-channel ponds outside the project boundary can also provide seasonal refuge and support the production of prey species, but also can allow for proliferation on non-native aquatic predators (e.g., bullfrogs, warm-water sport fishes) that threaten recruitment of turtles. Upland areas with sparse vegetation, low slope, and good solar exposure for nesting can be found in and around the project area, although soil condition was not specific evaluated. The cultivated fields adjacent to the south boundary would not be likely to produce successful nests and could serve as an ecological trap. Nest predation is a concern throughout the site, as meso-predator populations can be high near areas of rural habitations where apex predator numbers are reduced, and food subsidies can be found.

The proportion of turtles using aquatic versus terrestrial overwintering sites is unknown for Zanker Farm, but with the river as the dominant landscape force, a pattern of terrestrial overwintering is expected for most individuals in most years. Shrub and woodland habitat above the floodplain provide terrestrial overwintering habitat and nearby ponds may also be utilized for overwintering.

Enhancements that could be applied at Zanker Farm during rehabilitation to benefit this species include creation of additional side channels and off-channel aquatic habitats, addition of large woody debris to the river, side channels, and ponds to increase opportunities for basking and refuge, and expansion of shallow wetlands with emergent vegetation where hatchlings can find warmer waters, small invertebrates, and safety from larger aquatic predators. Improvements to nesting habitat include adding terraces above the floodplain using soils with a high fraction of silt or clay and maintained with sparse, low, native grasses and herbs. Nest soils should be at least four inches deep to accommodate the nest chamber (Bettelheim et al. 2006). In some situations, sediments removed from the channel can be used the create or enhance nesting by mimicking deposition from large flood events. Significant changes to site configuration may cause short-term impacts while turtles learn the new landscape.

8.2 Foothill Yellow-legged Frog

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. 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 was listed under the California Endangered Species Act (CESA 1970), receiving endangered status for the project area. The species is also currently in review for listing under the Federal Endangered Species Act (ESA 1973). Primary threats to the species include alteration of flow and thermal regimes and other habitat degradations associated with dam operations, changes in land use, invasive species pressure, and disease (Kupferberg et al. 2012, Adams et al. 2017).

FYLF has evolved strategies to sync reproduction with river hydrograph cycles to minimize scour and desiccation risks to eggs while maximizing development time for offspring. Individual breeding frogs decide when to initiate breeding based on a suite of environmental cues (Lind et al. 1996, Wheeler and Welsh Jr. 2008). 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. 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 oviposit (Lind et al. 1996, Lind et al. 2016). 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).

Individual frogs decide when to initiate breeding based on a suite of environmental cues (Wheeler and Welsh Jr. 2008). Water temperature and water quality also influence success of the cohort. During the breeding season, these frogs (and/or eggs) are conspicuous along stream margins making surveys feasible. Because they do not generally migrate long distances, they are good indicators of local site conditions. Breeding typically occurs in spring (late March to early June), depending on water year type, hydrograph timing, and water temperature. In wetter years with higher flows and colder water, breeding can be delayed into early summer (late June to early July). 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 overwinter survival of the cohort, relative to the main channel.

FYLF historically occurred in the Zanker Farm Project Area and does still occur in Tuolumne River upstream of Don Pedro Reservoir. 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. 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 re-create 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 the FYLF reproductive cycle promotes recovery and maintenance of this state listed frog.

8.2.1 Foothill Yellow-legged Frog Habitat Assessment

An individual-based simulation model has been developed to assess reproductive success of a site based on channel geometry and flow and water temperature. The Foothill Yellow-legged Frog Assessment Model (FYFAM, Railsback et al. 2016) provides a way to evaluate and compare various hydrographs and site designs. To facilitate future comparisons of site designs proposed for rehabilitation at Zanker Farm on the lower Tuolumne River, a simulation experiment using an individual based model was conducted to establish a baseline for FYLF recruitment potential at the site under existing conditions that can later be compared to design options. 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.

8.2.1.1 Methods

FYFAM was developed to predict and assess FYLF breeding phenology and mortality risks under various flow and thermal regimes and channel geometry (Railsback et al. 2016). FYFAM is an individual based model that simulates behavior of individual frogs, froglets, and tadpoles using combination of static inputs (channel topography, habitat suitability), time-series data (flow and water temperature), look-up tables (to interpolate values across a range of flows), and a chain of over two dozen submodels allotting decision-making processes to simulated frogs and tadpoles, controlling development rates of the cohort (eggs and tadpoles), and determining daily fate of offspring in response to changes in flow and water temperature. Many of FYFAM's submodels have user definable parameters. FYFAM version V2.0.3 A was used for this evaluation; model description and program code are published online (Railsback et al. 2021).

FYFAM evaluates daily or sub-daily environmental conditions and rate of change since the previous time-step to inform decisions made by breeding frogs and influence development and mortality risk for eggs and tadpoles. Breeding frogs (breeders) "decide" when and where to lay eggs (oviposition) based on daily cell conditions; egg and tadpole development rates are influenced by water temperature; and tadpoles can move to seek or maintain suitable depth and velocity for rearing. FYFAM predicts the risk of scour and desiccation for simulated embryos through development to froglets with reproductive success assessed as the number of new froglets produced and median metamorphosis date of the cohort, which is a metric for how seasonal timing of metamorphosis may affect factors such as food availability and water temperature that influence growth and over-winter survival of first year froglets. Simulation outputs also provide information on timing and causes of mortality by life stage (egg or tadpole), as well as location of each event (oviposition, hatching, metamorphosis, and all mortality events). FYFAM is not a population model; rather, its outputs provide index values to facilitate evaluation of potential effects of deviations in flow, water temperature, and channel condition on recruitment of that year's cohort. Flow and water temperature time-series data are derived from hydraulic model outputs and can be based on actual or hypothetical data. Probabilities built into many of FYFAM's submodels depict the effects of flow and water temperature on oviposition timing, breeding window duration, and flow-related risks to egg and tadpole survival, but other forms of mortality (e.g., predation, disease, competition) are not included in FYFAM simulations.

FYFAM was applied to the Zanker Farm Project Area to evaluate existing channel condition for future comparison to design conditions. Each simulation experiment consisted of 20 replicates of a scenario. Mean and standard deviation were calculated for primary metrics to compare scenarios. R-script was used to select the most typical run from an experiment. Each run within an experiment was ranked based on distance to the mean for two key metrics (froglets produced and median date of metamorphosis (R Core Team 2015). The run with the lowest combined ranked score was selected as "most typical" and that graph was chosen to represent the simulation experiment results for that scenario.

8.2.1.2 Model Inputs

Model simulations were based on topography for the existing 2021 ground condition at the Zanker Farm Project Area. Topography for this site was a regular grid with a 1-m^2 cell size. The center point of each cell was used to generate channel geometry files with x–y coordinates and elevation for each cell (n = 919,948 cells). With each time-step of the model, mobile life stages (frogs and tadpoles) can move to any cell within the specified movement radius and appropriate depth and flow for that life stage. Time-series input files of daily mean flow and water temperature were compiled using discharge data from the USGS gage downstream of LaGrange Dam (# 11-289650) and thermographs from a data logger positioned within the project boundary (at RM 45.5). Because flow and water temperature are critical for determining timing of oviposition, developmental rate, risk of mortality, and ultimately the fate of the cohort, we evaluated a range of environmental conditions in spring and summer to see how site topography interacted with water year type to influence reproductive success. We chose three years from the past decade to represent a range of water year types influential to reproductive success of this species (2015=DRY, 2016=MOD, 2019=WET), providing context for interpretation of the model's results.

8.2.1.3 Parameter Settings and Key Assumptions

The sub-model functions of FYFAM rely on many assumptions. Parameter values for these assumptions were based on literature and adapted from personal experience for use on the lower Tuolumne River (Lind et al. 1996, Wheeler et al. 2014, Railsback et al. 2016). The full set of parameter settings for this simulation experiment are archived with the model results to facilitate consistent settings for future comparisons. Key assumptions and settings are outlined here:

- A regular grid based on a 1.0 m^2 cell size was used (FYFAM version V2.0.3A).
- 1-day time-step with simulations initiated on March 1 and continuing until the fate of all embryos in the cohort has been predicted to experience either a mortality event or achieve metamorphosis.
- Each simulation started with 100 breeders (adult female frogs; ample males is assumed); this number is consistent with potential population size at a site of this size, although likely greatly exceeds the current number of frogs at the site, which could be as low as zero. The species still occurs nearby, and this was suitable habitat prior to development of the region and management of water resources.
- Breeder fecundity was set to one egg mass annually, with clutch size fixed at 1,000 embryos. Natural range of clutches is reported as 450–1,500 but by using a fixed value we can compare results across hydrograph scenarios and site designs.
- Breeders were programmed to choose a cell for oviposition with velocity closest to the "optimal" value for oviposition, set to 0.05 m/s for these simulations, and a cell depth that was expected to remain above zero over the incubation period (given the current cell depth and rate of change in depth set at 0.03 m/d), which typically requires approximately three weeks (20 days).
- Due to the site size and large expanses of unsuitable habitat for oviposition, breeder-habitat selection was increased to 30 m per day (default 5 m/d) and tadpole-movement was increased to 5 m per day (default 2 m/d).
- Breeding only occurs when water is above a set breeding threshold temperature, which was set at an intermediate value of 11.0 °C (default range is 10.0–12.0 °C) and occurs only on days with water temperature above the threshold. Breeding wis also limited to days with relatively steady flow, defined as a change in cell depth of less than 0.03 m/day. The breeding window can span up to 90 days.
- Breeder-exponent was set to a value of "4" to spread oviposition over a realistic time period. Whether each breeder was ready to oviposit on a day meeting these criteria was stochastic,

with the probability of oviposition increasing with the number of days that water temperature had remained above the breeding threshold value. We used a breeder readiness exponent of 4 to produce a realistic breeding window. Realistic timing of oviposition is important to properly assess mortality risks in relation to the hydrograph.

- Modeled development of eggs to tadpoles, and tadpoles to froglets, was influenced by water temperature, with growth optimized at 16 °C (61 °F, McBain and Kupferberg 2012, Kupferberg et al. 2013).
- Simulations run through death (i.e., mortality event by scour or desiccation) or metamorphosis to froglet for the last embryo of the cohort (i.e., simulations end when no eggs or tadpoles remain).
- For each flow scenario (2015, 2016, 2019) twenty replicate simulations were performed and the replicates within each scenario were ranked based on froglet production and median metamorphosis date.

8.2.1.4 Sources of Mortality

Only two kinds of mortality were simulated in the model, for both egg masses and tadpoles: desiccation (when the occupied cell went dry as flow decreased) and scour (increasingly likely as cell velocity increased). Predation, competition, starvation, disease, over-winter survival, and other mortality factors are not accounted for in the model.

To model desiccation, the egg mass elevation was set at 0.1 m above the cell bottom to account for typical egg mass attachment locations. Desiccation proceeds rapidly once the egg mass is above the water surface, with 90 to 100% mortality in the first day an egg mass was above the water surface elevation.

Egg mass scour was modeled as a Bernoulli trial (stochastic true/false event) using the daily probability of an egg mass being dislodged from the substrate and carried downstream. This probability used a logistic function of cell velocity, velocity shelters, and egg depth to describe the velocity to which egg masses were exposed. Low levels of scouring mortality could occur even at relatively modest velocities (e.g., 0.1 m/s). Longer exposure and higher flows increase the chance of egg mass scour mortality.

Tadpoles were also at risk of desiccation or scour, but unlike egg masses, tadpoles can move each day in response to changing cell conditions, presumably allowing tadpoles to reduce their risk of scour by seeking low velocity cells, and track receding flows to reduce desiccation risk (Kupferberg et al. 2011). Each time-step, simulated tadpoles considered conditions in cells that were within the allotted habitat selection radius (5-m) and had a water depth greater than zero, and then they selected a cell with minimum velocity. Probability of scour on any given day increases with increasing flow velocity. For these simulations, we set tadpole strength parameters (resistance to scour) so that at cell velocity of 0.15 m/s tadpole scour survival is 90%, at 0.3 m/s tadpole scour survival drops to 10%.

8.2.1.5 Froglet Production

Embryos not lost to scour or desiccation develop at a rate influenced by water temperature, leading to metamorphosis in two to four months. FYFAM simulations end when all embryos have died or reached metamorphosis. The number of embryos that survive to become froglets is tallied as “froglet production” and is used as a metric for evaluation of simulation results and comparison of scenarios.

Overwinter survival or contribution to future breeding efforts are not evaluated directly, so “Median Date of Metamorphosis” is used to predict the condition of froglets going into winter. A “thrive” cut-off date was set for the Autumnal Equinox (September 21). Froglets emerging after that date were presumed to have less opportunity to forage before winter dormancy.

8.2.2 Results

Number of froglets produced by each scenario were averaged for 20 replicates to provide mean and standard deviation for each year evaluated, then the outcome of each replicate was compared to the mean for that scenario and the replicates were ranked with the closest to the mean value being ranked #1 (Table 19). A similar process was conducted to rank median metamorphosis date (Table 19). The most typical run for each scenario was selected to represent that scenario.

For the 2015 scenario, a dry water year, most egg masses deposited prior to peak flows were lost to scour and there was considerable loss to desiccation on the descending limb, but overall production was high and early metamorphosis allowed froglets to grow before winter (Figure 54).

For the 2016 scenario, a moderate water year, peak flows after oviposition resulted in high scour mortality of eggs. Eggs not lost to scour hatched, and tadpoles had high survival and completed metamorphosis by early August (Figure 55).

For the 2019 scenario, a wet water year, high flow and low water temperature delayed the onset of oviposition leading to late metamorphosis (Figure 56). Froglets emerging after the Autumnal Equinox are presumed to have low over-winter survival.

Table 19. Modeled breeding phenology of foothill yellow-legged frogs under existing conditions at the Zanker Farm Project Area, showing number of froglets produced and median metamorphosis date for 2015 (DRY), 2016 (MOD), and 2019 (WET) hydrographs. Each simulation starts with 100,000 embryos (100 egg masses with 1,000 embryos each). Drier years are most favorable for this river-breeding frog.

Year_Threshold (°C)	Mean Froglets	Standard Deviation of Froglets	Median Metamorphosis Date	Metamorphosis Range
2015_11.0C	53,644	4,014	07/24/2015	07/24–07/25
2016_11.0C	25,290	3,264	07/31/2016	07/29–08/02
2019_11.0C	21,326	4,262	11/03/2019	10/28–11/06

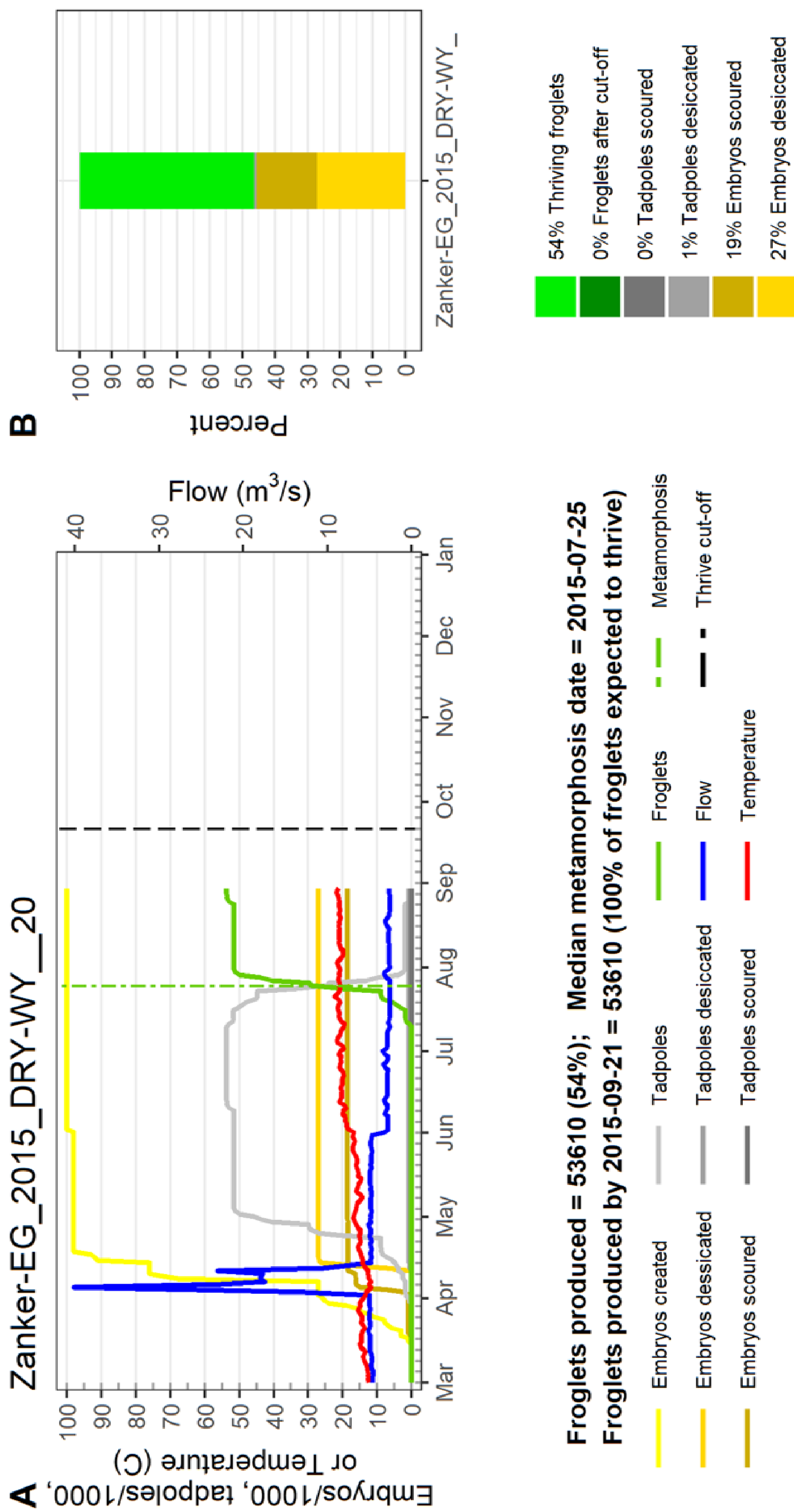


Figure 54. Typical FYFAM results for Zanker Farm existing ground in a dry year (2015) with the breeding threshold set at 11.0 °C. Graph (A) displays cumulative totals for life stage and mortality events in relation to flow and water temperature. The stacked percent bar graph (B) displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Most egg masses deposited prior to peak flows were lost to scour and there was considerable loss to desiccation on the descending limb, but overall production was high and early metamorphosis allows for froglets to grow before winter.

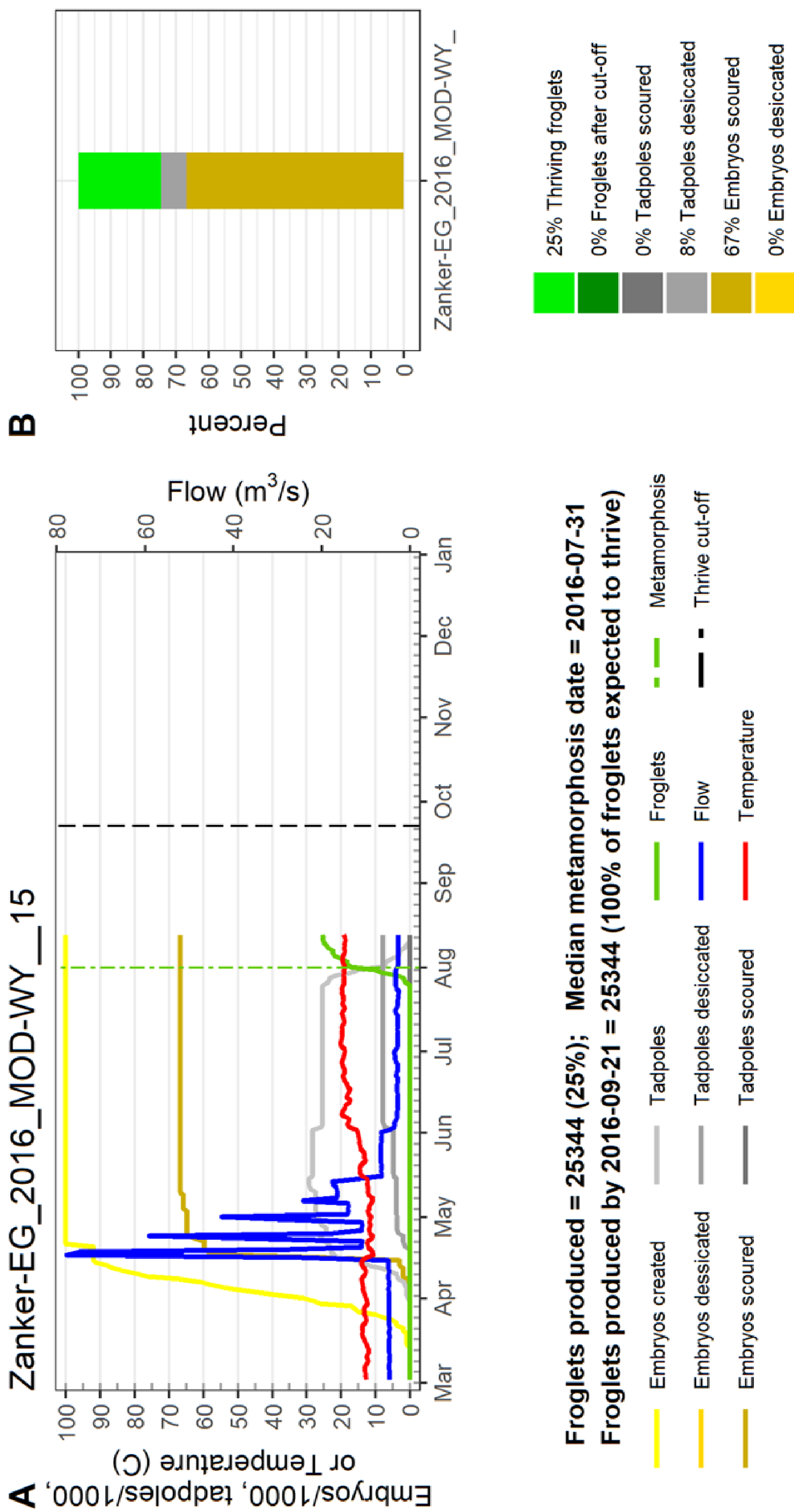


Figure 55. Typical FYFAM results for Zanker Farm existing ground in a moderate year (2016) with the breeding threshold set at 11.0 °C. Graph (A) displays cumulative totals for life stage and mortality events in relation to flow and water temperature. The stacked percent bar graph (B) displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. Peak flow after oviposition resulted in high scour mortality of eggs. Eggs not lost to scour had high survival and tadpoles completed metamorphosis by early August.

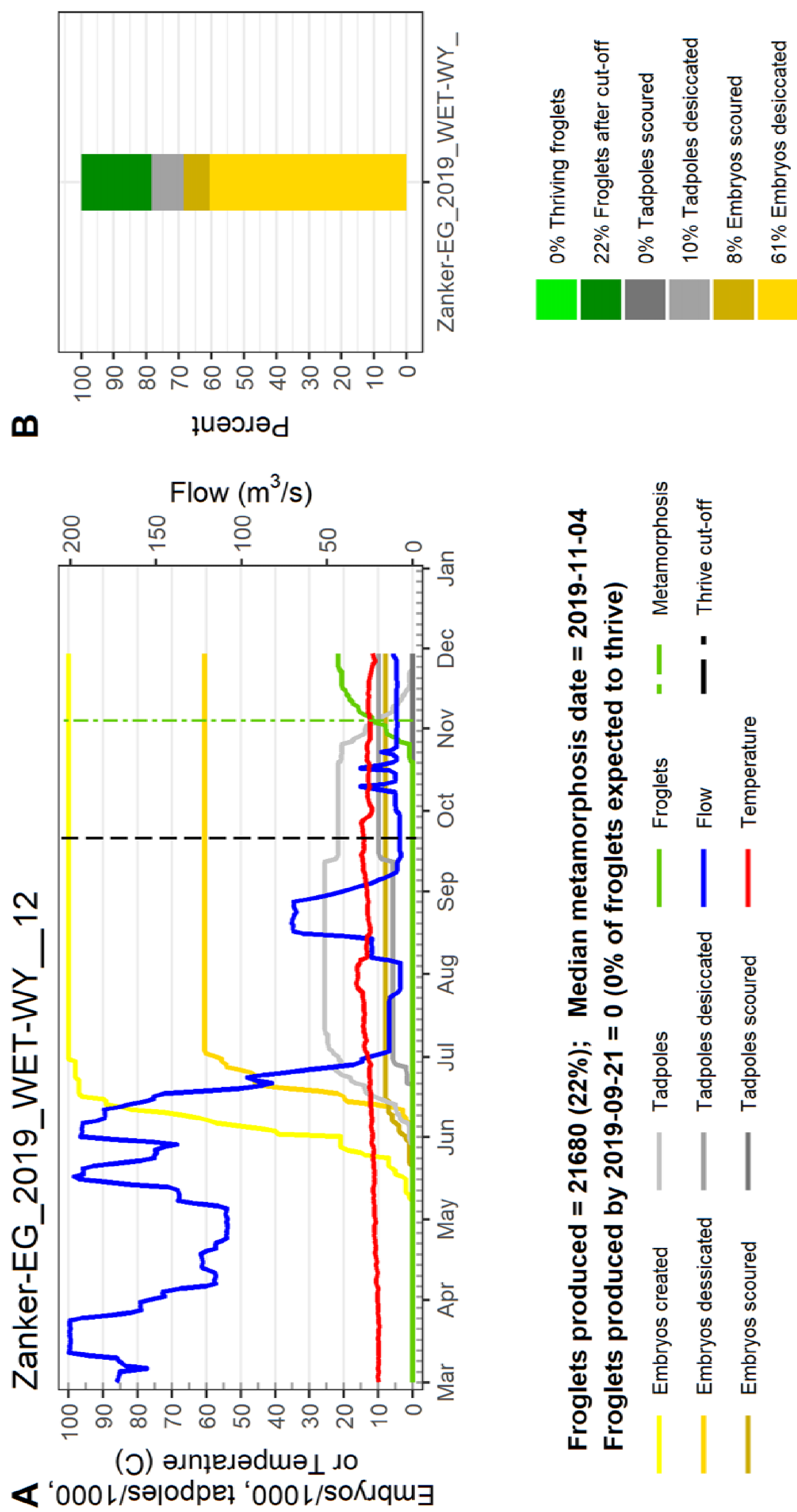


Figure 56. Typical FYFAM results for Zanker Farm existing ground in a wet year (2019) with the breeding threshold set at 11.0 °C. Graph (A) displays cumulative totals for life stages and mortality events in relation to flow and water temperature. The stacked percent bar graph (B) displays mortality factors (scour and desiccation) and froglet production for the simulated cohort of 100,000 embryos. High flow and low water temperature delayed the onset of oviposition leading to late metamorphosis.

8.2.2.1 Timing of Oviposition and Metamorphosis

Timing of oviposition is an important factor in the success of a cohort (Figure 54-A, Figure 56-A). With the breeding temperature threshold set to 11.0 °C oviposition occurred from late March to mid-June, depending on water year type. In the 2015 (dry) and 2016 (moderate) scenarios, warming water and stable flows prior to the spring hydrograph peak promoted breeding in late March through April. In the 2019 (wet) scenario, low water temperature in spring delayed oviposition to late May into June. Cooler summer water temperature (relative to 2015 and 2016) slowed the development of eggs and tadpoles. The delayed and prolonged rearing period lead to metamorphosis occurring late in October into November, far later then the presumed thrive cut-off date suggesting low over-winter survival for the cohort's froglets. Even though froglet production numbers were similar for the 2016 and 2019 scenarios, metamorphosis for 2019 was predicted to occur nearly four months later than for the 2016 scenario, reducing overwinter survival for the 2019 cohort.

8.2.2.2 Causes of Mortality

Causes of mortality for egg masses and tadpoles by scour and desiccation are quantified in a stacked percent bar graph (Figure 54-B, Figure 56-B). Percentages are based on a cohort size of 100,000 embryos (100 breeders, each producing a single egg mass containing 1,000 embryos). For all scenarios, mortality was highest for the immobile egg masses while tadpoles were able to move and track conditions favorable for survival.

In the 2015 scenario (Figure 54-B), about a quarter of the egg masses were deposited prior to the peak flow and most of these were lost to scour mortality (19%), as well as significant losses to desiccation on the descending limb (27%). Once hatched, tadpole mortality was low (1%) leading to successful metamorphosis for more than half of the embryos in the cohort (54%).

In the 2016 scenario (Figure 55-B), about 90% of egg masses were deposited prior to peak flows and scour mortality of egg masses was high (67%). The multiple peaks resulted in some loss of tadpoles to desiccation (8%). After the flow peaks, flow-related mortality was low and the warm summer water promoted development to metamorphosis by early August, leaving ample time for froglets to grow before overwintering.

In the 2019 scenario (Figure 56-B), egg mass scour mortality was low because most breeding occurred after the hydrograph peak in June. Egg mass mortality via desiccation was high because most oviposition occurred early on the descending limb of the peak, leading to dewatering of egg masses more half of the egg masses (61%) as flow decreased in the second half of June. Desiccation of young tadpoles in the last week of June reduced the cohort success by an additional 10%.

8.2.2.3 Froglet Production

For each scenario, the number of embryos reaching metamorphosis (i.e., not lost to scour or desiccation mortality) was tallied for each of twenty replicate simulations. These were averaged to provide the mean and standard deviation for froglets produced and median metamorphosis date at each breeding threshold value (Figure 54). Because timing of metamorphosis strongly influences over-winter survival it is an important consideration in predicting cohort success and population persistence. A cut-off date is used to evaluate potential survival of first year frogs. Froglets produced before and after the thrive cut-off date (September 21) can be visualized on a stacked percent bar graphs (Figure 54-B,Figure 55-B, Figure 56-B).

In the 2015 scenario, froglet production was the highest of the three years evaluated and metamorphosis was completed several weeks prior to the thrive cut-off date. The 2016 scenario produced half as many froglets as the 2015 scenario, but metamorphosis was completed more than a month before the thrive cut-off. Froglet production was similar in the 2016 and 2019 simulations, but metamorphosis occurred well after the thrive cut-off date in 2019. The later median metamorphosis date in the 2019 scenario left little time for new froglets to forage and gain weight before winter, lowering their probability of overwinter survival, so the expected contribution of this cohort to overall population success is low.

8.2.3 Discussion

These simulation experiments based on the existing ground condition at Zanker Farm provide a baseline for comparison of future channel conditions or proposed site designs. The differences in the results for the three water year types evaluated demonstrate the relationship between oviposition timing and predicted exposures to flow-related mortality events (i.e., scour and desiccation). With the model's breeding threshold temperature set at 11 ℃, the timing of oviposition is consistent with patterns reported for low elevation populations in Sierran foothills (Hayes et al. 2016).

The results showed lower scour and desiccation mortality and earlier metamorphosis dates in drier years. Wetter years had higher flow-related mortality and later metamorphosis dates, which are presumed to reduce overwinter survival of first year frogs (Catenazzi and Kupferberg 2013, Wheeler et al. 2014). And while three different flow/temperature scenarios were evaluated on a single topography, insights provided by FYFAM are quite useful for predicting how site configuration may affect reproductive success for this river-breeding frog.

Site configuration played an important role in determining the exposure of eggs and tadpoles to flow-related mortality events. In the 2015 and 2016 scenarios, peak flows were relatively low compared to 2019. In 2015 and 2016, egg masses were primarily deposited in the margins of the main channel where desiccation risk tends to be lower, but scour risk is higher. This strategy worked well in 2015, when most oviposition occurred on the descending limb of the peak flow, but in 2016, most egg masses were deposited in the main channel prior to the set of flow peaks resulting in high scour mortality as velocity increased in the confined channel. A wider channel with greater complexity would attenuate the flow velocity of the increased water volume and reduce the risk of scour mortality for egg masses and tadpoles. In contrast to 2016, egg mass scour mortality was low in 2019 because many of the egg masses were deposited on high floodplains that quickly dewatered on the descending limb, increasing desiccation mortality risk. This effect was especially evident towards the downstream end of the site on the right bank. Lowering of floodplains to increase the duration of floodplain inundation is expected to improve survival of egg masses to hatching.

Maybe one of the more important findings from this set of simulation experiments is that the large size of the site and the fragmented distribution of suitable oviposition habitat made it challenging for some of the virtual breeders to find suitable habitat within specified time and movement limits. The long, straight section of channel in the middle of the project area separates the areas of more suitable oviposition habitat at both ends the project area. Increasing channel complexity in this section is expected to increase availability of suitable oviposition habitat and improve connectivity across the site. Furthermore, rehabilitation at the Zanker Farm Project Area can improve connectivity between FYLF populations upstream and rehabilitation sites located just downstream, increasing the landscape scale of project benefits for this species.

8.3 California Red-legged Frog

The California Red-legged Frog (*Rana draytonii*) was named the official state amphibian in 2014; this animal is the likely subject of Mark Twain's short story, "Jumping Frog of Calaveras County," set in the nearby foothills. Dramatic population declines are reported from most of its range, largely due to land conversion for urbanization and agriculture, invasive species pressure, and historically, human consumption. In 1998, the species was federally listed as threatened under the Endangered Species Act (ESA 1973) and is a Priority 1 Species of Special Concern in California (Jennings and

Hayes 1994, Thomson et al. 2016). The CNDDB has reported localities south of the Zanker Farm Project Area, with occurrences on the Snelling USGS 7.5-minute quadrangle map. Current population status in the Project Area is unknown, but slow-moving portions of the river and adjacent ponds appear suitable for reproduction, and the surrounding riparian forest and grassland habitats could support these frogs outside of breeding season.

Adults are found in grasslands, shrublands, and forests near permanent or ephemeral waters from sea level to over 8,000 feet elevation. Breeding occurs in winter or early spring in wetlands, ponds, lakes, reservoirs, and stream pools. Tadpoles require at least four months to reach metamorphosis, and in some areas, they may overwinter as tadpoles, transforming the following year. Frogs may seek refuge underground, often in mammal burrows, when ephemeral waters dry.

Development of ponds and stream pools in the proposed project area is expected to improve aquatic habitat for this species, although there is some risk of impact to aestivating frogs in the upland during construction.

8.4 Western Spadefoot Toad

The Western Spadefoot Toad (*Spea hammondii*) historically occurred throughout the Central Valley, Salinas Valley, and southwest California. This species has been extirpated from much of the former range due to land conversion for agricultural and urban development and introduction of mosquito fish at some locations. It is considered a Species of Special Concern by CDFW and classified as Sensitive by BLM (Thomson et al. 2016). The CNDDB documents localities near the Zanker Farm Project and surrounding area, with occurrences reported from the Knights Ferry, Cooperstown, La Grange, Montpelier, Turlock Lake, and Snelling USGS 7.5-minute quadrangle maps. Current population status in the Project Area is unknown, but the habitat appears suitable for persistence of the Western Spadefoot Toad. Due to the primarily fossorial habits, sporadic emergence for breeding, and short aquatic larval stage, this species can be difficult to detect without appropriately timed surveys.

Breeding usually occurs in vernal pools and other temporary rain pools and cattle tanks, often with turbid water and little or no cover, but it can occur in pools of intermittent streams. Breeding typically occurs one to two days after heavy rains that form temporary shallow pools, typically from January to May, and peaking in February and March, but this species breeds opportunistically and can breed at any time if conditions are suitable. Egg and tadpole development are rapid, with tadpoles reaching metamorphosis in one to two months. A few nights after metamorphosis, juveniles leave the breeding pool but where they go and how they survive in dry conditions is not well-studied; they may burrow into mud of the drying pond bottom. Adults spend dry periods underground, emerging after rains to move to breeding pools. During dry years, breeding pools may not form, so breeding does not occur until rains return to saturate the land and form pools.

8.5 California Tiger Salamander

Since 2010 the California Tiger Salamander (*Ambystoma californiense*) has been listed as a Threatened Species under the California Endangered Species Act (CESA 1970). At the federal level, the Central California Distinct Population Segment (DPS) has been listed as Threatened since 2004, while the other DPS regions received Endangered status (ESA 1973). The CNDDB documents localities near the Zanker Farm Project and surrounding area, with occurrences reported from the Knights Ferry, Paulsell, Cooperstown, La Grange, Montpelier, Turlock Lake, and Snelling USGS 7.5-minute quadrangle maps. Current population status in the Project Area is unknown, but the habitat appears suitable for the California Tiger Salamander. Surveys for aquatic larvae are often used to detect presence of this species.

Adults are primarily terrestrial but are rarely seen due to nocturnal and fossorial habits, occupying mammal burrows through the dry season. With the onset of seasonal rains in late fall or winter, adults emerge from underground and migrate overland to breeding pools, seeking ephemeral waters for mating and egg-laying. Single eggs or small clusters are attached to submerged vegetation, branches, or other submerged structures and hatch in two to four weeks. The aquatic larvae feed on a wide variety of invertebrates. The diet shifts with ontogeny and older larvae may also consume vertebrate prey. Conversely, larvae are vulnerable to a wide variety of invertebrate and vertebrate predators. Larvae generally require three to six months to reach metamorphosis, transforming into terrestrial adults that emigrate from the pond to find subterranean refuge as breeding pools dry. Like the red-legged frog and spadefoot toad, this species is likely to benefit from proposed site rehabilitation, but animals hidden underground could be at risk from ground disturbance during construction. Addition of branches to ponds with barren substrates could provide egg attachment sites.

9 BENTHIC MACROINVERTEBRATES

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). The BMI assemblage can be used to assess the overall "health" of a riverine system. Indices measuring diversity and abundance calculated from BMI samples within a study area can be indicators of environmental stress including habitat degradation and pollution relative to undisturbed areas (Gasith and Resh 1999).

Habitat restoration efforts aimed to improve in-channel habitat in degraded reaches for salmonids and other riverine dependent species, including amphibians and turtles, typically focus on physical habitat elements (e.g., creating or increasing slow water habitats, enhancing channel complexity, improving connectivity to the floodplain, etc.). Ecological food webs play a large role in the success of restoration efforts aimed toward improving salmonid abundance if food resources are more limiting to salmonid production than abiotic factors such as physical habitat (Bellmore et al. 2017). High growth rates require abundant and diverse food resources, even when physical habitat and water quality conditions are favorable (Dill et al. 1981) and can be low when fish densities are high even in high quality habitat (Grant and Imre 2005).

BMI assemblage studies in the lower Tuolumne River downstream of La Grange Dam and near the project area have been conducted to assess point source sedimentation effects on restoration efforts (M&T 2008), and to document long-term conditions of physical habitat and aquatic ecosystem health downstream of the NDP Dam (Stillwater Sciences 2010). These studies can provide a baseline picture of BMI community assemblages in the Zanker Farm Project Area prior to construction. The 2009 *Aquatic Invertebrate Monitoring and Summary Update* report (Stillwater Sciences 2010) documented results of long-term BMI monitoring downstream of La Grange Dam (2002 to 2009). Results from 2009 sampling indicated percent EPT (Ephemeroptera, Pleocoptera, Trichoptera), a measure of species intolerant to impaired conditions, was relatively high at 77% in riffle 23C (RM 42.3, approximately 3 miles downstream of Zanker Farm) and at 67% in riffle 4A (RM 48.8, approximately 2 miles upstream), compared to other sampling sites (Figure 57). These findings indicated a decrease in sediment impairment in this section of the river compared to other sections. The study also found that increases in summer flows implemented in 1996 after the FERC Settlement Agreement have resulted in beneficial shifts in food supply for fishes from community composition of pollution-tolerant organisms towards those with higher food value for fish (Stillwater Sciences 2010, TID and MID 2013b). Unfortunately, the study did not collect any data in the Zanker Farm Project Area, which is a long, slow, channelized stretch likely to have minimal invertebrate production.

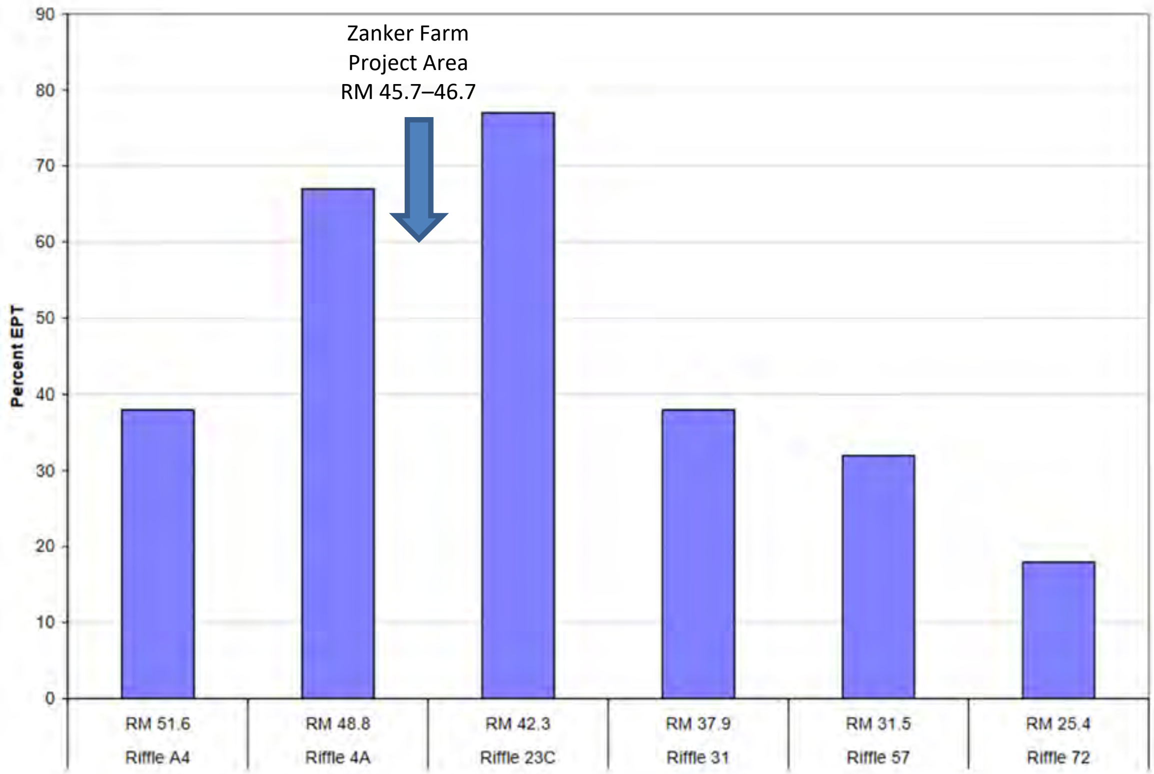


Figure 57. Percent EPT by site for 2009 aquatic invertebrate monitoring conducted for the 2009 FERC lower Tuolumne River annual report (Stillwater Sciences 2010).

The McBain & Trush study (M&T 2008) included two riffles close to the project area, riffle 17 (RM 44.5) and riffle 20 (RM 43.2 in the Bobcat Flat Phase I project area) that were not included in the long-term monitoring study conducted by Stillwater Sciences (2010). Percent EPT values for these two riffles can give a snapshot of habitat conditions closer to the project area. Percent EPT was 68% in riffle 17 and 54% in riffle 20. Compared to Percent EPT for riffle 4A and riffle 23C from the Stillwater Sciences study for 2008, sediment impairment near the project was relatively similar in relation to riffle 4A and 23C and less impaired compared to the entire extent of the study for the Stillwater Sciences study.

10 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 20, Figure 58), 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 20, Figure 58). 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 further into the design process. After a preliminary design has been developed, the blue elderberry plants that fall within or adjacent to the project footprint will be evaluated. Due to the dense overstory canopy, the accuracy of the GPS unit was limited. When further mapping is conducted, the shrub centerpoint 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 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 VELB. 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 feet 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).

Table 20. 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 58. 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.

11 BASIS OF DESIGN

Several lower Tuolumne River planning and monitoring documents provide the basis of information needed to design the Zanker Farm restoration project, including early phases of the nearby Bobcat Flat rehabilitation project located approximately 1.3 miles downstream:

Habitat Restoration Plan for the Lower Tuolumne River Corridor (M&T 2000).

Tuolumne River Floodway Restoration, Project Design Approach and Rationale. Coarse Sediment Mining Reach (River Mile 34.3 to 40.3) and Special Run Pools 9/10 (River Mile 25.0 to 25.9, M&T and Vick 2004).

Bobcat Flat RM 43 Coarse Sediment Introduction Design Document (M&T 2004a).

Coarse Sediment Management Plan for the Lower Tuolumne River (M&T 2004b).

Monitoring the Impacts on the Tuolumne River from Peaslee Creek Erosion and Runoff Events of January 2008 (M&T 2008).

Bobcat Flat River Mile (RM) 43 Phase II Restoration Final Design Document (M&T 2011).

Tuolumne River Bobcat Flat Salmonid Habitat Restoration, Duck Slough As-Built Final Submittal (MA 2018).

The documents above contain studies and data analyses that provide general design guidelines for the lower Tuolumne River, including the coarse sediment-bedded reach that encompasses Zanker Farm. Contemporary post-NDP Dam flood flows from 1970–2017 (excluding 1997) were used to determine a recommended bankfull discharge of approximately 3,500 cfs (Table 21). However, NDP Dam flood control releases often approach 5,400 cfs, making this a more reflective bankfull flow target (M&T 2004b). Recommended coarse sediment sizes for in-channel features are provided in Table 22. Coarse sediment may be harvested from channel-adjacent floodplains, which would then be backfilled to design grade with fine sediments. These coarse sediment sizes are appropriately scaled for contemporary flood flows (i.e., mobilization of D_{84} occurs at 5,400 cfs bankfull flow). Table 23 provides guidelines for mainstem channel design dimensions for the portion of the lower Tuolumne River that encompasses Zanker Farm. Side channel dimensions are not provided in Table 23; however, the construction and subsequent monitoring of Duck Slough, a successful side channel feature within the Bobcat Flat Phase II project, provide reasonable channel dimensions for the Zanker Farm Project (Figure 59). Constructed low-flow side channel widths ranged from 10–20 ft, representing 10–20% of mainstem channel low-flow widths (MA 2018).

Table 21. Post-New Don Pedro Project peak flow magnitudes using a Log-Pearson III fit of measured peak flows at USGS below La Grange Dam gaging station (USGS #11-289650), updated from McBain and Trush (2004b).

Recurrence Interval (years)	Post-New Don Pedro Dam Flow Magnitude at La Grange 1970–2017 (cfs)[1]
1.5	2,380
2	3,430
3	4,680
5	6,810
10	9,680
25	14,000

[1] Excludes January 1997 flood (59,000 cfs instantaneous peak).

Table 22. Recommended coarse sediment composition for spawning habitat (M&T 2011). Larger particles may be used in medial and point bars to decrease mobility and promote mainstem planform complexity.

Percent of Total Composition	Particle Size Range (mm)	Particle Size Range (in)
15%	6.5–12.5	¼ – ½
30%	12.5–25	½ – 1
35%	25–50	1–2
20%	50–100	2–4

Table 23. Summary of channel design dimension guidelines for the lower Tuolumne River, including channel slope dimensions from specific reaches and sites described in the Coarse Sediment Management Plan (M&T 2004b).

Channel Morphology Parameter	Dimension
Channel width at low water (150 cfs)	75–90 ft
Thalweg depth at low water (pools)	4–8 ft
Thalweg depth at low water (riffles)	0.5–1.5 ft
Width at spawning flow (150–300 cfs)	90–100 ft
Average thalweg depth at spawning flow (riffles)	1–2 ft
Average water velocity at spawning flow	1.3–2.5 ft/sec
Riffle slope at spawning flow	0.0019
Bankfull discharge	5,000 cfs
Bankfull flow target	5,400 cfs
Bankfull width	175–200 ft
Average bankfull depth	6 ft
Average bankfull water velocity	4.4 ft/sec
Maximum floodway width	> 500 ft
Minimum floodway width	500 ft
Maximum design floodway streamflow	15,000 cfs
Meander wavelength	1,600 ft
Amplitude	< 250 ft
Sinuosity	1.1
High flow energy slope	0.0014[a], 0.00068[b], 0.00043[c]

[a] 7/11, M.J. Ruddy, and Reed portion of Coarse Sediment Mining Reach
[b] Warner-Deardorff portion of Coarse Sediment Mining Reach
[c] SRP 9 and SRP 10

Floodplain benches typically would target bankfull flows associated with the 1.5-year (2,380 cfs) to 3-year (4,680 cfs) event (Table 21). However, by designing floodplain benches adjacent to the mainstem channel and side channels using flow targets ranging from 50 cfs to 2,380 cfs, floodplain benches will be inundated for long periods of time during the winter and spring, providing opportunities for off-channel salmonid fry and juvenile rearing. Higher surfaces designed to be inundated between 5,000 cfs and 9,000 cfs provide refugia for rearing salmonids during wetter water years and remove the armored layer of coarse sediment, allowing for native grasses or upland vegetation plantings. In addition, monitoring of the Bobcat Flat Phase I project after a mass wasting event occurred on Peaslee Creek in January 2008 showed constructed bars and low floodplain benches had accumulated up to several inches of fine sediment deposits (M&T 2008). With continued agricultural activities and potentially large amounts of fine sediment within the active channel upstream of the Zanker Farm Project Area, low and frequently inundated floodplain benches could accumulate fine sediment, which in turn will provide more suitable substrate for native riparian vegetation to establish. Over time, these surfaces should continue to evolve into an appropriately scaled floodplain. During construction of floodplains, mature riparian and upland trees will be salvaged for use as habitat features in proposed side channels.

Figure 59. Example of dredger slough reclamation from 2011 Duck Slough project, which successfully converted a slough full of invasive species into a functioning side-channel. Looking downstream pre-construction (top) and post-construction (bottom).

12 SUMMARY

The existing Tuolumne River reach through the Zanker Farm Project Area is a low-sinuosity channel exhibiting lake–cascade morphology and modest floodplain interaction. Historic mining activity and flow regulation has degraded the quality of spawning habitat for salmonids, while the lack of coarse sediment supply combined with a reduction in high flows necessary to mobilize the limited available coarse sediment has prevented recovery of natural channel morphology. The goal of the Zanker Farm restoration project is to restore the natural channel morphology within the reach, thereby creating favorable habitat conditions for native aquatic species, including listed salmonids, turtles, and amphibians. The design strategy is to increase channel complexity, improve hydraulic connectivity, reduce predatory fish habitat, restore geomorphic processes, increase coarse sediment storage, provide opportunities for native plantings (wetland, riparian, and upland) and natural recruitment, and increase salmonid habitat for all life stages. It is infeasible to restore natural geomorphic and ecological function to unimpaired (i.e., pre-dam) conditions, so all elements of the design strategy take into account the contemporary (regulated) flow regime and consider potential future changes to the flow regime.

The assessment of existing conditions presented in this report was conducted to establish a baseline for habitat analysis, ecological analysis, and conceptual design development in future stages of the project. The existing conditions assessment describes regional and local geology, hydrology, channel morphology, existing vegetation, existing biological resources, and site hydraulics. McBain Associates conducted an initial site investigation to collect data in support of this assessment, which consisted of streamflow measurement and monitoring; photopoint establishment and baseline monitoring; vegetation mapping; sediment mapping; and a survey of topography, bathymetry, and water surface elevation within the project area.

Based on geologic maps and 2005 test pit data, the geology of the site is comprised primarily of alluvium (late-Holocene alluvial terraces and recent river deposits) and dredger tailings. Limited exposures of clay hardpan were observed and may be laterally extensive across the site. Coarse sediment grain size distributions were obtained from surface sampling and from the existing test pit data. Flood frequency and flow duration analyses were performed using streamflow data from the USGS gage located below La Grange Dam using the post-New Don Pedro Dam flow regime, i.e., 1971 to present. Hydrologic data were used to identify significant flows with respect to salmonid habitat and riparian plant species, which informed 2-D hydraulic modeling efforts. Historic aerial imagery combined with survey data, grain size assessments, and field observations were used to describe channel morphology. Notable geomorphic features include the alcove/high-flow side channel at the upstream end of the site, the off-channel sloughs bisected by the remnant haul road on the left bank in the middle of the site, and a shift in mainstem alignment just downstream of the primary riffle control that occurred in response to 2017 peak flows. The island-riffle complex associated with the downstream hydraulic control is bordered by the clay hardpan, which prevents lateral migration to the south, concentrating hydraulic forces toward the northern portion of the channel, and contributing to bed scour and channel instability. Recent channel change and existing morphology indicate a potential for channel incision, which would lower the water surface elevation throughout most of the project area.

A 2-D hydraulic model was developed for the project to supply hydraulic data inputs for the vegetation zonation analysis, salmonid habitat evaluation, and foothill yellow-legged frog habitat assessment. Water surface elevation and shear stress results from the model will also be used to provide target elevations for design features (e.g., floodplain benches, riffle crests) and to determine appropriate grain-size distributions for fill material during the design stage of the project. The hydraulic model for the Zanker Farm Project was built using the calibrated Bobcat Flat Phase III model as starting point (MA 2020). The model terrain, which extends from upstream of the Zanker Farm Project Area to the downstream boundary of the Bobcat Flat property, was updated with topography and bathymetry collected in the Zanker Farm Project Area. Vegetation and substrate mapping in Zanker Farm was used to update the Manning's *n* roughness map for the model. The updated hydraulic model was then calibrated using water surface elevation data collected in the Zanker Farm Project Area at a flow of 110 cfs. Select flows were run and the depth and velocity results were exported to conduct the various ecological analyses.

Vegetation was mapped in the field within the project area and opportunistically outside the project area to create a high-resolution map of existing riparian and adjacent upland vegetation. Twenty-nine vegetated and five unvegetated cover types were mapped, with non-native grassland observed as the most abundant cover type within the project area. Sensitive natural communities were identified among the mapped vegetated cover types based on alliance.

Vegetation zonation created by hydrologic and physical gradients was described as a basis of revegetation design. The 80 cfs WSE hydraulic model results were used to assess existing vegetation zonation. This flow is considered to be in the range of the lowest seasonal flows in drier years and was used to approximate groundwater elevations for this period. Four vegetation zones and one aquatic zone were defined based on the median elevations of different cover types, with each zone defined as an elevation above the 80 cfs water surface elevation.

Available literature and monitoring data were used to evaluate existing habitat conditions for fish species, turtles, amphibians, and benthic macroinvertebrates in the Tuolumne River. Weighted usable area (WUA) curves depicting a weighted measure of habitat for targeted salmonid species and life history stages at different flows were calculated using modeled and mapped habitat data in the project area. WUA calculations used 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. The depth and velocity results from the hydraulic model for selected analysis flows were utilized along with mapped cover and substrate data to calculate WUA.

The Foothill Yellow-legged Frog Assessment Model (FYFAM) was used to quantitatively evaluate existing habitat for foothill yellow-legged frog. FYFAM is an individual-based model developed to predict and assess FYLF breeding phenology and mortality risks under various flow and thermal regimes and channel geometry. The model inputs included channel topography, habitat suitability data, flow data, water temperature data, and depth and velocity results from the hydraulic model. Time series of daily mean flow and water temperature data from three years in the past decade were used to represent a range of water-year types influential to reproductive success of this species (2015=DRY, 2016=MOD, 2019=WET). The model predicted froglet production, timing of oviposition and metamorphosis, and mortality for each water-year type simulated.

This documentation of existing conditions at the Zanker Farm Project Area establishes a baseline for future design and monitoring efforts with respect to the elements most important to the project goals and objectives. A description of existing topography/channel morphology and hydraulics is the foundation for development of conceptual restoration designs. In later design stages, the terrain model and grain-size distribution data will be used to calculate earthwork volumes and evaluate bed-mobility. The salmonid habitat, HAR, and FYFAM analyses are three primary tools to evaluate the potential for restoration designs to improve habitats relative to existing conditions. The vegetation zonation analysis will be used to evaluate riparian revegetation opportunities specific to each design alternative. Once a final design is selected, the zonation analysis will be used to develop revegetation designs that use height above river concepts to place plant species in design locations where they will grow successfully.

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APPENDIX A: TEST PIT DATA

Table A-1. The 55 test pits and associated data collected during 2003 subsurface exploration and grain size analysis.

Test Pit Name	Depth of test pit (ft)	Thickness of gravel in test pit (ft)	Percentage of sample < 8 mm	Percentage of sample > 128 mm	Percentage of sample between 8 mm and < 128 mm
03ZD01	7	0	61%	0%	39%
03ZD02	6.5	1.5	20%	0%	80%
03ZD03	5.5	2	25%	0%	75%
03ZD04-A	7	7	37%	0%	63%
03ZD04-B	7	7	37%	0%	63%
03ZD05	4	2	28%	17%	54%
03ZD06	5	4	9%	0%	91%
03ZD07	4.5	3.5	21%	0%	79%
03ZD08	7.5	7.5	15%	8%	77%
03ZD09	6	4.5	7%	0%	93%
03ZD10	5	3.5	19%	0%	81%
03ZD11	8.5	8.5	6%	22%	72%
03ZD12	6	0	100%	0%	0%
03ZD13	8.5	7.5	28%	0%	72%
03ZD14	6.5	5	8%	8%	84%
03ZD15	7	0	10%	12%	77%
03ZD16	8	5	9%	0%	91%
03ZD17	7	1.5	10%	34%	56%
03ZD18	6	2	18%	0%	82%
03ZD19	6	1	22%	0%	78%
03ZD20	7.5	1.5	19%	0%	81%
03ZD21	5.5	3.5	12%	0%	88%
03ZD22	6.5	6.5	11%	28%	61%
03ZD23	7	5.5	4%	10%	87%
03ZD24	7	3.5	12%	0%	88%
03ZD25	7	2	3%	9%	88%
03ZD26	6.5	1.5	3%	0%	97%
03ZD27	6	6	9%	39%	52%
03ZD28	7	0	100%	0%	0%
03ZD29	5	2	34%	0%	66%
03ZD30	4.5	2.5	5%	0%	95%
03ZD31	5.5	1	1%	0%	99%
03ZD32	4.5	0.7	21%	17%	62%
03ZD33	6	0	100%	0%	0%

Test Pit Name	Depth of test pit (ft)	Thickness of gravel in test pit (ft)	Percentage of sample < 8 mm	Percentage of sample > 128 mm	Percentage of sample between 8 mm and < 128 mm
03ZD34	6.5	6	25%	11%	65%
03ZD35	5	1.5	46%	0%	54%
03ZD36	5	0.5	100%	0%	0%
03ZD37	9	9	14%	13%	73%
03ZD38	8	8	12%	0%	88%
03ZD39	7	7	3%	10%	88%
03ZD40	7	7	22%	15%	63%
03ZD41	7	1	24%	0%	76%
03ZD42	6	0.5	9%	0%	91%
03ZD43	6.5	1	24%	15%	61%
03ZD44	7	1	15%	13%	72%
03ZD45	7.5	7.5	15%	8%	77%
03ZD46	5.5	5.5	12%	16%	72%
03ZD47	6	6	4%	0%	96%
03ZD48-A	6	6	9%	0%	91%
03ZD48-B	6	6	15%	1%	83%
03ZD49-A	7.5	1.5	2%	41%	57%
03ZD49-B	7.5	1.5	10%	0%	90%
03ZD50	6.5	2	14%	23%	63%
03ZD51	7	7	4%	0%	96%
03ZD52	6	1.5	7%	0%	93%
03ZD53	6.5	1	14%	0%	86%

APPENDIX B: LONGITUDINAL PROFILE AND CROSS SECTION SURVEYS

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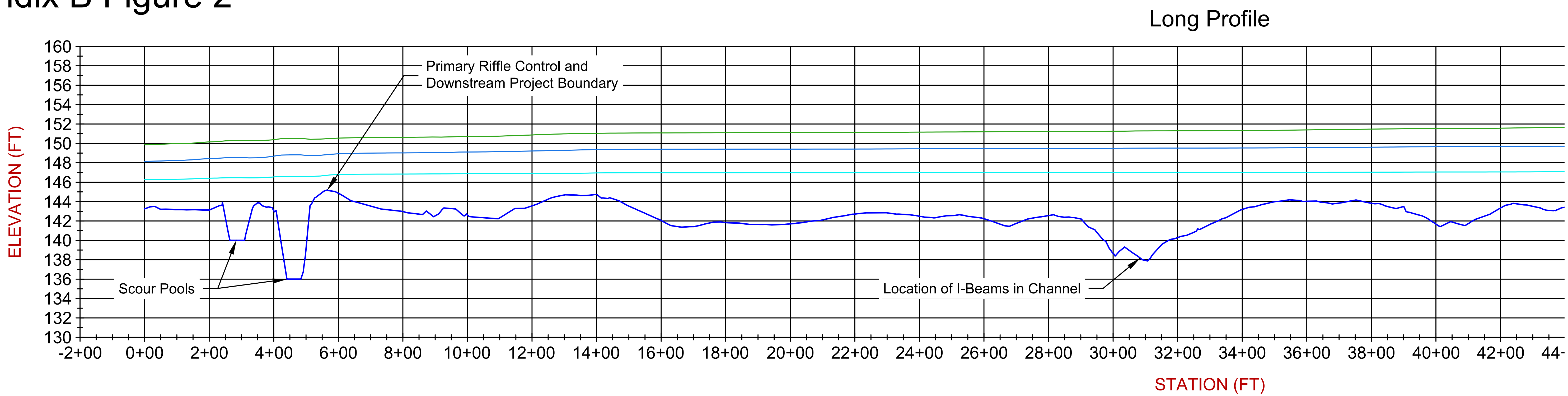
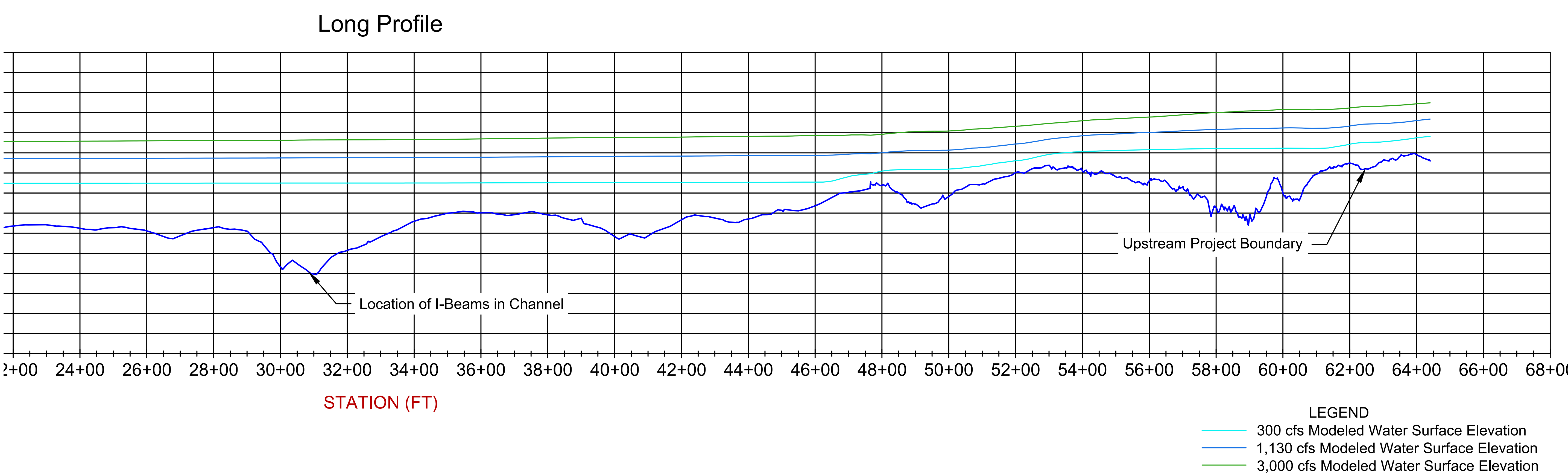
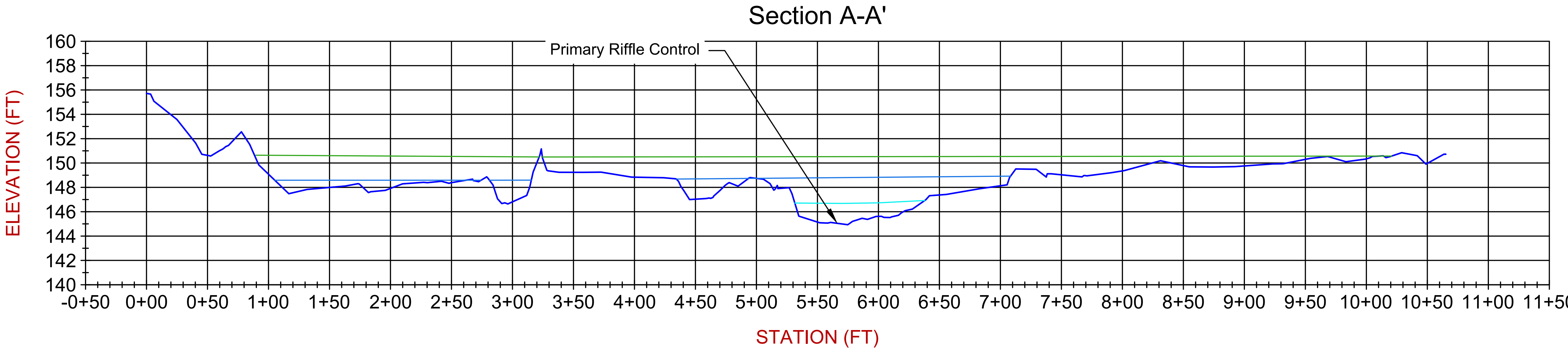
Appendix B
Figure 1

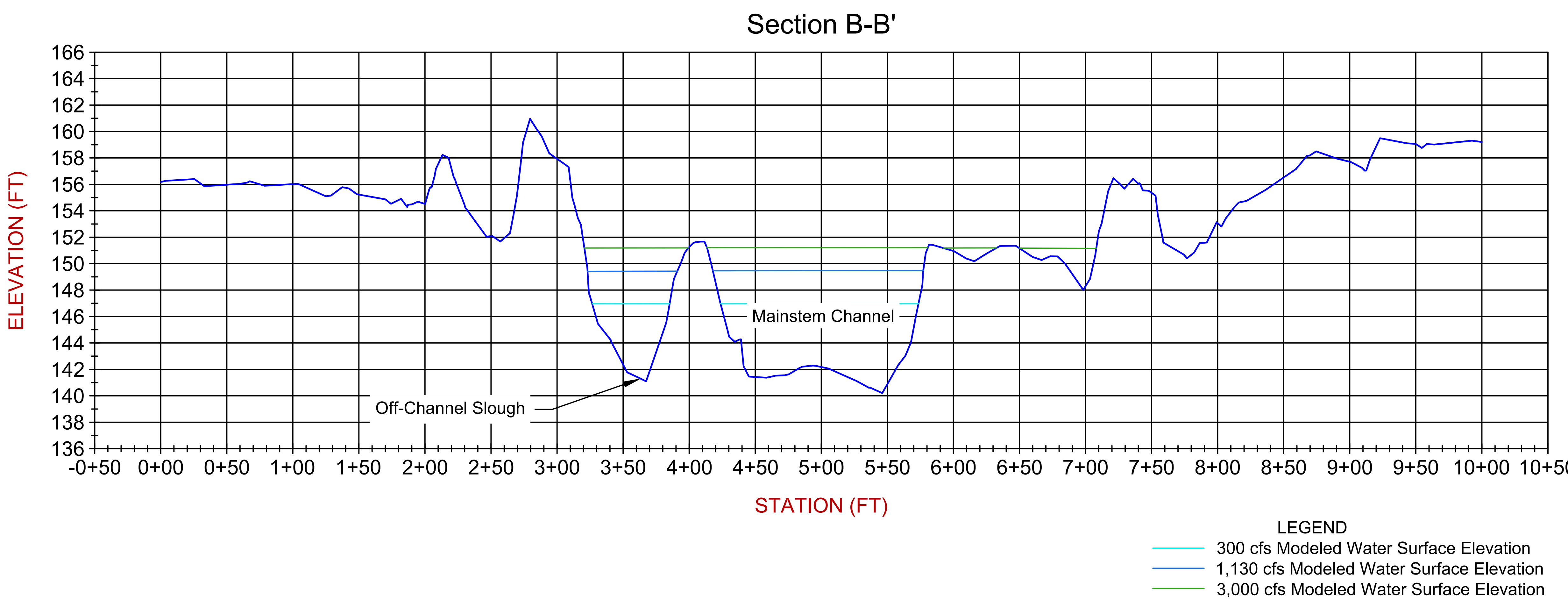
Appendix B Figure 2



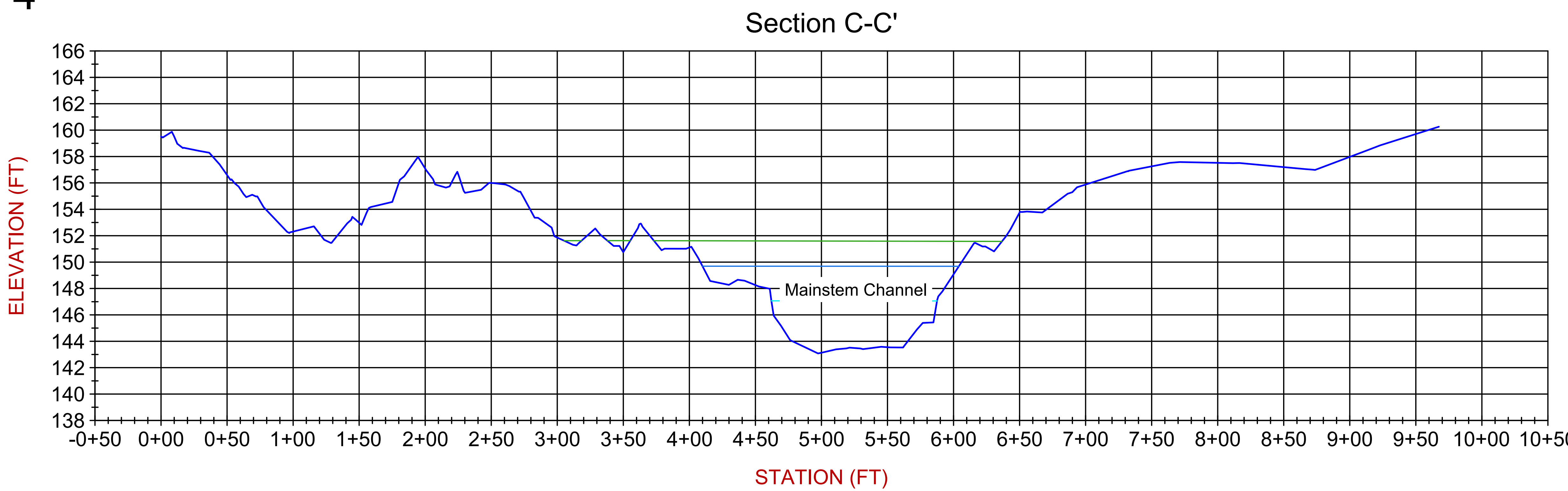


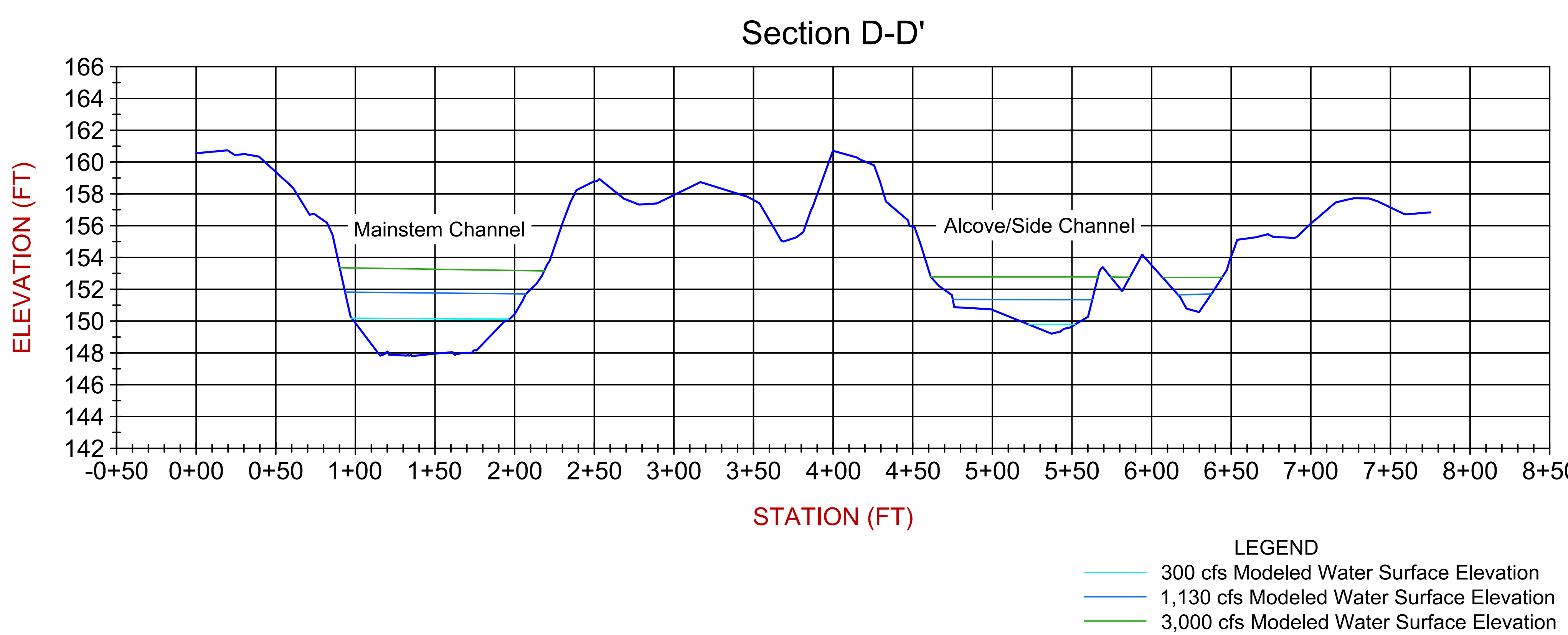
Appendix B
Figure 3





Appendix B
Figure 4





APPENDIX C: PHOTO ATLAS

Table C-1. Matrix of Zanker Farm photo points. Photo point number, file name, date of photo, northing and easting, and direction of photo. Red text denotes photographs have not been taken at this time.

PPT No.	File Name (*.jpg)	Photo Date	Location		Facing
			Northing	Easting	
1	_		20544443.812	6560662.789	WNW
2	Zanker_PP2	5/21/2021	2054278.858	6560050.371	WNW
3	Zanker_PP3	5/21/2021	2053297.910	6559059.210	NW
4	Zanker_PP4	5/21/2021	2053319.874	6558872.986	NE
5	Zanker_PP5	5/21/2021	2053391.534	6558762.827	NW
6			2052823.964	6558035.996	NE
7			2053324.796	6559621.943	NW
8	Zanker_PP8	5/21/2021	2052172.700	6556511.550	NW

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

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

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

PHOTOPOINT 1

Photopoint 1. PP-1 faces north overlooking the river and is located at the top of the Zanker Farm project site. Photos have not been taken at PP-1 at this time.

PHOTOPOINT 2

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

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

PHOTOPOINT 4

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

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.

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

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. Photos have not been taken at PP-6 at this time.

PHOTOPOINT 7

Photopoint 7. PP-7 has a vantage point over the left bank floodplain. Photos have not been taken at PP-7 at this time.

PHOTOPOINT 8

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.

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.