State of California
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California Department of Fish and Wildlife

INSTREAM FLOW EVALUATION: CLEAR LAKE HITCH PASSAGE IN TRIBUTARIES OF THE CLEAR LAKE WATERSHED, LAKE COUNTY

STREAM EVALUATION REPORT 2026-01

May 2026

Cover photo: Clear Lake Hitch, courtesy of Matthew Young from U.S. Geological Survey

California Department of Fish and Wildlife
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May 2026

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California Department of Fish and Wildlife Water Branch
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Stream Evaluation Report 2026-01

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PREFACE

This technical report presents the approach, methods and results that were used by the California Department of Fish and Wildlife (CDFW) to evaluate instream flow needs for the Clear Lake Hitch (CLH; *Lavinia exilicauda chi*) within the Clear Lake watershed in Lake County. The CLH is listed under the California Endangered Species Act and has been proposed under the Federal Endangered Species Act as a threatened species. Executive Order N-5-23 mandates CDFW in collaboration with the State Water Resources Control Board (SWRCB) to evaluate the minimum instream flows to protect the Clear Lake Hitch. CDFW is the Trustee Agency for California's fish and wildlife resources and a Responsible Agency under California Environmental Quality Act §21000 et seq. Fish and wildlife resources are held in trust for the people of the State of California under Fish and Game Code §711.7. As Trustee Agency, CDFW seeks to maintain natural communities and native fish, wildlife, and plant species for their intrinsic ecological values and for their benefits to all citizens in the State.

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ABBREVIATIONS AND ACRONYMS

2D	two-dimensional
BVR EPA	Big Valley Band of Pomo Indians Environmental Protection Agency
CDFW	California Department of Fish and Wildlife
CLH	Clear Lake Hitch
cfs	cubic feet per second
DSA(s)	depth sensitive area(s)
DEM	digital elevation model
EPA	Environmental Protection Agency
ft	foot/feet
ft/s	feet per second
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HMS	horizontal measurement solution
HUC8	8-digit hydrologic unit code
HUC10	10-digit hydrologic unit code
IFP	Instream Flow Program
lidar	light detection and ranging
MDSA	most depth sensitive area
QA	quality assurance
RTK-GPS	Real Time Kinematic Global Positioning System
SGMA	Sustainable Groundwater Management Act
SWRCB	State Water Resources Control Board
TEK	Traditional Ecological Knowledge
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
U.S.	United States
VMS	vertical measurement solution
WSE	water surface elevation

1.0 INTRODUCTION

The Clear Lake Hitch (*Lavinia exilicauda chi*; CLH) is a large minnow endemic to the Clear Lake watershed. The CLH, also known as chi, are a culturally important resource to California Native American Tribes in the Clear Lake region. There are seven federally recognized Tribal Nations in the Clear Lake region: 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. Traditional ecological knowledge (TEK) recounted by Tribal elders indicate historical chi populations were so abundant that they were a primary food staple for several Tribes. Each spring, the chi spawning runs provided a significant cultural event for the Tribes to gather with families to harvest and preserve the fish to consume throughout the year. Additional historical accounts indicate the CLH were in the millions, and that Clear Lake tributaries would be brimming with CLH during their spring migration (Miller 2012; USFWS 2020). Currently, the population has decreased with many government agencies considering the CLH population as imperiled (Ewing 2021; Miller 2012). In 2014, the CLH was listed on the California Endangered Species Act list as a "threatened" species (California Natural Diversity Database (CNDDB) 2023).

Several factors may have contributed to the overall population decline of the CLH. Anthropogenic impacts have led to the degradation of habitat within the Clear Lake watershed since the beginning in the 19th century when Euro-Americans first settled into the area (Suchanek et al. 2003). The Tribes began to witness a decline in CLH populations that coincided with reduced instream flow and drastic changes in land use (BV EPA 2023). While CLH spawning runs continue to be a significant cultural event for the Tribes, the experience and tradition of CLH harvesting has become almost inaccessible to the current youth of the Tribes (BV EPA 2023). Degradation of habitat and its impacts on CLH threaten tribal ways of life, subsistence, community growth and wellbeing, cultural survivability, financial resources, and human rights (BV EPA 2023).

Alterations to the Clear Lake watershed include artificially constructed instream passage obstacles, past mining activities, agricultural and urban development, flood control projects, wildfires and deforestation (CDFW 2014). These impacts have changed the hydrology, altered streamflow, and reduced the amount of water maintained in the tributaries during the CLH's migration, spawning, juvenile rearing, and outmigration period (USFWS 2020). CLH have been impacted due to the earlier drying of streams, particularly in spring, and the presence of migration barriers that have reduced the amount of historical instream habitat accessible to them (Macedo 1994; Moyle 2002). Surface water and groundwater interactions in the Clear Lake watershed are not well understood but recent efforts involving additional monitoring and modeling are underway (Lake County 2022; SWRCB 2025). Passage obstacles within the watershed include stream culverts, flood conveyance structures, streambed alterations, sedimentation, and overgrowth of vegetation that hinder access and migration of CLH. Future viability of CLH is dependent upon several environmental factors, in particular being those affecting habitat quality and essential access to spawning habitat (USFWS 2020).

On August 17, 2022, the Tribes in the Clear Lake region presented to the Fish and Game Commission requesting immediate action to protect the CLH (FGC 2022). As a result, a Task Force was formed to identify and implement short and long-term actions for the benefit of the CLH. The Task Force is facilitated by California Department of Fish and Wildlife (CDFW) and serves as a forum where California Native American Tribes, local, state, and federal agencies can collaborate on conservation efforts. In December 2022, the Tribes in Lake County hosted the first CLH Government Summit for government agencies to collaborate on the implementation of conservation and management actions to protect CLH. Following the CLH Government Summit, on March 24, 2023, Governor Newsom signed Executive Order N-5-23 that mandates the SWRCB and CDFW evaluate the minimum instream flows and other actions needed to protect CLH (State of California Executive Department 2023). This technical report describes CDFW’s scientific study to identify minimum instream flows to protect CLH passage and the habitats upon which they depend.

1.1 Study Goals and Objectives

The goal of this study was to identify minimum flows needed for CLH passage in select tributaries of the Clear Lake watershed. The results of this study may inform water management decisions such as emergency regulations, water rights condition development and protest resolution, and local Sustainable Groundwater Management Act (SGMA) implementation. The objectives for this project were to:

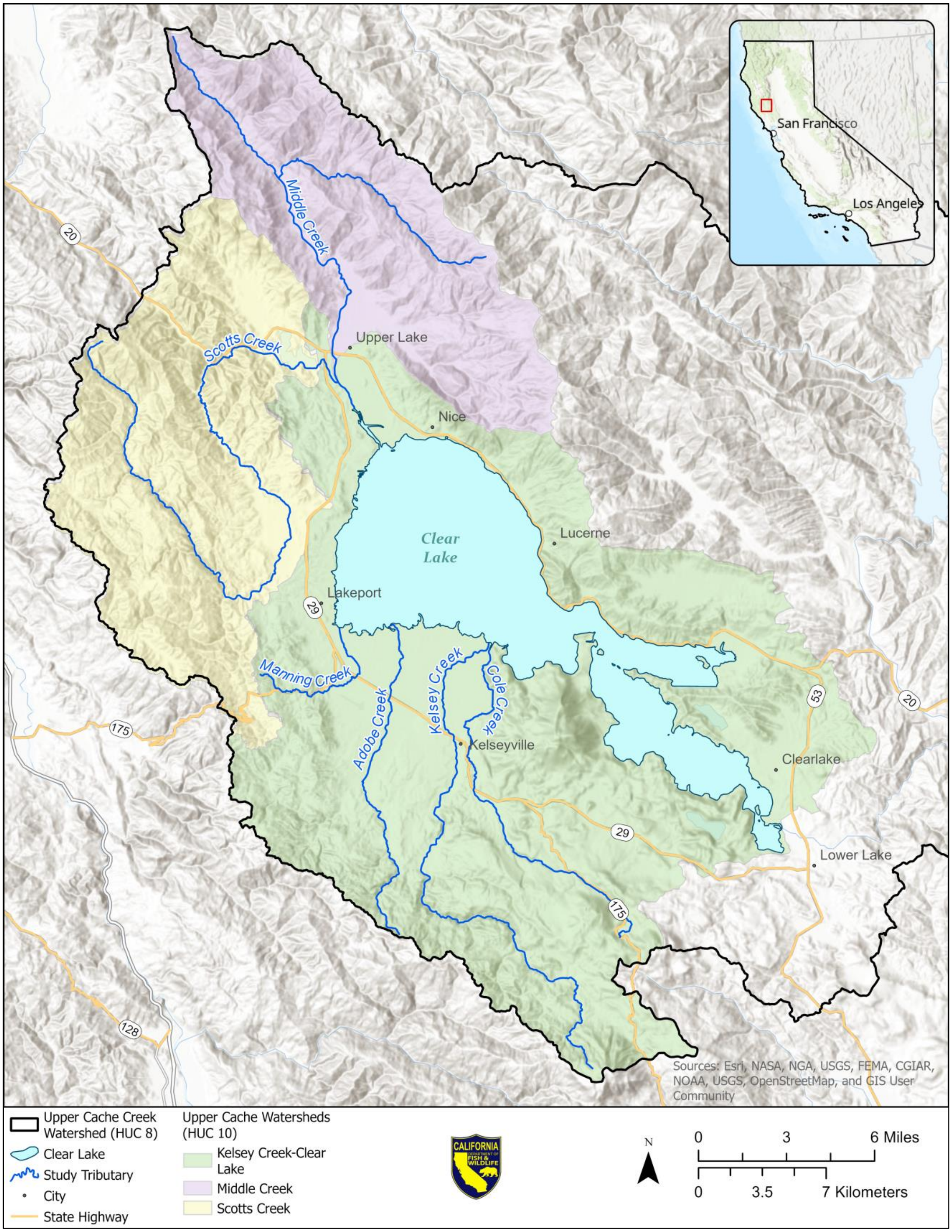
- Develop hydraulic habitat models to identify flows in depth sensitive areas (DSAs) for CLH passage.
- Identify relationships between streamflow and CLH passage using habitat and hydraulic modeling.
- Coordinate and collaborate with California Native American Tribes, local, state, and federal agencies.

1.2 Description of Watershed

Clear Lake is the largest natural freshwater lake located wholly in California, covering 68 square miles of surface area. The Clear Lake watershed is located approximately 100 miles north of San Francisco within Lake County. Sitting in the Coastal Range at an elevation of 1,319 ft, the area has a Mediterranean climate, with hot, dry summers and relatively cool, mild, wet winters. The wet season is not continuously wet and may be broken up by periods of warm clear weather. The Clear Lake watershed receives limited snowpack in most years and relies on precipitation from November through May. The lake and tributaries are part of the Upper Cache subbasin United States Geological Survey (USGS) 8-digit hydrologic unit code (HUC8). There are three primary HUC10 watersheds that drain to the lake: Kelsey Creek-Clear Lake, Scotts Creek, and Middle Creek. Combined, these HUC10 watersheds cover an area of 488 square miles and have numerous tributaries that flow throughout. The headwaters of many of these streams begin in the mountainous regions of the watershed, flowing through various alluvial terraces and valleys before entering the lake. Nestled in a valley within the Northern Coast Ranges and with historically easy access to water, Clear Lake and the surrounding areas have been a prime location for agriculture.

Clear Lake's watershed is bound by mountainous regions with small hills and flat valleys spread throughout and along the lake's shores. The elevations around the southeast to the southwest of Clear Lake range from 2,500 to 4,000 ft in the Mayacamas Mountains, while valley elevations near the lake range between 1,330 ft at the shoreline to 1,650 ft in the upland areas (Christensen Associates 2002). There are several small towns in flat areas around the lake including Upper Lake and Nice to the north, Lucerne and Clearlake to the east, Lakeport to the west, and Kelseyville in the south. The dominant land use that occurs in larger valleys is agriculture, consisting primarily of pear orchards, vineyards, pastures, and cannabis cultivation. As a result, agricultural water use is significantly higher than municipal and industrial use, with nearly 82% of the Clear Lake watershed's 55,000 acre-ft total water use going towards agriculture (Lake County 2010). More recent evaluations of water use reflect similar trends specifically within the Big Valley groundwater basin, which spans the lowland valley area south of Clear Lake and includes the city of Kelseyville. Estimated water use for agriculture accounted for approximately 80% of the basin's total water use during water year 2018 (Lake County 2022).

There are more than 15 tributaries surrounding Clear Lake that CLH may utilize. After discussions with the Task Force, six major tributaries were identified for an in-depth instream flow study to be completed by CDFW's Instream Flow Program (IFP). Figure 1 identifies the tributaries of interest on Adobe, Cole, Kelsey, Manning, Middle, and Scotts Creeks within each of their appropriate HUC10 boundaries. These tributaries provide the majority of surface water flowing into Clear Lake with Scotts, Middle and Kelsey Creeks accounting for about 73% of the inflow (Lake County 2010). The Task Force has provided sufficient evidence identifying CLH presence in each of these streams.



Sources: Esri, NASA, NGA, USGS, FEMA, CGIAR, NOAA, USGS, OpenStreetMap, and GIS User Community

Figure 1. Map of six study tributaries: Adobe, Cole, Kelsey, Manning, Middle, and Scotts Creeks.

1.3 Clear Lake Hitch

The CLH is only found in Clear Lake and its surrounding tributaries. While CLH is genetically similar to the two other sub-species of hitch, Monterey Hitch (*Lavinia exilicauda harengus*) and Sacramento Hitch (*Lavinia exilicauda exilicauda*), they differ morphologically. The CLH appear to exhibit deeper bodies, larger eyes, larger scales, and more numerous fine gill rakers than the other two sub-species of hitch (CDFW 2014; Feyrer et al. 2025; Figure 2). CLH are not considered strong swimmers or jumpers since they have adapted to their lacustrine environment with the low-gradient tributaries used for spawning (Baumsteiger et al. 2018; USFWS 2022). Additionally, CLH have reproductive traits that help them overcome their short spawning window due to the ephemeral nature of many Clear Lake tributaries. Compared to other hitch, CLH growth is quicker and they mature sooner, contributing to greater fecundity (Baumsteiger et al. 2018; USFWS 2022). Despite these advantageous reproductive traits, premature stream drying remains a primary concern during the spawning and migration window (Macedo 1994; Moyle 2002).

Figure 2. Adult Clear Lake Hitch, courtesy of Fred Feyrer from U.S. Geological Survey (Feyrer et al. 2025).

The CLH can live up to six years with males maturing by their second year and females maturing within their second or third year (CDFW 2014; Miller 2012). Potamodromous fish, such as CLH, complete their life cycle entirely within freshwater. Adult migration, spawning, embryo incubation, larval development, and adult/juvenile emigration all occur during a short temporal window during the spring season when dry streambeds become temporarily inundated from seasonal rains (Feyrer 2020). CLH are considered iteroparous, meaning they can reproduce multiple times over their lifespan (Feyrer et al. 2025). Although spawning has been observed along the lake's shoreline, CLH eggs can be susceptible to predation by Common Carp (*Cyprinus carpio*) (Kimsey 1960). Migration of CLH usually begins in March and ends in May; however, depending on seasonal hydrologic conditions, adult migration may begin as early as

February and juvenile rearing and outmigration may continue into summer (Luis Santana personal communication 2023; Moyle 2002).

The spatial extent of CLH spawning has declined compared to their historical distribution. It is believed that CLH once spawned throughout the Clear Lake watershed, including all major tributaries, smaller unnamed creeks, Thurston Lake, and the Blue Lakes (Miller 2012; USFWS 2022). Currently, CLH are known to spawn in a subset of tributaries, including Adobe, Cole, Kelsey, Manning, Middle, and Scotts Creeks.

1.4 Hydrology

Streamflow in most tributaries of the Clear Lake watershed are highest during the winter months, but by mid-summer, some tributaries become intermittent and go dry. CLH are found in Clear Lake most of the year; however, may enter Clear Lake tributaries as early as February to as late as summer while water is present (Luis Santana personal communication 2023; Moyle 2002; USFWS 2020). The major tributaries contributing surface water to Clear Lake are Scotts and Middle Creeks, which enter from Rodman Slough to the northwest, and Kelsey Creek to the south (Lake County 2010). Additional creeks located south of Clear Lake provide habitat for CLH, which include Adobe, Manning, and Cole Creeks (Miller 2012).

Historically, many tributaries surrounding Clear Lake maintained perennial or near perennial flows, with continuous flow from fall through late spring or early summer (Miller 2012). However, flows in these tributaries now diminish or become disconnected earlier in the migration season due to water diversions, groundwater pumping, channel modifications, and drought conditions (Miller 2012). Currently, most tributaries exhibit intermittent flow, with water present primarily during and shortly after fall, winter, and spring storm events (Miller 2012). Aquifer levels surrounding Clear Lake are considerably lower than they were 25 years ago, resulting in accelerated stream drying (Miller 2012). Environmental specialists have documented these tributaries drying by the end of May in 2012, whereas historically these same tributaries used to maintain flow through June or July (CBD 2022; Miller 2012). As streamflow continues to diminish at an expedited rate during spring, the CLH are at higher risk of stranding due to changes in connectivity (CDFW 2014; Miller 2012; USFWS 2022).

Several hydrology monitoring stations have operated across tributaries surrounding Clear Lake; however, meaningful hydrologic analysis has been limited by short periods of record, data gaps, and seasonal data collection. To address these limitations, the SWRCB expanded the gaging network and contracted with O'Connor Environmental, Inc. to conduct a groundwater-surface water study (SWRCB 2025). The study includes data collection, analysis, and development of a watershed-scale hydrologic model. This model will improve understanding of groundwater and surface water interactions in the Clear Lake watershed and provide flow estimates to inform our CLH passage study.

2.0 METHODS

CDFW used hydraulic habitat modeling to assess CLH passage conditions in each of the six study tributaries (Figure 1). Two-dimensional (2D) hydraulic habitat modeling was used to identify depth sensitive areas and/or velocity barriers that could limit CLH passage within model boundaries of the six tributaries. CDFW has used 2D hydraulic habitat modeling to evaluate fish passage conditions in several California streams. The IFP investigated passage and habitat connectivity flows for steelhead (*Oncorhynchus mykiss*) through depth sensitive natural, low gradient, critical riffle sites in the Big Sur River, California (Holmes et al. 2016). We also used 2D modeling to determine passage criteria for spring-run Chinook Salmon through a bedrock outcrop in Butte Creek (Cowan et al. 2016), and more recently applied high-resolution light detection and ranging (lidar) to estimate passage flows in a braided reach of the Ventura River (Cowan et al. 2021). In addition, the IFP developed flow–habitat relationships on Mark West Creek using 2D modeling (Carlin et al. 2022). The methods applied in these studies were adopted here to evaluate upstream passage needs for CLH.

Utilization of minimum depth criteria is a common approach worldwide for determining minimum flows for fish passage (Bovee 1982; Grantham 2013; Holmes et al. 2016; Reinfelds et al. 2019). In California, minimum depth criteria for adult salmonids range between 0.7–0.9 ft (R2 Resource Consultants Inc. 2008). We utilized a 0.5-ft depth criterion based on prior hydraulic modeling studies in the Clear Lake watershed (BV EPA 2020; BV EPA 2023). Observations from TEK and (Feyrer 2020) suggest a 0.5-ft depth criterion as appropriate since CLH have been observed in water depth levels as low as approximately 0.8 ft. Our study focuses on adult upstream migration and outmigration since CLH are iteroparous, where adults do not appear to die after spawning (Feyrer et al. 2025). For the longer streams, Adobe Creek, Kelsey Creek, Middle Creek, and Scotts Creek, we provide two flow criteria, one for upstream migration and another for downstream.

Fish passage assessments commonly focus on stream sections that become shallow and restrict movement as flows recede. For this study, the six tributaries are alluvial channels with most of the DSAs typically occurring in low-gradient riffles. Riffles are mesohabitat units characterized by shallow, turbulent, swiftly flowing water and partially exposed cobble substrate along the crest where swift flow initiates (McCain 1990). This study encompasses over 50 river miles of streambed across the six tributaries of interest.

CDFW's study approach is summarized in the high-level conceptual model presented in Figure 3. The blue boxes represent the types of field data collected and generated for the 2D hydraulic habitat modeling and are further described in Section 2.1. The green boxes outline the hydraulic habitat modeling framework, showing how field data were incorporated into the 2D models. The yellow boxes illustrate the process used to identify DSAs in each study tributary. Detailed methods for hydraulic habitat modeling and CLH passage assessment are provided in Section 2.2.

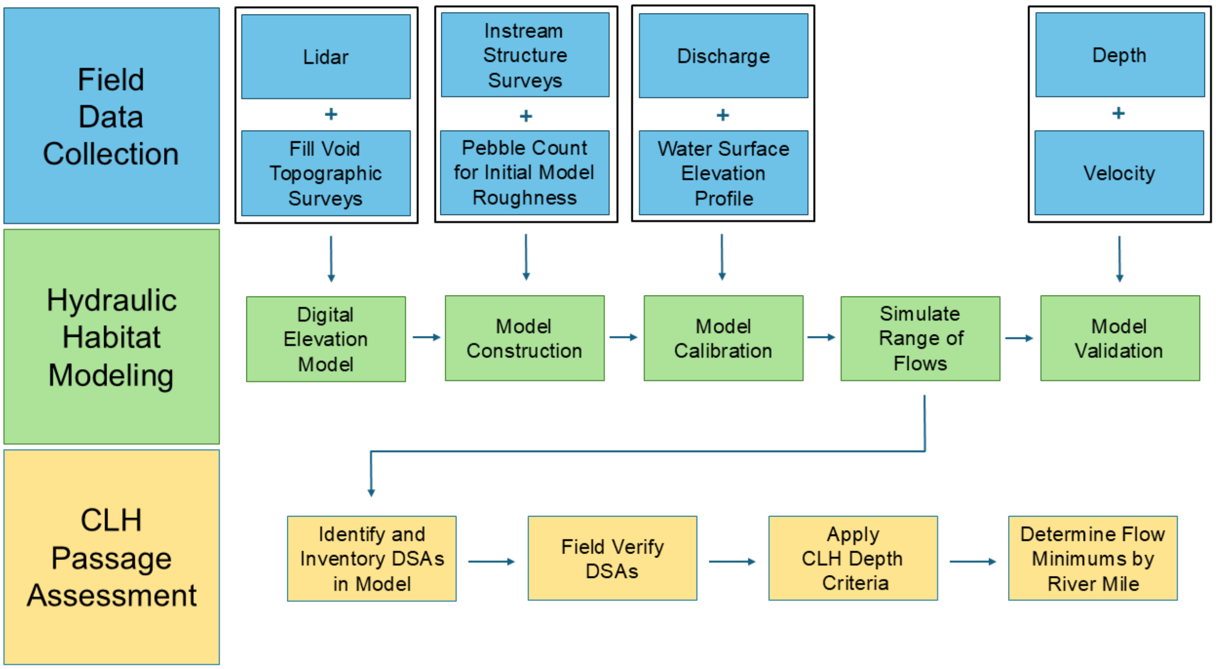


Figure 3. Conceptual model of CDFW's study approach integrating field data collection, hydraulic habitat modeling, and Clear Lake Hitch passage assessment.

In general, 2D hydraulic habitat modeling is a hydraulic area model, where hydraulic parameters, depth and velocity, are predicted within the wetted portion of the model boundary. The basis of each tributary 2D model is the digital elevation model (DEM), a digital representation of the stream surface and over-bank areas. For this study, the source of the DEM was a combination of lidar and topographic survey data. Initial flow simulations were executed within the boundary of each tributary model at the flow levels measured in the field. Each tributary model was calibrated using the data collected in the field consisting of the initial estimates of streambed roughness from pebble counts and the water surface elevation profile measured by staff. Each tributary model was validated by comparing depths and velocities measured in the field at randomly selected locations with their simulated counterparts in areas of known discharge.

2.1 Field Data Collection Procedure

2.1.1 Lidar

CDFW contracted with NV5 to conduct airborne lidar surveys to map the topographic and bathymetric (underwater) terrain for each of the six study tributaries. Airborne lidar is an active remote sensing method in which sensors on an aircraft measure the time of flight for emitted laser light pulses to reach reflective surfaces (e.g., the ground or vegetation) and return to the detector on the aircraft (Kinzel et al. 2012). Two types of laser sensors were used: near infrared for capturing streambanks, dry areas, and exposed substrate in the channel, and bathymetric green wavelength to capture beneath the water's surface. Figure 4 compares a field photograph (left) with lidar data (right), which digitally represents the topography and bathymetry. NV5 acquired the lidar data between the dates of April 6th–April 8th, 2024, when weather and water conditions were most favorable. Figure 5 shows the area of interest (AOI) where NV5 flew flight lines to obtain data. Horizontal and vertical control was also established by NV5. All data are referenced to the California Coordinate System of 1983 (2011) epoch 2022.50 and the North American Vertical Datum of 1988, Geoid 18. Units for the data are in U.S. survey feet. The lidar data had a spatial resolution of 1.5 ft. More information about the lidar acquisition, processing, and output data can be found in Appendix A.

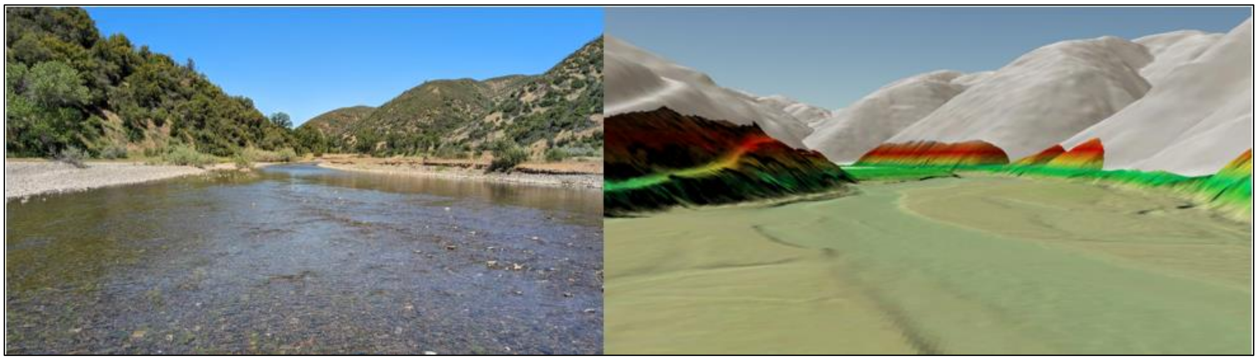


Figure 4. Scotts Creek looking upstream. On the left is a picture taken in the field, and on the right is an example of how the terrain is displayed digitally from lidar data.

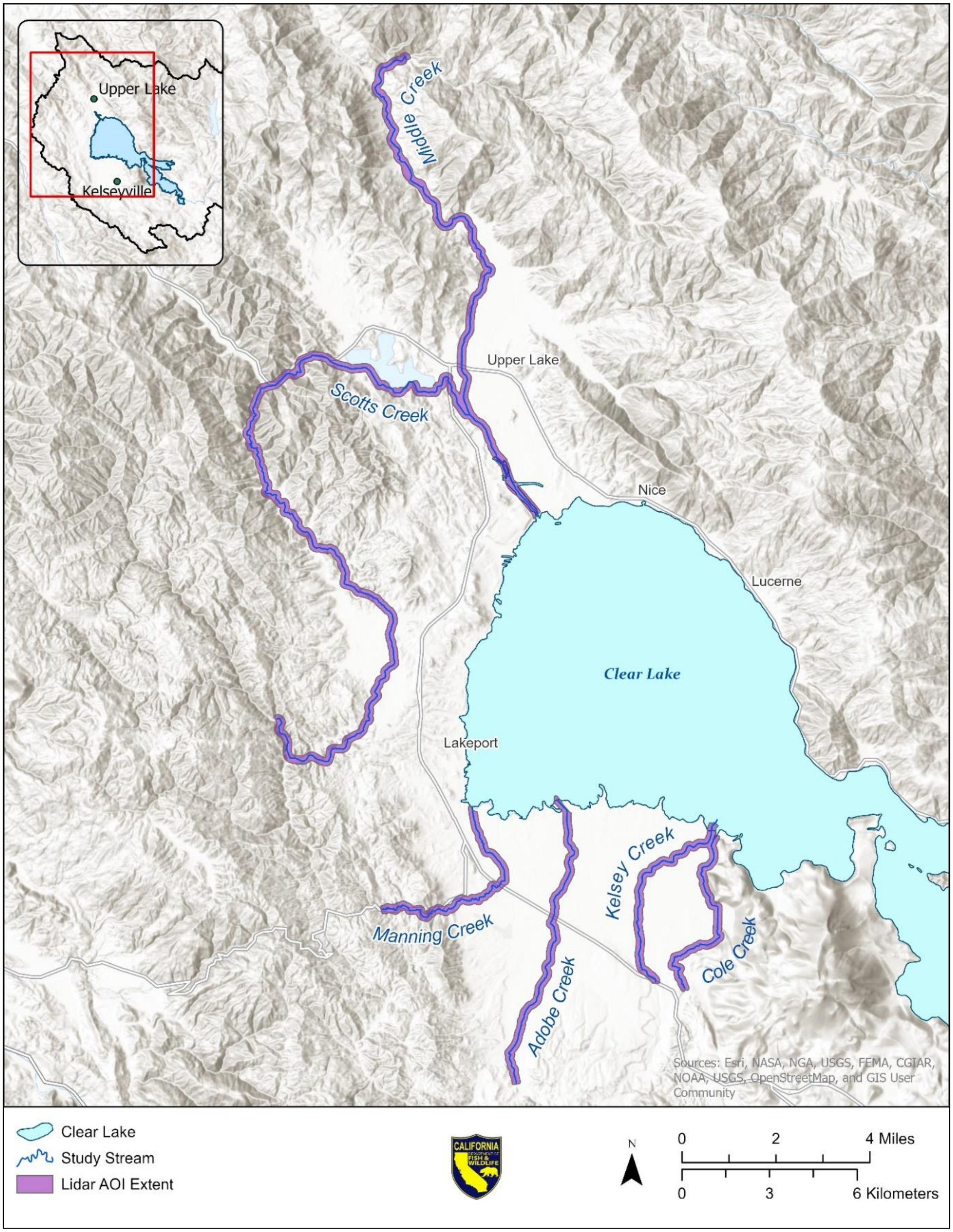


Figure 5. Map of the lidar area of interest in the Clear Lake watershed.

2.1.2 Topographic Surveying to Fill Lidar Voids

CDFW completed additional topographic surveys to fill in voids where the lidar pulses could not penetrate, for example in areas with vegetative cover, under bridge decks, or when water was too deep or turbid. We used a total station and Real-Time Kinematic Global Positioning System (RTK-GPS) to collect high density topography points to fill lidar voids in depth limiting areas that could limit upstream passage for CLH. Figure 6 provides an example of CDFW using a total station for a bridge on Manning Creek. Figure 7 provides an example with CDFW using an RTK-GPS in a DSA on Adobe Creek. By filling these voids, CDFW was able to generate a high-resolution digital elevation model to accurately simulate flows in the 2D hydraulic habitat models. For more detailed information about the CDFW topographic surveying to fill lidar voids, see Appendix B.

Figure 6. CDFW staff collecting location and elevation data under a bridge on Manning Creek using a total station.

Figure 7. CDFW staff collecting location and elevation data under vegetation within Adobe Creek using an RTK-GPS unit.

2.1.3 Discharge for Calibration

CDFW collected field discharge measurements along the longitudinal profile for each tributary length to calibrate the 2D hydraulic models (Figure 8). Discharge measurements followed CDFW's Instream Flow Program's *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California* (CDFW 2020). Field staff used a Hach FH950 velocity flow meter at locations with a reasonably straight flow path and with flow perpendicular to the cross sectional transect. Field staff selected transects in reaches with steady, uniform flow and were free of obstructions like large rocks or vegetation. Each transect was aligned perpendicular to the channel and wide enough to capture at least twenty sub-section flow measurements following the mid-section method. For more information about discharge methods and locations, see Appendix C.

Figure 8. CDFW staff collecting discharge on Kelsey Creek.

2.1.4 Water Surface Elevations for Calibration

CDFW collected water surface elevation (WSE) measurements at the same location where discharge was collected and throughout the channel along the wetted edge of each tributaries' longitudinal profile (Figure 9). This allowed CDFW to associate discharge with water depth, which is needed for 2D model calibration. Measurements were collected with RTK-GPS surveying equipment in "Fixed only" mode to ensure the highest-precision solution and accuracy. In this mode, the RTK-GPS rover records points only when the signal fix is within preset horizontal measurement solution (HMS) and vertical measurement solution (VMS) displayed in the data collector. For this study, both HMS and VMS were set to 0.05 ft. Each WSE point was logged as a 30-second continuous average with the RTK-GPS rover. Measurements were tied to benchmarks established by NV5 using an RTK-GPS base station. We collected WSE data across a range of flow conditions and channel geometries, including sections with riffles, pools, culverts, and other instream features. For more information on WSE methods and locations, see Appendix C.

Figure 9. CDFW staff use an RTK-GPS unit to collect water surface elevation data on Adobe Creek.

2.1.5 Depth and Velocity Measurements for Validation

Water depth and velocity measurements were recorded at randomly selected locations during the data collection of the WSE longitudinal profile (Figure 10). These measurements were used to validate water depths and velocities simulated at the corresponding flow levels and locations in the georeferenced 2D models for each tributary. Field staff collected data in wadeable sections of stream with discernible flow. Each validation point included a depth and velocity measurement using a Hach 950 flow meter and wading rod, with the exact location recorded by RTK-GPS. Following (USFWS 2011) recommendations, we collected a minimum of 50 validation measurements per stream. For more information about methods and locations for depth and velocity measurements for validation, see Appendix D.

Figure 10. CDFW staff using an RTK-GPS unit and a Hach flow meter attached to a top setting rod to collect validation data on Adobe Creek.

2.1.6 Pebble Counts to Estimate Initial Channel Roughness

CDFW completed pebble count surveys to estimate initial channel roughness, in terms of Manning's *n,* for each tributary's 2D model (Figure 11). We selected pebble count sites near surveyed structures and DSAs to ensure representativeness and reasonable field access. Pebble count transects were conducted by walking diagonally across the stream channel until reaching the bankfull channel edge (WVDEP 2025). Field crews recorded RTK-GPS point locations on the bankfull edge at each turn of a transect. Field staff collected pebbles at random using the step-toe procedure and categorized into size bins (WVDEP 2025). Each pebble's intermediate axis was measured with a gravelometer (Figure 12), with a minimum of 100 pebbles per site (SWRCB 2010). For more information about pebble count methods and substrate size classifications for each tributary, see Appendix E.

Figure 11. CDFW staff conducting a pebble count survey in Middle Creek.

Figure 12. Image of a gravelometer.

2.1.7 Instream Structure Measurements

CDFW measured the dimensions and elevations of instream structures, such as bridges, culverts, low flow crossings, and flood control structures, to accurately represent and simulate flows for each 2D tributary model. For bridges, we used the RTK-GPS to record the horizontal locations and elevations at the four pavement notches on the top of the decks (Figure 13). We measured deck thickness with a stadia rod and then subtracted that value from the RTK-GPS elevations to calculate the elevation for each deck bottom. A measuring tape was used to determine the station of each abutment and pier, while a stadia rod was used to measure the width and length of each pier. Figure 14 and Figure 15 shows field staff measuring the dimensions of example bridges. For culverts, we used an RTK-GPS to record the horizontal locations and elevations of both ends of each culvert's invert, along with the paving notches of the road surface, while a stadia rod was used to measure the diameter of each culvert. Lastly, for flood control structures and low flow crossings, we used a total station and RTK-GPS to measure points of interest. For more information about the methods used for measuring instream structures, see Appendix F.

Sources: Esri, NASA, NGA, USGS, FEMA, CGIAR, NOAA, USGS, OpenStreetMap, and GIS User Community

Figure 13. View of survey points at bridge paving notches at Soda Bay Road bridge crossing Adobe Creek.

Figure 14. CDFW staff collecting instream structure measurements of Highway 20 bridge crossing on Middle Creek.

Figure 15. CDFW staff collecting instream structure measurements of Eickhoff Road bridge crossing on Scotts Creek.

2.2 Two-Dimensional Hydraulic Habitat Modeling

We used 2D hydraulic habitat modeling to simulate flow conditions for CLH in each of the six study tributaries over a range of flows. Depth and velocity criteria are important biological parameters in hydraulic habitat modeling for assessing fish passage (Bovee et al. 1982). We utilized the same criteria from previous modeling efforts for CLH at 0.5 ft for depth and <5 feet per second (ft/s) for velocity (BV EPA 2023). The depth criterion specifies the minimum depth needed for adult CLH migration and outmigration, while the velocity criterion identifies potential flow conditions that may exceed CLH swimming capabilities, and therefore, impede passage. We developed 2D hydraulic habitat models to estimate depth and velocity across each study creek to evaluate CLH passage conditions. The 2D module of Hydrologic Engineering Center's River Analysis System (HEC-RAS Version 6.5; USACE 2018) was used to estimate depth and velocity in the modeled boundaries of each tributary.

The initial terrain for each 2D model was generated from the lidar data and converted to raster format to identify void areas where there were limited or no laser returns. These voids resulted from factors such as vegetation, bridges, and limited water clarity. Where voids overlapped with tributary flow paths that could be potential depth sensitive areas for CLH passage, CDFW conducted additional topographic surveys using RTK-GPS and total station to fill the gaps. We converted the horizontal and vertical point data from these surveys and overlaid them on the lidar void areas in HEC-RAS. The lidar data at the downstream extent of each tributary was limited by expansive voids caused by lake level ingress, depth and water clarity beyond the penetration capability of the green wavelength laser, and overhead canopy cover. Due to access limitations and unwadeable depths to survey these areas, we assumed they did not constrain depth or velocity for CLH passage.

Each tributary 2D model geometry included a flow boundary, inflow and outflow boundary conditions, and a computational mesh (Figure 16). We incorporated instream structures such as bridge abutments and piers as one-dimensional features using the Surface Area/2D Area editor in HEC-RAS. The 2D model boundary, referred to as 2D flow area, was digitized around the target stream area above and beyond the wetted flow boundary expected for each tributary. Inflow boundaries were assigned at the upstream extent and at tributary junctions, while outflow boundaries were placed at the downstream end of each model. We applied an initial 10-foot computational mesh across each 2D flow area and inserted refinement zones with 3-foot cell sizes at designated DSAs (Figure 16). Boundary conditions consisted of a constant inflow hydrograph and constant downstream water stage hydrograph or a normal depth boundary condition. We executed simulations in the unsteady mode using the following 2D flow solver settings: the Shallow Water Equations –

Eulerian-Lagrangian Method (SWE-ELM) equation set and the conservative turbulence model, with a longitudinal mixing coefficient of 0.3, a lateral mixing coefficient of 0.1, and a Smagorinsky coefficient of 0.05.

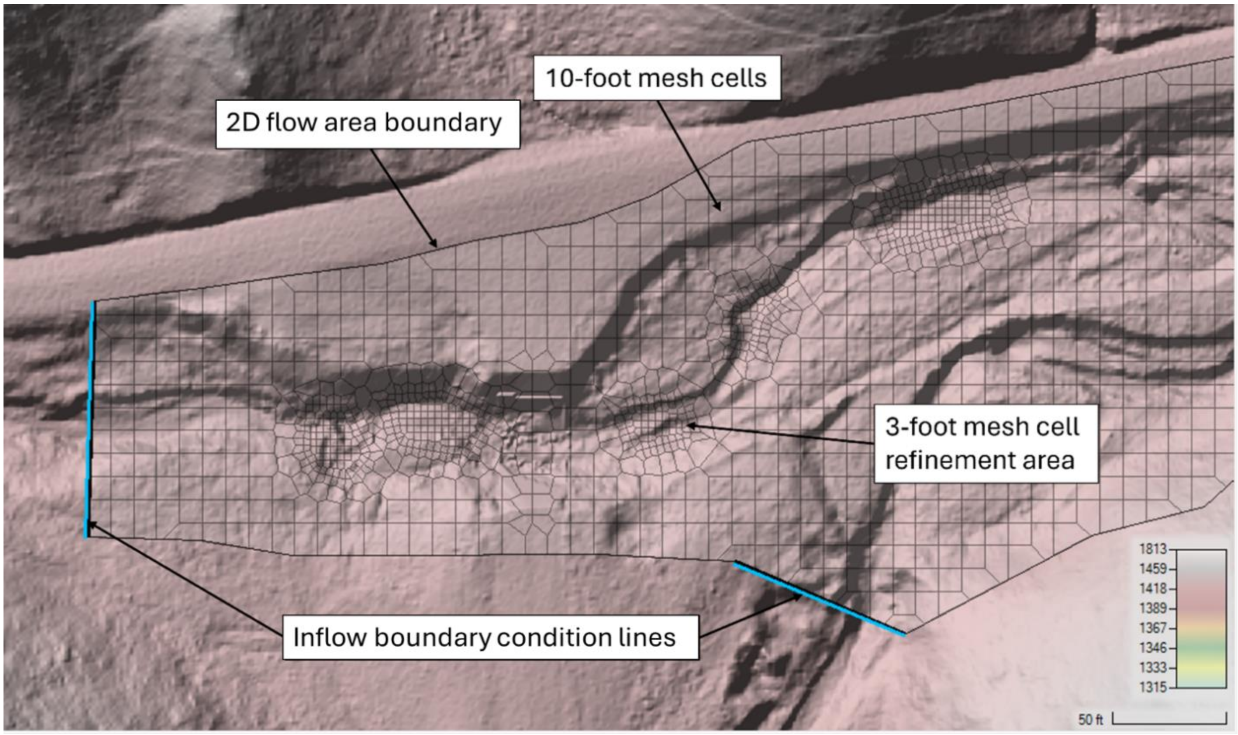


Figure 16. HEC-RAS 2D flow area geometry over the underlying lidar derived terrain layer, example view of the upstream boundary of Manning Creek.

We calibrated each 2D model using a step-back WSE-discharge approach (Waddle 2001). We set the upstream and inflow downstream tributary boundary conditions as constant hydrographs based on field measured discharge. For downstream boundary conditions, we applied a normal depth condition, and the friction slope, an initial estimate of the downstream hydraulic energy grade loss, calculated from the difference in elevation and distance from the two most downstream WSEs measured during the field WSE profile. One notable exception was Middle Creek, where the downstream boundary was best expressed as a constant water stage due to the influence of lake level within the modeled boundary. Initial Manning's *n* values were generated from the pebble count data (Appendix E). We ran the initial 2D model simulations at the field measured discharge to calibrate the models by comparing the field measured WSE profile (Figure 17) with the simulated WSE profile (Hardy 2006; Legleiter et al. 2011). The initial Manning's *n* values and downstream boundary friction slopes, and stage in the case of Middle Creek, were varied until the simulated WSEs matched the measured WSE (Appendix G).

Figure 17. Water's edge water surface elevation points collected along Kelsey Creek over the water depth raster simulated flow exported from HEC-RAS. Discharge was collected along a transect between points 3147 and 3148.

For the validation process, we simulated the same flows that were measured while in the field and collecting depth and velocity validation data (Appendix D). Represented as a georeferenced raster, we exported both depth and velocity values estimated for each validation flow simulated and then imported the rasters into ArcGIS for mapping purposes (Figure 18). We then compared field measured and simulated depth and velocity values to evaluate goodness of fit (Appendix G).

Following calibration and validation, we set downstream inflow tributary flows to zero to maintain constant flow and simulated a range of discharges within each tributary. Initial flow simulations were conducted at the same discharge measured in the field, as described in Section 2.1.3, to identify depth sensitive areas (DSAs) for each tributary. The 2D model simulations were performed to identify the flow levels needed to maintain a depth of 0.5 ft through each DSA thalweg (i.e., deepest point across a channel cross-section). We then verified five to seven of the most depth sensitive areas (MDSAs) in the field at each tributary by surveying the shallowest course from bank to bank using the RTK-GPS and measuring the deepest thalweg depth along the shallowest course using a stadia rod. Once the MDSAs were field verified, we performed additional flow simulations over a range of flows specific to each tributary to fully resolve the flows needed to maintain at least 0.5-ft of thalweg depth at each MDSA. The range of simulated flows are listed for each tributary in Section 3.2. Lastly, we identified the critical MDSA in each study tributary as the location requiring the greatest flow for CLH passage, which also coincides with the minimum flow criterion necessary to provide full upstream and downstream access to the stream.

Figure 18. Field validation points collected along Kelsey Creek over the water depth raster simulated flow exported from HEC-RAS.

2.2.1 Depth Sensitive Area Method

After we completed the field verifications for the MDSAs, we applied three-foot mesh refinement regions around each of the most DSAs in HEC-RAS (Figure 16). The other DSAs were displayed for us to determine the amount of flow needed to maintain passage up to the MDSAs. We then reran the models with the improved refinement geometries over a range of flows to evaluate whether the depth criterion of 0.5 ft was maintained through the thalweg of each MDSA. Then, for each MDSA, we digitized the thalweg and shallowest course from bank to bank. We used the location where the thalweg and shallowest course intersect (Figure 19) to estimate the minimum passage depth at each MDSA at a specific simulated flow. Lastly, we examined velocity results across all simulated flows to confirm that bank-to-bank velocities of 5 ft/s or greater did not create velocity barriers to limit CLH upstream passage.

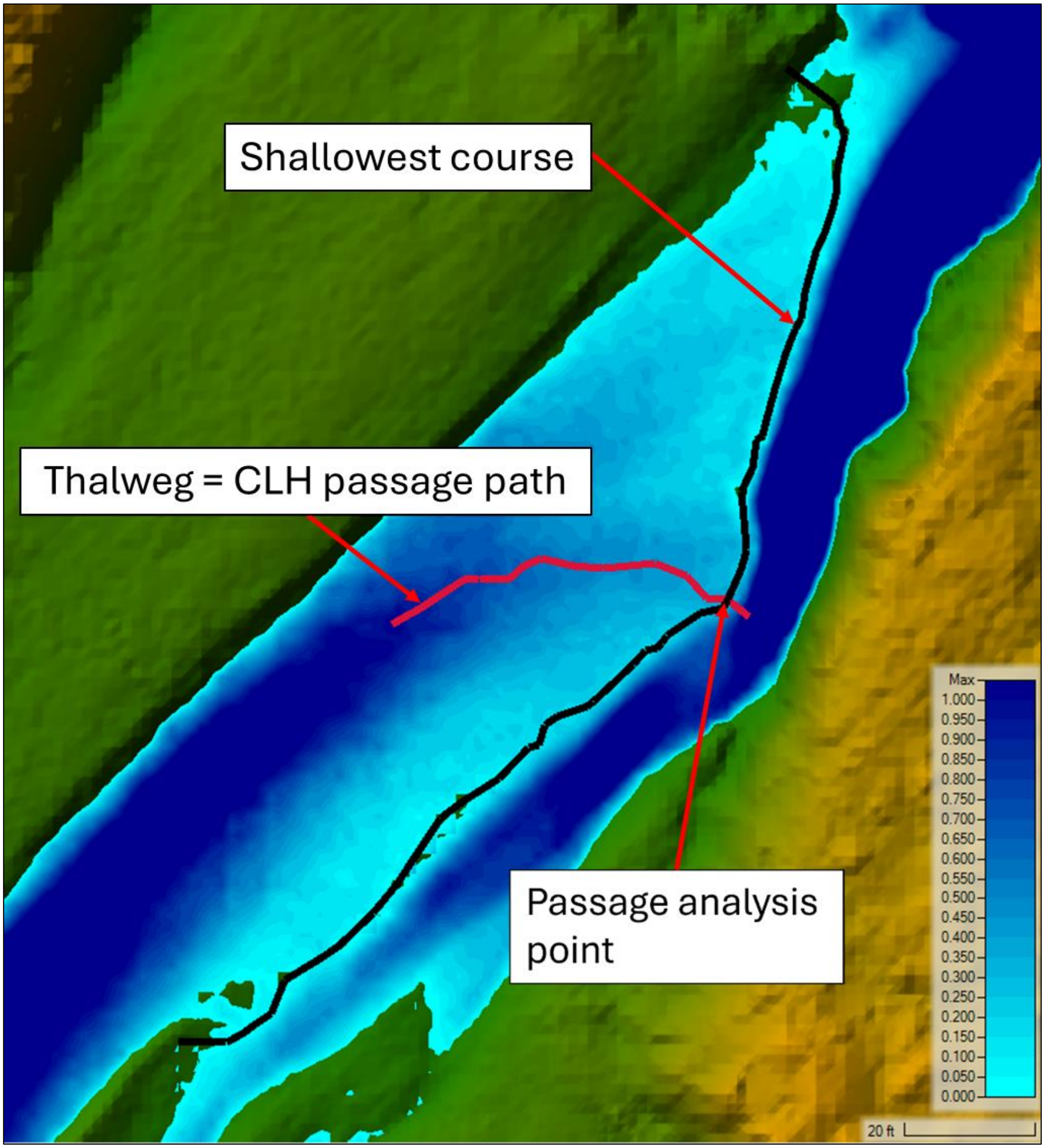


Figure 19. Depth sensitive area passage depth determination.

2.3 Data Management and Quality Assurance

This study followed CDFW's Scientific Data Governance Policy to ensure transparency and reproducibility in scientific data collection, documentation, and management. Data management for this study included a data management plan and metadata, and data were archived appropriately. CDFW will respond to requests for scientific data within a reasonable time, in accordance with all applicable laws, including the California Public Records Act.

Additionally, we followed the applicable quality assurance (QA) systems outlined within the Instream Flow Program's Quality Assurance Plan (CDFW 2023). The Quality Assurance Plan is a detailed document that describes quality assurance systems within the IFP related to project management, data generation and acquisition, assessment and oversight, and data validation and usability. It follows the scope and format specified in the US Environmental Protection Agency (EPA) Region 9 document *EPA Region 9 Requirements for Quality Assurance Program Plans*. This promotes IFP comparability with other California agencies utilizing QA program plans and QA project plans.

3.0 RESULTS

3.1 Field Data Collection Summary

Most of the lidar data acquired and processed by NV5 was effective in mapping a majority of the topobathymetry of the six study tributaries. However, the green lidar was unable to collect bathymetric data in the downstream-most portions of Adobe, Cole, Kelsey and Manning Creek due to backwatering by Clear Lake. A similar effect was seen in Scotts Creek due to backwatering from Rodman Slough. Field surveys downstream of the hydraulic model boundaries indicated that these areas were mostly deep pools, without depth-sensitive locations. Adobe and Scotts Creeks had the most voids due to deep pools and turbid conditions, while Middle Creek had the least voids (only under bridges). Overall, CDFW conducted 71 topographic surveys to fill voids in the lidar surface within the planned model domains. Together, the lidar and topographic surveys provided a more accurate representation of tributary bathymetry that was used as the base model terrain structure in the 2D HEC-RAS models (Appendix A and B).

We collected field data, as described in Section 2.1, to construct 2D hydraulic models for each of the study tributaries during March through July 2024. During the spring recession period (March-May 2024), we collected over 40 discharge measurements until flows receded to near zero (Appendix C). In this period, more than 1,100 WSE measurements and over 600 depth-velocity validation measurements were collected (Appendix D). We used field discharge and WSE measurements to create flow-WSE rating curves to calibrate each of the 2D models (Appendix G). Most of the 40 pebble count surveys were conducted during June and July of 2024, under low to no-flow conditions. The pebble count surveys allowed us to accurately estimate initial channel bed roughness coefficient (Manning’s *n*) for each model (Appendix E). The depth-velocity measurements were used to validate the final model results against the water conditions observed during spring 2024 (Appendix G). Figure 20 shows the spatial extent of the field data and the 2D hydraulic model domain boundaries across each of the six study tributaries. The model boundaries were derived from the lidar topobathymetry and the additional CDFW field topographic surveys, which are shown with an added 400-foot buffer for figure display purposes.

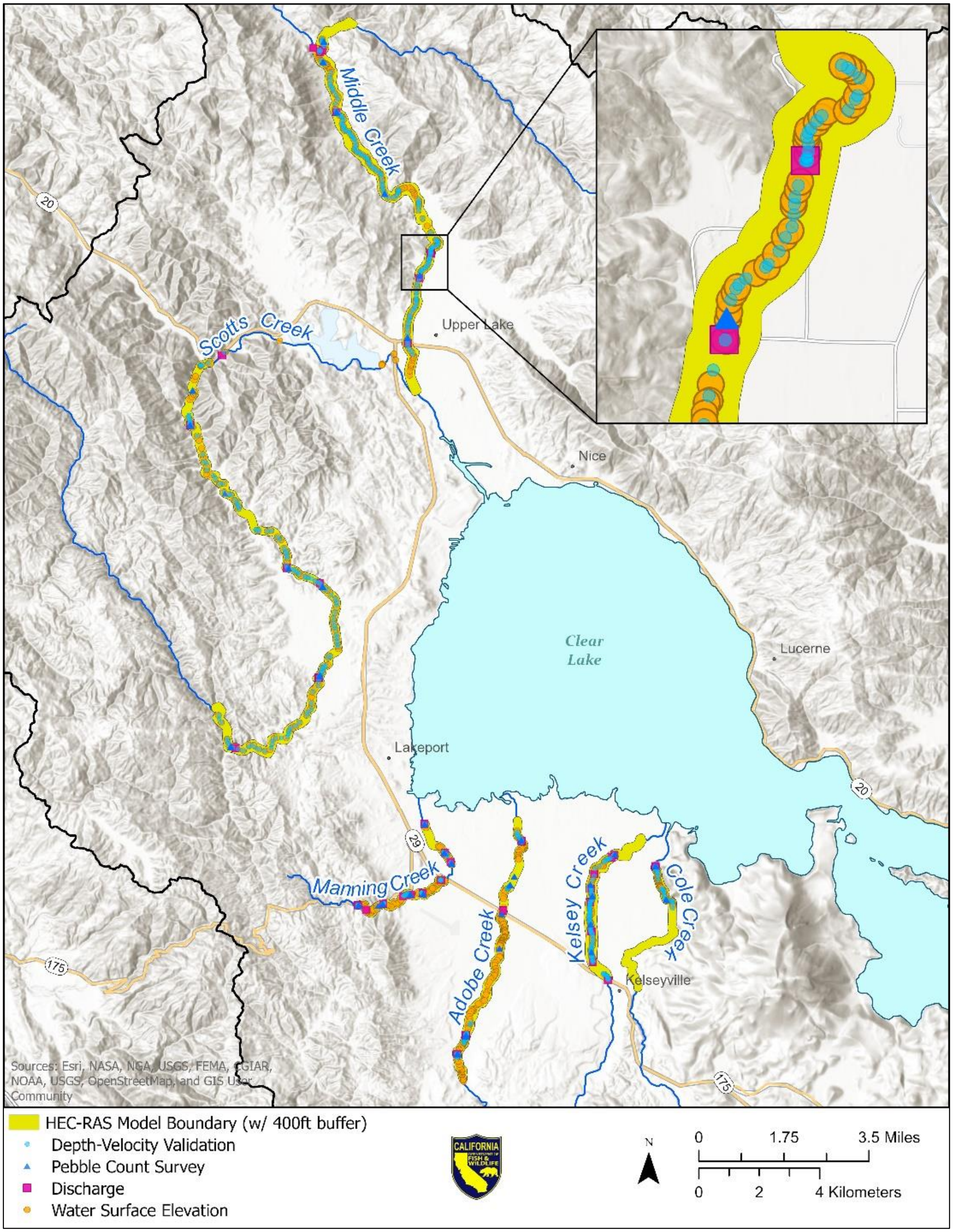


Figure 20. Spatial distribution of the various field data collection points (discharge, WSE, depth-velocity validation, and pebble counts) within the six 2D hydraulic model domains for all study tributaries (2D model boundaries shown in the map have a 400-foot buffer added for visualization).

3.2 Hydraulic Habitat Modeling Results

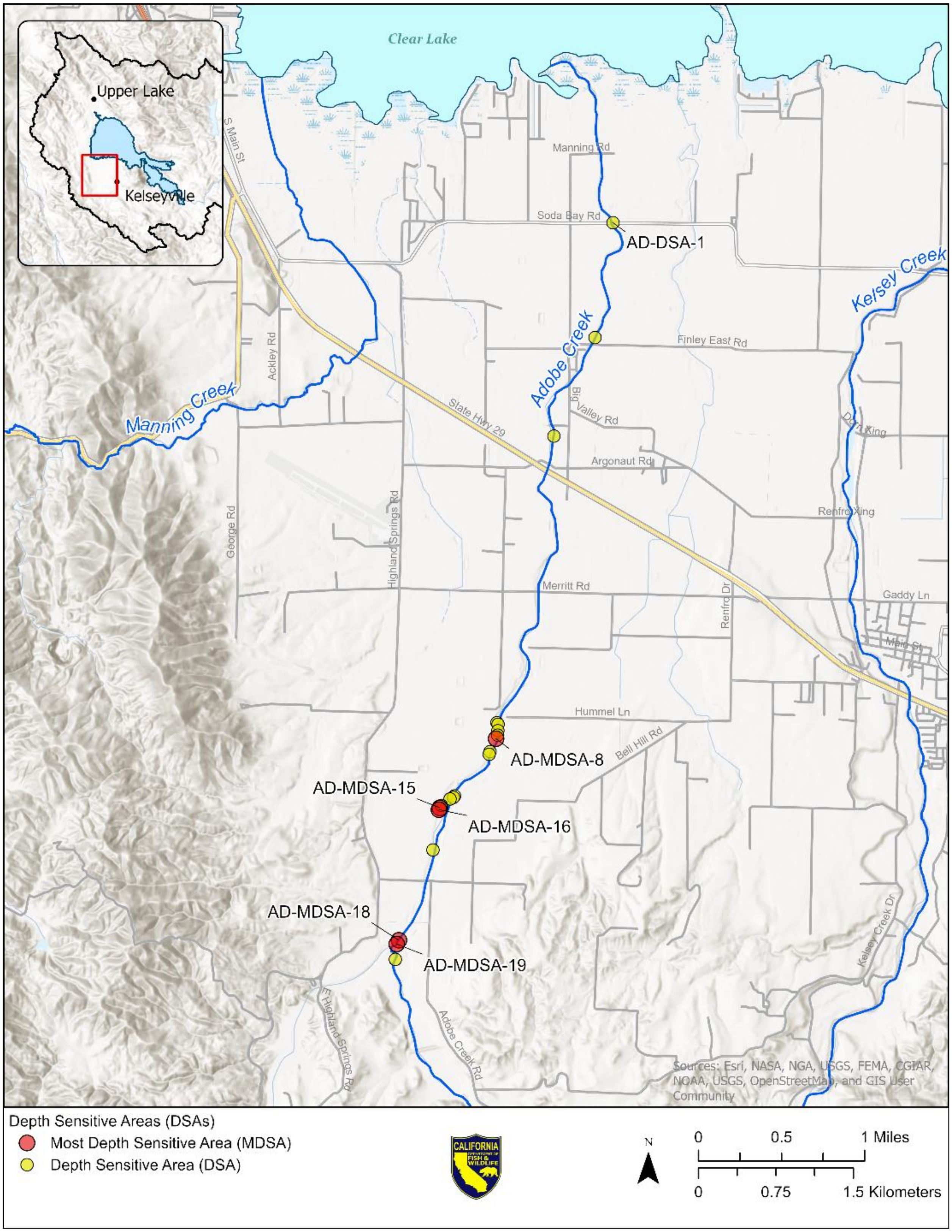
In the following sections we provide a summary for each of the six study tributaries. The maps for each tributary show DSAs. In each map red points indicate the five to eight MDSAs and yellow points show the remaining DSAs. Additionally, we report the water depth at the thalweg of the shallowest course for each MDSA location for each flow simulation shown both graphically and in tabular format. The remaining DSA locations are described further in Appendix H. Lastly, Table 1 summarizes the final model characteristics including the channel length, channel roughness, average gradient, and the range of simulated flows for each of the six study tributaries. Two Manning's *n* values are reported for Manning Creek due to a section of inaccessible private property; therefore, Manning Creek was divided into two separate model domains, Upper and Lower Manning Creek (see Section 3.2.4).

Table 1. Model characteristics for each of the six study tributaries.

Tributary	Channel Length (miles)	Channel Roughness (Manning's n)	Average Gradient (%)	Range of Simulated Flows (cfs)
Adobe Creek	6	0.040	0.3	5–74
Cole Creek	3.8	0.01	0.4	9.8–100
Kelsey Creek	3.6	0.041	0.2	10–80
Manning Creek	3.6	0.030, 0.063	0.4	5–30
Middle Creek	11	0.039	0.3	10–100
Scotts Creek	14.4	0.033	0.2	10–140

3.2.1 Adobe Creek

We ran flow simulations in Adobe Creek, as described in Section 2.2, resulting in a simulated range between 5 to 74 cfs. Twenty DSAs along the 6-mile channel length were identified, beginning downstream of Soda Bay Road and moving upstream to Adobe Reservoir. Of these, the five MDSAs are indicated as red points in Figure 21. All five MDSAs are located upstream of Hummel Lane, extending to the confluence with Highland Creek. Table 2 provides more information about each of the MDSAs with the river mile location, the transect length, and passage flow at the thalweg. Figure 22 illustrates the water depth at the intersection of the thalweg and shallowest course for each MDSA and simulated flow. The most critical MDSA was AD-MDSA-16, where 52 cfs is required for CLH to access the full length of Adobe Creek. While the MDSAs identified through hydraulic analysis are all located upstream of State Highway 29 and represent the most challenging passage corridors for CLH, the DSAs located downstream of the highway are important to determine flows needed for outmigration. Adobe Creek at Soda Bay Road (AD-DSA-1) is highlighted in Figure 21 and Table 2 since outmigration is a key stressor and stranding events occur in this area most years, making it an area of particular concern. Tables H-1 through H-3 in Appendix H provide additional information on river mile locations and simulated flows for the DSAs.



Sources: Esri, NASA, NGA, USGS, FEMA, CGIAR, NOAA, USGS, OpenStreetMap, and GIS User Community

Figure 21. Depth sensitive areas identified on Adobe Creek.

Table 2. Attributes of most depth sensitive areas in Adobe Creek.

Tributary	Depth Sensitive Area	River Mile	Shallowest Course Length (ft)	Passage Flow at Thalweg (cfs)
Adobe	AD-DSA-1	1.2	72.9	36
Adobe	AD-MDSA-8	4.7	98.6	36
Adobe	AD-MDSA-15	5.2	606.8	47
Adobe	AD-MDSA-16	5.2	929.7	52
Adobe	AD-MDSA-18	6.1	131.2	27
Adobe	AD-MDSA-19	6.2	169.5	31

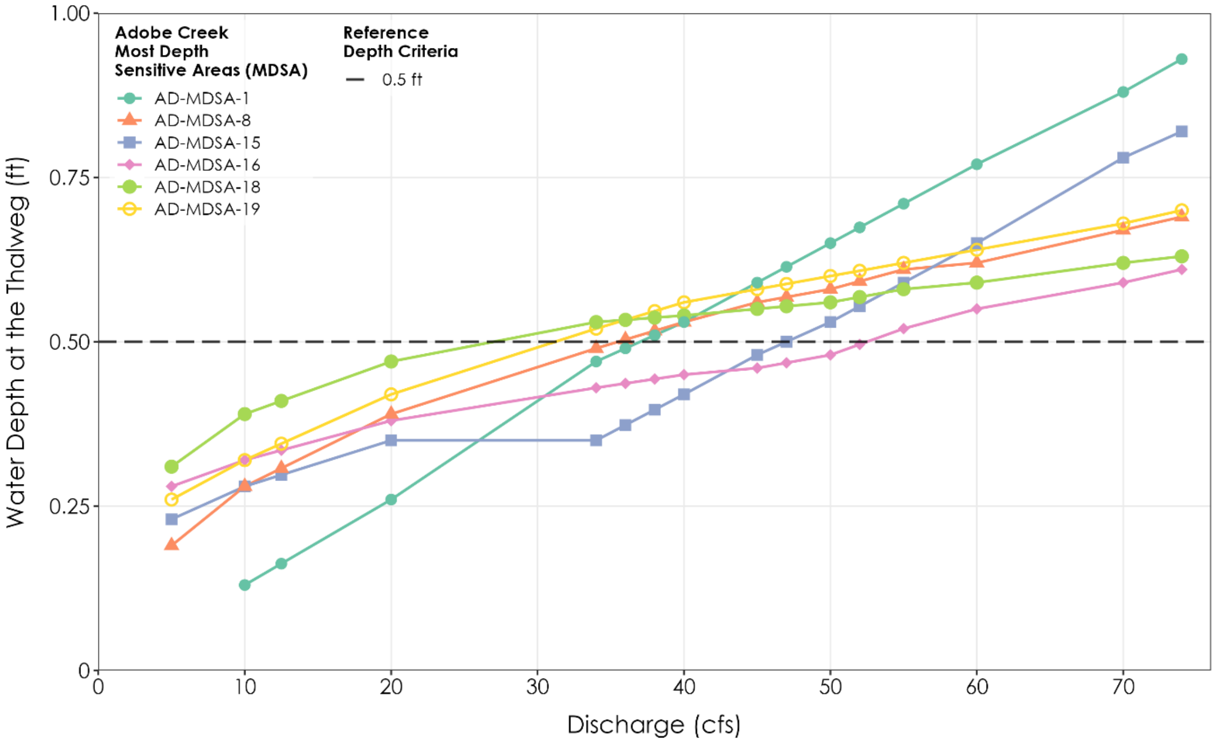


Figure 22. Relationship between discharge and water depth at the thalweg for the most depth sensitive areas in Adobe Creek. Each colored line represents a different depth sensitive area location, with the horizontal dashed line indicating the 0.5 ft minimum depth criterion for Clear Lake Hitch passage.

3.2.2 Cole Creek

We ran flow simulations in Cole Creek, as described in Section 2.2. resulting in a simulated range between 9.8 to 100 cfs over a 3.8-mile modeled reach, extending from downstream of Soda Bay Road to upstream near Konocti Road. Since Cole Creek was re-routed and channelized in the mid-20th century, it now exhibits a uniformly flat bed, trapezoidal shape, and predominately fine sediments. Five of the six MDSAs occur within 1.5 river miles from Cole Creek's confluence with Clear Lake, and the sixth lies approximately 4 river miles upstream near Sylar Lane bridge (Figure 23). Table 3 summarizes each MDSA with the river mile distance upstream from Clear Lake, the shallowest channel length, and minimum passage flow. The depth at the intersection of the thalweg and shallowest course are plotted for each MDSA and simulated flow (Figure 24).

MDSAs 14 through 19 were especially depth sensitive because a portion of Cole Creek's flow disperses onto an adjacent floodplain within this reach (Figure 25). This reach of Cole Creek is widely recognized as a flood risk zone and storm debris can accumulate (Cole Creek Flooding 2024). During the study survey, the most critical MDSA was CO-MDSA-17 where 90 cfs was needed for CLH to pass an instream barrier composed of refuse and storm debris (Figure 26 and Figure 27). However, as of December 15, 2025, the debris barrier was cleared and removed by the California Conservation Corps in coordination with CDFW, and Lake County (Nathan Cullen personal communication 2025). The next most critical MDSA was CO-MDSA-14 at 32 cfs for CLH to access the full length of Cole Creek.

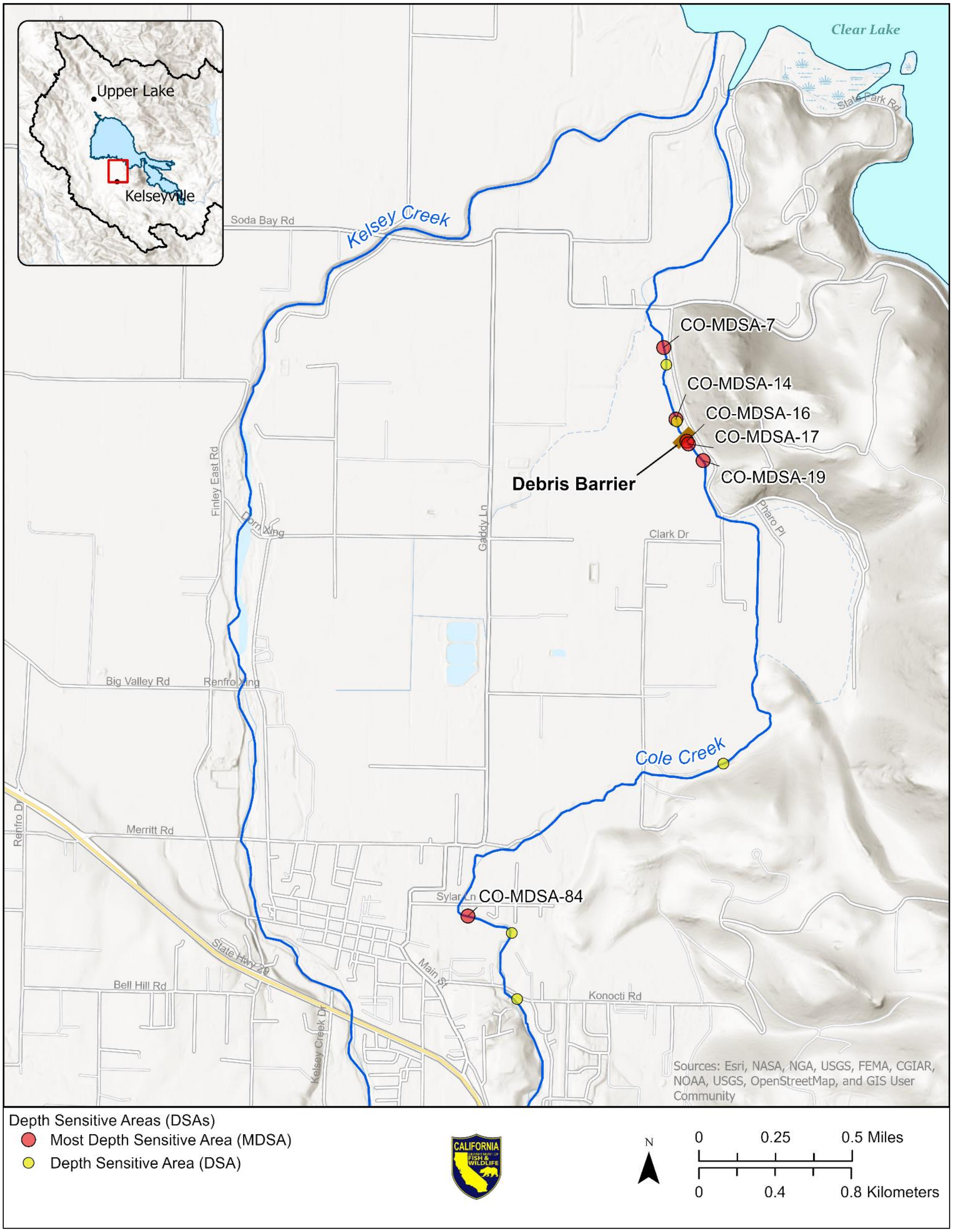


Figure 23. Depth sensitive areas identified on Cole Creek.

Table 3. Attributes of most depth sensitive areas in Cole Creek.

Tributary	Depth Sensitive Area	River Mile	Shallowest Course Length (ft)	Passage Flow at Thalweg (cfs)
Cole	CO-MDSA-7	1.1	14.7	22
Cole	CO-MDSA-14	1.4	13.8	32
Cole	CO-MDSA-16	1.4	16.2	31
Cole	CO-MDSA-17	1.4	27.4	90
Cole	CO-MDSA-19	1.5	21.8	23
Cole	CO-MDSA-84	3.9	16.6	31

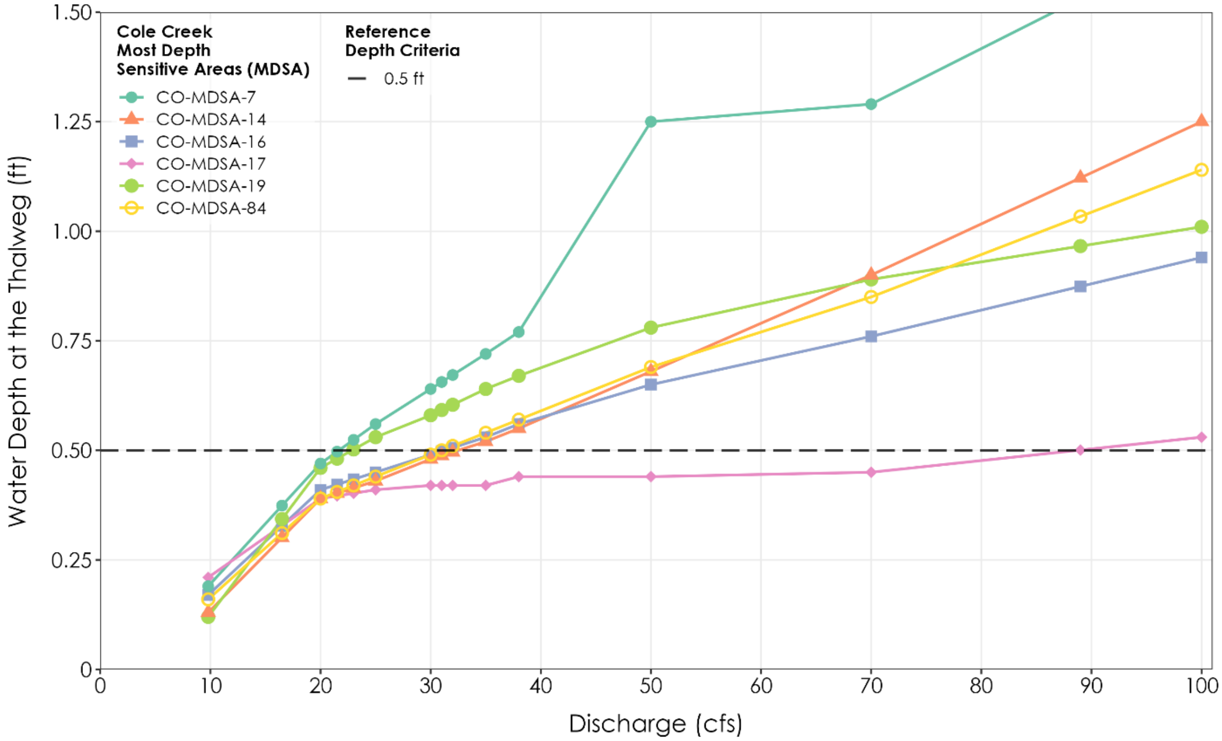


Figure 24. Relationship between discharge and water depth at the thalweg for the most depth sensitive areas in Cole Creek. Each colored line represents a different depth sensitive area location, with the horizontal dashed line indicating the 0.5 ft minimum depth criterion for Clear Lake Hitch passage.

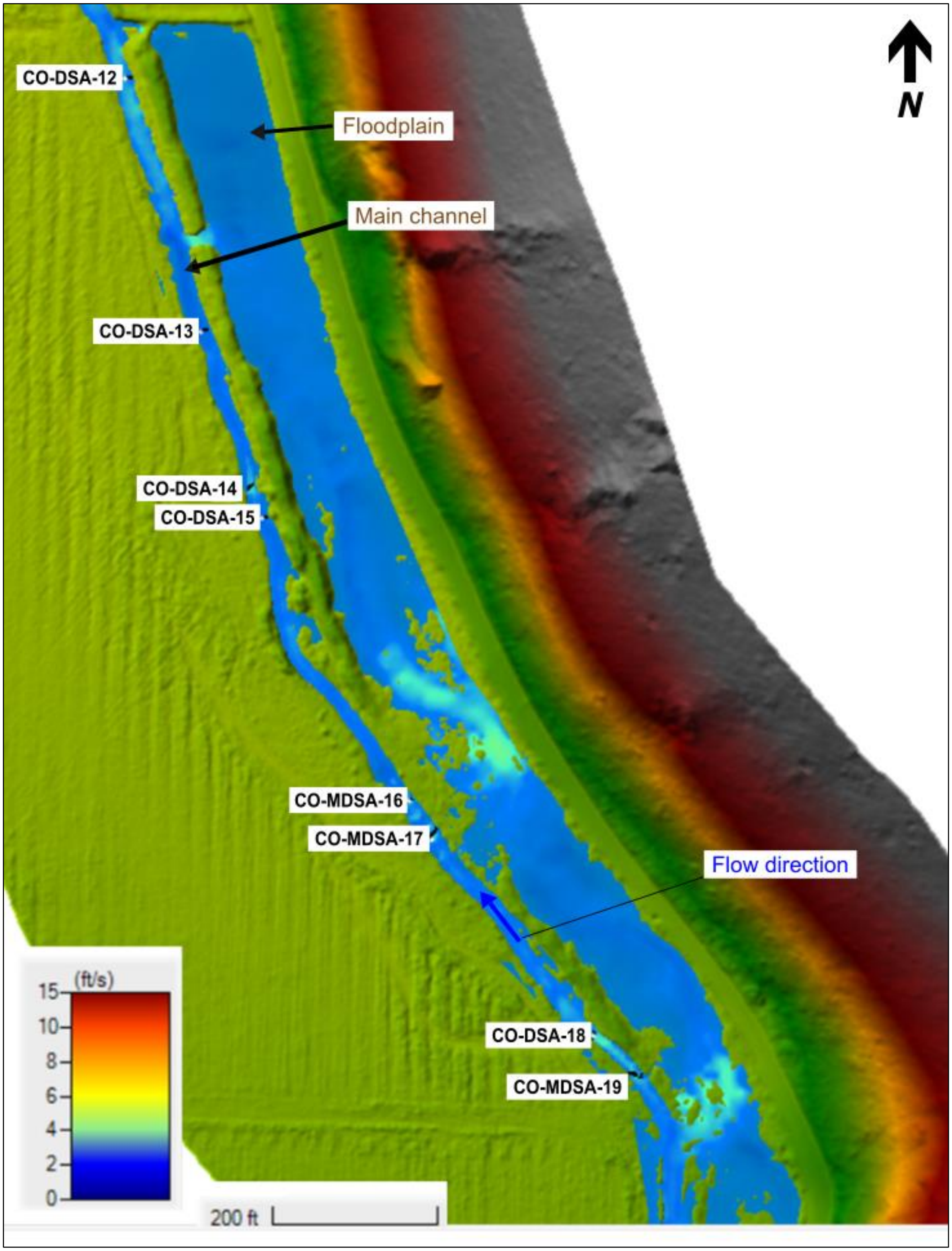


Figure 25. Cole Creek floodplain at Cole Creek flow of 100 cfs. Flow enters the floodplain upstream of CO-MDSA-19 and returns to Cole Creek downstream of CO-MDSA-13.

Figure 26. Artificial debris barrier located at Cole Creek near MDSA-17 at approximately 1 cfs.

Figure 27. Artificial debris barrier within Cole Creek looking downstream from CO-MDSA-17. Woody debris is floating in the channel leading up to a larger debris pileup in the background.

3.2.3 Kelsey Creek

We ran flow simulations in Kelsey Creek, as described in Section 2.2, resulting in a simulated range between 10 to 80 cfs. Thirty-one DSA's along the 3.6-mile channel length were identified, beginning just downstream of Soda Bay Road and moving upstream to State Highway 29. Of these, six were later field verified as the MDSAs, indicated as red points in Figure 28. All six of the MDSAs were located between Soda Bay Road and Merritt Road. Table 4 provides more information about each of the MDSAs with the river mile location, the transect length, and passage flow at the thalweg. Figure 29 illustrates the water depth at the intersection of the thalweg and shallowest course for each MDSA and simulated flow. The most critical MDSA was KE-MDSA-2 at 70 cfs for CLH to access the full length of Kelsey Creek. While the hydraulic analysis identified the MDSAs upstream of Soda Bay Road as the most challenging corridors for CLH, the downstream DSAs are important for determining flows that support outmigration. Tables H-7 through H-12 in Appendix H provide additional information on river mile locations and simulated flows for the DSAs.

Figure 28. Depth sensitive areas identified on Kelsey Creek.

Table 4. Attributes of most depth sensitive areas in Kelsey Creek.

Tributary	Depth Sensitive Area	River Mile	Shallowest Course Length (ft)	Passage Flow at Thalweg (cfs)
Kelsey	KE-MDSA-1	2.3	115	32
Kelsey	KE-MDSA-2	2.9	176	70
Kelsey	KE-MDSA-3	3.1	202	52
Kelsey	KE-MDSA-4	3.4	185	40
Kelsey	KE-MDSA-5	3.9	72	31
Kelsey	KE-MDSA-6	4.0	60	48

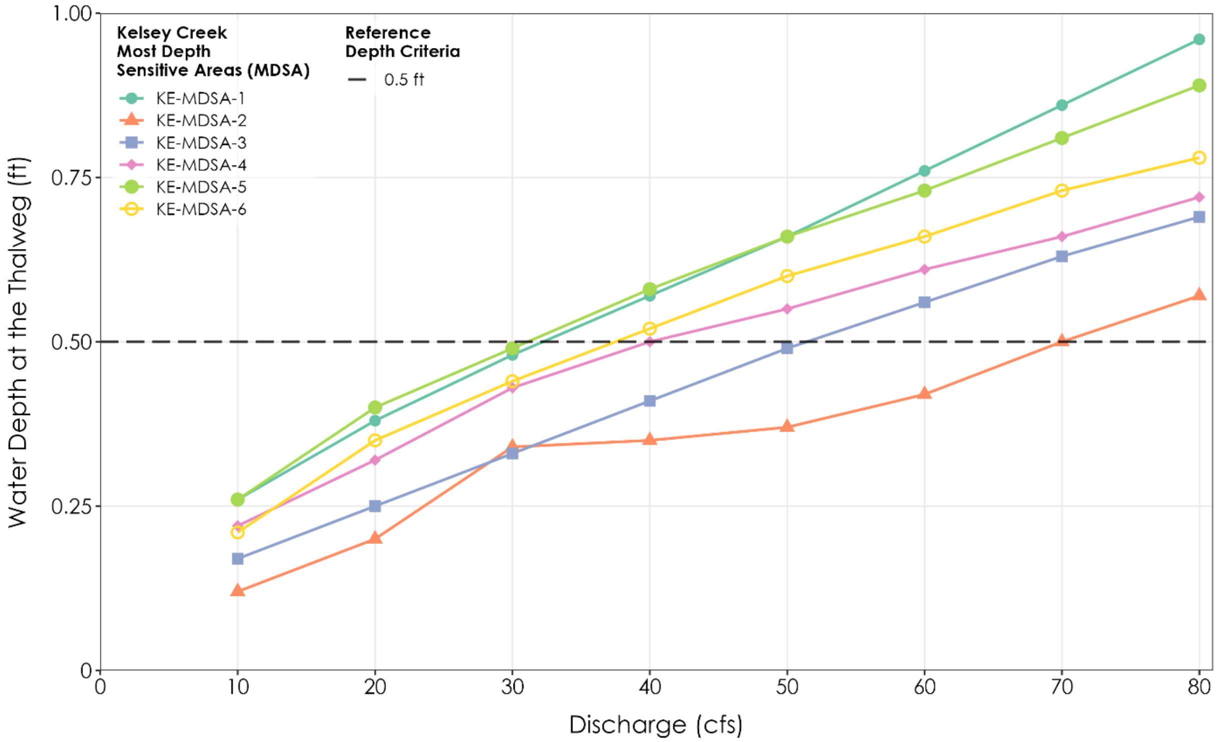
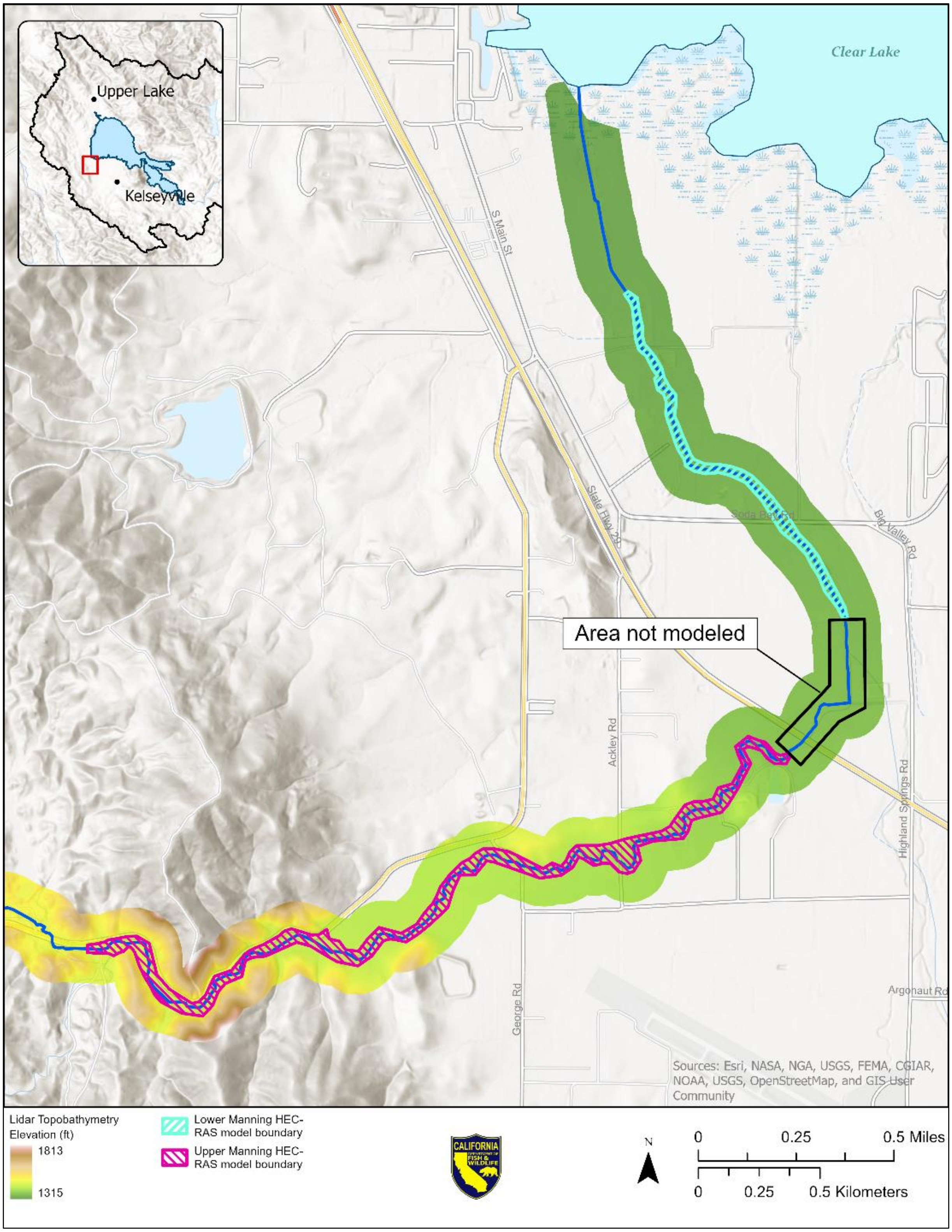


Figure 29. Relationship between discharge and water depth at the thalweg for the most depth sensitive areas in Kelsey Creek. Each colored line represents a different depth sensitive area location, with the horizontal dashed line indicating the 0.5 ft minimum depth criterion for Clear Lake Hitch passage.

3.2.4 Manning Creek

Manning Creek was divided into two separate 2D models because the reach downstream Highway 29 and upstream Soda Bay Road was inaccessible for data collection (Figure 30). Staff could not traverse this portion of the creek due to restricted access to private property, deep backwatered conditions that prevented wading, and large instream obstacles such as woody debris and storm deposits. We estimated the gap to be 0.4 miles near State Highway 29.

We ran flow simulations in Manning Creek, as described in Section 2.2, resulting in simulated range between 5 to 30 cfs. Thirty-nine DSA’s along a 3.6-mile channel length were identified, beginning downstream of Soda Bay Road at the Land Trust property and moving upstream to Granite Road Bridge. Of these, five MDSAs are indicated as red points in Figure 31. All five of these MDSAs are located upstream of State Highway 29. Table 5 provides more information about each of the MDSAs with the river mile location, the transect length, and passage flow at the thalweg. Figure 32 illustrates the water depth at the intersection of the thalweg and shallowest course for each MDSA and simulated flow. The most critical MDSA was MA-MDSA-25 at 26.7 cfs for CLH to access the full length of Manning Creek. While the MDSAs identified through hydraulic analysis are all located upstream of State Highway 29 and represent the most challenging passage corridors for CLH, the DSAs located downstream of the highway are important to determine flows needed for outmigration. Tables H-13 through H-20 in Appendix H provide additional information on river mile locations and simulated flows for the DSAs.



Sources: Esri, NASA, NGA, USGS, FEMA, CGIAR, NOAA, USGS, OpenStreetMap, and GIS User Community

Figure 30. Spatial extent of the Manning Creek hydraulic model. Light blue shading indicates the downstream model boundary, while pink shading indicates the upstream model boundary.

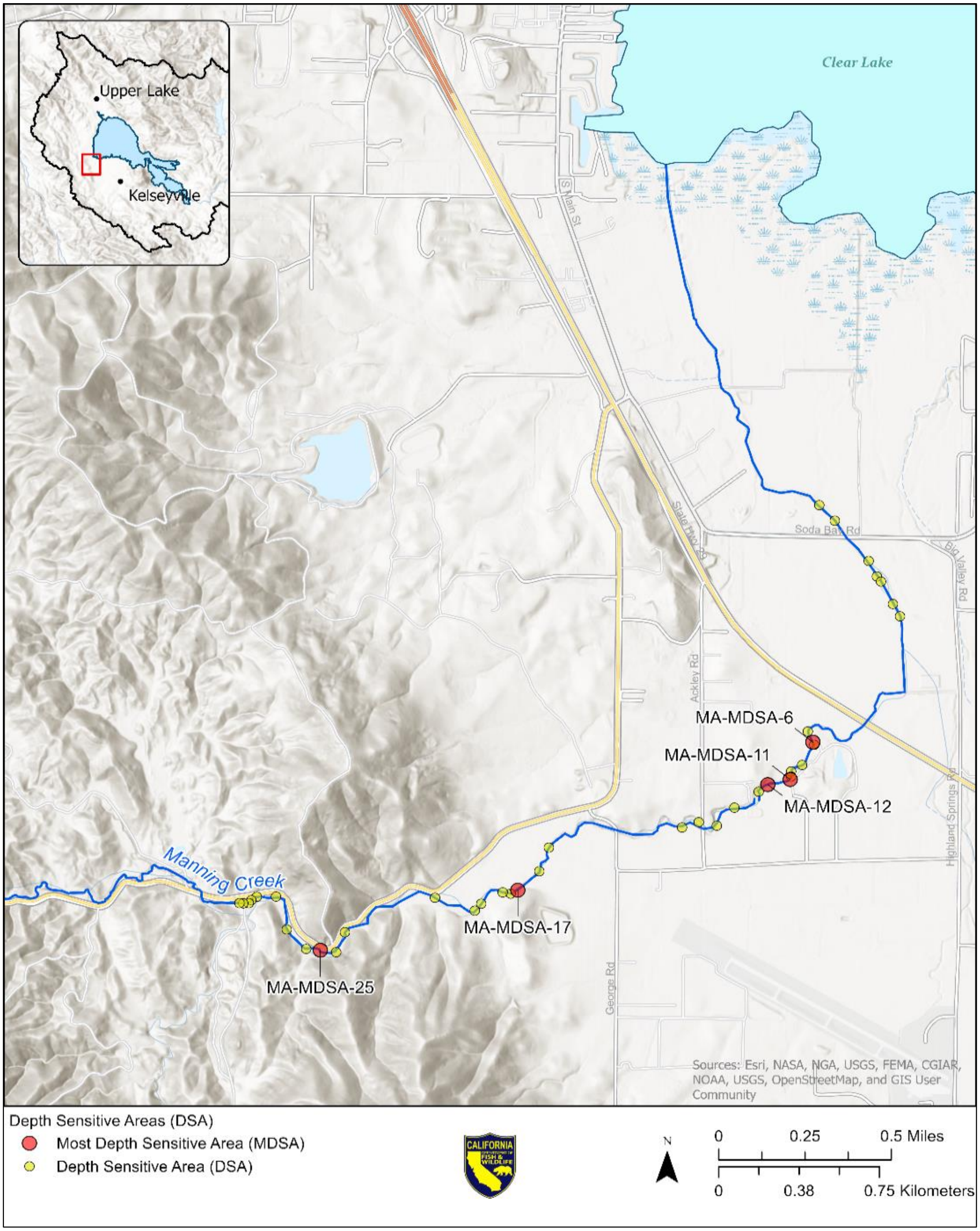


Figure 31. Depth sensitive areas identified on Manning Creek.

Table 5. Attributes of most depth sensitive areas in Manning Creek.

Tributary	Depth Sensitive Area	River Mile	Shallowest Course Length (ft)	Passage Flow at Thalweg (cfs)
Manning	MA-MDSA-6	2.3	31.2	22
Manning	MA-MDSA-11	2.4	16.4	22
Manning	MA-MDSA-12	2.5	27.1	25
Manning	MA-MDSA-17	3.5	42.6	21
Manning	MA-MDSA-25	4.3	28.5	27

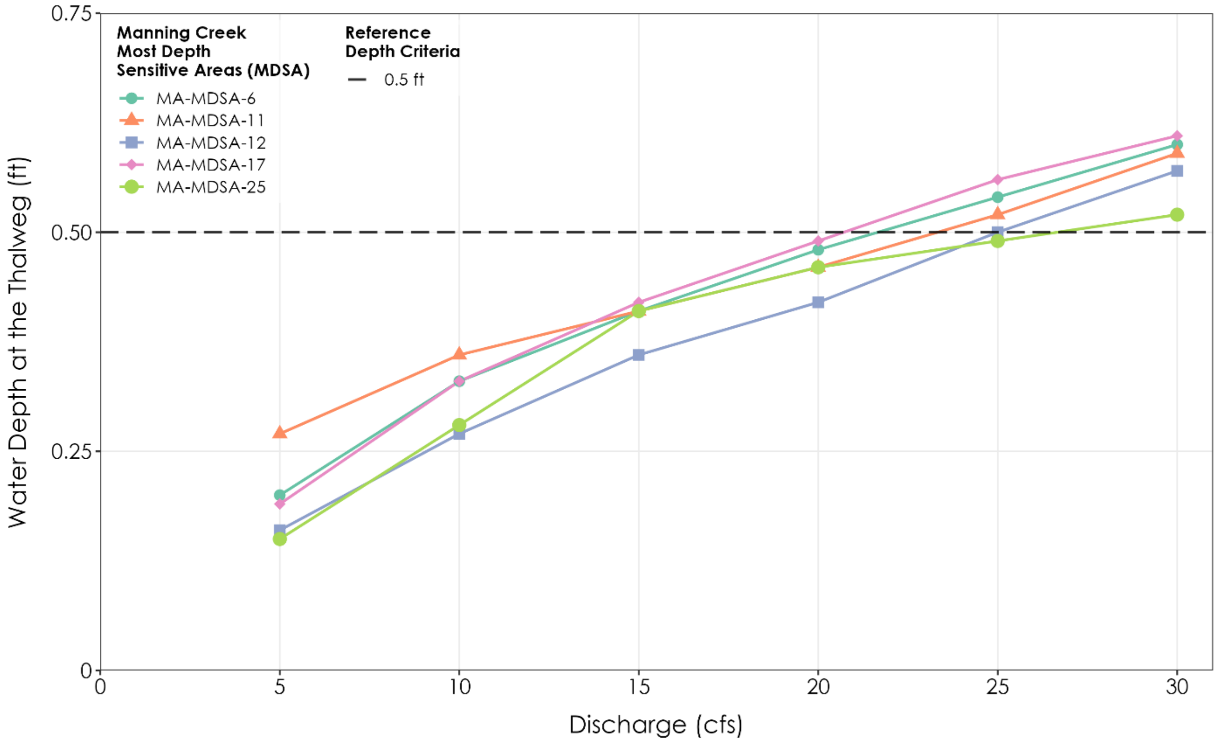


Figure 32. Relationship between discharge and water depth at the thalweg for the most depth sensitive areas in Manning Creek. Each colored line represents a different depth sensitive area location, with the horizontal dashed line indicating the 0.5 ft minimum depth criterion for Clear Lake Hitch passage.

3.2.5 Middle Creek

We ran flow simulations in Middle Creek, as described in Section 2.2, resulting in a simulated range between 10 to 100 cfs. Fifty-nine DSAs along the 11-mile channel length were identified, beginning at the confluence of Rodman Slough, moving upstream along East Fork Middle Creek, ending just north of Middle Creek Campground. Figure 33 illustrates the six MDSAs in red dots we identified, starting near the bridge at Rancheria Road and continuing upstream. Figure 34 illustrates the water depth at the intersection of the thalweg and shallowest course for each MDSA and simulated flow. The most critical MDSA was MI-MDSA-21 at 90 cfs for CLH to access the full length of Middle Creek (Table 6). Tables H-21 through H-24 in Appendix H provide additional information on river mile locations and simulated flows for the DSAs.

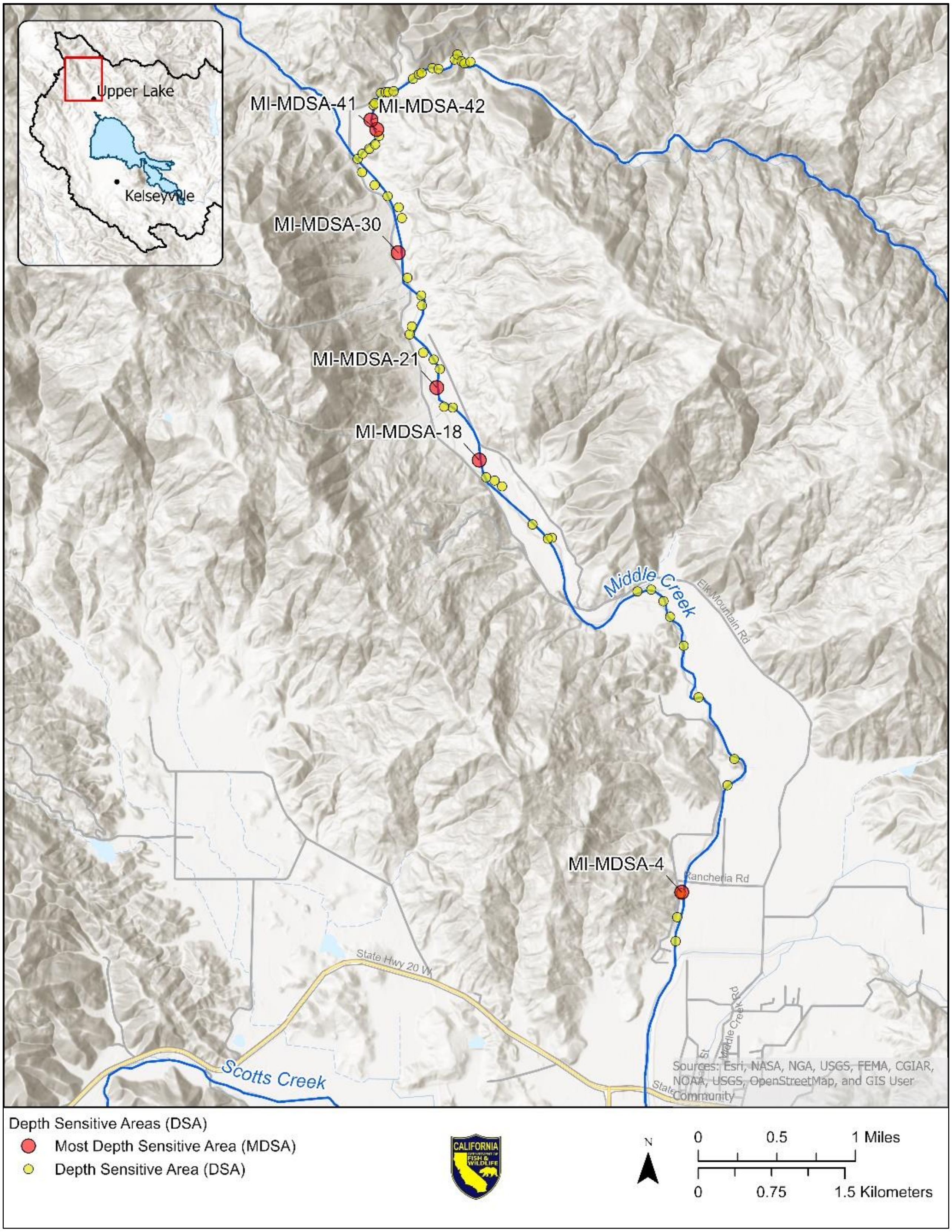


Figure 33. Depth sensitive areas identified on Middle Creek.

Table 6. Attributes of most depth sensitive areas in Middle Creek.

Tributary	Depth Sensitive Area	River Mile	Shallowest Course Length (ft)	Passage Flow at Thalweg (cfs)
Middle	MI-MDSA-4	2.4	20.0	61
Middle	MI-MDSA-18	6.8	313.3	80
Middle	MI-MDSA-21	7.4	175.5	90
Middle	MI-MDSA-30	8.4	306.4	68
Middle	MI-MDSA-41	9.4	130.0	80
Middle	MI-MDSA-42	9.5	114.9	68

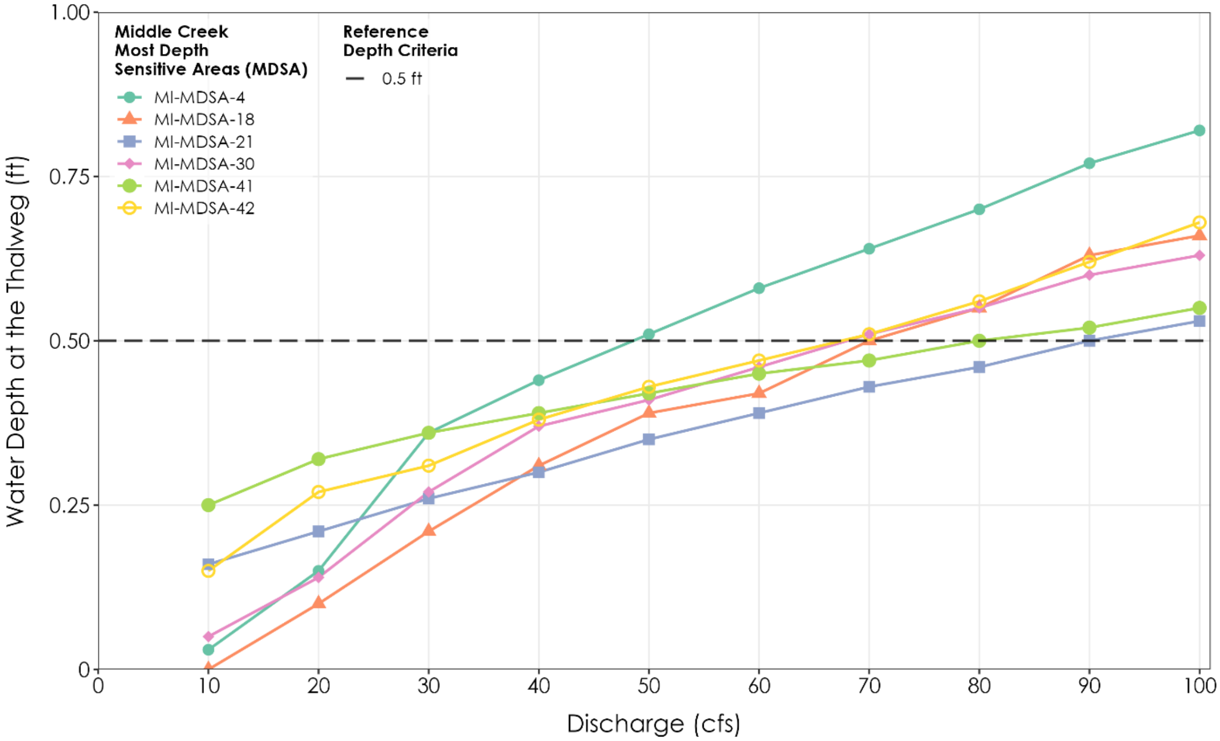


Figure 34. Relationship between discharge and water depth at the thalweg for the most depth sensitive areas in Middle Creek. Each colored line represents a different depth sensitive area location, with the horizontal dashed line indicating the 0.5 ft minimum depth criterion for Clear Lake Hitch passage.

3.2.6 Scotts Creek

We ran flow simulations in Scotts Creek, as described in Section 2.2, resulting in a simulated range between 10 to 140 cfs. Fifty-seven DSAs along the 14.4-mile channel length were identified, beginning near Lower Blue Lake and moving upstream to the confluence with South Fork Scotts Creek. Of these, seven are indicated as MDSAs (red points) in Figure 35. Table 7 provides more information about each of the MDSAs with the river mile location, the transect length, and passage flow at the thalweg. Figure 36 illustrates the water depth at the intersection of the thalweg and shallowest course for each MDSA and simulated flow. The most critical MDSA was SC-MDSA-57 at 140 cfs for CLH to access the full length of Scotts Creek. Tables H-25 through H-28 in Appendix H provide additional information on river mile locations and simulated flows for the DSAs.

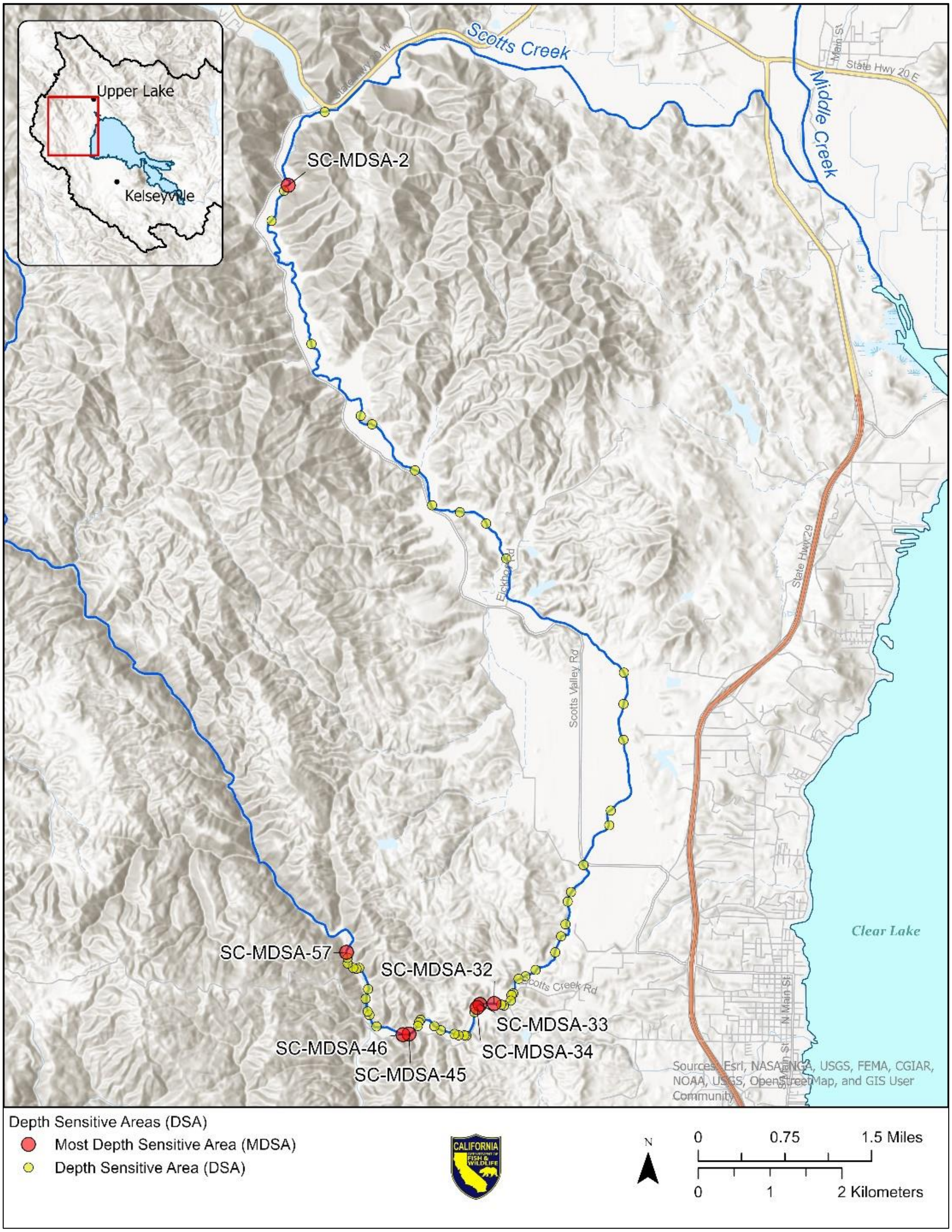


Figure 35. Depth sensitive areas identified on Scotts Creek.

Table 7. Attributes of most depth sensitive areas in Scotts Creek.

Tributary	Depth Sensitive Area	River Mile	Shallowest Course Length (ft)	Passage Flow at Thalweg (cfs)
Scotts	SC-MDSA-2	6.9	89.1	47
Scotts	SC-MDSA-32	17.1	577.1	62
Scotts	SC-MDSA-33	17.3	344.9	32
Scotts	SC-MDSA-34	17.3	318.7	44
Scotts	SC-MDSA-45	18.2	256.6	75
Scotts	SC-MDSA-46	18.2	442.8	100
Scotts	SC-MDSA-57	19.2	422.3	140

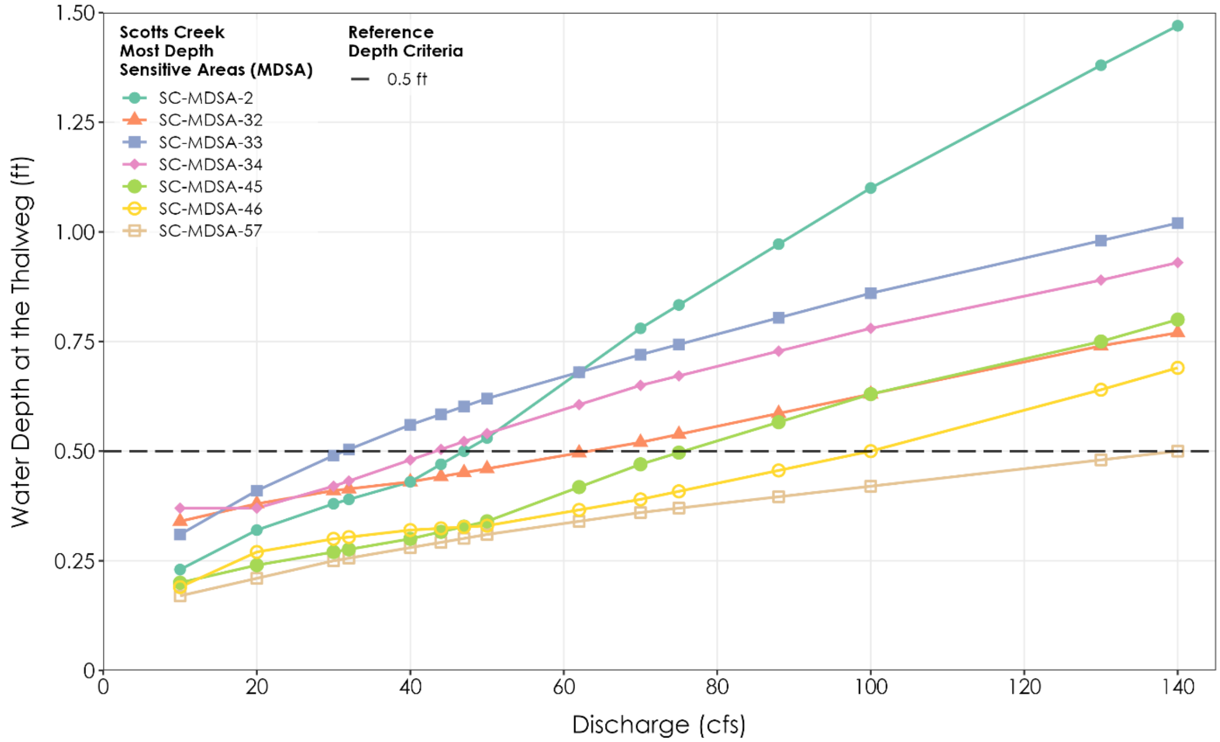


Figure 36. Relationship between discharge and water depth at the thalweg for the most depth sensitive areas in Scotts Creek. Each colored line represents a different depth sensitive area location, with the horizontal dashed line indicating the 0.5 ft minimum depth criterion for Clear Lake Hitch passage.

4.0 DISCUSSION

This study identified minimum flows needed to protect CLH passage as required by Executive Order N-5-23. CDFW collaborated and coordinated with California Native American Tribes, local, state, and federal agencies to gather vital information needed for this study. We developed 2D hydraulic habitat models in tributaries of the Clear Lake watershed for: Adobe Creek, Cole Creek, Kelsey Creek, Manning Creek, Middle Creek, and Scotts Creek. For each tributary, we established flow criteria at each critical MDSA, representing the minimum flow required for fish passage throughout the tributary (Table 8). These minimum flows for CLH passage ranged from 27 cfs in Manning Creek to 140 cfs in Scotts Creek. For the longer streams, Adobe Creek, Kelsey Creek, Middle Creek, and Scotts Creek, we provide two flow criteria, one for upstream migration and another for downstream (denoted in bold and asterisk) outmigration considerations.

Table 8. Flow criteria for the six study tributaries: Adobe, Cole, Kelsey, Manning, Middle, and Scotts Creeks. Bold rows with an asterisk (*) denote downstream criteria for the four longest creeks on Adobe, Kelsey, Middle, and Scotts.

Tributary	Critical MDSA	River Mile	Passage Flow (cfs)
Adobe Creek*	**AD-DSA-1***	**1.2***	**36***
Adobe Creek	AD-MDSA-16	5.2	52
Cole Creek	CO-MDSA-14	1.4	32
Kelsey Creek*	**KE-MDSA-1***	**2.3***	**32***
Kelsey Creek	KE-MDSA-2	2.9	70
Manning Creek	MA-MDSA-25	4.3	27
Middle Creek*	**MI-MDSA-4***	**2.4***	**61***
Middle Creek	MI-MDSA-21	7.4	90
Scotts Creek*	**SC-MDSA-2***	**6.9***	**47***
Scotts Creek	SC-MDSA-57	19.2	140

Due to the highly variable flows in the Clear Lake watershed, some of the flows described in this document may not be naturally available every year. However, in years or months when these flows are naturally available, they are likely to be critical to the survival of the CLH population and should be prioritized for protection. The SWRCB's watershed-scale hydrologic model being developed by O'Connor Environmental Inc. will be valuable to understand flow dynamics in the Clear Lake watershed. Our 2D hydraulic habitat models along with SWRCB's hydrological model will be helpful with informing water management decisionmaking processes. Lastly, our DSA results suggest possible management actions. For example, storm debris should continue to be cleared as needed to prevent barrier formation, such as CO-MDSA-17 on Cole Creek when the survey took place (Figure 26 & Figure 27). If the debris barrier was not cleared during December 2025, then our modeled results indicate CLH would have needed 90 cfs for passage instead of 32 cfs (Table 3). The other identified DSAs should be further evaluated for potential restoration or other appropriate management actions.

ACKNOWLEDGEMENTS

We would like to thank Big Valley Band of Pomo Indians, Robinson Rancheria Tribe of Pomo Indians, and Habematolel Pomo of Upper Lake for sharing local knowledge, providing land access, and technical expertise. Thank you to CDFW's North Central Region Office, Fisheries Branch, and Conservation Engineering Branch for their assistance, technical expertise, and guidance throughout the study. We'd also like to thank all participants in the CLH Task Force for providing valuable input or additional land access. Finally, we extend a special thanks to the landowners who granted access to their property to allow CDFW staff to conduct fieldwork, without which we would have been unable to complete this study.

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