State of California
Natural Resources Agency
California Department of Fish and Wildlife

INSTREAM FLOW EVALUATION: JUVENILE REARING OF STEELHEAD AND COHO SALMON IN UPPER MARK WEST CREEK, SONOMA COUNTY

STREAM EVALUATION REPORT 2022-01

August 2022

Cover photo: Mark West Creek, view upstream, Sonoma County.

California Department of Fish and Wildlife
Stream Evaluation Report 2022-01

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Water Branch
Instream Flow Program
Stream Evaluation Report 2022-01

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Suggested Citation:

Carlin, T., W. Cowan, B. Stanford, J. Allen, and N. Gephart (2022). Instream flow evaluation: Juvenile rearing of steelhead and Coho Salmon in upper Mark West Creek, Sonoma County. California Department of Fish and Wildlife, Instream Flow Program (CDFW), West Sacramento, CA. Stream evaluation report 2022-01.

PREFACE

Mark West Creek is an essential watershed for the recovery and perpetuation of native California Coastal Chinook Salmon (*Oncorhynchus tshawytscha*), Central California Coast Coho Salmon (*O. kisutch*), and Central California Coast steelhead trout (*O. mykiss*; CEMAR 2015). Mark West Creek was identified as a priority stream under the California Water Action Plan, which outlines actions to address challenges and promote reliability, restoration, and resilience in the management of California's water (CNRA et al. 2014; CNRA et al. 2016). Under Action 4 of the California Water Action Plan, the California Department of Fish and Wildlife (Department) and the State Water Resources Control Board were directed to implement actions to enhance instream flows within at least five priority stream systems that support critical habitat for anadromous fish. Mark West Creek, a tributary to the Russian River, is among these five priority streams due to its high biological resource value and potential for species recovery.

The Department holds fish and wildlife resources in California in trust for the people of the state and has jurisdiction over the conservation, protection, and management of those resources (Fish and Game Code §711.7; Fish and Game Code §1802). The Department seeks to manage California's diverse fish, wildlife, native plants, and natural communities for their intrinsic and ecological value and their use and enjoyment by the public. The Department's Instream Flow Program develops scientific information to determine the flows needed to maintain healthy conditions for fish, wildlife, and the habitats on which they depend. The Department recommends using the Instream Flow Incremental Methodology (IFIM) to evaluate and develop instream flow criteria for actions that may affect California's aquatic resources. The IFIM process and instream flow evaluations, in general, should include broad consideration of the structure and function of riverine systems, and examination of five core riverine components (i.e., hydrology, biology, geomorphology, water quality, and connectivity).

To address the California Water Action Plan in the Mark West Creek watershed, the Department has conducted an instream flow study and has also produced a watershed-wide flow criteria report. The instream flow study described in this this technical report evaluates flows for maintaining ecological condition and rearing habitat for juvenile steelhead and Coho Salmon in the upper Mark West Creek watershed. As part of the California Water Action Plan, the State Water Resources Control Board is working with the United States Geological Survey to refine a hydrologic model for the Russian River watershed, including Mark West Creek. The model will quantify the relationship between surface and subsurface flow, providing a better understanding of water supply, water demand, and instream flows in the watershed. Integration of the Department's study results with the State Water Resources Control Board's groundwater-surface water model will be essential to enhancing instream flows and informing water management within Mark West Creek.

This technical report describes data collection efforts, hydraulic modeling, and the resulting flow-habitat relationships developed for juvenile steelhead and Coho Salmon in Mark West Creek. The flow-habitat relationships, along with any other supporting information, are intended to be used to identify instream flow needs for rearing anadromous salmonids and long-term stream ecosystem health in the upper Mark West Creek watershed. The goals and objectives of this study can be found in the *Study Plan: Habitat and Instream Flow Evaluation for Anadromous Steelhead and Coho Salmon in Upper Mark West Creek, Sonoma County* (CDFW 2018). Additional flow criteria can be found in the companion report *Watershed-Wide Instream Flow Criteria for Mark West Creek* (CDFW 2022).

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ABBREVIATIONS AND ACRONYMS

2D	two-dimensional (physical habitat simulation model)
AWS	area-weighted suitability
CCC	Central California Coast
cfs	cubic feet per second
cm	centimeter(s)
COMID	common identifier (as used by USGS National Hydrography Dataset)
Department	California Department of Fish and Wildlife
DTM	digital terrain model
ft	foot (feet)
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HSC	habitat suitability criteria
IFIM	Instream Flow Incremental Methodology
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NFD	Natural Flows Database
NMFS	National Marine Fisheries Service
PHABSIM	Physical Habitat Simulation System
PT	pressure transducer
PVC	polyvinyl chloride
RTK-GPS	real-time kinematic global positioning system
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WSEL	water surface elevation
XS-1	cross section 1
XS-2	cross section 2
WY	water year

CONVERSIONS

1 cubic foot per second ≈ 2.83 × 10^{-2} cubic meters per second
1 inch = 2.54 centimeters
1 foot ≈ 0.31 meters
1 square mile ≈ 2.59 square kilometers
1 mile ≈ 1.61 kilometers
°C = (°F - 32) ÷ 1.8

1.0 INTRODUCTION

Mark West Creek, located in Sonoma County, California, is one of the largest tributaries to the Russian River. Mark West Creek has a high potential to support anadromous salmonids, and was ranked by the National Marine Fisheries Service (NMFS) as a Phase 1 Priority Stream for salmonid passage, viability, and water quality within the Central California Coast Coho Salmon Recovery Plan (NMFS 2012b). Mark West Creek currently supports three anadromous salmonid populations: Central California Coast (CCC) rainbow trout/steelhead (*Oncorhynchus mykiss*), California Coastal Chinook Salmon (*O. tshawytscha*), and CCC Coho Salmon (*O. kisutch*). All three of these anadromous fish populations are listed under the Federal Endangered Species Act; however, the Central California Coast Coho Salmon has been identified by NMFS as the most at-risk of extinction (NMFS 2012a).

Prior assessments (e.g.,Grantham et al. 2012; NMFS 2008; Obedzinski et al. 2016) have indicated that impaired streamflow is a factor affecting steelhead and Coho Salmon survival in the Russian River watershed. The Central California Coast Coho Salmon Recovery Plan (NMFS 2012b) and Coastal Multispecies Recovery Plan (NMFS 2016) also identified insufficient baseflow conditions as a limiting factor facing rearing juvenile salmonids within the Russian River and Mark West Creek populations, respectively.

While agriculture and domestic water use peaks during dry summer and fall months in the region (Grantham et al. 2012), Mark West Creek receives most of its precipitation between November and April. As a result, diversions and groundwater pumping occur during the dry summer months when salmonids are rearing in the creek (Deitch et al. 2009). Instream water diversions and pumping from near-stream shallow groundwater wells during the dry summer period can accelerate streamflow depletion, which can lead to reductions in stream connectivity, increases in water temperature, and decreases dissolved oxygen concentration (Bradford and Heinonen 2008; Grantham et al. 2012). All of these can put additional physiological stress on juvenile salmonids during their rearing period (Grantham et al. 2012).

In Mark West Creek, intensifying climate change is expected to result in warmer temperatures, longer dry seasons, and a subsequent increase in water demand from riparian vegetation (Ackerly 2018). Climate change is also expected to result in more extreme wet and extreme dry years, with fewer moderate years. Together, these shifts may lead to more extreme high and low flows, increased human demand for water resources, and resulting loss of habitat for cold-water fishes, including salmonids.

As described in the *Study Plan: Habitat and Instream Flow Evaluation for Anadromous Steelhead and Coho Salmon in Upper Mark West Creek, Sonoma County* (CDFW 2018), the main goal of this study was to develop streamflow versus habitat relationships for juvenile steelhead and Coho Salmon in upper Mark West Creek. An understanding of the connection between streamflow and habitat in Mark West Creek can be used to develop life-history-based flow criteria that enhance flows for the conservation, restoration, and protection of juvenile salmonids. Additional study objectives are addressed in the companion report *Watershed-Wide Instream Flow Criteria for Mark West Creek* (CDFW 2022).

2.0 DESCRIPTION OF STUDY AREA

Mark West Creek is located roughly 5 miles north of the city of Santa Rosa (Figure 2). The Mark West Creek watershed is the second largest in the Russian River basin, with an area of approximately 59 square miles. From its headwaters in the Mayacamas Mountain Range, water drains in a general westward direction for approximately 34 miles towards its confluence with the Russian River. Elevations in the watershed range from approximately 2,350 feet (ft) at its uppermost extent to about 30 ft at its confluence. The upper watershed contains coniferous forest, hardwood forest, grasslands, and shrubs, while the lower watershed contains mainly urban land uses and irrigated crop land (predominantly vineyards; CEMAR 2015; Sonoma RCD 2015). This study focuses on upper Mark West Creek, which is approximately 6 miles long and has a drainage area of approximately 13 square miles.

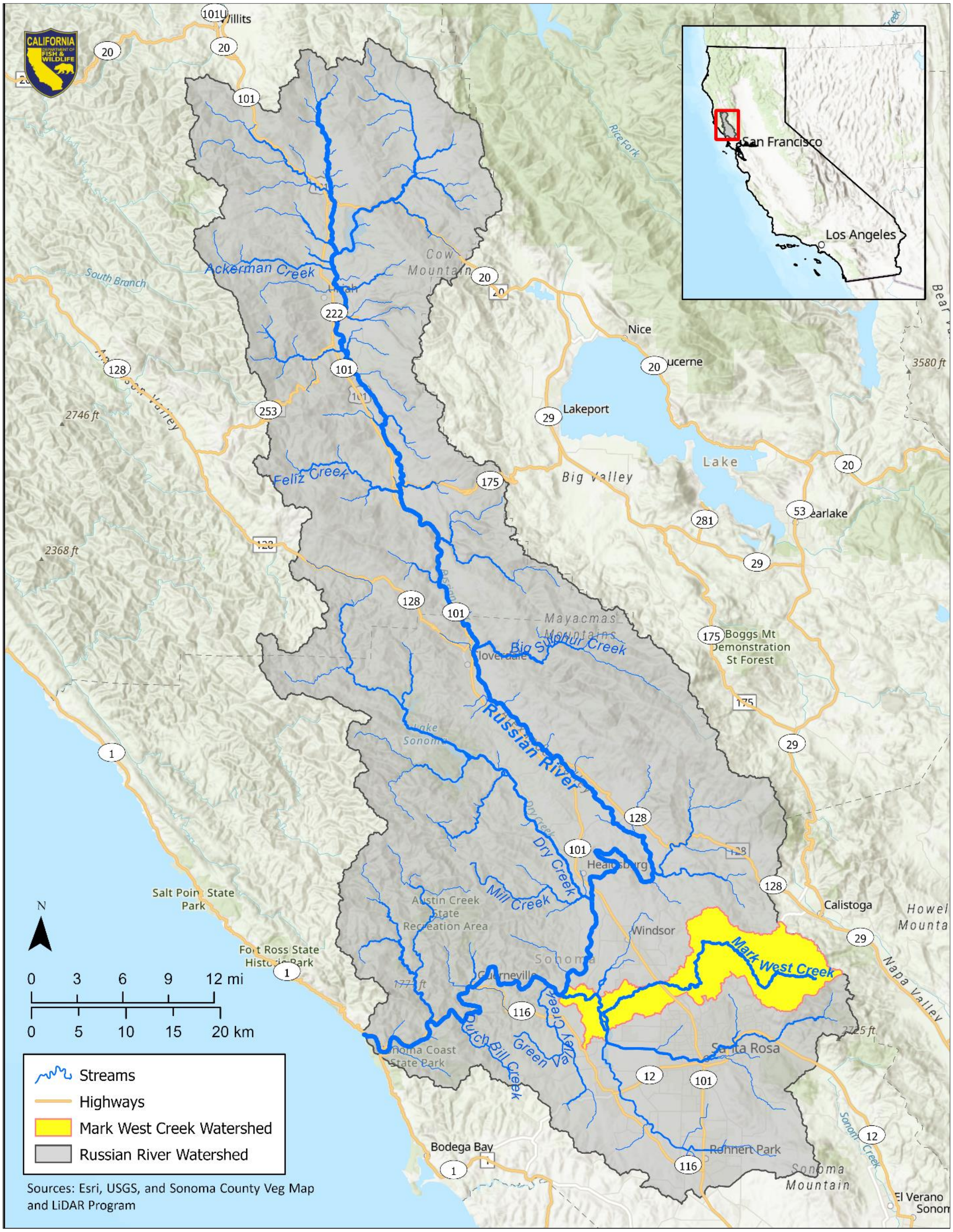

Figure 1. Russian River watershed, showing the location of Mark West Creek.

In October 2017, the Tubbs Fire burned across Napa, Sonoma, and Lake counties, including the Mark West Creek watershed. Approximately 22 square miles (37%) of the Mark West Creek watershed was burned, spanning the entire north-south extent of the watershed, and was concentrated from just west of Highway 101 to Calistoga and Petrified Forest roads to the east. Due to the possibility that the Tubbs Fire would lead to channel instability over the course of the study (e.g., bank erosion and channel aggradation), the study area was limited to the upper reaches of Mark West Creek. In this study, upper Mark West Creek is defined as the area above Calistoga Road (Figure 2). All hydraulic modeling sites were restricted to this upper portion of the watershed (Figure 3). In October 2020, the Glass Fire burned through a portion of the upper watershed. The Glass Fire occurred after all field data collection had been completed.

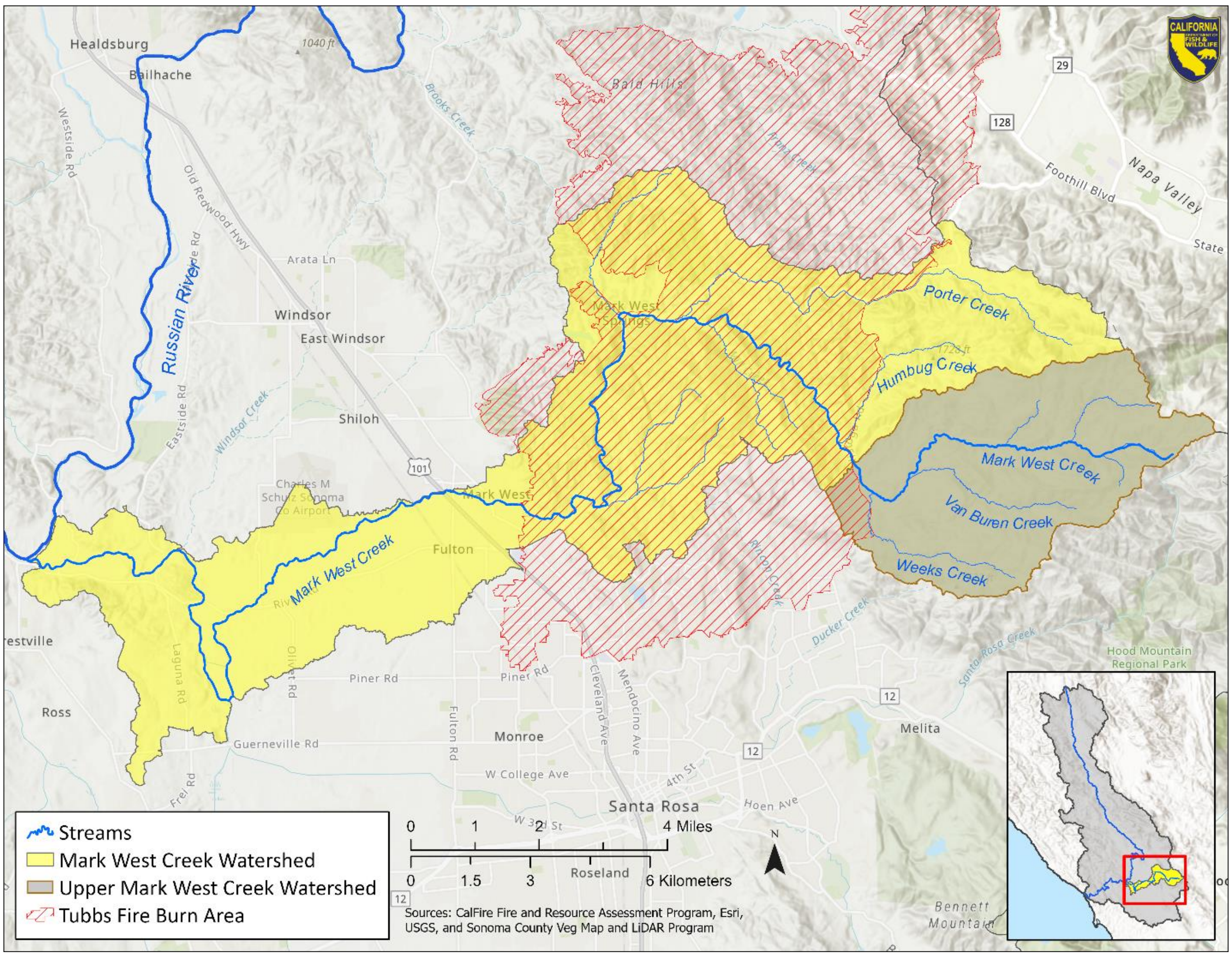

Figure 2. Mark West Creek watershed.

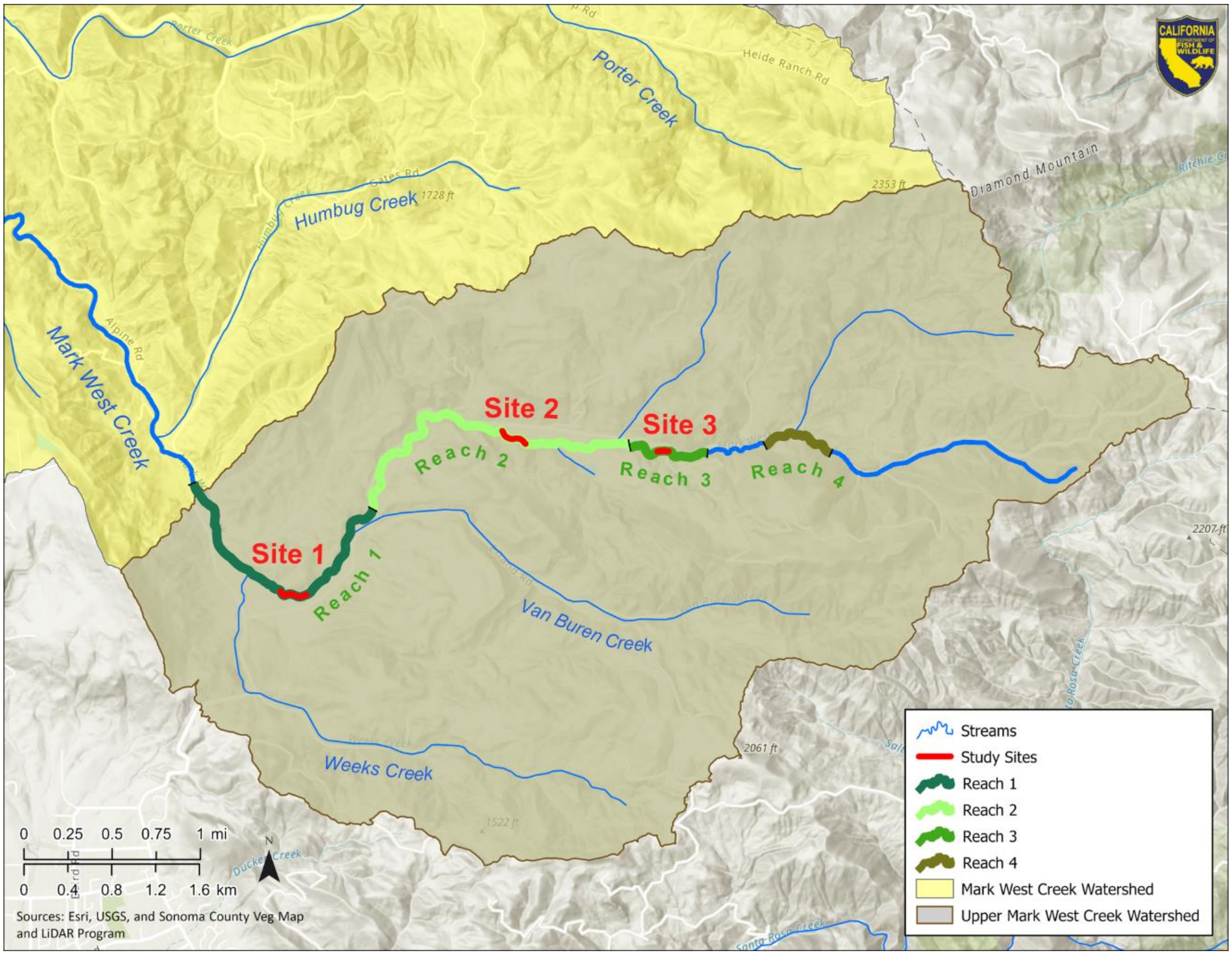

Figure 3. Upper Mark West Creek study sites and study reaches.

2.1 Fish Species and Periodicity

Historically, the Mark West Creek watershed supported three federally listed anadromous salmonid species: threatened California Coastal Chinook Salmon (64 Federal Register 50394), threatened CCC steelhead (62 Federal Register 43937), and endangered CCC Coho Salmon (70 Federal Register 37160), though only steelhead and Coho Salmon are commonly found in the upper watershed. CCC Coho Salmon are also listed as endangered north of San Francisco Bay under the California Endangered Species Act (CDFG 2004), and may exist as part of a single, functionally independent population that is at very high risk of extirpation (NMFS 2008). All three study sites are located within the designated critical habitat of both steelhead and Coho Salmon on the mainstem of Mark West Creek. Other native aquatic species known to exist in the upper Mark West Creek watershed are listed in Table 1.

Table 1. Non-salmonid native aquatic and amphibian species found in upper Mark West Creek. Species status is indicated next to the common name with an asterisk (*) for species of special concern or double asterisks (**) for federally threatened species.

Common name	Scientific name	Source
California Giant Salamander*	*Dicamptodon ensatus*	Thomson et al. (2016)
California Newt	*Taricha torosa*	CDFW (2019)
California Red-legged Frog**	*Rana draytonii*	(61 Federal Register 25813)
California Roach*	*Lavinia symmetricus*	Moyle et al. (2015)
Foothill Yellow-legged Frog*	*Rana boylii*	Thomson et al. (2016)
Hardhead*	*Mylopharodon conocephalus*	Moyle et al. (2015)
Inland Threespine Stickleback	*Gasterosteus aculeatus*	CDFW (2014a)
Northwestern Pond Turtle*	*Actinemys marmorata*	Thomson et al. (2016)
Pacific Lamprey*	*Entosphenus tridentata*	Moyle et al. (2015)
Prickly Sculpin	*Cottus asper*	CDFW (2014b)
Red-bellied Newt*	*Taricha rivularis*	Thomson et al. (2016)
Rough-skinned Newt	*Taricha granulosa*	CDFW (2016)
Russian River Tule Perch*	*Hysterocarpus traski pomo*	Moyle et al. (2015)
Sacramento Pikeminnow	*Ptychocheilus grandis*	CDFW (2014c)
Sacramento Sucker	*Catostomus occidentalis*	CDFW (2014d)
Western Brook Lamprey*	*Lampetra richardsoni*	Moyle et al. (2015)
Western River Lamprey	*Lampetra ayresi*	(A. McClary personal communication 05/2021)

Department surveys from as early as 1953 documented steelhead observations throughout the Mark West Creek watershed where habitat remained wetted through the summer and fall dry seasons (CDFG 1953; CDFG 1966; CDFG 1969; CDFG 1971). Current steelhead densities are thought to be significantly reduced from observations made from the 1950s to the 1970s (NMFS 2016). Information on the historical presence and distribution of Coho Salmon within the Russian River watershed, and upper Mark West Creek, specifically, is much more limited (NMFS 2008; Spence et al. 2005). Nonetheless, both Brown and Moyle (1991) and Spence et al. (2005) found evidence that Coho Salmon populations historically existed in Mark West Creek. Surveys conducted in 2000 and 2001 in the lower Russian River watershed also found juvenile steelhead and Coho Salmon in Mark West Creek (Conrad et al. 2006; Merritt Smith Consulting 2003). Although Chinook Salmon are known to be present in the lower reaches of Mark West Creek, observations are rare in upper Mark West Creek and Chinook Salmon do not oversummer in the watershed. Therefore, Chinook Salmon were not included in this study.

Steelhead and Coho Salmon both spawn in the winter and oversummer in Mark West Creek as juveniles (Figure 4). Steelhead adults normally arrive in mid-October and leave at the end of April, and Coho Salmon adults arrive at the beginning of November. Coho Salmon smolts leave the watershed by mid-February. However, juveniles of both species are present year-round. Because the juvenile life stages of steelhead and Coho Salmon rear in the creek throughout the summer and fall months (Figure 4), maintaining adequate streamflow conditions during this period is essential to support the species' recovery (NMFS 2008).

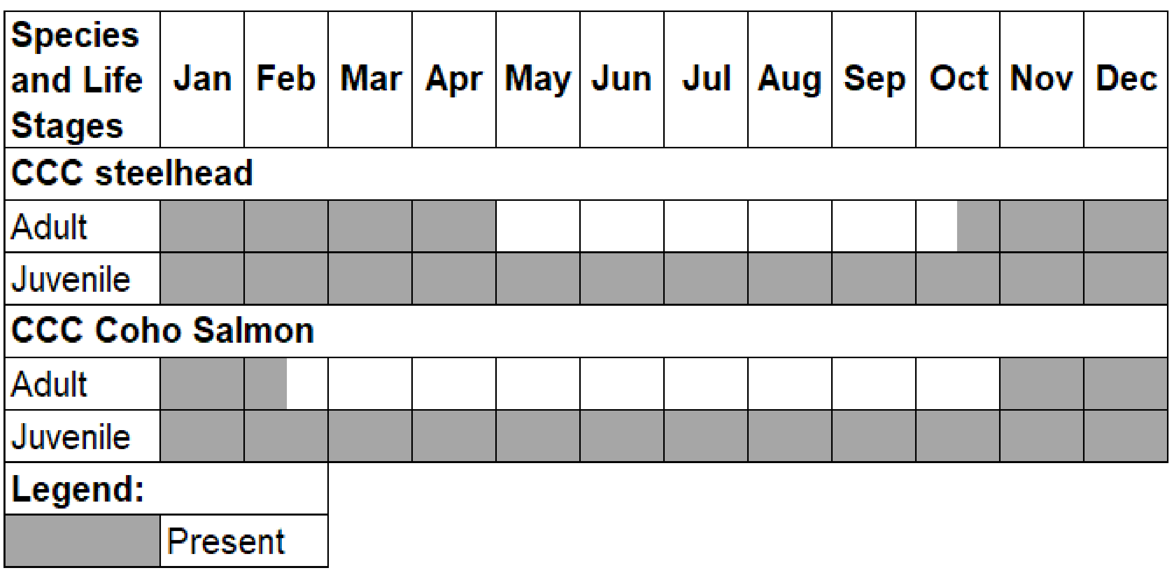

Figure 4. Generalized seasonal periodicities of salmonid species Central California Coast (CCC) steelhead and Coho Salmon in upper Mark West Creek (NMFS 2012b; NMFS 2016; R2 Resource Consultants Inc. and Stetson Engineers Inc. 2007; Steiner Environmental Consulting 1996).

2.2 Hydrology

Upper Mark West Creek has a Mediterranean climate characterized by arid summers and occasional storm events during the winter and spring months with varying volumes of annual precipitation. The upper Mark West Creek watershed receives an estimated annual average precipitation of approximately 45 inches (PRISM Climate Group 2021). Most of upper Mark West Creek's streamflow from November through April is derived from rainfall runoff, while baseflow is the primary contributor to streamflow during the low-flow months from May through October (Woolfenden and Nishikawa 2014). Springs and seeps such as those that contribute to Neal Creek, a small spring-fed tributary in the headwater region, play an important role in maintaining water connectivity and perennial flows within Mark West Creek (CEMAR 2015; Nishikawa 2013). Previous streamflow monitoring conducted downstream of Neal Creek indicates that upper Mark West Creek maintains wetted conditions throughout the summer and fall months even in dry years, though streamflow conditions remain very low (CEMAR 2015).

Upper Mark West Creek has no major dams, reservoirs, or pumping facilities. However, there is water extraction for irrigated agriculture, residential use, wineries, and small commercial industries (CEMAR 2015), as well as licensed and unlicensed cannabis operations. As with many streams in Mediterranean climates, the timing of higher streamflow in upper Mark West Creek in the late winter and spring does not coincide with the high demand in the summer and fall dry seasons (Deitch and Dolman 2017). Total annual rainfall and discharge generally surpass demand (CEMAR 2015); however, demand in the summer and fall exceeds surface water availability, which leads to a reliance on well and spring diversions to meet dry-season water needs (Deitch and Dolman 2017). Pumping from near-stream wells can have cumulative impacts on baseflow conditions (Zipper et al. 2019). Though direct surface-water diversions are limited in upper Mark West Creek, water use from wells and springs in this portion of the watershed likely contributes to the low-flow conditions observed throughout the dry season, especially during extended periods of low rainfall (CEMAR 2015; Sonoma RCD 2015; SRPBAP 2014).

The hydrology analysis in this report uses modeled natural flows, from the Natural Flows Database (Zimmerman et al. 2020). Natural hydrology is particularly useful as a baseline for comparison because it represents conditions that should fully support a healthy ecological community and represent flow conditions in the absence of human water use. The Natural Flows Database provides two types of natural hydrology data: monthly natural flow estimates, and seasonal natural functional flow metrics. Both are discussed below. In addition, this section includes an assessment of current conditions using gage data collected by Department staff. No appropriate long-term gages were available in upper Mark West Creek for use in this study.

The United States Geological Survey (USGS) is currently working to update a hydrologic model for the Santa Rosa Plain, in partnership with the State Water Resources Control Board. The update is based on an existing model completed by the USGS in 2014 (Woolfenden and Nishikawa 2014), and will model both unimpaired and actual conditions.

Monthly Natural Flows

The Natural Flows Database provides monthly flow estimates for natural conditions over a 65-year period of record for every stream reach in the state (Zimmerman et al. 2018; Zimmerman et al. 2020). This database was developed using machine learning tools that predict flows using watershed characteristics (including geology) and temperature and precipitation data, along with a set of reference gages. The database includes both mean and median monthly flows. Median monthly flows over the entire period of record were used in the habitat duration time series analysis (Section 3.6).

To evaluate monthly flow variability, the 50% exceedance (or median) flow was calculated using the Natural Flows Database for three water month types: dry, moderate, and wet (Zimmerman et al. 2020). Water month types were defined using exceedance percentage ranges for each month: 100–70%, 70–30%, and 30–0%, respectively. Monthly data from the Natural Flows Database for the period October 1, 1950, to September 30, 2015, were used to calculate median monthly flows in cubic feet per second (cfs) for each site for each water month type (Figure 5, Table 2–Table 4). See Figure 3 for site locations, and Section 3.1 and Section 4.1 for discussion of site selection. First, mean monthly flows were used to assign water month types. Next, the median monthly flow value was calculated for each water month type over the period of record. Although these monthly flows obscure important daily variation, they are helpful for estimating typical water availability. Natural flow estimates presented here do not incorporate expectations about future shifts in hydrology under projected climate change scenarios.

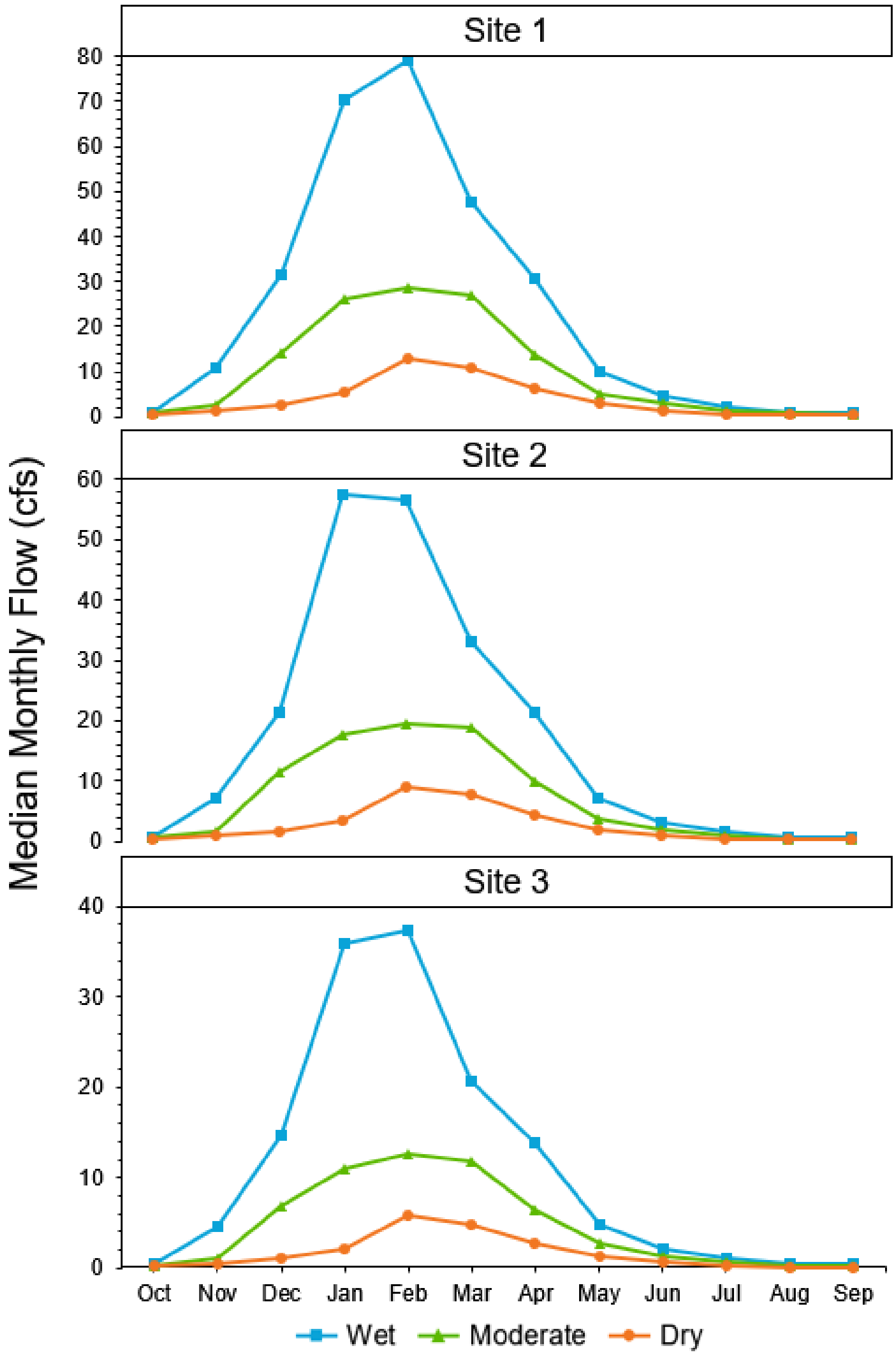

Figure 5. Mark West Creek estimated median monthly flow (cfs) by water month type using Natural Flows Database estimates from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020). Note the different y-axis scales for sites.

Table 2. Mark West Creek Site 1 median monthly flow (cfs) by water month type using Natural Flow Database estimates for COMID 8272525 from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020).

Water Month Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Dry	<1	2	2	5	13	11	6	3	2	1	<1	<1
Moderate	1	3	14	26	29	27	14	5	3	1	1	1
Wet	1	11	32	70	79	48	31	10	5	2	1	1

Table 3. Mark West Creek Site 2 median monthly flow (cfs) by water month type using Natural Flow Database estimates for COMID 8272511 from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020).

Water Month Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Dry	<1	1	2	4	9	8	4	2	1	<1	<1	<1
Moderate	1	2	11	18	20	19	10	4	2	1	1	<1
Wet	1	7	21	57	57	33	21	7	3	2	1	1

Table 4. Mark West Creek Site 3 median monthly flow (cfs) by water month type using Natural Flow Database estimates for COMID 8272499 from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020).

Water Month Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Dry	<1	1	1	2	6	5	3	1	1	<1	<1	<1
Moderate	<1	1	7	11	13	12	6	3	1	1	<1	<1
Wet	<1	5	15	36	37	21	14	5	2	1	<1	<1

Functional Flows

Functional flows for California include the fall pulse flow, wet-season baseflow, peak flows, spring recession, and dry-season baseflow (Yarnell et al. 2020). Each of these flows performs a distinct function critical to long-term maintenance of a healthy stream ecosystem. Fall pulse flows are produced by the first storm event of the season. These flows help to redistribute fine sediment to provide spawning habitat and migratory cues

(Yarnell et al. 2015; Yarnell et al. 2020). Wet-season baseflows are elevated following storm events and typically increase as the wet season progresses. These elevated flows support connectivity and allow salmonids to migrate up and down stream. Spring recession flows cue outmigration, and a natural reduction in flow from winter to summer baseflows (median 7% per day decrease in magnitude in this watershed) prevents stranding of aquatic species and promotes survival of riparian vegetation. Finally, the dry-season baseflow represents the gradual reduction in flow over the summer and higher water temperatures when groundwater-fed baseflows are often critical. Variation both within and between years is a key component of the functional flows (Yarnell et al. 2015).

The median values and ranges characterize patterns in the five functional flows that have been identified for California (Yarnell et al. 2020). Predicted functional flow metrics were developed using random forest models that were trained on a set of reference gages located across the state of California, following the process described by Zimmerman et al. (2018) for the monthly flow predictions described above. Some metrics (including the spring recession rate) were calculated from reference gages in the same hydrologic stream class. For the functional flows analyses in Table 5, Table 7, and Table 9, water year types were defined using the following exceedance percentage ranges: 100–66.67%, 66.66–33.34%, and 33.33–0%, for dry, moderate, and wet water year types, respectively. Peak flow metrics were not calculated by water year type, and instead are presented for all years in Table 6, Table 8, and Table 10.

The functional flows approach has been developed through a collaborative process under the Environmental Flows Technical Workgroup, a subgroup of the California Water Quality Monitoring Council[a]. This group is preparing a detailed guidance document describing the California Environmental Flows Framework and an approach to setting instream flow criteria using functional flows. The California Environmental Flows Framework was named as a priority in Action 9.1 of the recently released California Water Resilience Portfolio (State of California 2020).

[a] For more information see https://mywaterquality.ca.gov/monitoring_council/environmental_flows_workgroup/index.html

Table 5. Predicted functional flow metrics for Mark West Creek Site 1 by water year type. Values represent median predictions within each water year type, with 10th–90th percentile ranges in parentheses. Fall pulse flows may not occur every year. Functional flow metrics with asterisks (*) have inferred ranges that are not modeled by water year type. Data from the Natural Flows Database, COMID 8272525 (California Environmental Flows Working Group 2020).

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Fall pulse flow magnitude (cfs)	15 (3–102)	7 (2–44)	5 (1–24)
Fall pulse flow duration (days)*	4 (2–9)	4 (2–9)	4 (2–9)
Fall pulse flow timing	Oct 22 (Oct 8–Nov 13)	Oct 27 (Oct 9–Nov 21)	Oct 27 (Oct 8–Nov 21)
Median wet-season flow magnitude (cfs)	44 (23–84)	21 (12–39)	11 (5–22)
Wet-season baseflow magnitude (cfs)	11 (4–20)	6 (2–12)	3 (1–6)
Wet-season duration (days)	128 (74–175)	114 (66–154)	94 (54–151)
Wet-season start timing	Nov 30 (Nov 13–Dec 15)	Dec 10 (Nov 18–Dec 31)	Dec 11 (Nov 15–Jan 17)
Spring recession start magnitude (cfs)	205 (54–684)	128 (32–397)	80 (20–260)
Spring recession duration (days)	42 (26–95)	43 (25–93)	48 (26–103)
Spring recession start timing	Apr 8 (Mar 5–Apr 29)	Apr 1 (Mar 7–May 2)	Mar 28 (Mar 8–May 1)
Spring recession rate of change (%)*	7 (4–15)	7 (4–15)	7 (4–15)
Dry-season baseflow magnitude (cfs)	1 (<1–3)	1 (<1–2)	1 (<1–2)
Dry-season high baseflow magnitude (cfs)	5 (2–11)	4 (1–8)	2 (1–7)
Dry-season duration (days)	194 (144–249)	187 (142–246)	194 (138–259)
Dry-season start timing	May 22 (Apr 28–Jun 24)	May 28 (Apr 18–Jul 1)	Jun 1 (Apr 17–Jul 9)

Table 6. Predicted peak functional flow metrics for Mark West Creek Site 1. Values represent median predictions, with 10th–90th percentile ranges in parentheses. Peak flows may not occur every year. Functional flow metrics with asterisks (*) have inferred ranges that are not modeled by water year type. Data from the Natural Flows Database, COMID 8272525 (California Environmental Flows Working Group 2020).

Functional Flow Metric	All Years
2-year peak flow magnitude (cfs)	327 (109–717)
2-year peak flow days/year when present*	3 (1–10)
2-year peak flow events/year when present*	2 (1–5)
5-year peak flow magnitude (cfs)	539 (251–979)
5-year peak flow days/year when present*	1 (1–4)
5-year peak flow events/year when present*	1 (1–2)
10-year peak flow magnitude (cfs)	549 (259–1,080)
10-year peak flow days/year when present*	1 (1–3)
10-year peak flow events/year when present*	1 (1–2)

Table 7. Predicted functional flow metrics for Mark West Creek Site 2 by water year type. Values represent median predictions within each water year type, with 10th–90th percentile ranges in parentheses. Fall pulse flows may not occur every year. Functional flow metrics with asterisks (*) have inferred ranges that are not modeled by water year type. Data from the Natural Flows Database, COMID 8272511 (California Environmental Flows Working Group 2020).

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Fall pulse flow magnitude (cfs)	10 (2–63)	5 (1–29)	4 (1–16)
Fall pulse flow duration (days)*	4 (2–9)	4 (2–9)	4 (2–9)
Fall pulse flow timing	Oct 22 (Oct 8–Nov 13)	Oct 27 (Oct 8–Nov 20)	Oct 26 (Oct 8–Nov 22)
Median wet-season flow magnitude (cfs)	33 (18–62)	16 (8–27)	7 (4–16)
Wet-season baseflow magnitude (cfs)	9 (3–18)	4 (2–9)	2 (1–4)
Wet-season duration (days)	129 (74–176)	113 (65–155)	97 (55–153)
Wet-season start timing	Nov 30 (Nov 13–Dec 16)	Dec 10 (Nov 18–Jan 2)	Dec 4 (Nov 14–Jan 18)
Spring recession start magnitude (cfs)	142 (37–460)	86 (21–275)	57 (14–180)
Spring recession duration (days)	43 (26–98)	44 (25–94)	50 (26–102)
Spring recession start timing	Apr 8 (Mar 5–Apr 30)	Mar 31 (Mar 7–May 3)	Mar 29 (Mar 8–May 1)
Spring recession rate of change (%)*	7 (4–15)	7 (4–15)	7 (4–15)
Dry-season baseflow magnitude (cfs)	1 (<1–2)	1 (<1–2)	<1 (<1–1)
Dry-season high baseflow magnitude (cfs)	3 (2–8)	2 (1–6)	2 (1–5)
Dry-season duration (days)	192 (143–251)	185 (140–246)	194 (136–258)
Dry-season start timing	May 23 (Apr 27–Jun 28)	May 29 (Apr 18–Jul 4)	Jun 5 (Apr 17–Jul 14)

Table 8. Predicted peak functional flow metrics for Mark West Creek Site 2. Values represent median predictions, with 10th–90th percentile ranges in parentheses. Peak flows may not occur every year. Functional flow metrics with asterisks (*) have inferred ranges that are not modeled by water year type. Data from the Natural Flows Database, COMID 8272511 (California Environmental Flows Working Group 2020).

Functional Flow Metric	All Years
2-year peak flow magnitude (cfs)	204 (70–497)
2-year peak flow days/year when present*	3 (1–10)
2-year peak flow events/year when present*	2 (1–5)
5-year peak flow magnitude (cfs)	359 (167–628)
5-year peak flow days/year when present*	1 (1–4)
5-year peak flow events/year when present*	1 (1–2)
10-year peak flow magnitude (cfs)	441 (165–720)
10-year peak flow days/year when present*	1 (1–3)
10-year peak flow events/year when present*	1 (1–2)

Table 9. Predicted functional flow metrics for Mark West Creek Site 3 by water year type. Values represent median predictions within each water year type, with 10th–90th percentile ranges in parentheses. Fall pulse flows may not occur every year. Functional flow metrics with asterisks (*) have inferred ranges that are not modeled by water year type. Data from the Natural Flows Database, COMID 8272499 (California Environmental Flows Working Group 2020).

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Fall pulse flow magnitude (cfs)	6 (2–34)	3 (1–21)	3 (1–11)
Fall pulse flow duration (days)*	4 (2–9)	4 (2–9)	4 (2–9)
Fall pulse flow timing	Oct 22 (Oct 7–Nov 13)	Oct 27 (Oct 9–Nov 20)	Oct 26 (Oct 7–Nov 22)
Median wet-season flow magnitude (cfs)	22 (12–41)	10 (5–18)	5 (2–10)
Wet-season baseflow magnitude (cfs)	5 (2–11)	2 (1–5)	1 (<1–3)
Wet-season duration (days)	130 (72–176)	116 (63–156)	97 (55–154)
Wet-season start timing	Nov 30 (Nov 12–Dec 16)	Dec 11 (Nov 18–Dec 31)	Dec 4 (Nov 11–Jan 19)
Spring recession start magnitude (cfs)	89 (23–273)	54 (15–169)	35 (8–110)
Spring recession duration (days)	43 (25–100)	43 (25–97)	50 (26–104)
Spring recession start timing	Apr 8 (Mar 2–May 1)	Mar 30 (Mar 7–May 3)	Mar 29 (Mar 8–May 3)
Spring recession rate of change (%)*	7 (4–15)	7 (4–15)	7 (4–15)
Dry-season baseflow magnitude (cfs)	1 (<1–2)	<1 (<1–1)	<1 (<1–1)
Dry-season high baseflow magnitude (cfs)	2 (1–5)	2 (1–4)	1 (<1–3)
Dry-season duration (days)	187 (138–243)	183 (131–241)	190 (130–250)
Dry-season start timing	May 23 (Apr 28–Jul 1)	May 30 (Apr 18–Jul 5)	Jun 4 (Apr 15–Jul 18)

Table 10. Predicted peak functional flow metrics for Mark West Creek Site 3. Values represent median predictions, with 10th–90th percentile ranges in parentheses. Peak flows may not occur every year. Functional flow metrics with asterisks (*) have inferred ranges that are not modeled by water year type. Data from the Natural Flows Database, COMID 8272499 (California Environmental Flows Working Group 2020).

Functional Flow Metric	All Years
2-year peak flow magnitude (cfs)	125 (42–304)
2-year peak flow days/year when present*	3 (1–10)
2-year peak flow events/year when present*	2 (1–5)
5-year peak flow magnitude (cfs)	220 (102–381)
5-year peak flow days/year when present*	1 (1–4)
5-year peak flow events/year when present*	1 (1–2)
10-year peak flow magnitude (cfs)	285 (103–480)
10-year peak flow days/year when present*	1 (1–3)
10-year peak flow events/year when present*	1 (1–2)

Gage Data

To evaluate current conditions in upper Mark West Creek, Department staff installed pressure transducers (gages) at each site in upper Mark West Creek. Gage data collection was initiated on April 24, 2018, for Site 1, April 16, 2018, for Site 2, and April 17, 2018, for Site 3. Gage data collection concluded for all three sites on May 3, 2020. The plots below compare monthly natural flow estimates from the Natural Flows Database for each site in upper Mark West Creek to median monthly gage data representing current conditions by water year (WY; Figure 6 to Figure 8). The plots also contrast flows in a wet year (2019) and dry years (2018 and 2020).

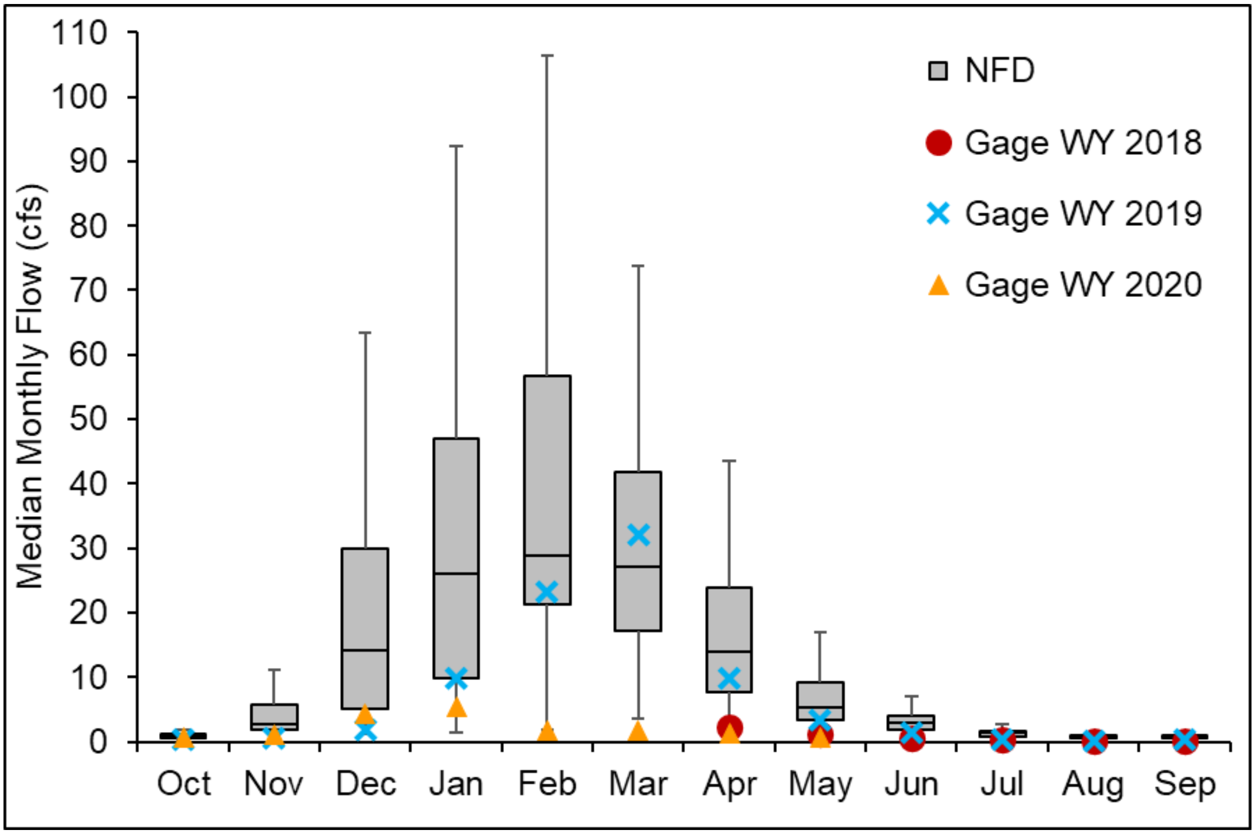

Figure 6. Comparison of median monthly Natural Flows Database (NFD) and gage data collected at Site 1 in Mark West Creek. The boxplots show median monthly values for estimated natural flow from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020). The grey bars represent 25th–75th percentile values, whiskers show data within the 1.5x interquartile range, and horizontal lines are the median values. Outliers are not shown.

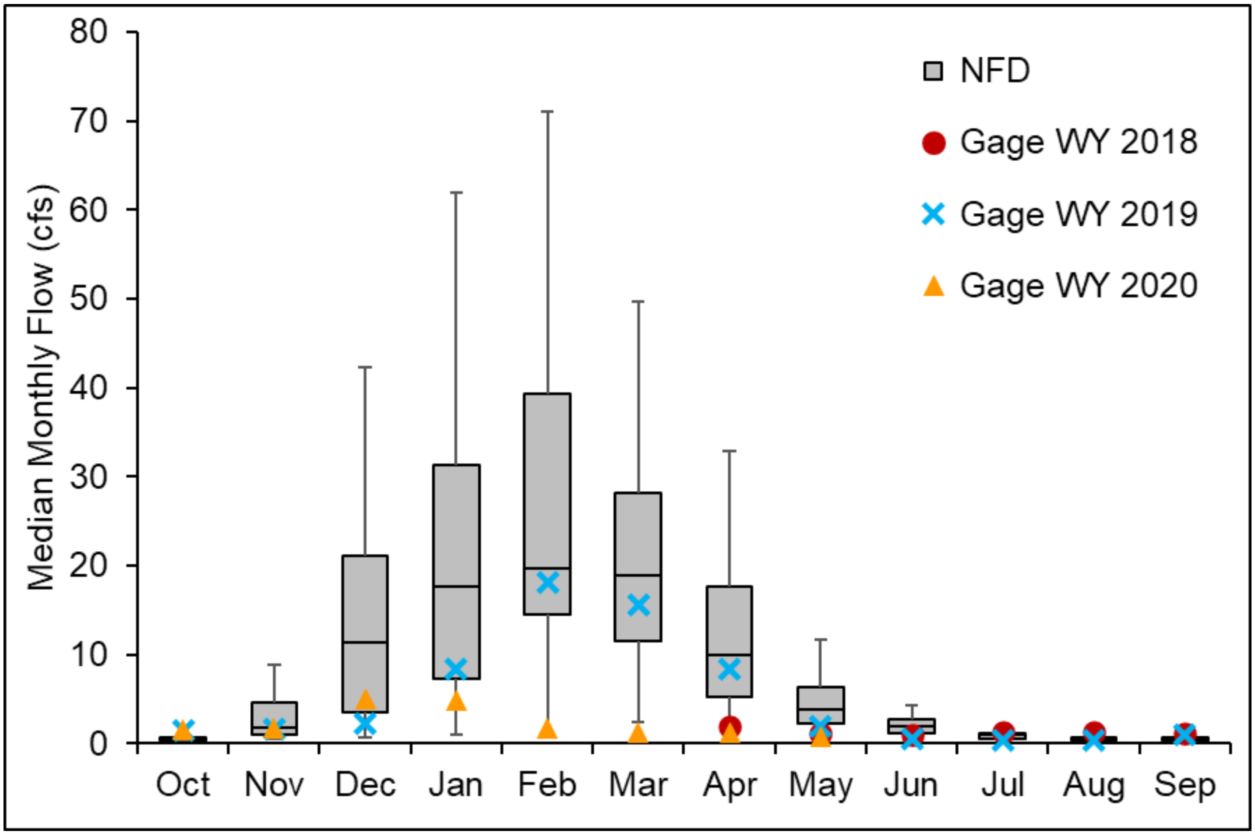

Figure 7. Comparison of median monthly Natural Flows Database (NFD) and gage data collected at Site 2 in Mark West Creek. The boxplots show median monthly values for estimated natural flow from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020). The grey bars represent 25th–75th percentile values, whiskers show data within the 1.5x interquartile range, and horizontal lines are the median values. Outliers are not shown. Estimated natural flow data: COMID 8272511.

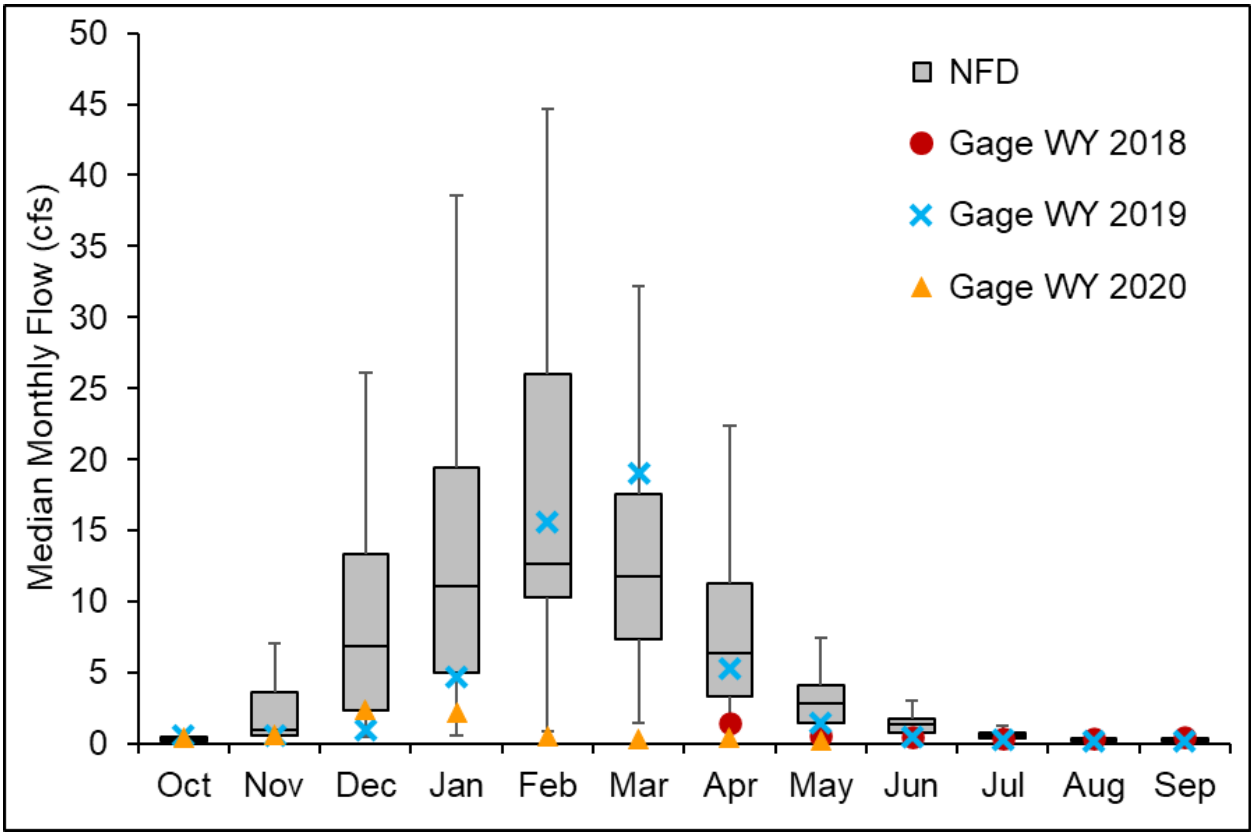

Figure 8. Comparison of median monthly Natural Flows Database (NFD) and gage data collected at Site 3 in Mark West Creek. The boxplots show median monthly values for estimated natural flow from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2020). The grey bars represent 25th–75th percentile values, whiskers show data within the 1.5x interquartile range, and horizontal lines are the median values. Outliers are not shown. Estimated natural flow data: COMID 8272499.

3.0 METHODS

The Department uses the Instream Flow Incremental Methodology (IFIM) to conduct instream flow evaluations in California's streams and rivers (CDFG 2008). The IFIM framework was used to guide instream flow evaluations and associated decision-making processes. In upper Mark West Creek, the Department's focus was to determine instream flows to support juvenile steelhead and Coho Salmon rearing.

The two-dimensional (2D) modeling approach was used to combine the two major analytical components (river hydraulics and physical habitat modeling) to simulate the relationship between streamflow and physical habitat for various life stages of fish species (CDFG 2008). Hydraulic and topographic survey field data were used to construct 2D hydraulic models for each study site. The 2D model results were combined with habitat suitability criteria (HSC) to estimate the flow-habitat relationship for each juvenile salmonid species. Habitat was assessed using area-weighted suitability (AWS; Jowett et al. 2014). Finally, hydrology time series data were used to identify flows associated with median habitat by water month type (habitat duration time series analysis). These results can be combined with other information to develop instream flow criteria or recommendations.

The schematic of the process used to assess instream flows to support juvenile salmonids is presented in Figure 9. This report describes the sampling strategy (in blue), hydraulic data collection and modeling (in green), and habitat modeling (in yellow). Hydraulic data collection and modeling (in green) is briefly described here and covered in more detail in Appendix A.

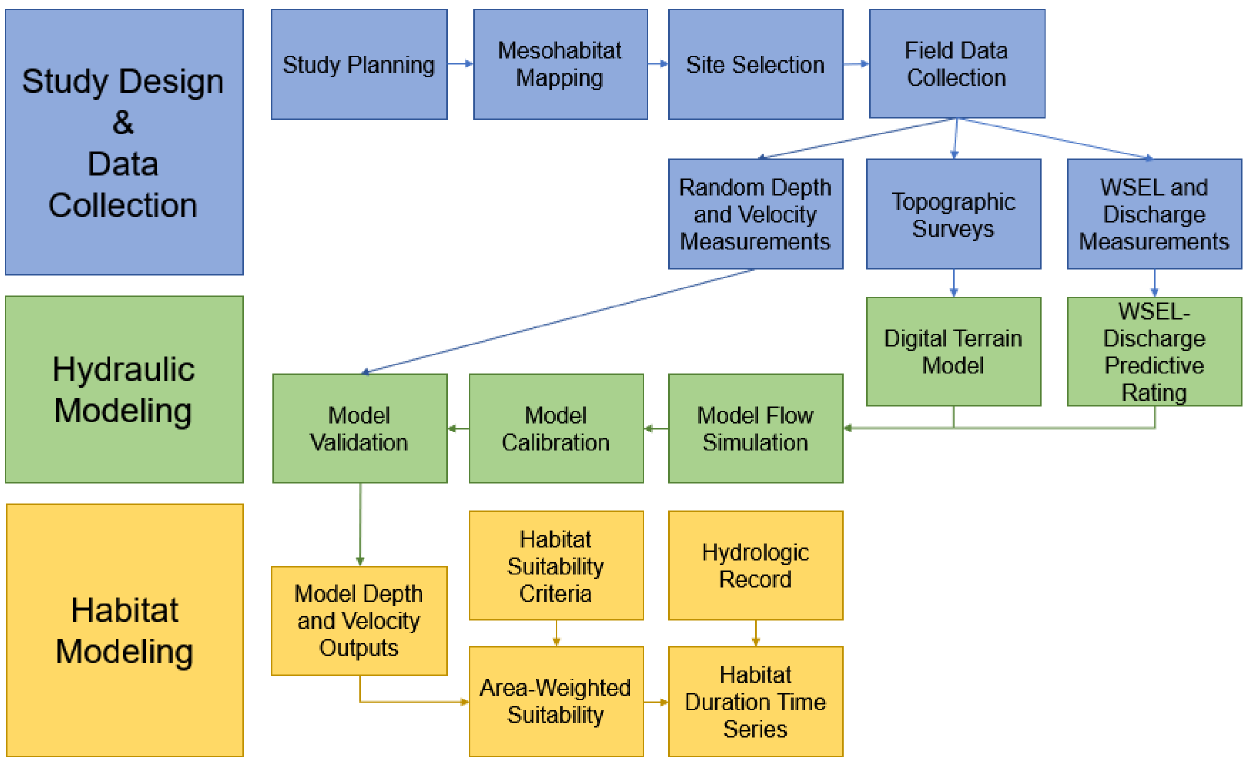

Figure 9. General schematic of 2D model development for Physical Habitat Simulation system (PHABSIM).

3.1 Habitat Inventory and Identification of Study Sites

The first step of 2D model construction is the selection of representative sites. Department staff assessed stream habitat types through a habitat inventory, delineated reaches using slope and habitat type composition, and then used the habitat inventory to select sites for intensive sampling within each of the reaches.

Habitat Inventory

Staff performed mesohabitat mapping and discharge surveys on upper Mark West Creek (upstream of Calistoga Road) between December 11th and December 13th of 2017. The surveys followed approved Department guidance for mesohabitat delineation (CDFW 2015a) and discharge measurements (CDFW 2020). Mesohabitats were mapped and typed through on-the-ground surveys using the Level IV habitat type classifications described in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 2010). This level of habitat delineation allows data to be used in other analyses or aggregated into less-detailed classifications, depending on the needs of an individual study.

Habitat classifications were based on characteristics such as channel morphology, gradient, substrate composition, and hydraulic properties. These habitat type classifications were then used to guide study site selection within each of the morphological reaches for hydraulic habitat modeling (CDFW 2015b). Staff measured the length of each mesohabitat unit and recorded other attributes as applicable, such as maximum pool depth, presence of a flow input or diversion, and artificial influences (e.g., rip rap, weir).

Reach Identification

Reach identification ensures that the selected study sites are representative of the range of stream channel characteristics that exist within the watershed. Distinct morphological reaches in upper Mark West Creek were identified through the habitat inventory and discussions with regional Department staff and other entities that work in the watershed.

Site Selection

Within each reach, study sites were selected for model development. Appropriate site selection ensures that the AWS results are representative of conditions within the larger stream reach. To provide meaningful results, the extent of channel encompassed by the 2D models must include a representative proportion of the habitat unit types observed in the stream reach. Sampling protocols for PHABSIM, developed by the United States Fish and Wildlife Service (USFWS 2011), recommend that the length of the sampled study area be at least 4% of the total reach length. In addition, each 2D model study area should contain a representative number and type of the different habitat unit types inventoried in the study reach. Ideally, each study site includes at least three units of each observed habitat type (Payne et al. 2004).

Level IV mesohabitat units were aggregated into broader mesohabitat categories of riffle, run, pool, and “other.” Riffle, run, and pool mesohabitat types are described in

Table 11. Units that fell into the “other” category included culverts, cascades, secondary channel pools, and bedrock sheet habitat types. Combined “other” mesohabitat types comprised less than 1% of the total surveyed reach length. Habitat units should constitute at least 5% of the overall reach length to be included in the analysis (CDFG 2008), so habitat units in the “other” category were excluded.

Table 11. Mesohabitat type definitions adapted from the California Salmonid Stream Habitat Restoration Manual (Flosi et al. 2010) and Snider et al. (1992).

Mesohabitat Type	Definition
Riffle	Below-average depth, above-average velocity, thalweg has relatively uniform slope going downstream, substrate of uniform size and composed of large gravel and/or cobble or bedrock), change in gradient noticeable. Primary determinants are relatively high gradient and surface turbulence.
Run	Moderate gradient, mixed-substrate particle sizes composed of small cobble and gravel with some large cobble and boulders, above-average water velocities, usually slight gradient change from top to bottom, generally associated with downstream extent of riffles, thalweg has relatively uniform slope going downstream. Primary determinants are moderate turbulence and average depth.
Pool	Uniform substrate, below-average water velocity, above-average depth, tranquil water surface. Primary determinant is downstream control – thalweg gets deeper moving upstream from tail of pool. Depth is not used exclusively to determine whether a mesohabitat unit is a pool.

3.2 Site Topographic Survey

2D models use a digital terrain model (DTM) to represent stream topography. A DTM is composed of a series of cartesian coordinate points collected using topographic survey techniques. The Department uses two types of topographic survey technology: real-time kinematic global positioning system (RTK-GPS) and the total station. RTK-GPS requires an unobstructed view of the sky to maintain satellite reception. The stream channel sections evaluated in Mark West Creek were obscured by thick forest cover or steep canyon walls, preventing the use of RTK-GPS. Instead, staff used two total stations to conduct the topographic survey of the stream channel needed to create the DTMs for each study site’s 2D model.

The Hydrologic Engineering Center’s River Analysis System (HEC-RAS; HEC-RAS 2018) was used to develop the 2D models. HEC-RAS requires that the DTM used in the 2D model is georeferenced. Horizontal and vertical control points were established at each study site to georeference the total station data. Static surveys were used to establish survey control benchmarks so that survey data could be correctly georeferenced. To perform a static survey, an RTK-GPS unit is set up over a stable predefined point (Figure 10) and run in autonomous mode for at least two hours. The point location coordinates are then translated into a National Spatial Reference System coordinate system[b].

Figure 10. Static survey using RTK-GPS rover in an area near a site with an unobstructed view of the sky.

The initial setup of a total station requires two points with known horizontal coordinates and vertical elevations. The points can be existing survey benchmarks or located using static survey methods. The azimuth angle between the two points is used to orient the

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[b] Point location coordinates were uploaded to the National Geodetic Survey Online Positioning User Service. This webpage uses the NOAA Continuously Operating Reference Stations Network to triangulate the uploaded data into a National Spatial Reference System coordinate system, with data available in both State Plane and Universal Transverse Mercator units.

total station to magnetic north. The total station is set up on one of the two points, the coordinates of the two points are input into the total station data logger along with the azimuth angle, and finally a survey shot is executed on the backsight to confirm the bearing angle between the two benchmarks (Figure 11).

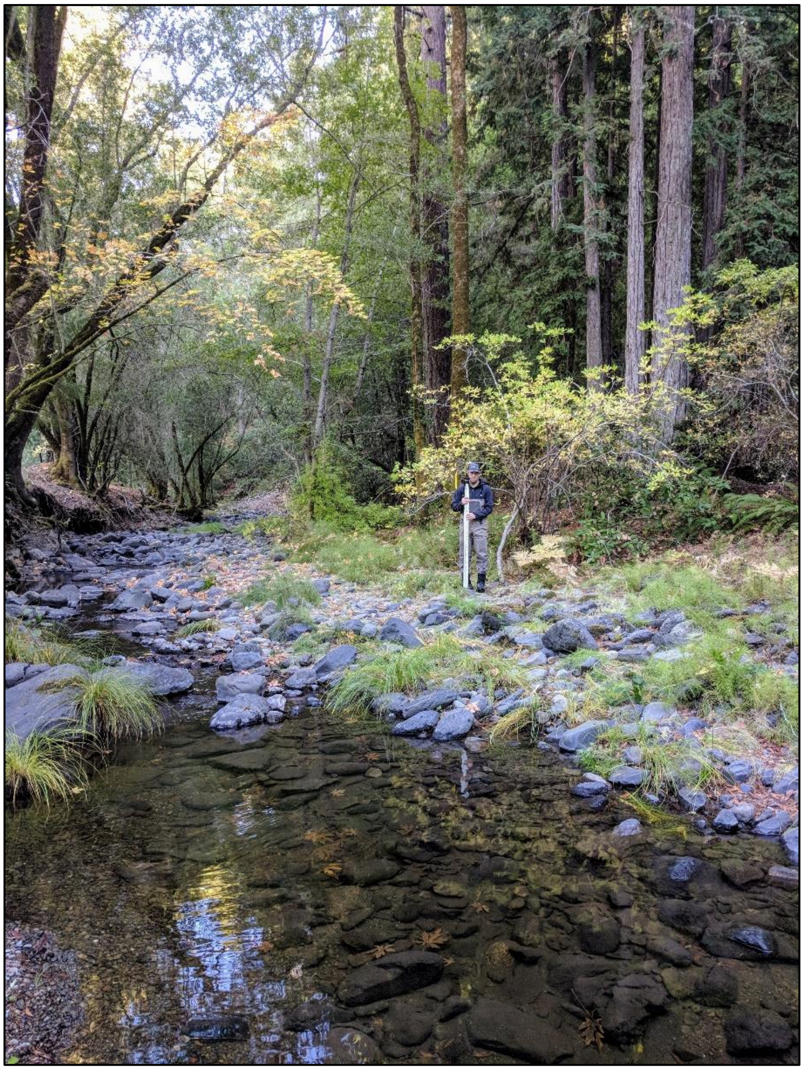

Figure 11. Total station backsight, with staff member holding a reflector mounted to a stadia rod at an established control point.

The total station surveys were used to create the DTM of each study site. To efficiently capture the topography of the streambed, staff collected more survey points in complex areas containing cobbles, boulders, and undulating bedrock outcroppings (Figure 12). Survey point density was lower in smoother areas like pools dominated by sand and clay substrate.

For all point collection, the North American Datum of 1983 (NAD 83) was used for horizontal control and the North American Vertical Datum of 1988 (NAVD 88) for vertical control. The Department uses the updated NA2011 version of the NAD 83 datum. The coordinates were projected across a Universal Transverse Mercator (UTM) cartesian plane using metric units. The Mark West Creek study sites are in UTM Zone 10.

As part of the topographic survey, substrate and cover coding were assigned to each survey point collected. Detailed information about substrate and cover coding is provided in Section A.2.3 of Appendix A.

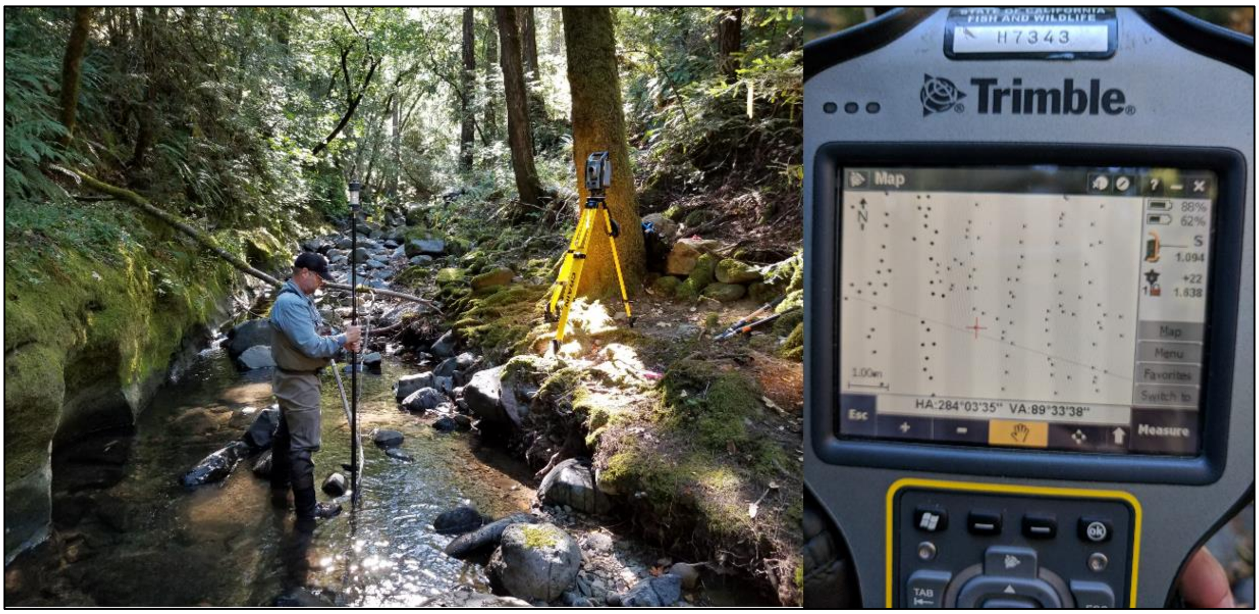

Figure 12. Total station surveying (left) and example of unbalanced survey point density (right). Photo from Mark West Creek Site 3.

3.3 Hydraulic Data Collection

Hydraulic data were collected to calibrate and validate the juvenile rearing habitat 2D models. For model calibration, the relationship between the flow rate (discharge) and the water surface elevation (WSEL) was defined at the upstream and downstream boundaries of each 2D site. Discharge and WSEL were measured and recorded at the upstream and downstream ends of the site for several flows to create a predictive rating curve. The flow-WSEL rating curves were then used to calibrate flow simulations over a range of flows. For more details, refer to Appendix A.

The upstream and downstream boundaries were placed in the pools where the water surface was flat, such that the flow was laminar and uniform in the downstream direction (Figure 13). The downstream boundary consisted of a straight transect perpendicular to flow. The transect was used as the downstream water stage control point for model simulation. The upstream boundary is where simulated flows enter the model. A second straight transect was placed in the upstream boundary pool, downstream of the model boundary. The upstream and downstream transects were marked by pieces of rebar at the headpin and tailpin. During each hydraulic data survey, a fiberglass tape was attached to the headpin, stretched across the transect, and tied to the tailpin (Figure 13). A temporary staff gage was used to detect if any changes in water level occurred during discharge and WSEL measurements.

Discharge measurements were collected in a suitable location to be representative of the flow passing through each site and in accordance with the Department's Instream Flow Program's *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California* (CDFW 2020). Discharge was measured at a minimum of three distinct flow levels. During the discharge-measuring events, WSEL was recorded at the upstream and downstream transects. Discharge and velocity were collected using a Hach FH950 velocity meter. Water surface elevations were collected using auto level and stadia rod following the Department's Instream Flow Program's *Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013).

Figure 13. Transect field survey with fiberglass tape and auto level at the downstream boundary (XS-1) of Site 3.

Hydraulic data were also collected at representative locations within each site to validate model results. Depths and velocities measured in the field were compared with depths and velocities predicted by the model at the same location and flow level. Discharge was measured before the validation data were collected and a model simulation was performed at that same discharge level. A minimum of 50 depth and velocity validation measurements were collected in each site.

Model validation data were collected as follows:

- Set up total station on horizontal benchmark and perform backsight.
- Measure discharge at the predetermined location within the study site using the approved Department methods (CDFW 2020).
- Occupy representative locations within the study site. At each location:
    - Record position using the total station
    - Measure depth using the survey stadia rod, and
    - Measure water velocity using the Hach FH950 velocity meter.
- Close total station survey with a check on the backsight.

The 2D model calibration and validation methods, data, and results are presented in Appendix A.

3.4 2D Hydraulic Model Development

A 2D hydraulic model was constructed for each study site using field data to represent the contours of the streambed and to calibrate the relationship between flow and WSEL. Each 2D model estimated depth and velocity across a range of flows. A brief overview of the 2D hydraulic modeling process is provided here, and additional details are provided in Appendix A.

The models used the 2D unsteady flow simulation component in HEC-RAS. The 2D models were developed by importing the topographic survey data into HEC-RAS as a raster. The study site geometry was then defined in HEC-RAS by digitizing a boundary around the study site raster, referred to in HEC-RAS as the 2D flow area (Figure 14). The edges of the 2D flow area, where flow enters and exits the site, were defined in HEC-RAS using features called boundary condition lines. The model geometry was completed by adding a computational grid, which is a regularly spaced square grid. In this study, computational grid cells were 0.5m x 0.5m or $0.25m^2$.

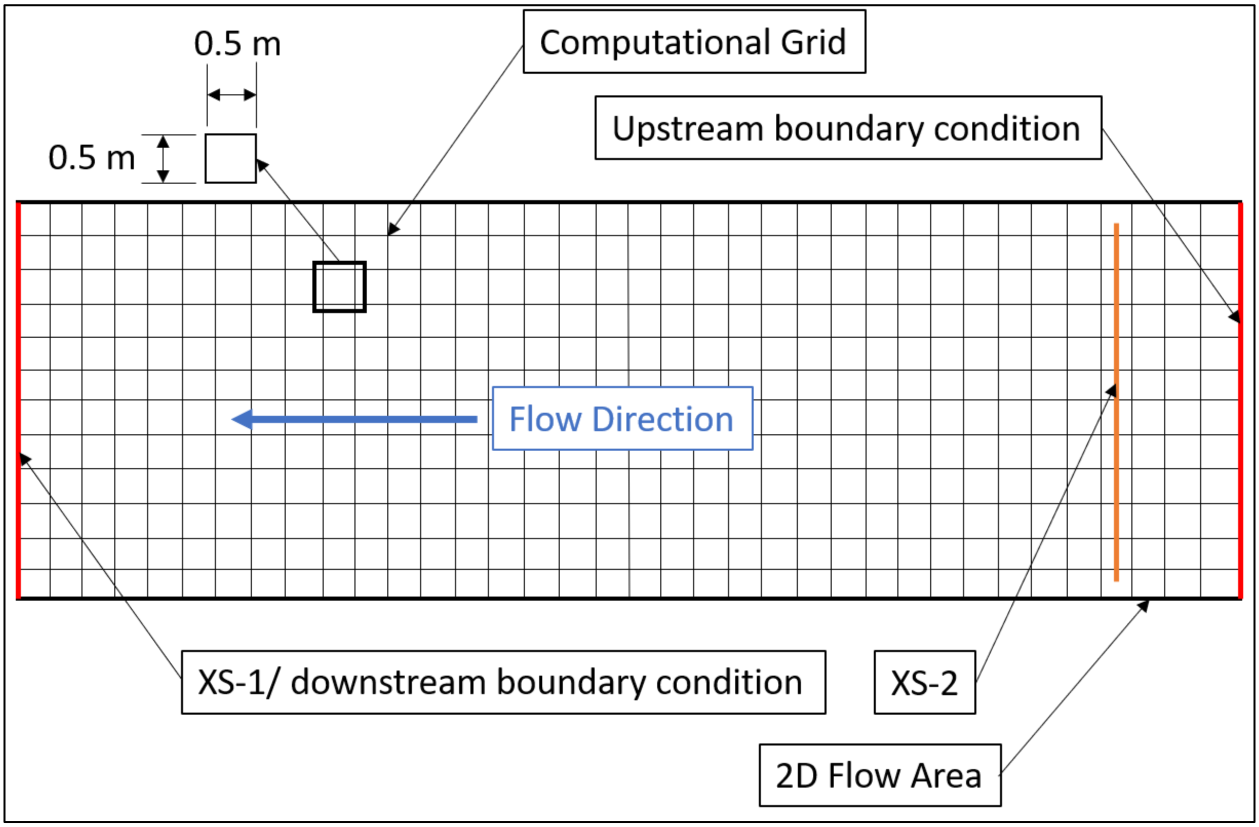

Figure 14. Conceptual model of HEC-RAS 2D flow area geometry components and boundary conditions.

Next, hydraulic parameters were defined at the upstream and downstream boundary condition lines. A constant flow hydrograph was defined at the upstream boundary condition line and a constant stage hydrograph was defined at the downstream boundary condition line. For every simulated flow, the WSEL at the downstream boundary and the flow entering the site at the upstream boundary were defined using the rating curve data mentioned in in Section 3.3 and described in detail in Section A.2.2 of Appendix A.

Flow simulations were calibrated by monitoring the WSEL at XS-2. Calibration was achieved when the simulated WSEL at XS-2 was within 0.1 ft of the WSEL predicted by the XS-2 rating curve for that site (Appendix A, Tables A-13 through A-15). Detailed data entry procedures, selected model settings, hydraulic model tolerances, and calibration results for each study site are provided in Appendix A.

3.5 Area-Weighted Suitability and Habitat Suitability Criteria

The relationships between streamflow and physical habitat for steelhead and Coho Salmon were modeled using life-stage-specific HSC and the outputs of the hydraulic modeling process described above and in Appendix A. These data were combined to estimate AWS (also referred to as weighted usable area) for each study site by species and life stage over a range of flows. Defined simply, AWS is a scoring index that can be used to assess the relative suitability of different flows for a given species and life stage (Payne and Jowett 2013). AWS represents the available habitat area weighted by the suitability of that habitat.

Within each study site, the 2D model predicted depth and velocity values for each raster cell in the computational model grid (Figure 15). Like a photo, a raster is composed of a grid of cells (or pixels) that represent information in the image, which in this case were the depth and velocity values.

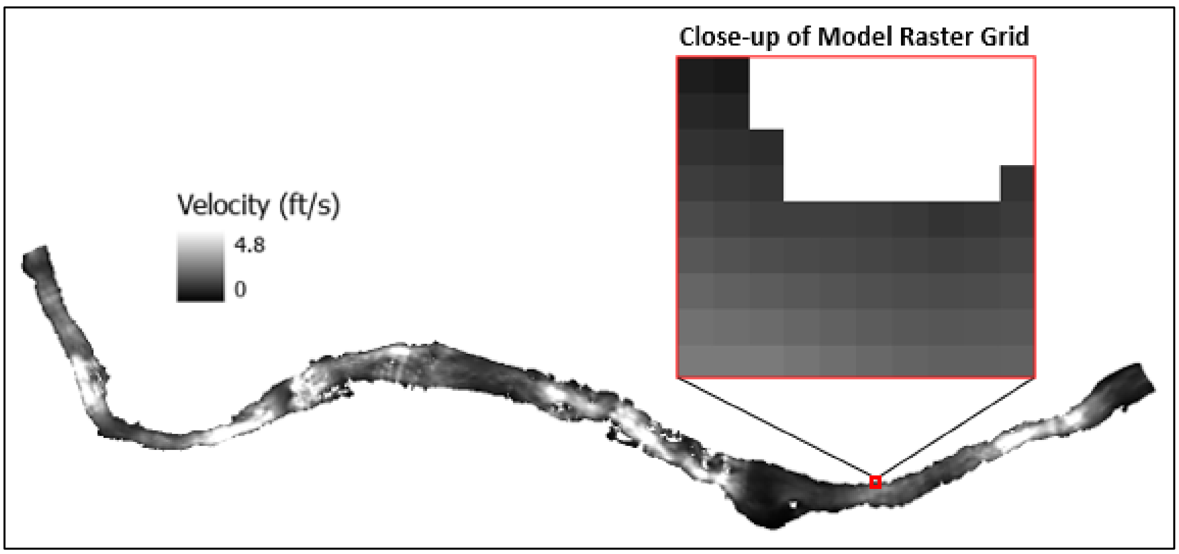

Figure 15. Example raster map showing model-predicted velocities in Site 1 at 10 cfs and a close-up view of the model raster grid cells.

Relative suitability of instream conditions for steelhead and Coho Salmon juveniles at each simulated flow was defined using preference curves. Preference curves express the relative preference of rearing juveniles for depth and velocity values on a scale from 0 to 1 (Bovee 1982). The HSC preference curves used in this report were developed in Hollow Tree Creek, a tributary to the South Fork Eel River, using data collected by the Department in the spring of 2017 and 2018 (Gephart et al. 2020). Hollow Tree Creek was determined to be a suitable candidate for HSC development due to the presence of similar species assemblages and life-stage timing, as well as relatively unaltered natural flow. The Hollow Tree Creek study used an equal-area sampling design stratified by mesohabitat type within each of three reaches. Habitat units used for sampling were randomly selected within each mesohabitat type. The distribution of depths and velocities occupied by fish was compared to the distribution of available depths and velocities to determine fish habitat preference. This observed preference was used to assign habitat suitability index values to each depth or velocity cell value (Figure 16).

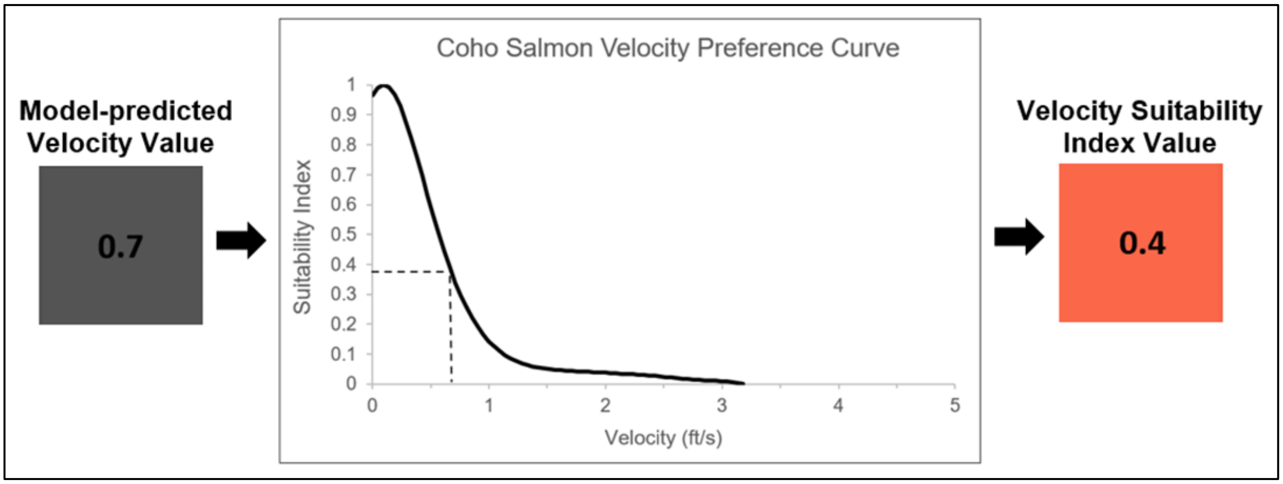

Figure 16. Conceptual model showing how model-predicted raster cell values are used along with a species' preference curve to determine suitability index values. In this example, velocity values are compared against the Coho Salmon velocity preference curve to identify the corresponding suitability index on the y-axis of the curve.

Gephart et al. (2020) developed fish habitat preference curves for two fish size classes, measured in centimeters (cm), for both steelhead and Coho Salmon: <6 cm (fry) and ≥6 cm (juveniles). These preference curves were used to map site-wide species suitability for both depth and velocity, as shown in Figure 17 and Figure 18, respectively.

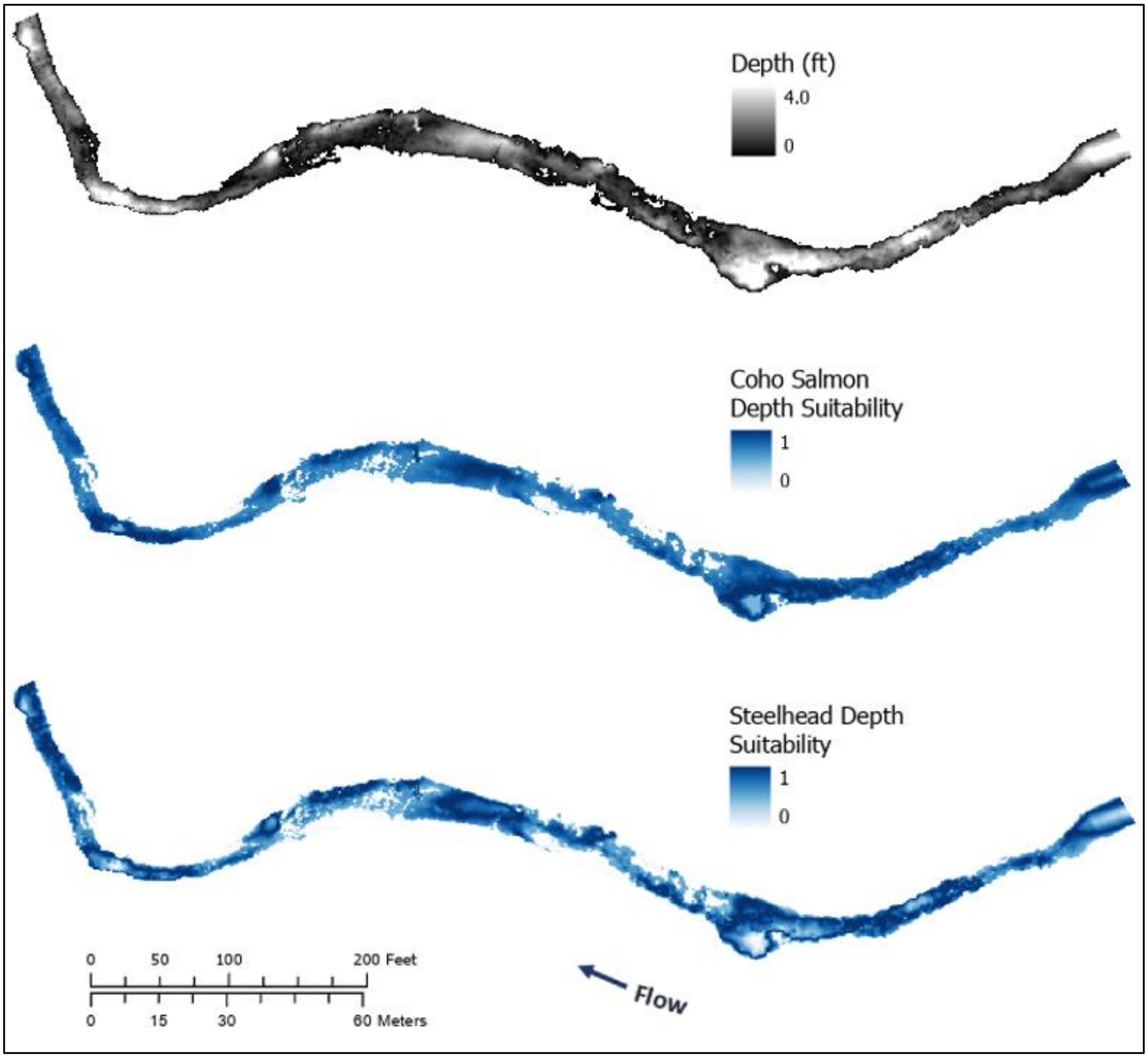

Figure 17. Modeled depth output raster for Site 1 at 10 cfs and the resulting depth suitability rasters for steelhead and Coho Salmon on a scale from 0 to 1.

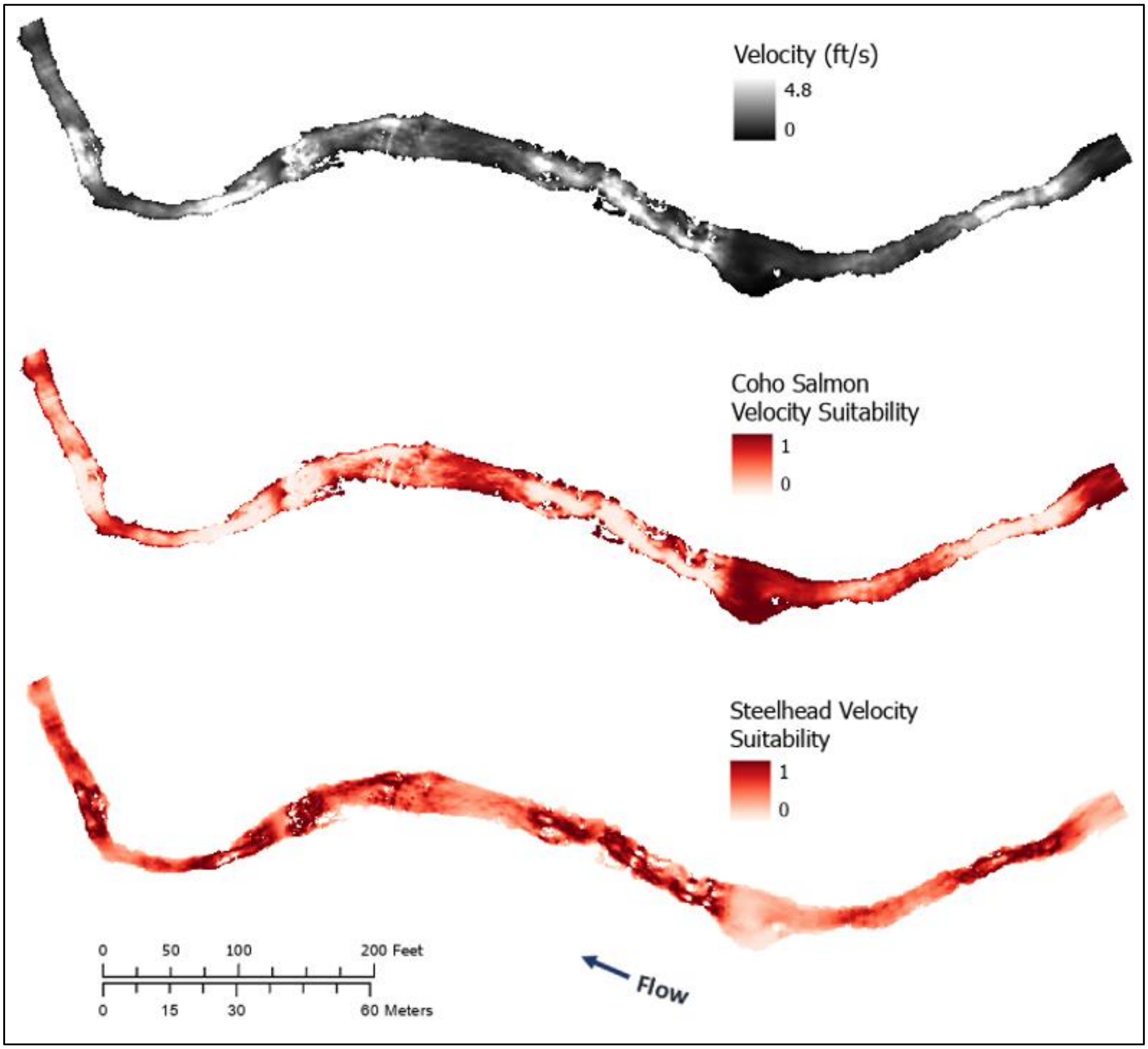

Figure 18. Modeled velocity output raster for Site 1 at 10 cfs and the resulting velocity suitability rasters for steelhead and Coho Salmon on a scale from 0 to 1.

When using preference-type HSC curves, the suitability for a species and life stage is expressed as a combined suitability function. The depth and velocity suitability index values for each model raster cell are multiplied together (Figure 19) to create the combined suitability function as follows:

Combined suitability function = f(d) x f(v) (adapted from Bovee 1982)

where:

f(d) = the depth suitability index value on a scale from 0 to 1

f(v) = the velocity suitability index value on a scale from 0 to 1

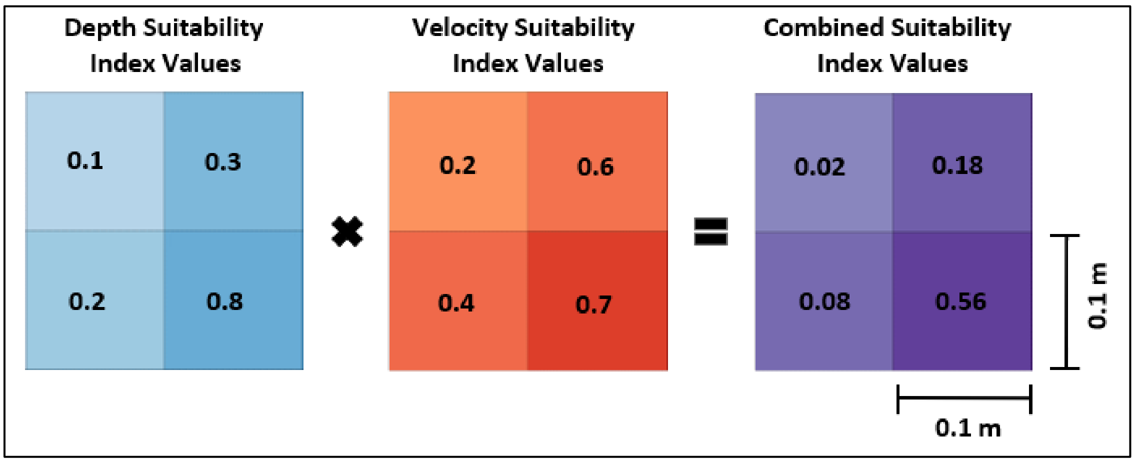

Figure 19. Conceptual model showing example of combined suitability calculations for individual model raster cells and the raster cell dimensions used in the analyses.

The result of this cell-by-cell computation is a site-wide combined suitability map for a given species, life stage, and flow magnitude (Figure 20). Using these results, AWS is calculated by summing the product of each computational grid cell's surface area and that cell's score of combined suitability as follows:

$AWS = \sum A_i \times C_{i,s}$ (adapted from Bovee 1982)

where:

A_i = surface area of computational grid cell (i)

$C_{i,s}$ = combined suitability index of cell (i), by the target species (s)

The computation of composite suitability for each cell and summation of AWS per flow simulation was automated using a Python script in an Esri ArcGIS Pro environment.

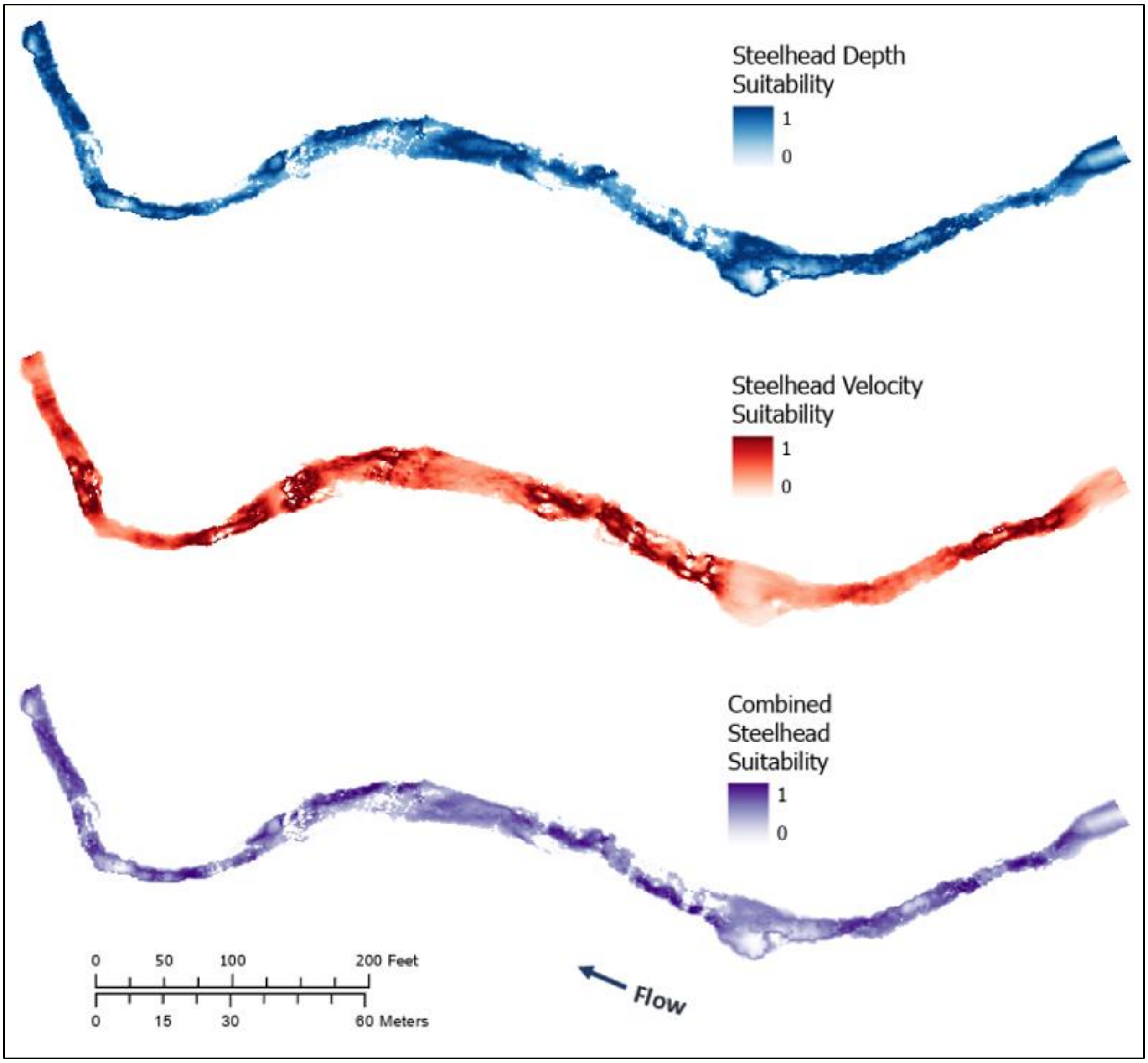

Figure 20. Visual workflow example showing the depth and velocity suitability raster maps used to calculate the combined suitability output on a scale from 0 to 1 for steelhead in Site 1 at 10 cfs.

3.6 Habitat Duration Analysis

To ensure that flow criteria do not exceed naturally available (unimpaired) flows, a habitat duration time series analysis was used to select protective flows for each month and water month type. Habitat duration analysis uses unimpaired hydrology to generate a time series of daily AWS values that would likely occur under unimpaired conditions based on the AWS-flow relationships described in Section 3.5. The flows associated with median AWS values calculated for each month and water month type represent the naturally occurring conditions within a site and generate protective flow criteria (CDFG 2008). The use of unimpaired flows ensures that the full range of natural variation is represented, rather than an altered present-day baseline.

To complete this analysis, estimated unimpaired flows (Zimmerman et al. 2020) were used to generate a time series of AWS using the AWS-flow relationships. For all sites, juvenile steelhead (≥6 cm) AWS-flow relationships were used for the analysis. The relationships between AWS and flow by site were then used to generate a time series of AWS values over the period of record. This time series was used to calculate median monthly AWS values under unimpaired conditions for each of the three water month types (CDFG 2008). Next, these median AWS values were converted to a flow. AWS-flow relationships typically predict increasing AWS with additional flow up to a point, known as the AWS peak, and then decreasing AWS with additional flow (Figure 21). As a result, equivalent AWS values can appear on both the ascending and descending limbs of the curve. When the median monthly flow in a given water month type was greater than the flow associated with the AWS peak for a given site, the AWS peak flow was selected. When the median monthly flow was less than the flow associated with the AWS peak, the flow on the left (ascending) side of the curve associated with the median AWS value was selected. This approach ensures that the selected flow will not exceed unimpaired water availability for a given month and water month type (CDFG 2008).

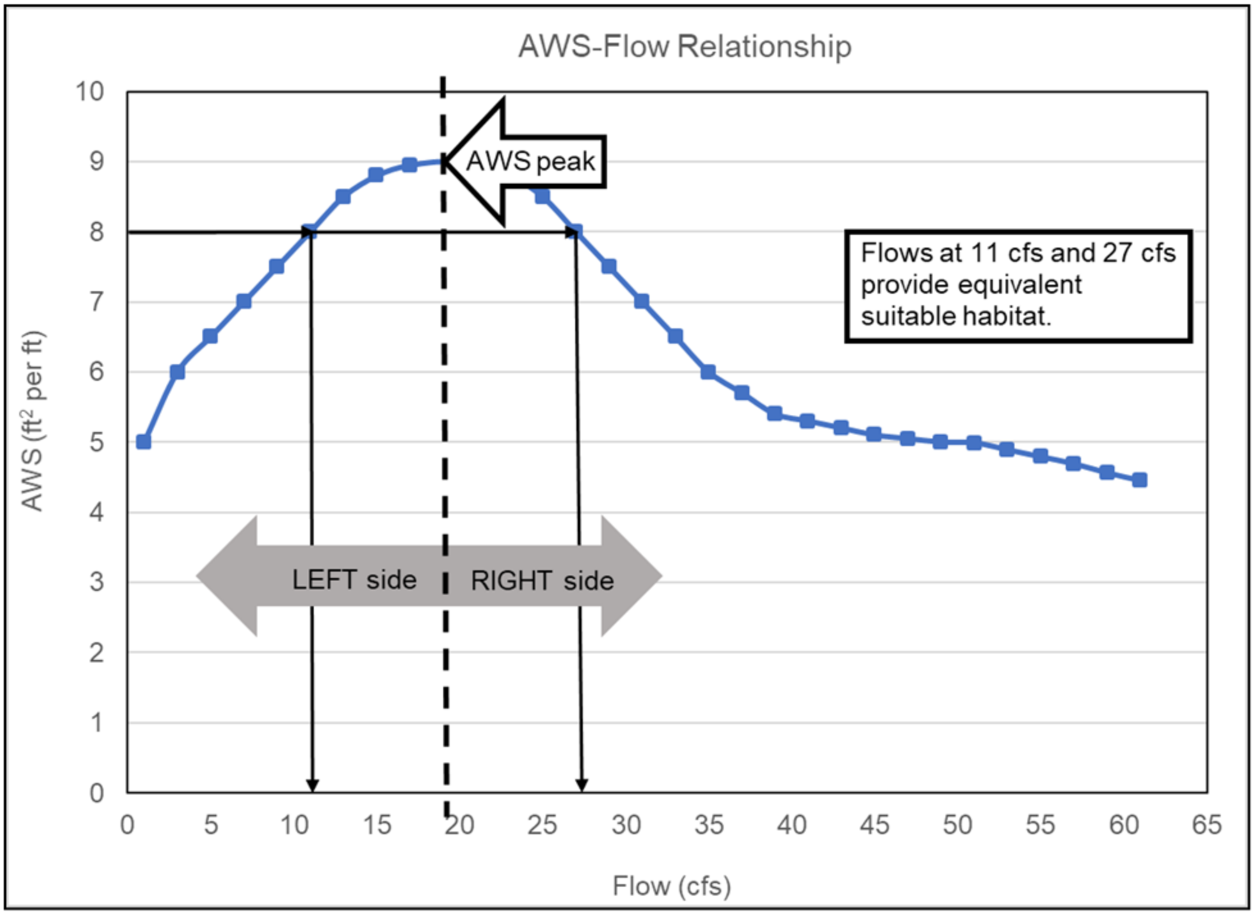

Figure 21. A generalized example of an AWS-flow relationship; the same amount of suitable habitat can be provided by flows both above and below the AWS peak flow.

3.7 Monitoring Data Collection

Unvented Solinst Levelogger pressure transducers (PTs) and HOBO® dissolved oxygen loggers were installed within each study site to monitor water temperature, water level, and dissolved oxygen. A Solinst Barologger was also installed at Site 2 to record barometric pressure and air temperature. The Barologger data were used to convert the absolute pressure readings from the unvented PTs into water levels. The Barologger was installed at Site 2 in the cavity of a tree trunk and the dissolved oxygen loggers were installed in covered and/or shady locations to minimize the impact of diurnal temperature fluctuation on the data. All monitoring data were recorded at a 15-minute time interval. The PT and Barologger data were collected from April 2018 through April 2020.

The PTs were installed using the methodology described in the standard operating procedure developed by the State of Utah Division of Water Quality (DWQ 2014). The PTs were suspended in the water column by a metal cable inside a vault constructed of polyvinyl chloride (PVC) pipe (Figure 22). The PTs were placed in pool habitat units where the water surface would remain flat over a wide range of flows. The PVC vaults were located to minimize the exposure of the PT to storm debris (Figure 22). The vaults were positioned so that the PTs could be easily extracted from the PVC pipe using the cable to upload the data logs to a laptop computer or other computer storage device. The converted water level readings were used with flow measurements collected on site to create flow-water level rating curves. The rating curves were then used to convert the water level logs into flow time series.

Figure 22. PT and dissolved oxygen vaults near the downstream boundary of Site 1.

We conducted continuous in-situ water quality monitoring at each of our study sites during the low-flow season (i.e., summer–fall), which is a critical period for the survival of rearing steelhead and Coho Salmon juveniles in Mark West Creek. We deployed

HOBO® U26-001 loggers to measure dissolved oxygen and temperature conditions at 15-minute time increments. Monitoring data were collected from April–November 2018 and from June–December 2019.

At each of the study sites, the HOBO® data loggers were deployed in pool habitat types that were expected to stay wetted throughout the monitoring period and, where possible, in areas that minimized diel temperature fluctuations from incident solar radiation (i.e., in pools with overhead tree cover). The loggers were housed and suspended in a PVC pipe that was perforated near the sensor to allow for adequate water mixing.

The data loggers were calibrated in the office using the manufacturer's standard calibration procedures and, after deployment, field calibration measurements were taken adjacent to the logger using a YSI Pro20 dissolved oxygen meter. At the end of each monitoring season, the loggers were removed from the creek and the data were downloaded and analyzed using the HOBOware® Pro software program.

4.0 RESULTS

The following section presents the results of the data collection and analysis described in Section 3. Refer to Appendix A for a more detailed description of the 2D model construction, calibration, and validation.

4.1 Mesohabitat Mapping and Site Selection

The 4.5-mile stream segment of upper Mark West Creek included in the habitat inventory was divided into four reaches (Figure 3). The downstream-most reach (Reach 1) starts at the Calistoga Road overcrossing and extends approximately 2,930 yards (1.7 miles) upstream to a natural, bedrock waterfall feature that is adjacent to the lowest St. Helena Road overcrossing. This reach is a semi-confined alluvial channel dominated by gravel, cobble, and small boulders. The middle reach (Reach 2) stretches approximately 3,600 yards (2.0 miles) from the waterfall up to the Tarwater Road bridge. This reach is also semi-alluvial, though it has larger substrate and is more confined with areas of bedrock outcroppings. Lastly, the upper two reaches (Reach 3 and Reach 4) stretch approximately 2,130 yards (1.2 miles) from the Tarwater Road bridge up to an impassable rock feature that is downstream of Neal Creek Road. These upstream-most reaches have a narrow, bedrock-confined channel and the substrate is comprised mainly of cobble, medium–large boulders, and bedrock. Although they share similar morphology, no access was permitted in the intervening stream reach, so they were treated separately.

Table 12 provides a summary of the mesohabitat types by length within each of the four reaches. Riffles, pools, and runs were identified in each of the four reaches, and each made up more than 5% of the reach length in each case. Although a fourth habitat type, “other” was identified in Reach 1, Reach 2, and Reach 4, this habitat type made up less than 1% of total reach length, and so was not included in site selection.

Table 12. Summary of mesohabitat types surveyed by reach in the upper Mark West Creek study area.

Reach	Mesohabitat Type	Number of Units	% of Total Length
Reach 1	Riffle	23	15.6
Reach 1	Pool	46	53.8
Reach 1	Run	21	30.5
Reach 1	Other	1	0.1
Reach 2	Riffle	25	8.6
Reach 2	Pool	67	38.3
Reach 2	Run	49	52.2
Reach 2	Other	2	0.9
Reach 3	Riffle	5	13.7
Reach 3	Pool	14	54.4
Reach 3	Run	8	31.9
Reach 4	Riffle	10	18.5
Reach 4	Pool	19	44.9
Reach 4	Run	14	35.9
Reach 4	Other	1	0.7

Study sites were selected in each reach to be representative of the habitat types observed in that reach. Site length and location were constrained by the presence of appropriate mid-channel pools for boundary transect placement, which are required at the upstream and downstream end of each site. The site chosen within each reach was selected to contain each of the three habitat types and was greater than 4% of the length of the reach in each case (Table 13). The upstream-most reach (Reach 4) lacked appropriate pools for the construction of a 2D model, so no sites were selected in this reach. Instead, models were constructed for Site 1, Site 2, and Site 3, selected within Reach 1, Reach 2, and Reach 3, respectively.

Table 13. Comparison of reach and site length and the total number of habitat units within each selected site.

Reach	Reach Length (yards)	Site Length (yards)	Site/ Reach (%)	Pools in Site	Runs in Site	Riffles in Site
1	2,927	313	10.7%	7	4	3
2	3,606	261	8.9%	5	4	3
3	762	178	6.1%	3	2	3

Each site contained at least three units of each habitat type with one exception; there were only two runs in Site 3. Site selection in Reach 3 was constrained by the lack of mid-channel pools that are ideal for boundary transect placement. The site with the best pair of mid-channel pools for boundary transect placement only contained two run units.

The riffles in Reach 3 were also different from riffles found in the other two reaches. Reach 3 lacked alluvial riffles with a crest composed of coarse gravel and cobbles. In alluvial stream beds, such as Reach 1, hydraulic grade breaks occur along riffle crests (Figure 23). In Reach 3, which was confined and bedrock-dominated, hydraulic grade breaks instead occurred at the crest of step-run habitat units. The riffles reported in Table 13 for Site 3 are more accurately described as steps rather than alluvial riffles (Figure 24).


Figure 23. Alluvial type riffle crest stream grade break in Reach 1.

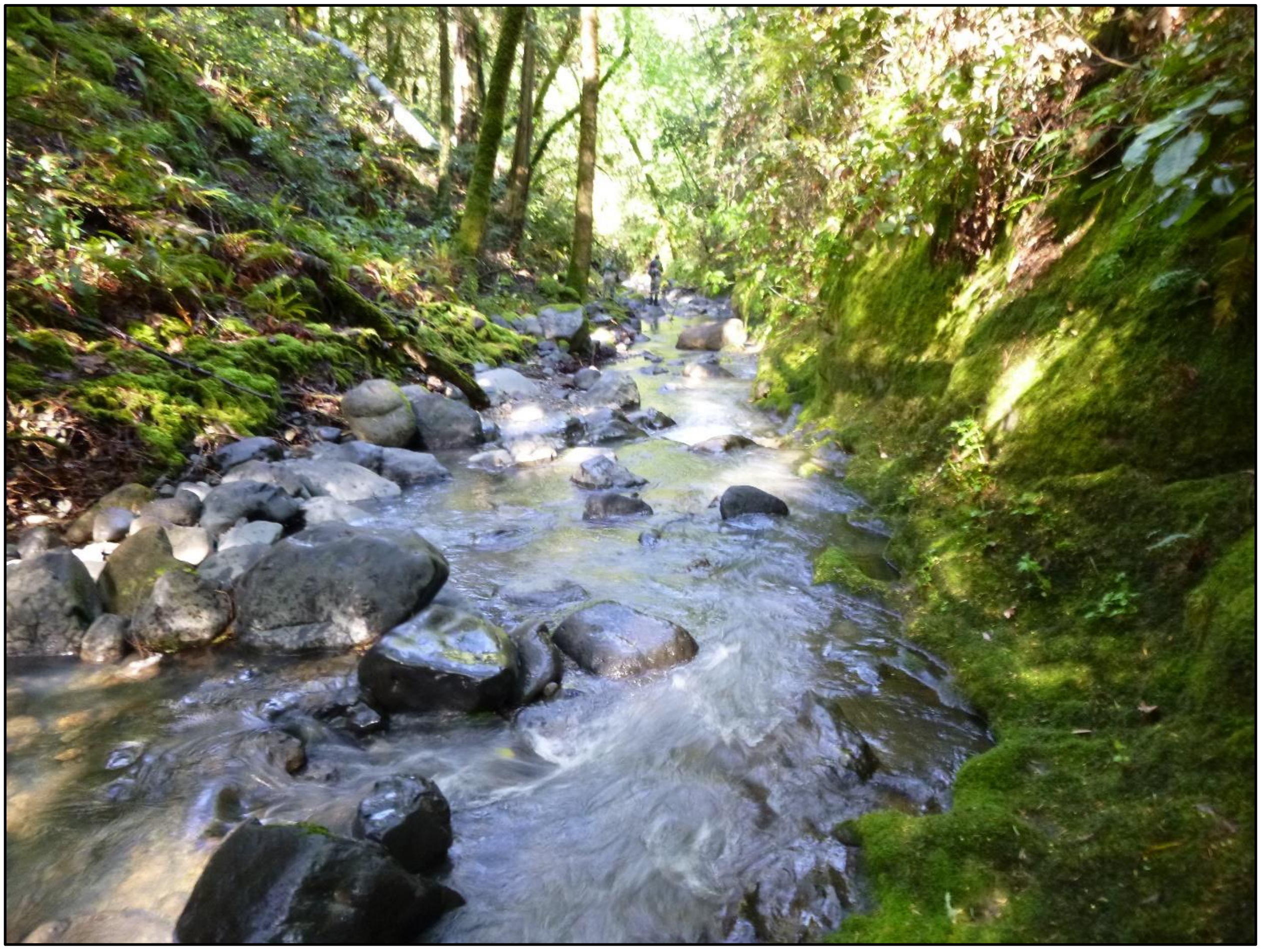

Figure 24. Step-run type stream grade break in Reach 3.

4.2 Topographic Data Collection

Topographic survey point density increased moving upstream from Site 1 to Site 3 (Table 14). Survey point density was calculated as the number of points within the wetted area of the model boundary. Point density was computed by dividing the number of points within the wetted area by the wetted area of the highest simulation flow. Table 14 reports the point density of the highest flow simulation for each site.

Table 14. Topographic survey point density. Point density represents point density within the wetted channel at the highest simulation flow.

Site	Max Simulation Flow (cfs)	Number of Survey Points	Wetted Area (ft^2)	Point Density ($points/ft^2$)
1	70	7,714	26,120	0.30
2	70	5,778	14,672	0.39
3	50	4,406	4,942	0.89

The higher density of survey points in Site 3 is likely a result of the larger substrate size observed in the upper watershed (Table 15; Figure 25–Figure 27). When substrate size was large (e.g., boulders), more survey points were required to accurately capture the shape of the stream bed (Figure 27). Median substrate size was estimated from the substrate codes collected at each topographic survey point (see Appendix A, Section A.2.3). Median substrate size increased from Site 1 to Site 2 and again from Site 2 to Site 3.

Table 15. Median particle size by site.

Site	Median Substrate Code	Median Particle Size (in)	Median Particle Size (ft)
1	3.5	4	0.33
2	6.8	7	0.58
3	9	>12	>1.00

Figure 25. Example of Site 1 sand, gravel, cobble, and boulder substrate.

Figure 26. Example of Site 2 gravel, cobble, and boulder substrate.

Figure 27. Example of Site 3 gravel, cobble, boulder, and bedrock substrate.

4.3 Hydraulic Model Calibration

The objective of the study was to estimate the AWS, or suitability of habitat available for juvenile steelhead and Coho Salmon rearing over a range of flows simulated in HEC-RAS. Depth and velocity were the hydraulic parameters used to estimate AWS for juvenile rearing. Each flow simulation in HEC-RAS was calibrated to provide the best prediction of depth and velocity. The range of simulated flows is summarized in Table A-12 of Appendix A. Refer to Appendix A for detailed explanation of the model construction, calibration, and validation processes and outcomes.

Model development requires that prior to model construction the flow-WSEL relationship be established at the upstream and downstream transect. The flow measurements and accompanying WSEL measurements used to develop rating curves at the downstream and upstream transect in each site are provided in Appendix A, Table A-4 through Table A-9. The associated rating curves are provided in Appendix A, Figure A-9 through

Figure A-14. The goodness of fit (R^2) for each rating curve is summarized in Table 16 below.

Table 16. Rating curve R^2 results.

Site	Transect	R^2
Site 1	XS-1	0.9988
Site 1	XS-2	0.9994
Site 2	XS-1	0.9918
Site 2	XS-2	0.9982
Site 3	XS-1	0.9999
Site 3	XS-2	0.9997

Flow simulation parameters were monitored during the simulation process and included energy grade slope at the upstream boundary condition, Courant number, and Froude number in each computational grid cell. The suggested thresholds for these parameters are provided in Appendix A, Section A.2.9. A summary of the energy grade slope results is provided in Appendix A, Table A-17. The Courant number and Froude number simulation results are provided in Appendix A, Tables A-18 through A-20.

4.4 Flow and Habitat Relationships

Estimated streamflow–AWS relationships for steelhead and Coho Salmon in upper Mark West Creek varied by site and life stage (Figure 28–Figure 30). AWS is an index that weights available habitat area by the suitability of that area. AWS reflects both changes in total wetted area as well as changes in depth and velocity suitability conditions with flow.

Steelhead fry (<6 cm) habitat availability peaked at simulation flows of 1–3 cfs in all sites. Optimal flows for juvenile steelhead (≥6 cm) steadily increased from 20 cfs at Site 3 to 45 cfs at Site 1. AWS for Coho Salmon fry (<6 cm) peaked at 2 cfs for Site 1 and at 1 cfs for Sites 2 and 3. Habitat availability for juvenile Coho Salmon (≥6 cm) increased with drainage area to a maximum of 4 cfs.

The data used to develop these figures are presented in Appendix C. Juvenile steelhead (≥6 cm) have the highest flow requirements of the species and life stages assessed and were therefore used to estimate median habitat duration in Section 4.5.

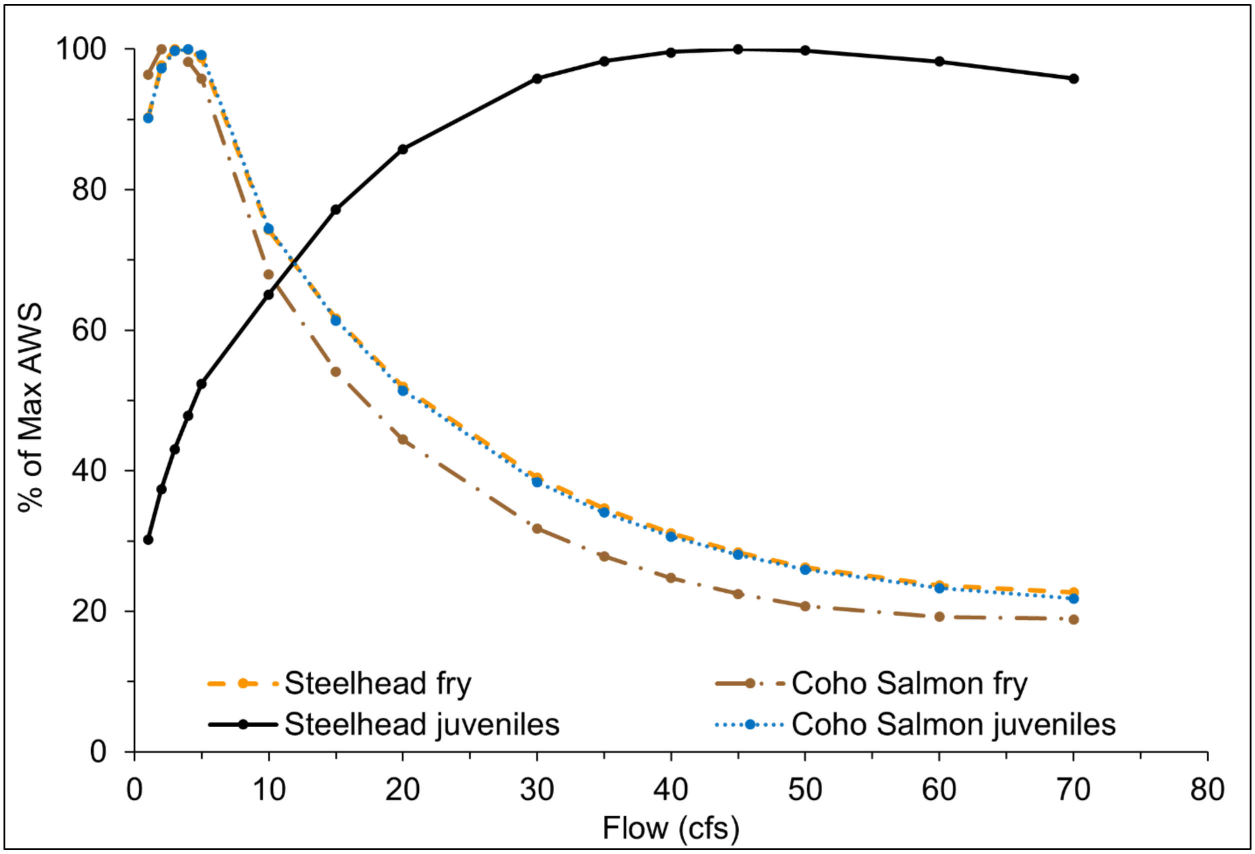

Figure 28. Site 1 fry and juvenile steelhead and Coho Salmon streamflow – AWS (habitat) relationships. Markers on curves represent simulated flows used to develop AWS curves.

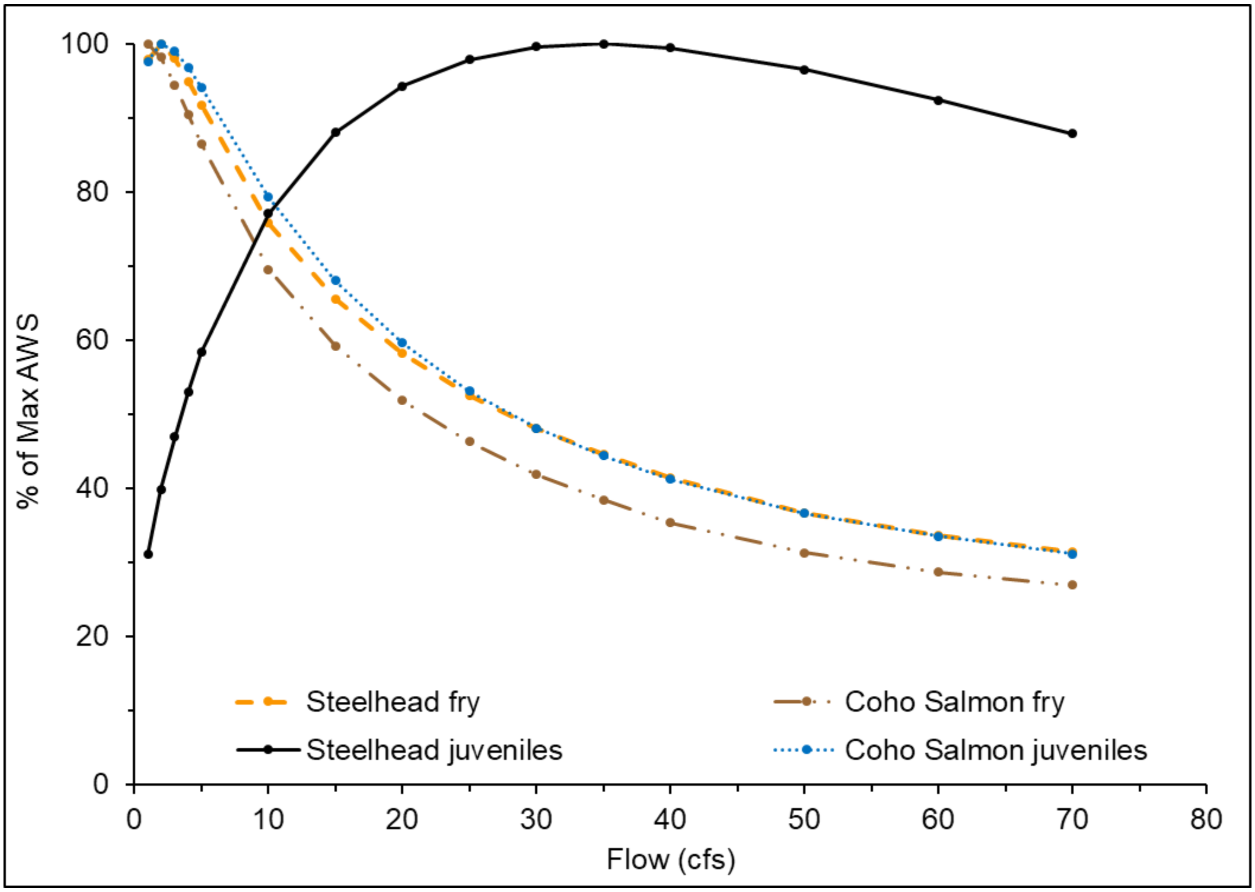

Figure 29. Site 2 fry and juvenile steelhead and Coho Salmon streamflow – AWS (habitat) relationships. Markers on curves represent simulated flows used to develop AWS curves.

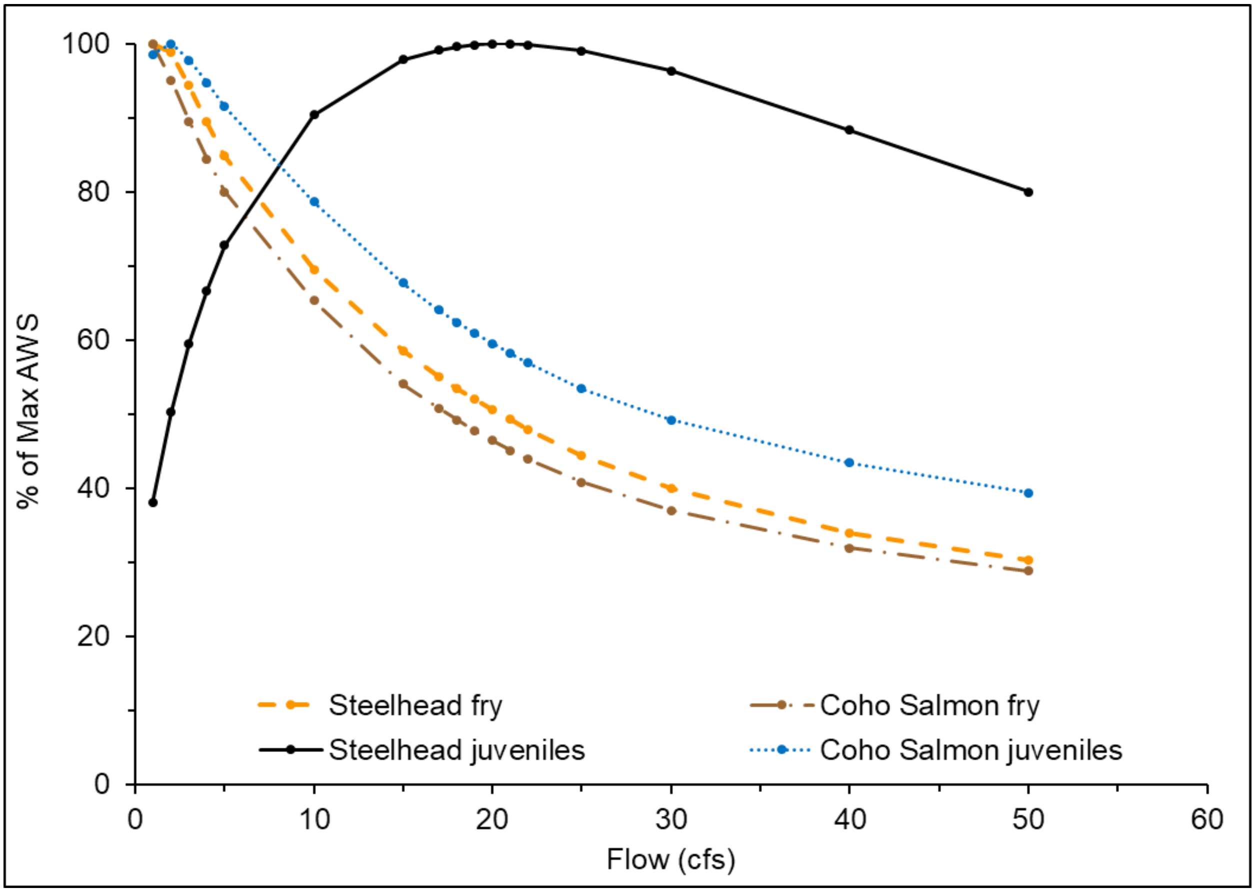

Figure 30. Site 3 fry and juvenile steelhead and Coho Salmon streamflow – AWS (habitat) relationships. Markers on curves represent simulated flows used to develop AWS curves.

4.5 Habitat Duration Analysis

Streamflow for steelhead rearing derived from habitat duration time series analyses are presented by monthly water type for the three study sites in Table 17 through Table 19. Juvenile steelhead (≥6 cm) streamflow-habitat relationships from Section 4.4 were used to represent habitat since this species and life stage had the highest flow requirements of those assessed. Since the habitat duration time series analyses used the monthly flow values from the Natural Flows Database (Zimmerman et al. 2020) combined with the juvenile steelhead AWS values, the median habitat values (and associated flows) generally increased in wetter months and decreased in drier months. Only in the winters of wet water month types were peak AWS flows available based on the unimpaired flow estimates.

Table 17. Site 1 protective steelhead juvenile rearing flows in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	45	26	5
February	45	29	13
March	45	27	11
April	31	14	6
May	10	5	3
June	5	3	2
July	2	1	1
August	1	1	<1
September	1	1	<1
October	1	1	<1
November	11	3	2
December	32	14	2

Table 18. Site 2 protective steelhead juvenile rearing flows in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	35	18	4
February	35	20	9
March	28	19	8
April	21	10	4
May	7	4	2
June	3	2	1
July	2	1	<1
August	1	1	<1
September	1	<1	<1
October	1	1	<1
November	7	2	1
December	21	11	2

Table 19. Site 3 protective steelhead juvenile rearing flows in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	20	11	2
February	20	13	6
March	20	12	5
April	14	6	3
May	5	3	1
June	2	1	1
July	1	1	<1
August	<1	<1	<1
September	<1	<1	<1
October	<1	<1	<1
November	5	1	1
December	15	7	1

4.6 Monitoring Data

Flow time series were developed from the water levels recorded by the PTs and discharge measurements recorded at each site. The PT water level readings recorded during the discharge measurements at each site (Table 20–Table 22) were used to create rating curves. These rating curves were then used to construct a daily time series of flow for each site (Figure 31). Field discharge measurements were not taken at high flows, so the high-flow estimates are unreliable; the focus of this study and the calibration of the rating was low-flow and baseflow conditions.

The PTs were installed in early to mid-April 2018 and removed in summer 2020. Water level readings were recorded until mid-December 2019, so it is possible that storms in winter 2020 may have caused some shifts in the flow-depth relationship, although the lack of substantial storms that year makes this unlikely. The PTs also recorded water temperature, shown in Figure 32. Dissolved oxygen data are available by request.

Table 20. Discharges recorded to develop flow time series in Site 1.

Date	Flow (cfs)
4/24/2018	3.2
5/16/2018	1.2
1/10/2019	29.2
1/11/2019	13.8
3/13/2019	21.8
4/23/2019	4.6
6/4/2019	2.7
12/9/2019	5.1

Table 21. Discharges recorded to develop flow time series in Site 2.

Date	Flow (cfs)
4/16/2018	5.3
4/18/2018	3.7
4/25/2018	1.6
5/16/2018	0.8
1/11/2019	10.5
1/18/2019	26.3
1/31/2019	2.2
3/13/2019	12.9
4/23/2019	2.7
6/4/2019	1.4

Table 22. Discharges recorded to develop flow time series in Site 3.

Date	Flow (cfs)
4/17/2018	2.9
4/18/2018	2.6
4/25/2018	1.3
5/16/2018	0.5
1/11/2019	6.8
1/18/2019	16.8
3/14/2019	8.1
4/24/2019	2.0
6/4/2019	1.0

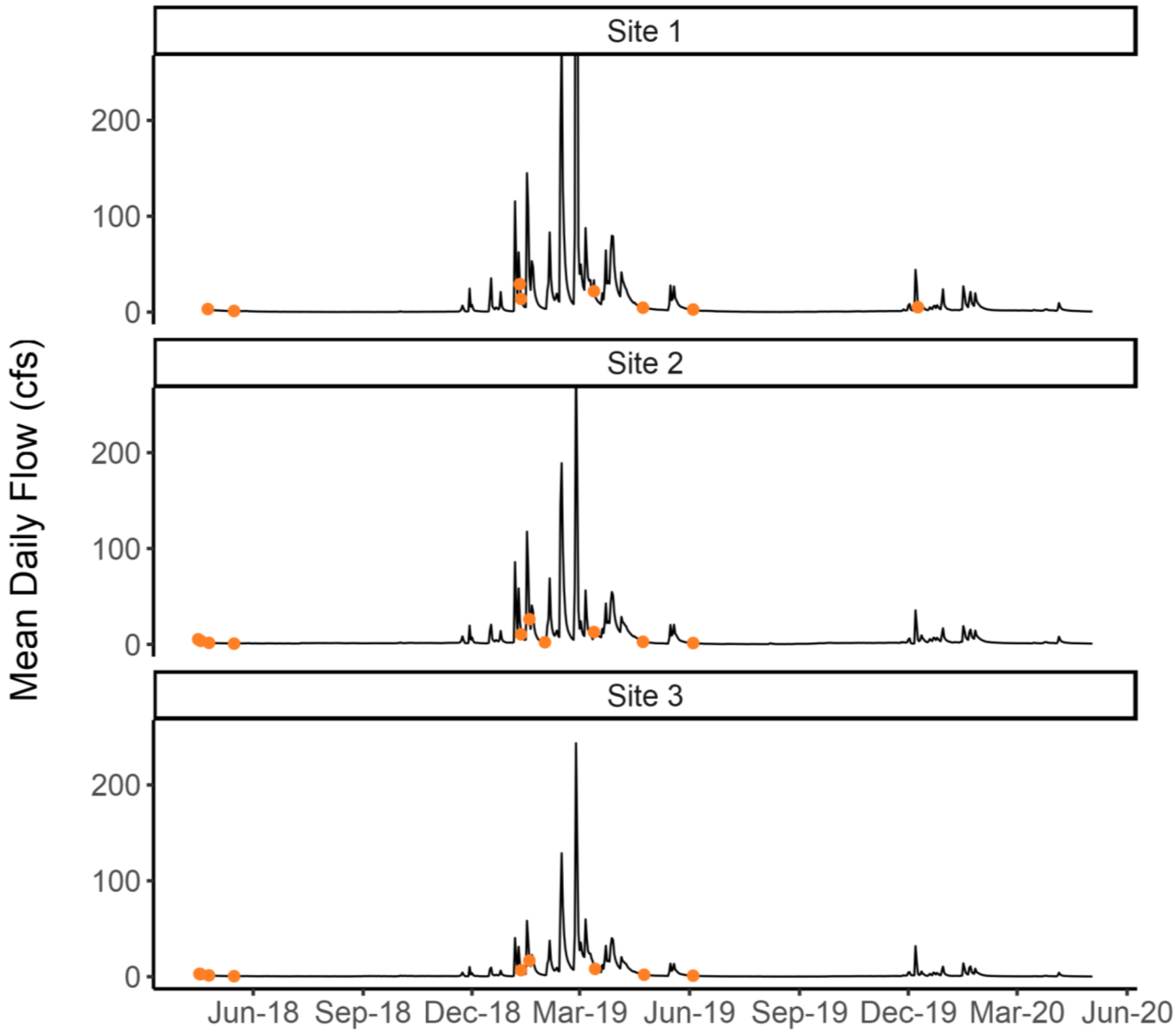

Figure 31. Hydrology data at the three sites. Orange dots represent field discharge measurements. The peak mean daily flow was estimated at 970 cfs for Site 1 and 300 cfs for Site 2, although due to a lack of calibration discharge measurements at this flow, the true flow may have been higher or lower.

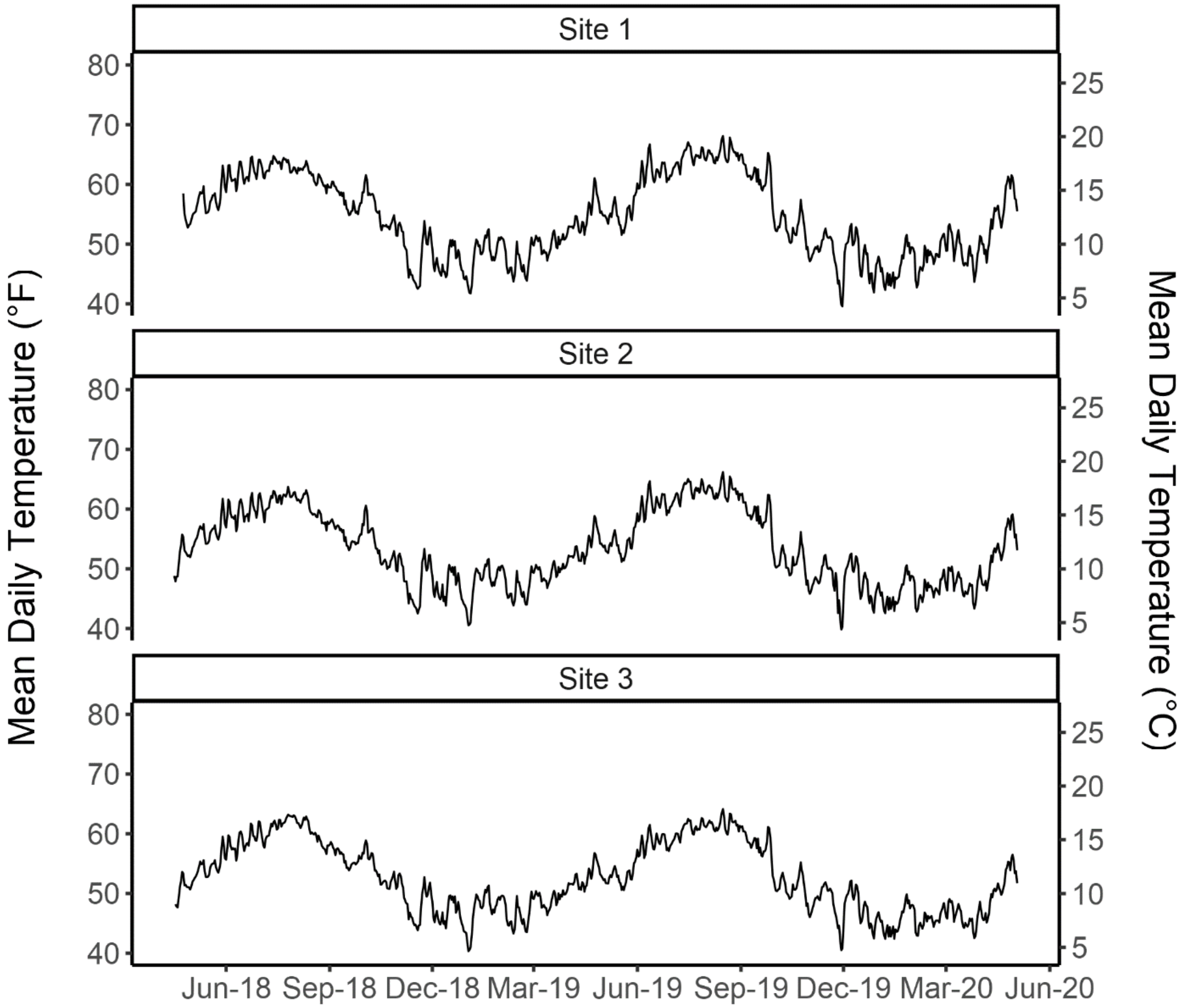

Figure 32. Mean daily temperature time series at the three sites. These data were collected at the same locations as the PT data.

4.7 Field Observations

Examples of study transects in Site 1, Site 2, and Site 3 are provided in the paired figures below (Figure 33–Figure 35). The figures display field conditions at the lower and higher flows surveyed for 2D model development. See Appendix B for additional photographs of the three sites.

Figure 33. Downstream view of Site 1, XS-1 at 4.5 cfs (upper photo, 01/29/2019) and 21.8 cfs (lower photo, 03/13/2019).

Figure 34. Downstream view of Site 2, XS-2 at 2.4 cfs (upper photo, 01/30/2019) and 26.3 cfs (lower photo, 01/18/2019).

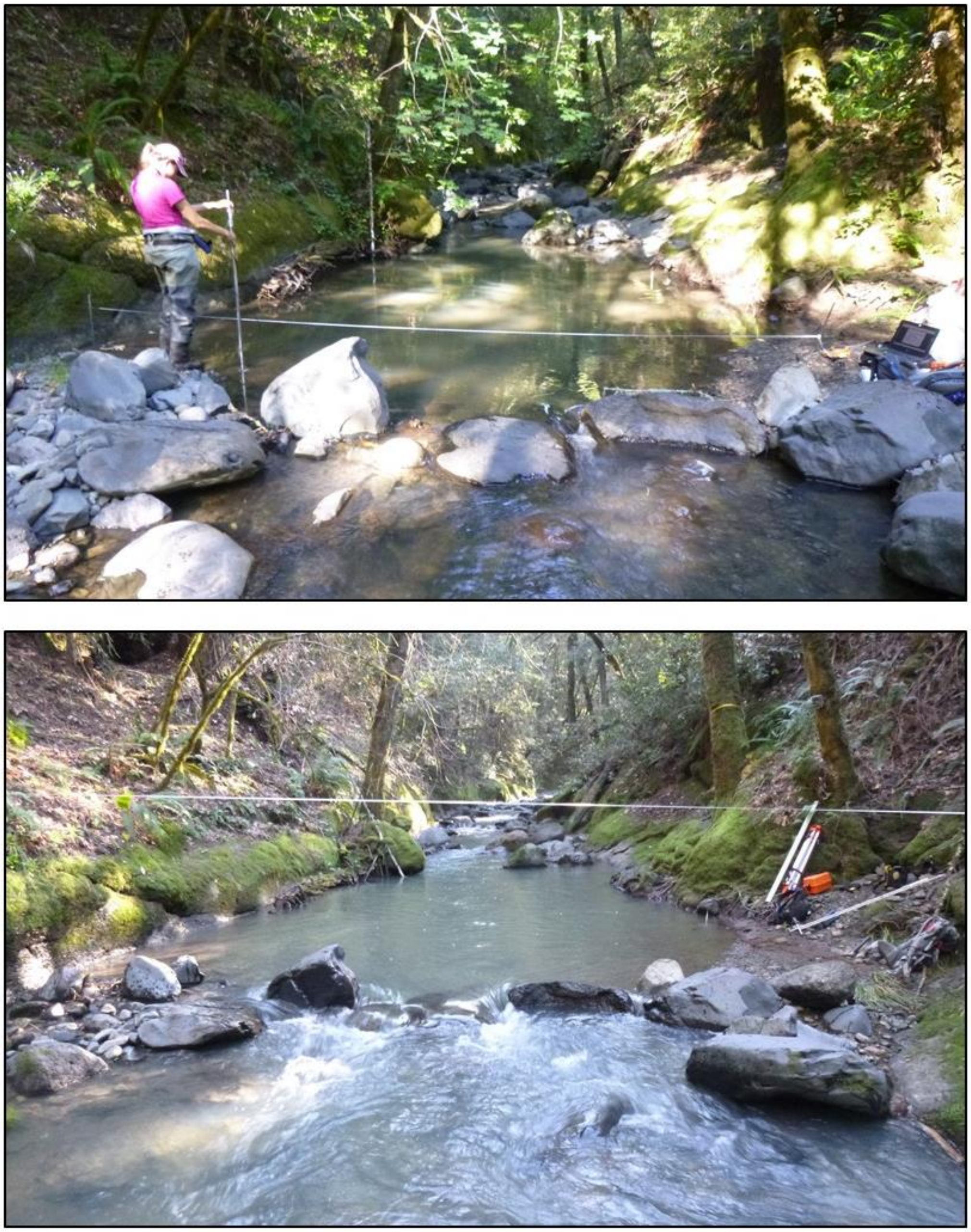

Figure 35. Upstream view of Site 3, XS-1 at 1.0 cfs (upper photo, 06/04/2019) and 8.1 cfs (lower photo, 03/14/2019).

5.0 FLOW CRITERIA

A primary objective for the Mark West Creek watershed is to optimize rearing habitat for the production of fry and juvenile salmonids. Results of the 2D modeling and habitat duration analysis (Table 17–Table 19) presented in this report can be used to achieve this objective because they identify the flows needed in each reach to create suitable hydraulic conditions for rearing juvenile salmonids. Developing flow criteria to inform water management decisions will be an important step to improve stream conditions for salmonid production.

In addition to the habitat duration analysis results presented in this report, water management decisions should consider incorporating the following:

- Functional flow metrics. Additional flows for ecosystem functions are provided in the functional flow metrics (presented in Table 5–Table 10). These flows support a broader set of ecosystem functions that may not be captured by the salmonid rearing flows developed in this report using 2D modeling. In particular, functional flows incorporate information about the magnitude and timing of wet season baseflows, dry season baseflows, fall pulse flows, the spring recession, and winter peak flows (or flood flows).
- Criteria developed in the companion Department Watershed Criteria Report *Watershed-wide Instream Flow Criteria for Mark West Creek* (CDFW 2022). The Watershed Criteria Report presents flow criteria for reaches throughout the watershed using a combination of desktop analyses and field-based methods.
- Unimpaired flow data. Unimpaired flow estimates for the Mark West Creek watershed are being developed by the USGS in an update to the Santa Rosa Plain groundwater-surface water model (Woolfenden and Nishikawa 2014).

Along with the above considerations, climate change could result in a future adjustment to these criteria. The Department is committed to minimizing the effects of climate change on California’s natural resources. Changes in temperature and precipitation could result in alteration to existing freshwater systems and an overall reduced availability of water for fish and wildlife species. Given the uncertainty associated with climate change impacts, the Department may modify the instream flow criteria for the Mark West Creek watershed as the science and understanding of climate change evolves or as new information becomes available.

ACKNOWLEDGEMENTS

We would like to thank Derek Acomb and David Hines of the Department's Bay Delta Region, Paige Uttley of the Department's Water Branch, and local partner agencies for their assistance and guidance with study planning. We would like to thank Jessie Maxfield of the Department's Bay Delta Region and Joseph Kermish-Wells and Elijah Portugal of the Department's Fisheries Branch for providing review of the report. We would also like to thank Rob Sherrick and Mark Gard of the Department's Conservation Engineering Branch for assistance with modeling, data analyses, and data review.

In addition, we would like to thank several members of the Department's Instream Flow Program. Hanna Casares, Brionna Drescher, Danielle Elledge, Mike Hancock, Michael Maher, and Lanette Richardson assisted with field data collection. Sam Larkin, Hanna Casares, Diane Haas, and Lanette Richardson helped review, edit, and finalize the report.

Finally, we extend a special thanks to the landowners who granted access to their property to allow Department staff to conduct fieldwork, without which we would have been unable to complete this study.

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