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

STUDY PLAN
Habitat and Instream Flow Evaluation for Steelhead in the VENTURA RIVER, Ventura County

STUDY PLAN

January 2017

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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 Southern California steelhead trout in the Ventura River, in Ventura and Santa Barbara counties. 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. 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 Ventura River is among these five priority streams. The Department plans to begin work on the Ventura River study in late 2016 as part of a suite of actions to address instream flow enhancement for anadromous steelhead species.

The Department is the 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 the 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/

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1.0 BACKGROUND

Steelhead trout (*Oncorhynchus mykiss*) (herein referred to as steelhead or southern steelhead) are one of six pacific salmonid species that are native to the west coast of North America, and are currently the only species of this group that naturally reproduce within the coastal watersheds of southern California (NMFS 2012). In 1997, the National Marine Fisheries Service (NMFS) listed the Southern California Evolutionarily Significant Unit (ESU) of steelhead as endangered under the federal Endangered Species Act (ESA) (Entrix 2003, NMFS 2012). CDFW has identified the Ventura River Watershed as a high-priority watershed providing important habitat necessary for maintaining the overall health of the Southern California Steelhead ESU (Normandeau 2015).

Southern steelhead are generally distributed in coastal streams from the Santa Maria River to the U.S. - Mexico border. Of the 46 watersheds historically supporting southern steelhead run populations, over half have been extirpated, and all of the four largest watersheds,(which includes the Ventura River) have experienced declines in run sizes of 90% or more (Moyle et al. 2008). Steelhead and resident rainbow trout were listed as present in the watershed in a 1934 California Department of Fish and Game survey (Titus et al. 2010). In 1996 the Department released the Steelhead Restoration and Management Plan for California (CDFG 1996), which reported that the Ventura River at one time likely supported one of the largest runs of steelhead on the south coast (runs of 4,000-5,000 fish). In the 1940’s prolonged drought and the construction of Matilija Dam further devastated the population, and in 1947 an estimated 250-300 adult steelhead were observed in the watershed (Titus et al. 2010). More recent steelhead population assessments conducted by Mark Allen of Normandeau and Associates for 2006-2012 show near zero densities of steelhead abundance in the lower reaches of the Ventura River below Matilija Dam (Normandeau 2015).

Although there is no single factor responsible for the decline of southern steelhead, the destruction and modification of habitat has been identified as one of the primary causes for the deterioration of the Southern California Steelhead Distinct Population Segment (DPS) (NMFS 2012). Factors such as urbanization, dams and barriers, loss of habitat, water diversions, flood control, and poor ocean conditions have all contributed to a decrease in the number of viable steelhead populations as well as limited their distribution (NMFS 2012; Moyle et al. 2008). With salmonid populations at a fraction of their historical abundance, the National Marine Fisheries Service (NMFS) have listed 28 salmon and steelhead populations along the Pacific West Coast under the federal ESA.

Southern steelhead are dependent on winter rains to provide upstream passage through seasonally opened estuaries and intermittent sections of mainstem rivers. The reliance on rainstorms for permitting passage through the lower portions of southern California watersheds suggests a restricted and rapid spawning period for steelhead (Moyle et al.2008). Summer observations of adult steelhead holding in the lower Ventura River following sand bar breaches during high tides and large swells suggests movement into freshwater is highly opportunistic (Moyle et al. 2008).

1.1 Project Background

The Ventura River Watershed supports multiple sensitive aquatic and terrestrial species. Notable species include: steelhead, California red-legged frog, foothill yellow-legged frog, western pond turtle, arroyo toad, and the western spadefoot toad. In 2015, the Ventura River

Watershed Council published the Ventura River Watershed Management Plan (Walter 2015). In this assessment, the Ventura River Watershed was divided into five subwatersheds: Matilija Creek, North Fork Matilija Creek, San Antonio Creek, Canada Larga Creek, and Coyote Creek, in addition to the maintstem Ventura River (Figure 1). This division was based on several landscape features including geology, climate patterns, vegetation, and land use. Steelhead have been documented in the Ventura River and all of the subwatersheds, but for this study plan the Department is focusing on the mainstem Ventura River below Matilija Dam and San Antonio Creek. San Antonio Creek is extremely important to steelhead production and recovery (Entrix 2003), as it is the only known tributary in the lower mainstem that supports significant spawning and rearing habitat in the watershed (Normandeau 2015).

Run and riffle habitats dominate the mainstem Ventura River, which increase the need for adequate available pool habitat. Furthermore, San Antonio Creek lacks suitable pool habitat, which puts more pressure on the mainstem pools. The limited suitable habitat in San Antonio Creek is a result of fine sediment aggregation from anthropogenic activities adjacent to the stream including flood control, grazing, and development (Entrix 2003). Pool habitats are sensitive to changes in streamflow which results in decreased water depth, and consequently increased water temperatures. Adequate water depths and temperatures in holding pools are necessary to allow for steelhead rearing and holding.

Several limiting factors have been identified across all subwatersheds of the Ventura River for steelhead production and recovery. These factors include altered flow regimes due to dams and barriers; insufficient stream habitat availability such as lack of spawning gravel and sufficient pool habitat; drought and climate change; decrease in riparian habitat due to urbanization; and poor water quality associated with increased water temperatures related to reduced canopy cover and water diversions (Moyle et al. 2008; Walter 2015).

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 overall 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. This study will identify the necessary flow regimes to protect steelhead lifestages and the habitats that support them in the Ventura River and San Antonio Creek. These flow regimes may be used to assist with flow enhancement activities in the Ventura River Watershed through CWAP and other salmonid restoration and recovery efforts.

2.0 PROJECT ORGANIZATION

2.1 Project Personnel

The Department intends to use existing staff resources from the Water Branch, and the South Coast Region to conduct studies within the Ventura River.

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 South Coast Region. Conservation Engineering and Fisheries Branch will review technical project components and reports produced by the South Coast Region and the Water Branch.

Table 1. Roles and responsible parties in Department's Ventura River study.

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

3.0 PROJECT TASK DESCRIPTION

3.1 Study Goals and Objectives

The goal of this study is to develop streamflow versus habitat relationships in the Ventura River and San Antonio Creek. These relationships can then be utilized to enhance instream flows to support critical habitat for steelhead the Ventura River and its tributaries. 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:

- Identify the relationships between streamflow and habitat using a combination of habitat and hydraulic modeling, and empirical approaches.
- Identify flows for maintaining passage for steelhead in the mainstem Ventura River.
- Identify steelhead spawning, rearing, and habitat maintenance flows, as well as productive riffle habitat flows in San Antonio Creek.

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 include evaluating critical passage locations, and riffle productivity in the Ventura River and assessing spawning, rearing, riffle productivity, and habitat maintenance flows on San Antonio Creek.

The watershed encompasses important and diverse steelhead habitats; the selection of study methods may vary among tributaries and individual reaches.

4.0 PROJECT DESIGN AND METHODOLOGY

4.1 Watershed Description

The Ventura River Watershed is composed of 226 square miles, and is the smallest of three major watersheds in Ventura County. The Ventura River lies in western Ventura County, with a small portion in eastern Santa Barbara County; the river drains a 33.5 mile run flowing south from the headwaters in the Transverse Ranges through an estuary to the mouth of the Ventura River at the Pacific Ocean (Walter 2015, LARWQCB 2016). Groundwater basins in the Ventura River Watershed are composed of alluvial aquifers deposited along the surface water system, and are highly interconnected with surface water. These basins are quickly recharged or depleted dependent on surface water flow conditions (LARWQCB 2016).

The northern watershed is within the Los Padres National Forest, while the southern watershed includes two cities, the City of Ojai and a portion of the City of Ventura, as well as multiple small communities (Pitterle 2010). Approximately 40% of land use in the watershed lies within the Los Padres National Forest, with an additional 9,401 acres manages by the Bureau of Reclamation (Walter 2015). The remaining watershed is comprised of agriculture and grazing land, oil extraction and industry, urban development, and a homeless community near the lower Ventura River bottom (Pitterle 2010; Walter 2015).

There has been a long history of concerns over land use impacts in the Ventura River Watershed. Considerable amounts of urban, agricultural, and industrial development has occurred in the floodplain of the Ventura River thus resulting in substantial loss of riparian and wetland habitat, as well as alterations of the river and stream corridors for flood control purposes (Pitterle 2010). Some of these alterations include channelization, bank armoring, unpermitted stream bank alteration, cattle access, low flow crossings, and dam construction. Additionally, human activates which include poaching, littering, and transient habitation have had negative effects to ecosystem health (Pitterle 2010). These actions have impacted the watershed with changes to sediment transport, water quality, and reduced available habitat for steelhead and other important aquatic species.

Currently, there are five major urban water suppliers in the Ventura River Watershed which provide water for roughly 42,000 connections; the City of Ventura supplies the majority with 32,000 service connections alone. These major suppliers use a combination of surface water withdrawals and groundwater withdrawals to meet the demand (Walter 2015). In addition to the five major water suppliers, the watershed has a number of mutual water companies, which also withdraw groundwater to meet their demands. Lastly, private wells and surface water diversions are taking place in the watershed and it is estimated that there are roughly 442 private wells and 21 surface water withdrawals (Walter 2015).

Figure 1. Map of the Ventura River Watershed.

4.2 Biology

4.2.1 Target Species and Life Stages

The Ventura River was once home to one of the largest steelhead runs on the south coast, and is considered one of the four major steelhead bearing watersheds in the Southern California Steelhead Recovery Plan (NMFS 2012). Currently, southern steelhead are listed as endangered under the federal ESA (NMFS 2012, Entrix 2003). In 2005, thirty-two watersheds including the Ventura River and its tributaries were designated as critical habitat for southern steelhead (NOAA 2005). Today over half of the historically available spawning and rearing habitat in the Ventura River Watershed is impeded by the Matilija Dam and Robles Diversion dam. Furthermore, development and water withdrawals from below the Matilija dam and Robles Diversion dam have further degraded the remaining spawning and rearing habitat (Entrix 2003).

Southern steelhead life histories are presumed to be similar to northern California steelhead runs; however, they are unique in that southern steelhead are considered to be ecologically and physiologically adapted to the seasonally warm and intermittent coastal streams of southern California (Moyle et al. 2008; Titus et al. 2010). Another factor that differentiates southern steelhead is their reliance on intermittent winter rainstorms to permit passage through the lower watershed and seasonally opened estuaries. This small window for passage suggests that they encounter a restricted and rapid spawning period (Moyle et al. 2008). Due to less than ideal fresh water conditions (low flows, increased water temperatures) southern steelhead may migrate to the ocean or spend much of their first year in coastal lagoons. Outmigration is controlled by the breaching of estuary sandbars.

The distribution and abundance of steelhead has diminished substantially compared to their historic range. Regardless, populations have the potential to recover in the Ventura River and its tributaries, specifically San Antonio Creek. Maintaining or increasing these populations is the goal and responsibility of the Department, and is also critical to the recovery of steelhead along the southern California coast. A crucial factor in the recovery of this species is the availability of suitable habitat including adequate streamflow conditions.

4.2.2 Habitat Suitability and Biological Criteria

The methods selected for this study do not require the use of Habitat Suitability Criteria (HSC). However, steelhead depth criteria from the Department’s Critical Riffle SOP (CDFW 2015a) will be used to evaluate passage through the intermittent reach on the mainstem Ventura River.

4.3 Hydrology

There are approximately 74 miles of stream, draining 226 square miles in the Ventura River Watershed (Beller et al. 2011; Walter 2015). The watershed is composed of five significant tributaries to the mainstem Ventura River. These tributaries include Matilija Creek, North Fork Matilija Creek, San Antonio Creek, Coyote Creek, and Cañada Larga. Coyote and Matilija Creeks are currently impounded, and the Robles Diversion Dam impounds Ventura River water into Lake Casitas, which is located in the Coyote Creek subwatershed. The Robles Diversion Dam was constructed in 1958, and acted as a complete barrier to upstream migration until 2004 when a fish passage facility was constructed (Normandeau 2015). The Robles Diversion Dam has a required minimum bypass flow of 20 cubic feet per second (cfs), and the ability to divert up to 500 cfs (Leydecker and Grabowsky 2006). Like many coastal watersheds in California, the

Ventura River is characterized by a Mediterranean climate, with approximately 90% of rain falling in the wet season (November-April).

The watershed experiences a high level of interannual variability, where cycles of wet and dry years can last decades. Beller et al. (2011) describes the extremely inconsistent hydrologic regime of the Ventura River being caused by climatic variability. The headwaters begin in the Transverse Ranges. These mountains offer a steep landscape (about 600 feet per mile elevation gain from the valley floor), creating an orographic effect that causes rapid flashy storm events (Walter 2015). Rainfall in the Ventura River greatly differs both seasonally and annually. Over the last 75 years, mean annual discharge has varied from 5 to 3,400 cfs (Leydecker and Grabowsky 2006). Thus, average annual rainfall does not accurately portray the extreme variability in the watershed (Leydecker and Grabowsky 2006).

4.3.1 Unimpaired Hydrology

In the Ventura River Watershed, annual precipitation is highly seasonal and episodic, resulting in long periods of near-zero flow interrupted by moderate to extremely high discharges (Stillwater Sciences 2014). This hydrologic pattern is common among the western Transverse Ranges and is motivated by intense rainstorms in steep catchments, leading to high energy runoff events (Stillwater Sciences 2014). The average annual precipitation in the Ventura River Watershed is approximately 20 inches per year. Near the mouth of the Ventura River rainfall is approximately 17 inches per year, while the average annual rainfall upstream of Matilija Dam is about 24 inches per year (USBR 2006). Over 90% of the rainfall occurs between November and April (USBR 2006), and summer months are typically hot with no measurable precipitation (Figure 2 and Figure 3). Many reaches and tributaries to the Ventura River are intermittent or ephemeral and experience dry conditions from late spring to the onset of fall rain events (Daniel B. Stephens and Associates, Inc. 2006).

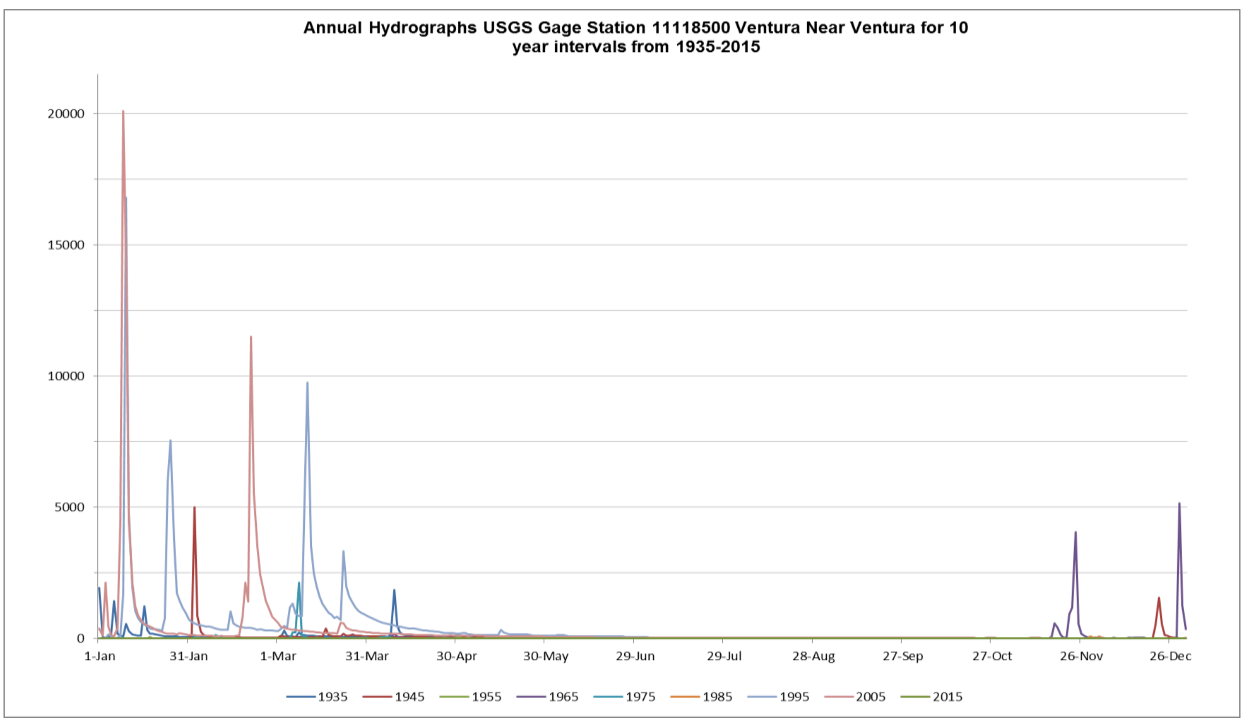

Figure 2. Annual Hydrographs USGS Gage Station 11118500 Ventura River near Ventura for 10 year intervals from 1935-2015.

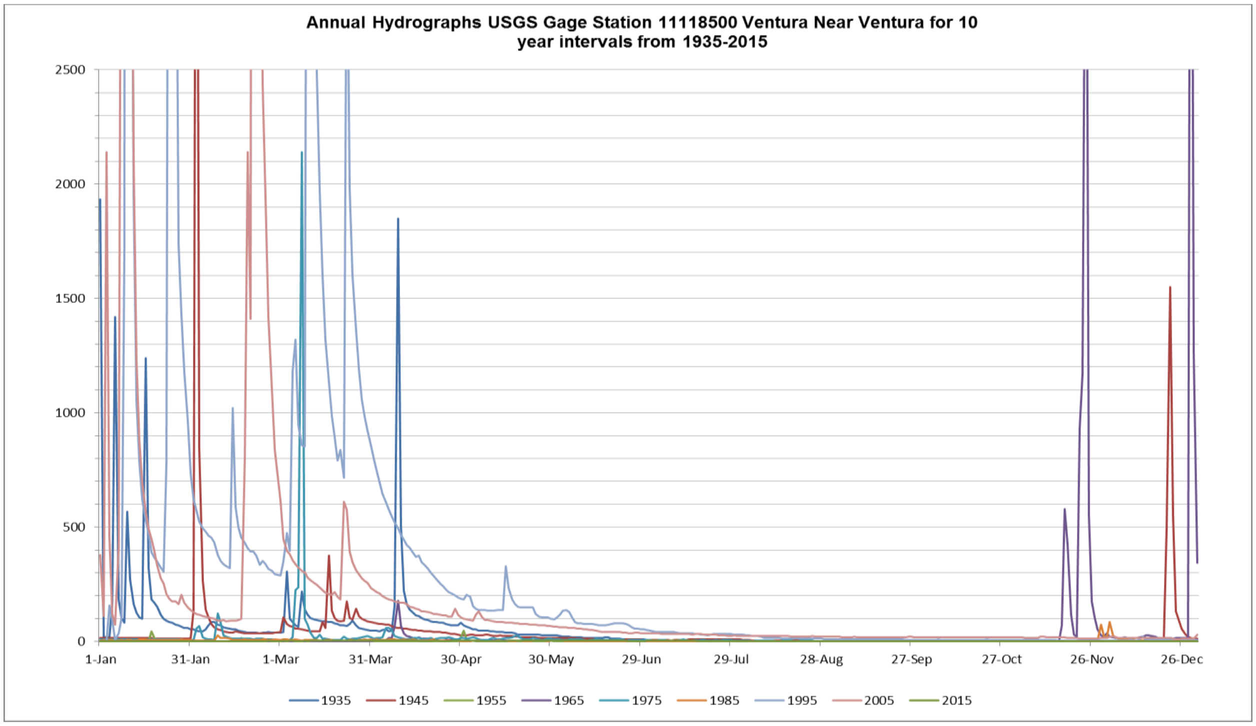

Figure 3. Annual Hydrographs USGS Gage Station 11118500 Ventura River near Ventura for 10 year intervals from 1935-2015, y-axis adjusted to show more detailed hydrograph.

4.3.2 Groundwater Hydrology

The Ventura River Watershed has four significant groundwater basins: Upper Ventura River, Lower Ventura River, Upper Ojai, and Ojai Valley Basins (Figure 4). The Upper Ventura Basin lies under or adjacent to the Ventura River from the confluence of North Fork Matilija Creek and Matilija Creek down to Foster Park, and supplies the most groundwater in the watershed due to the basin being tilted and unconfined (Walter 2015; Entrix 2001). At Foster Park, an underground dam provides the boundary between the upper and lower Ventura River groundwater basins (Entrix 2001). The Upper Ventura River Basin is unconfined, with alluvial deposits; this causes a direct relationship with surface water flows (Walter 2015; Entrix 2001; VCFD 1971). Due to this feature the basin is known to be a dry reach, meaning surface waters disappear underground after passing storms (Walter 2015). The area of the dry reach is dependent on the level of groundwater storage and the precipitation from the previous year. The dry reach generally exists downstream of the Robles Diversion to above the confluence with San Antonio Creek. Groundwater levels within the Upper Ventura River Basin fluctuate seasonally, which is typical of shallow, unconfined alluvial systems. Groundwater rises during winter and spring as a response to precipitation, runoff and recharge, and subsequently declines in dry summer months and into fall (Entrix 2001). This rapid response to precipitation is a result of the unconfined basin, and a direct relationship with surface water flows (Walter 2015; Entrix 2001; VCFD 1971).

At one time San Antonio Creek was identified as its own groundwater basin; however, it is now considered part of the Upper Ventura River Basin. The Lower Ventura River Basin behaves similarly to the Upper Ventura River Basin. Additionally, it underlies the river and extends from the Foster Park dam to offshore alluvial deposits (Walter 2015).

Many watersheds containing steelhead south of Santa Barbara County are experiencing heavy urbanization and development in the floodplains, and associated riparian corridors for agriculture, residential, and industrial uses. Due to this development, the four largest of these watersheds, which includes the Ventura River, are heavily impacted by both surface and subsurface water diversions, as well as flood plain development (Moyle et al. 2008).

The effects of groundwater extraction likely intensify the seasonal patterns of the groundwater basins, even more so when pumping occurs during the already dry summer months (Entrix 2001). The surface water/groundwater interconnection is an important feature of the Ventura River Watershed (Walter 2015), as the unconfined groundwater systems supply critical water for fish and wildlife during the dry periods in Mediterranean climates, including that of the Ventura River and its tributaries.

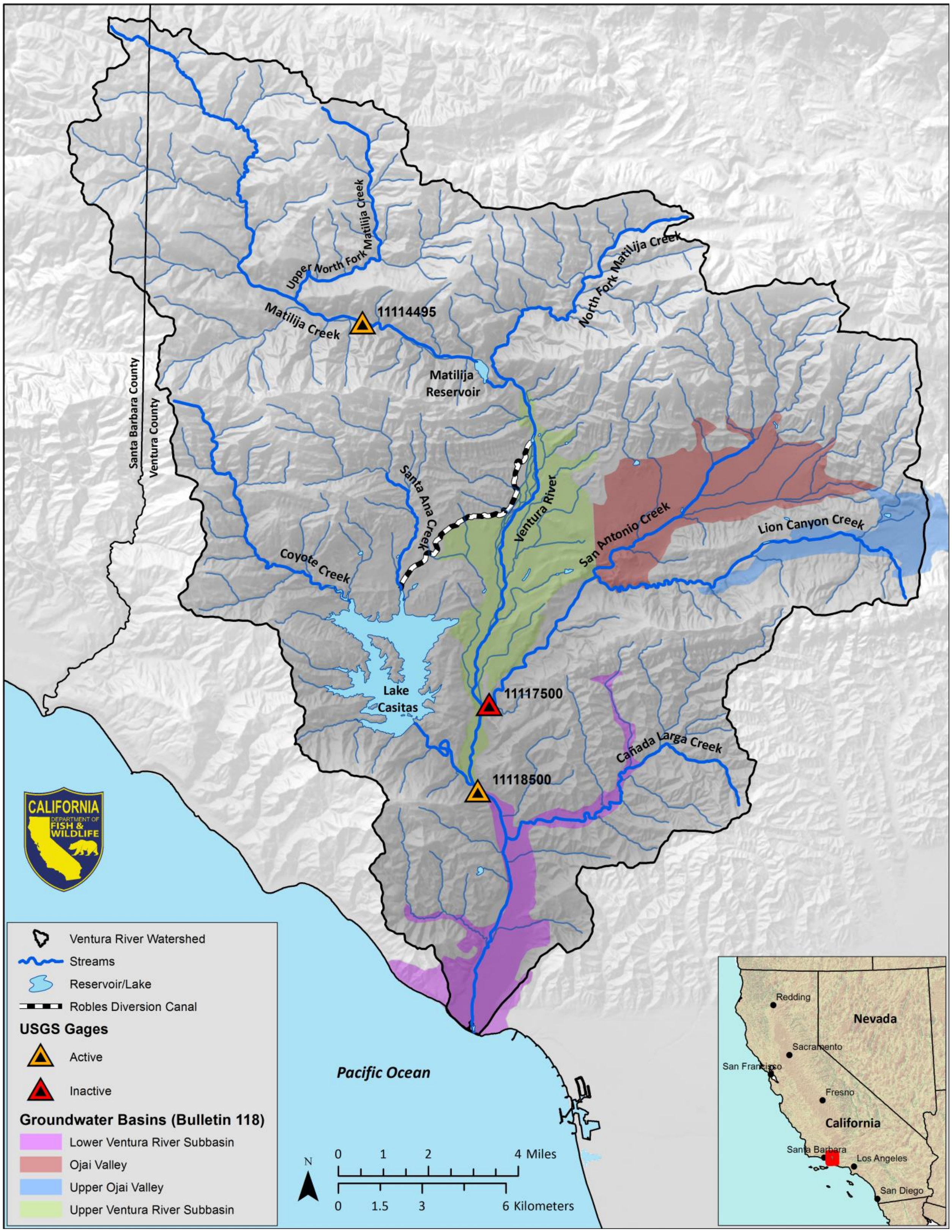

Figure 4. Map Ventura River Gaging Stations and Groundwater Basins

4.3.3 Target Flows for Sampling

Multiple flow levels are necessary to accommodate different instream needs and provide adequate enumeration to resolve predictive models (Annear et al. 2004). The likelihood of a particular flow occurring in the Ventura 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 a 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). The Ventura River and its tributaries are characterized by lower magnitude base flows and short, high intensity, storm events. As a result, data collection in the Ventura River and its tributaries may be shifted from the typical 20 to 80 percent exceedance range to capture flows more representative of migration conditions for steelhead in this watershed.

Annual exceedance flows for the Ventura River and San Antonio Creek were computed using data from USGS stream gages, Station 11118500 and Station 11117500 respectively. The 20, 50, and 80 percent flows on the Ventura River were estimated to be 22 cfs, 3.6 cfs, and 0.04 cfs (Figure 5 and Figure 6 respectively).

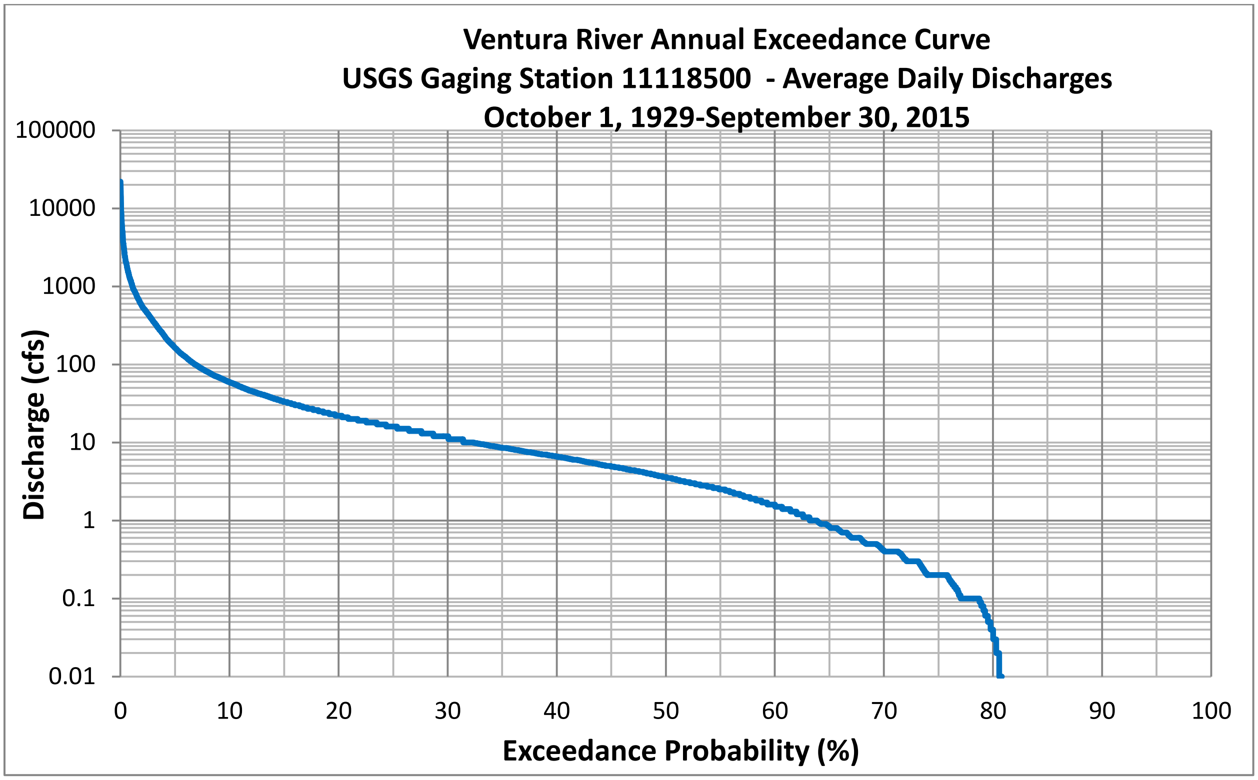

Figure 5. Annual Exceedance Flows for USGS Gage Station 11118500 Ventura River near Ventura from October 1, 1929-September 30, 2015

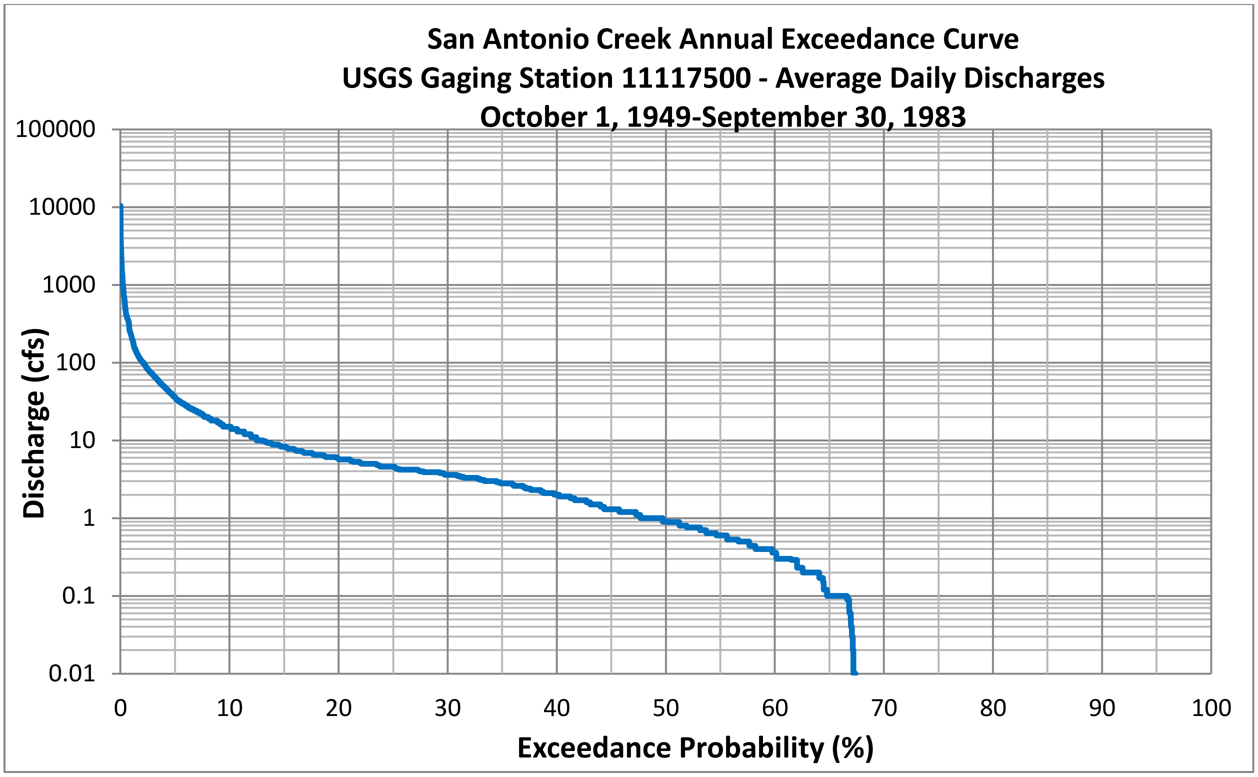

Figure 6. Annual Exceedance Flows for USGS Gage Station 11117500 on San Antonio Creek from October 1, 1949 to September 30, 1983.

4.4 Connectivity

Low flow conditions in the Ventura River are dictated by the complex interaction of precipitation, discharge from springs, groundwater levels, effects of surface water diversions, water storage, treated wastewater discharge, and groundwater extractions. Along the mainstem, surface flows dry up in locations between the Robles Diversion and the confluence of San Antonio Creek. Subsequently, low summer flows are maintained above the Robles Diversion, and between Foster Park and the confluence of San Antonio Creek (Entrix 2001; Entrix and WCC 1997). Low flows limit the hydrologic connectivity of riverine habitats, and inhibit critical salmonid life history strategies. Steelhead also frequently use pool habitat for holding and/or rearing, especially as fish grow larger during the rearing season; pools provide the necessary water depth, cover elements, and food sources for successful rearing (Entrix 2003).

4.5 Geomorphology

Within stream channels, water flow creates and maintains stream-forming processes. When natural flow patterns are altered, fluvial processes, conditions of the valley, the stream, and all other ecological components change as a consequence. The fluvial geomorphology of the Ventura River Watershed can be described as steep tectonically active mountains with intense storm runoff events, and highly erosive sediments (Walter 2015). The watershed can be divided by mountain and foothill (made up of the Transverse Ranges), valley floor, and coastal segments. The dominant geology of the Transverse Ranges is sedimentary rocks: sandstone, siltstone, conglomerates, and shales. While the valley floor is made up of alluvial deposits of silt, sand, gravel, cobbles, and boulders that have eroded from the surrounding Transverse Ranges

(Walter 2015). The alluvial features of the valley floor are responsible for the groundwater surface water interactions in the lower watershed (Entrix 2001; Entrix and WCC 1997; Walter 2015). The coastal segment has been developed by sediment deposits which travel via floodwater and are deposited when the floodwaters are able to spread out and slow down at the Ventura River delta (Walter 2015). The Ventura River delta is an actively expanding delta; sediment deposits here provide southern beaches with new sand supply (Entrix 2001; Entrix and WCC 1997).

The Ventura River has the highest suspended sediment load, and sediment bed load yield of any watershed in southern California, this is due to weak highly erodible rocks found at extremely steep angles (Walter 2015). Geomorphic processes such as sheet erosion, dry land sliding, earth flows and debris flows contribute sediments to the active stream channel (Hill and McConaughy 1988). Sediments are primarily transported by infrequent high intensity rain storms, which can result in 93 percent of the annual total suspended sediment load (Hill and McConaughy 1988).

4.6 Water Quality

The Ventura River Estuary and the Ventura River (including tributaries) have been identified on the 1998, 2002, 2006, and 2010 Clean Water Act Section 303(d) list of impaired waterbodies due to algae, eutrophic conditions, low dissolved oxygen, nitrogen, pumping and water diversions (U.S. EPA 2012). The Los Angeles Regional Water Quality Control Board (Regional Water Board) developed and the United States Environmental Protection Agency (U.S. EPA) adopted Algae, Eutrophic Conditions, and Nutrients Total Maximum Daily Loads for Ventura River and its Tributaries (LARWQCB 2012). The Department will coordinate with the Regional Water Board regarding any monitoring data collected during implementation of the 2012 TMDL. Historic water quality monitoring data may be used by Department staff to empirically evaluate the relationship between instream flows and presence of algae, eutrophic conditions, low dissolved oxygen, and nitrogen in key habitat refuges and tributaries of the watershed.

5.0 PROCEDURES AND PROTOCOLS

5.1 Study Design

The goal of this study is to evaluate instream flow needs for steelhead in the Ventura River and San Antonio Creek. This information is critical for protecting listed salmonids and to meet the NMFS recovery goals for future flow enhancement 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

The Ventura River study is focused on passage issues in the mainstem Ventura River. Therefore, the Department will evaluate and confirm critical passage locations utilizing existing information (i.e. Casitas Municipal Water District 2010) to aid in critical riffle site selection. San Antonio Creek will be evaluated for spawning and rearing flows using hydraulic habitat modeling. San Antonio Creek will also be evaluated for habitat maintenance and riffle productivity flows using the Habitat Retention Method (HRM) (CDFW 2016). Site selection for the latter will follow the HRM SOP (CDFW 2016), and will involve evaluating representative riffle sites, that have roughly rectangular bed profiles.

Hydraulic habitat modeling requires evaluation of current stream habitat types. Existing stream surveys conducted by Department staff from the South Coast Region will be used to facilitate site selection for hydraulic habitat modeling within each reach selected for the flow study on San Antonio Creek. Planned survey work includes habitat mapping (CDFW 2015b), streamflow measurements (CDFW 2013a), and fish habitat use surveys in the anadromous zones of San Antonio Creek using the level III-IV habitat mapping as described in the *California Salmonid Stream Restoration Manual* (Flosi et al. 2010). Habitat classification is based on channel morphology, gradient, substrate composition, and hydraulic characteristics. Habitats are generally classified as riffle, run, glide, or pool.

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). In addition, each habitat mapping unit will be verified and characterized as modelable or non-modelable according to the limitations of standard (i.e., 1D or 2D) hydraulic modeling methods, and prior to site selection and installation. Modelable is a term used to characterize a habitat unit's hydraulic properties and refers to whether the unit's water surface along a 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 have been 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 pools with undifferentiated riffles in between.

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. The HRM will be used to assess habitat maintenance and riffle productivity flows. HRM is a single transect biology-based method (Nehring 1979; CDFW 2016) used to estimate hydraulic characteristics (i.e., average depth, average velocity, wetted perimeter, and hydraulic radius (Table 2)) over a range of flows, and may also be used to evaluate fish passage/habitat connectivity and overall habitat maintenance flows at riffle sites where appropriate.

5.4 Hydraulic Habitat Modeling

One Dimensional (1D) Hydraulic 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 multiple cross-sections. Any currently available standard software package that meets the standards set by Waddle et al. (2000) may be used for the 1D habitat modeling. 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. The Department will utilize 1D habitat modeling to evaluate spawning and rearing flows in San Antonio Creek.

Two Dimensional (2D) Hydraulic Modeling

2D hydraulic modeling procedures appropriate for examining complex stream habitats, such as those found on the mainstem Ventura River, are a preferred approach for determining fish passage (Cowan et al. 2016; Holmes et al. 2015). 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). The River2D model (Steffler and Blackburn 2002) has the ability to evaluate fish passage criteria for depth and velocity with site-specific topographic features and produce relationships between flow and passage conditions consistent with the study objectives. For evaluating passage in the Ventura River we will use minimum depth criteria for adult steelhead discussed in the SOP for Critical Riffle Analysis for Fish Passage in California (CDFW 2015a).

5.5 Field Data Collection Procedures

Habitat Retention Method

Site selection for the HRM method starts with surveying sites when flow conditions are at or around maintenance flow. Department staff will identify a minimum of three representative riffle sites. These sites will be representative of the overall geomorphic structure and shape of the river segment of interest (CDFW 2016).

Once sites are selected, 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. A bed elevation survey is then completed for each transect using an auto level and stadia rod (CDFW 2013b) using differential leveling techniques. After the bed profile survey, water surface elevation and riffle length is determined. Discharge is then paired with the survey data to estimate hydraulic properties using Manning's equation for open channel flow.

Table 2. 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 Northwest Hydraulic Consultants (NHC) Hydraulic Calculator (HydroCalc, Molls 2010) 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.

Hydraulic Habitat Modeling

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

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 and 2D simulations. To that end, the Department's standard for any flow versus 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 classifications 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 change during calibration measurements. In the event a noticeable fluctuation (>0.05 ft) in stage occurs it may be necessary to re-measure discharge and WSELs at one or more transects. Bed topography and substrate data will be collected at a low flow.

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 at a lower density 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.

Once calibrated, the downstream WSEL 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 change in outflow. Ideally, the change between final outflow at two solutions will become sufficiently small (i.e., less than 0.00001). 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).

5.6 Hydraulic Habitat Modeling Protocols

1D hydraulic modeling procedures appropriate to the study site and level of data collection will be used for modeling WSELs and velocities across each cross-section. For WSELs, these procedures include the development of stage-discharge rating curves using log-log regression (a regression analysis expressed using logarithmic scales), hydraulic conveyance (Manning's stage discharge (MANSQ) or similar), and/or step backwater models (Water Surface Profile Model (WSP), Hydrologic Engineering Center's River Analysis System (HEC-RAS)), direct comparison of results, and selection of the most appropriate and accurate method. Water velocities will be simulated using 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 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 et al. (2000) may be used for the 1D habitat modeling.

2D model calibration consists of adjusting the roughness values in the model until a reasonable match is obtained between the simulated WSELs and the surveyed WSELs 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. A 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.

6.0 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 the manufacturer's instructions each day before use in the field as described in the Discharge Measurements in Wadeable Streams in California SOP (CDFW 2013a). Velocities will be measured to the nearest 0.01 ft/s. WSELs will be measured to the nearest 0.01 ft using standard surveying techniques (differential leveling) as described in the Streambed and Water Surface Elevation Data Collection in California 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 range of flows simulated will go up to the mean unimpaired flow in the highest flow month. 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 40 percent of the lowest calibration flow and the highest simulated flow is no more than 2.5 times the highest calibration flow. Data collected for 2D and HRM model(s) will be reviewed by Department staff for errors and completeness. The accuracy of the 2D 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 2D 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 ft of the WSEL, 5) Velocity Validation, the correlation between at least 50 spatially-distributed measured and simulated velocities should be greater than 0.6 ft/s. The Department Project Coordinator will be notified of any errors and will work with staff to resolve issues with data errors or missing data.

The Department is committed to protecting the state's diverse fish, wildlife, and plant resources. Field equipment will be decontaminated as needed using the Departments Aquatic Invasive Species Decontamination Protocol (CDFW 2013).

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.

7.0 DATA MANAGEMENT AND REPORTING

Field data will be collected by Department staff from the Water Branch and South Coast Region staff. A final technical report will be prepared by Water Branch staff, with assistance from the South Coast Region staff and reviewed 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 steelhead in the Ventura River and San Antonio Creek. This information is critical for future flow enhancement efforts through the CWAP by stakeholders, the Department, the Water Board, and the 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

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

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