ADOBE CREEK CHI HABITAT SUITABILITY ASSESSMENT

Prepared for the Big Valley Band of Pomo Indians

November 13, 2023

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FlowWest

Chi in Adobe Creek at Soda Bay Road on April 15th, 2023. Photo by Marlon Jack, Big Valley Environmental Protection Agency.

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PURPOSE AND NEED

This study investigates habitat requirements for the Clear Lake hitch *Lavinia exilicauda chi* (chi) in Adobe Creek, with a specific focus on minimum streamflow for passage. Adobe Creek is a tributary to Clear Lake, the largest natural freshwater lake within California, and provides spawning habitat for chi. Adobe Creek flows from upstream in the Coastal Range, just under seven miles to the southwestern boundary of Clear Lake, and provides recharge to the aquifers within the Big Valley subbasin (see Figure 1). Both Adobe Creek and its tributary Highland Springs have been dammed since 1962; Highland Springs Reservoir has a storage capacity of 1,090 acre-feet and Adobe Creek Reservoir has a capacity of 90 acre-feet (County of Lake 2023). Channelization for flood control and historic gravel mining have led to downcutting of the Adobe Creek channel bed, lowering the creek elevation by as much as six feet in some areas (County of Lake 2010). Building on Big Valley Band of Pomo Indians Environmental Protection Agency's (BVR EPA) Water Climate Adaptation Plan on Adobe Creek (BVR EPA 2020) this study involved the acquisition of new topographic, imagery, and pressure transducer data; the development of a 2-D hydrodynamic model of Adobe Creek; and the compilation of Traditional Ecological Knowledge (TEK) from tribal members on creek habitat. The results from the 2-D model are integrated into habitat suitability curves to identify percent habitat within the creek at a variety of flows and identify the minimum flows required to support chi migration. The findings from this study are intended to support management actions of water resources in the Big Valley Subbasin, which are urgently needed to protect the chi.

The chi are a critical resource for Pomo people and other Indigenous peoples who have lived in the Clear Lake watershed since time immemorial. Tribal members of the Big Valley Band of Pomo Indians and the other Tribes in the watershed have observed degrading habitat conditions and declining chi numbers for decades. The chi were listed as threatened under the California Endangered Species Act (CESA) in 2014. In 2020, USFWS rejected the 2013 petition to list the chi as a federally threatened species, and that ruling was contested in 2021. USFWS has stated they will issue another ruling in 2025, although Tribes in the Clear Lake watershed are advocating for action sooner and cite the dire population surveys conducted in 2022 by the California Department of Fish and Wildlife (CFDW) and United States Geological Survey (USGS). In the winter and spring of 2022, CDFW conducted visual surveys along seven tributaries in the Clear Lake watershed to monitor spawning of the chi (Ewing 2022). The 2022 CDFW survey observed 306 chi in total, all of the fish were observed in Adobe and Kelsey Creeks. These counts were the second lowest on record, after 2021 with a total count of 120 chi. The USGS conducts summer gill net surveys in Clear Lake annually (with the exception of 2020 due to the COVID-19 pandemic), and a stark decreasing trend in chi counts (280 in 2017, 290 in 2018, 76 in 2019, and 40 in 2021) culminated with a count of only six chi observed in 2022 (Feyrer et al. 2022). Additionally, USGS measures the chi surveyed in the lake to estimate fish age and researchers observed a pattern of minimal juvenile recruitment beginning in 2018 (Figure 2). Typically, chi have a six-year life span and females mature in their second or third year of life. Juvenile chi not recruiting to the population for several years, when the species only has a six-year life span, is of deep concern to the Tribes of Clear Lake.

FIGURE 1: PROJECT AREA

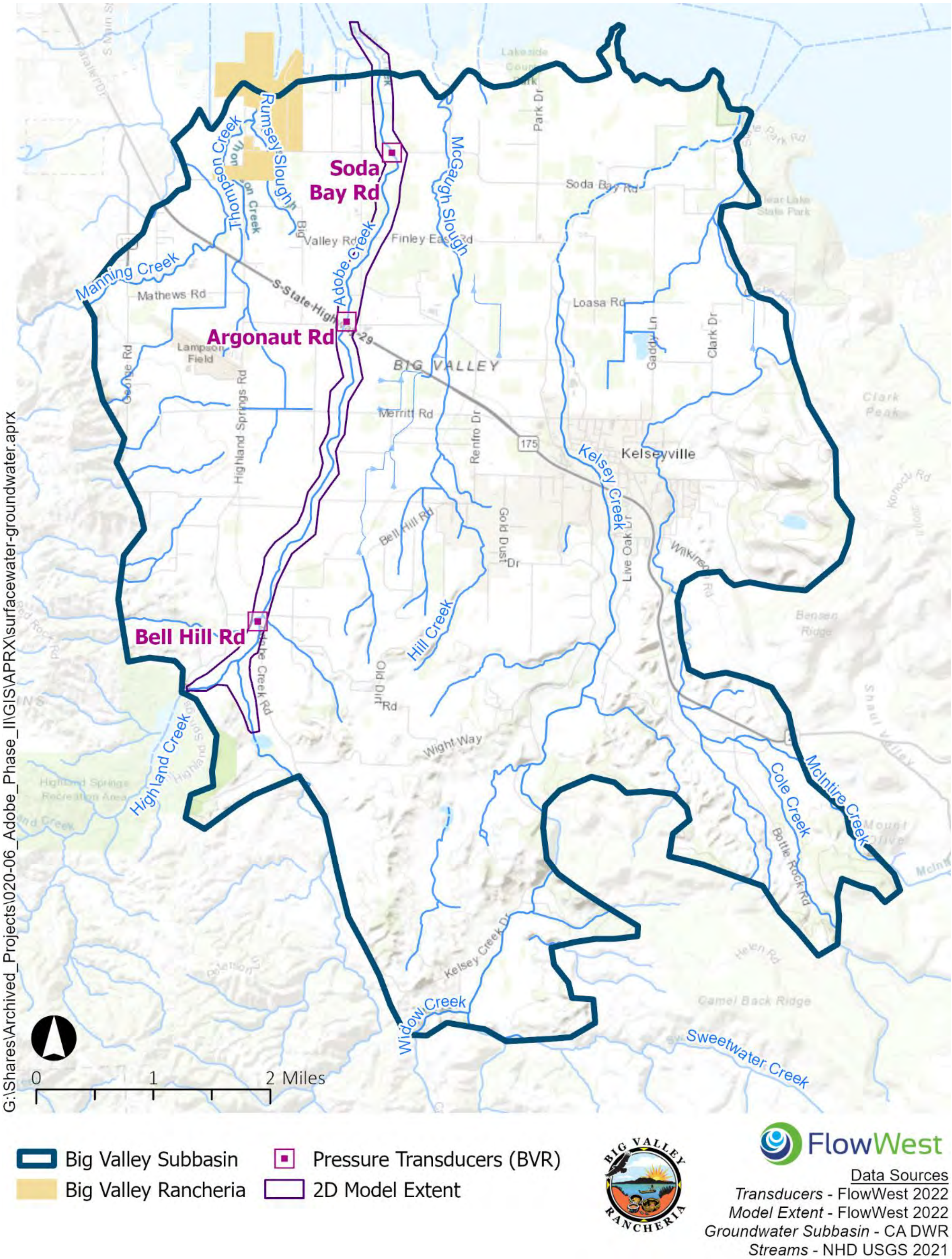
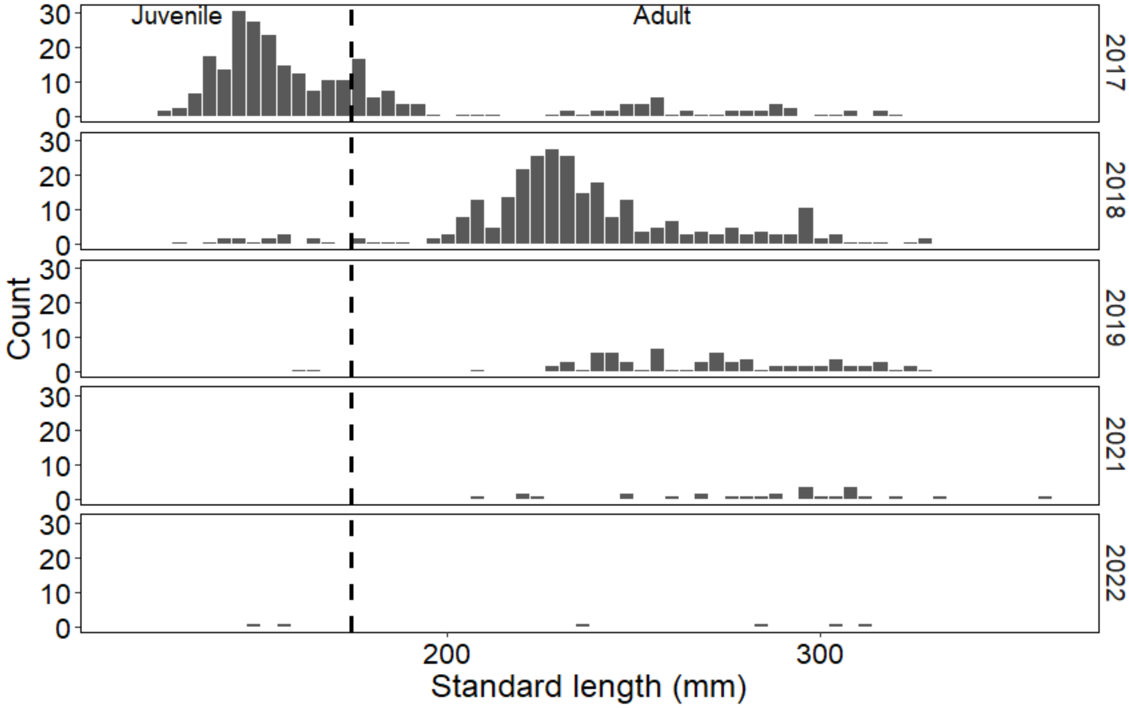


FIGURE 2: USGS CHI ABUNDANCE AND DISTRIBUTION SURVEY DATA 2017-2022. USED WITH PERMISSION FROM FEYRER ET AL. (2022).



TRADITIONAL ECOLOGICAL KNOWLEDGE

The Indigenous peoples of Clear Lake have contributed little to the causes of aquatic habitat loss and degradation in the watershed, yet face disproportionate impacts from ecosystem disruption, which is further exacerbated by climate change. Habitat loss and impacts to native species threaten tribal ways of life, subsistence, community growth and wellbeing, cultural survivability, financial resources, and human rights (Briones 2022; Maldonaldo et al. 2014; Rodriguez 2022; USGCRP 2018). Pomo and other Indigenous peoples of Clear Lake have been caretakers of the watershed since time immemorial. Their knowledge and perspectives are valuable and must be integrated into the understanding of the ecosystem and means to protect it–particularly within the regulatory frameworks used by federal and state agencies to evaluate species status and resource sustainability. Recent guidance from the Executive Office of the President (2022) directs federal agencies to include traditional ecological knowledge (TEK) as “a valid form of evidence for inclusion in Federal policy, research and decision making” and highlights this inclusion as essential to the United States’ trust responsibility to Tribal Nations. The seven federally recognized Tribal Nations of the Clear Lake region are: Big Valley Band of Pomo Indians, Elem Indian Colony, Robinson Rancheria of Pomo Indians, Habematolel Pomo of Upper Lake, Scotts Valley Band of Pomo Indians, Middletown Rancheria of Pomo Indians, and Koi Nation. These nations have been actively working to study, protect, and implement habitat restoration projects in Clear Lake for decades, using both western science and traditional knowledge approaches. For this project, TEK was gathered by BVR EPA staff through the transcription of several meetings at which tribal members offered public comment, and through additional information requests by BVR EPA to tribal members.

The chi are a deeply integral part of life for the Pomo people of Clear Lake. In the Spring, the chi spawning runs are a significant cultural event bringing together families and friends to harvest the fish, clean them, and preserve chi to eat throughout the year (Weber 2022; Montez 2022). This annual event was an opportunity for multigenerational gathering, sharing of culture and nourishment, and passing down of tradition. Pomo traditions are oral and are passed down through shared experience, rather than written down. Facets of the chi harvest included teaching youth how much fish to catch (to not take too much), as well as catching and preparing fish for elders and others who needed assistance (Crandell 2022; Weber 2022). All parts of the chi were used by the tribal community; inedible portions were used as fertilizer in gardens (Rodriguez 2022). Chi have always been a primary food staple for the Pomo, eaten daily at times (Gonzalez 2022; Montez 2022; Rodriguez 2022; Weber 2022). The chi sustained the Native people of Clear Lake, and tribal members describe the importance of the chi in times of scarcity and economic hardship. As with the lands, waters, and other natural resources of Clear Lake, tribal members are in a symbiotic relationship with the chi and a practice of mutual care is essential to this sacred, cultural relationship (Briones 2022; Montez 2022; Weber 2022).

In the 1950s, the chi runs were abundant with fish numbers in the thousands (Briones 2022; Montez 2022). In the mid-20th century, chi would swim up the creeks, irrigation canals, and out into adjacent farm fields with standing water. Tribal members observed declining chi populations that tracked with declining instream flows in the Big Valley subbasin in the latter half of the 20th century, as well as the influx of vineyards in the region (Briones 2022; Montez 2022; Weber 2022). Tribal members also describe the chi population decline in terms of generational access—members who are currently elders saw the last of the abundance of chi, members who are approximately in midlife were able to harvest chi, but in more limited numbers, and the current youth of the Tribes have little to no access to the experience and tradition of chi harvest (McCloud 2022; Weber 2022). Tribal members have observed chi moving and spawning in a variety of creek depths over the decades and note that at depths under six inches they begin to struggle with passage (Gomez G. 2023; Gomez L. 2023; Rodriguez 2023; Weber 2023).

A variety of native plants that contribute to ecosystem function in aquatic and riparian habitats are gathered by tribal members for basketry, medicines, and other purposes. Franklin (2023) organizes a tribal basket-weaving group and provided information about plant types and harvest periods to BVR EPA. Tules are gathered in early Spring throughout the watershed—near the lake and at Highland Springs Reservoir. Gray pine nuts are also gathered in the upper watershed near Highland Springs Reservoir. Within the riparian corridors, Western redbud is gathered after the first frost, willows in the Spring, and dogwood are harvested in the Fall after the leaves drop. Sedges are gathered year-round. Mugwort is gathered from Spring to Fall, and dogbane is also gathered in the Fall. Tribal members have limited access to traditional areas for gathering due to private property along most of Adobe Creek. However, gathering still occurs at Finley Road on Adobe Creek and along Highland Springs Creek. They also have increasing concerns about the decreasing numbers of plants and increasing contaminants in the watershed (Franklin 2022).

Adobe Creek Gages and Rating Curve Development

In order to better understand the hydrology of Adobe Creek and availability of flow to support the chi, the BVR EPA obtained funding to conduct more in-depth monitoring of flows and evaluate data. In December 2018, BVR EPA worked with FlowWest to install three pressure transducers in Adobe Creek to measure stage and temperature at 15-minute intervals. Stage values are added to recorded elevations for each transducer to determine water surface elevations. Since then, BVR EPA and FlowWest have conducted discharge measurements at the transducer locations to develop streamflow rating curves. These transducer locations are shown in Figure 1.

BVR EPA also secured funding to install two additional transducers: one downstream of Highland Springs Dam and one downstream of Adobe Creek Dam. Both transducers are located on County of Lake (County) property and the Tribe signed a Memorandum of Understanding with the County in April 2023 to maintain and operate the transducers. The installation of the transducers downstream of the dams was completed on May 3rd, 2023, and is a critical component to developing flow criteria for the chi in Adobe Creek going forward. Data from the transducers at the dams were not used in the development of this model due to the timing of the installation, but can be used in modeling efforts going forward to evaluate flow releases from the dams on chi habitat.

FlowWest and BVR EPA have conducted four discharge measurements at the transducers since installation, on January 21st 2020, December 16th 2021, April 22nd 2022, and January 24th 2023. Preliminary data that will be used to build rating curves at the transducer locations are presented in Figure 3 through Figure 5. There are more flow measurement points at the Bell Hill Road site because during a high flow event in December 2021, conditions were unsafe to conduct measurements at the downstream sites. Regular maintenance and quality review of these data are important because of the mobility of channel bed material in Adobe Creek. In Figure 4, the plot of water surface elevation (WSE) in the creek versus flow at Argonaut Road shows flow measurements of both 12 cubic-feet per second (cfs) and 20 cfs result in approximately the same water surface elevation. This indicates a datum shift at this transducer and requires additional data collection to create a rating curve that can be used for flow estimation. The Bell Hill Road and Soda Bay Road flow measurement data were used to calibrate the 2-D model.

FIGURE 3 BELL HILL ROAD WSE VERSUS FLOW PLOT

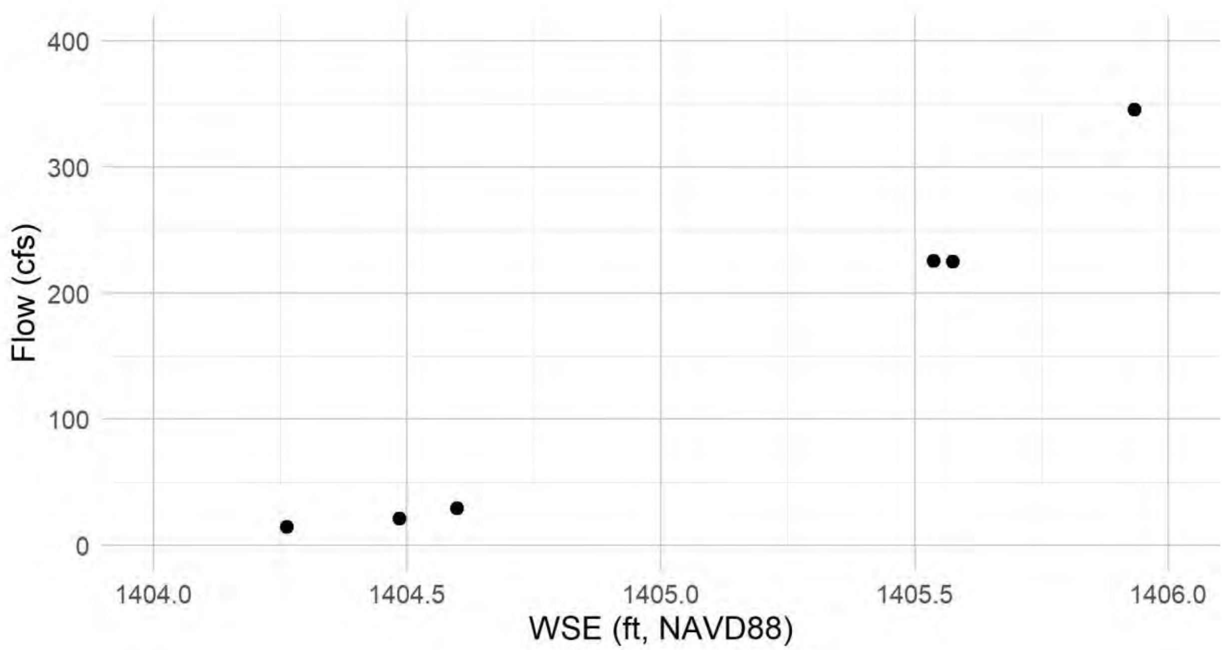


FIGURE 4: ARGONAUT ROAD WSE VERSUS FLOW PLOT

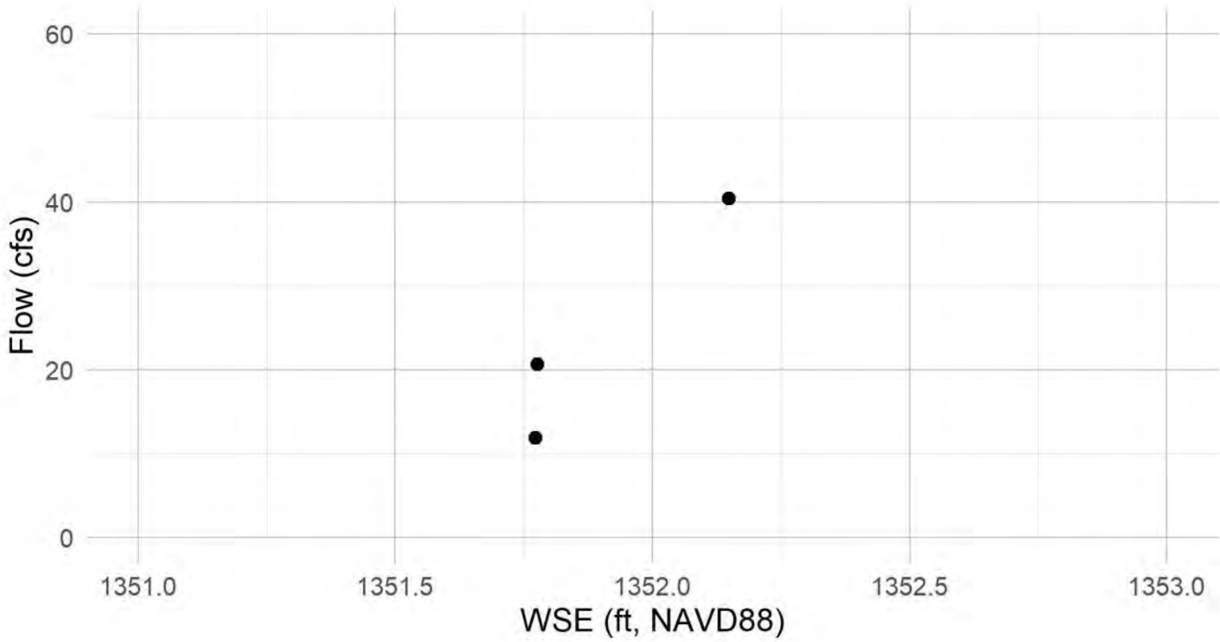
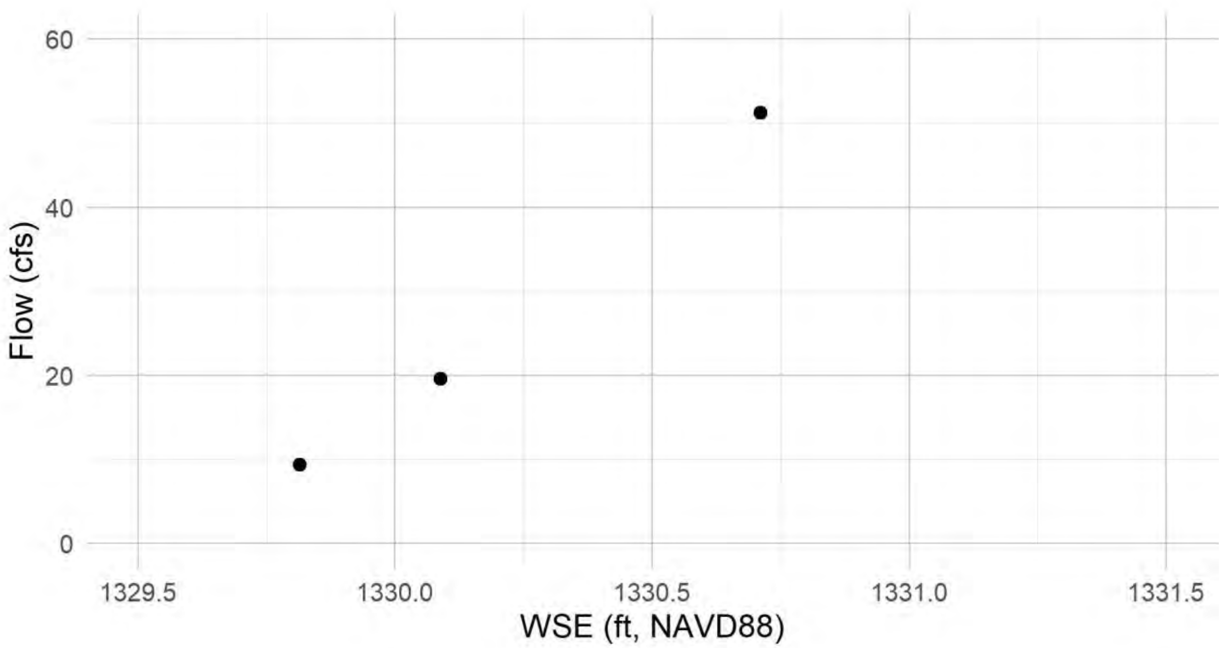


FIGURE 5: SODA BAY ROAD WSE VERSUS FLOW PLOT



2-D Hydrodynamic Model Development

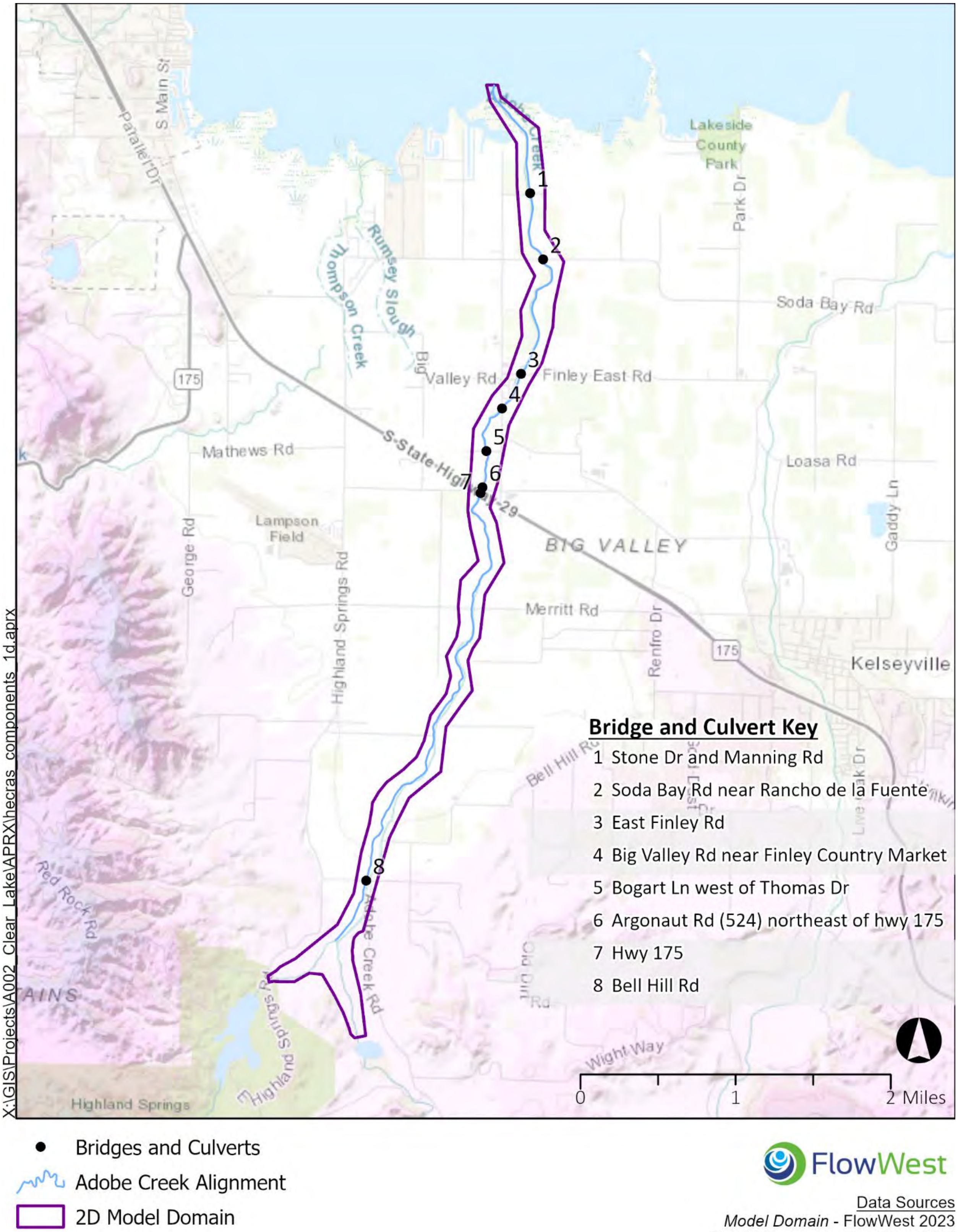
Summary and Background

A 2-D hydrodynamic model of Adobe Creek was created to provide a more detailed evaluation of chi passage conditions relative to the 1-D model created in 2020 (BVR EPA 2020). The model was built using Hydrologic Engineering Center's River Analysis System (HEC-RAS) version 6.3. Passage criteria and results are presented in the Chi Habitat Suitability Analysis section. Details regarding the 2-D model development and data sources are presented in the sections that follow.

Model Domain

The model domain extends along approximately 6.75 miles of Adobe Creek from Clear Lake to Adobe Creek Reservoir (Figure 6). Eight road crossings exist within the model domain—seven bridges and one projecting nine-pipe culvert. Because the model is focused on relatively low habitat flows, the lateral extent of the model boundary extends 100 – 400 feet past the banks and does not extensively cover the Adobe Creek floodplain. Break lines—line segments along which the model mesh is enforced—were drawn along linear topographic features (e.g., roads, channel banks, thalwegs, etc.) to align mesh cells with these features and create a more accurate representation of them in the model. The model mesh has a base cell size of 20 feet, with smaller cell sizes (i.e. 10 feet) along the break lines tracing hydraulically relevant features of interest.

FIGURE 6: MODEL DOMAIN



FlowWest

Data Sources
Model Domain - FlowWest 2023
Creek Alignment - FlowWest 2023

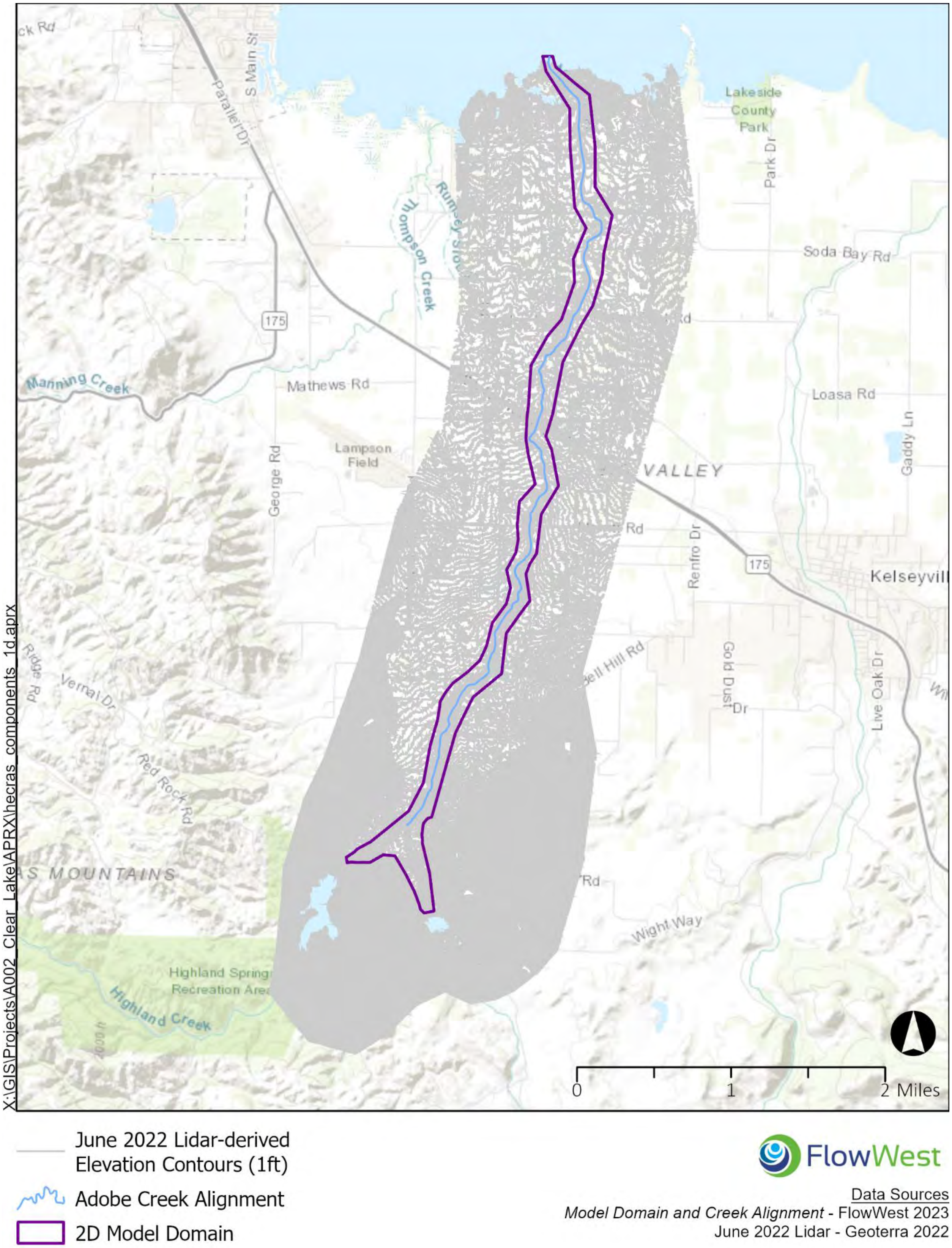
Model Input Data

Data types and sources used in the development of the 2-D hydrodynamic model are summarized in Table 1. The horizontal datum of all spatial data is the North American Datum of 1983 (NAD83), and the vertical datum is the North American Vertical Datum of 1988 (NAVD88). The projection of all spatial data is CA State Plane Zone II, U.S. survey feet. The extent of the lidar data collected by a licensed surveyor (GeoTerra) for BVR EPA in June 2022 is shown in Figure 7, and the aerial imagery extent is shown in Figure 9.

TABLE 1: MODEL DATA INPUTS

Model Input	Use in 2-D Model	Data	Date	Source
Topography and Bathymetry	Terrain	Lidar Survey	2022	BVR EPA
Bridge and Culvert Specifications	2-D Hydraulic Structures	Field Survey	2019	BVR EPA
Land Cover	Manning's Roughness Coefficients	Aerial Imagery	2022	BVR EPA
Clear Lake Water Elevation	Downstream Boundary Condition	Gage Height (15-min)	2022	USGS (11450000)
Highland Creek Historical Flow	Upstream Flows	Streamflow (mean daily)	1965–1977	USGS (11449010)
Adobe Creek Historical Flow	Upstream Flows	Streamflow (mean daily)	1970–1977	USGS (11448500)
Adobe Creek Synthetic Flows	Upstream Flows	Streamflow (mean monthly)	2020	BVR EPA
Adobe Creek Flow	Calibration	Flow Measurement Event	2021–2023	BVR EPA
Adobe Creek Stage	Calibration	Water Surface Elevation (15-min)	2018–2023	BVR EPA

FIGURE 7: JUNE 2022 LIDAR DATA EXTENT ALONG ADOBE CREEK



Topography and Channel Bathymetry

Model topography and channel bathymetry were developed for baseline creek conditions using a 3-foot resolution digital elevation model (DEM), developed from a June 15, 2022 lidar flight by GeoTerra. The lidar flight was conducted in June to reduce the likelihood of water in the Adobe Creek channel. Lidar does not penetrate water, so conducting the survey during dry conditions is important for using this terrain data to quantify instream habitat for chi, which often occurs in shallow depths of streamflow. During the flight, Adobe Creek was mostly dry, with the exception of two locations. The first location was downstream of Bell Hill Road, where two pools were observed by Big Valley EPA staff (Figure 8). The pools were described as a main pool approximately 7 feet wide with a 1.75 feet depth at its deepest, with a smaller pool wrapping around the outside of the main pool for 15 feet with approximately 3.5 feet of depth. BVR EPA field observations of the pool were reported to GeoTerra, who interpolated the terrain surface in this area to adjust for the pool. The second wetted area was caused by backwater from Clear Lake, and was observed only via aerial imagery. This wetted area extended upstream of the Adobe Creek mouth by approximately 2,500 feet, and was not corrected in the DEM.

FIGURE 8: SMALL POOLS PRESENT AT BELL HILL ROAD DURING JUNE 2022 LIDAR FLIGHT. PHOTO COURTESY ALIX TYLER AT BIG VALLEY EPA.

Hydraulic Structures

Eight road crossings exist in the model domain (Figure 6); seven were included in the model and one was not due to HEC-RAS technical limitations. The modeled crossings include Bell Hill Road, Highway 175, Argonaut Road, Bogart Lane, East Finley Road, Soda Bay Road, and Stone Drive. The Big Valley Road crossing was removed from the model because it was causing unrealistic model results, likely related to the extreme skew of the road crossing relative to the flow direction. All other crossings have been modeled as 2-D connection structures in HEC-RAS—with culvert, deck, and pier dimensions taken from the December 2019 FlowWest survey (see Table 1).

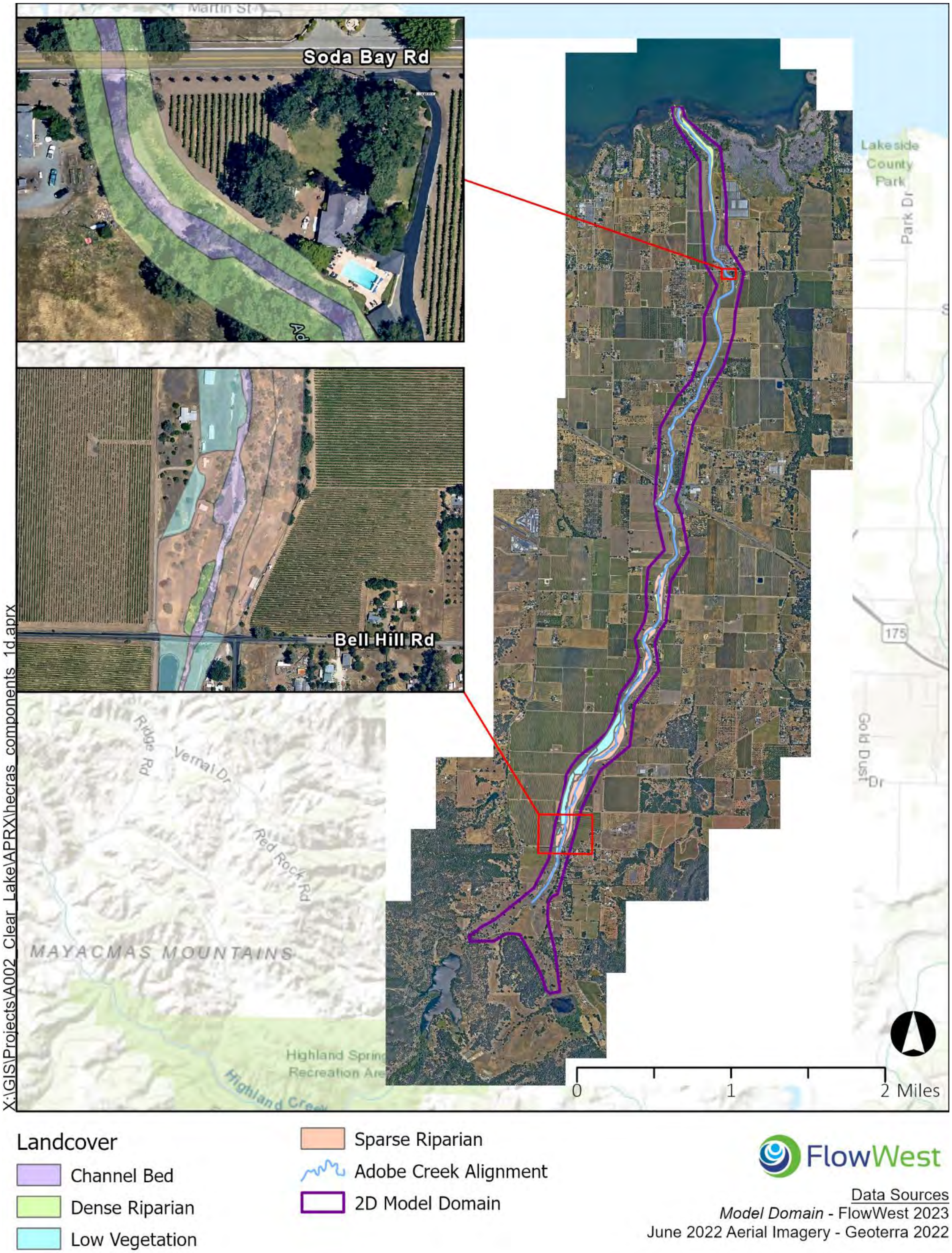
Land Cover and Roughness

Land cover types were digitized from 0.5 feet pixel resolution aerial imagery captured by GeoTerra in June 2022. These categories were assigned Manning's roughness coefficients using the USACE HEC-RAS 2-D User's Manual (USACE 2023) as a guide, and refined based on professional judgement, field observation, and model calibration. Land cover categories and their corresponding Manning's roughness coefficients are shown in Table 2. Two Manning's roughness coefficients were used for the channel bed, a value of 0.04 upstream of Finley, and a value of 0.03 downstream. This decision is discussed in the Model Calibration section. The landcover data extent as well as select reaches shown to illustrate the landcover classification level of detail are shown in Figure 9. Landcover assignments and digitized extents were based on professional judgement and observations of the variable geomorphological characteristics of Adobe Creek.

TABLE 2: LAND COVER CATEGORIES AND CORRESPONDING ROUGHNESS VALUES

Land Cover/Vegetation	Manning's Roughness Coefficient
Channel Bed	0.03 to 0.04
Dense Riparian	0.075
Sparse Riparian	0.06
Low Vegetation	0.045
No Value/ Default	0.04

FIGURE 9: JUNE 2022 AERIAL IMAGERY EXTENT AND DERIVED 2-D MODEL LANDCOVER DATA



Hydrology and Boundary Conditions

Hydrodynamic models require user input of upstream and downstream boundary conditions to perform model runs. In a fluvial system, flow hydrograph boundary conditions (i.e., graphs of flow rate over a period of time) typically define the upstream and lateral flow input locations along a river or stream. The downstream boundary condition could be a rating curve (i.e., a graph of water surface elevation versus flow), a normal depth (i.e., uniform flow conditions are assumed, and water surface elevation is calculated using the Manning's equation), or a defined water surface elevation timeseries (i.e., a graph of water surface elevation over time). A total of two boundary conditions (one upstream flow input timeseries and one downstream water surface elevation timeseries boundary) were used for this study. Details regarding the upstream flows and downstream boundary are described in the sections that follow.

Upstream Habitat Suitability Flows

Upstream flows for this model were derived from the historic record of the USGS gage on Adobe Creek and the BVR EPA (2020) synthetic hydrographs for Adobe Creek; these flows represent mean monthly flows during the chi spawning season (Table 3). The development and derivation of these flows is detailed in BVR EPA (2020) and a brief summary is provided here. Since the USGS gage on Adobe Creek has been inoperative since 1977, a Generalized Additive Model (GAM) was developed to estimate flows in Adobe Creek based on the period during which both the Adobe Creek and Kelsey Creek USGS gages were in operation (1971-1977). The GAM was then used to estimate mean daily stream flows in Adobe Creek for the years 1978–2019. Mean monthly flows were then derived using the historic 7-year record combined with the synthetic 41-year record. These flows along with a high flow recorded at Bell Hill in December of 2021 (i.e., the Upper Connectivity Flow) were used to evaluate habitat suitability in Adobe Creek (Table 3).

TABLE 3: ADOBE CREEK FLOWS FOR EVALUATION OF HABITAT SUITABILITY

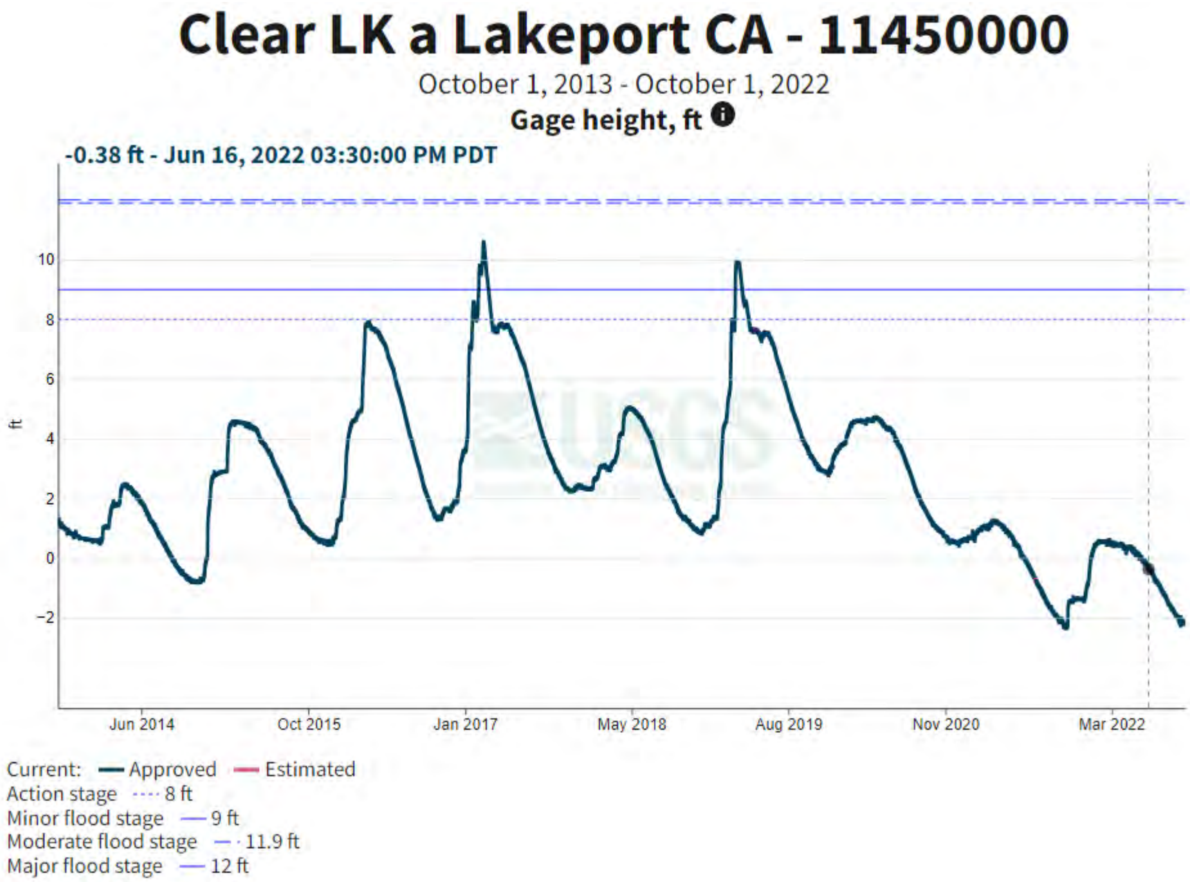
Description	Flow (cfs)
June	3
May	11
April	34
March	85
February	107
Upper Connectivity Flow (Bell Hill, 12/16/2021)	225

Downstream Stage Boundary Condition

A downstream boundary condition is required to solve the equations used by the HEC-RAS model. The Adobe Creek model downstream boundary is defined as a constant water surface elevation using Clear Lake gage height data (USGS 11450000). The vertical datum of the Clear Lake gage is reported at 1318.26 ft-NGVD29, which was converted to ft-NAVD88 using a conversion factor of +2.5 ft using the NOAA NGS Coordination Conversion and Transformation Tool (NCAT). Water surface elevations recorded at the Lakeport gage for the past 10 years are shown in Figure 10. As shown, water surface elevations tend to peak between January and April and reach their lowest point between October and December.

The downstream boundary of the model was set to a constant stage of 1320.46 ft NAVD88, representing -0.30 ft gage height—the average water level of Clear Lake on June 15, 2022. This day was selected because it corresponds with the date of lidar data collection. These levels represent severe drought conditions and are among the lowest recorded levels in the past 10 years (Figure 10). The sensitivity of the model results to the downstream boundary condition is investigated and summarized in the Model Sensitivity section.

FIGURE 10: CLEAR LAKE WATER SURFACE ELEVATIONS, OCTOBER 2013 TO OCTOBER 2022 (USGS 2023)



Model Calibration

Calibration of a hydraulic model involves comparison of model predictions at a defined flow against corresponding field survey data and adjustments to model parameters (e.g., roughness coefficients and downstream boundary) to improve model accuracy. A subset of collected flow measurement and water surface elevation data were used for model calibration and are presented in Table 4. These data were selected based on completeness of data collection, data quality, and relationship to habitat suitability flows. The Argonaut Road data were not included in the calibration analysis due to measurement uncertainty related to a datum shift (i.e., a bed elevation change). Please see the Adobe Creek Gages and Rating Curve Development section for more details on data collection methods and data quality.

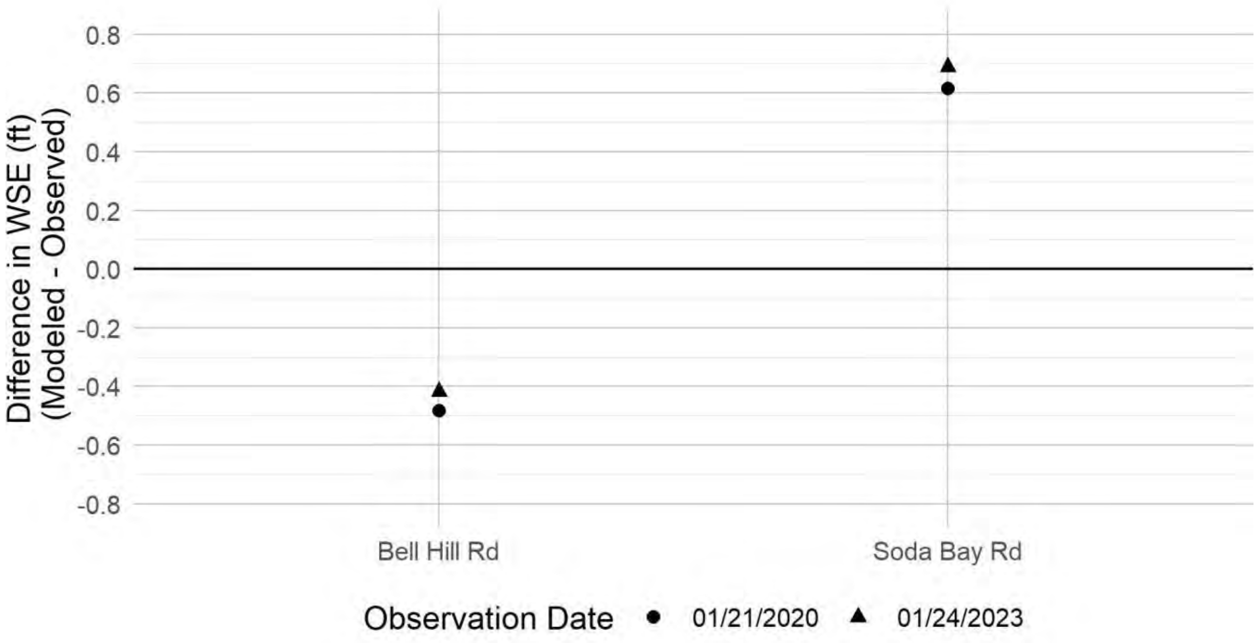
TABLE 4: MEASURED CALIBRATION FLOWS AND WATER SURFACE ELEVATIONS

Flow	WSE	Location	Date of Observation
21.3	1404. 5	Bell Hill Road	1/21/2020
19.6	1330.1	Soda Bay Road	1/21/2020
29.4	1404.6	Bell Hill Road	1/24/2023
51.3	1330.7	Soda Bay Road	1/24/2023

Note: The Argonaut Road transducer was not used for calibration due to apparent datum shift.

Flows used for calibration were measurements from January 2020 and 2023. Differences between the uncalibrated model results and measured water surface elevations for both calibration runs are shown in Figure 11. Values greater than zero indicate the model results were higher than the surveyed values, and values less than zero indicate model results were lower than the surveyed values. These results indicate that the model is underestimating water surface elevations upstream at Bell Hill Road by a bit more than -0.4 ft, and overestimating water surface elevations downstream at Soda Bay Road by approximately +0.7 ft for the range of calibration flows.

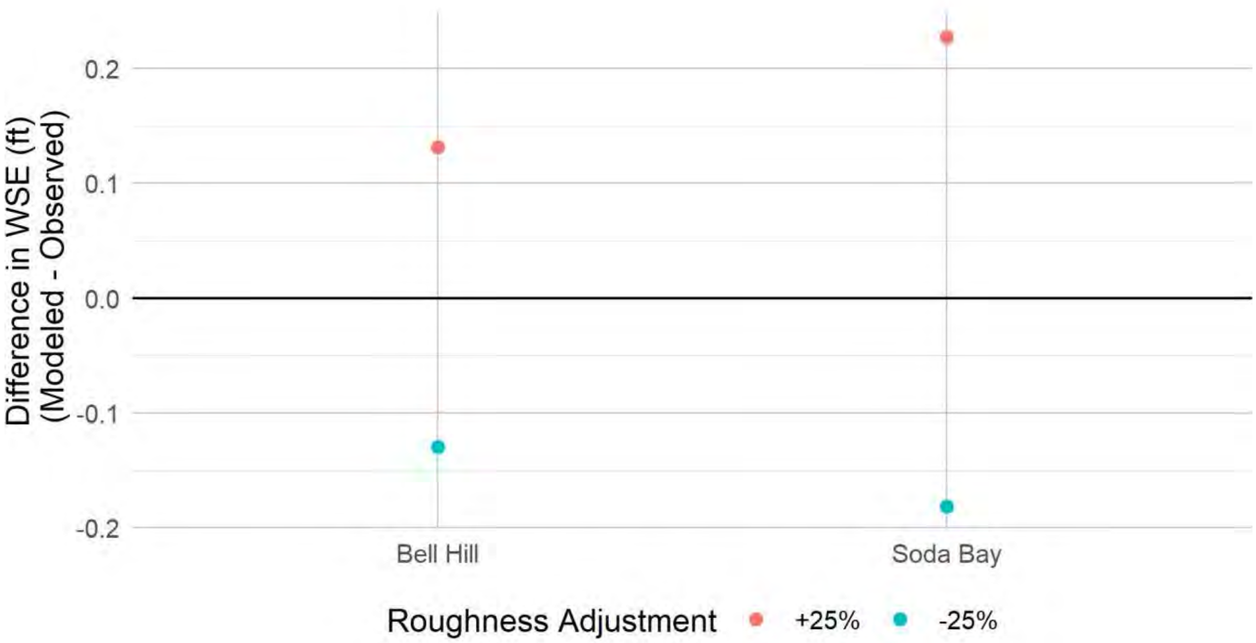
FIGURE 11: PRE-CALIBRATION MODEL ACCURACY AT TWO CALIBRATION FLOWS



Overall, such differences are considered reasonable and would not indicate much need for calibration given the uncertainty of the transducer equipment, data collection techniques, and accuracy of the 2-D hydrodynamic model simulation relative to real-world conditions. However, since the flows and water surface elevations of interest are low, these results represent a relatively large uncertainty when it comes to estimating aquatic habitat for the chi.

Considering this, we attempted to calibrate the model for better accuracy by adjusting the Manning's roughness coefficients used in the model's landcover layer. Figure 12 shows the results of a roughness sensitivity run performed during the calibration process. Details on this sensitivity run are provided in the Manning's Roughness Coefficient subheading in the Model Sensitivity section. Figure 12 shows that at both calibration locations, water surface elevation responses to substantial roughness changes (±25%) are fairly limited. Additionally, shifting the roughness values in one direction (increasing or decreasing) will improve accuracy at one calibration location but decrease accuracy at the other. Considering this, and further informed by in-field observations that instream conditions changed markedly upstream and downstream of Finley Road—with a rougher, less incised channel upstream and a smoother, more incised channel downstream—the base channel roughness value of 0.035 was increased to 0.04 upstream of Finley Road and decreased to 0.03 downstream of Finley Road. This has the effect of slightly increasing accuracy at both calibration locations while reflecting field observations. The final calibrated model is underestimating water surface elevations upstream at Bell Hill Road by slightly less than -0.4 ft, and overestimating water surface elevations downstream at Soda Bay Road by slightly less than +0.7 ft at the calibration flows. Additional collection of flow and water surface elevation conducted by BVR EPA may help reduce uncertainty in subsequent stages of the model development for this system.

FIGURE 12: ROUGHNESS SENSITIVITY RESULTS



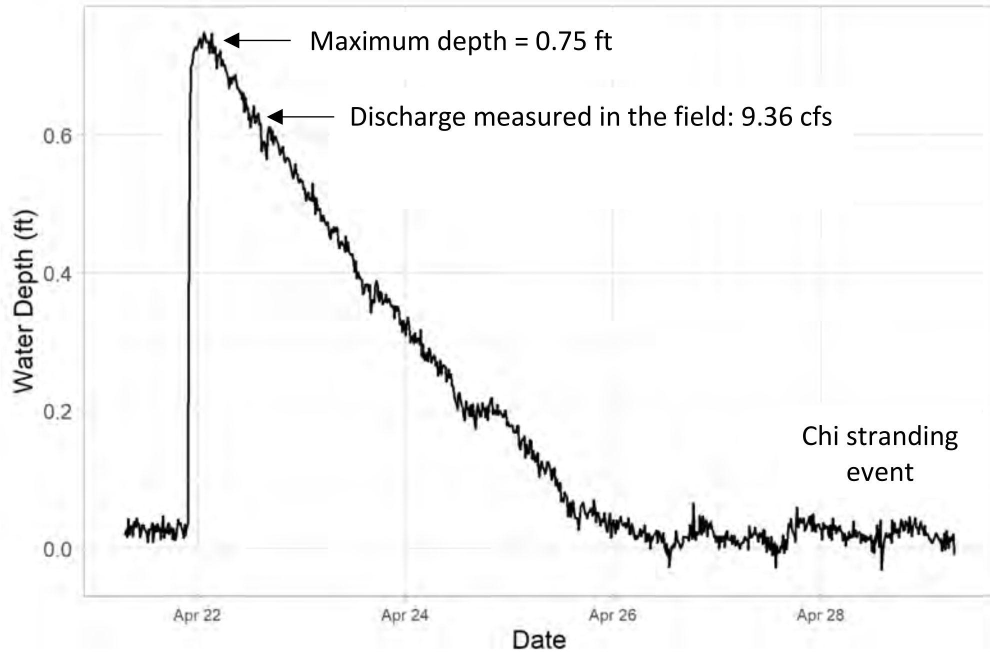
It should be noted that measured flows in January of 2020 show approximately 1.7 cfs of flow loss in the downstream direction from Bell Hill Road to Soda Bay Road, whereas, January 2023 measurements show approximately 21.9 cfs of flow gains between the two gages. This pattern indicates some annual variation in subsurface flow exchanges, likely dependent on antecedent water year hydrologic conditions. Since HEC-RAS does not support direct incorporation of non-point-source flow losses such as to groundwater or evapotranspiration into the model, we ran every flow separately and compared water surface elevation results at the respective measurement locations.

Model Verification

After calibration, efforts were made to further verify and ground-truth the model. Documented fish stranding locations provided by CDFW were compared to model results of low-flow chi habitat suitability rasters, and a cross-sectional depth field measurements were compared to model depth results at that location.

Model results show unsuitable depth limitations upstream and downstream of Soda Bay Road at low flows, which are in agreement with observations during the 2022 spawning season. Figure 13 shows a time series of water depth from the transducer at Soda Bay Road spanning the period from 4/21/2022 to 4/29/2022. Between 4/11/2022 and 4/23/2022 the Adobe Creek area received approximately 1.8 inches of rain (averaged rainfall totals from the National Weather Service LAKEPORT 0.6 SE and KELSEYVILLE 2.8 NNE stations; NWS 2023). As shown in Figure 13, water depth at the Soda Bay Road transducer peaked at 1:30 AM on 4/22/2022 with a depth of 0.75 ft. FlowWest manually measured the discharge just downstream of Soda Bay Road bridge at 3:30 pm on 4/22/2023 and found it to be 9.36 cfs. Flows and water depths continued to fall over subsequent days, and fish rescues were performed by CDFW and Tribal staff on 4/28/22. Depths measured by the transducer during the fish stranding event on 4/28/22 were between 0.0 ft and 0.05 ft.

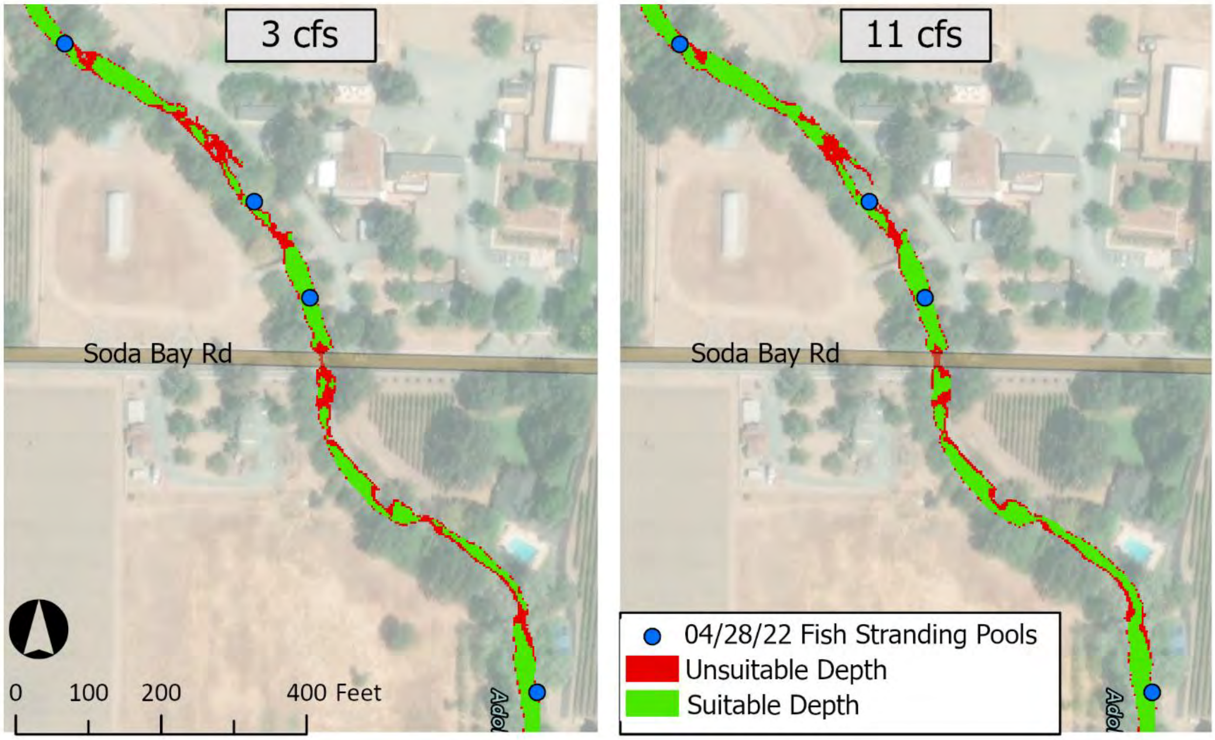
FIGURE 13: TRANSDUCER DATA AND FIELD MEASUREMENTS AT SODA BAY ROAD IN LATE APRIL 2022



Note: Depths values from the transducer that oscillate around 0.0 are associated with error from the equipment.

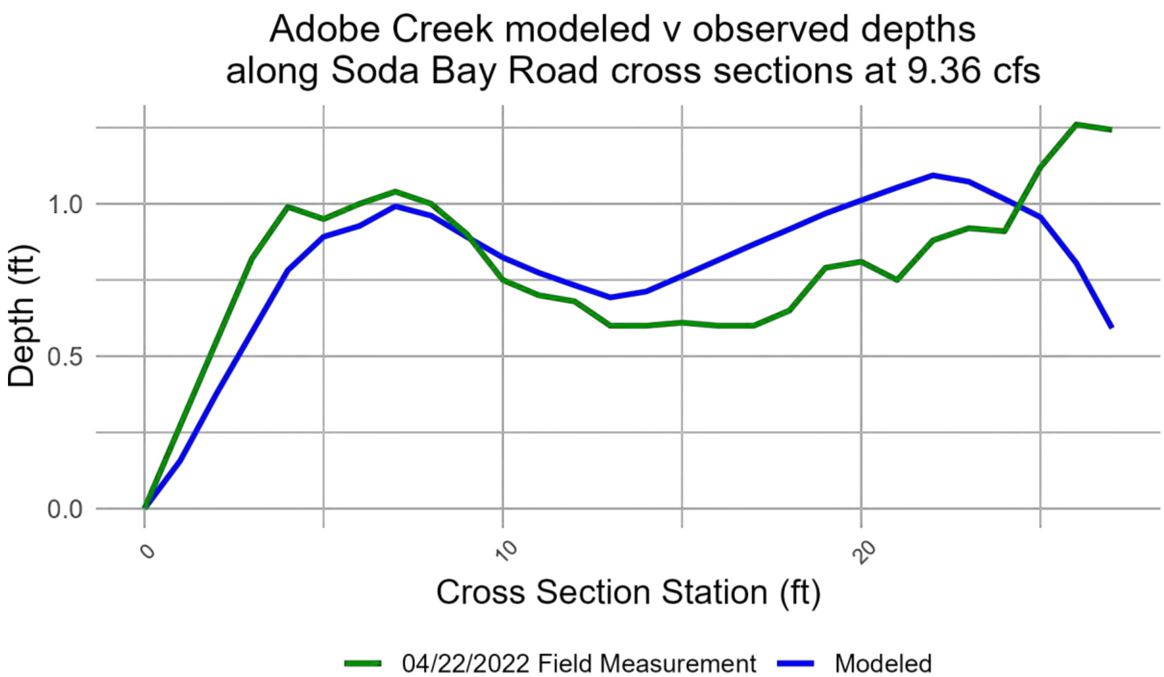
Model results in the vicinity of Soda Bay Road for 3 cfs and 11 cfs show depths under 0.5 ft at the transducer location, which are in alignment with unsuitable values measured by the transducer during this event with flows falling from a value slightly above 9.36 cfs to 0.0 cfs. Figure 14 shows the overlay of the pools on Adobe Creek near Soda Bay Road and locations of chi stranding as observed on 4/28/2022 (CDFW 2022). Model results identify the pool locations as isolated areas of suitable habitat at 3 cfs and 11 cfs. This provides a verification that the model is depicting suitable and unsuitable habitat areas similar to those identified in the field.

FIGURE 14: MODEL RESULTS AT 3 CFS AND 11 CFS OVERLAID WITH FISH STRANDING LOCATIONS ON 4/28/2022.



When flow was measured on 4/22/2022, depth measurements were taken along a cross section just downstream of Soda Bay Road. These cross-sectional depth measurements, taken at 9.36 cfs, were compared to depth results on a representative cross section from a 9.36 cfs steady state model run. Figure 15 overlays the modeled and surveyed cross sections of water depth at 9.36 cfs. The cross sections are fairly similar, with maximum depths within 2.5 inches of each other and a qualitatively similar cross sectional depth pattern (depth decrease in the center of the channel with peaks on either side). These two verification analyses suggest that the model is adequately representing low flow conditions in Adobe Creek, and can be used to estimate chi habitat suitability.

FIGURE 15: CROSS SECTIONAL DEPTH COMPARISON FOR MODEL VERIFICATION



Model Sensitivity

Sensitivity analysis is the process of investigating the effects of model input parameter variation on model results. These analyses can be used to provide insight into model uncertainty and assist with model calibration. Model sensitivity to the Manning's roughness coefficients and downstream boundary water surface elevation were performed at various flows of interest. Results of these analyses are summarized in the sections that follow.

Downstream Boundary

Sensitivity of the model to the downstream boundary condition was investigated by running the model at 11 cfs and 34 cfs with an 8-ft higher Clear Lake water surface elevation (1328.76 ft-NAVD88) and comparing the result to the low (drought) Clear Lake water surface elevation from June 2022 (1320.46 ft-NAVD88). The 8-ft "Action Stage" has the potential for minor flooding of some lakeside residents, and has been met or exceeded 3 times in the past 10 years (Figure 10). Figure 16 and Figure 17 illustrate the effect this boundary condition change has on the model results at 11 cfs and 34 cfs, respectively. Increasing the downstream boundary water surface elevation creates a backwater effect from Clear Lake upstream to Soda Bay Road (approximately 1.20 miles; up to River Station 6300) for both flows analyzed. Results for both flows show a constant water surface elevation to approximately River Station 5700, and then water surface elevation increases by values of 0.5-ft or less until reaching Soda Bay Road. These sensitivity results indicate that modeled habitat suitability and connectivity would be affected by Clear Lake water surface elevations up to Soda Bay Road.

FIGURE 16: MODEL SENSITIVITY TO DOWNSTREAM LAKE LEVEL BOUNDARY CONDITION, AT 11 CFS

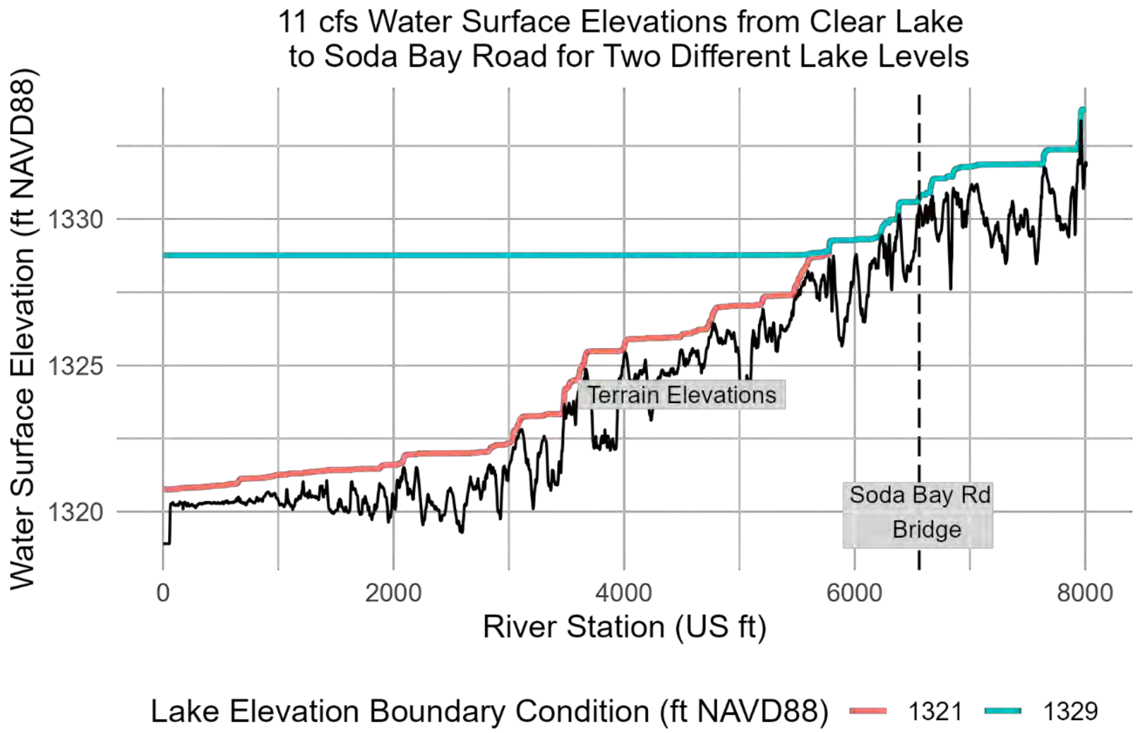
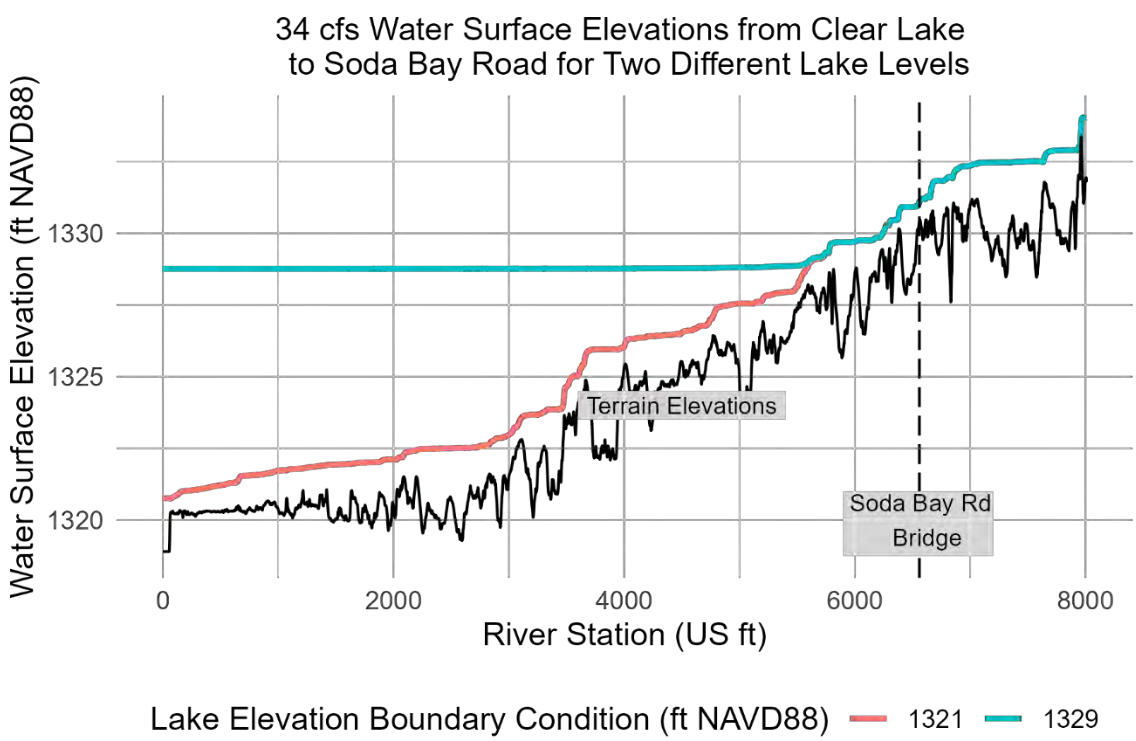


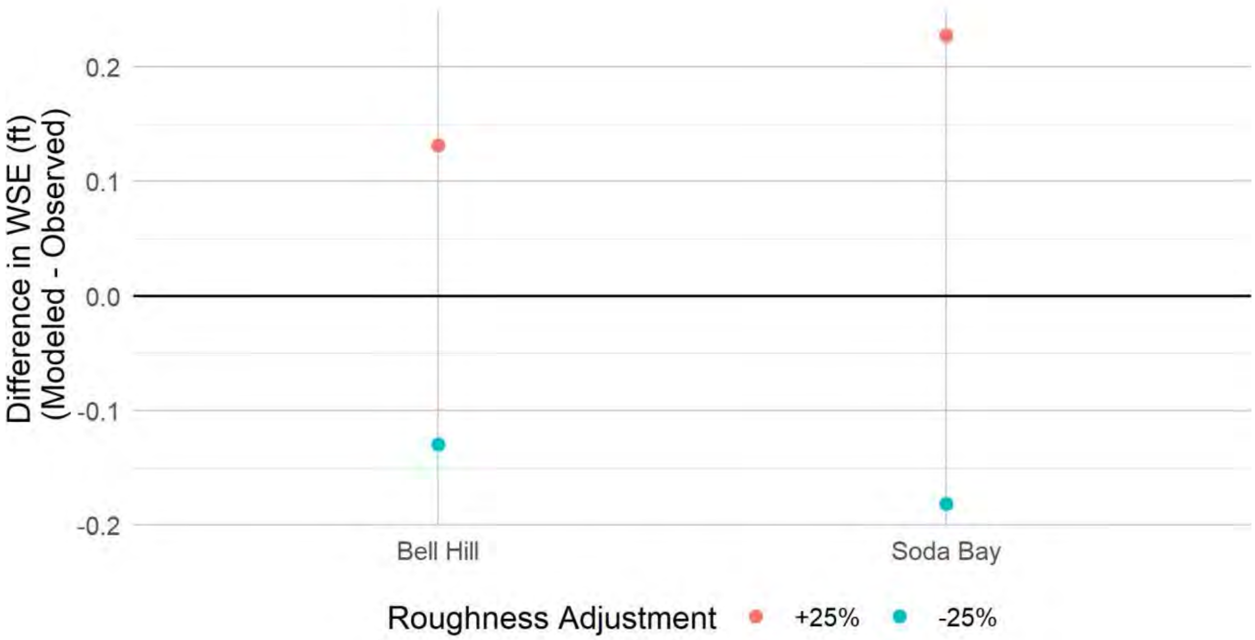
FIGURE 17: MODEL SENSITIVITY TO DOWNSTREAM LAKE LEVEL BOUNDARY CONDITION, AT 34 CFS



Manning's Roughness Coefficient

Model sensitivity to Manning's roughness coefficient was tested by running 225 cfs (the Upper Connectivity Flow) with all Manning's roughness coefficients adjusted by ±25% and comparing the results. Overall, results show that sensitivity to Manning's roughness coefficient is greater at Soda Bay Road as compared to Bell Hill Road (Figure 18). Increases range from +0.23 ft at Soda Bay Road to +0.13 ft at Bell Hill Road. Decreases range from -0.13 ft at Soda Bay Road to -0.18 ft at Bell Hill Road. These results illustrate the range of uncertainty in water surface elevations stemming from imprecise determination of roughness at a particular location and at a particular flow.

FIGURE 18: MODEL RESULTS SENSITIVITY TO MANNING'S ROUGHNESS COEFFICIENT



Model Use Limitations and Data Gaps

This model was created to assess the existing habitat conditions of Adobe Creek as part of efforts to restore chi populations. Described below are model use limitations and data gaps that should be considered when reviewing model results.

Water Surface and Flow Measurement Uncertainty

Uncertainty exists in the transducer and flow data used to calibrate and verify the model. Sources of uncertainty include sediment accumulation on the transducer, elevation data collection uncertainty, and flow measurement uncertainty. Overall, we estimate the uncertainty could be up to 0.5 ft in water surface elevation. Unfortunately, this estimated uncertainty is relatively large when compared to the depths and flows of interest for this study. Ongoing data collection and verification of models of this system will help reduce uncertainty and improve predictions of chi habitat conditions.

Limited Flow Record

The upstream flow input into this model is based on a synthetic hydrograph of Adobe Creek downstream of its confluence with Highland Creek. Mean monthly flows were derived using the historic Adobe Creek 7-year record combined with the synthetic 41-year record; see BVR EPA (2020) for synthetic hydrograph methodology. Further, flows above 30 cfs in Adobe Creek begin to present dangerous conditions that make it difficult or impossible to wade across the creek and measure with a flow meter. Without an official gage record on Adobe Creek, flow data is limited.

Surface water-Groundwater Interactions

HEC-RAS is not designed to model groundwater losses in streams, and groundwater losses are not accounted for in the model. Groundwater losses likely contribute to reduction in suitable instream habitat, particularly in the downstream reach near Soda Bay Road when spawning runs occur late in the season (April and May). Integrated hydrologic modeling performed for the Big Valley Groundwater Sustainability Plan analysis included results of streamflow depletions in Adobe Creek up to 90% of total streamflow in the month of April (LCWPD 2021). Streamflow infiltration to groundwater may have been a factor in the relatively quick reduction in streamflow from 4/22/2022 to 4/28/2022 that led to the chi rescue on 4/28/2022, but adequate surface water and groundwater monitoring data is not yet available to quantify these interactions at finer spatial resolutions (e.g. Adobe Creek at Soda Bay Road) and over shorter time scales (i.e. days or weeks).

Chi Habitat Suitability Analysis

Model Results Summary

This section summarizes model results for the chi habitat suitability analysis conducted on Adobe Creek. All flows presented in Table 3 were modeled under steady state conditions to evaluate chi habitat suitability and connectivity based on known passage criteria. Results are presented in the sections that follow.

Suitability Criteria

More research is needed to better understand the stream ecology of the chi, including data on suitable habitat flows, velocities, water temperature, substrate, and migration triggers (Feyrer 2019). Tribal members interviewed to inform the model development have observed chi in the streams, irrigation canals, and on flooded fields in the Big Valley watershed at a variety of depths since the 1950s, and noted they were able to migrate in very low depths (less than 6 inches) but seemed to struggle at depths below 6 inches (Gomez G. 2023; Gomez L. 2023; Rodriguez 2023; Weber 2023). Minimum depth and maximum velocity criteria developed on Adobe Creek were provided to BVR EPA and FlowWest by Tom Smythe at the Lake County Water Resources Department and are presented in Table 5. Feyrer (2019) observed hitch spawning in Kelsey Creek at approximately 0.8 ft of depth during April of 2018. FlowWest, BVR EPA, USGS, and CDFW staff discussed revising the minimum depth criteria shown in Table 5 in February 2023 but ultimately determined these values are appropriate estimates given field observations by tribal members, USGS, CDFW, and BVR EPA (Ewing 2023; Feyrer 2023).

TABLE 5: CHI PASSAGE CRITERIA

Criteria	Value
Velocity	< 5 ft/s
Depth	> 0.5 ft

Total Suitable Area in Adobe Creek

Methodology

Analyses presented in this section consider two aspects of riverine physical habitat suitability—flow depth and velocity. Depth and velocity rasters were extracted from the model at the six habitat suitability flows shown in Table 3. Raster cells with velocity less than 5 ft/s were given a suitability value of 1 (i.e., suitable) and cells with velocity greater than or equal to 5 ft/s were given a suitability value of 0 (i.e., not suitable). Likewise, raster cells with depths greater than 0.5 ft were given a suitability value of 1 (i.e., suitable) and cells with depths less than or equal to 0.5 ft were given a suitability value of 0 (i.e., not suitable). The depth and velocity results rasters were then multiplied together to represent combined suitability for each flow. Habitat use and suitability also depend on many other factors including barriers, sediment continuity and quality, water quality, and predation, which are not evaluated in this model. Results are presented in the following section.

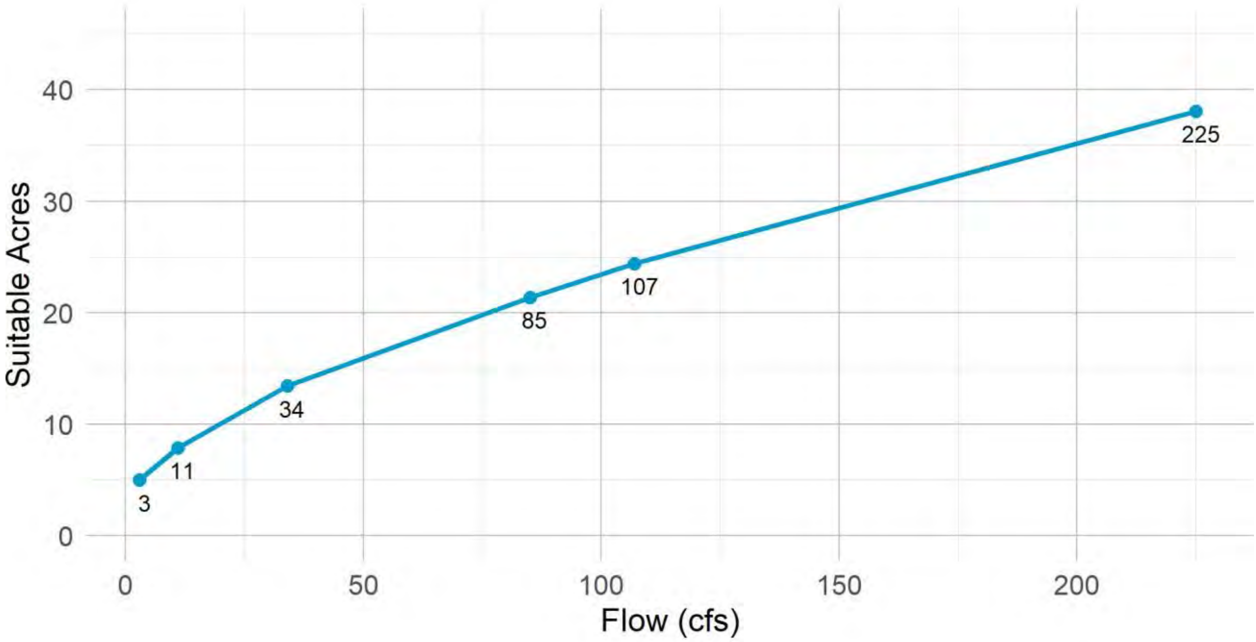
Results

Model results show that suitable habitat acreage and percent suitable area in Adobe Creek increase with flow (Table 6, Figure 19). Of the 47.1 total acres inundated in Adobe Creek at 225 cfs, 38.1 acres are suitable, which is 81% of the total inundated area. At the lowest flow evaluated, 3 cfs, 64% of the total acreage is shown to be suitable habitat. Suitable acreage in Adobe Creek ranges from 12.3 acres at the lowest flow evaluated to 38.1 at the highest flow. These results represent habitat suitability based on the combined effects of depth and velocity. At lower flows, depths tend to be the limiting factor. As flows increase, velocities increase and start to play a larger role in habitat suitability calculations.

TABLE 6: SUITABLE AREA RESULTS

Flow (cfs)	Total Inundated Acreage	Suitable Acreage	Percent Suitable
3	19.1	12.3	64%
11	23.1	16.1	70%
34	28.9	21.9	76%
85	36.0	28.0	78%
107	38.3	30.0	78%
225	47.1	38.1	81%

FIGURE 19: ADOBE CREEK SUITABLE HABITAT BY FLOW



Connectivity to Clear Lake

Methodology

Analyses presented in this section consider streamwise connectivity of suitable habitat based on limiting channel depth and velocity. Lack of connected, suitable habitat creates barriers for upstream chi migration from Clear Lake. These analyses are split into a depth connectivity (representing suitability for juvenile rearing and migration) and combined depth and velocity connectivity (representing potential adult upstream migration barriers). This distinction was made by assuming velocity would not be a barrier to out-migration. Habitat disconnection points were determined from the depth suitability and combined suitability raster data, developed in the total suitable area analysis (described above). At each flow, the first point of habitat disconnection was recorded in river miles, as measured from the mouth of Adobe Creek. Disconnection was defined where there were more than 6 feet of longitudinal separation between suitable and unsuitable habitat. Apparent disconnection points within the backwater of Clear Lake and under bridges were ignored due to unreliability of lidar data in these locations. Connectivity results represent the proportion of in-channel habitat accessible to chi from Clear Lake moving upstream at various flows. Results are presented in the following section.

Results

Connectivity results are summarized in Table 7, with the connectivity curves illustrated in Figure 20 and Figure 21. Connectivity results are also mapped in Figure 22. Model results show that Adobe Creek habitat connectivity is generally low at 3 cfs and 11 cfs, becoming disconnected from Clear Lake downstream of Soda Bay Road due to depth suitability limitations at river mile 0.53 and 0.58, respectively (Figure 22). However, these results are influenced by Clear Lake water surface elevations (see Downstream Boundary section). At high Clear Lake levels (1328.76 ft-NAVD88, the 8-ft “Action Stage”), the location where depths become unsuitable shifts upstream, to river mile 1.25 for both flows. Connectivity increases significantly at 34 cfs, however, velocity limitations approximately 0.25 miles upstream of Soda Bay Road (at River Mile 1.51) diminish the combined habitat connectivity relative to the depth connectivity (Table 7, Figure 22). This velocity limitation was investigated during a site visit and is discussed in more detail at the end of this subsection. On a depth basis, 34 cfs connectivity stretches upstream 5.35 miles, approximately 0.5 miles downstream of Bell Hill Road (Figure 22). At 85 cfs, Adobe Creek is fully connected on a depth basis, but the model indicates velocity barriers 3.00 miles upstream, just upstream of State Highway 29. This velocity barrier persists until 225 cfs.

TABLE 7: CONNECTIVITY ANALYSIS RESULTS

Flow (cfs)	Depth Suitability Connectivity		Combined Depth and Velocity Suitability Connectivity	
	River Mile	Percent	River Mile	Percent
3	0.53	8.3%	0.53	8.3%
11	0.58	9.1%	0.58	9.1%
34	5.35	83.8%	1.51	23.6%
85	6.39	100%	3.00	46.8%
107	6.39	100%	3.00	46.8%
225	6.39	100%	6.39	100%

FIGURE 20: ADOBE CREEK CONNECTIVITY BY FLOW – BASED ON DEPTH SUITABILITY

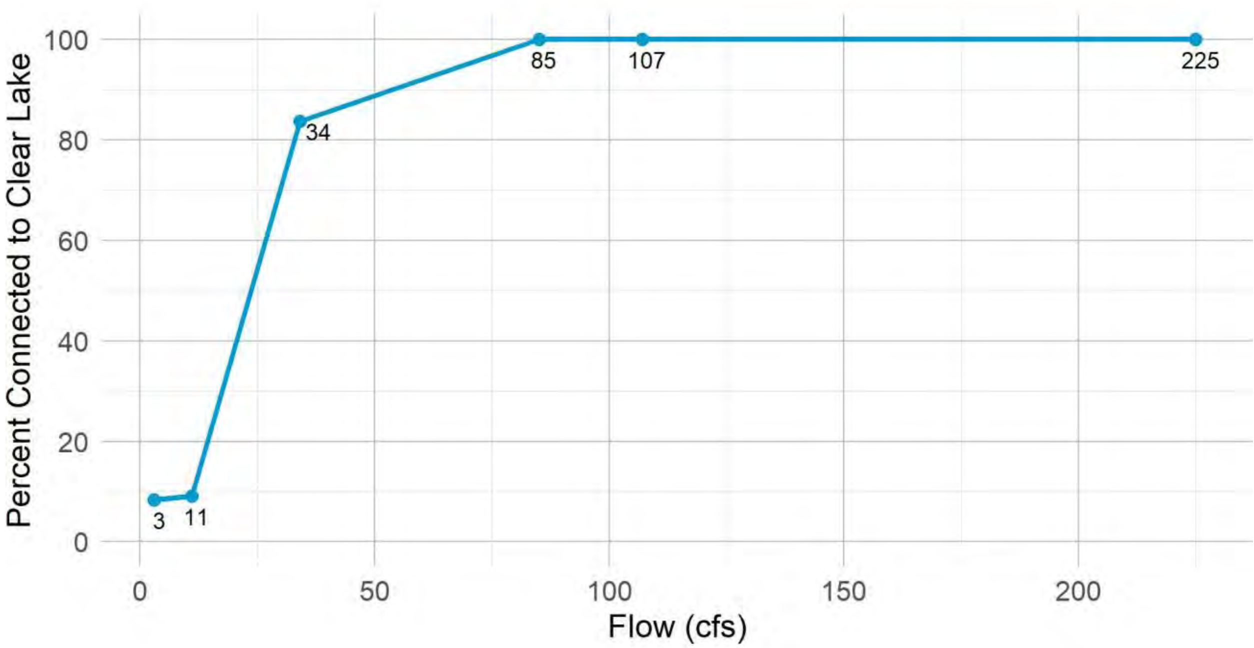


FIGURE 21: ADOBE CREEK CONNECTIVITY BY FLOW – BASED ON COMBINED DEPTH AND VELOCITY SUITABILITY

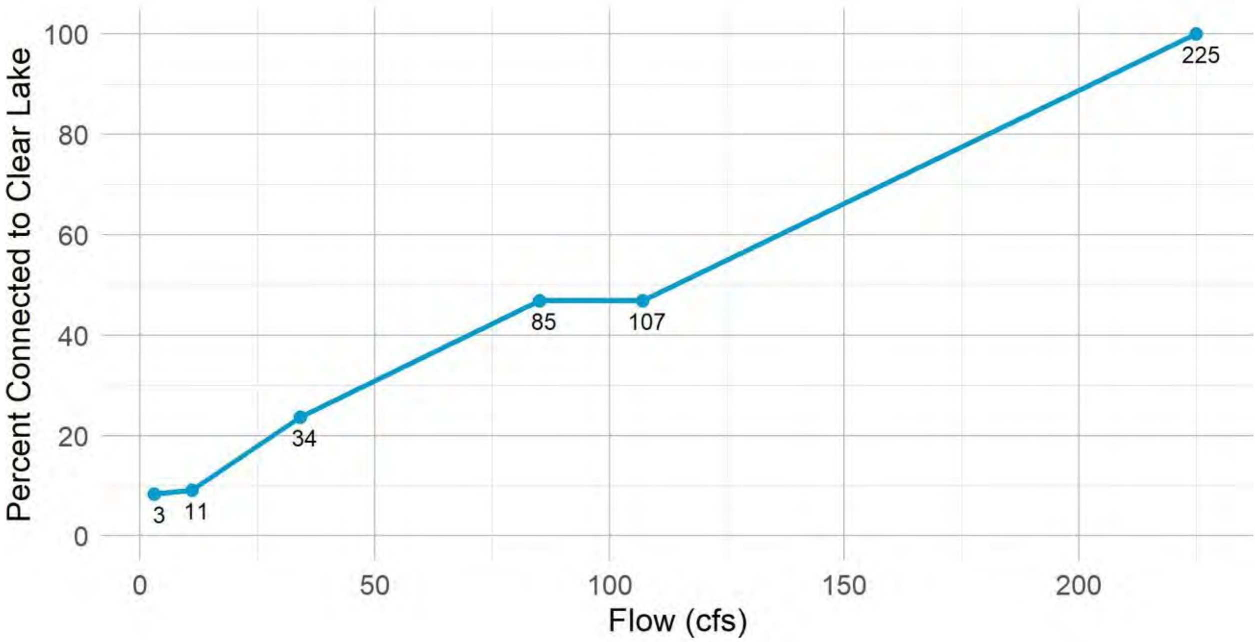
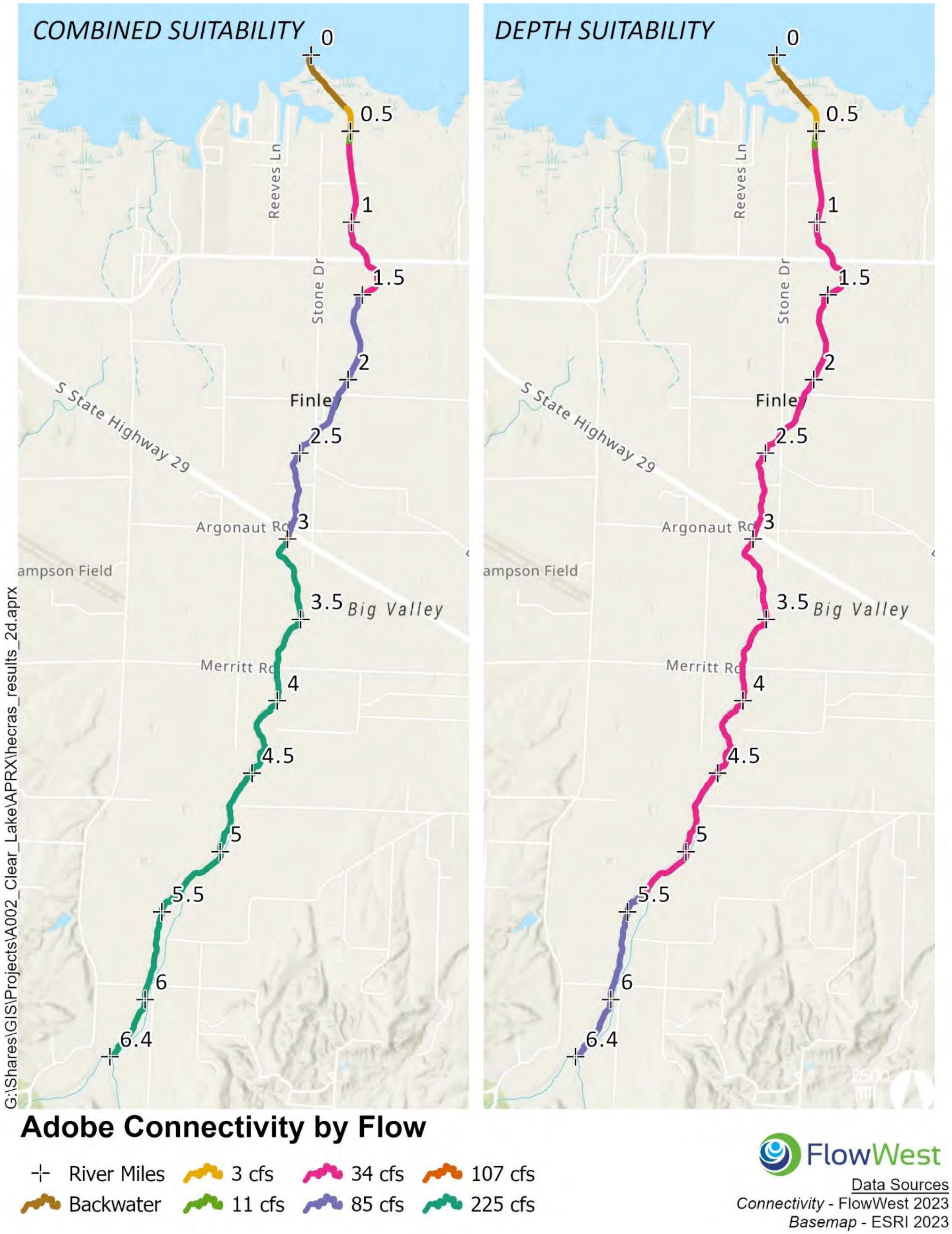


FIGURE 22: ADOBE CREEK HABITAT CONNECTIVITY COMPARISON BY FLOW AND LOCATION



As previously mentioned, the velocity limitation at 34 cfs located upstream of Soda Bay Road was investigated during a site visit (see Appendix A for additional information and photos). We found the channel in this area to be significantly overgrown with willows and accumulated woody debris. Figure 23 shows the woody debris that has accumulated around a large willow growing in the center of the channel. Figure 24 shows the current low flow path through this overgrown area, which is very narrow and incised and overlain with woody debris. Field observation of this site contextualizes and nuances the disconnection shown in the model. There could be a high-velocity-caused disconnection here due to the narrowed and incised bypass pictured in Figure 24. However, there could also be bathymetry inaccuracies in this region (caused by woody debris obstructing lidar) that indicate a false velocity limitation for chi. This illustrates the importance of field observation to supplement and contextualize model results. If time and funding allowed, this area would be a great candidate for a bed elevation survey to improve future modeling efforts. Additionally, other disconnections identified in the modeling effort would be better understood through field observation.

FIGURE 23: WOODY DEBRIS FOUND AT 34 CFS VELOCITY DISCONNECTION

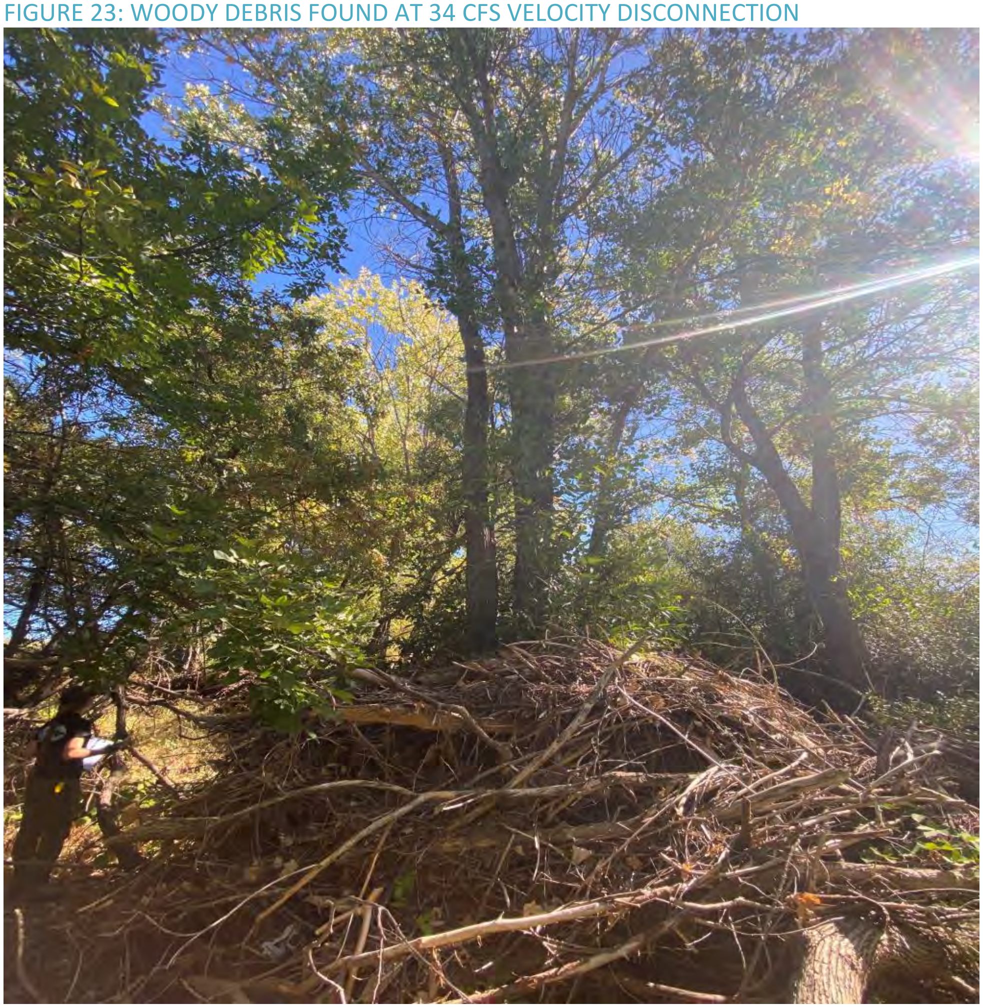


FIGURE 24: LOW FLOW CHANNEL THROUGH 34 CFS VELOCITY DISCONNECTION


CONCLUSIONS

BVR EPA (2020) identified 34 cfs as a minimum passage flow for upstream migrating chi based on 1-D model depth results. This study developed a 2-D model of Adobe Creek and produced a series of suitable habitat rasters at various flows of interest. After examining total percent suitable habitat throughout the creek, we analyzed connected suitable habitat to try to identify where depth and velocity barriers may exist for the chi as they move from Clear Lake upstream on Adobe Creek. This study found 34 cfs provides suitable habitat for the chi based on the depth criteria (> 0.5 ft) for most of Adobe Creek—upstream to approximately River Mile 5.5 (Figure 22). Habitat results at 34 cfs for combined depth and velocity criteria identify a connectivity limitation due to a velocity barrier upstream of Soda Bay Road at River Mile 1.5 (Figure 22). When velocity is considered, connectivity of suitable habitat in the creek at 34 cfs is generally low—only allowing passage 1.5 miles upstream from the confluence with Clear Lake. This results in nearly five miles of Adobe Creek inaccessible to chi at this flow using a combined depth and velocity habitat suitability metric.

Velocity is a complex attribute and can vary significantly in a small area and vertically in the water column, and chi velocity limitations have not been fully studied. Velocity in the model is both horizontally and vertically averaged at each cell. Therefore, the model does not capture complex velocity patterns that are present in nature that could provide resting spots for adult migrating anadromous species, for example a low velocity zone behind a boulder or log. It is possible that adult chi could get past these high velocity sections in Adobe Creek at 34 cfs, but more observations are needed to understand these migration dynamics. A limited field effort was performed to examine creek channel conditions between Finley and Soda Bay Roads at locations of breaks in the connected habitat results from the model (see Appendix A). We found variability in bed material and vegetation that are not captured in the model parameters due to the limitations of the remotely sensed data, from which much of the model was developed. We also identified debris in the channel that may be represented as terrain in the lidar data, and could misrepresent the channel geometry in this reach. This field effort highlights the need for additional field data collection and surveys to integrate into these representations of habitat.

RECOMMENDATIONS

Below are a set of recommendations for Big Valley Band of Pomo Indians, agencies, researchers, project partners, and collaborators engaged in improving instream habitat for the chi. These recommendations are aimed at broadening our understanding of chi habitat needs on Adobe Creek and advancing restoration of their population.

1. Continue to collaborate with Traditional and Indigenous Knowledge holders to expand our understanding of chi habitat and passage criteria. Preliminary TEK collected through this study verified the depth suitability criteria for chi. Additional gaps in understanding related to chi life cycle and instream habitat needs should be pursued through additional TEK sessions or a more comprehensive TEK program, as well as through Western science approaches. We strongly recommend the formation of a TEK Advisory Group to advise on all research and policy recommendations related to preservation of the chi in the Clear Lake watershed.

2. Focus additional resources and studies on Adobe Creek from Clear Lake upstream to Finley Road. It would be helpful to learn whether velocity barriers in this reach are in fact limiting chi migration around Soda Bay Road, and if addressing velocity barriers would restore access to upstream habitat as indicated in the model results. It would also be helpful to assess whether dense vegetation and debris in this reach are adding habitat value for the chi by creating instream habitat complexity and cover from predators. This reach of the creek would be a great candidate for a potential restoration project developed in collaboration with tribal members and local landowners.
3. Identify all velocity barrier locations and measure velocities at flows near 34 cfs, 85 cfs, and 107 cfs. Determine if chi are able to pass those locations. If these barriers truly exist, identify restoration actions that could provide low velocity zones and resting spots for adult up-migration.
4. Identify and reduce or adjust for uncertainties in transducer and field collected data. We have estimated potential uncertainty related to sedimentation on transducers to be greater than 0.5 feet, which is equal to 100% of the depth suitability criteria. This represents a large relative uncertainty in field data, and consequently, model results. Additional uncertainties related to flow measurements and survey data would add to this number. Therefore, we recommend efforts aimed at documenting and reducing all known uncertainties. We also recommend adjusting model results to account for the remaining uncertainty (i.e., showing upper and lower bounds of suitability at various flows).
5. Continue compilation and analysis of chi observation and stranding event data to verify and reduce model uncertainty. Pool locations documented by CDFW during the April 2022 stranding event proved to be a useful model verification tool for this study. BVR EPA conducted extensive field monitoring of the Big Valley Subbasin creeks during the 2023 spawning season; this should be done on an on-going basis.
6. Expand surface water and groundwater data collection and analysis near Adobe Creek to further understanding of groundwater-surface water interactions. Flow data collected between Bell Hill and Soda Bay Road in January 2020 (showing flow loss of 1.7 cfs) versus January 2023 (flow gain of 21.9 cfs) indicate that groundwater-surface water interactions can vary on an annual basis in the same month. This may include installing additional transducers and sensors in closer proximity to each other along the creek, and funding to support more frequent downloading and analysis of these data to identify trends and potential maintenance issues more quickly.
7. Install a stream gage on Adobe Creek that is maintained by a state or federal agency. BVR EPA has funded the transducers on Adobe Creek through a series of grants that operate over approximately 2-year timeframes. In addition to the Tribe's streamflow monitoring efforts, a USGS- or DWR-maintained stream gage will help better understand the hydrology of Adobe Creek and improve all modeling of this system going forward.
8. Expand future modeling of this system to include the transducers downstream of the Adobe Creek and Highland Springs reservoirs to investigate the potential for habitat flow releases from the reservoirs and their impacts on suitable habitat in Adobe Creek.

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APPENDIX A: ADOBE CREEK SUITABLE HABITAT RESULTS FIELD INVESTIGATION—FINELY ROAD TO SODA BAY ROAD

PREPARED FOR:	Big Valley Band of Pomo Indians
PREPARED BY:	Anna Kladzyk Constantino, Cameron Tenner, Aidan Kelleher
DATE:	October 2023

DESCRIPTION

This appendix includes images taken from the FlowWest and BVR EPA creek walk on 10/4/2023 with a figure showing the approximate location for each image. This field visit was made to investigate locations of unsuitable habitat identified by the model. Site points and associated geolocated images are available upon request; please contact the authors: akladzykconstantino@flowwest.com, ctenner@flowwest.com, and akelleher@flowwest.com.

FIGURE 1: UNSUITABLE HABITAT RESULTS FROM 2D MODEL USED IN FIELD EFFORT

Locations of Unsuitable Habitat at 11 cfs

Site 1- Photos from left to right, clockwise: Looking upstream (1); Looking upstream (2); Looking downstream.

SITE 1- LOOKING DOWNSTREAM.

Site 2- Photos from left to right, clockwise: Looking Downstream (1); Looking Downstream (2); Looking upstream.

Site 3- Top: Looking Upstream; Bottom: Big Willow near Site 3

Site 4- Left: Looking Upstream; Right: Facing West

Site 4- Top: Looking Downstream; Bottom: Looking Upstream

SITE 4- WILLOW THICKET LOOKING UPSTREAM

Site 5- Looking Downstream (1); Looking Downstream on the Bar (2)

Site 6- Top: Looking Downstream; Bottom: Looking Upstream

SITE 6- LOOKING UPSTREAM

SITE 7- LOOKING UPSTREAM

Site 8- Looking Downstream

SITE 9- TOP: NEAR SITE LOOKING UPSTREAM; BOTTOM: LOOKING UPSTREAM

SITE 9- TOP: DOWNSTREAM DIVERGENCE; BOTTOM: COTTONWOODS IN CREEK CHANNEL

SITE 9- BAR NEAR SITE 9

SITE 10- DOWNSTREAM VIEW

SITE 11- TOP: LOOKING DOWNSTREAM (1); BOTTOM: LOOKING DOWNSTREAM (2)

Site 11- Top: Facing West; Bottom: Sand Downstream

SITE 12- UNABLE TO REACH LOCATION, DENSE VEGETATION BLOCKING ACCESS

34 CFS MODEL RUN VELOCITY DISCONNECT LOCATIONS

SITE A

SITE B