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



STUDY PLAN Habitat and Instream Flow Evaluation for Anadromous Salmonids in the SOUTH FORK EEL RIVER AND TRIBUTARIES, Humboldt and Mendocino Counties



STUDY PLAN

February 2016

Instream Flow Study Plan- South Fork Eel River February, 2016

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Preface

This study plan document outlines the approach that will be used by the California Department of Fish and Wildlife (Department or CDFW) to evaluate instream flow needs for anadromous salmonids in the South Fork Eel River, Humboldt County. The California Water Action Plan¹ (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. Included in Action Four of the CWAP, the Department and State Water Resources Control Board (Water Board) were directed to implement a suite of actions to enhance instream flows within five priority watersheds. The South Fork Eel River is among these five priority streams. The Department plans to begin work on the South Fork Eel River study in early 2016 as part of a suite of actions to address instream flow enhancement for anadromous salmonid species.

The Department is Trustee Agency for California's fish and wildlife resources and as 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, CDFW seeks to maintain native fish, wildlife, plant species, and natural communities for their intrinsic and ecological value and for their benefits to all citizens in the State. This includes habitat protection and maintenance of habitat in sufficient amounts and quality to ensure the survival of all native species and natural communities.

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

Instream Flow Study Plan- South Fork Eel River February, 2016

Table of Contents

	3
1. Background	7
1.1 Project Background	8
2 Project Organization	۵
2.1 Project Dersonnel	J
2.1 Project Personner initial	9 0
	9
3. Project Task Description	10
3.1 Study Goals and Objectives	10
3.2 General Approach	11
4. Drainat Design and Mathedalamy	4.4
4. Project Design and Methodology	
4.1 Watershed Description	11
4.2 Biology	14
4.2.1 Larget Species and Lifestages	14
4.2.2 Habitat Suitability and Biological Criteria	15
4.3 Hydrology	16
4.4 Connectivity	
4.5 Geomorphology	22
4.6 water Quality	22
5. Procedures and Protocols	23
5.1 Study Design	23
5.2 Stream Survey and Habitat Mapping Procedures and Protocols	23
5.3 Empirical Methods	25
5.3.1 Connectivity	25
5.3.1 Connectivity 5.3.2 Ecological Benthic Invertebrate Productivity	25 28
5.3.1 Connectivity 5.3.2 Ecological Benthic Invertebrate Productivity 5.4 Field Data Collection Procedures and Hydraulic Model Protocols	25 28 28
5.3.1 Connectivity 5.3.2 Ecological Benthic Invertebrate Productivity 5.4 Field Data Collection Procedures and Hydraulic Model Protocols 5.5 Hydraulic Habitat Modeling	25 28 28 31
5.3.1 Connectivity 5.3.2 Ecological Benthic Invertebrate Productivity 5.4 Field Data Collection Procedures and Hydraulic Model Protocols 5.5 Hydraulic Habitat Modeling 5.6 Geomorphology Methods	25 28 28 31 33
 5.3.1 Connectivity	25 28 28 31 33 33
5.3.1 Connectivity 5.3.2 Ecological Benthic Invertebrate Productivity 5.4 Field Data Collection Procedures and Hydraulic Model Protocols 5.5 Hydraulic Habitat Modeling 5.6 Geomorphology Methods 5.7 Temperature Monitoring	25 28 31 33 33
 5.3.1 Connectivity	25 28 31 33 33 33
 5.3.1 Connectivity	25 28 31 33 33 34 34
 5.3.1 Connectivity	25 28 31 33 33 33 34 34 35
 5.3.1 Connectivity	25 28 31 33 33 33 34 34 35
 5.3.1 Connectivity	25 28 31 33 33 33 34 34 35 35
 5.3.1 Connectivity	25 28 31 33 33 33 34 34 35 35 35 35
 5.3.1 Connectivity	25 28 31 33 33 33 34 34 35 35 35 36 36
 5.3.1 Connectivity	25 28 28 31 33 33 34 34 35 35 35 35 36 36

Table 1: Roles and Responsible Parties	. 9
Table 2. South Fork Eel River Salmonid Lifestage Periodicity	15

Figure 1. Map of the South Fork Eel River Watershed	13
Figure 2. Map of South Fork Eel River Gaging Stations.	18
Figure 3. Annual Exceedance Flows for USGS Gage Station 11475800	20
Figure 4. Annual Exceedance Flows for USGS Gage Station 11475560	20
Figure 5. Annual Exceedance Flows for USGS Gage Station 11476600	21

1. Background

Salmon and steelhead (*Oncorhynchus* sp.) were historically distributed throughout the North Pacific Ocean from southern California to Point Hope Alaska, inhabiting most coastal streams within this range. However, factors such as overfishing, loss of habitat, and poor ocean conditions have led to a decrease in the number of viable salmonid populations as well as limited their distribution along the Pacific West Coast (NOAA 2011a). With salmonid populations at a fraction of their historical abundance, the National Marine Fisheries Service (NMFS) has listed 28 salmon and steelhead populations along the Pacific West Coast under the federal Endangered Species Act (ESA). The Department listed Southern Oregon/Northern California Coasts Evolutionarily Significant Unit (SONCC) coho salmon as threatened pursuant to the California Endangered Species Act.

The Eel River watershed historically supported a significant number of spawning SONCCcoho salmon with populations present in the Van Duzen, South Fork, Mainstem Eel River, North Fork, Middle Fork, Middle Mainstem, and Upper Mainstem Eel River (NMFS 2014). Although historically a prolific breeding ground for coho salmon, the number of independent coho salmon populations present within the Eel River watershed has continued to decrease with observed numbers critically low and some populations thought to be extirpated (Yoshiyama & Moyle 2010). Coho salmon have undergone a minimum 70% decline in abundance since the 1960s, and are currently at 6 to 15% of 1940s abundance estimates (CDFG 2004). Further, within the SONCC, only the South Fork Eel River population of coho salmon is likely to be above its depensation threshold (NMFS 2014). Underlying themes to recovery activities identified in the NMFS 2014 Final Recovery Plan for the Southern Oregon/Northern California Coasts Evolutionarily Significant Unit of Coho Salmon include; the removal of migration barriers, the establishment of fish passage facilities at dams, the reduction in unpermitted water diversions, establishing sufficient water quantity and quality, restoration and improvement of instream and riparian habitat, and creation of suitable estuarine nurseries.

The threatened status of California Coastal Chinook (CC Chinook) was also reviewed. Although individual watersheds indicated short term increases in CC Chinook population abundance, overall long term negative population trends were realized (NOAA 2011b). However, NOAA (2011b) recognized a high level of uncertainty surrounding the available abundance information pertaining to the CC Chinook ESU, and suggested that more exhaustive and spatially representative surveys be completed to evaluate the population status within the ESU.

In 1996 the Department released the Steelhead Restoration and Management Plan (CDFG 1996). The plan reported that California's north coast supports the largest populations of North Coast steelhead and contains the greatest amount of steelhead habitat in the State. The Eel River watershed specifically, supports both summer and fall runs of steelhead. However, it has been documented that all steelhead populations present in the Eel River watershed, including the South Forth Eel River, have declined significantly from historic levels (CDFG 1996; NOAA 2011c). The key elements outlined in the Steelhead Restoration and Management Plan (CDFG 1996), necessary for improved steelhead populations include: watershed restoration and protection, adequate streamflows, and restoration of access to headwaters.

1.1 Project Background

The South Fork Eel watershed supports listed salmonids and sensitive aquatic and terrestrial species including freshwater mussels, pond turtles, yellow-legged frogs, pacific fishers and other sensitive species. In 2014, the Department's Coastal Watershed Planning and Assessment Program published the South Fork Eel River Basin Assessment Report (CWPAP 2014). In this assessment the South Fork Eel River watershed was divided into three subbasins, the eastern, northern, and western (Figure 1). This division was based on several landscape features including geology, climate patterns, vegetation, and land use. Chinook salmon, coho salmon, and steelhead trout have been documented in all of the subbasins but are more prolific in the Western subbasin streams. Headwater streams in the Western subbasin have some of the highest quality habitat in the entire South Fork Eel River, and historically supported large populations of salmonids.

CWPAP (2014) identified a series of limiting factors common across all subbasins for salmon and steelhead production. These factors include altered flow regimes; summer flows that are significantly lower than historic records; increased water temperatures associated with reduced canopy cover and water diversion during summer low flow period; and loss of habitat complexity as a result of increased sedimentation and changes in flow regime, especially during the summer low flow period.

Developing an understanding of the flow regimes is needed to address the CWPAP (2014) limiting factors, such as 1) assessing the relationship between low-flow habitat availability and habitat needs for rearing salmonids; 2) identifying temperature versus flow thresholds for salmonids; 3) identifying habitat maintenance flows that flush fine sediments from crucial habitat

areas; and 4) identifying flows to support benthic invertebrate production; are a necessary critical first step on the path to enhancing instream flows in the South Fork Eel River and its tributaries. This study will identify the necessary flow regimes to protect salmonid lifestages and the habitats that support them, which may be used to assist with flow enhancement activities in the South Fork Eel River watershed through CWAP and other salmonid restoration and recovery efforts.

2. Project Organization

2.1 Project Personnel

The Department intends to use existing staff resources from the Water Branch, and the Northern Region to conduct studies within the South Fork Eel and its tributaries.

2.2 Roles and Responsibilities

The CWAP calls for a suite of individual and coordinated actions to enhance flow and the availability of stream habitat for anadromous fish. Department staff will be coordinating and carrying out data collection, conducting data analysis, and composing technical reports. Stakeholder coordination and outreach will be a vital component and conducted by the Department's Northern Region. Conservation Engineering and Fisheries Branch will review technical project components and reports produced by Northern Region and Water Branch.

Department's Lead	Role
Water Branch	Technical Study Project Coordinator Field Data Collection Data Analysis Data Reporting Engineering
Northern Region	Local Watershed Project Coordinator Field Data Collection Stakeholder Outreach and Coordination Project Review
Conservation Engineering	Project Review
Fisheries Branch	Project Review

Table 1: Roles and Responsible Parties in Department's South Fork Eel River Watershe	ed
Study	

3. Project Task Description

3.1 Study Goals and Objectives

The degradation and loss of freshwater habitat consisting of high water quality and sufficient water quantity, is one of the leading causes of salmonid decline in California (CDFG 2004). Suitable instream flows are important in maintaining freshwater habitat for migration, spawning, incubation, and juvenile rearing of salmonids (CDFG 1997). The CWAP recognizes the need for fish and wildlife to have access to suitable habitat, and enough cold, flowing clean water at key times of the year to support all lifestages for anadromous fish species.

The goal of this study is to develop streamflow versus habitat relationships in the South Fork Eel River watershed. These relationships can then be utilized to enhance instream flows to support critical habitat for anadromous fish in the South Fork Eel River and its tributaries. To achieve this goal, the Department will undertake a suite of actions aimed at identifying and analyzing instream flows required to protect anadromous species. Actions will include the evaluation and development of relationships between habitat and streamflow for salmonid lifestages within the South Fork Eel River watershed. This information will be used to enhance flows in the watershed in several ways, including the development of flow criteria and identification of important flow thresholds for conservation, restoration, and protection of salmonids.

The objectives of this project include:

- Evaluation of anadromous juvenile salmonid habitat selection and habitat availability in the South Fork Eel River watershed.
- Identify the relationships between streamflow and habitat using a combination of habitat modeling, hydraulic and empirical approaches for anadromous salmonid lifestages including juvenile rearing for coho salmon, Chinook salmon, and steelhead.
- Identify flows for maintaining habitat connectivity for anadromous salmonid species and lifestages.
- Identify flows for providing productive riffle habitats for benthic invertebrate production.
- Identify flows for maintaining water quality conditions, including temperature, which support healthy aquatic habitats.
- Identify flows for maintaining appropriate fluvial geomorphic conditions.

3.2 General Approach

The relationship between streamflow and habitat will be developed using a compilation of common and scientifically defensible methods as described by the Instream Flow Council (Annear et al. 2004). Study components may include habitat typing of multiple stream reaches in the South Fork Eel River watershed as well as other modeling, hydrologic, and empirical components. The watershed encompasses an important and diverse mainstem and tributary salmonid habitats; the selection of study methods may vary among tributaries and individual reaches.

4. Project Design and Methodology

4.1 Watershed Description

The South Fork Eel River watershed is composed of 689 square miles, and is the second largest sub basin of the Eel River. The South Fork Eel River lies within Mendocino and Humboldt counties, and runs in a northwestern direction from its headwaters in the town of Branscomb, to its mouth near the town of Weott (CWPAP 2014). The landscape varies from the east to west sides of the river. The west side is largely vegetated with redwood and Douglas-fir, while the east side is composed of grasslands and oak woodlands with sparse redwood occurrences (BLM et al. 1996). Approximately 20% of land ownership is publically owned by the California State Park system or the U.S. Department of Interior, Bureau of Land Management (BLM et al. 1996). Large timber companies, ranches, small communities, and rural residential areas make up the remaining lands.

Around the 1850's, homesteaders and ranchers began to populate the South Fork Eel River watershed, which previously was inhabited by a Native American population reliant on the fishery, in part, for subsistence. However, due to the remote location of the area, the South Fork Eel River watershed did not have rapid population growth until the 1900's (NMFS 2014). Beginning in the mid 1900's, particularly after World War II, a significant increase in timber harvesting occurred within the watershed which, along with ranch development and urbanization, had a sizable impact on sedimentation in the South Fork Eel River (NMFS 2014, Bodin et. al. 1982).

In recent years, parcelization of ranches and timberlands into rural residential and ranch estates has increased the rural population and conversely water withdrawals in the area, especially

during the low-flow period. Low summer flows and warm water temperatures are of critical concern in the South Fork Eel River watershed. These issues are partially a result of extended dry periods in winter and early spring, and increases in both legal and illegal water diversions. Other factors that contribute to decreased flows in the watershed include changes in morphology due to erosion and aggradation, and excessive sediment inputs (CWPAP 2014). Consequently, the exploitation of natural resources in the basin has led to fish populations declining substantially during and after the post-World War II era (Yoshiyama and Moyle 2010).



Figure 1. Map of the South Fork Eel River Watershed

4.2 Biology

4.2.1 Target Species and Lifestages

Tributaries to the South Fork Eel River are the most productive for anadromous fish in the entire Eel River Basin (BLM et al. 1996). The South Fork Eel watershed supports the most extensive run of wild Pacific salmon populations remaining in California (CWPAP 2014). All three major salmonids species in the South Fork Eel River have populations that are recognized as distinct for the north coast region (Yoshiama and Moyle 2010). The South Fork Eel River watershed currently supports populations of SONCC coho salmon (*Oncorhynchus kisutch*), fall-run CC ESU Chinook salmon (*Oncorhynchus tshawytscha*), and North Coast DPS steelhead trout (*Oncorhynchus mykiss*). SONCC coho salmon are currently listed as "threatened" pursuant to both the federal Endangered Species Act (ESA) and the California Endangered Species Act (CESA). CC Chinook salmon and North Coast steelhead are listed as "threatened" pursuant to the ESA.

Chinook salmon, coho salmon, and steelhead trout utilize a diverse array of instream habitats and have variable life histories (See Table 2), and each species encounter similar flow and temperature requirements at various times throughout the year.

The distribution and abundance of salmonids has diminished substantially compared to their historic condition. Regardless, populations appear to be more abundant in the western tributaries to the South Fork Eel River than in other tributaries. Maintaining or increasing these populations is the goal and responsibility of the Department and is also critical to recovery of salmon and steelhead along the North Coast (CWPAP 2014). A crucial factor in the recovery of these anadromous species is the availability of suitable habitat including adequate streamflow conditions. The Department intends to evaluate anadromous juvenile salmonid habitat selection and habitat availability in relation to streamflow, and estimate habitat index versus flow relationships using a combination of modeling, hydrologic, and empirical approaches. The Department also anticipates identifying flows, which provide productive riffle habitat conditions for benthic invertebrate production.

	-											
Species and Lifestages ¹	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
CC Chinook												
Adult												
Juvenile												
SONCC coho										-	-	
Adult												
Juvenile												
NC steelhead												
Adult												
Juvenile												
Legend:										•		
	Presen	t			1							
Peak migratory period				1								

Table 2. South Fork Eel River Salmonid Lifestage Periodicity

¹Adult migration data from personal communication with Allan Renger, January 13, 2016; Sproul Creek and Hollow Tree spawning ground surveys 1988 to present; and SF Eel basin wide spawning ground surveys 2010 to present. Juvenile migration is from SF Eel downstream migrant trapping, 2015.

4.2.2 Habitat Suitability and Biological Criteria

Accurate representation of available habitat versus discharge requires linking stream channel hydraulics over a range of flows, with known habitat suitability criteria (HSC) for the target species and lifestages (CDFG 2008). For the HSC component of this project, the target species and lifestages are the juvenile CC Chinook, juvenile SONCC coho, and juvenile North Coast steelhead trout. Even though appropriate HSC are a critical element of 1-D and 2-D flow studies, no site-specific HSC have been developed for the above listed species in the Eel River watershed.

Creation of suitable HSC require a minimum sample size of fish observations (typically greater than 150 per lifestage, mesohabitat category, and microhabitat component) made under a rigorous study plan that accounts for the influence of habitat availability on observed habitat use (Bovee 1986). Preparation of a detailed site-specific HSC study plan incorporating these elements would be the first task of this study component. The HSC will be developed using water depth, velocity, cover, and other important site-specific microhabitat components. General guidelines for HSC development are contained in Bovee (1986); Bovee and Zuboy (1988); and CDFG (2008). The primary objective of the HSC study is to develop HSC for rearing juvenile salmonids in mostly unaltered tributaries of the South Fork Eel River. HSC developed from mostly intact tributaries of the South Fork Eel watershed should help to avoid the potential biases from application of HSC developed from areas of the South Fork Eel River watershed with altered flow and habitat conditions or HSC developed from other non-local coastal watersheds. To accomplish this, field based techniques including fish snorkel surveys and measurements/classification of physical habitat attributes will be employed based on methods described by Holmes et al. (2014).

4.3 Hydrology

There are approximately 1,040 miles (1,674 km) of stream in the South Fork Eel River watershed (CWPAP 2014). Like many coastal watersheds in California, the South Fork Eel is characterized by a Mediterranean climate, typically experiencing cool, wet winters and warm, dry summers. The watershed has a wide range in annual discharge because of the prevailing Mediterranean climate and the limited groundwater storage (BLM et al. 1996).

Similar to other watersheds in Humboldt and Mendocino Counties, there are numerous small water diversions taking water from the South Fork Eel and its tributaries during the dry summer months, when base streamflow is critical for rearing salmonids (CWPAP 2014). Additionally, there are a large number of shallow wells in alluvial deposits that pull water from "surface water underflow" rather than from groundwater in fractured bedrock within the watershed (CWPAP 2014). Surface water underflow can be defined as the flow of water though the permeable deposits that underlie a stream but are limited by rock with low permeability such as bedrock (http://water.usgs.gov/wsc/glossary). Surface water underflow is often a primary source of water for fish and wildlife during the dry period in Mediterranean climates including the South Fork Eel River.

4.3.1 Unimpaired Hydrology

In the South Fork Eel River watershed, annual precipitation is primarily higher on the west side of the watershed, as compared to the east side (BLM et al. 1996). Annual precipitation in the western tributaries ranges from roughly 60 inches in the Hollow Tree Creek drainage to upwards of 80 inches in the Redwood Creek drainage (CWPAP 2014), with the highest annual precipitation averaging 115 inches in the headwaters of Bull Creek (BLM et al. 1996). Due to varied precipitation and run off rates, the discharge is characterized by low flows in the summer and peak storm events in the winter (CWPAP 2014).

Using precipitation data obtained from a rain gauge in the Standish-Hickey State Recreation Area (CDEC Station SNH; period of record: 10/1/1948 to present), mean annual rainfall in the region was estimated at 71.96 inches. Patterns of precipitation are highly seasonal, with 80% of the rainfall occurring in the five-month period from November through March. On average, the wettest month is January (mean monthly rainfall = 14.48 inches) and the driest month is July (mean monthly rainfall = 0.09 inches). There are two USGS flow gages located on the South Fork Eel River; one near Miranda, CA (USGS Station 11476500, period of record: 10/1/1939 to present), and one near Leggett, CA (USGS Station 11475800, period of record: 10/1/1965 to present). Based on data from the Leggett gage (see Figure 2 below), mean daily flow is highest during the month of January (2120 cubic feet per second (cfs)) and lowest during the month of September (26 cfs).

Page 18 of 40



Figure 2. Map of South Fork Eel River Gaging Stations.

Page 19 of 40

4.3.2 Target Flows for Sampling

Multiple flow levels are necessary to accommodate different instream needs and provide adequate enumeration to resolve predictive models (Annear st al. 2004). The likelihood of a particular flow occurring in the South Fork Eel River is calculated by means of a flow duration analysis, which estimates the likelihood a stream discharge is equaled or exceeded. The likelihood is expressed as percent of exceedance probability and referred to as the exceedance flow (CDFW 2013c). Target flows typically fall within the exceedance range of 20 to 80 percent (CDFW 2013c); data collection in the South Fork Eel River and its tributaries will likely occur within this range. Some smaller tributaries are characterized by lower magnitude base flows [higher percentage of exceedance] and short, high intensity, storm events. If any tributaries surveyed as part of the study have the above characteristics, sampling maybe shifted to the higher exceedance flows to capture flow more representative of summer rearing conditions, when juvenile salmonids are expected to be in these stream types.

Annual exceedance flows for the South Fork Eel were computed using data from USGS stream gage near Leggett (Station 11475800). The 20, 50, and 80 percent flows were estimated to be 962 cfs, 147 cfs, and 30 cfs respectively (Figure 3). USGS Station 11475560 on Elder Creek and USGS Station 11476600 on Bull Creek may be used to calculate exceedance flows representative of some smaller streams and tributaries within the South Fork Eel watershed. Annual exceedance probabilities for Elder Creek indicate 20, 50, and 80 percent flows of 32 cfs, 5.3 cfs, and 1.3 cfs respectively (Figure 4), while annual exceedance probabilities for Bull Creek were estimated to be 143 cfs, 22 cfs, and 3.2 cfs respectively (Figure 5). The Department plans to use exceedance flows to guide the timing of sampling efforts for the study. Flows sampled may be influenced by the water year type, method selection, and staff safety.



Figure 3. Annual Exceedance Flows for USGS Gage Station 11475800 (Leggett) on the South Fork Eel River from October 1, 1965 to May 5, 2015.



Figure 4. Annual Exceedance Flows for USGS Gage Station 11475560 on Elder Creek from October 1, 1967 to June 5, 2015.



Figure 5. Annual Exceedance Flows for USGS Gage Station 11476600 on Bull Creek from October 1, 1960 to October 9, 2014.

4.4 Connectivity

Increased water demand and resulting diversion in the South Fork Eel River and its tributaries has contributed to low summer flows. These low flows limit the hydrologic connectivity of riverine habitats, and inhibit critical salmonid life history strategies. Adequate water depths and temperatures in holding pools are necessary to allow for summer juvenile salmonid rearing. Juveniles typically experience decreased feeding activity during late summer/early fall and migrate into deeper pools, to hold until precipitation resumes in the late fall or early winter (CDFG 2004). Pool habitats are sensitive to changes in streamflow due to decreased water depth, and consequently increased water temperatures. In addition, sediment loads and lack of woody debris have resulted in a simplified channel structure and reduced pool depth (NMFS 2014).

Ecological flow needs are defined as the flows and water levels required in a water body to sustain the ecological function of the flora and fauna and habitat processes present within that water body and its margins. Low-flow thresholds (i.e., floor values) are applied to conserve and protect fisheries, and it is widely recognized that having such a threshold can preserve

ecosystem structure and function in riverine ecosystems that support fisheries (DFO 2013). The Department intends to use a combination of site specific and regional approaches to assess habitat connectivity as well as low-flow thresholds for anadromous salmonid lifestages at key mainstem and tributary locations in the watershed. To assess ecological flow requirements for salmonids, the Department will use methodologies appropriate for the stream such as Nehring (1979) and CDFW (2013d).

4.5 Geomorphology

Within stream channels, water flow creates and maintains stream-forming processes. When natural flow patterns are altered, fluvial processes, condition of the valley, the stream, and all other ecological components change as a consequence (Lotspeich 1980, as cited in Hill et al. 1991). The fluvial geomorphology of the South Fork Eel River watershed can be described as moderately steep tributaries with incised valleys draining into a low gradient mainstem (BLM et al. 1996). The dominant geology of the South Fork Eel River watershed changes by subbasin. The northern subbasin is comprised mostly of Yager terrane, the eastern subbasin consists of central belt mélange, and coastal terrane is the dominate substrate in the western subbasin; all of which are naturally unstable producing high rates of sedimentation (CWPAP 2014). Large storms in the winter of 1955 and 1964 led to flooding, landslides, and extreme changes in the river and its tributary streams (USEPA 1999).

The South Fork Eel River watershed has the highest natural sediment load in the United States due to highly erodible soils in the area (Brown and Ritter 1971). Anthropogenic impacts have resulted in increased surface erosion and mass wasting events causing increased sediment loads. Because of the anthropogenic sediment inputs, pools have filled in and poor substrate quality resulted in greatly degraded spawning and rearing habitat (Brown and Ritter 1971). The Department intends to use empirical and/or office based geomorphology models to identify channel forming and maintenance flows (e.g., the Meyer-Peter Mueller formula or Einstein method as discussed in Annear et al. (2004), and calculations of the 1.5 year reoccurrence flow as described in Leopold 1994).

4.6 Water Quality

The primary water quality issues in the South Fork Eel River include heightened sedimentation throughout the wet season, increased water temperatures during the summer low flow period, and excessive nutrient inputs. The USEPA recognizes the South Fork Eel River as impaired due

to sediment and temperature, as defined by section 303(d) of the Clean Water Act. The North Coast Regional Water Quality Control Board (Regional Water Board) developed and the USEPA adopted Total Daily Maximum Loads (TMDL) for Sediment and Temperature in the South Fork Eel River (USEPA 1999). The Department will coordinate with the Regional Water Board regarding any monitoring data collected during implementation of the 1999 TMDL. Historic water quality monitoring data may be used in addition to temperature data collected by Department staff to monitor and empirically evaluate the relationship between temperature and flow in key habitat refuges and tributaries of the watershed.

5. Procedures and Protocols

5.1 Study Design

The goal of this study is to evaluate instream flow needs for anadromous salmonids in the South Fork Eel River watershed including key tributaries. This information is critical for protecting listed salmonids and to meet the CWAP goals for future flow enhancements efforts by the Department and other interested parties, such as the State Board, Regional Board, and local restoration groups.

5.2 Stream Survey and Habitat Mapping Procedures and Protocols

Stream surveys will be conducted by Department staff from the Water Branch and the Northern Region. The survey work includes habitat mapping (CDFW 2015b), streamflow measurements (CDFW 2013a), temporary water quality monitoring stations, and fish habitat use surveys in the anadromous zones of the South Fork Eel River watershed. Department staff anticipates using the level III-IV habitat mapping portion of the survey work as described in the *California Salmonid Stream Restoration Manual* (Flosi et al. 2010) to facilitate site selection for hydraulic habitat modeling within each reach selected for flow study(s) (CDFW 2015c). Habitat classification is based on channel morphology, gradient, substrate composition, and hydraulic characteristics. Habitats will be generally classified as riffle, run, glide, or pool. Review of historical habitat classification carried out by Snider in 1989 (unpublished data) suggests that pools may be further classified into lateral scour pools and main channel pools in the anadromous zones. Other habitat types may be further identified and classified based upon the future habitat mapping to be conducted.

The preferred mapping approach is by on-the-ground survey, consisting of identification of habitat types using specified criteria, along with measurements of habitat unit lengths, channel width, average or maximum depth, road crossings, streambank alterations, and any other attributes necessary to acquire a complete inventory of existing mesohabitat conditions. Mapping not done on-the-ground cannot accurately determine depth or gradient, and water reflection may obscure even obvious features (such as transitions between similar habitat types), among other limitations. In some smaller or heavily vegetated, limited-access channels, sub-segments of a reach may be mapped and their extent of representativeness evaluated using aerial photography or other visual means.

Mesohabitats mapped using the on-the-ground method should be 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). In addition, each habitat unit should be characterized as modelable or non-modelable according to the limitations of standard (i.e. 1-D or 2-D) hydraulic modeling methods. Modelable is term use to characterize a habitat unit's hydraulic properties and refers to whether the unit's water surface along and transect remains steady and flat over a broad enough range of flows to develop a predictive model. This characterization is necessary for the data set to be compatible with stratified random study site and transect selection, where unusable mesohabitat units must be rejected prior to the selection process.

Below, habitat types have been classified into a modified Level III with sufficient detail for the purpose of transect placement, hydraulic data collection, and transect weighting consistent with river stratification for hydraulic habitat modeling.

The following mesohabitat types are generally considered modelable and should be retained for study site and transect selection:

- Pools (Mid-Channel, Trench, Lateral, Plunge)
- Glide
- Run/Step-run
- Pocket Water
- Low Gradient Riffle

The following mesohabitat types are generally considered non-modelable 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 can sometimes be sampled but must be determined on a case by case basis.

All field surveys will be conducted under flow conditions at which the mesohabitat types are readily apparent. That is, not when flows are so high that all types are either run or riffle or so low that there is only pool with undifferentiated riffles in between. For safety purposes, field surveys will be conducted by teams of at least two technicians familiar with salmonid habitat requirements, either already with experience or with recent training in this type of mapping. Biological technicians (or higher) are specified due to their ability to recognize habitat features important to rearing and spawning salmon and steelhead. At least one member of each mapping team should be sufficiently experienced with hydraulic habitat modeling to describe each mesohabitat unit as modelable or non-modelable, irrespective of mesohabitat unit type.

5.3 Empirical Methods

Empirical field methods provide a way to evaluate habitat and flow relationships through direct and indirect observations. Field data collected can be analyzed quantitatively or qualitatively and provide empirical evidence. The Department supports a number of empirical methods; however, the selection of study methods used may vary among tributaries and individual reaches dependent on the question being evaluated.

5.3.1 Connectivity

Critical Riffle Analysis

The critical riffle analysis, an empirical instream flow method that identifies flows for protecting salmon and trout passage and overall habitat connectivity (Thompson 1972; CDFW 2015a), may be used to assess salmonid passage at riffles sites where site conditions are appropriate. After a minimum of four to six critical riffle transect measurement events are completed over a

range of appropriate discharges, stream discharge rates and percent of transect which meets the minimum depth criteria for the species are compiled and plotted. Each criterion (e.g., percent total and percent contiguous of the transect) must be met and then the higher flow rate found to meet the depth criteria from either the total portion or the contiguous portion of the critical riffle may then be used to identify passage flows for the target species.

Once a riffle has been identified for critical riffle analysis, the passage transect is established, marked on each bank with flagging and rebar, and photographed. The passage transects are typically not linear, but instead follow the contours of the riffle along its shallowest course from bank to bank. Water depths will be measured along each passage transect to the nearest 0.10 ft with a stadia rod. A temporary staff gage is used to record the stage at the beginning and end of each data collection event. Staff gage measurements are used to assess flow levels during data collection.

Regional Regression Formula

The regional regression formula for fish passage (fp), given below, was developed as part of the Policy for Maintaining Instream Flows in California North Coast Streams (Policy; SWRCB 2014), and may be employed to evaluate protective flows for salmonid passage. The basis of the regression formula is that upstream passage flow needs for anadromous salmonids are influenced by physical factors such as channel size, reflected in the formula by watershed drainage area and runoff magnitude.

The regional regression formula is:

$$Q_{fp} = 19.3 Q_m D_{min}^{2.1} DA^{-0.71}$$

Where *Qfp* is the minimum fish passage flow in cubic feet per second, *Qm* is the mean annual flow in cubic feet per second estimated for the stream using long-term unimpaired data from the closest stream gage station, *Dmin* is the minimum fish passage depth criterion in feet, and *DA* is the drainage area in square miles.

Habitat Retention Method

The Habitat Retention Method (HRM), a single transect biology based method (Nehring 1979) used to estimate hydraulic characteristics (i.e., average depth, average velocity, wetted perimeter, and hydraulic radius (Table 3)) over a range of flows, may also be used to evaluate

fish passage/habitat connectivity and overall habitat maintenance flows at riffle sites where appropriate. Cross-sectional transects are established at the hydraulic control point of selected riffles with a headpin and a tailpin positioned on the left bank and right bank, at or above the bankfull elevation. For the purposes of this method, bankfull elevation is defined as the location where the grassline emerges at the toe of the bank. A bed elevation survey is completed for each transect using an auto level and stadia rod (CDFW 2013b). Water surface slope is computed by dividing the change in water surface elevation by the riffle length. A discharge measurement is recorded for each HRM transect or by pairing nearby gage flow data with the days and times the HMR transect was surveyed. Discharge is paired with the survey data to estimate hydraulic properties using Manning's equation for open channel flow.

Table 3. Key flow parameters used to determine flow criteria using HRM in riffle habitats. Percent wetted perimeter is relative to bankfull conditions.

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

Bed elevation data are used to calculate the flow area (A), wetted perimeter (P), hydraulic radius (R), and channel slope (S), while flow data are used to calculate the discharge (Q) 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:

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

The commercially available software program NHC Hydraulic Calculator (HydroCalc; Molls 2008) is based on Manning's equation and can be used to develop rating curves for discharge and hydraulic parameters. When the criteria for depth and at least one other parameter are met, then flows are deemed to be suitable for habitat connectivity and aquatic ecosystem habitat maintenance.

5.3.2 Ecological Benthic Invertebrate Productivity

Wetted Perimeter Method

The Wetted Perimeter Method (WPM) may be used to assess riffle productivity in riffles with rectangular streambed profiles (CDFW 2013d). Riffle sites are selected because they are typically shallow, depth-sensitive areas of a stream that are most impacted by changes in flow, and they are critical habitats for benthic macroinvertebrates production, an important food source for salmonids. Additionally, when wetted perimeter length is plotted with discharge, a breakpoint or point of inflection develops in the data. Transects are placed at the hydraulic control of riffles and surveyed at approximately five flows to develop discharge vs wetted perimeter relationship curves.

The sampling transects are initially established with a head pin and a tail pin at each transect. The transect length is then measured from head pin to tail pin, then the length from wetted edge to wetted edge is measured to obtain the wetted width. Beginning at the left wetted edge near the head pin, the water depth is measured at 1-ft intervals, or smaller intervals as needed, across the transect to the right bank wetted edge. A flow measurement must be recorded for each WPM transect measurement. Flow will be measured near the site using a flow meter and top setting rod or by pairing nearby gage flow data with the days and times the streambed was surveyed.

Once wetted perimeters and associated flows for the streambed cross sections are obtained for the range of important flows (CDFW 2013c), a wetted perimeter discharge curve is developed by plotting wetted perimeter against discharge. The breakpoint and incipient asymptote, as thresholds of desired habitat conditions, are then identified to determine instream flow needs necessary for maintaining riffle production of benthic macroinvertebrates. This recommendation can be used in conjunction with other flow analysis methods to develop a more holistic instream flow regime for environmental purposes.

5.4 Field Data Collection Procedures and Hydraulic Model Protocols

The preferred approach for determining the relationship between streamflow and habitat suitability is 1D hydraulic modeling in conjunction with depth, velocity, and substrate/cover criteria for target fish species and lifestages. A one-dimensional (1D) or two-dimensional (2D)

hydraulic model provides more useful results than empirical analysis because a hydraulic model is designed to predict hydraulic conditions within a reasonable range of flow levels not sampled.

Most reaches of most river channels can be adequately evaluated with standard 1D hydraulic models such as those in PHABSIM (Waddle 2001), SEFA (Payne and Jowett 2012), and similar programs. In highly complex channels where depth and velocities cannot be accurately predicted because the hydraulics of the unit cannot be described using a single transect approach, a 2D hydrodynamic model is often used to predict flow characteristics and features of ecological importance and has been well studied (Crowder and Diplas 2000; Waddle 2010). While virtually any available 2D model can be used for hydraulic assessment, River2D (Steffler & Blackburn 2002) has the ability to link with habitat suitability criteria and produce relationships between flow and habitat suitability consistent with the study objectives. Most comparisons of the two modeling approaches have concluded there is little difference in habitat index results when applied to the same study sites (Waddle et al. 2000; Gard 2009; Gast and Riley 2013).

Study site selection for 2D modeling will depend on reach access, the need for applying a two dimensional model, and channel complexities identified through habitat mapping. Depth averaged two-dimensional hydrodynamic models use a detailed topography of the study site to solve governing equations for conservation of mass and conservation of momentum in two horizontal directions to simulate water depths and velocities allowing for the modeling of complex flow patterns. Model inputs are bed topography, channel roughness, as well as the upstream and downstream boundary conditions. The most important data requirements are detailed topographic measurements of the streambed at the site. The upstream boundary requires an inflow amount and the downstream boundary requires the corresponding water surface elevation for the given inflow.

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 river flows, mesohabitats, and microhabitats be effectively sampled in order to develop applicable and usable 1D simulation. To that end, the Department's standard for any flow verses habitat analyses is to initially include: a) sampling three distinct river flows; b) three units of each significant mesohabitat type within each generally homologous river segment; and c) for simulations, at least three transects within each mesohabitat unit. The actual number of flows, mesohabitats, or transects actually sampled is dependent upon

complexity in riverine conditions and investigation objectives. 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 three flows. Collaborating parties should evaluate sampling design and needs in the field, and document the decision making process.

Hydraulic and structural parameters will be measured using a combination of standard techniques of 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 will include: 1) water surface elevations (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 these same locations as well as at locations where dry ground elevations were surveyed (CDFW 2013b; CDFW 2015c). If there is a hydraulic control downstream of a given transect, the stage of zero flow in the thalweg downstream of that transect will be surveyed using differential leveling.

Temporary staff gage levels located adjacent to the study site and the time of day should be recorded at the beginning and end of each transect measurement to identify changes in discharge. Continuous recording level-loggers may be deployed in certain reaches to monitor changes in stage during the calibration measurements. A continuous record of stage is useful to determine if flows do change during calibration measurements. In the event a noticeable fluctuation (>0.05') in stage occurs it may be necessary to re-measure discharge and WSELs at one or more transects. Each cluster of transects should have at least one transect capable of accurately computing discharge, even if it has to be added for the purpose. Bed topography and substrate data will be collected at a low flow. Only water surface elevations at the upstream and downstream ends of the sites, flow, and edge velocities will be needed at moderate and high flows.

For any 2D hydraulic habitat modeling, data will be collected between the upstream and downstream transects and will include: bed elevation; horizontal location; substrate composition; and cover. The bed topography data will be collected with a total station, and/or Real Time Kinematic Global Positioning System (RTK GPS) surveying equipment. Data will be collected at least up to the location of the water's edge; representing the highest flow to be simulated. Bed topography data will be collected at a higher density of points in areas with rapidly varying

topography and patchy substrate and cover, and lower densities of points in areas with more uniform topography, substrate, and cover.

Topography data will be 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. At least 50 randomly selected depth and velocity paired measurements will be collected (in addition to the depths and velocities measured along the upstream and downstream transects), to validate the 2-D model² (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 the gage data is available. If gage data is not available, the flow present during validation data collection will be measured.

Once calibrated, the downstream water surface elevation and the inflow of the 2D model will be changed to simulate the flows of interest. Each modeled flow is run to a steady state solution. That is, for a constant inflow, 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 (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).

5.5 Hydraulic Habitat Modeling

1D Hydraulic modeling procedures appropriate to the study site and level of data collection will be used for modeling water surface elevations and velocities across each cross-section. For water surface elevations, these procedures include: the development of stage-discharge rating curves using log-log regression, hydraulic conveyance (MANSQ or similar), and/or step backwater models (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

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

adjustment factors or VAFs). Data file construction, calibration, simulation, reporting, review, and consultation will follow standard procedures and guidelines.

Mesohabitat types will be weighted and combined to develop a representation of hydraulic characteristics and fish habitat suitability for each 1D reach or sub-reach. Mesohabitat weighting will be 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 will be produced by combining hydraulic simulations over a range of flows with HSC for selected species and lifestages. Any currently available standard software package that meets the standards set by Waddle (2000) may be used for the 1-D habitat modeling.

2D 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 and water's 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.

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). Output will include 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 lifestage of interest. Output will also include image files of the plan view of change in suitability for each habitat parameter at selected flows for each species/lifestage.

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 the habitat time series (HTS) analysis. An HTS integrates the habitat index versus flow function with hydrology to provide a dynamic analysis of flow versus habitat. Results of the HTS are most useful when the broadest possible range of hydrology is entered into the model. For this reason it may be necessary to extend the stage discharge flow rating curve beyond 2.5 times the highest calibration flow with additional

stage/discharge measurements made during field data acquisition.

5.6 Geomorphology Methods

Channel maintenance and flushing flows may be assessed in this study plan, and are valuable components for developing and/or maintaining a stream's diverse morphological and hydraulic characteristics. These flows, which are generally associated with peak runoff during the winter and spring, are required to maintain the quality of the substrate and channel conditions for salmonid lifestages. The 1.5 year recurrence event is often used to estimate the average bankfull flood (Leopold 1994). Recurrence flows will be estimated using the methods given in the Policy (SWRCB 2014) for flood frequency analysis. Channel maintenance flows are low frequency flows far higher in magnitude then needed for salmonid spawning, fry, and rearing lifestages, and will only be considered in the overall stream management plan for channel maintenance and flushing streamflows, in the South Fork Eel River Watershed.

5.7 Temperature Monitoring

Ambient water temperature may be collected and evaluated as part of this study plan. Water temperature data collected will be recorded ta a frequency of no less than hourly at key locations throughout the study reaches using digital data thermographs. HOBO® thermographs and/or TidbiT® thermographs will be used where water depths are anticipated too shallow to use the larger HOBO® thermographs. Calibration, placement, sampling interval, and data processing of thermographs will be consistent with guidance provided by the U.S. Department of Agriculture (Dunham et al. 2005). Thermographs will be anchored to exposed roots along the banks of the river in pool habitats using plastic cable zip ties. Suspending the thermographs will keep them from being buried by sediment load and keep the instruments out of sight to avoid tampering by humans and/or animals. The temperature data will be collected and combined with any existing temperature monitoring data when appropriate to assess temperature and discharge relationships during the summer rearing period.

6. Quality Assurance/Quality Control

6.1 Quality Control

All field equipment, including the Marsh-McBirney and HACH FH 950 velocity meters will be calibrated according to manufacturer's instructions each day before use in the field as described in the Discharge Measurements SOP (CDFW 2013a). Velocities will be measured to the nearest 0.01 ft/s. Water surface elevations will be measured to the nearest 0.01 ft (0.3 cm) using standard surveying techniques (differential leveling) as described in the Water Surface SOP (CDFW 2013b). Wetted streambed elevations will be determined by subtracting the measured depth from the surveyed WSEL at a measured flow. Dry ground elevations to points above bankfull discharge will be surveyed to the nearest 0.1 ft (0.03 m). 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 not to be representative 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).

The range of flows simulated will go up to the mean unimpaired flow in the highest flow month. Water surface elevations 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. Data collected for 2D model(s) (if applicable) will be reviewed by Department staff for errors and completeness. The accuracy of the bed topography elevations collected will be 0.1 ft (0.03 m), and the accuracy of the horizontal locations will be at least 1.0 ft (0.3 m).

USFWS (2011) standards for calibrating and validating any two-dimensional hydraulic habitat modeling will be used by the Department. Standards include; 1) 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; 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; 3) Froude Number, the maximum Froude number for low gradient streams should be less than one; 4) 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); 5) Velocity Validation, the correlation between at least 50 spatially-distributed measured and simulated velocities should be greater than 0.6, and 6) Biological Verification, the Mann-Whitney U test should be used to determine whether the combined suitability predicted by the hydraulic habitat model was higher at locations where redds, fry or juveniles were present, versus locations where redds, fry or juveniles were absent. The Department Project Coordinator will be notified of any errors and work with staff to resolve issues with data errors or missing data.

6.2 Corrective Action

If data collection errors or missing data are discovered, the Project Coordinator will review the issues with the appropriate Quality Assurance/ Quality Control personnel to develop a plan for corrective action. Data collection will be reviewed upon return to the office so that resampling, if required, can be scheduled to occur during the current sampling season.

7. Data Management and Reporting

Field data will be collected by Department staff from the Water Branch and Northern Region staff. A final technical report will be prepared by Water Branch staff, with assistance from the Northern Region office staff and review by Department Engineering and Fisheries Branches staff.

7.1 Target Audience and Management Decisions

Using its public trust authority, the Department has the responsibility to conserve, protect, and manage fish, wildlife, native plants, and their associated habitats. Thus, the Department has 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 data generated from the flow study(s) herein, the Department intends to develop flow criteria for anadromous salmonids in the South Fork Eel River watershed. This information is critical for future flow enhancements efforts through the CWAP by stakeholders, Department, Water Board, and Regional Board.

7.2 Coordination and Review

To the extent possible, entities or stakeholders which might have an interest in the results and interpretation of habitat index modeling will be involved in study scoping and implementation.

7.3 Data Management and Reporting

Field data will be collected by Department staff from the Water Branch and Northern Region staff. All data generated by this project will be maintained in field log books and/or data sheets, and electronic spreadsheet format. A final technical report will be prepared by Water Branch staff, with assistance from the Northern Region office staff and review by Department Engineering and Fisheries Branches staff. The Department will store the hard copies and electronic data. Final documents will be posted on the Department's website.

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Instream Flow Study Plan- South Fork Eel River February, 2016

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