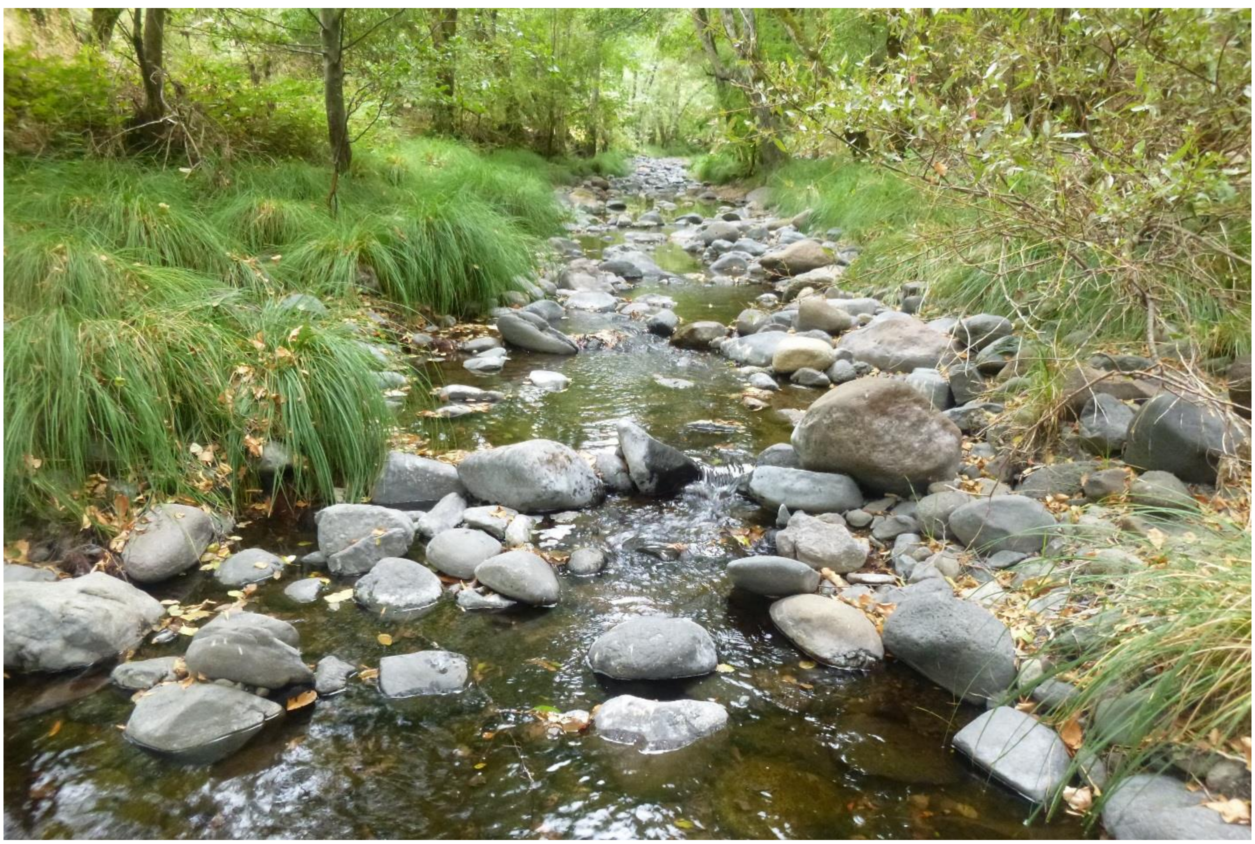
State of California
Natural Resources Agency
California Department of Fish and Wildlife

STUDY PLAN
Habitat and Instream Flow Evaluation for Anadromous Steelhead and Coho Salmon in UPPER MARK WEST CREEK, Sonoma County



STUDY PLAN

June 2018

Cover photo: Mark West Creek, view upstream.

Approvals

Gregg Erickson
Regional Manager, Bay-Delta Region

Gregg Erickson ______________________________ Date 6/21/18

Robert W. Hughes, P.E.
Supervising Hydraulic Engineer, Conservation Engineering Program

______________________________ Date 6/20/2018

Kevin Shaffer
Branch Chief, Fisheries Branch

______________________________ Date 6/29/2018

Scott Cantrell
Branch Chief, Water Branch

Scott Cantrell ______________________________ Date 6/21/18

PREFACE

This study plan outlines the approaches that may be used by the California Department of Fish and Wildlife (Department) to evaluate instream flow needs for anadromous steelhead and Coho Salmon in upper Mark West Creek, Sonoma County. The California Water Action Plan[1] (CWAP) outlines ten actions and associated sub-actions to address water management challenges and promote reliability, restoration, and resilience in the management of California's water resources. Action Four of the CWAP, to protect and restore important ecosystems, directs the Department and the State Water Resources Control Board (State Water Board) to implement a suite of actions to enhance instream flows within at least five priority stream systems. Mark West Creek, a tributary to the lower Russian River, is among these first five priority streams. The Department plans to begin work on the upper Mark West Creek study in 2018 as part of the suite of actions to address instream flow enhancement for anadromous salmonid species present within upper Mark West Creek.

The Department is the Trustee Agency for California's fish and wildlife resources and a Responsible Agency under CEQA §21000 *et seq*. Fish and wildlife resources are held in trust for the people of the State of California under FGC §711.7. As Trustee Agency, the Department seeks to maintain natural communities and native fish, wildlife, and plant species for their intrinsic ecological values and for their benefits to all citizens in the State. This includes habitat protection and maintenance of habitat of sufficient amount and quality to ensure the survival of all native species and natural communities. The results of the study may be used to assist with flow enhancement activities in upper Mark West Creek through the CWAP and other salmonid restoration and recovery efforts.

[1] More information about Proposition 1 and the California Water Action Plan can be found at http://resources.ca.gov/california_water_action_plan/

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ABBREVIATIONS

°F	degrees Fahrenheit
1D	one-dimensional (physical habitat simulation model)
2D	two-dimensional (physical habitat simulation model)
BMI	benthic macroinvertebrate
CC	California Coastal
CCC	Central California Coast
CCR	California Code of Regulations
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife (previously CDFG)
CEMAR	Center for Ecosystem Management and Restoration
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CNFD	California Natural Flows Database
CWAP	California Water Action Plan
cfs	cubic feet per second
DPS	distinct population segment
DWR	Department of Water Resources
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FGC	Fish and Game Code
FN	Froude number
FR	Federal Register
FRAP	Fire Resource Assessment Program
ft	foot/feet
ft/s	feet per second
GIS	geographic information system
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HRM	Habitat Retention Method
HSC	habitat suitability criteria
HTS	habitat time series
HUC12	12-digit hydrologic unit code
IFP	Instream Flow Program
LiDAR	Light Detection and Ranging
MANSQ	Manning's stage discharge
NMFS	National Marine Fisheries Service
NRCS	Natural Resources Conservation Service
PACT	Priority Action Coho Team
PHABSIM	Physical Habitat Simulation Model
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCD	Resource Conservation District
RIVER2D	River2D Model
RRCWRP	Russian River Coho Water Resources Partnership
RRISRP	Russian River Independent Science Review Panel

RTK	real time kinematic
SCWA	Sonoma County Water Agency
SEFA	System for Environmental Flow Analysis
SOP	standard operating procedure
SRPBAP	Santa Rosa Plain Basin Advisory Panel
SRPHM	Santa Rosa Plain Hydrologic Model
SWRCB	State Water Resources Control Board
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WPM	Wetted Perimeter Method
WSEL	water surface elevation
WY	water year
WSP	water surface profile
VAF	velocity adjustment factor
VDI	Voluntary Drought Initiative

CONVERSIONS

1 cubic foot per second ≈ 2.83 × 10^{-2} cubic meters per second
1 inch = 2.54 centimeters
1 foot ≈ 30.48 centimeters
1 square mile ≈ 2.59 square kilometers
1 mile ≈ 1.61 kilometers
1 foot ≈ 0.31 meters
°C = (°F - 32) ÷ 1.8

1.0 INTRODUCTION

The Russian River watershed, to which Mark West Creek is a tributary, currently supports several species of anadromous salmonids, including anadromous Rainbow Trout (commonly known as steelhead; *Oncorhynchus mykiss*), Chinook Salmon (*O. tshawytscha*), and Coho Salmon (*O. kisutch*). Salmon and steelhead populations within coastal California watersheds, including those found within the Russian River watershed have declined significantly due to habitat modification, overfishing, and environmental stressors (Steiner 1996; CDFG 2004; NMFS 2008; NMFS 2012; CDFW 2015b; NMFS 2016). The National Marine Fisheries Service (NMFS) has consequently made several listing determinations pursuant to the federal Endangered Species Act (ESA) for the Distinct Population Segments (DPS)/ Environmentally Significant Units (ESU) of the respective species. These determinations cover all anadromous salmonid species found within the Mark West Creek subwatershed: Central California Coast (CCC) steelhead, listed as threatened in 1997 (62 FR 43937); California Coastal (CC) Chinook Salmon, listed as threatened in 1999 (64 FR 50394); and CCC Coho Salmon, listed as endangered in 2005 (70 FR 37160). CCC Coho Salmon north of San Francisco Bay were also listed as endangered under the California Endangered Species Act (CESA) in 2005.

Despite the CESA/ESA listings, populations of anadromous salmonid species continue to decline in the Russian River watershed and throughout their ranges. The Russian River population of Coho Salmon was nearly extirpated in the late 1990s (CDFG 2004; NMFS 2008). In response to the decline, county, state, and federal agencies formed the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program) in hopes of preventing imminent extirpation. This collaborative effort has been supporting species recovery by breeding Coho Salmon from local genetic stocks and releasing juveniles into streams historically inhabited within the Russian River watershed, including Mark West Creek.

The degradation and loss of freshwater habitat, caused by a decrease in water quality and insufficient water quantity, is one of the leading causes of salmonid decline (CDFG 2004; NMFS 2012). Water diversions, modifications to riparian vegetation, and sediment delivery to streams that provide critical habitat to salmonid species in the Russian River watershed have contributed to the degradation and loss of habitat (NMFS 2008; Sonoma RCD 2015). This instream flow study conducted by the Department of Fish and Wildlife (Department) will provide information to help support the recovery of anadromous species within upper Mark West Creek by identifying the flow regimes necessary to support salmonids and the habitats upon which they depend.

2.0 PROJECT BACKGROUND

The Mark West Creek subwatershed provides habitat for listed anadromous salmonid species including CCC steelhead, CC Chinook Salmon, and CCC Coho Salmon as well as various other aquatic species of special concern such as the California Roach (*Lavinia symmetricus*), Northwestern Pond Turtle (*Actinemys marmorata*), and Foothill Yellow-Legged Frog (*Rana boylii*). One of the primary motivations for this flow study is the California Water Action Plan (CWAP). Released by Governor Brown in 2014, the CWAP directs the Department and State Water Resources Control Board (State Water Board) to initiate a suite of actions to enhance water flows in at least five stream systems that support critical habitat for anadromous fish species. Mark West Creek was established as a priority CWAP stream. In addition to being a CWAP priority stream, limiting factors and recovery actions identified in recovery plans for the listed salmonid species inhabiting Mark West Creek (CDFG 2004; NMFS 2012; NMFS 2016) provide contextual background for this instream flow study.

Prior assessments (e.g., NMFS 2008; Grantham et al. 2012; Obedzinski et al. 2016) have indicated that impaired streamflow is a factor affecting steelhead and Coho Salmon survival in the Russian River watershed. The State's Steelhead Restoration and Management Plan (CDFG 1996) suggests that water diversions have led to insufficient flow conditions within the Russian River watershed, contributing to the decline of steelhead populations. Part of the difficulty in managing the impacts of water diversions, the plan stated, stems from the lack of studies to determine the instream flow requirements for salmon and steelhead within the Russian River and its tributaries (CDFG 1996). The Department's Coho Salmon Recovery Strategy (CDFG 2004) suggested that altered flow regimes were likely presenting an obstacle to Coho Salmon recovery within the Russian River watershed. Finally, both the CCC Coho Salmon Recovery Plan (NMFS 2012) and Coastal Multispecies Recovery Plan (NMFS 2016) identified insufficient baseflow conditions as a limiting factor facing rearing juveniles within the Russian River and Mark West Creek focus populations, respectively. To aid in the prioritization of recovery actions from the Coho Salmon recovery plans, the Department and NMFS formed the Priority Action Coho Team (PACT). The PACT identified Mark West Creek as one of the top ten streams north of San Francisco Bay in which flow enhancements could benefit the recovery of the species.

In 2014, prolonged drought conditions and the likelihood of significant impacts to listed salmonid species prompted the Department and NMFS to develop the Voluntary Drought Initiative (VDI) Program[2]. Mark West was identified as a priority watershed in which to implement the VDI Program, one of four within the entire CCC steelhead DPS and CCC Coho Salmon ESU. In 2015, as poor conditions persisted, the State Water

[2] Governor Brown declared a State of Emergency in 2014 due to ongoing drought conditions and subsequently issued an Executive Order directing the Department to coordinate with other agencies and landowners to minimize the combined impacts of the drought on listed species within priority watersheds. The VDI Program aimed to incentivize landowners to reduce water use and "prevent unreasonable impacts to fishery resources."

Board adopted an emergency regulation titled “Enhanced Water Conservation and Additional Water User Information for the Protection of Specific Fisheries in Tributaries to the Russian River” (CCR Title 23 Section 876). This regulation applied to the four Russian River subwatersheds identified in the VDI effort (i.e., Dutch Bill, Green Valley, Mill, and Mark West creeks), and mandated that landowners reduce water use and provide water use information on surface and subsurface diversions.

The Russian River Coho Water Resources Partnership (RRCWRP) identified Mark West Creek as one of five critical subwatersheds within the Russian River basin where important water management strategies could help restore the Coho Salmon population (RRCWRP 2017). In order to help address the low-flow limiting factor, developing an understanding of flow regimes and the relationship between streamflow and available salmonid habitat within upper Mark West Creek is required. This study will develop these habitat-flow relationships and identify the flows necessary to provide suitable habitat to support species recovery and guide future management decisions.

3.0 PROJECT DESCRIPTION

Department staff will conduct the instream flow study within upper Mark West Creek. Department Water Branch staff will coordinate and carry out data collection, data analysis, and generate a technical report (Table 1). Given the diverse nature of interests within the watershed, stakeholder coordination and outreach will be a vital component of the project. Bay-Delta Region staff will identify key outreach opportunities and will be supported by Water Branch staff participation. Bay-Delta Region, Conservation Engineering, and the Fisheries Branch will review the study plan, technical project components, and reports produced by the Water Branch.

Table 1. Roles and responsibilities in the Department's Mark West Creek study.

Department Lead	Role
Water Branch	Technical Study Project Coordination Study Planning Field Data Collection Engineering Data Management and Analysis Data Reporting
Bay-Delta Region	Project Context and Objectives Study Plan Review Field Data Collection (resources permitting) Project Review
Shared (Water Branch and Region)	Study Design Stakeholder Identification, Coordination, and Outreach Landowner Access
Conservation Engineering	Study Plan Review Project Consultation and Review
Fisheries Branch	Study Plan Review Project Review

3.1 Study Goals and Objectives

The goal of this study is to develop relationships between streamflow and salmonid habitat in upper Mark West Creek. Information developed will identify important flow thresholds for the protection and maintenance of anadromous steelhead and Coho Salmon juvenile rearing, and may be used to generate Department flow recommendations.

The objectives of this study are to:

- Identify and develop relationships between streamflow and available salmonid habitat using a combination of empirical approaches and hydraulic habitat modeling.
- Determine flows needed to maintain rearing habitat and connectivity for juvenile salmonids.
- Identify flows that support productive riffle habitats for benthic macroinvertebrates, an important food source for juvenile salmonids.
- Monitor water quality conditions, including temperature and dissolved oxygen.

3.2 General Approach

Relationships between streamflow and habitat within upper Mark West Creek will be developed using a combination of scientifically defensible methods, which may include hydraulic habitat modeling and empirical approaches described by the Instream Flow Council in *Instream Flows for Riverine Research Stewardship* (Annear et al. 2004). The resulting relationships will serve as a basis to help identify important flow thresholds for the conservation, restoration, and protection of salmonids and other aquatic resources within the watershed. Study components include assessing rearing habitat, riffle productivity and connectivity flows in upper Mark West Creek. In addition, monitoring of temperature and dissolved oxygen will be conducted to evaluate water quality conditions.

4.0 WATERSHED DESCRIPTION

Depending on the source of information, the boundary of the Mark West Creek subwatershed can vary. The U.S. Geological Survey (USGS) National Hydrologic Dataset and the Sonoma County Water Agency (SCWA) define Mark West Creek as a tributary to the Russian River (Nishikawa 2013). However, several other sources identify Mark West Creek as a tributary to the Laguna de Santa Rosa, which then flows into the Russian River (Sloop et al. 2007; Baumgarten et al. 2014; CEMAR 2015). The discrepancy stems in part from the complex lower reaches of the creek. Lower Mark West Creek's channel has undergone natural course migrations across its alluvial fan, but has also been subject to substantial anthropogenic modifications since the late 1800s (Baumgarten et al. 2014). For the purposes of this study, we are defining the Mark West Creek subwatershed using a modified USGS 12-digit hydrologic unit code (HUC12) boundary[3] and Mark West Creek as a tributary to the Russian River. Mark West Creek enters the Russian River near river mile 24 (Figure 1).

[3] Quantum Spatial developed these hydrologic data products for the Sonoma County Vegetation Mapping and LiDAR Program based on high-resolution LiDAR data collected in 2013.

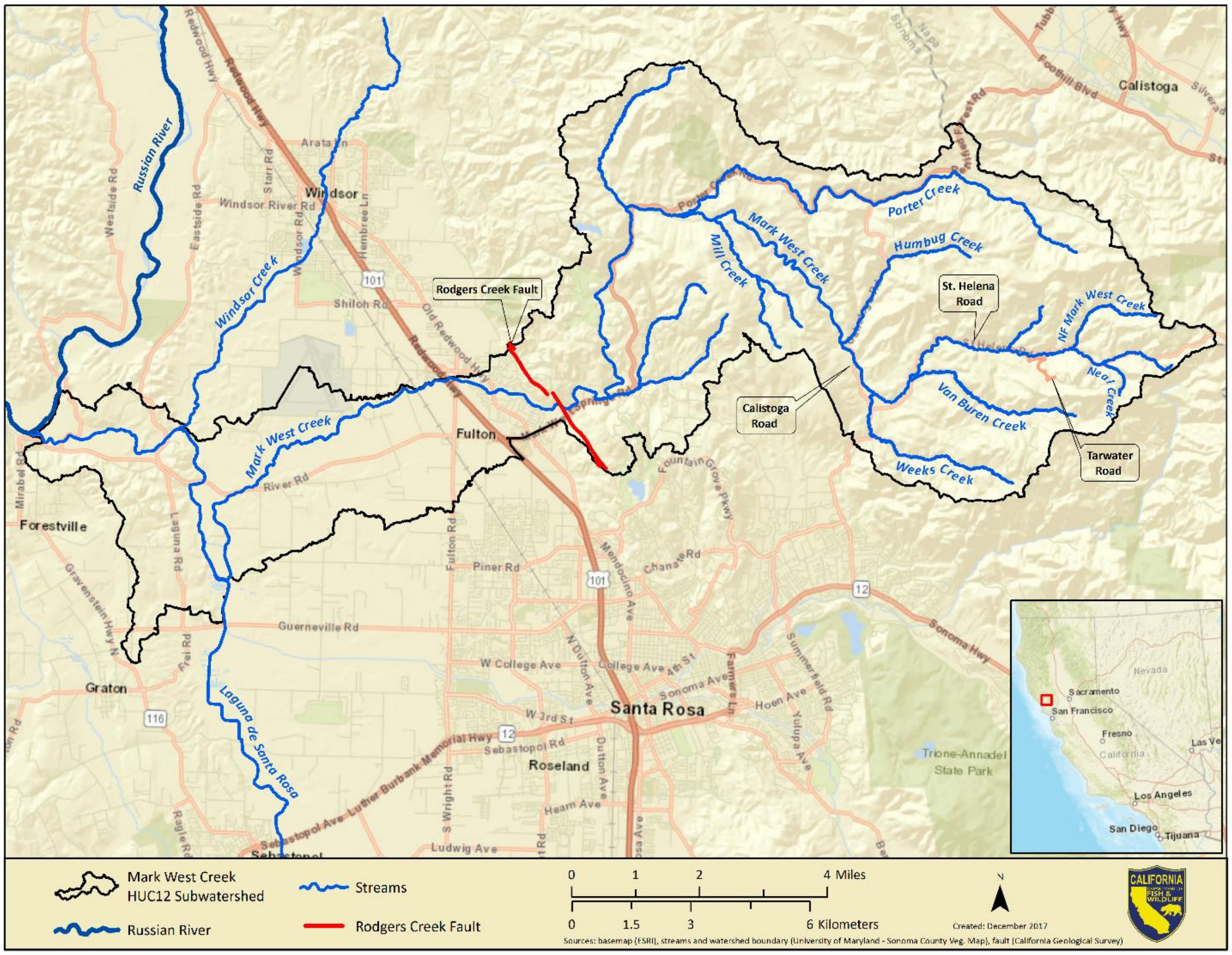

Figure 1**.** Mark West Creek HUC12 subwatershed**.**

Situated about five miles north of the City of Santa Rosa along the eastern boundary of Sonoma County, the Mark West Creek HUC12 subwatershed is the second largest in the Russian River basin, draining an area of approximately 59 square miles. Mark West Creek stretches roughly 34 miles from its confluence with the Russian River to its headwaters in the Mayacamas Mountains. The three main tributaries to Mark West Creek are Windsor and Porter creeks, and the Laguna de Santa Rosa. Smaller significant tributaries include Mill, Humbug, Weeks, Van Buren, North Fork Mark West, and Neal creeks.

With a maximum elevation of approximately 2,350 feet, the watershed drains a portion of the Mayacamas Mountain Range in a general westward direction towards its confluence with the Russian River, which occurs at an elevation of roughly 30 feet. Longitudinally, the watershed's topography varies greatly. Towards its western boundary, the watershed encompasses a low relief valley area. The Rodgers Creek fault that runs northwest and lies approximately mid-watershed marks a noticeable topographic boundary at the foot of the Mayacamas Mountain Range (Figure 1; Sloop et al. 2007). From this point, the watershed begins to climb into rolling foothills and ultimately terminates in the steep-walled, narrow valleys of the mountainous headwater region along its eastern boundary (Honton and Sears 2006).

The watershed's land uses and land cover differ between the lower valley and upper mountainous region. Around the mid-19th century, the lower watershed underwent a conversion from a landscape dominated by oak savannah, seasonal and perennial wetlands, to a landscape structured around grazing and ranching; this later shifted to dairy farming, orchards, hay fields, and row crops (Honton and Sears 2006; Sloop et al. 2007). In the mid-20th century, rapid urbanization began to shift land use from agriculture (Sloop et al. 2007). Today, most of the lower watershed's land cover is dominated by urbanized land and irrigated cropland (predominantly vineyards), and to a lesser extent native hardwood forests, riparian forests, and grassland (CEMAR 2015).

Ranching and timber harvest were the major early land uses in the eastern mountainous region of the watershed (i.e., the upper watershed; Sonoma RCD 2015). Mirroring population growth and changes in the lower watershed, land use in the upper watershed began to shift in the mid-20th century when parcels were subdivided, allowing for the expansion of rural residential development (Sotoyome RCD 2008). Like the lower watershed, vineyards emerged as a dominant crop towards the end of the 20th century (Sonoma RCD 2015), although vineyard land cover by percentage area is far smaller in the upper watershed as compared to the lower watershed with approximately 2% and 37%, respectively[4]. Coniferous forest, hardwood forest, grassland, and shrubs presently dominate land cover in the upper watershed (CEMAR 2015; Sonoma RCD 2015). Approximately 90% of the land within the Mark West Creek subwatershed is privately owned.[5]

4.1 Target Species and Life Stages

Collectively, CCC steelhead, CC Chinook Salmon, and CCC Coho Salmon utilize the Mark West Creek subwatershed year-round to carry out the freshwater stages of their life histories. CCC steelhead and CC Chinook Salmon are both listed as threatened under the federal ESA, while CCC Coho Salmon are listed as endangered under both the ESA and CESA. Bjorkstedt et al. (2005) and Moyle et al. (2008) concluded that CCC steelhead within Mark West Creek exist as an essential, potentially independent population within the steelhead DPS. CCC Coho Salmon in lower Russian River tributaries, including Mark West Creek, exist as part of a single, functionally independent population that is at high risk of extirpation (NMFS 2008). NMFS (2008) suggests that, historically, CCC Coho Salmon populations in the lower Russian River were the most abundant population source for other streams within the CCC ESU. Accordingly, the persistence of CCC steelhead and CCC Coho Salmon populations in

[4] Vineyard land cover estimate from GIS analysis using the fine-scale vegetation and habitat map data from the Sonoma County Vegetation Mapping and LiDAR Program.
[5] Land ownership estimate from GIS analysis using data from the California Department of Forestry and Fire Protection, Fire Resource and Assessment Program (FRAP).

the Russian River is necessary to support the recovery of the species within their respective DPS/ESU (NMFS 2008). The Department identified the juvenile life stages of steelhead and Coho Salmon as the focus for this instream flow and habitat assessment project. Because the juvenile life stages of these species rear in the creek throughout the summer and fall months (Table 2), maintaining adequate streamflow conditions during this period is essential to support the species' recovery (NMFS 2008).

Table 2. Generalized seasonal periodicities of target salmonid species in upper Mark West Creek.

Species and Life Stages	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
CCC steelhead												
Adult												
Juvenile												
CCC Coho Salmon												
Adult												
Juvenile												
Legend:												
	Present											

Sources: Steiner (1996); R2 Resource Consultants, Inc. and Stetson Engineers, Inc. (2007); NMFS (2012); NMFS (2016).

Long-term systematic fish surveys are lacking within the Mark West Creek subwatershed (NMFS 2016). Several short-term studies have been conducted and observations have been noted during periodic habitat analyses conducted by the Department and other entities. Historically, steelhead were observed over a wide range of Mark West Creek where habitat remained wetted through the summer and fall seasons (CDFG 1953, 1966, 1969, 1971), though current densities are thought to be significantly reduced from observations noted through the 1950s to 1970s (NMFS 2016). Information on the historical presence and distribution of Coho Salmon within the Russian River watershed, and Mark West Creek, specifically, is much more limited (Spence et al. 2005; NMFS 2008). Nonetheless, both Brown and Moyle (1991) and Spence et al. (2005) found evidence from past stream surveys to conclude that Coho Salmon populations historically existed in Mark West Creek.

In the early 2000s, the Broodstock Program conducted surveys in the lower Russian River and found limited numbers of wild juvenile Coho Salmon in only five creeks, including Mark West (Conrad 2006). A study conducted by Merritt Smith Consulting (2003) during the summer and fall months from 1993-2002 observed small numbers of Coho Salmon across their three Mark West Creek study reaches in 2001 only. Steelhead were observed in moderate numbers in each of the study reaches in most years, with greater abundances in the upper watershed (Merritt Smith Consulting 2003). The SCWA also conducted electrofishing distribution/abundance surveys in Mark West

Creek to detect steelhead and Coho Salmon in 2001 and found only steelhead throughout the creek, with numbers increasing from the most downstream to upstream survey sites (Cook and Manning 2002).

4.2 Habitat Suitability and Biological Criteria

Accurate representation of available habitat in relation to discharge requires linking stream channel hydraulics, over a range of flows, with known habitat suitability criteria (HSC) for the target species and life stages (CDFG 2008). The target species and life stage for this project have been identified as juvenile CCC steelhead and juvenile CCC Coho Salmon. Appropriate HSC are a critical element of hydraulic habitat modeling. No site-specific HSC have been developed for the above listed species in the Russian River watershed.

The creation of suitable HSC requires a minimum sample size of fish observations (typically greater than 150 per life stage/species, mesohabitat category, and microhabitat component) while also accounting for the influence of habitat availability on observed habitat use (Bovee 1986). HSC are developed by associating fish observations with water depth, velocity, cover, and other important site-specific microhabitat components, ideally in systems that have a minimally altered flow regime. To accomplish this, field-based techniques including fish snorkel surveys and measurements/classification of physical habitat attributes are employed based on methods described by Holmes et al. (2014). General guidelines for HSC development can be found in Bovee (1986), Bovee and Zuboy (1988), and CDFG (2008).

Obtaining representative and unbiased information is an important step in developing HSC. There are two factors that make the development of HSC uncertain in Mark West Creek. First, Mark West Creek has an impaired hydrograph and can be subject to sustained low flow conditions. Because of this, hydraulic habitat availability and associated fish behavior observed in a HSC study may not be representative of ideal conditions since fish are unable to utilize preferred habitat. Second, estimates of current Coho Salmon populations within Mark West Creek have been very low and it would likely be difficult to observe the required sample size. Instead, HSC from two coastal California watersheds will likely be used to support the habitat analysis of juvenile CCC steelhead and CCC Coho Salmon life stages in Mark West Creek: the Big Sur River (Holmes et al. 2014) and the South Fork Eel River (to be completed in 2018/2019).

4.3 Hydrology

The watershed's Mediterranean climate is characterized by arid to semi-arid summers and punctuated storm events during the winter and spring months. Long-term meteorological data coverage in the Mark West Creek subwatershed is limited and records from existing monitoring stations often have short periods of record, contain significant data gaps, or are situated in the lower elevations of the watershed making it difficult to characterize precipitation patterns in the mountainous upper watershed (Woolfenden and Nishikawa 2014). Because precipitation within the watershed is strongly influenced by topography (Nishikawa 2013), many analyses rely upon PRISM (Parameter-elevation Regressions on Independent Slopes Model) datasets, which use elevation and nearby meteorological stations to interpolate precipitation values for ungaged locations. Average yearly precipitation values vary from about 30 inches in the valley floor to about 47 inches in the Mayacamas Mountains, with a watershed average of approximately 40 inches[6] (800m PRISM 30-year normal, 1981-2010). In a 2015 report, the Center for Ecosystem Management and Restoration (CEMAR) presented information from a landowner in the upper watershed who recorded an annual average of approximately 65 inches (1965-2011), indicating that the PRISM normals are likely underestimates, at least in the upper watershed (CEMAR 2015). Although winter temperatures may be conducive to snow formation at the higher elevations, nearly all of the precipitation in the watershed falls as rain (Nishikawa 2013). Rantz (1972) analyzed streamflow and precipitation records (1931-1970) in relatively undeveloped watersheds including nearby Mill and Santa Rosa creeks, and found that roughly half of the precipitation that fell in those watersheds was converted into streamflow.

Springs and seeps such as those that contribute to Neal Creek, a small tributary in the headwater region of Mark West Creek, play an important role in maintaining water connectivity and perennial flows within the upper watershed (Nishikawa 2013; CEMAR 2015). Some of the tributaries to Mark West Creek also maintain minimal perennial flows through the dry season, though the majority undergo significant drying and generally lose surface connectivity with Mark West Creek (SRPBAP 2014). Baseflow, which comprises only a small portion of the hydrograph in Mark West Creek, is an extremely important component of flow during the dry season (Nishikawa 2013). Results from the USGS Santa Rosa Plain Hydrologic Model (SRPHM)[7] indicate that surface runoff is the main component of the hydrograph in Mark West Creek from November through April, while baseflow is dominant from May through October (Woolfenden and Nishikawa 2014). CEMAR (2015) indicated their multiyear streamflow monitoring conducted in upper Mark West Creek showed that, while consistently low, flows were relatively more stable over the course of each dry season compared to other Russian River tributaries in their monitoring network.

As with many streams subject to the seasonality of Mediterranean climates, the timing of higher streamflow in Mark West Creek and other Russian River tributaries in the late winter and spring does not coincide with the high demand in the summer and fall dry seasons (Deitch and Dolman 2017). CEMAR (2015) found that total annual rainfall and discharge generally surpass demand; however, demand in the summer and fall exceeds surface water availability leading to a reliance on wells and springs to meet dry season

[6] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed September 2017.
[7] The SRPHM is a groundwater-surface water model that was developed by the USGS. It is used to characterize a water balance including streamflow, groundwater recharge and storage, and the impacts of diversions on these hydrologic components. The model utilized information and data collected during a hydrologic characterization of the Santa Rosa Plain completed by the USGS in 2013 (Nishikawa 2013).

water needs (Deitch and Dolman 2017). This reliance upon wells and springs can have cumulative impacts on baseflow and likely contributes to the low flow conditions observed throughout the dry season, especially during extended periods of low rainfall (SRPBAP 2014; CEMAR 2015; Sonoma RCD 2015). Results from the 2015 informational order (see Section 2) show dense concentrations of groundwater wells along areas of Mark West Creek and its tributaries (Figure 2).

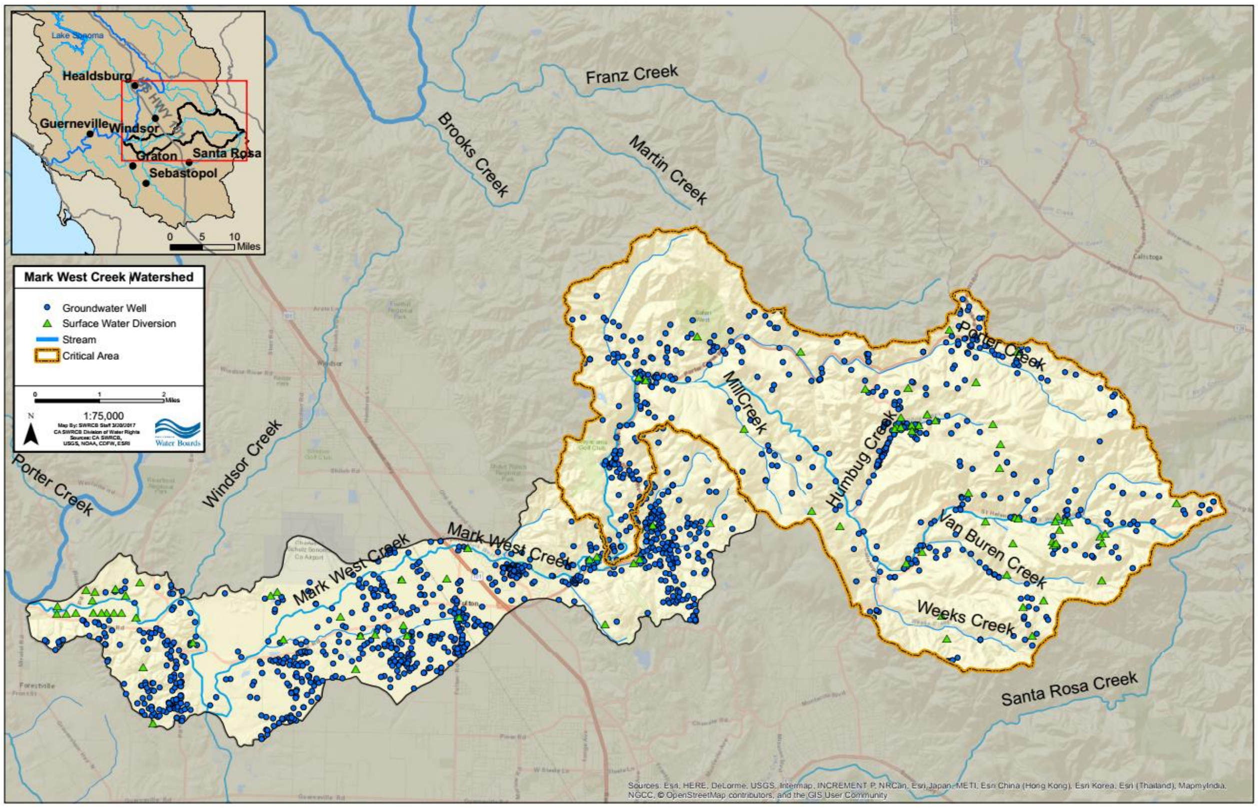

Figure 2**.** Diversions within the Mark West Creek subwatershed. Figure from SWRCB (2017).

Numerous streamflow gages have been operated across the Mark West Creek subwatershed (Figure 3 and Table 3), though meaningful hydrologic analysis is constrained by short periods of record, data gaps, and seasonal data collection (Sloop et al. 2007; Nishikawa 2013). A USGS gage near Mirabel Heights (USGS 11466800) has the longest period of record within the watershed, with approximately 12 years of data starting in the 2006 water year (WY). This gage is located downstream of Mark West Creek's confluence with two large tributaries, the Laguna de Santa Rosa and Windsor Creek. The lack of flow information for these contributing tributaries means the amount of flow originating from upper Mark West Creek cannot accurately be discerned. CEMAR has operated three gages to varying lengths during WY 2010-WY 2017. One of these gages, MW01, is located high in the watershed near Tarwater Road. This gage provides the best available indicator of conditions in the upper watershed during the dry season. Average daily streamflow at MW01 has generally dropped below 1 cubic foot per second (cfs) by May or June. The minimum and maximum average daily summer flows captured at MW01 over the period of record were 0.06 and 11.8 cfs, respectively. The mean and median average daily flows during the same period were 0.41 and 0.22 cfs, respectively. The lack of a long-term, year-round gage network throughout the watershed makes it difficult to assess flow regimes and to understand how the range of flows can affect biological processes and species recovery in the creek (Honton and Sears 2006).

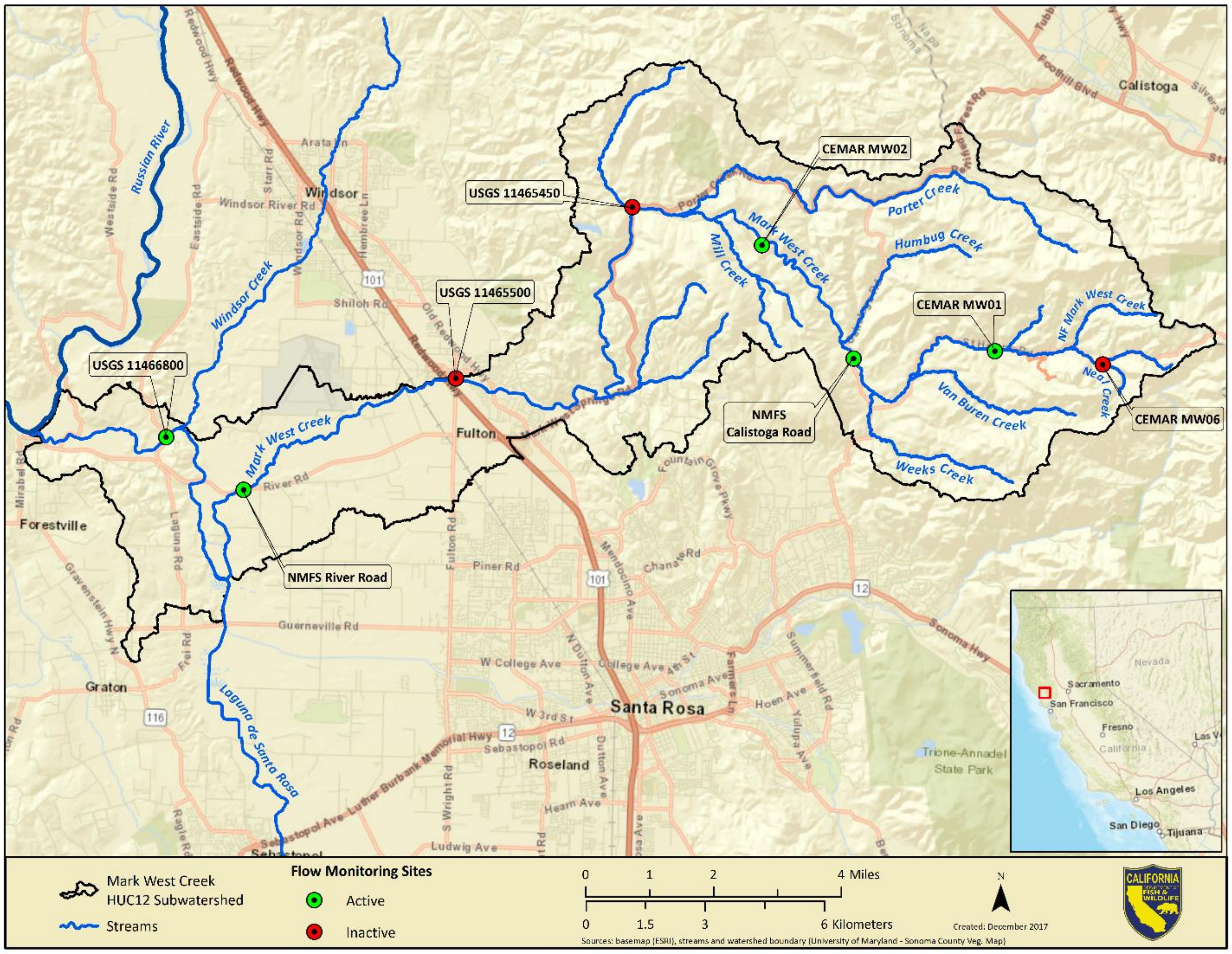

Figure 3. Streamflow monitoring gages in the Mark West Creek subwatershed.

Table 3. Streamflow monitoring gages within the Mark West Creek subwatershed.

Operator	Gage Identifier	Period of Record	Notes
USGS	11466800 Mark West Creek near Mirabel Heights	October 2005-Present	Some small data gaps in record, and a large gap for most of WY 2010. Gage sometimes influenced by backwatering from Russian River during high flows.
NMFS	Mark West Creek at River Road	November 2011-Present	Significant data gaps.
USGS	11465500 Mark West Creek near Windsor	October 2006-April 2008	Significant data gap in second half of WY 2007.
USGS	11465450 Mark West Creek at Mark West Springs	1958-1962	Peak annual discharges only.
CEMAR	MW02 Mark West Creek above Porter Creek	May 2010-Present	Record covers mostly low flow periods. Significant recent data gaps.
NMFS	Mark West Creek at Calistoga Road	October 2011-Present	Discharge extrapolated above 30 cfs. Some data gaps.
CEMAR	MW01 Mark West Creek below Tarwater Road	March 2010-Present	Early records were mostly year-round with discharges estimated below 50 cfs only. Some small data gaps. Since WY 2015, only seasonal low flow measurements taken.
CEMAR	MW06 Mark West Creek at Neal Creek	June 2011-November 2014	Record covers mostly low flow periods. Some small data gaps.

Long-term unimpaired streamflow records are generally used by the Department IFP to aid in the determination of a range of representative target flows for field data collection. The lack of long-term gages in the Mark West Creek subwatershed, as well as the surrounding watersheds, complicates the unimpaired streamflow determination. Given this, to identify target flows for data collection in upper Mark West Creek the Department intends to select an appropriate range of flows based on unimpaired average monthly flow estimates (1950-2015) from the California Natural Flows Database[8] (CNFD; Zimmerman et al. 2017). The unimpaired average monthly flow estimates in the stream reach (COMID 8272495) located near the CEMAR MW01 gage will serve as the basis for a flow duration analysis, which estimates the likelihood of a particular discharge value being equaled or exceeded (referred to as an exceedance flow; CDFW 2013b; Searcy 1969). The unit of time used to calculate exceedance flows affects the utility of the flow duration curve (i.e., a shorter time unit will result in a greater representation of flow variability). The CNFD only provides average monthly unimpaired flow estimates. While exceedance calculations using the average monthly estimates may result in diminished flow variability, the CNFD provides the best available information for calculating target flows. Target flows for data collection on upper Mark West Creek will likely fall within the 20 to 80 percent exceedance flow range (CDFW 2013b). The 20, 50, and 80 percent exceedance flows estimated for this reach of upper Mark West Creek are 23.5, 2.9, and 0.5 cfs, respectively.

4.4 Groundwater Hydrology

The Mark West Creek subwatershed overlies three groundwater subbasins identified in the Department of Water Resources' (DWR) Bulletin 118 (DWR 2003), though the subbasins' areal extent within the watershed varies. The upper Mark West Creek subwatershed overlies small sections of both the Rincon Valley Subbasin (1-55.03) and the Alexander Subbasin (1-54.01). Most of the lower Mark West Creek subwatershed overlies the Santa Rosa Plain Subbasin (1-55.01). In addition to these named subbasins, small, localized aquifers likely exist within the alluvial deposits along the stream channels in the middle watershed (Nishikawa 2013). The Sonoma Volcanics, which comprise a significant portion of the Mayacamas Mountains in the upper watershed, can also contain disconnected aquifers within fractured or porous strata (Cardwell 1958; Nishikawa 2013). Groundwater that discharges from springs and seeps provides a significant source of baseflow in parts of Mark West Creek (Nishikawa 2013), especially within the Sonoma Volcanics (Cardwell 1958).

The geologic heterogeneity surrounding Mark West Creek, especially in the mountainous upper watershed, results from the numerous fault zones that traverse the area as well as the interaction between the North American and Pacific tectonic plates that formed the Mayacamas Mountains and northern California Coast Ranges (SRPBAP 2014; RRISRP 2016). The interactions that result from the juxtaposition and

[8] The California Natural Flows Database was a collaborative effort between the USGS and The Nature Conservancy to develop estimates of natural (unimpaired) flows for all of the streams in California from 1950-2015 (Zimmerman et al. 2017).

interfingering of these geologic units can affect groundwater flow and yields (Nishikawa 2013). For example, evidence suggests that Mark West Creek likely gains streamflow near the Rodgers Creek fault zone, where shallow groundwater originating in the mountainous upper watershed mounds and discharges to the creek as a result of the horizontal flow barrier (SRPBAP 2014).

Several surficial geologic units are present in the upper Mark West Creek subwatershed including Quaternary Alluvium, the Sonoma Volcanics, and the Franciscan Assemblage (Nishikawa 2013; CEMAR 2015); the Sonoma Volcanics are the dominant unit in terms of areal coverage (Nishikawa 2013). The Sonoma Volcanics are generally porous and can be highly fractured in areas, allowing for development of wells (RRISRP 2016), though their yield is highly variable and is dependent upon the extent of fracturing (Cardwell 1958; Nishikawa 2013). Due to the inconsistent fracturing within the Sonoma Volcanics, determining the direct impacts of groundwater pumping is difficult (CEMAR 2015). Although domestic wells have tapped into areas of fractured bedrock that underlie the Sonoma Volcanics, the existence of groundwater within the Franciscan complex is much more limited and the wells consistently have low yields (Nishikawa 2013). Where wells exist in the upper Mark West Creek subwatershed, the alluvial deposits generally consist of coarse material (Nishikawa 2013), which leads to higher streambed conductivities and a greater potential for groundwater-surface water interactions (SRPBAP 2014).

Lower in the watershed, both the Sonoma Volcanics and the Glen Ellen Formation outcrop in the area surrounding the Rodgers Creek fault zone (SRPBAP 2014). In the lower Mark West Creek subwatershed, the valley is comprised of quaternary alluvium and loosely consolidated alluvial deposits of the Glen Ellen Formation (SRPBAP 2014). Well pumping yields within the Glen Ellen Formation are highly variable (DWR 1975) and the alluvial deposits are generally comprised of finer material than those found in the upper Mark West Creek subwatershed, leading to lower conductivities and infiltrative capacity (SRPBAP 2014).

4.5 Connectivity

Low streamflow can limit the hydrologic connectivity of riverine habitats, impacting water quality, food production, and critical salmonid life history strategies. Salmonids have learned to survive in systems with long low flow periods by rearing in deep pools and runs throughout the summer and fall months (Moyle 2002; CDFG 2004). Disconnected stream segments can prevent juvenile salmonids from relocating to suitable over-summer holding habitat having adequate cover and water quality conditions. Due to various factors such as climate, water diversions, antecedent precipitation, and groundwater-surface water interactions, sections of Mark West Creek become disconnected during the dry season. Merritt Smith Consulting conducted seasonal fisheries surveys from 1993-2002 along three reaches of Mark West Creek and observed that the reach in the upper watershed downstream of Calistoga Road occasionally became intermittent in the late spring and summer months, forcing fish to rear in isolated pools (Merritt Smith Consulting 2003).

The watershed's Mediterranean climate and lack of precipitation during summer months is a significant factor contributing to seasonal low flows and intermittence in Mark West Creek (CEMAR 2015). Additionally, springs and seeps that help maintain stream connectivity in the upper watershed are frequently diverted during the dry season when streamflow is already naturally low. While unintentional, baseflow may be impacted by the cumulative impact of diversions, depending on the extent of groundwater-surface water interconnection (CEMAR 2015).

In 2013, the UC Cooperative Extension added Mark West Creek to their list of streams monitored for wetted habitat conditions (wet/dry mapping)[9] during the low flow period. The objective of the wet/dry mapping effort is to document the extent and location of wet, dry, and intermittent instream habitat during the driest period of the year, which usually occurs in September. The effort has indicated that Mark West Creek remains wetted through most of the middle and upper watershed, though streamflow remains low. In the alluvial reach near the Porter Creek confluence (middle watershed), Mark West Creek has experienced dry or intermittent conditions each year since 2013, with the exception of 2014.

4.6 Geomorphology

The Mark West Creek subwatershed is situated within the Northern Coast Range geomorphic province. The Mayacamas Mountain Range that comprises much of the terrain in the upper Mark West Creek subwatershed was formed as a result of complex tectonic interactions between the North American and Pacific plates. Mark West Creek and its tributaries have eroded the Mayacamas Mountains over time, transporting and depositing sediment into the mountain valleys and alluvial fan in the valley below. The northwest trending Rodgers Creek fault zone acts as a rough boundary between the sediment production zone of the upper watershed and the depositional zone in the valley floor (Sloop et al. 2007).

Hydrologic soil group classifications (NRCS 2007), which are based on soil properties such as permeability and soil thickness, can be a useful tool in understanding a watershed's response to precipitation. In general, soils in the lower portion of the watershed have low-moderate runoff potential, while soils in the mountainous upper watershed are thinner with a significant amount of exposed bedrock, leading to a moderate-high runoff potential (Nishikawa 2013). Landscape alteration and disturbance can also affect runoff, erosion processes, and sediment transport. Historical landscape changes in the Mark West Creek subwatershed such as road development, timber harvest, and rural subdivisions, as well as shifting land use practices (e.g., grazing and vineyard development), have contributed to higher rates of runoff and sedimentation (Sloop et al. 2007; Sonoma RCD 2015).

[9] Information on wet/dry mapping available at: https://caseagrant.ucsd.edu/project/coho-salmon-monitoring/flow-and-survival-study.

The upper and middle portions of the watershed are comprised of moderate gradient channels that drain steep hillsides (Nishikawa 2013). In the valley floor, as Mark West Creek traverses its alluvial fan, the channel assumes a more modified character with a relatively straight, channelized, and entrenched channel (RRISRP 2016). An analysis of generalized stream typologies presented in the 2016 RRISRP report, developed by Walls (2013), suggests that five different stream types exist within Mark West Creek: dissected alluvium, unconfined alluvial, alluvial fan, semiconfined alluvial, and bedrock canyon. The alluvial channel forms are dominant in the valley floor up to the transition zone near the Rodgers Creek Fault. With the exception of a dissected alluvium channel downstream of the Porter Creek confluence, bedrock canyons and semiconfined alluvial channels dominate the upper watershed (RRISRP 2016).

Few on-the-ground assessments of the stream channel have been completed in Mark West Creek; the most recent watershed-wide mainstem survey was conducted by the SCWA in 1996 (CDFG 2006). The surveyors identified six different reaches and channel types from the downstream extent up to the Neal Creek confluence: F4, F2, B2, B3, C3, and B1-2 (Table 4). Flatwater habitat was the dominant Level II habitat type and comprised approximately 50% of the stream length, followed by approximately 40% pool habitat, 8% riffle habitat, and 1% dry channel (CDFG 2006).

Table 4. Mark West Creek channel types, presented from downstream to upstream.

Channel Type	Description
F4	Entrenched, meandering riffle/pool channel with low gradient and high width/depth ratio; gravel-dominated substrate
F2	Entrenched, meandering riffle/pool channel with low gradient and high width/depth ratio; boulder-dominated substrate
B2	Moderately entrenched, riffle-dominated channel with moderate gradient; boulder-dominated substrate
B3	Moderately entrenched, riffle-dominated channel with moderate gradient; cobble-dominated substrate
C3	Low-gradient, meandering, riffle/pool alluvial channel with well-defined floodplain; cobble-dominated substrate
B1-2	Moderately entrenched, riffle-dominated channel with moderate gradient; boulder- and bedrock-dominated substrate

Source: Rosgen (1994).

Following two landslides that contributed large amounts of fine sediment to upper Mark West Creek in the mid-2000s, Li and Parkinson (2009) assessed instream habitat in a small section of the upper watershed from Tarwater Road up to the confluence with North Fork Mark West Creek. In this assessment, pools were identified as a the dominant Level II habitat type and comprised approximately 68% of the stream length, followed by approximately 20% riffle habitat, 11% flatwater habitat, and 1% dry channel (Li and Parkinson 2009).

4.7 Water Quality

Pursuant to section 303(d) of the Clean Water Act, the State Water Board is responsible for assessing, protecting, and restoring surface water quality and submitting a list of impaired water bodies to the U.S. Environmental Protection Agency (EPA). The State Water Board has listed Mark West Creek and its tributaries upstream of the confluence with the Laguna de Santa Rosa as 303(d) impaired water bodies for sedimentation and temperature. Downstream of the confluence with the Laguna, Mark West Creek is also impaired for aluminum, dissolved oxygen, phosphorous, and manganese.

The NMFS Multispecies Recovery Plan (2016) also rates the entirety Mark West Creek as poor for temperature and watershed processes/sediment transport as they relate specifically to the rearing life stage of juvenile steelhead. Because juveniles rear in the creek throughout the year, Moyle (2002) and NMFS (2008) highlight the importance of maintaining temperatures below approximately 57°F, the maximum optimal temperature for rearing steelhead and Coho Salmon. Additionally, Reiser and Bjornn (1979) and Moyle (2002) note that high levels of suspended fine sediments can adversely impact rearing habitat and food availability, and can negatively impact survival by damaging the gills of juvenile fish. In an attempt to help address impairments caused by sediment, Pacific Watershed Associates assessed approximately half of the unpaved roads in the upper Mark West Creek subwatershed for potential sediment delivery sites (Sonoma RCD 2015). Other water quality related assessments in the watershed have generally been short-term and sporadic in nature, focused mainly on temperature. In general, targeting the causes of temperature-related impairments has been difficult. The Sonoma Resource Conservation District (RCD) noted that temperature loggers deployed over several years in reaches along St. Helena Road have consistently recorded water temperatures below 70°F through the low flow season, whereas temperatures lower in the creek near the Porter Creek confluence are significantly warmer, typically surpassing 70°F by mid-June (Sonoma RCD 2015). In the lower reaches, it is suspected that the higher temperatures result from lack of riparian canopy cover (NMFS 2016) and cold-water spring inputs (Sonoma RCD 2015).

4.8 Tubbs Fire

In October 2017, the Tubbs Fire burned approximately 57 square miles across sections of Napa, Sonoma, and Lake counties, including approximately 22 square miles (37%) of the Mark West Creek subwatershed. The burn area spanned 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. In addition to water quality and biological impacts, the fire may affect the hydrology of Lower Mark West Creek. Depending on the upslope burn severity, CalFire (2017) predicted that the 10%

exceedance flow (CDFW 2013b) in reaches of Mark West Creek could increase anywhere from 9-25%. Due to the likelihood of channel instability (e.g., channel aggradation) after the Tubbs fire, the potential study area has been constrained to the reaches of Mark West Creek above Calistoga Road (Figure 4).

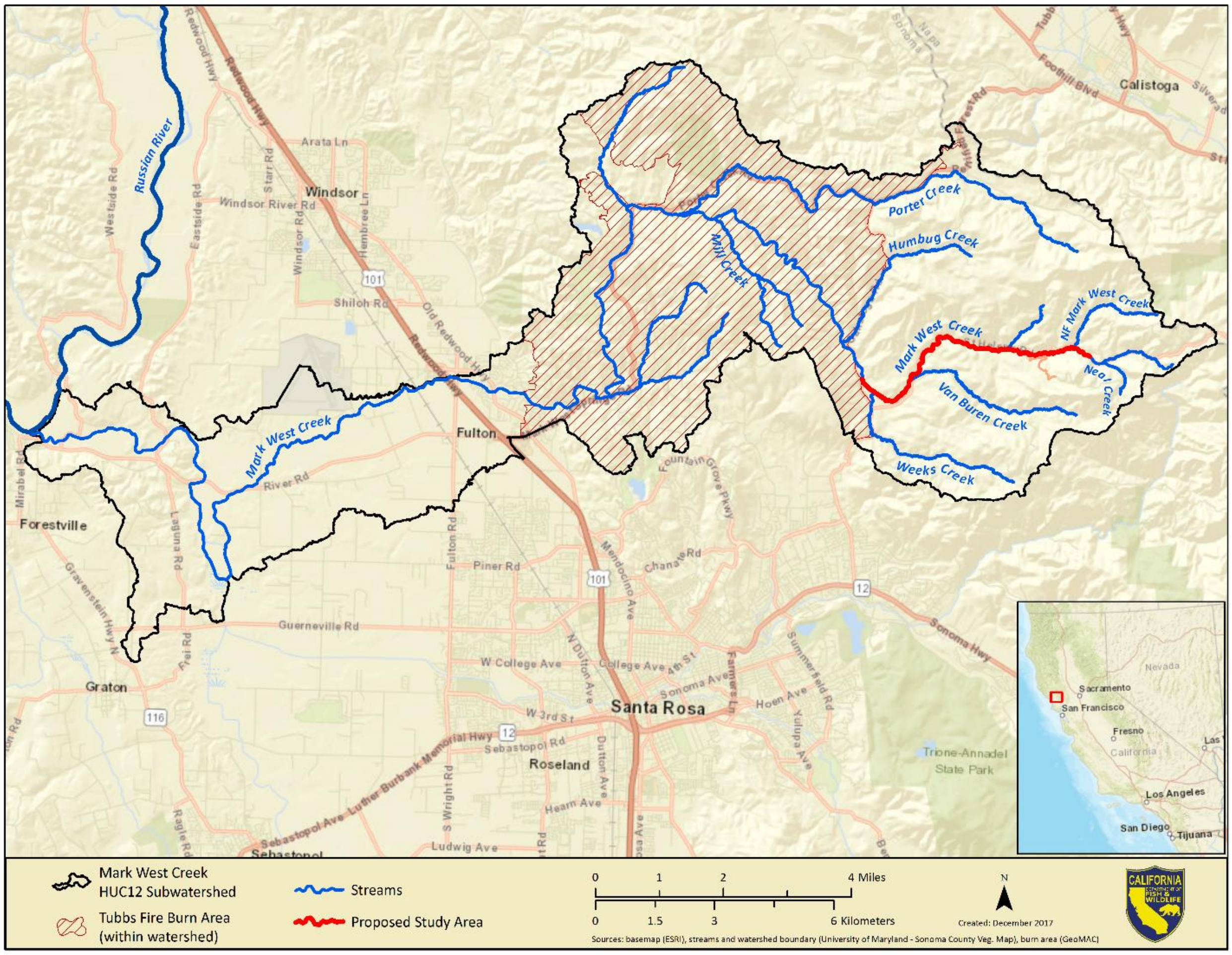

Figure 4. Map of the Mark West Creek subwatershed showing the Tubbs Fire burn area and the proposed study area.

5.0 METHODS AND PROTOCOLS

Department staff will conduct a stream survey within upper Mark West Creek following the Level III-IV (i.e., modified Level III) habitat type survey classifications, as described in the *California Salmonid Stream Restoration Manual* (Flosi et al. 2010) to identify mesohabitat types (CDFW 2015a). A corresponding discharge measurement (CDFW 2013a) will be measured each day of the survey; data will only be collected where landowner access is granted. Upon completion of the survey, the modified Level III mesohabitat classifications will be grouped into riffle, pool, run, or glide categories. The classification of different habitat types is based on characteristics such as channel morphology, gradient, substrate composition, and hydraulic characteristics. The assemblage and overall proportion of each mesohabitat type will help guide site selection for hydraulic habitat modeling (CDFW 2015c).

Mesohabitats were mapped using the on-the-ground method and are typed to the most detailed level III-IV typing as described in Flosi et al. (2010). This level of habitat delineation allows data to be used for other studies or aggregated into less detailed levels depending on the needs of individual studies (e.g. hydraulic habitat modeling). These surveys entail the identification of habitat types using specified criteria, along with measurements of habitat unit length and maximum pool depth for pool units. In addition, landmarks such as road crossings, bridges, and significant streambank alterations are noted.

Each habitat unit will be characterized as modelable or unmodelable according to the limitations of standard one-dimensional (1D) and two-dimensional (2D) hydraulic modeling methods. Modelable, in this context, is a term used to characterize a habitat unit's hydraulic properties and refers to whether the unit's water surface along a hypothetical transect would remain steady and flat over a broad enough range of flows to develop a predictive model. This characterization is necessary for the dataset to be compatible with stratified study site and transect selection techniques, where unmodelable mesohabitat units may be rejected prior to the selection process.

Below is a list of modified Level III mesohabitat types containing sufficient detail for the purpose of transect placement, hydraulic data collection, and transect weighting consistent with stratified sampling for hydraulic habitat modeling. The following mesohabitat types are generally considered modelable and should be retained for study site and transect selection:

- Pool (e.g., mid-channel, lateral scour, channel confluence)
- Glide
- Run/Step-run
- Pocket Water
- Low-Gradient Riffle

The following mesohabitat types are generally considered unmodelable and should be excluded from study site and transect selection:

- Cascade
- Chute
- High-Gradient Riffle

For hydraulic data collection, cascade and chute types are not sampled. High-gradient riffles may occasionally be sampled, but the determination must be done on a case-by-case basis.

Ideally, surveys will be conducted under flow conditions at which the mesohabitat types are readily apparent. That is, not when flows are so high that it appears as though all unit types are either runs or riffles or so low that there are only pools with undifferentiated riffles in between. For safety purposes, the survey team(s) will consist of at least two staff members familiar with salmonid habitat requirements. Team members will already have experience with or will have received recent training in habitat typing methods. At least one member of each survey team should be sufficiently experienced with hydraulic habitat modeling to classify each mesohabitat unit as modelable or unmodelable, irrespective of mesohabitat unit type.

5.1 Single Transect Hydraulic Based Habitat Methods

Single transect hydraulic based habitat methods require site-specific data to be collected along one or more transects within a stream reach. The site-specific data are used with a computer program to model hydraulic parameters. Single transects are placed across the shallow portion (i.e., hydraulic control) of representative riffles. Single transect hydraulic based habitat methods assume that if adequate conditions are maintained over the shallow portions of a stream reach, then the hydraulic habitat in other parts of the stream reach will also be sufficient (Annear et al. 2004).

5.1.1 Habitat Retention Method

The Habitat Retention Method (HRM; CDFW 2016) is a single-transect biology-based method (Nehring 1979) used to estimate hydraulic characteristics (i.e., average depth, average velocity, and percent wetted perimeter) over a range of flows. The HRM quantifies a minimum flow, sufficient to provide a basic survival level for fish during times of the year when streamflow is at its lowest (Annear et al. 2004). With a goal of sampling at least three representative riffles per reach, the method assumes that if a prescribed flow adequately meets hydraulic criteria at the shallowest part of the riffles (i.e., the hydraulic control), then conditions throughout the remainder of the reach should also be sufficient (Nehring 1979; Annear et al. 2004). The HRM may also be used to evaluate fish passage and/or habitat connectivity flows at riffle sites.

5.1.2 Wetted Perimeter Method

The Wetted Perimeter Method (WPM) is used to determine flows that support the maintenance of benthic macroinvertebrate (BMI) habitat and productivity in riffles with rectangular streambed profiles. The WPM is typically applied during the summer and/or fall low flow months (Annear et al. 2004, CDFW 2013d). The wetted perimeter refers to the perimeter of a cross-sectional area of the wetted streambed along a transect, which varies according to discharge. After collecting WPM data and corresponding discharges, a relationship between discharge and wetted perimeter can be developed. Historically, application of the WPM required collecting data over an expansive range of discharge events to determine the relationship between wetted perimeter and discharge at each site. Recent applications of the WPM generally use computer-based water surface profile modeling programs based on the Manning's equation to develop this relationship (Annear et al. 2004). Using the graphical relationship between wetted perimeter and discharge, the inflection point on the wetted perimeter/discharge curve is identified as a threshold where it is assumed that the corresponding flow can protect BMI production at an adequate level to sustain fish populations (Annear et al. 2004).

5.2 Hydraulic Habitat Modeling

Hydraulic modeling, in conjunction with depth, velocity, and substrate/cover criteria for the target fish species and life stage(s) can be used to determine the relationship between streamflow and suitable habitat. One-dimensional or two-dimensional hydraulic-based habitat models are designed to predict hydraulic conditions within a reasonable range of flow levels that are not sampled. Study site selection for 1D or 2D modeling will depend on reach access, the need for applying a 2D model, and channel complexities identified through habitat mapping.

Any currently available standard software package that meets the standards set by Waddle (2000) can be used for 1D habitat modeling. Except in reaches with highly complex channel hydraulics, reaches of most river channels can be adequately evaluated with standard 1D hydraulic models such as those found in PHABSIM (Waddle 2001), SEFA (Payne and Jowett 2012), or similar programs.

In highly complex channels where depth and velocities cannot be accurately predicted using a single transect approach, a 2D hydrodynamic model is often used to predict flow characteristics and features of ecological importance (Crowder and Diplas 2000; Waddle 2010). While virtually any available 2D model can be used for hydraulic assessment, the modeling software River2D (Steffler & Blackburn 2002) is frequently used by the Water Branch. River2D has the ability to evaluate fish passage criteria for depth and velocity along with site-specific topographic features to produce relationships between flow and habitat suitability or passage conditions.

5.3 Single Transect Hydraulic Based Habitat Method Data Collection

Department staff identify representative riffle sites for HRM and WPM that are representative of the overall geomorphic structure and shape of the reaches of interest within the study area (CDFW 2016). Once sites are selected, cross-sectional transects are established along the hydraulic control of each riffle with a measuring tape and a headpin and tailpin positioned on the left bank and right bank, respectively. The pins are placed at or above the bankfull elevation. For the purposes of this method, bankfull elevation is defined as the location where the vegetation emerges at the toe of the bank, there is a change in slope along the cross-sectional channel profile, and/or there is a change in substrate composition from coarser to finer material (CDFW 2016). Bed elevations are measured along each transect using an auto level and surveying stadia rod at one-foot intervals following the procedures set forth in the Department's standard operating procedure (SOP) for Streambed and Water Surface Elevation Data Collection (CDFW 2013c). Smaller increment measurements are taken in areas with highly variable bed topography. In addition, water surface elevations (WSELs) are measured mid-channel and near each bank to determine the water surface profile along the transect (CDFW 2013c). The length of the riffle along with WSELs measured near the left and right bank at the downstream extent of the riffle are used to compute the water surface slope. A temporary staff gage is used to monitor the stage at the beginning and end of each data collection event to ensure that flow levels do not fluctuate during the course of data collection. A discharge measurement is taken for each transect using a flow meter and top setting wading rod (CDFW 2013a), or if one exists, flow data from a nearby stream gage can be paired with the date and time the transect was surveyed. Discharge measurements are then associated with the survey data to estimate hydraulic properties using Manning's equation for open channel flow.

Along with the measured discharge (Q) and calculated channel slope (S), the bed elevation data are used to calculate the flow area (A), wetted perimeter (P), and hydraulic radius (R) for the cross-section. These values are then used to calculate the Manning's roughness coefficient (n) using the Manning's equation for open channel flow, given below:

$$\mathrm{Q} = \left(\frac{1.486}{\mathrm{n}}\right)\mathrm{AR}^{\frac{2}{3}}\mathrm{S}^{\frac{1}{2}}$$

While several programs are capable of modeling these hydraulic parameters, the Department generally uses the commercially available software program Hydraulic Calculator (HydroCalc; Molls 2008). HydroCalc is based on the Manning's equation and can be used to develop discharge rating curves in addition to estimating the listed hydraulic parameters (see HRM SOP for procedures; CDFW 2016).

For HRM, when the criteria for average depth and at least one other parameter are met (Table 5), flows are assumed to be adequate for habitat connectivity and aquatic ecosystem habitat maintenance. For the WPM analysis, a relationship between discharge and wetted perimeter is developed (CDFW 2016). The breakpoint and incipient asymptote (curve inflections), are identified as thresholds of desired habitat conditions. These curve inflections (i.e., the breakpoint and incipient asymptote) are used to determine the instream flow needs necessary to maintain riffle habitat and production of benthic macroinvertebrates.

Table 5. Key flow parameters used to determine flow criteria in riffle habitats using the HRM.

Bankfull Width (ft)	Average Depth (ft)	Average Velocity (ft/sec)	Wetted Perimeter (%)
1-20	0.2	1.0	50
21-40	0.2-0.4	1.0	50
41-60	0.4-0.6	1.0	50-60
61-100	0.6-1.0	1.0	70

Sources: Nehring 1979; CDFW 2016

5.4 Hydraulic Habitat Modeling Data Collection

The number and range of river flows, mesohabitats, reaches, and transects sampled within river segments influence the extrapolation range, representativeness, applicability, reliability, and utility of any model. It is critical that discharges, mesohabitats, and microhabitats are effectively sampled in order to develop usable 1D and/or 2D simulations. The Department's standard for 1D analyses is to include: a) sampling of at least three distinct river flows; b) sampling of three units of each significant mesohabitat type within each generally homogeneous river segment; and c) for simulations, at least three transects within each mesohabitat unit. The actual number of flows, mesohabitats, or transects sampled may be dependent upon the complexity of riverine conditions, the length of homogeneous reaches, the study objectives, and landowner access. In specific cases, it may be appropriate to sample less or more than three replicates of each mesohabitat unit, three microhabitat transects per unit, and/or water depth and velocity characteristics at a range of at least three flows.

Hydraulic and structural parameters are measured using a combination of standard techniques from the U.S. Fish and Wildlife Service (USFWS) methodology (Trihey and Wegner 1981; Bovee 1982; Bovee 1997; Bovee et al. 1998; USFWS 2011). The data collected at the upstream and downstream transects at each site (i.e., site boundaries) include: 1) WSELs; 2) wetted streambed elevations; 3) dry ground elevations to points above bankfull discharge; 4) mean water column velocities measured at the points where bed elevations are taken; and 5) substrate and cover classification at locations where wetted streambed and dry ground elevations are surveyed (CDFW 2013c; CDFW 2015c). If there is a hydraulic control downstream of a given transect, differential leveling is used to survey the stage of zero flow, which is found in the thalweg downstream of the transect.

Each cluster of transects, or each transect if need be, should have a corresponding discharge that accurately represents the conditions at the time of survey. A temporary staff gage is used to monitor the stage at the beginning and end of each data collection event to ensure that flow levels do not fluctuate during the course of data collection.

Continuously recording water level loggers may be deployed in certain reaches to monitor changes in stage during calibration measurements. Bed topography, substrate data, instream/overhead cover, water surface elevations, velocity profiles, and associated discharges are collected.

Two-dimensional hydrodynamic models use depth-averaging techniques to simulate water depth and velocity in sites with complex flow patterns. Data collection for 2D models consists of detailed bed elevations, horizontal position, estimates of substrate composition, and instream/overhead cover. Transects at the upstream and downstream extent of a site are established and used to define the boundary conditions, which are determined by water stage, flow, and channel roughness. Channel roughness is an important hydraulic parameter that is characterized in the model by the bed topography and, to a lesser degree, the substrate size estimates. The upstream boundary requires an accurate inflow amount and the downstream boundary requires a corresponding WSEL for the given inflow. The bed topography data are collected with a total station and/or Real Time Kinematic Global Positioning System (RTK GPS) surveying equipment. Bed topography data are collected at a higher point density in areas with highly variable topography and patchy substrate and cover, and at a lower point density in areas with more uniform topography, substrate, and cover. Topography data are collected at a distance of one channel width upstream of the upstream transect to improve the accuracy of the flow distribution at the upstream end of the sites.

5.5 Hydraulic Habitat Modeling

One-dimensional hydraulic modeling procedures, appropriate to the study site, will be used to model water surface elevations and velocities at each selected cross-section. For WSELs, these procedures include the development of stage-discharge rating curves using log-log regression, hydraulic conveyance (MANSQ or similar), and/or step-backwater models (e.g., WSP, HEC-RAS); direct comparison of results; and selection of the most appropriate and accurate method. Water velocities will be simulated using the Manning's n method of velocity distribution across all transects, with calibrations generally consisting of correction of over- or under-simulated velocities at individual sample points (i.e., velocity adjustment factors, or VAFs). Data file construction, calibration, simulation, reporting, review, and consultation will follow standard procedures and guidelines.

Mesohabitat types are weighted and combined to develop a representation of hydraulic characteristics and fish habitat suitability for each 1D reach or sub-reach. Mesohabitat weighting is based on the relative proportion of each of the modeled mesohabitats within the reach or sub-reach. A final habitat index for each study site is produced by combining hydraulic simulations over a range of flows with HSC for the target species and life stage(s). Any currently available standard software package that meets the standards set by Waddle (2000) can be used for 1D habitat modeling.

Two-dimensional model calibration consists of adjusting the roughness values in the model until a reasonable match is obtained between the simulated water surface elevations and the surveyed water surface elevations as well as the channel's wetted edge measurements taken along the study site at a given flow. Models may be calibrated at a single flow and then validated at the two other flows, or the model can be calibrated at each measured flow.

Once calibrated, the downstream water surface elevation and the inflow to the 2D model site are changed to simulate the flows of interest. Each modeled flow is then run to a steady state solution. That is, for a constant inflow to the site, the model is run until there is a constant outflow and the two flows are essentially equal. Typical convergence tolerance is 1% of the inflow. Another measure of convergence is the solution change. Ideally the solution change will become sufficiently small (e.g., 0.00001) once converged. In some cases, the solution change will reach a relatively small value and refuse to decrease any further indicating a small, persistent oscillation at one or more points. This oscillation is often associated with a shallow node that alternates between wet and dry. This oscillation may be considered acceptable if the size of the variation is within the desired accuracy of the model (Steffler and Blackburn 2002).

At least 50 randomly selected paired depth and velocity measurements are collected (in addition to the depths and velocities measured along the upstream and downstream transects) to validate the 2D model[10] (USFWS 2011). The locations of the validation measurements will be distributed randomly throughout the site. The flow present during validation data collection will be determined from gage readings, if gage data are available. If gage data are not available, staff will measure the flow during validation data collection.

The fish habitat component of River2D is based on the same habitat index utilized in standard 1D models. The habitat index for the entire site is calculated by expanding the composite suitability index for every point in the model domain with the area associated with that point, and then summing those values for all points. The composite suitability is calculated as the product of suitability values for depth, velocity, and channel index (cover and substrate codes). The output includes node characteristics of habitat suitability values for depth, velocity, channel index (substrate and/or cover), and combined parameters at a number of flows for each species and life stage of interest. Model outputs at selected flows will also include image files of the plan view showing any change in suitability for each habitat parameter for each species and life stage.

The habitat index versus discharge function is a static relationship between discharge and habitat that does not represent how often a specific flow/habitat relationship occurs. For this reason, in many cases the index alone should not be considered the final result of a 1D or 2D model. A more complete analysis is known as a habitat time series (HTS) analysis. A HTS analysis integrates the habitat index versus flow function with hydrology to provide a dynamic analysis of flow versus habitat. Results of the HTS are

[10] 2D model calibration and validation will follow USFWS (2011) standards, as discussed in Section 6.1 Quality Assurance.

most useful when the broadest possible range of hydrology is used for the model. For this reason, it may be necessary to extend the stage-discharge rating curve beyond 2.5 times the highest calibration flow with additional stage-discharge measurements made during field data collection to support the analysis.

5.6 Temperature Monitoring

Water temperature data may be collected and evaluated as part of this study. Water temperature data would be recorded at a frequency of no less than hourly measurements at key locations throughout the study reaches using digital HOBO®, Solinst®, or TidbiT® data loggers. TidbiT® data loggers are used where water depths are anticipated to be too shallow to use the larger HOBO® or Solinst® loggers. Calibration, placement, sampling interval, and data processing of the logger data is done in a manner consistent with guidance provided by the U.S. Department of Agriculture (Dunham et al. 2005). Data loggers are generally placed in secured stilling wells or anchored to exposed roots along the banks of the creek in pool habitats using plastic cable zip ties. Suspending the loggers prevents them from being buried by sediment and keeps the instruments out of sight to avoid tampering by humans and/or animals. Any temperature data collected may be combined with existing temperature monitoring data when appropriate to assess temperature and discharge relationships during the rearing period.

6.0 QUALITY ASSURANCE/QUALITY CONTROL

All field equipment, including the Marsh-McBirney and HACH FH950 flow meters, will be calibrated according to manufacturer's instructions before data collection begins. Discharges will be measured following the protocols set forth in the SOP for Discharge Measurements in Wadeable Streams (CDFW 2013a). Velocities will be measured to the nearest 0.01 cfs. Water surface and bed elevations will be measured to the nearest 0.01 ft using standard surveying techniques (i.e., differential leveling) as described in the Streambed and Water Surface Elevation SOP (CDFW 2013c).

Wetted streambed elevations will be determined by subtracting the measured depth from the surveyed WSEL at a measured flow. WSELs will be measured at a minimum of three locations along each transect. WSELs measured along each transect for each survey event will be averaged together unless the surface is found to be sloped along the transect line or if a portion of the surface is determined to be unrepresentative of the water surface with respect to the transect stage-discharge relationship. The WSELs measured at each transect will be evaluated and a single representative WSEL will be derived consistent with the guidance provided in the PHABSIM User's Manual (Waddle 2001). WSELs will be collected at a minimum of three relatively evenly spaced calibration flows, spanning approximately an order of magnitude. Model calibration flows will be selected so that the lowest simulated flow is no less than 0.4 of the lowest calibration flow and the highest simulated flow is at most 2.5 times the highest calibration flow. If a 2D model is used for the study, the accuracy of the 2D bed topography elevations collected should be 0.1 ft and the horizontal accuracy should be at least 1.0 ft (USFWS 2011).

The Department will use the USFWS (2011) standards for calibrating and validating any two-dimensional hydraulic habitat model, if used. The standards include:

- Mesh Quality: the quality of the fit between the final bed profile and the computational mesh, as measured by the Quality Index value, should be at least 0.2.
- Solution Change/Net Flow: when the model is run to steady state at the highest flow simulated, the solution change should be less than 0.00001 and the net flow should be less than one percent.
- Froude Number (FN): the maximum FN for low gradient streams should be less than one.
- Water Surface Elevation: if developing a 2D model, WSELs predicted at the upstream transect should be within 0.1 foot of the WSEL predicted by PHABSIM for the highest simulated flow (or observed at the highest measured flow).
- Velocity Validation: the correlation between at least 50 spatially-distributed measured and simulated velocities should be greater than 0.6.

Data sheets will be checked in the field by a designated field team lead to ensure that all data and relevant information has been collected for the given method(s) being used. All data are transferred from field data sheets into an electronic format upon returning from field data collection events, and quality control checks will be conducted for every electronic data sheet to ensure that the data were translated correctly. If data collection errors are discovered, the Project Coordinator will review the issues with the appropriate personnel to develop a plan for corrective action so that resampling, if required, can be scheduled during the same sampling season.

7.0 DATA MANAGEMENT AND REPORTING

Field data will be collected by Department staff from the Water Branch and, with resources permitting, Bay-Delta Region staff. Water Branch staff will prepare a final technical report with assistance from Bay-Delta Region staff. The Bay-Delta Region, Department Engineering, and Fisheries Branch will review the technical report.

7.1 Target Audience and Management Decisions

The Department has the responsibility to conserve, protect, and manage fish, wildlife, native plants, and their associated habitats. Accordingly, the Department has an interest in assuring that water flows within streams are maintained at levels that are adequate for long-term protection, maintenance, and proper stewardship of fish and wildlife resources. Using criteria generated from the flow study, the Department intends to develop flow recommendations for juvenile steelhead and Coho Salmon in upper Mark West Creek. These recommendations are not requirements that will be self-executing. Rather, they will represent beneficial uses relating to fish and wildlife preservation and enhancement to be considered by the Water Board in any future proceedings that the Water Board may or may not hold regarding applications for new diversions, permit requests, or other proceedings as set forth in Section 1257.5 of the California Water Code.

7.2 Coordination and Review

To the extent possible, entities or stakeholders that have an interest in the results and interpretation of the study may be involved in study scoping and implementation.

7.3 Data Management and Reporting

All data generated by this project will be maintained in field log books and/or data sheets, as well as in an electronic spreadsheet format. The Department will store the hard copies and electronic data. Final documents, including the technical report, will be posted on the Department's website.

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State of California
Natural Resources Agency
Department of Fish and Wildlife
Water Branch, Instream Flow Program
830 S Street
Sacramento, CA. 95811