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

INSTREAM FLOW EVALUATION: JUVENILE STEELHEAD AND COHO SALMON REARING IN REDWOOD CREEK, HUMBOLDT COUNTY

STREAM EVALUATION REPORT 2021–04

OCTOBER 2021

Cover photo: Lower China Creek (transect LCT32) 4/20/2016, Humboldt County.

California Department of Fish and Wildlife
Stream Evaluation Report 2021–04

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Water Branch
Instream Flow Program
Stream Evaluation Report 2021–04

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PREFACE

The South Fork Eel River is the most productive subwatershed in the Eel River basin for salmonids and other anadromous fish (USBLM and USFWS 1996). The South Fork Eel River watershed contains important spawning and rearing habitat for Northern California anadromous Rainbow Trout (*Oncorhynchus mykiss*), commonly known as steelhead; Southern Oregon/Northern California Coast Coho Salmon (*O. kisutch*); and fall-run California Coastal Chinook Salmon (*O. tshawytscha*; CDFW 2014). It was also identified as a priority stream under the California Water Action Plan (CWAP), 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 Four of the CWAP, the California Department of Fish and Wildlife (Department) and the State Water Resources Control Board (State Water Board) were directed to implement actions to enhance instream flows within five priority stream systems that support critical habitat for anadromous fish. The South Fork Eel River was selected as one of these five streams. The Department selected Redwood Creek watershed, tributary to the South Fork Eel River, for evaluation because of its high biological resource value, potential for species recovery, and competing water needs.

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, plant species, and natural communities for their intrinsic and ecological value and their use and enjoyment by the public. The Department 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 CWAP in the South Fork Eel River watershed, the Department has conducted an instream flow study in Redwood Creek, tributary to the South Fork Eel River, and produced two reports: this report, as well as a watershed-wide flow criteria report. The study described in this report evaluates flows for maintaining ecological condition and juvenile steelhead and Coho Salmon rearing habitat in the Redwood Creek watershed. This technical report describes data collection efforts and the resulting flow-ecology relationships developed for juvenile steelhead and Coho Salmon for Redwood Creek and selected tributaries. The results of this study, along with other supporting information and data, are intended to be used to identify instream flow needs for rearing anadromous salmonids and long-term stream ecosystem health in the Redwood Creek watershed.

To fulfill obligations under the CWAP, the State Water Board is developing a groundwater-surface water model. The groundwater-surface water 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 Board's groundwater-surface water model will be essential to enhancing instream flows and informing water management within the South Fork Eel River watershed.

Specific details regarding planning, data analysis, modeling, and related studies used to support the development of flow criteria can be found in several companion Department documents. The goals and objectives of this study can be found in the *Study Plan: Habitat and Instream Flow Evaluation for Anadromous Salmonids in the South Fork Eel River and Tributaries, Humboldt and Mendocino Counties* (CDFW 2016). The development of an unimpaired flow record is presented in *Flow Monitoring and Unimpaired Flow Estimation Report for Redwood Creek, Humboldt County* (Cowan 2018). The hydraulic models used in this study are presented in *Hydraulic Model Calibration Report for Instream Flow Evaluation: Juvenile Steelhead and Coho Salmon Rearing in Redwood Creek, Humboldt County* (Cowan 2021). Steelhead preference curves were developed in *Habitat Suitability Criteria for Juvenile Salmonids in the South Fork Eel River Watershed, Mendocino and Humboldt Counties* (Gephart et al. 2020). Additional flow criteria for the South Fork Eel River watershed are presented in *Watershed-Wide Instream Flow Criteria for the South Fork Eel River* (CDFW 2021b).

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ABBREVIATIONS AND ACRONYMS

1D	one-dimensional (hydraulic model)
AWS	area-weighted suitability
cfs	cubic foot (feet) per second
cm	centimeter(s)
COMID	common identifier (as used by USGS National Hydrography Dataset)
CWAP	California Water Action Plan
Department	California Department of Fish and Wildlife
ESA	Endangered Species Act
ft	foot (feet)
ft^2	square foot (feet)
HSC	habitat suitability criteria
IFIM	Instream Flow Incremental Methodology
mi	mile(s)
mi^2	square mile(s)
SEFA	System for Environmental Flow Analysis (software)
SONCC	Southern Oregon/Northern California Coast (Coho Salmon)
State Water Board	State Water Resources Control Board
USGS	United States Geological Survey

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 mile ≈ 1.61 kilometers
1 square mile ≈ 2.59 square kilometers

1.0 INTRODUCTION

The South Fork Eel River watershed is a critical salmonid resource on California's north coast. The South Fork Eel River flows north nearly 104 stream miles (mi) through Mendocino and Humboldt counties from Laytonville, California to its confluence with the Eel River, approximately 40 mi upstream from the Pacific Ocean. The South Fork Eel River is currently one of the largest producers of wild Pacific salmonids in California (CDFW 2014). Populations include Northern California anadromous Rainbow Trout (*Oncorhynchus mykiss*), commonly known as steelhead; Southern Oregon/Northern California Coast (SONCC) Coho Salmon (*O. kisutch*); and fall-run California Coastal Chinook Salmon (*O. tshawytscha*). SONCC Coho Salmon are currently listed as "threatened" pursuant to both the federal Endangered Species Act (ESA; 62 Federal Register 33038) and the species is listed under the California ESA (14 California Code of Regulations §670.5). Both Northern California steelhead and fall-run California Coastal Chinook Salmon are listed as "threatened" pursuant to the federal ESA (64 Federal Register 72960; 65 Federal Register 36074).

California's north coast maintains the most abundant steelhead populations and largest amount of remaining steelhead habitat in the state (CDFG 1996), and the Eel River watershed sustains both summer and winter-run Northern California steelhead (Yoshiyama and Moyle 2010). However, population estimates show that steelhead populations are below their established viability targets (NMFS 2016). Salmonid recovery within the South Fork Eel River watershed will require multiple restoration and conservation strategies, addressing land use impacts, riparian cover, instream habitat quality, flow, and headwater access (CDFG 1996; NMFS 2014).

In California, SONCC Coho Salmon abundance has undergone a minimum 70% decline since the 1960s; current abundance is at 6 to 15% of 1940s estimates (CDFG 2004). Although the Eel River watershed was historically a prolific breeding ground for Coho Salmon, the number of independent Coho Salmon populations present have decreased and are continuing to decline (Yoshiyama and Moyle 2010). The South Fork Eel River population of SONCC Coho Salmon has also declined but is believed to be the only population within the Eel River watershed not suffering from reproductive failure due to extreme scarcity of spawning adults (NMFS 2014).

Fall-run California Coastal Chinook Salmon inhabit streams from Redwood Creek near Orick in Humboldt County south to the Russian River in Sonoma County. The Eel River and the Russian River are the two largest watersheds inhabited by California Coastal Chinook Salmon and likely hold the largest populations (CDFW 2016). However, the quality and quantity of California Coastal Chinook Salmon population data are very limited, which has made it difficult to establish population status and trends (CDFW 2016). As California Coastal Chinook Salmon are typically only present in the Redwood

Creek watershed for a few months and do not oversummer[a], they will not be evaluated in this study.

Redwood Creek was identified by the Department as a stream of significant value for salmonid recovery in the South Fork Eel River watershed and consequently in northern California. It was selected for a site-specific instream flow study because of several factors including: the high potential for flow improvement based on the number and type of anticipated water right and permit requests; the generally positive landowner attitudes within the watershed toward watershed improvements; and the existence of historical stream habitat inventories confirming the presence of juvenile salmonids within the watershed.

1.1 Study Goals and Objectives

The goal of this study is to determine flow-habitat relationships for juvenile Coho Salmon and steelhead in the Redwood Creek watershed. The objectives of this study include the following:

1. Estimate of unimpaired flow for Redwood Creek and its tributaries;
2. Development and calibration of predictive hydraulic models for the Redwood Creek watershed;
3. Measurement of representative hydraulic habitat in Redwood Creek and its major tributaries at a minimum of three distinct flows;
4. Development of area-weighted suitability (AWS) projections for juvenile steelhead and Coho Salmon in the watershed by combining the hydraulic models with regionally specific habitat suitability curves; and
5. Development of habitat duration time series by month for three water month types.

This report focuses on data collection, development of AWS projections, and habitat duration time series (objectives three through five). The generation and validation of an unimpaired hydrologic record for Redwood Creek is described in the *Flow Monitoring and Unimpaired Flow Estimation Report for Redwood Creek, Humboldt County* (Cowan 2018) referred to here as the Flow Report. The development and calibration of hydraulic models and data quality validation procedures are covered in the *Hydraulic Model Calibration Report for Instream Flow Evaluation: Juvenile Steelhead and Coho Salmon*

[a] Renger, A., Department Northern Region Senior Environmental Scientist Supervisor, personal communication May 6, 2019.

Rearing in Redwood Creek, Humboldt County (Cowan 2021) referred to here as the Calibration Report. Additionally, the development of the biological component of the study—habitat suitability criteria (HSC)—was discussed in *Habitat Suitability Criteria for Juvenile Salmonids in the South Fork Eel River Watershed, Mendocino and Humboldt Counties* (Gephart et al. 2020).

2.0 DESCRIPTION OF STUDY AREA

Redwood Creek flows into the South Fork Eel River (Figure 1), which has both State (Public Resources Code §5093.5-5093.71) and Federal (46 Federal Register 7484) designations as a wild and scenic river. Rivers categorized as wild and scenic have exceptional natural, cultural, or recreational values and should be preserved in a free-flowing condition for current and future generations.

Within the 26 square mile (mi^2) watershed, Redwood Creek receives flow from multiple tributaries including Upper Redwood (also known as Pollock), Seely, Somerville, Miller, and China creeks (USGS 2018). Redwood Creek flows east from its headwaters, located west of the town of Briceland, to its confluence with the South Fork Eel River, near the town of Redway. According to United States Geological Survey (USGS) topographic maps, the Redwood Creek drainage ranges from ~250 feet (ft) in elevation at its confluence with the South Fork Eel River to ~1,200 ft at its uppermost extent. Mixed hardwood and mixed conifer trees are prevalent throughout the watershed (CDFG 2009a). With the exception of the John B. Dewitt Redwoods State Natural Reserve lands at the confluence of Redwood Creek and the South Fork Eel River, the watershed is privately owned and contains rural subdivisions (CDFG 2009a) and sections managed for timberland (CDFG 2009b).

Environmental impacts associated with historical and current land use continue to affect the study area. Timber harvesting and associated impacts due to logging road construction have been documented throughout the Eel River watershed (Klein and Ozaki 2016; Klein 2011). Road placement can trigger increased runoff and lead to increased sedimentation within nearby creeks (NCRWQCB 2005). In addition, the conversion of forest for cannabis cultivation has led to reductions in flow, which can lead to an increase in temperature and an associated reduction in dissolved oxygen (Bauer et al. 2015).

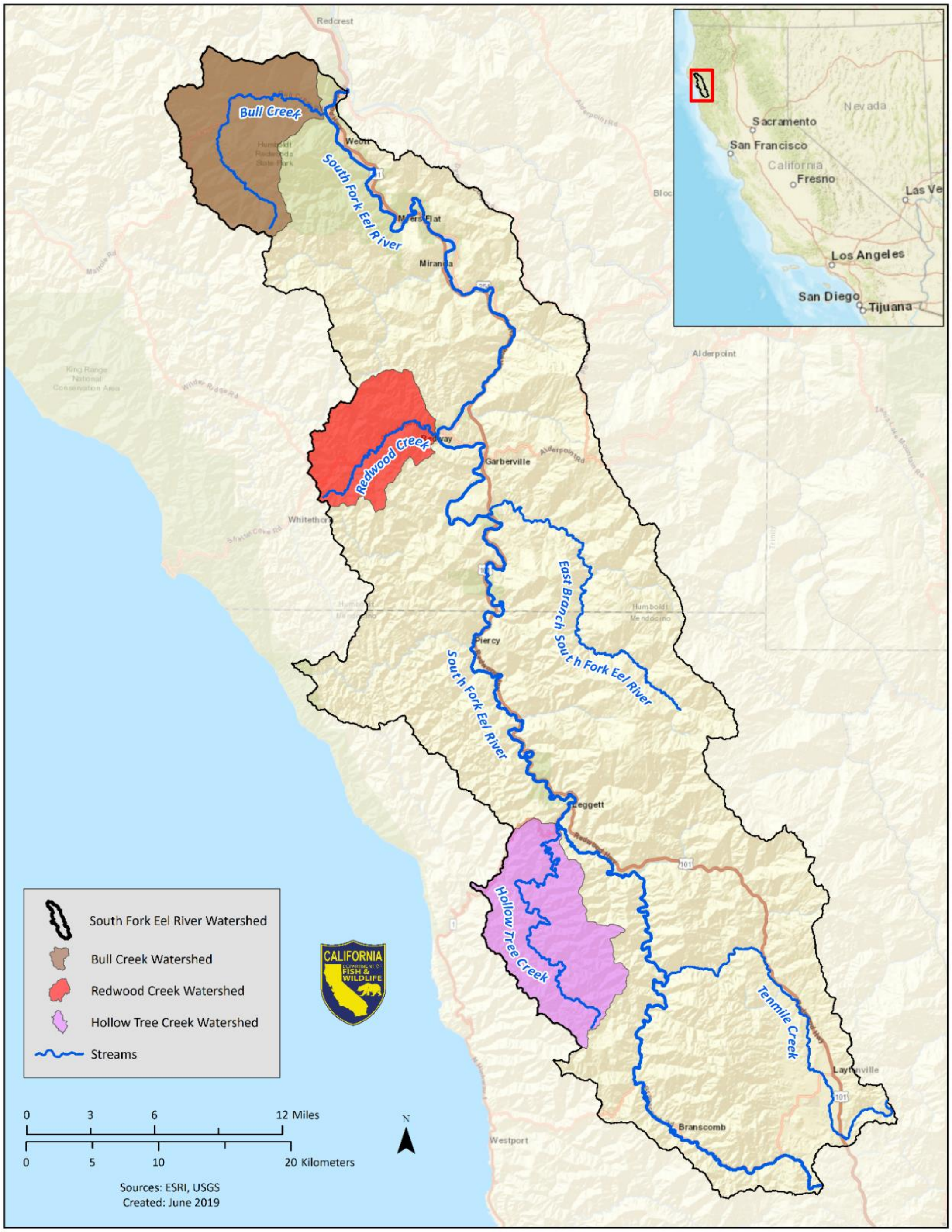

Figure 1. Map of the South Fork Eel River watershed showing major tributaries and study subwatersheds. Redwood Creek is the focus of this report. Gage data from Bull Creek were used in the flow report (Cowan 2018), and fish preference data (habitat suitability criteria) were collected in Hollow Tree Creek (Gephart et al. 2020).

Although Coho Salmon, Chinook Salmon, and steelhead are the focus of this study, many other species are found in the South Fork Eel River and Redwood Creek. Fish species native to the Redwood Creek watershed include Humboldt Sucker (*Catostomus occidentalis humboldtianus*), Threespine Stickleback (*Gasterosteus aculeatus*), and Western Brook Lamprey (*Lampetra richardsoni*; Bell et al. 2014). Fish species native to the South Fork Eel River include Coastrange Sculpin (*Cottus aleuticus*), Prickly Sculpin (*Cottus asper*), and Pacific Lamprey (*Lampetra tridentata*; Brown and Moyle 1997). Amphibian and reptile species found in the South Fork Eel River include Coastal Giant Salamander (*Dicamptodon tenebrosus*; CDFW 2019b), Red-bellied Newt *(Taricha rivularis*; CDFW 2019a), Western Toad (*Anaxyrus boreas*; BLM 1990), Northern Red-legged Frog (*Rana aurora*; BLM 1990), Foothill Yellow-legged Frog (*Rana boylii*; CDFW 2019c), Pacific Treefrog (*Pseudacris regilla*; BLM 1990), and Western Pond Turtle (*Actinemys marmorata*; CDFW 2019c).

2.1 Salmonids[b]

Steelhead, Coho Salmon, and Chinook Salmon all spawn in Redwood Creek. Juvenile steelhead and Coho Salmon also oversummer in Redwood Creek, while Chinook Salmon smolts typically leave the Redwood Creek watershed by the end of spring (CDFW 2016). Although timing varies year to year, steelhead, Coho Salmon, and Chinook Salmon in the Redwood Creek watershed each follow a largely predictable life cycle (Figure 2).

Most steelhead in the Eel River watershed are winter-run steelhead (Yoshiyama and Moyle 2010). Adult steelhead typically enter the Redwood Creek watershed late December through April, with a shorter peak migration window (January and February). Eggs generally take about 30 days to hatch, and fry emergence occurs four to six weeks later (CDFG 1996). Most juvenile steelhead rear for one to two years in freshwater before they emigrate to the ocean. Adults return up to four years later to spawn (NMFS 2013).

Adult Coho Salmon in the Eel River commonly begin upstream migration from November to January. In general, egg deposition for Coho Salmon occurs from late

[b] Unless otherwise referenced, adult migration timing is from personal communications with Department staff Allan Renger, May 6, 2019, David Kajtaniak March 25, 2021, and Christopher Loomis, March 18, 2021; Sproul Creek and Hollow Tree spawning ground surveys 1988 to 2016; and South Fork Eel River basin spawning ground surveys, 2010 to 2016. Spawning timing is from personal communications with David Kajtaniak, March 25, 2021, and Christopher Loomis, March 18, 2021. Egg deposition timing from David Kajtaniak, April 8, 2021.

November into February. Coho migration into the Redwood Creek watershed begins in November and ends in March with the peak migratory period in December and January. Spawning in the watershed peaks in January and ends in early February. Eggs incubate in the gravels from November through April with fry emergence occurring between March and July. Coho Salmon generally rear for an entire year in freshwater before migrating downstream to the ocean in late March or early April of the subsequent year. Peak outmigration generally occurs from April to early June (CDFW 2021a).

Fall-run adult California Coastal Chinook Salmon begin migration into the Redwood Creek watershed from October to February with peak migration occurring in November and December. Typically, juvenile Chinook Salmon outmigrate as smolts during the first spring/summer after hatching and spend one to five years in the ocean before returning to spawn (CDFW 2016). Except for occasional drought years, juveniles do not oversummer in Redwood Creek[c]. For this reason, juvenile Chinook Salmon were not evaluated in this study. However, flows protective of juvenile Northern California steelhead and Coho Salmon rearing habitat are expected to be protective of juvenile Chinook Salmon outmigration.

[c] Renger, A., Department Northern Region Senior Environmental Scientist Supervisor, personal communication May 6, 2019.

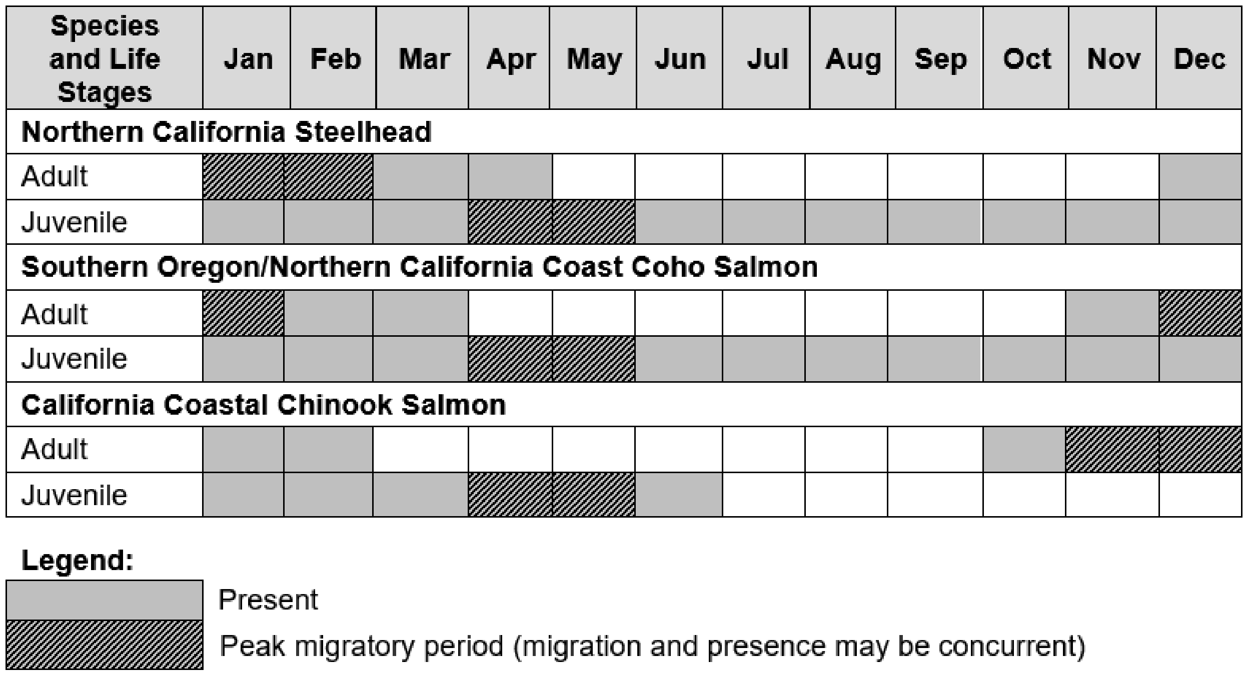

Figure 2. Species and life stage periodicity in the Redwood Creek watershed.[d]

2.2 Hydrology

The Redwood Creek watershed does not have any large-scale diversion structures, reservoirs, or pumping facilities. However, there are nearly 200 active water diversions registered by the State Water Board within the watershed (California State Water Resources Control Board 2021). In addition to registered diversions, multiple small unregulated diversions within the watershed have a significant impact on available surface flow and the aquatic species it supports. This is especially true on the many smaller tributaries during the summer low-flow period (Bauer et al. 2015). Depending on timing and water availability, studies have shown that pumping to support daily water demand for cannabis cultivation requires an estimated 34–165% of the annual seven-day low flow within the Redwood Creek watershed (Bauer et al. 2015). Low flow monitoring conducted by the Salmonid Restoration Federation shows that most of the tributaries in the Redwood Creek watershed are disconnected by the end of the summer, with at least one occurrence associated with pumping (Nystrom 2020).

[d] Adult migration data from personal communication with Allan Renger, May 6, 2019; Sproul Creek and Hollow Tree spawning ground surveys 1988 to 2016 and South Fork Eel River basin spawning ground surveys, 2010 to 2016. Juvenile migration is based on South Fork Eel River downstream migrant trapping, 2015.

Decreased flow and the dewatering of streams within the watershed can prevent migration and diminish or even eliminate juvenile and adult salmonid habitat, thus increasing mortality (CDFG 2004).

This report was informed by an understanding of current conditions, based on temporary gages, and reference hydrology, based on a nearby reference stream and the Natural Flows Database (Zimmerman et al. 2018a). Reference hydrology is particularly useful as a baseline for comparison because it represents conditions that should fully support a healthy ecological community. Each of these datasets is described below.

Datasets

Current conditions were evaluated using pressure transducers, which act as temporary stream gages. These temporary gages and barometric pressure loggers (barologgers) were installed at several locations throughout the watershed to measure water pressure and air pressure, respectively, to enable an estimate of water depth (stage) and flow (Figure 3). Analysis of this dataset is presented in the accompanying Flow Report (Cowan 2018). Although not analyzed as part of this study, the installed pressure transducers simultaneously measured and recorded water temperature data, which is available upon request.

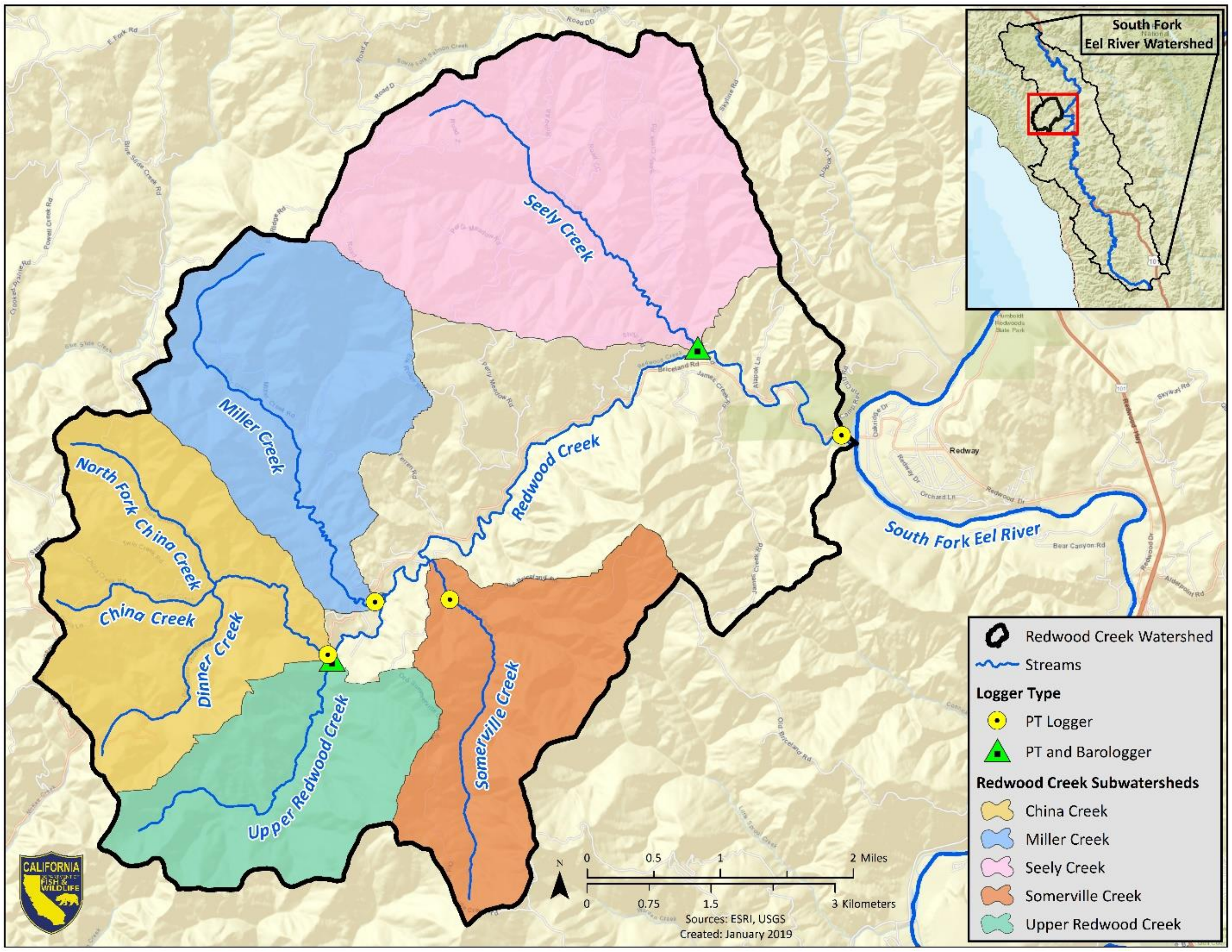

Figure 3. Barologger and pressure transducer (PT) locations within the study area.

Estimated unimpaired flow was assessed using the Natural Flows Database, which estimates unimpaired monthly flow over a 65-year period of record for every reach in the state (Zimmerman et al. 2018a; Zimmerman et al. 2018b). 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 specific to each reach over the entire period of record were used in the habitat duration time series analysis (Section 3.4). A list of USGS NHDPlus common identifiers (COMIDs) corresponding to each reach that were used to obtain flow data are available in Appendix C.

Although these monthly estimates are helpful for estimating typical water availability, they obscure important daily variation. Daily flow variation in the Redwood Creek watershed was estimated using scaled flow data based on a nearby long-term reference gage in Bull Creek, as described in Cowan (2018). Gage data were scaled by comparing drainage area and mean annual precipitation. The Bull Creek watershed (Figure 1) was used as a reference watershed to assess daily flow variation because of its proximity to Redwood Creek, limited number of water diversions, and similarities in drainage area size, soil profile, and meteorological patterns. Bull Creek has a gage covering 57 years continuously, from water year 1961 through water year 2018 (USGS 11476600 Bull Creek near Weott CA, or Station 11476600)[e].

In addition to these datasets, predicted functional flow metrics are also available for the Redwood Creek watershed and can provide helpful information on the timing, magnitude, and duration of key functional flows under natural conditions (California Environmental Flows Working Group 2020; CDFW 2018). The functional flows approach is being developed through a collaborative process under the Environmental Flows Technical Workgroup, a subgroup of the California Water Quality Monitoring Council[f]. This group is currently preparing to release a detailed guidance document describing the California Environmental Flows Framework, which helps water managers develop ecological and environmental 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). The California Environmental Flows Framework provides guidance on using functional flows to evaluate ecological needs and develop environmental flow recommendations.

The State Water Board is currently developing a model that will describe unimpaired flow for Redwood Creek, as well as the rest of the SF Eel River watershed (Paradigm Environmental 2018). When available, the results of that model should be considered along with these datasets.

Reference Hydrology

The hydrology of Redwood Creek is characterized by low summer flows and frequent high-flow storm events in the winter, consistent with other north coast streams. To illustrate these patterns, the scaled daily flow estimates derived from the Bull Creek record are presented in three ways below. First, estimated mean daily flows in cubic feet per second (cfs) for Lower Redwood Creek are presented in Figure 4. Second, Figure 5 presents daily exceedance flows, based on a flow duration analysis. Flow duration analysis estimates the probability that a stream discharge is equaled or exceeded over the entire period of record (CDFW 2013b). This likelihood is expressed as a percent exceedance probability, and the discharge associated with that probability is referred to as an exceedance flow. Exceedance flows were calculated using the

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[e] Gage USGS 11476600 was reactivated on February 28. 2020.

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

Standard Operating Procedure for Flow Duration Analysis in California (CDFW 2013b). Finally, the process was repeated to calculate monthly exceedance values, which show the likelihood of a particular flow occurring in any given month (Table 1).

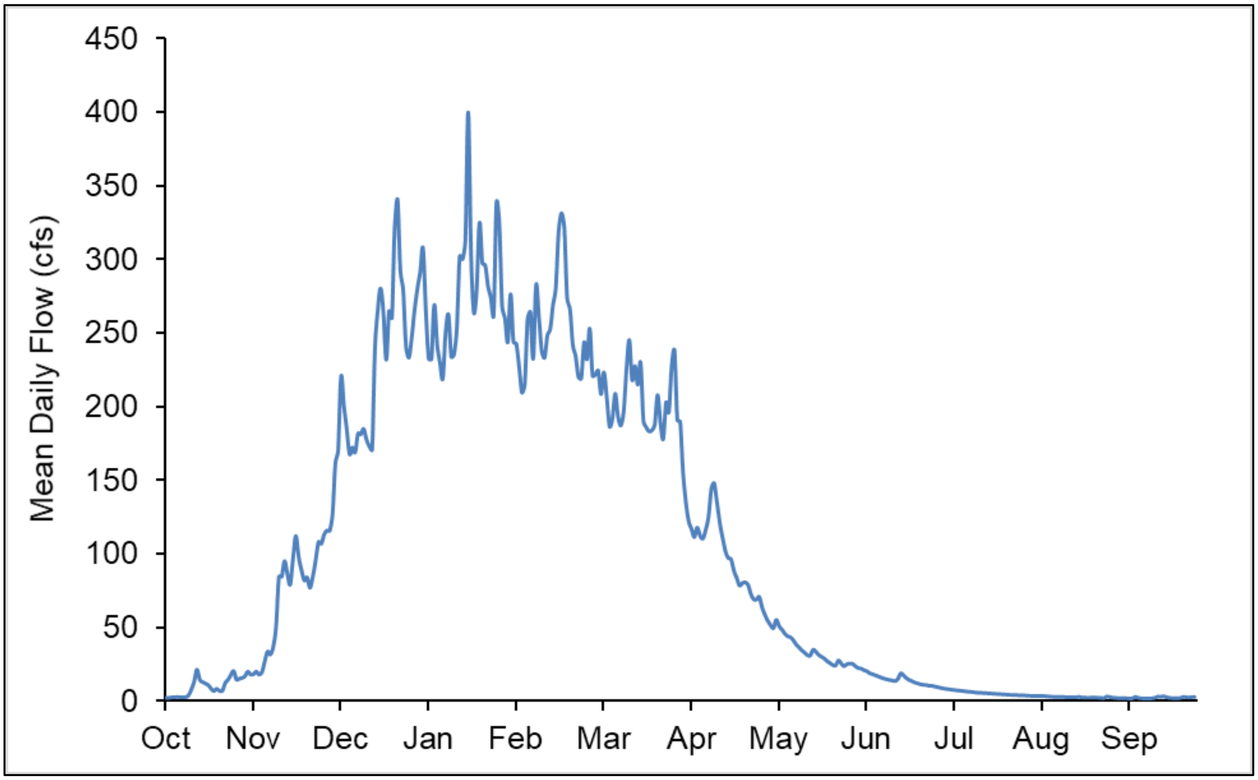

Figure 4. Estimated mean daily flow for Lower Redwood Creek scaled from the daily flow record for Station 11476600 from October 1, 1960, to September 30, 2017.

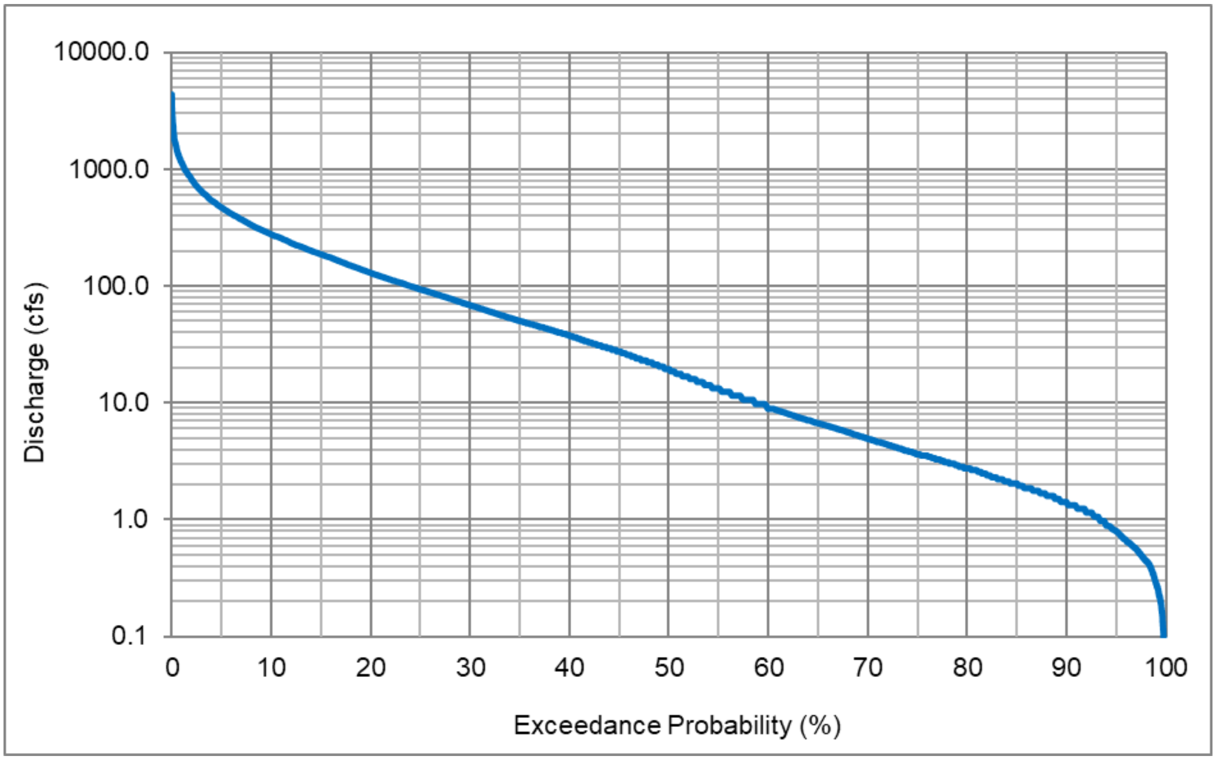

Figure 5. Estimated Lower Redwood Creek exceedance flows. Lower Redwood Creek results are scaled from the daily flow record for Station 11476600 on Bull Creek from October 1, 1960, to September 30, 2017.

Table 1. Estimated Lower Redwood Creek monthly exceedance flows (cfs) scaled from the daily flow record for Station 11476600 from October 1, 1960, to September 30, 2017.

Exceedance	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
90%	25.7	33.7	41.5	24.8	12.2	5.5	2.0	0.6	0.4	0.6	2.7	5.8
80%	43.5	53.1	58.2	30.9	15.1	7.1	2.8	1.1	0.6	1.0	3.8	26.6
70%	62.1	74.9	78.1	37.3	17.7	8.4	3.5	1.5	0.8	1.2	5.2	51.4
60%	93.1	105.6	99.3	47.0	20.8	9.8	4.2	1.9	1.1	1.6	7.5	76.3
50%	132.2	139.3	125.1	60.3	24.0	10.6	5.0	2.2	1.3	2.2	12.9	112.7
40%	196.0	191.6	163.2	78.9	29.3	12.4	5.9	2.7	1.6	3.0	24.5	164.1
30%	276.8	267.9	213.8	105.6	36.8	15.1	6.7	3.2	2.0	3.9	45.2	226.2
20%	408.9	392.1	290.1	148.1	47.0	17.7	7.9	3.8	2.3	6.3	86.9	333.5
10%	674.1	620.0	441.7	228.9	71.0	26.6	9.8	4.8	3.4	18.2	218.2	585.4

To evaluate monthly flow variability, the 50% exceedance (or median) flow was calculated using estimated unimpaired flow from the Natural Flows Database (Zimmerman et al. 2018a) for three water month types: dry, moderate, and wet. Water month types were defined using exceedance percentage ranges for each month: 100–70.01%, 70–30.01%, and 30–0%, respectively. First, mean monthly flows were used to assign water month types. Next, predicted median monthly flows were used to calculate the median monthly flow value for each water month type over the period of record. The median monthly flow for a given water month type represents the typical flow value within Redwood Creek for each month. Examples are presented in Table 2 and Table 3 for two reaches within the watershed. One water year may contain several different water month types depending on timing of precipitation.

Table 2. Lower Redwood Creek estimated median monthly discharge (cfs) by water month type using the Natural Flow Database estimates for COMID 8285238 from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2018a).

Water Month Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry	26	54	58	30	14	8	3	2	2	2	4	12
Moderate	90	119	89	45	21	11	4	2	2	2	10	57
Wet	244	202	149	117	44	18	8	4	3	5	38	168

Table 3. Somerville Creek estimated median monthly discharge (cfs) by water month type, using the Natural Flow Database estimates for COMID 8285288, at the confluence with Redwood Creek, from October 1, 1950, to September 30, 2015 (Zimmerman et al. 2018a).

Water Month Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry	4	6	7	4	2	1	<1	<1	<1	<1	1	1
Moderate	12	16	12	6	3	1	1	<1	<1	<1	1	7
Wet	29	25	20	16	6	2	1	1	<1	1	5	25

Reference flow estimates presented here do not incorporate expectations about future shifts in hydrology under climate change. In Redwood Creek, intensifying climate change is expected to result in warmer temperatures, increased storm intensity, a shorter wet season, and reduced summer streamflow (Grantham 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 demand for water resources, and resulting loss of habitat for cold water fishes, including salmonids.

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). Peak flows of varying magnitudes in the South Fork Eel River watershed (e.g., two-, five-, and ten-year recurrence interval floods, defined as 50%, 20% and 10% exceedance peak flow events) scour and reshape the channel, recruit wood, redistribute sediment, and alter aquatic community composition to maintain diverse aquatic food webs over time (Power et al. 2008; Power et al. 2015). Wet-season baseflows are elevated following storms 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 prevents stranding of aquatic species and promotes survival of riparian vegetation (Kupferberg et al. 2012). 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 (Power et al. 2015). Variation both within and between years is a key component of the functional flows (Yarnell et al. 2015).

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. (2018b) 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 analysis, water year types were defined using the following exceedance percentage ranges: 100–66.68%, 66.67–33.34%, and 33.33–0%, for dry, moderate, and wet year types, respectively. These seasonal functional flow metrics were calculated for each water year type to illustrate interannual variation in flow. Peak flow metrics were not calculated by water year type, and instead are presented for all years.

Predicted functional flow metrics for Lower Redwood Creek and Somerville Creek are provided in Table 4 through Table 7 for three water year types and predictions for Lower Redwood Creek are also shown in Figure 6. Predictions for the remaining eight study reaches are provided in Appendix D. After careful evaluation of functional flows compared to the gaged flows at Bull Creek, it was determined that in this rain-driven system the predicted spring start magnitude reflects the final storm of the wet season, rather than the start of the spring baseflow recession[7]. The median wet-season flow was determined to be a better representation of spring flows at the beginning of the spring recession and was substituted for the spring recession start magnitude in Figure 6.

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[7] By contrast, in snowmelt systems this final pulse flow of the winter does typically reflect the beginning of the snowmelt-driven spring recession.

Table 4. Predicted functional flow metrics for Lower Redwood Creek by water year type. Values represent median predictions within each water year type, with 10th–90th percentile ranges in parentheses. Functional flow metrics with asterisks (*) are not dependent on water year type. Fall pulse flows may not occur every year. Data from the Natural Flows Database, COMID 8285238 (California Environmental Flows Working Group 2020).

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Fall pulse flow magnitude (cfs)	30 (11–124)	23 (8–90)	17 (6–82)
Fall pulse flow duration (days)*	3 (2–7)	3 (2–7)	3 (2–7)
Fall pulse flow timing	Oct 19 (Oct 6–Oct 30)	Oct 20 (Oct 8–Nov 9)	Oct 25 (Oct 5–Nov 3)
Median wet-season flow magnitude (cfs)	136 (77–244)	87 (47–171)	53 (26–99)
Wet-season baseflow magnitude (cfs)	44 (22–88)	35 (17–66)	16 (7–34)
Wet-season duration (days)	148 (103–180)	135 (85–176)	129 (77–170)
Wet-season start timing	Nov 21 (Nov 6–Dec 8)	Nov 27 (Nov 15–Dec 14)	Nov 29 (Nov 7–Jan 6)
Spring recession start magnitude (cfs)	377 (128–1,080)	240 (96–799)	196 (54–573)
Spring recession duration (days)	39 (26–73)	42 (26–77)	48 (27–94)
Spring recession start timing	Apr 16 (Mar 23–May 2)	Apr 15 (Mar 14–May 3)	Apr 5 (Mar 12–May 9)
Spring recession rate of change (%)*	6 (3–10)	6 (3–10)	6 (3–10)
Dry-season baseflow magnitude (cfs)	4 (2–8)	4 (2–6)	3 (1–5)

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Dry-season duration (days)	183 (143–229)	177 (143–227)	181 (131–226)
Dry-season start timing	May 25 (May 4–Jul 18)	May 30 (May 5–Jun 22)	Jun 1 (Apr 24–Jun 30)

Table 5. Predicted peak functional flow metrics for Lower Redwood Creek by yearly intervals. Values represent median predictions with 10^{th}–90^{th} percentile ranges in parentheses. Peak flows may not occur every year. Data from the Natural Flows Database, COMID 8285238 (California Environmental Flows Working Group 2020).

Functional Flow Metric	All Years
2-year peak flow magnitude (cfs)	1,760 (1,340–2,390)
2-year peak flow days/year when present	3 (1–19)
2-year peak flow events/year when present	2 (1–5)
5-year peak flow magnitude (cfs)	2,520 (1,770–3,890)
5-year peak flow days/year when present	2 (1–6)
5-year peak flow events/year when present	1 (1–3)
10-year peak flow magnitude (cfs)	3,250 (2,050–4,120)
10-year peak flow days/year when present	2 (1–3)
10-year peak flow events/year when present	1 (1–2)

Table 6. Predicted functional flow metrics for Somerville Creek by water year type. Values represent median predictions within each water year type, with 10th–90th percentile ranges in parentheses. Functional flow metrics with asterisks (*) are not dependent on water year type. Fall pulse flows may not occur every year. Data from the Natural Flows Database, COMID 8285288 (California Environmental Flows Working Group 2020).

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Fall pulse flow magnitude (cfs)	4 (1–17)	3 (1–11)	2 (1–12)
Fall pulse flow duration (days)*	3 (2–7)	3 (2–7)	3 (2–7)
Fall pulse flow timing	Oct 22 (Oct 7–Nov 3)	Oct 23 (Oct 8–Nov 13)	Oct 22 (Oct 7–Nov 5)
Median wet-season flow magnitude (cfs)	22 (11–33)	13 (7–25)	8 (4–13)
Wet-season baseflow magnitude (cfs)	6 (3–11)	5 (2–8)	2 (1–4)
Wet-season duration (days)	147 (94–178)	142 (79–171)	123 (75–159)
Wet-season start timing	Nov 25 (Nov 9–Dec 10)	Nov 25 (Nov 7–Dec 16)	Dec 3 (Nov 8–Jan 2)
Spring recession start magnitude (cfs)	44 (17–164)	34 (14–103)	27 (8–74)
Spring recession duration (days)	44 (29–114)	47 (30–108)	51 (31–111)
Spring recession start timing	Apr 16 (Mar 17–Apr 30)	Apr 11 (Mar 12–May 1)	Apr 2 (Mar 10–May 4)
Spring recession rate of change (%)*	6 (3–10)	6 (3–10)	6 (3–10)
Dry-season baseflow magnitude (cfs)	1 (<1–1)	<1 (<1–1)	<1 (<1–1)

Functional Flow Metric	Wet Year	Moderate Year	Dry Year
Dry-season duration (days)	180 (127–227)	174 (128–230)	178 (121–228)
Dry-season start timing	May 28 (May 6–Jun 21)	Jun 1 (Apr 28–Jun 24)	May 28 (Apr 24–Jul 6)

Table 7. Predicted peak functional flow metrics for Somerville Creek by yearly intervals. Values represent median predictions 10^{th}–90^{th} percentile ranges in parentheses. Peak flows may not occur every year. Data from the Natural Flows Database, COMID 8285288 (California Environmental Flows Working Group 2020).

Functional Flow Metric	All Years
2-year peak flow magnitude (cfs)	205 (156–287)
2-year peak flow days/year when present	3 (1–19)
2-year peak flow events/year when present	2 (1–5)
5-year peak flow magnitude (cfs)	293 (284–394)
5-year peak flow days/year when present	2 (1–6)
5-year peak flow events/year when present	1 (1–3)
10-year peak flow magnitude (cfs)	379 (337–482)
10-year peak flow days/year when present	2 (1–3)
10-year peak flow events/year when present	1 (1–2)

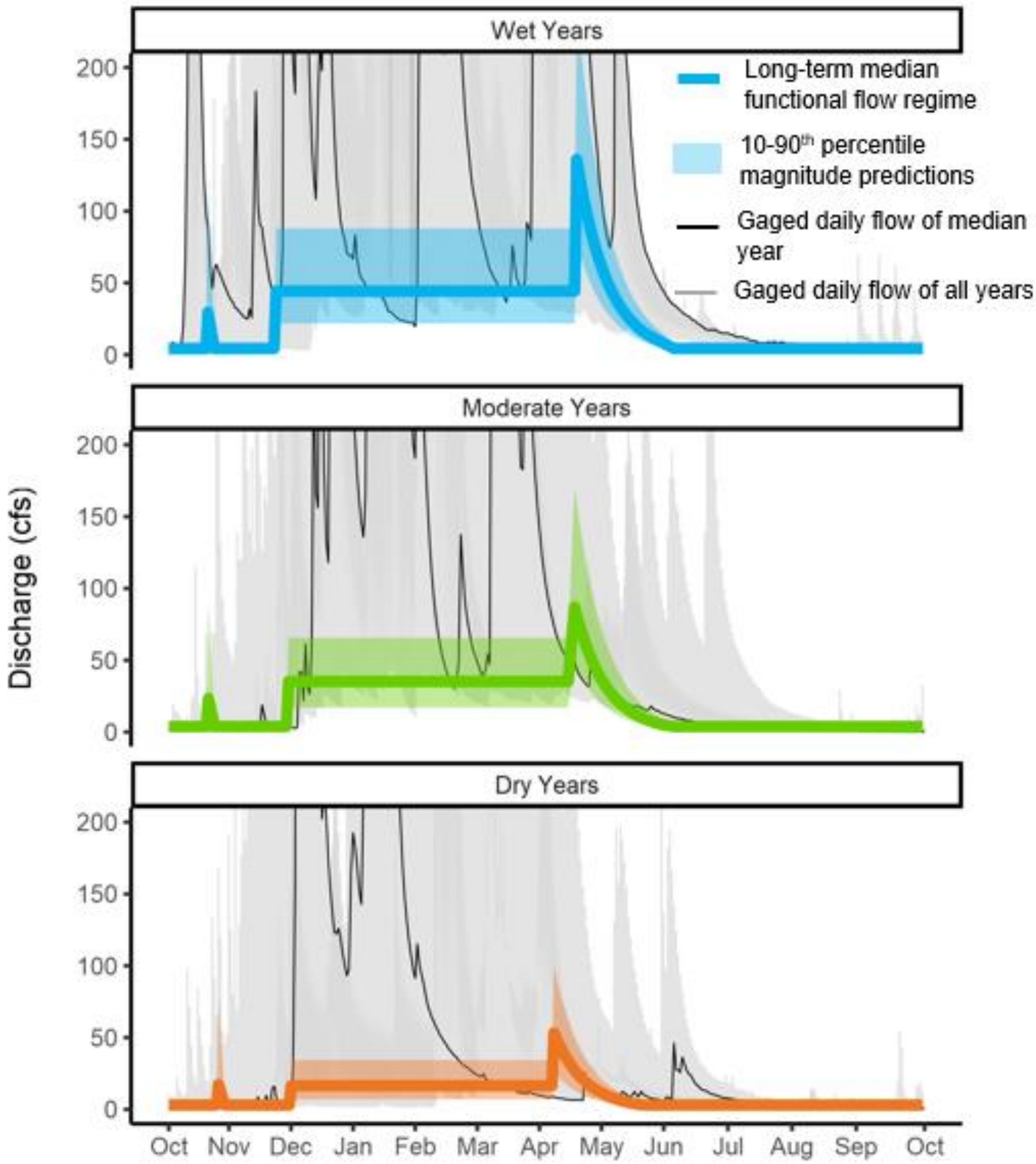

Figure 6. Functional flow regime for Lower Redwood Creek by water year type, plotted over scaled gaged daily flow by water year type. This example functional flow regime uses the median values presented in Table 4, with the wet-season baseflow representing the wet season, and the median wet-season flow representing the spring recession. Peak flows are not shown but would also be included in the flow regime. Gage data: scaled from the daily flow record for Station 11476600 from water years 1960 to 2017 (USGS 2020). Functional flow metrics: COMID 8285238 (California Environmental Flows Working Group 2020).

3.0 METHODS

The Department uses the Instream Flow Incremental Methodology (IFIM) to conduct aquatic instream flow evaluations in California’s streams and rivers (CDFG 2008). IFIM is a framework used to guide instream flow evaluations and associated decision-making processes. In Redwood Creek, the Department’s focus was on instream flows required for juvenile salmonid rearing. To make a flow determination that maximizes rearing habitat availability, the Department selected one-dimensional (1D) hydraulic modeling to characterize the relationship between instream conditions and flow. The 1D modeling approach uses a computer program to combine three major analytical components (river hydraulics, species and life stage HSC, and physical habitat modeling) to represent the relationship between streamflow and physical habitat for various life stages of fish species (CDFG 2008). The approach focuses on physical habitat conditions and site-specific habitat suitability; however it does not include other potential factors that could affect fish rearing, (e.g., species interactions, water quality, and food availability). Staff defined mesohabitat units, identified reaches, and then used stratified random sampling to collect field data on physical and hydraulic channel characteristics. These field data were used to construct a series of 1D hydraulic models which were then combined with HSC to construct habitat duration time series. Finally, the time series were used to identify flow criteria for each life stage and water month type. Each of the 1D modeling steps is summarized in Figure 7. This report describes the sampling strategy (in blue) and habitat modeling (in yellow). Hydraulic data collection and modeling (in green) is briefly described here and covered in more detail in the companion Calibration Report (Cowan 2021).

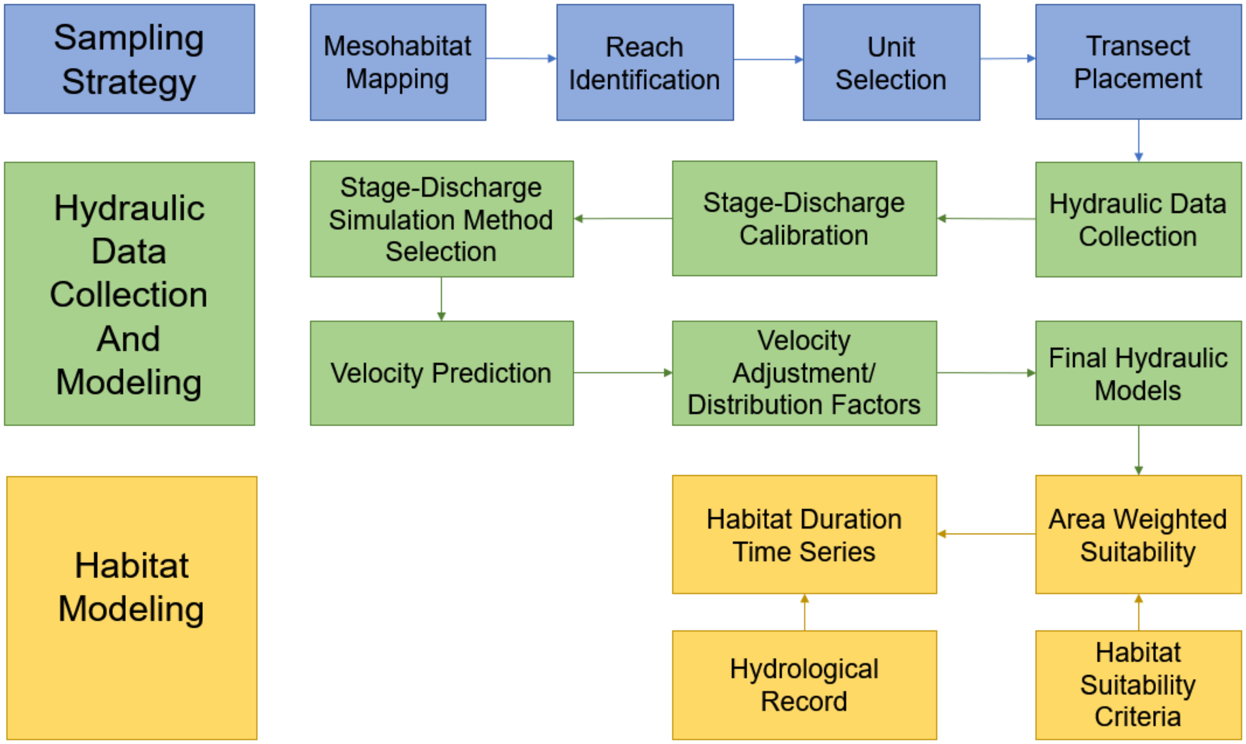

Figure 7. General schematic of 1D model development for physical habitat simulation.

3.1 Identification of Sampling Units and Sampling Strategy

This study focused on mainstem Redwood Creek and several connecting subwatersheds (Figure 8). Mainstem Redwood Creek was subdivided into three study reaches (lower, middle, and upper; see Figure 8 and Figure 9) defined by changes in slope and the distribution of mesohabitat types. The Lower Redwood Creek survey length extends upstream 3.2 mi from the confluence with the South Fork Eel River to approximately 2 mi east of Briceland. The Middle Redwood Creek reach continues 4.5 mi through Briceland up to the confluence with Lower China Creek. The Upper Redwood Creek (also known as Pollock Creek) reach starts at the confluence of Lower China Creek and continues upstream to the uppermost extent of habitat mapping (approximately 1.2 mi) through land historically used for commercial logging.

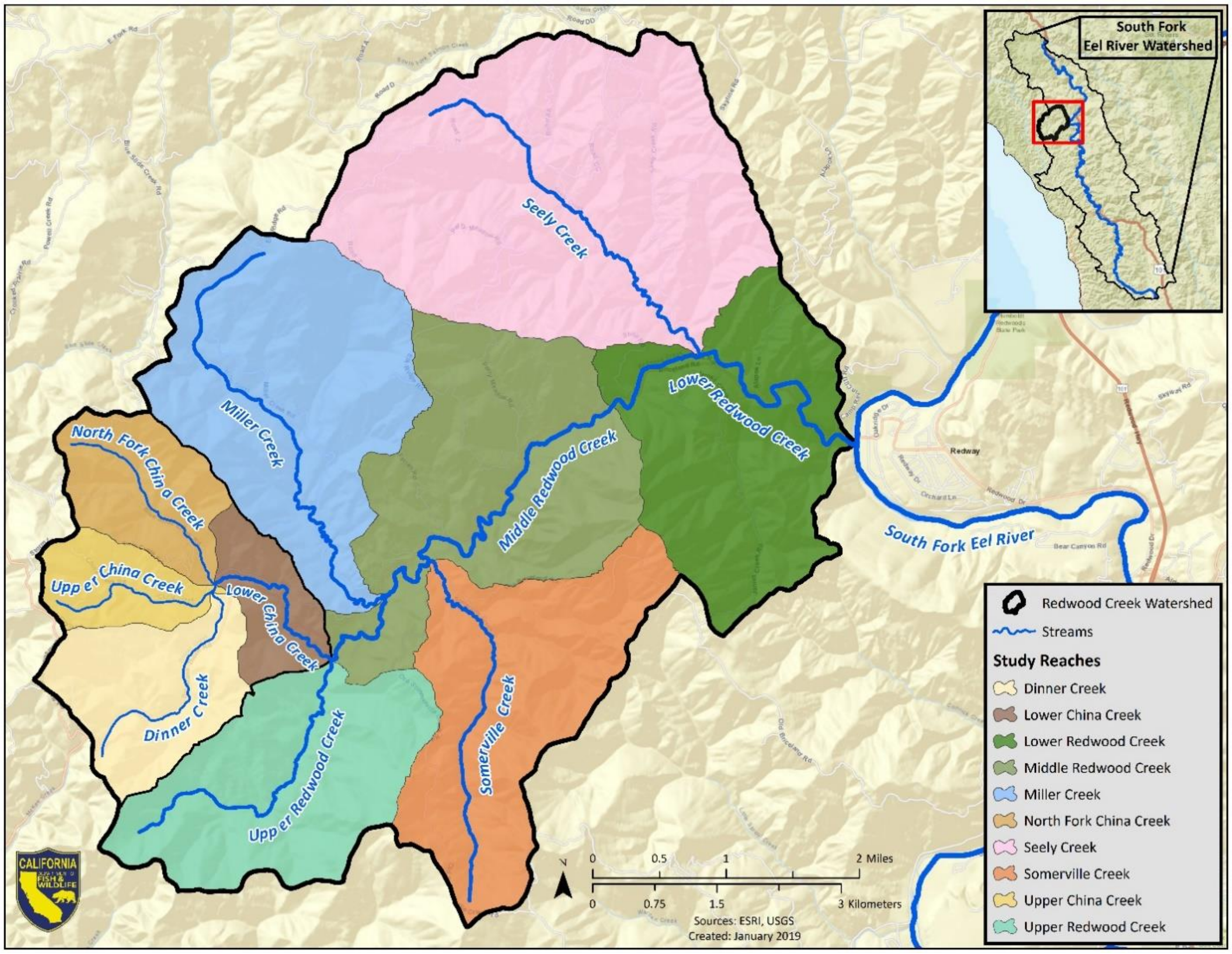

Figure 8. Redwood Creek study reaches.

Each of the tributary subwatersheds forms a study reach. Three tributaries converge within the China Creek subwatershed: Upper China Creek (also known as Twin Creek), North Fork China Creek, and Dinner Creek. Upper China Creek, North Fork China Creek, and Dinner Creek were each considered individual reaches. Lower China Creek, extending from its confluence with Redwood Creek upstream to its confluence with North Fork China Creek, was considered one reach.

Three other major tributaries to Redwood Creek were identified and included as study reaches: Seely Creek, Somerville Creek, and Miller Creek. The elevation profile for Redwood Creek and its confluence points with the Somerville, Miller, and China Creek tributary reaches is shown in Figure 9. The mapped reach lengths and associated drainage area for each reach are shown in Table 8 (total mapped length was 16.9 mi).

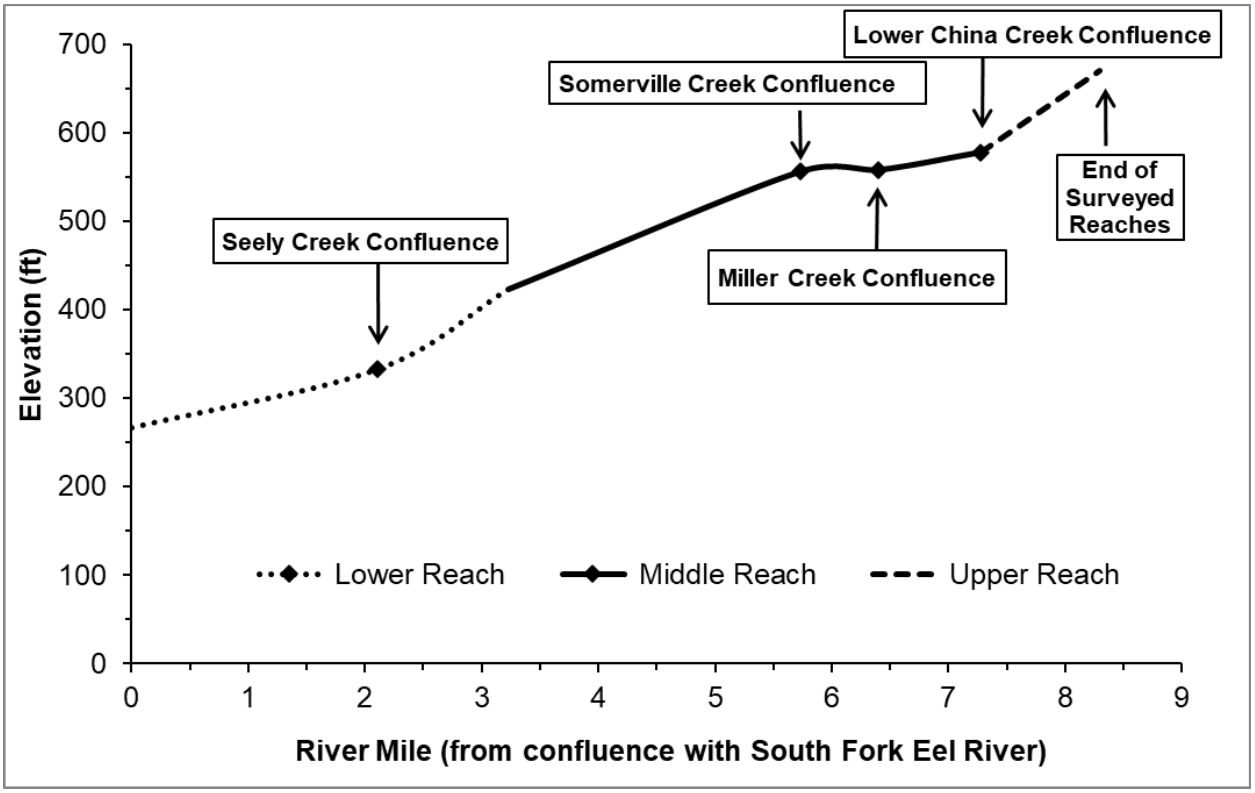

Figure 9. Elevation profile of Redwood Creek and selected confluences.

Table 8. Reach length included in habitat mapping and total drainage area for each reach.

Reach	Mapped Length (mi)	Drainage Area (mi^2)
Lower Redwood Creek	3.2	26.0
Middle Redwood Creek	4.5	17.0
Upper Redwood Creek	1.2	2.7
Seely Creek	1.4	5.8
Somerville Creek	1.3	3.0
Miller Creek	1.8	3.7
Lower China Creek	1.7	3.9
Upper China Creek	0.6	0.7
North Fork China Creek	0.6	1.1
Dinner Creek	0.6	1.5

Mesohabitat Mapping

A mesohabitat mapping survey was performed within each of the ten study reaches. The survey was conducted intermittently between December 2015 and April 2016, dependent on precipitation events and safe wading conditions. All efforts followed the approved Department mesohabitat delineation guidance (CDFW 2015) and protocols described in the study plan for the South Fork Eel River (CDFW 2016). Mesohabitat mapping focused on the portion of each reach with documented salmonid presence (CDFG 1993a; CDFG 1993b; CDFG 2009a; CDFG 2009b) and extended upstream of this point where possible.

Mesohabitat units were mapped and numbered sequentially, beginning at the first habitat unit at the lower end of each creek and working upstream. Level IV mesohabitat delineation standards were applied as outlined in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 2010). To allow for mesohabitat type weighting in subsequent hydraulic models and to increase the overall comparability between the stream reaches, Level IV mesohabitat units were aggregated into broader mesohabitat categories of riffle, pool, glide, run, and "other." Riffle, pool, glide, and run mesohohabitat unit types are described in Table 9. Mesohabitat unit types that fell into the "other" category included culverts, cascades, secondary channel pools, bedrock sheet, and dry sections. Combined "other" mesohabitat types comprised less than 1% of the total mesohabitat types surveyed. These "other" mesohabitat types were excluded from further sampling because 1D modeling guidelines require any given mesohabitat type constitute a minimum of 5% of the overall mesohabitat composition within a reach (CDFG 2008).

Staff measured the length of each mesohabitat unit and recorded other attributes as applicable, such as maximum pool depth, presence of flow input or diversion, and artificial influences (e.g., rip rap or a weir). Table 10 provides a summary of the mapped mesohabitat types by length within each of the 10 study reaches.

Table 9. 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.
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 to determine whether a mesohabitat unit is a pool.
Glide	Low gradient, uniform substrate across channel width with channel composed of small gravel and/or sand/silt or bedrock, depth below average and similar across channel width, below average water velocities, generally associated with tails of pools or heads of riffles, width of channel tends to spread out, thalweg has relatively uniform slope going downstream. Primary determinants are no turbulence (surface smooth, slow, and laminar) and no downstream control.
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.

Table 10. Number of mesohabitat units by type for each reach in the Redwood Creek study area, with the percent of the reach that each mesohabitat type covers in parentheses.

Reach	Riffle	Pool	Glide	Run	Other
Lower Redwood Creek	21 (9.2%)	36 (30.8%)	12 (9.1%)	29 (50.0%)	1 (0.9%)
Middle Redwood Creek	34 (13.1%)	115 (46.3%)	11 (5.9%)	90 (33.8%)	5 (0.9%)
Upper Redwood Creek	23 (7.6%)	83 (56.4%)	3 (2.4%)	46 (33.7%)	0 (0.0%)
Seely Creek	23 (23.1%)	18 (21.5%)	10 (16.8%)	25 (38.7%)	0 (0.0%)
Somerville Creek	26 (20.5%)	38 (19.8%)	2 (1.7%)	35 (57.6%)	1 (0.3%)
Miller Creek	29 (13.1%)	74 (51.3%)	2 (1.7%)	41 (33.3%)	1 (0.6%)
Lower China Creek	15 (5.4%)	91 (53.8%)	6 (2.6%)	49 (37.6%)	1 (0.5%)
Upper China Creek	16 (16.4%)	35 (30.4%)	3 (6.5%)	18 (44.4%)	2 (2.3%)
North Fork China Creek	11 (11.0%)	31 (35.0%)	3 (3.5%)	18 (50.6%)	0 (0.0%)
Dinner Creek	9 (26.9%)	26 (40.1%)	3 (5.5%)	11 (26.2%)	1 (1.2%)
Study Totals	**207 (13.1%)**	**547 (40.1%)**	**55 (5.9%)**	**362 (40.2%)**	**12 (0.7%)**

Unit Selection

Survey locations for 1D sampling were selected using a stratified random sampling design in each of the ten reaches. Only mesohabitat types representing more than 5% of the total reach by length were sampled for 1D model development. Five of the ten reaches (Lower Redwood, Middle Redwood, Seely, Upper China, and Dinner) were represented by four mesohabitat types: riffles, pools, glides, and runs. The other five reaches (Upper Redwood, Somerville, Miller, Lower China, and North Fork China) did not contain a representative proportion of glides by length and therefore, only riffles, pools, and runs were sampled.

Next, each of the mesohabitat units within a reach were separated by type (i.e., riffle, pool, glide, run). Each mesohabitat unit was then assigned a number from one to the total number of mesohabitat units of that type, in order of occurrence from downstream to upstream. The Microsoft Excel random number generator was then used to select a number within the mesohabitat unit type range. For example, there were 21 potential riffle units identified in Lower Redwood Creek following habitat mapping surveys. The random number generator selected the number 14. The 14th riffle unit identified in the Lower Redwood Creek reach was therefore selected as the first potential riffle mesohabitat unit. This process was repeated until three survey units of each mesohabitat type (riffle, pool, glide, and run if applicable) were selected in each of the ten reaches. The 1D models were not able to accurately represent high gradient riffles (defined as boulder-dominated with >4% grade), so while high gradient riffles were included in the overall riffle mesohabitat type percentage calculated for each reach, the 17 high gradient riffles were excluded from riffle survey unit selection. If a high gradient riffle was randomly selected by the random number generator, it was thrown out and a new number was generated. In total, 105 mesohabitat units were selected for 1D sampling across the 10 reaches.

Transect Placement

Staff established transects for sampling within each of the selected mesohabitat units. One transect was surveyed per selected mesohabitat unit and transects were placed in either the top, middle, or bottom third of the unit. Placement within a unit was determined in the office using the random number generator to reduce placement bias. Figure 10 is a schematic of the transect placement process for a transect placed in the top of the third riffle unit.

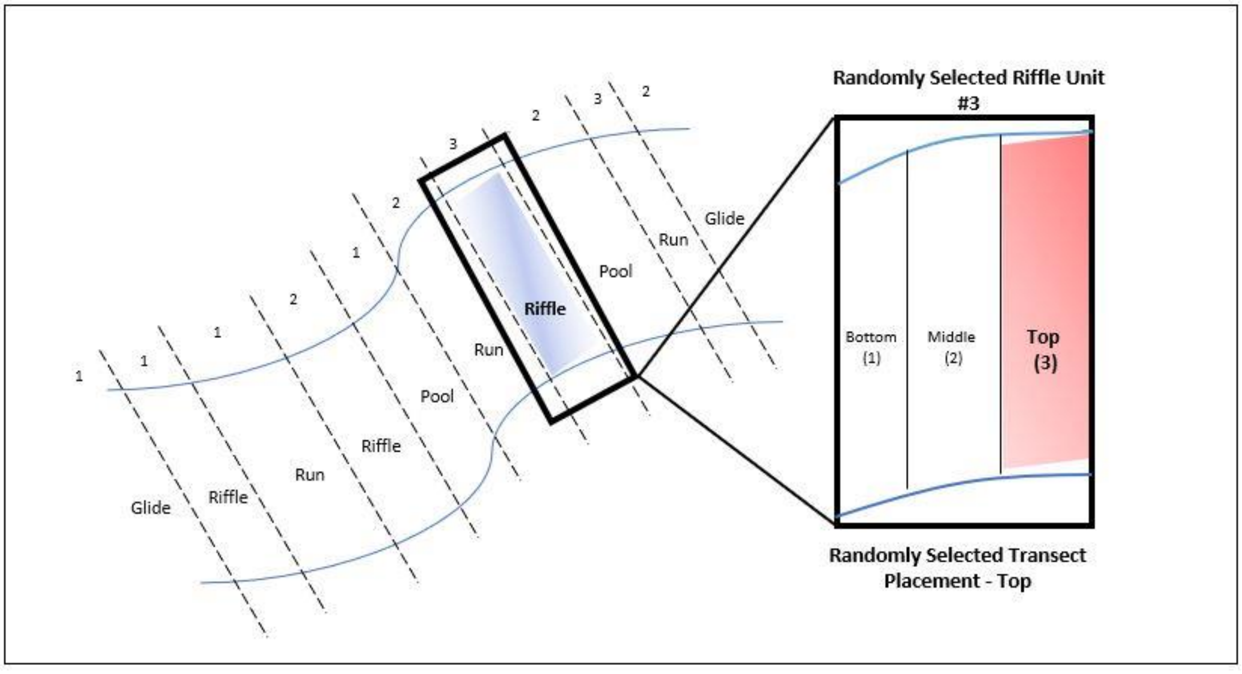

Figure 10. Schematic showing mesohabitat unit site selection and transect placement.

Once mesohabitat units and associated transect locations were randomly identified, Department staff evaluated each site in the field to confirm that it represented the mesohabitat type identified during the mapping process and that survey measurements could be accomplished. If the mesohabitat unit or the transect location was not representative of the mesohabitat type or contained complex channel characteristics such as split channel flow, large woody debris, undercut banks, or anthropogenic inputs or diversions, the senior project manager would determine if the transect could be moved within the mesohabitat unit to allow sampling. If it was determined that the entire mesohabitat unit was not representative or was too complex for 1D modeling, the closest mesohabitat unit of the same mesohabitat type was located and assessed. This process continued until all 105 transects were installed.

3.2 Hydraulic Data Collection and Model Development

The following data were collected at each transect to develop predictive hydraulic models:

- Transect elevation profiles;
- Discharge measurements using approved Department methods (CDFW 2013a; CDFW 2020) in a suitable location close enough to the transect to be representative of the flow passing through the transect;
- Water surface elevations (WSELs) using approved Department methods (CDFW 2013c) along the transect line and paired with the discharge measurements mentioned previously;
- Velocity profile taken along the transect line at the mid or high of the three flow levels recorded; and
- Stage of zero flow elevations in units where the grade of the water surface is a function of a downstream control point.

Discharge, velocity, and water surface data were collected at a minimum of three distinct flows. Hydraulic data collection procedures were consistent with pre-established standards and protocols intended to characterize the hydraulic habitat potential in each representative mesohabitat unit type (Bovee 1997; CDFW 2013c; CDFW 2020). A detailed description of the data collection procedures listed above is provided in the Calibration Report (Cowan 2021).

The data were compiled in the office by staff and entered in the commercially available program System for Environmental Flow Analysis (SEFA; Jowett et al. 2017). SEFA estimates depth and velocity along each transect over a range of flows. The hydraulic model tolerances and calibration results for each transect are provided in the Calibration Report (Cowan 2021).

3.3 Habitat Suitability Criteria and Area-Weighted Suitability

The relationship between streamflow and physical habitat for fish was modeled using life-stage specific HSC and the outputs of the hydraulic modeling process described above and in the Calibration Report. These data were combined to estimate AWS (also known as weighted usable area) for each reach by species over a range of flows. Defined simply, AWS is a scoring index that describes the amount of suitable habitat per unit of length (e.g., ft, yard) at a specified flow for a given species and life stage (Payne and Jowett 2013).

The HSC for juvenile steelhead and Coho Salmon used in this report were developed in Hollow Tree Creek (see Figure 1), a nearby tributary to the South Fork Eel River, using data collected 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 its proximity to Redwood Creek, similarity in species assemblages and life stage timing, and minimal anthropogenic influences. In comparison to the 163 registered active diversions in the Redwood Creek watershed, Hollow Tree Creek had a relatively unimpaired flow regime with only two registered active diversions (California State Water Resources Control Board 2018). Although adult Chinook Salmon are known to spawn in tributaries to the South Fork Eel River, including Hollow Tree Creek, juveniles are not residents in the watershed, so juvenile Chinook salmon were not evaluated in this study.

The Hollow Tree Creek study used an equal area sampling design stratified by mesohabitat type within each of three defined 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 values to each depth and velocity value. Fish habitat preferences were developed for two fish size classes for both steelhead and Coho Salmon: <6 centimeters cm (fry) and ≥6 cm (juveniles).

AWS was calculated at a range of flows for each life stage and species using modeled depth and velocity values and species habitat preferences (HSC). AWS represents the available habitat area weighted by the suitability of that habitat per square foot (ft^2) of channel. To calculate AWS, each transect was subdivided into a series of cells, and the area of each cell was multiplied by the HSC values associated with that cell's depth and velocity. AWS was summed across each transect, and then weighted by the percent of the reach that the transect habitat type occupies (see Table 10) and summed to develop a set of reach-wide AWS values (Payne and Jowett 2013).

3.4 Habitat Duration Analysis

To ensure that flow criteria did 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 generates a time series of median monthly AWS values that would likely occur under unimpaired conditions based on the AWS-flow relationships described in Section 3.3. The flows associated with median AWS values were calculated for each month and water month type to represent the range of naturally occurring conditions within a reach and generate protective flow criteria (CDFG 2008). The use of unimpaired flows ensured 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. 2018a) were used to generate a time series of AWS using the AWS-flow relationships. For each reach, the lowest modellable flow was set by the recommended velocity adjustment factor (VAF) range, as described in Section 2.3 of the Redwood Creek Calibration Report (Cowan 2021). Where AWS at 0 cfs was not modellable, an AWS value at 0 cfs was estimated for each reach using linear interpolation so that median habitat duration could be calculated. For all reaches, juvenile steelhead (≥6 cm) AWS-flow relationships were used for the analysis. Juvenile steelhead consistently preferred higher flows than the other species and life stages evaluated in this study. COMIDs associated with each stream reach used in for this analysis are listed in Appendix C.

The relationships between AWS and flow by reach 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 11). 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 reach, 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 ensured that the selected flow did not exceed unimpaired water availability for a given month and water month type (CDFG 2008).

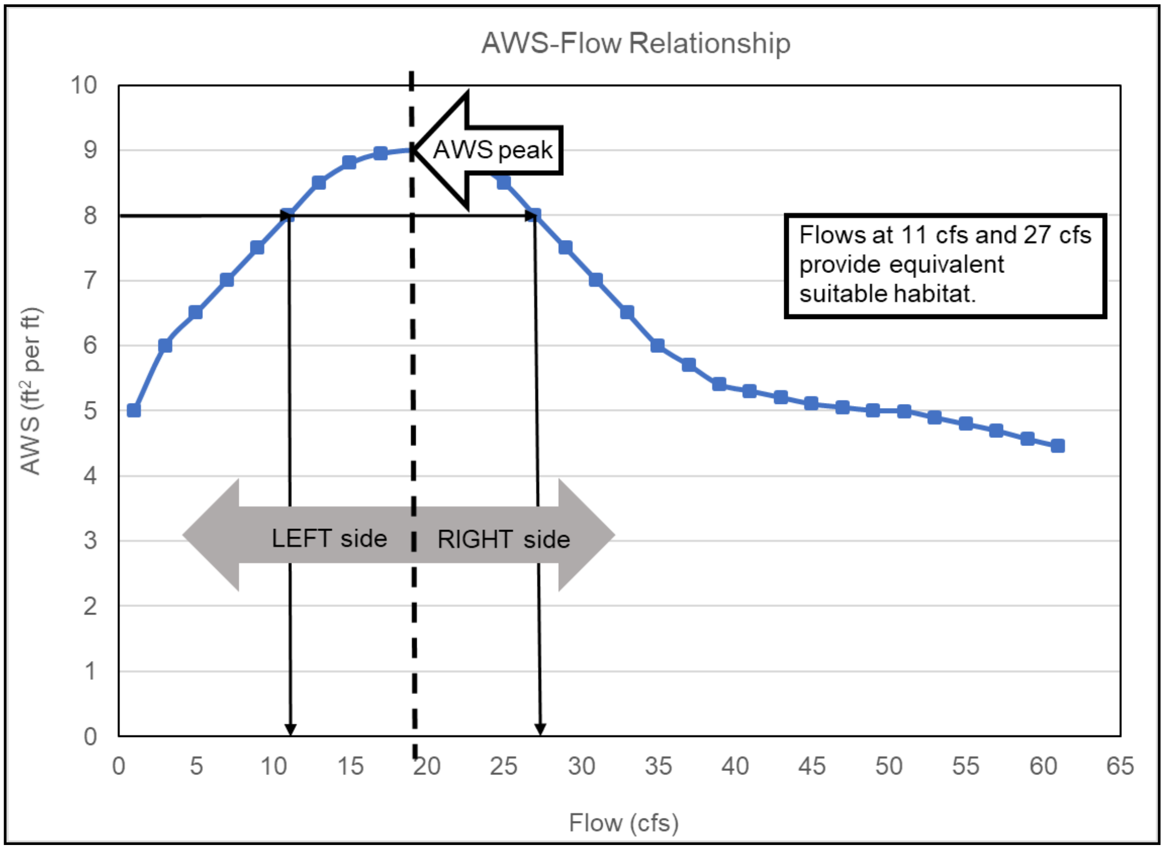

Figure 11. An example of an AWS-flow relationship; the same amount of suitable habitat can be provided by flows both above and below the AWS peak flow.

4.0 RESULTS

The following section presents the results of the analysis described in Section 3. A total of 75 transects were used in development of the 1D models. The transects represent the variation in available steelhead and Coho Salmon habitat present in the study area (see Figure 22 to Figure 31). The final tally is consistent with the number of transects needed for robust modeling of flow and habitat relationships (CDFG 2008; Gard 2005; Payne et al. 2004).

4.1 Hydraulic Model Calibration

Data were collected on 105 randomly selected survey transects in 2016, with three transects selected per mesohabitat type in all ten reaches. The hydraulic calibration of 1D transects involves applying guidance standards from the literature to the model outputs to ensure the model performance meets existing standards. In situations where transect outputs do not meet the standards, the transect data is further evaluated. Data were evaluated to determine whether an error was made in the data collection or entry process, if the stage-discharge relationship was altered between surveys by a change in the transect lateral or longitudinal profile, or if the transect was a poor candidate for hydraulic modeling in 1D.

Based on this assessment, 30 survey transects had to be omitted from further analyses. The recommended output guidance and the rationale for omitted survey transects are provided in Calibration Report Section 2.1 and Calibration Report Appendix C (Cowan 2021). The final number of survey transects that attained a predictive relationship for the hydraulic model was 75. The final transect locations for each reach are provided in Appendix A (Figure A-1 to Figure A-10).

To develop reach-wide estimates of habitat suitability (AWS), each transect is weighted by the length of the reach that it represents. In other words, if pools represent 30% of the reach length, and there are three pool transects, each pool transect receives a weight of 10%. Section 3.1 of the Calibration Report summarizes the weight of each mesohabitat type, the final number of calibrated transects in each mesohabitat type, and the resulting transect weights used in SEFA to compute AWS.

4.2 Flow and Habitat Relationships

Estimated AWS-flow relationships for steelhead and Coho Salmon in the Redwood Creek watershed varied by reach and life stage. Steelhead fry (<6 cm) habitat availability peaked at simulation flows of 1–6 cfs in all reaches. Optimal flows for juvenile steelhead (≥6 cm) steadily increased with watershed area to a maximum of 66 cfs in Lower Redwood Creek.

AWS for Coho Salmon fry (<6 cm) peaked at 6 cfs in Lower Redwood Creek. AWS for Coho Salmon fry in the remaining reaches peaked at 1 or 2 cfs. Generally, total habitat availability for juvenile Coho Salmon (≥6 cm) increases with watershed area.

Figure 12 through Figure 21 show habitat-streamflow relationships (AWS by flow) for each species and life stage by reach. AWS expresses habitat in ft^2 of suitable habitat per foot of reach length but is not a true area. For example, an AWS of 5 ft^2/ ft could represent 5 ft^2 of perfectly suitable (optimal) juvenile steelhead habitat per linear foot of stream length, 10 ft^2 of 50% suitable habitat, or 20 ft^2 of 25% suitable habitat. The data used to develop these figures are presented in Appendix B (Table B-1 to Table B-10).

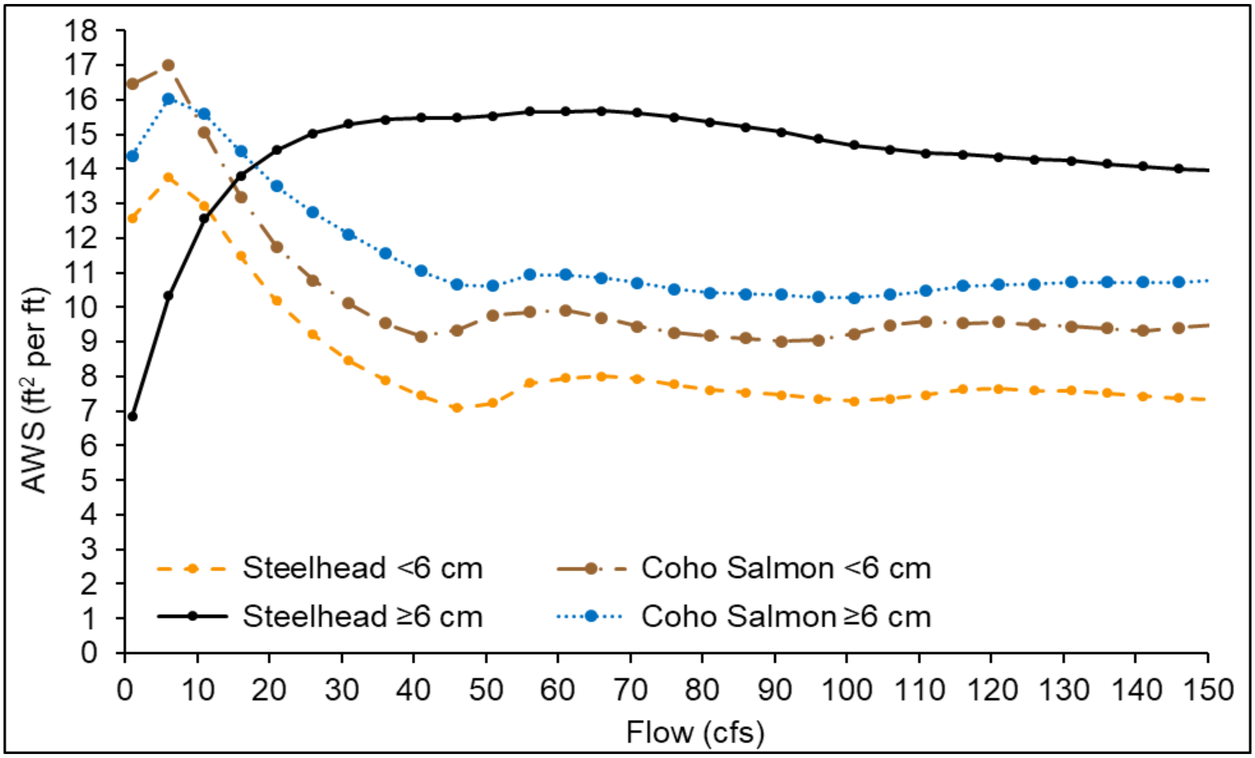

Figure 12. Lower Redwood Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

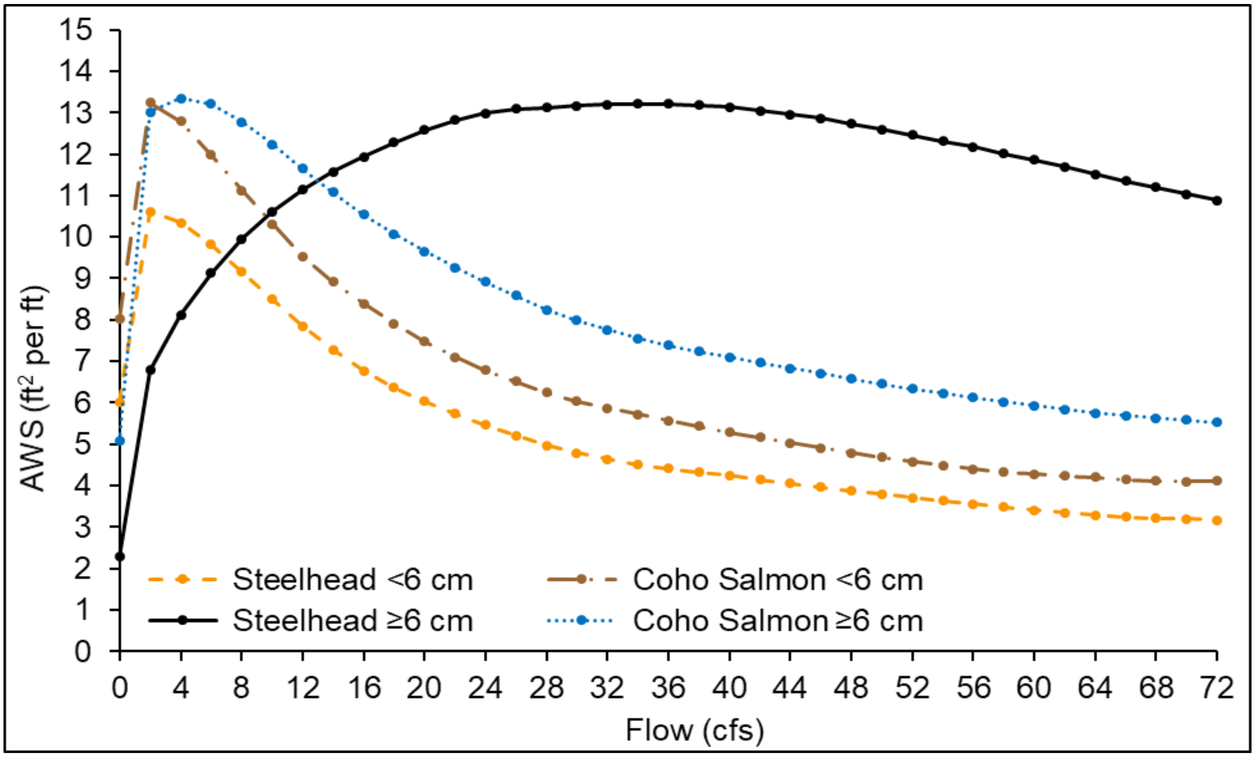

Figure 13. Middle Redwood Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

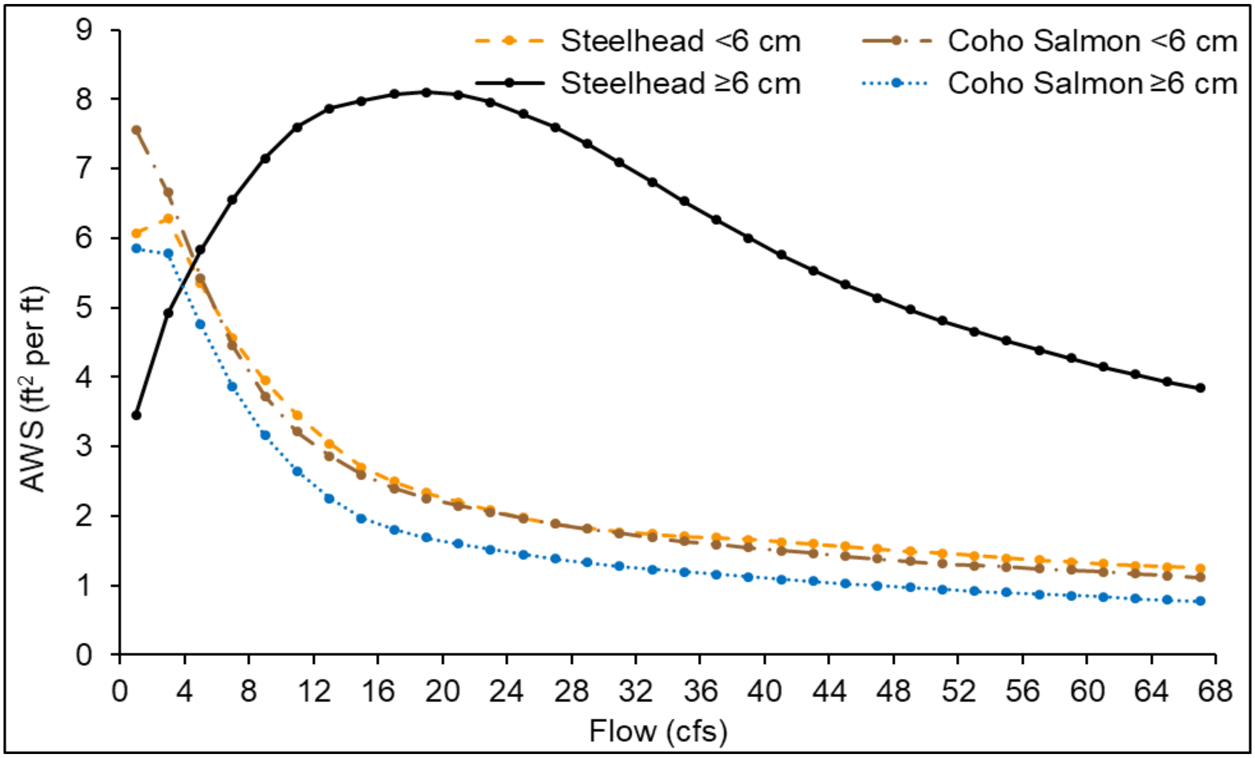

Figure 14. Upper Redwood Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

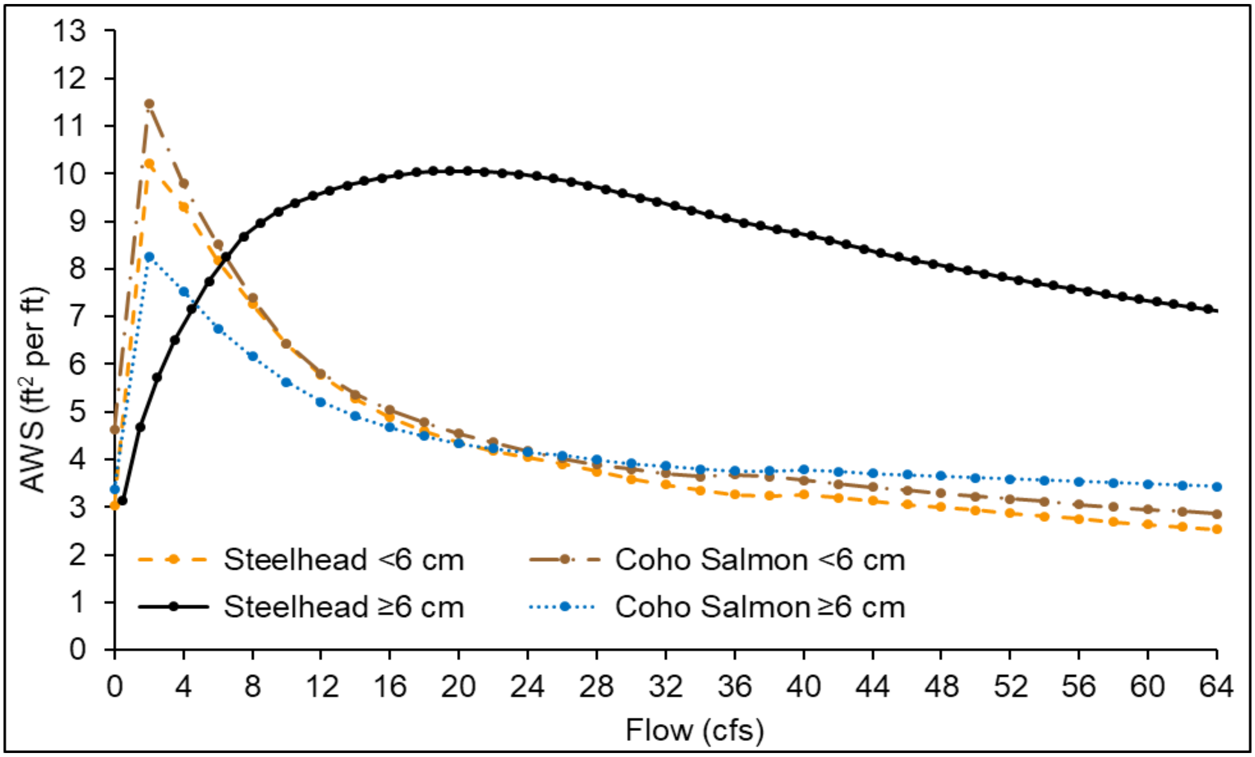

Figure 15. Seely Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

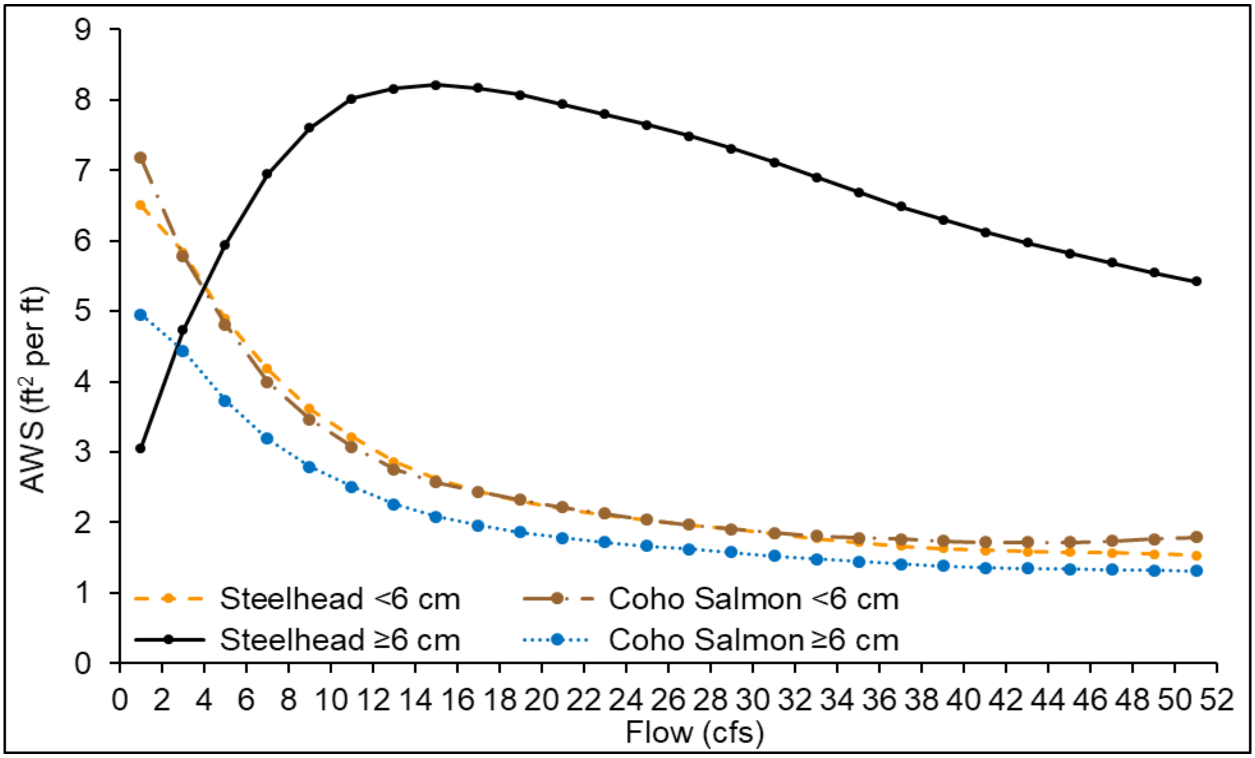

Figure 16. Somerville Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

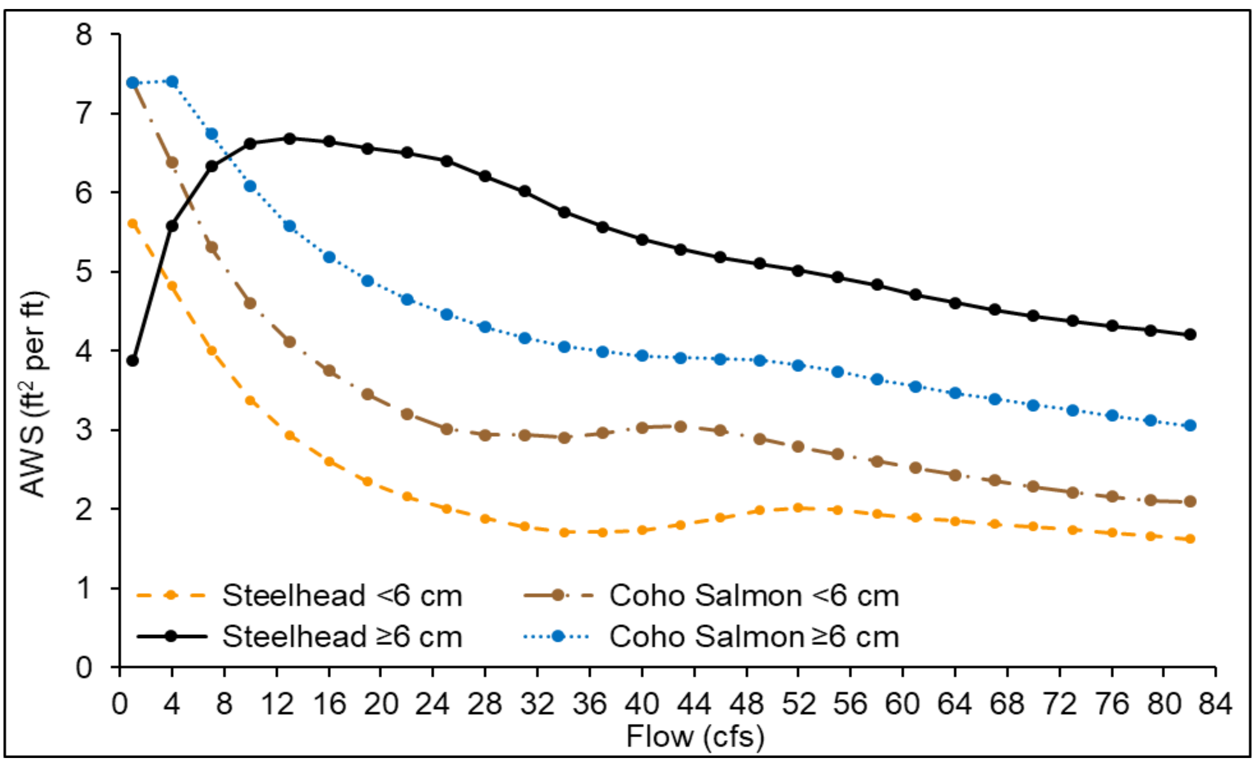

Figure 17. Miller Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

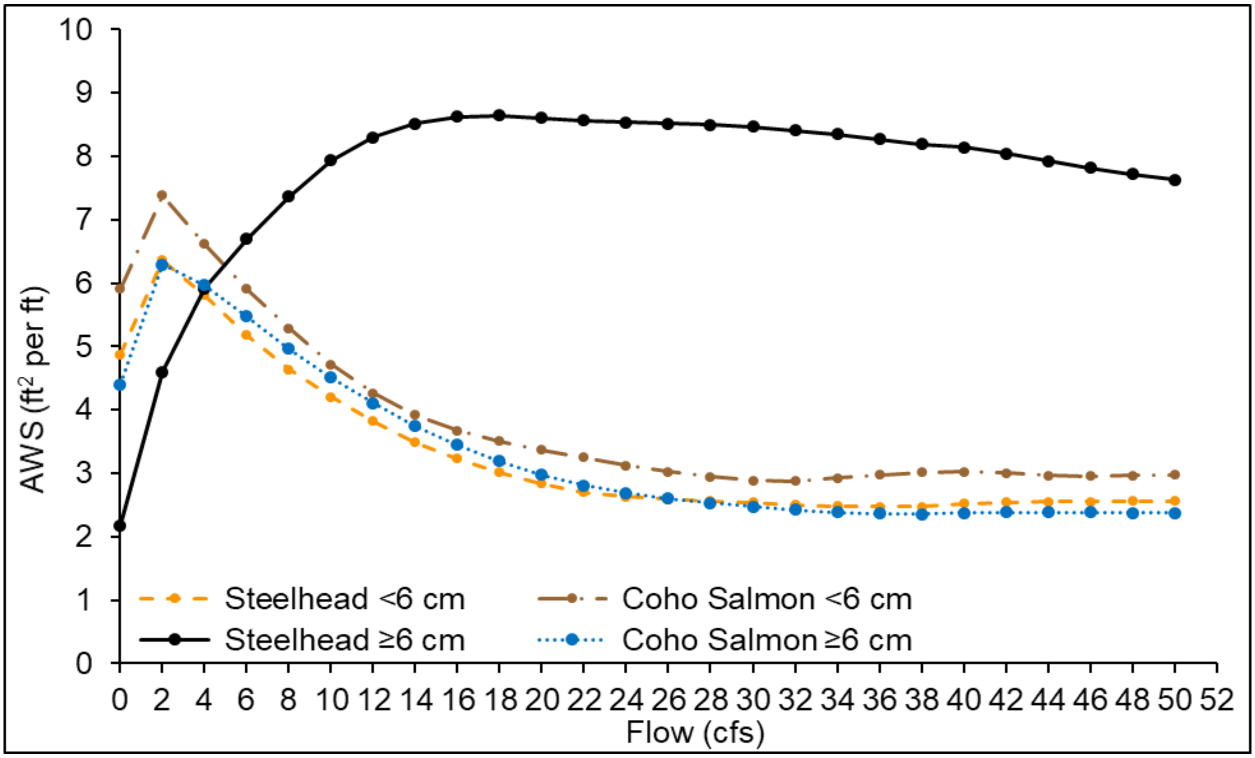

Figure 18. Lower China Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

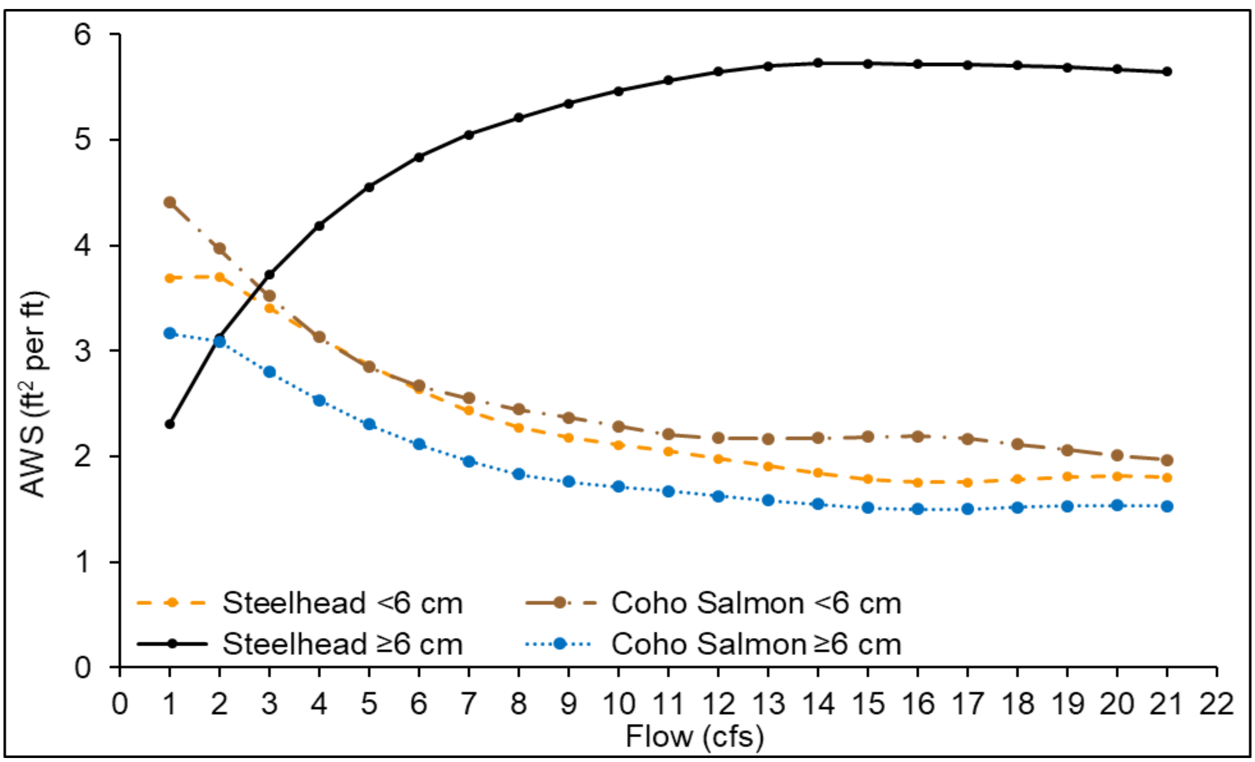

Figure 19. Upper China Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

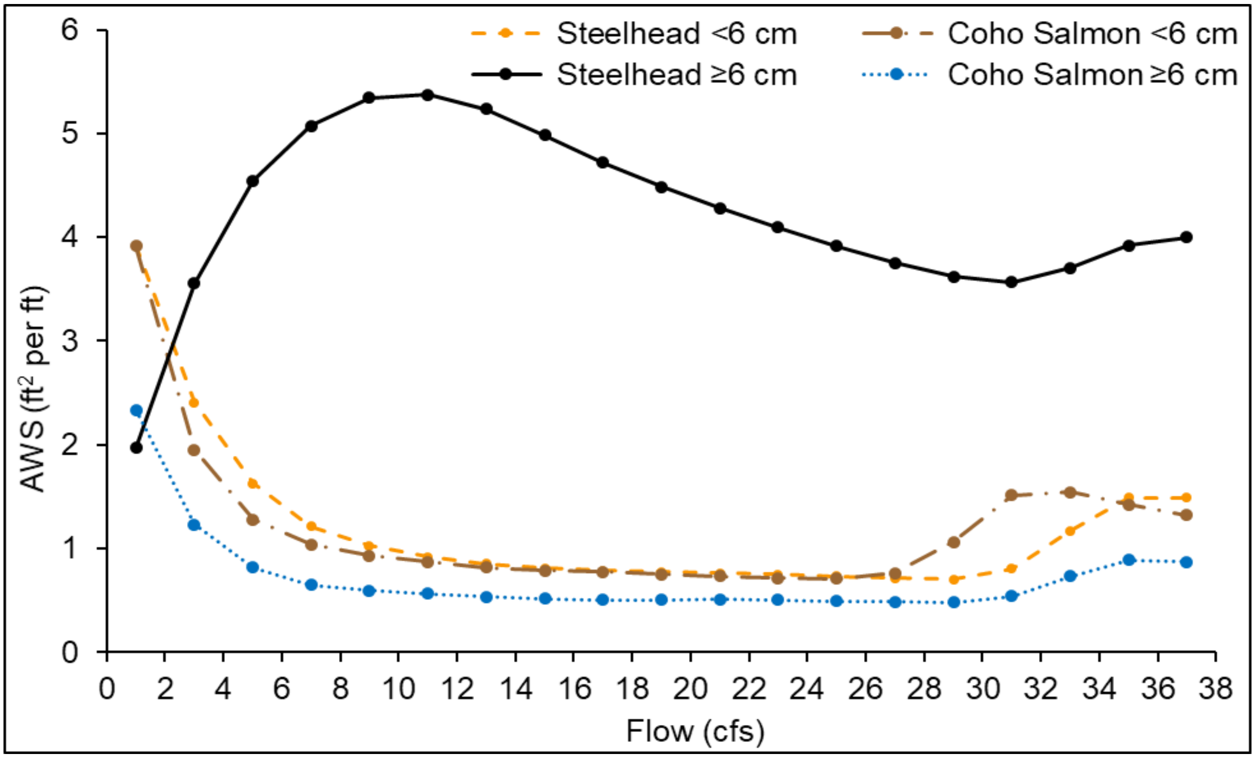

Figure 20. North Fork China Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

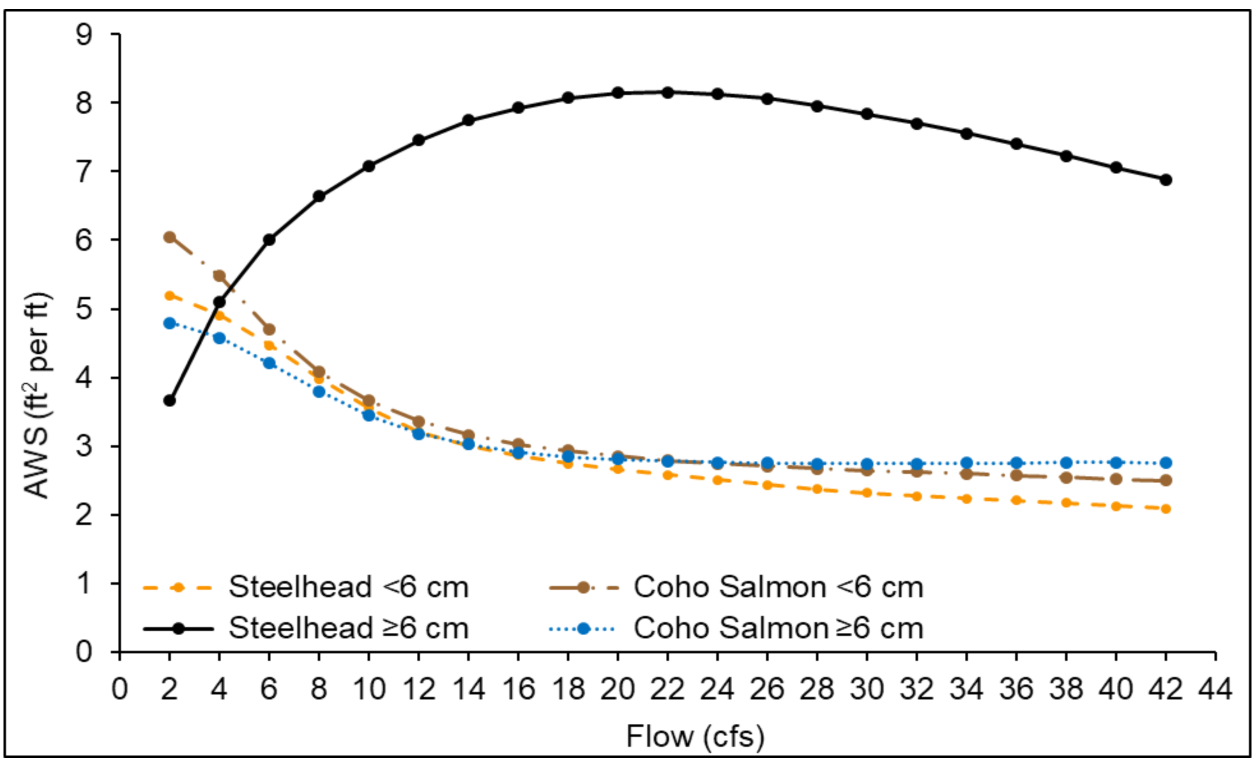

Figure 21. Dinner Creek steelhead and Coho Salmon AWS habitat-streamflow relationship (AWS by flow).

4.3 Habitat Duration Analysis

Streamflows for steelhead rearing derived from habitat duration time series analyses are presented by monthly water type for the ten study reaches in Table 11 to Table 20. Since the flows identified by the habitat duration time series analyses were derived for each month using the life-stage-specific AWS curves and local unimpaired hydrology, the median habitat values (and associated flows) generally increased in wetter months and decreased in drier months.

Juvenile steelhead (≥6 cm) have the highest flow requirements of the species and life stages assessed. Coho and fry prefer very low velocity areas, which can be found at channel margins at any flow. Flows that support juvenile steelhead will produce a broader array of depths and velocities and are therefore considered to be protective of other steelhead and Coho Salmon life stage flow needs. Juvenile steelhead (≥6 cm) flow requirements were used in the development of habitat duration time series. The tables and data presented below are for juvenile steelhead (≥6 cm) because these are the highest and most protective flow requirements.

Table 11. Lower Redwood Creek protective steelhead juvenile rearing flow criteria in cfs by water month type results from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	66	66	26
February	66	66	46
March	66	66	54
April	66	44	30
May	44	21	14
June	18	11	8
July	8	4	3
August	4	2	2
September	3	2	2
October	5	2	2
November	32	10	4
December	66	44	12

Table 12. Middle Redwood Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	34	34	19
February	34	34	34
March	34	34	34
April	34	29	21
May	29	15	10
June	13	8	6
July	5	3	2
August	3	2	2
September	2	2	1
October	3	2	1
November	19	7	3
December	34	34	9

Table 13. Upper Redwood Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	19	11	3
February	19	14	6
March	13	10	6
April	13	5	3
May	5	2	2
June	2	1	1
July	1	<1	<1
August	1	<1	<1
September	<1	<1	<1
October	1	<1	<1
November	4	1	1
December	19	6	1

Table 14. Seely Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	20	20	6
February	20	20	12
March	20	18	13
April	20	9	6
May	10	5	3
June	4	2	1
July	2	1	1
August	1	<1	<1
September	1	<1	<1
October	1	1	<1
November	7	2	1
December	20	13	3

Table 15. Somerville Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	15	11	4
February	15	15	6
March	15	12	7
April	15	6	4
May	6	3	2
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

Table 16. Miller Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	13	13	4
February	13	13	8
March	13	13	8
April	13	7	5
May	7	3	2
June	3	2	1
July	1	1	1
August	1	<1	<1
September	<1	<1	<1
October	1	<1	<1
November	5	1	1
December	13	8	2

Table 17. Lower China Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	18	14	5
February	18	18	9
March	18	15	9
April	18	8	5
May	7	3	2
June	3	2	1
July	1	1	1
August	1	<1	<1
September	<1	<1	<1
October	1	<1	<1
November	6	2	1
December	18	10	2

Table 18. Upper China Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	7	3	1
February	6	4	2
March	4	3	2
April	3	1	1
May	1	1	<1
June	1	<1	<1
July	<1	<1	<1
August	<1	<1	<1
September	<1	<1	<1
October	<1	<1	<1
November	1	<1	<1
December	6	2	<1

Table 19. North Fork China Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	11	4	1
February	7	6	2
March	7	4	3
April	5	2	1
May	2	1	1
June	1	<1	<1
July	<1	<1	<1
August	<1	<1	<1
September	<1	<1	<1
October	<1	<1	<1
November	2	<1	<1
December	9	3	1

Table 20. Dinner Creek protective steelhead juvenile rearing flow criteria in cfs by water month type from habitat duration time series analysis.

Month	Wet	Moderate	Dry
January	13	6	2
February	11	8	3
March	10	6	4
April	7	3	2
May	3	1	1
June	1	1	<1
July	<1	<1	<1
August	<1	<1	<1
September	<1	<1	<1
October	<1	<1	<1
November	2	1	<1
December	13	4	1

4.4 Survey Photographs

Examples of study transects in each study reach at lower and higher flows are provided in the paired figures below (Figure 22 to Figure 31).

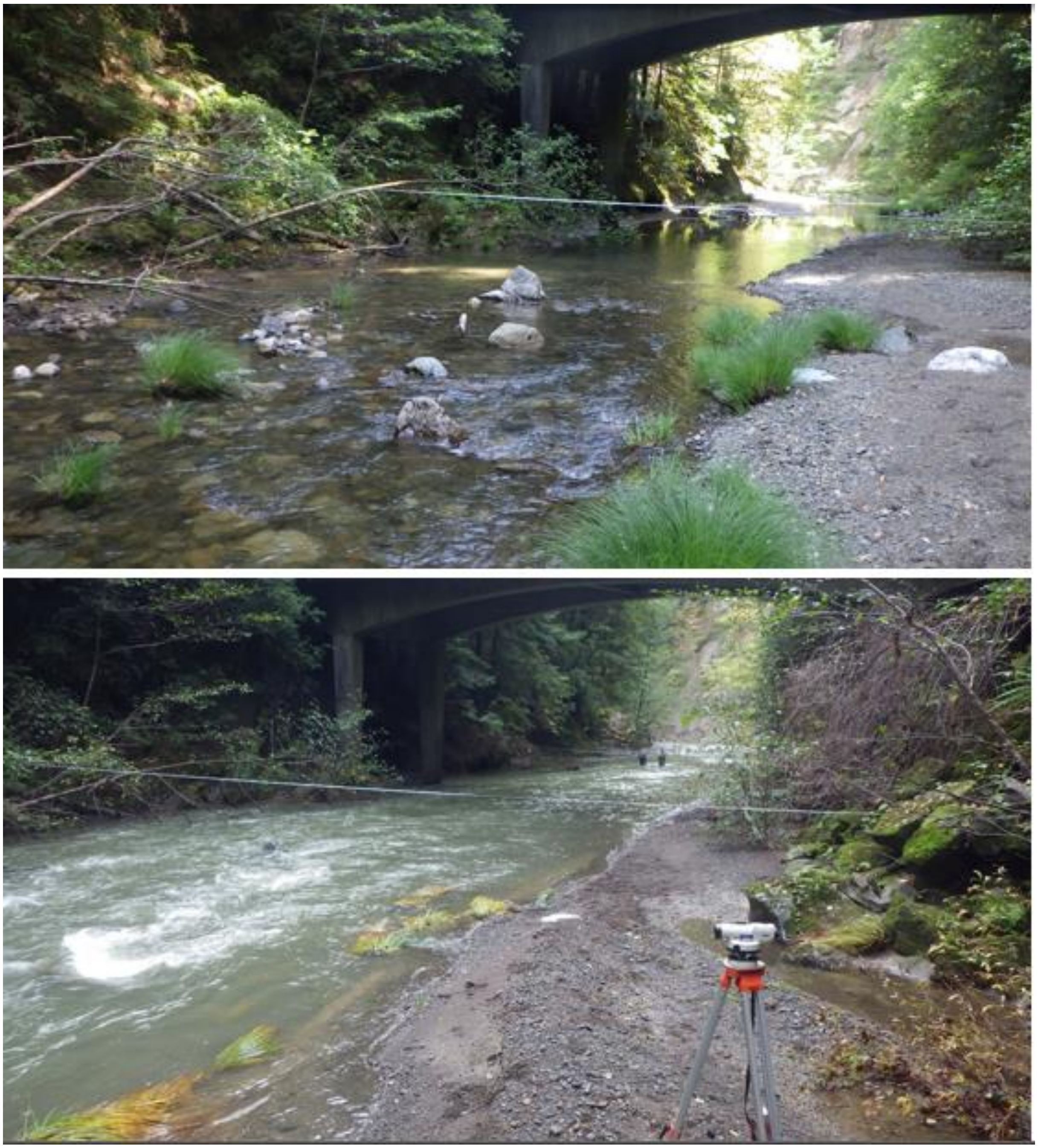

Figure 22. Downstream view of transect LRT16 (Lower Redwood Creek) at 9.5 cfs (top) and 132.8 cfs (bottom).

Figure 23. Downstream view of transect MRT129 (Middle Redwood Creek) at 2.3 cfs (top) and 28.8 cfs (bottom).

Figure 24. Downstream view of transect URT25 (Upper Redwood Creek) at 0.5 cfs (top) and 26.6 cfs (bottom).

Figure 25. Downstream view of transect ST16 (Seely Creek) at 1.2 cfs (top) and 26.2 cfs (bottom).

Figure 26. Downstream view of transect SCT12 (Somerville Creek) at 0.7 cfs (top) and 19.5 cfs (bottom).

Figure 27. Downstream view of transect MCT17 (Miller Creek) at 3.6 cfs (top) and 32 cfs (bottom).

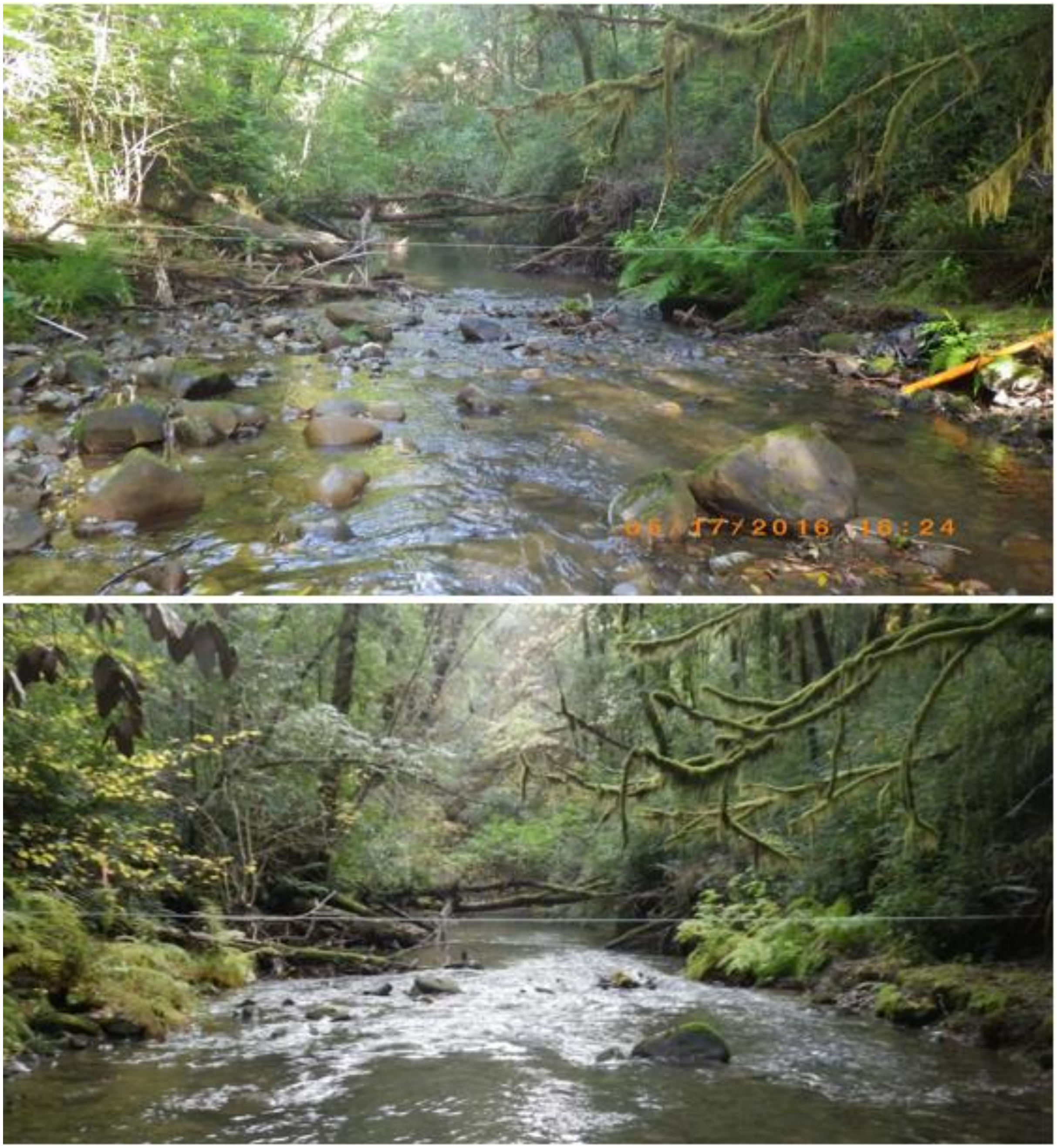

Figure 28. Downstream view of transect LCT32 (Lower China Creek) at 1.6 cfs (top) and 15.1 cfs (bottom).

Figure 29. Downstream view of transect UCT13 (Upper China Creek) at 0.3 cfs (top) and 4.2 cfs (bottom).

Figure 30. Downstream view of transect NFCT25 (North Fork China Creek) at 0.4 cfs (top) and 7.3 cfs (bottom).

Figure 31. Upstream view of transect DT17 (Dinner Creek) at 0.5 cfs (top) and 14.6 cfs (bottom).

5.0 FLOW CRITERIA

A primary objective for the Redwood Creek watershed is to optimize rearing habitat for the production of fry and juvenile salmonids. Results of the 1D modeling and habitat duration analysis (Table 11–Table 20) 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 results presented in this report, water management decisions should consider incorporating the following:

- Additional flows for ecosystem functions are provided in the functional flow metrics (presented in Table 4 through Table 7, and in Table D-1 through D-16 of Appendix D). These flows support a broader set of ecosystem functions that may not be captured by the salmonid rearing flows developed in this report using 1D 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).
- Further criteria were developed in the companion Department Watershed Criteria Report *Watershed-wide Instream Flow Criteria for the South Fork Eel River* (CDFW 2021b). Although not all reaches in Redwood Creek were assessed as part of the Watershed Criteria Report, site-specific data were collected for several of the Redwood Creek reaches.
- Unimpaired flow data in the South Fork Eel River watershed is being developed using the State Water Board's groundwater-surface water interaction model (Paradigm Environmental 2018).

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 Redwood Creek watershed as the science and understanding of climate change evolves or as new information becomes available.

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