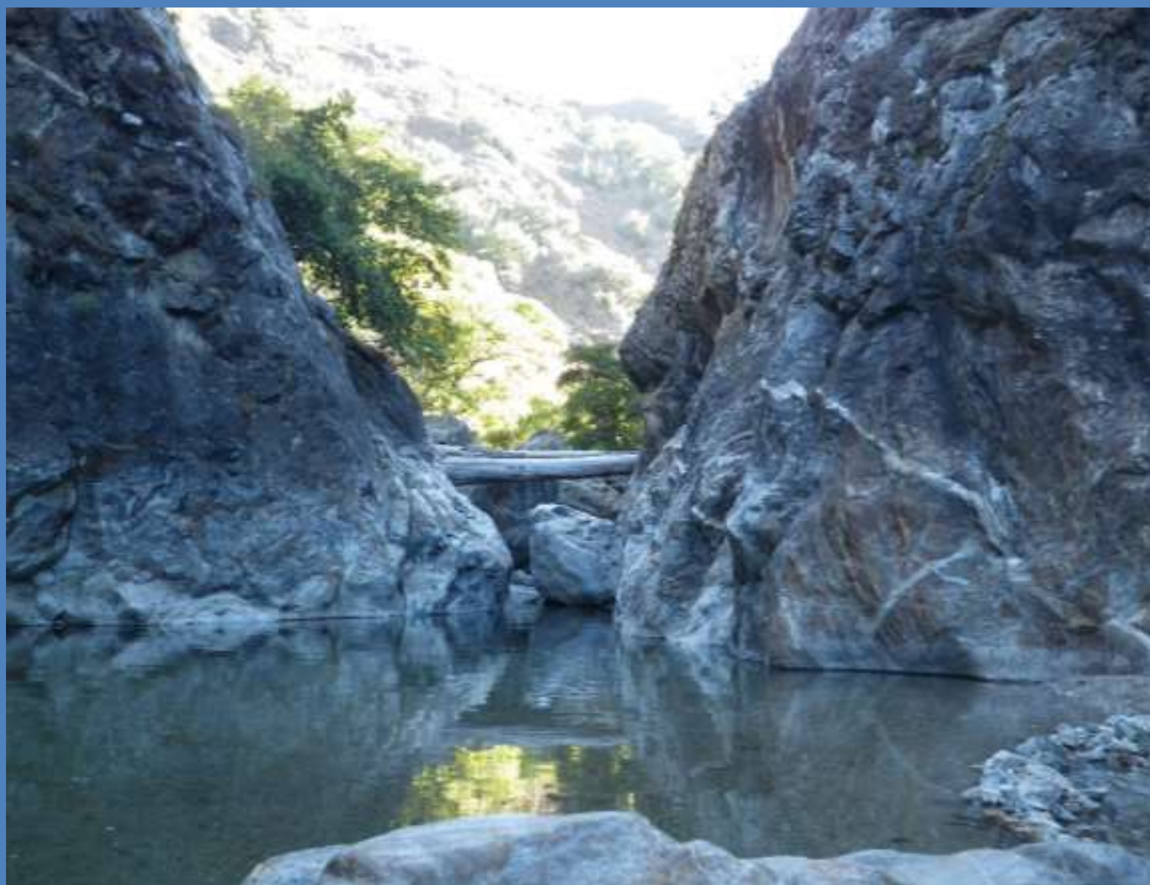
Instream Flow Regime Recommendations
BIG SUR RIVER, Monterey County



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Preface

The Department of Fish and Wildlife (Department) has interest in assuring that water flows within streams are maintained at levels which are adequate for long-term protection, maintenance and proper stewardship of fish and wildlife resources. The Department has developed recommended instream flow regimes for the Big Sur River, Monterey County for transmittal to the State Water Resources Control Board (Water Board) and consideration as set forth in 1257.5 of the Water Code. Submission of these flow recommendations to the Water Board complies with Public Resources Code (PRC) §10001-10002.

The Department is recommending instream flow regimes for the lower Big Sur River from Pfeiffer Big Sur State Park at U.S. Geological Survey (USGS) Gage 11143000 downstream through Molera State Park. The recommendations are separated into six monthly hydrological condition types (i.e., critically dry, dry, below median, above median, wet, and extremely wet) and are presented in the form of an annual schedule for each of three mainstem river reaches (i.e., Lower Molera, Molera, and Campground). The recommended instream flow regimes are summarized in the current document, along with justification for the recommendations and reference to the data sources.

The Department files the enclosed set of instream flow regime recommendations for the Big Sur River that we believe to be comprehensive and substantially complete. The recommendations were based upon information developed through recent PRC instream flow evaluations by the Department, and earlier information. The Department may revise its recommended instream flow regimes for the Big Sur River at a later date based upon any new scientific information that may become available.

Cover photo: Big Sur River Gorge in Pfeifer Big Sur State Park.

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Statement of Findings

The Big Sur River is a significant watercourse for which instream flow regime levels need to be established in order to assure the continued viability of stream-related fish and wildlife resources. The free-flowing, unregulated, Big Sur River was selected for development of flow recommendations because it is a significant watercourse with high resource value, and because it is an important source stream for the South-Central Coast Distinct Population Segment (DPS) of south-central coast steelhead (*Oncorhynchus mykiss*) per NOAA's South-Central California Steelhead Recovery Plan (NMFS, 2013). The Big Sur River steelhead population represents a Core 1 population that is intended to serve as a foundation stock source for the recovery of steelhead in the South-Central California Coast Steelhead Evolutionary Significant Unit (ESU); therefore, it is imperative that this steelhead population be restored to viable self-sustaining population levels that maintain persistence through time and which is capable of becoming a substantial donor stock source to enable recovery of steelhead populations in adjacent streams within the South Central Coast Steelhead ESU. California's south-central coast steelhead populations have declined significantly and as a result are listed as threatened (NMFS, 2011). Insufficient instream flow has been identified as a key factor preventing recovery of steelhead population viability in the Big Sur River. Increasing instream flows is expected to provide substantive progress towards recovery of steelhead in the Big Sur River.

Background

The instream flow regime recommendations for the lower Big Sur River apply from Pfeiffer Big Sur State Park at U.S. Geological Survey (USGS) Gage 11143000 downstream through Molera State Park. There are three reaches of mainstem river within the anadromous zone of the Big Sur River which provide critical habitat for rearing and spawning steelhead (Figure 1). The reaches represent homologous stream segments based upon gradient, geomorphology, hydrology, riparian zone types, flow accretion, diversion influence, and channel metrics. Outlined below is the background information on the Big Sur River Watershed, and the status and trends of steelhead in the South-Central DPS and its life history requirements. Following the background information is an overview of the data sources, water month type definitions, low-flow thresholds, and flow losses evaluation used to develop the instream flow regime recommendations. Lastly, the instream flow regime recommendations are outlined, followed by an overview of the uncertainty associated with climate change impacts and the Department's commitment to minimizing such impacts to the State's natural resources.

Big Sur River Watershed

The Big Sur River, located in southern Monterey County, originates in the steep canyons of California's Ventana Wilderness within the Los Padres National Forest. The river flows northwesterly through federal and private lands, two state parks (Pfeiffer Big Sur and Andrew Molera), and a small estuary before emptying into the Pacific Ocean about 2.8 mi (4.5 km) southeast of Point Sur. The Big Sur River has a watershed of approximately 60 square miles (150 km^2) with no major dams, surface water diversions, or reservoirs.

The climate in the Big Sur area is mild year-round, with sunny, dry summers and falls, and cool, wet winters. Coastal temperatures vary little during the year, ranging from the 50s Fahrenheit (°F) at night to the 70s °F by day from June through October, and in the 40s °F to 60s °F from November through May. Average annual rainfall in Big Sur is 41.94 inches (1,065 mm), with measurable precipitation falling an average of 62 days each year.

The Big Sur River is situated in the Big Sur River Valley, which contains one of the three small towns (Posts in the Big Sur River Valley; Lucia near Limekiln State Park; and Gorda on the southern coast) that occur in the greater 90 miles of “Big Sur” coastline running from the Carmel River south to near Gorda and Ragged Point. Big Sur is generally described as the sparsely populated region of California’s Central Coast where the Santa Lucia Mountains rise abruptly from the Pacific Ocean. The name “Big Sur” is derived from the Spanish-language “el sur grande” meaning “the big country of the south”, referring to its’ location south of the Monterey Peninsula on California’s Central Coast.

South-Central Steelhead

California's south-central coast steelhead populations have declined from about 25,000 spawning adults per year to fewer than 500 (NMFS 2007). Consequently, the south-central steelhead DPS was listed as threatened in 1997 (NMFS 1997) and reaffirmed in 2006 (NMFS 2006). The National Marine Fisheries Service (NMFS) later issued the results of a five-year review and concluded that south-central steelhead should remain listed as threatened (NMFS 2011).

Figure 1. Map of Big Sur River showing study reaches.

The Big Sur River is among the larger central coast watersheds supporting south-central steelhead south of San Francisco Bay (Titus et al. 2010), and is identified as a California steelhead stronghold (Wild Salmon Center 2010). Steelhead are an anadromous member of the salmonid family, spending their adult life in the ocean and returning to freshwater to spawn (Shapovalov and Taft 1954). In the Big Sur River, steelhead return to the river as spawning adults between November and May (Table 1). Steelhead spawn in gravel areas throughout the river between the lagoon and the impassable bedrock barrier in the gorge area of Pfeiffer State Park. Spawning generally occurs at the tail of pools or head of riffles, where water depth, velocity, and substrate composition are favorable. Eggs are deposited in redds or nests excavated by the females, then covered with gravel. The eggs generally hatch from about 19 days at an average temperature of 60 °F to about 80 days at an average temperature of 40 °F (Wales, 1941).

Table 1. Life stage periodicity for south-central steelhead in the Big Sur River.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Adult Migration												
Spawning												
Egg Incubation												
Emergence/Fry												
Juvenile Rearing												
Smolt Emigration												

Shapovalov and Taft (1954) provide a comprehensive life history study of steelhead from a Central Coast stream. Generally, the newly hatched steelhead fry remain in the gravel until the yolk-sac is absorbed. Upon emerging from the gravels fry (approximately 1.5-4 cm fork length (FL)) typically move into nearby shallow slow-water habitats to feed and grow until making the transition to young of year (YOY) juvenile fish (approximately 6-9 cm FL). As they grow young steelhead typically seek deeper water and faster velocities (Shapovalov and Taft 1954). Young steelhead may emigrate to the ocean as YOY, or remain in the freshwater river for a year or longer before emigrating to the ocean. Young steelhead generally reach 14-15 cm FL or larger before smolting, a physiological change which prepares the fish for migrating to, and life in, the ocean (Moyle 2002).

Data Sources and Methods

There were several technical studies conducted during 2009 – 2013 as part of the Department's Instream Flow Incremental Methodology (IFIM) evaluation for steelhead flow needs in the Big Sur River that were utilized to inform the instream flow regime recommendations presented in this report. For clarity purposes, this report does not include all the technical details and results of each IFIM technical study report. However, electronic links to these technical reports are provided in the literature cited section of this report. The overall design of the Big Sur River IFIM addresses the structure and function of the riverine ecosystem (Annear et al. 2004) by means of the five core riverine components. The five components are as follows:

- Biology
- Connectivity
- Geomorphology
- Hydrology
- Water Quality

Major elements of the Big Sur River IFIM investigations included: a lagoon study (Allen and Riley 2012); steelhead spawner surveys (CDFW 2014); a steelhead passage and habitat connectivity study (Holmes et al. 2014a); site-specific habitat suitability criteria (HSC) study for juvenile steelhead rearing (Holmes et al. 2014b); one-dimensional (1D) hydraulic habitat modeling of steelhead rearing and spawning flow needs, channel-maintenance flow analysis, water quality monitoring, and a low-flow threshold evaluation (Holmes and Cowan 2014). Summaries of the methods used in each element of the Big Sur River IFIM are outlined below. Please see each report for a full description of the methods used for each study.

<u>Lagoon Study (Allen and Riley 2012):</u>

Fifteen cross-sectional transects were established to represent the longitudinal changes in channel character and complexity of instream habitat, with the upstream-most transect placed just above the riffle terminating the original lagoon boundary. Lagoon physical habitat characteristics monitored during this study included bathymetry, temporal/spatial changes in tidal heights, tidal changes in water's edge, substrate/cover mapping, transect velocity characteristics, and estimated river inflow. Monitored chemical parameters included water temperature, water salinity, and dissolved oxygen. Biological monitoring involved dive counts of steelhead (and other species) along standardized cross-sectional and bank-oriented transects. Photographs were taken across each transect and at various other locations within the lagoon at different tidal heights. Digital photographs were taken during each trip to depict general lagoon characteristics, transect profiles, substrate composition, and cover types.

Lagoon bathymetry was assessed in the lower, deeper areas of the lagoon in July 2010 using a 1200kHz TRDI Rio Grande Acoustic Doppler Current Profiler (ADCP) mounted on a Oceanscience trimaran. ADCP data was collected by traversing the trimaran across the stream channel in a zigzag manner, with location data recorded on a Trimble Pathfinder Pro DGPS. The GPS antenna was mounted directly over the ADCP with location data streamed via radio modem to a Panasonic Toughbook laptop running WinRiver® software. Manual depth measurements and GPS locations were collected at 3-5 feet (ft) intervals along cross-sectional transects in the upper half of the lagoon where shallow depths (<1 ft) made use of the ADCP infeasible. All depth measurements were related to local water surface elevations (WSEL) and converted to relative elevation by reference to established benchmarks distributed near the top and bottom of the lagoon. WSEL were measured with an auto level and stadia rod.

Elevation maps were created in GIS software (Global Mapper) by combining ADCP depth data, transect depth data, and measured water surface elevations. Depths at all measured points were converted into local bed elevations based on bench mark number 1 (elevation 100.00 ft) and using water surface elevations measured at each transect. Elevation contours were created using a linearly interpolated triangulated network (TIN). Changes in tidal height were regularly monitored by measuring relative WSEL with an auto level and stadia rod at the cross-sectional transects and by measuring depths over three instream reference pins established in the lower, middle, and upper portions of the lagoon. Tidal changes in WSEL were also measured by monitoring depths over four temporary reference pins located in the middle portion of the lagoon. Changes in the water's edge of the lagoon were assessed at low tide and high tide by recording a tracklog with the Trimbol GPS unit while walking along the lagoon margin and encircling any midchannel bars. Changes in the high tide water's edge over the lower half of the lagoon were assessed by recording a tracklog in a Garmin handheld GPS unit.

Substrate types were mapped throughout the lagoon. Areas containing a predominant particle size were mapped by encircling each patch while recording a tracklog on the Garmin GPS receiver. Cover types were assessed along each margin by recording waypoints at the upstream and downstream edges of each type, with isolated cover types (e.g., large woody debris) individually marked with unique waypoints as they occurred. Streamflow was measured during each site visit at Transect #10, just above the riffle demarcating the head of the lagoon. Streamflow was measured by recording depth and mean column velocity at 20 or more stations using the wading rod and velocity meter described above. Mean column velocities were measured at manual depth locations along all transects during the May survey, and along the lower transects during the July survey, using a Marsh-McBirney flow meter on a four-ft top-setting wading rod. Velocity measurements represented low and high incoming tides during May, and high tide or mid-outgoing tides in July.

Water quality parameters were measured throughout the lagoon using a YSI 30 meter for water temperature and salinity and a YSI 550 meter for dissolved oxygen. Water quality data were recorded along transects at one to five locations across each transect and at one or more depths. Measurements were typically taken at a single mid-column or bottom reading in shallow water (<2 ft), at surface and bottom positions for depths 2-4 ft, and at surface, mid-column, and bottom positions at depths >4 ft. In some locations swift and deep water prevented multiple readings. Additional measurements were made in small pockets and scour holes between transects, downstream of the transects in the outlet channel, and in the surf zone just south of the lagoon.

Dive counts were conducted by one or two snorkelers in order to estimate a seasonal index of abundance of juvenile steelhead in the Big Sur lagoon. Dive counts were conducted along the 10 primary cross-sectional transects as well as along the intervening margin areas in a zigzag pattern. Counts conducted along cross-sectional transects were labeled with an “X”, whereas counts conducted along alternating left bank or right bank transects (looking upstream) were labeled with an “L” or “R” (e.g., 0X, 0R, 1X, 1L, 2X, 2R,… 9L, 10X). The same set of transects were surveyed during each day of the three site visits, for a total of six dive counts. A second diver conducted dive counts along alternating transects during the spring survey, otherwise all dive counts were conducted by the same diver. The fork lengths of individual steelhead were eye-estimated to the nearest cm on transects having low abundance; on transects with high abundance counts were made according to size class (<10cm or >10cm). Other aquatic species were noted when observed. Beginning and ending dive times were recorded and underwater visibility was estimated in order to assess the effective search width of each transects dive count.

<u>Steelhead Spawner Surveys (CDFW 2014):</u>

Steelhead redd surveys began on February 1, 2012 and continued through to June 13, 2012. Low flow conditions observed during November 2011 through mid- January 2012, and the very high flow conditions in late January precluded redd surveys during the early part of adult steelhead migration time period. The mainstem river was sampled on roughly two week time intervals, depending on flow conditions, consistent with Gallagher et al. (2007) throughout the season from the upper end of the lagoon to the gorge. Most of the survey area was within state park property. In addition, the entire anadromous portion of Post Creek (222 meters) was surveyed once after adequate flows would have allowed adult steelhead access.

Steelhead Passage and Habitat Connectivity (Holmes et al. 2014a):

Twenty critical riffle sample sites were identified by surveying the entire length of the Big Sur River available for spawning from the lagoon mouth in Molera State Park upstream through Pfeiffer State Park. Depth profile surveys were conducted at each site and the data from each site were compared to river flow at time of measurement using either flow data obtained from USGS gage 11143000, USGS gage 11143010, or by measuring flow onsite. Onsite discharge measurements were made following procedures of Rantz (1982). Depth profile surveys were conducted during summer of 2009 to identify critical riffles in the lower 1.5 miles of stream. Riffle surveys in 2010 were expanded to include the rest of the anadromous area of the Big Sur River. Out of the twenty critical riffle sites surveyed, the four most depth-sensitive critical riffle sites in the river were identified and sampled using CDFW (2012) critical riffle analysis methodology. These sites occur in the lagoon, lower river, middle river, and upper river areas of the river and reflect the four most flow- and depth-sensitive critical riffle sites throughout the anadromous portion of the Big Sur River.

Once a riffle had been identified for critical riffle analysis, the passage transect was established, marked on each bank with flagging and rebar, and photographed. The passage transects were not linear, but instead followed the contours of the riffle along its shallowest course from bank to bank. Initial determination of the shallowest course was based upon subjective judgment but was confirmed with multiple depth measurements. Water depths were measured along each passage transect to the nearest 0.01 ft with a stadia rod. The headpin for each critical riffle transect was located on the left bank of the river looking upstream, and the tailpin on the right bank looking upstream. The headpin served as the starting point for each critical riffle water depth measurement, starting from zero feet, and the tailpin served as the end point of the measurements. A temporary staff gage was used to record the stage at the beginning and end of each data collection event. Staff gage measurements were used to determine whether flow levels had changed during data collection.

River 2D (Steffler and Blackburn 2002) two-dimensional (2D) models were also developed for the lagoon and lower river critical riffle sites consistent with USFWS (2011) standards. The lagoon 2D study site was established in October 2011. The lower river 2D study site was established in November 2009. Study site boundaries (upstream and downstream) were selected so that the site included all of each critical riffle, with the downstream transect moved downstream of the critical riffle and the upstream transect moved upstream of the critical riffle to locations (single-thread channel with uniform cross-channel water surface elevation and all velocities perpendicular to the transect) that were optimal for 1D transects. A 1D transect was placed at the upstream and downstream end of each study site, and the downstream transect was modeled with the physical habitat simulation model (PHABSIM) to provide water surface elevations as an input to the 2D model. The upstream transect was used in calibrating the 2D model - bed roughness's are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM.

Elevational benchmarks were established at each site and all elevations referenced to these benchmarks. Horizontal benchmarks were also established at each site and used to reference all horizontal locations (i.e., northings and eastings) to these benchmarks. The precise northing and easting coordinates and vertical elevations of two horizontal benchmarks were established for each site using survey grade Real Time Kinematic (RTK) GPS. The elevations of these benchmarks were tied into the vertical benchmarks on the sites using differential leveling. Structural data collection for the lower river 2D site began in October 2009 and was completed in December 2009. Hydraulic data for the lower river 2009 2D model were collected in October and November 2009. Structural data were recollected in 2011 at the lower river site to assess temporal changes in required passable flows between the two winters. Hydraulic data for the lower river 2011 2D model were collected between May and October 2011. Flows for calibrating the 2D model were measured onsite and using USGS 11143010 for the 2009 and 2011 models.

Structural data collection for the lagoon 2D site began in October 2011 and was completed in February 2012. Hydraulic data collection for the lagoon 2D site began in October 2011 and was completed in July 2012. All flows used for calibrating the model were measured onsite. Cross section 1 (XS1) of the 2D Big Sur River lagoon site was within the lagoon's upper extent of tidal influence, and therefore hydraulic data (including water surface elevations) were collected at high and low tides to account for any tidal influence on water surface elevation and flow relationships when calibrating the model. Flows were measured at XS2 in the lagoon site, which was not affected by tidal influence during data collection events. Tide heights were obtained from Station 9413450 (NOAA 2012).

The data collected on the upstream and downstream transects included: 1) WSELs, measured to the nearest 0.01 ft (0.003 m) at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bank-full discharge surveyed to the nearest 0.1 ft (0.031 m); 4) mean water column velocities measured at a mid- to high-range flow at the points where bed elevations were taken; and 5) substrate and cover classifications at these same locations and also where dry ground elevations were surveyed. In between the transects, the following data were collected: 1) bed elevation; 2) horizontal location (northing and easting, relative to horizontal benchmarks); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the site.

Water surface elevations were measured at each bank and in the middle of each 2D transect. Bed topography data between the upstream and downstream transects were obtained by measuring the bed elevation and horizontal position of each sample point using a total station or survey-grade RTK GPS. Substrate was visually assessed at each point by one observer based on the visually-estimated average of multiple grains. Topography data, including substrate and cover, were also collected for a minimum of a half-channel width upstream of the upstream transect to improve the accuracy of the flow distribution at the upstream end of the sites.

Steelhead Habitat Suitability Criteria Study (Holmes et al. 2014b):

Sampling to develop site-specific HSC was conducted within the Big Sur River from June 2010 through May 2012. Sampling effort for HSC development was stratified by season, reach, study site, and mesohabitat type. Seasonal stratification was important to reflect juvenile steelhead life history characteristics during the rearing period on a coastal stream and how they may change as the fish grow during this period. The study area included three reaches (i.e., Lower Molera, Molera, and Campground), each representing generally homogenous stream segments based upon gradient, geomorphology, hydrology, riparian zone type, flow accretion, and channel metrics.

Mesohabitat classification consisted of partitioning the reaches into low gradient riffle, pool, glide, and run mesohabitat types (Flosi et al. 2010). Study sites were then selected using a stratified random sampling design. First, each study reach was partitioned into three approximately equal sub-reaches based upon the number of mesohabitat units. A study site was then randomly selected in the lower third, middle third, and upper third of each sub-reach. This process was repeated until each sub-reach contained one of each mesohabitat type. Additional mesohabitat units, beyond the initial random draw, were also randomly selected from each reach/mesohabitat type stratum if needed to achieve equal-area (i.e., square meter) sampling and adequate sample numbers of fish (Bovee et al. 1998).

The equal-area sampling approach was intended to account for the influence of habitat availability on fish selectivity by sampling the same surface area of mesohabitats composed of different depths and velocities, then allowing the relative density of observations in each microhabitat to dictate the shape of the final HSC curve (Thomas and Bovee 1993; Allen 2000). For example, pools can be generally characterized as having an abundance of deep and slow microhabitats, whereas riffles are dominated by shallow and fast microhabitats. In like manner, runs are relatively deep and fast, whereas glides are comparatively shallow and slow. These four mesohabitat types thus approximate the four combinations of depth and velocity, and were the basis for the equal-area sampling design within the mesohabitat stratum.

Steelhead fry and juvenile life stages were sampled during three seasons (i.e., summer, fall, and spring). Habitat use data were collected for all undisturbed steelhead observed via direct underwater observation. Potential diving scenarios for collecting HSC data depended upon 1) fry/juvenile densities, 2) water clarity, and 3) channel width. Where narrow channel widths and adequate water visibilities allowed, a single diver collected HSC data with support from a data recorder. Where channel widths prevented a single diver from fully covering the entire sampling area, two divers or more worked upstream together, communicating to avoid replicate observations. Each diver transferred HSC data to one or two data recorders.

In each sampling (mesohabitat) unit, the observers entered the water about 6 meters (m) downstream of the site, and moved slowly upstream through the site, observing steelhead and determining their focal positions. Location markers (weights with numbered flags) were placed where undisturbed steelhead (1 or more) were observed. Where large groups (>20 individuals) of fry or other juveniles were distributed over a larger (0.30 m^2) area that encompassed different water depths and velocities, they received several measurements which were treated as individual observations to characterize the different microhabitats and different sizes of fish within the groups.

Divers attempted to move around rather than move through fish positions to avoid herding fish within or out of the site. Fish that were disturbed by the diver prior to identification of the fish's focal position were not marked, but were noted as present and not included in subsequent analyses. Fish marker number, number of fish, estimated size (fork length(s) to nearest cm for each fish by reference to an underwater ruler), fish activity (e.g., holding, feeding), and focal height (i.e., actual distance above the substrate or relative height in the water column) were recorded for each observation. A numbered marker was placed underneath individual fish or sub-group focal position and the data were transmitted to the nearby data recorder. The observer then proceeded upstream and marked all undisturbed fish in the sampling unit.

After the dive was completed, habitat characteristics were measured at all observation markers. Habitat characteristics recorded for each marked fish location were: water depth, mean column water velocity (mean velocity), focal velocity, overhead cover (in-water and out-of-water cover type) presence, distance to escape cover, and distance to bank. Escape cover was defined as any object capable of concealing a juvenile steelhead from aquatic or terrestrial predators, including unembedded cobbles and boulders, woody debris, instream branches, or overhead branches within 46 cm of the water surface. When multiple cover types were present at a fish focal position, the object type possessing the greatest concealment opportunity for a fish was recorded. Distance to that cover object was then measured to the nearest 1.5 cm; cover objects >3.1 m from a focal position were considered no cover. Water depth was measured with a graduated top-setting rod to nearest 30.5 mm. Velocity was measured with a Marsh McBirney electromagnetic water velocity meter to the nearest 3.0 mm/sec following standard U.S. Geological Survey procedures (Rantz 1982). River stage was monitored to assess potential changes in stage during the surveys using USGS 11143000 and USGS 11143010.

Habitat availability data were collected in each sampled mesohabitat unit during each seasonal sampling event immediately upon conclusion of fish observation and data collection procedures using a random point sampling design that consisted of a) random selection of cross-sectional transects, then b) random selection of measurement points along each transect. In order to keep the level of effort for habitat availability data consistent with the effort for fish habitat selection data (i.e., according to the equal-effort design), the number of availability measurement points in each sampled habitat unit was roughly proportional to the size of that habitat unit (e.g., larger individual mesohabitat units have more availability points than smaller units, but the overall number of availability points were equal among the mesohabitat types). This design provided a minimum of three habitat availability measurements from each of two- to six-transects per sampling unit. The total number of measurements per unit was based on unit size in order to maintain an equal-effort in both the habitat availability and the fish habitat use datasets.

Separate HSC were developed for each size class (e.g., <6 cm, 6-9 cm, 10-15 cm) and each seasonal period, but data were pooled among reaches and mesohabitat types in order to produce HSC representing the anadromous reach of the Big Sur River. Data were compiled into frequency histograms using bin size intervals of 0.03 meters for water depth, and 3.0 cm/s for mean water and focal water velocity, respectively. Kernel-smoothing techniques (Jowett and Davey 2007) were used to develop HSC curves from the frequency of habitat selectivity, habitat availability, and preference (U/A) HSC curves, using the curve-fitting component of System for Environmental Flow Analysis (SEFA), an instream flow modeling toolkit (Payne and Jowett 2012). All smoothed curves were standardized by dividing them by their maximum values to provide suitability indices ranging from 0 to 1.

To further evaluate the representativeness of the equal-area selectivity HSC curves, and the potential effects of habitat availability on these curves, alternative HSC curves were derived using the U/A forage ratio methodology. While the equal-area HSC are intended to reflect habitat selectivity (i.e., habitat choice) by the fish, the forage ratio criteria (Moyle and Baltz 1985) are also intended to reflect fish “preference”, or habitat use adjusted for habitat availability (i.e., U/A). The U/A forage ratio is the proportion of habitat of a particular microhabitat category (e.g., water depths between 0.3 meters and 0.34 meters) selected by a fish, divided by the proportion of habitat units of that category available (Manly et al. 2002). Smoothed preference HSC were calculated within SEFA using the forage ratio formula as outlined and described by Jowett and Davey (2007).

The statistical analyses assessed whether habitat availability differed from the habitat characteristics where fish were observed (habitat selected) to evaluate microhabitat selectivity. Separate 2-Way for steelhead <6 cm and 3-Way ANOVAs (Analysis of Variance) for larger juveniles (6-9 cm, and 10-15 cm) were conducted for each of the fish length classes using IBM® SPSS® 20. The ANOVAs were used to identify temporal and spatial parameters that influenced habitat selectivity, and to guide the selection of variables most applicable for development of HSC. The factors in the statistical analysis were depth and velocity selection (fish habitat use, habitat available), mesohabitat (runs, riffles, pools and glides) and sample period (spring, summer, and fall for 6-9 cm fish, summer and fall only for 10-15 cm fish). Fish <6 cm were only abundant in the spring so sample period was not assessed. Significant effects associated with selection (habitat used vs. habitat available) would indicate habitat selectivity. Log-linear analyses were also used to examine potential for three-way interaction between presence and absence of steelhead and overhead cover

<u>One-dimensional Hydraulic Habitat Modeling of Steelhead Spawning and Rearing Flows (Holmes and Cowan 2014):</u>

Mesohabitat types (Flosi et al. 2010) were numbered sequentially, beginning at the first habitat unit at the lower end of the Molera Reach and working upstream through the Campground Reach. Study sites for the 1D model sampling were selected using a stratified random sampling design. First, each study reach was partitioned into three approximately equal sub-reaches based upon the number of mesohabitat units. A study site was then randomly selected in the lower third, middle third, and upper third of each sub-reach. This process was repeated until each sub-reach contained one of each of mesohabitat types. Transect locations within each site were also identified using the stratified random sampling design outlined above. One-hundred and seventeen transects were then placed in the three reaches of the Big Sur River and used to collect hydraulic habitat data using differential leveling surveying techniques (CDFW 2013b, USFWS 2011) at three distinct flows (low, mid, and high) ranging from 24 to 175 cubic feet per second (cfs) during April through September 2011.

Flow duration analyses (CDFW 2013a) were used to identify target exceedance flows for sampling based upon the 20, 50, and 80 percent exceedance values. Structural and hydraulic data were collected along the descending limb of the hydrograph from April through September of 2011 at as close as possible to each of the three target exceedance flows (i.e., high, mid, and low). The data collected on the transects included: 1) water surface elevations, measured to the nearest 0.01 ft (0.003 m) at a minimum of three significantly different stream discharges using differential leveling surveying techniques (CDFW 2013b); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points at bank-full discharge surveyed to the nearest 0.1 ft (0.031 m); 4) mean water column velocities measured at the points where bed elevations were taken; and 5) substrate and cover classifications at these same locations and also where dry ground elevations were surveyed.

Elevational benchmarks were established at each site and all elevations were referenced to these benchmarks. Water surface elevations were measured at each bank and in the middle of each transect. If the difference between the three measurements was less than 0.1 ft (0.031 m), the average of these three values were considered the transect water surface elevation. If the difference in elevation exceeded 0.1 ft, the water surface elevation for the side of the river that was considered most representative was used. Onsite discharge measurements were made following procedures of Rantz (1982). The stage of zero flow, the elevation stage at which flow is equal to zero, was measured at all pool sites and used for model stage/discharge calibration. All substrate data collected on the transects were assessed by one observer based on the visually-estimated average of multiple grains.

Temporary staff gages were installed and monitored for stream discharge changes (water surface elevation) during the transect data collection. All field data were checked for accuracy and completeness by the field crew leader at the end of each field day. Data were transcribed into electronic format in the office and verified by a quality assurance reviewer. Digital pictures were taken at each site during each sampling flow. Schematic drawings of each site were also prepared for each sampling unit.

The 60-year unimpaired flow record was then partitioned into six monthly water type categories as follows: critically dry, dry, below median, above median, wet, and extremely wet based upon monthly exceedance percentage as follows: 99-90, 89-70, 69-50, 49-30, 29-10, 9-0%, respectively. One-dimensional hydraulic habitat models were developed using Riverine Habitat Simulation (RHABSIM[1]) for each of the three reaches of the Big Sur River. To account for water availability, the 1D habitat index vs discharge relationships for each lifestage were used to calculate monthly median habitat duration analyses and habitat time series (CDFW 2008) based upon the monthly water types. Monthly habitat duration values were determined by computing daily habitat index values by monthly water type and steelhead lifestage, then by conducting a habitat duration analyses which included calculating a median habitat index for each water month and steelhead lifestage. Using the monthly water type and habitat index

[1] RHABSIM is a commercially available software program from Thomas R Payne and Associates (currently Normandeau and Associates), Arcata, California. RHABSIM contains the suite of PHABSIM computer models developed by Milhous et al. 1989.

results ensures corresponding flow recommendations are consistent with natural water availability.

Water Quality Monitoring (Holmes and Cowan 2014):

Ambient water temperature data were recorded on 30-minute increments from June 3 - November 1, 2011 at 9 sites throughout the lagoon/Lower Molera Reach, the Molera Reach, and Campground Reach using digital data thermographs. HOBO® thermographs were used at the lower 6 sites and TidbiT® thermographs were used at the upper 3 sites where water depths were anticipated to be too shallow to use the larger HOBO® thermographs. Calibration, placement, sampling interval, and data processing of thermographs were consistent with guidance provided by the U.S. Department of Agriculture (Dunham et al. 2005). Thermographs were anchored to exposed roots along the banks of the river in pool habitats using plastic cable zip ties. Suspending the thermographs kept them from being buried by sediment load and kept the instruments out of sight to avoid tampering by humans and/or animals. The temperature data were collected to assess temperature and discharge relationships during the summer rearing period. In addition, we compared the seven day average of daily maximums (7DADM) to USEPA (2003) temperature criteria for trout.

Low-flow Threshold (Holmes and Cowan 2014):

A low-flow threshold for protection of the Big Sur River steelhead fishery was determined using the wetted perimeter method (Annear et al. 2004) and Manning's equation for open channel flow. Nine transects, each selected using a stratified random process from three randomly identified riffles in the Lower Molera Reach, were used to evaluate the discharge versus wetted perimeter relationships. The fixed cross-channel transects were established at each riffle with 0.5 inch rebar (i.e., headpin and tailpin) and surveyed to bankfull discharge level. Three sets of field data, which included water surface elevations, dry bed elevations, water depths, average water velocities, substrate composition, and stream width, were collected at a maximum of 1 ft intervals across each transect from headpin to tailpin at each of three distinct flows (i.e., low, medium, and high).

The commercially available software program NHC Hydraulic Calculator (Hydro Calc; Molls 2000) was used to estimate wetted perimeter over a range of flows, typically from 1 to 250 cfs. Water depth measurements and stream width (i.e., wetted width) were used to calculate flow area (A) and wetted perimeter (P). Water surface elevation level and the distance between transects within each riffle were used to estimate the slope of the water surface. Manning's equation is described below.

$Q = 1.486/n\ AR^{2/3}S^{1/2}$ or $n = 1.486/Q\ AR^{2/3}S^{1/2}$, where:

Q = discharge in cubic feet per second (cfs)
n = Manning's roughness coefficient (dimensionless)
A = flow area in square feet (sf)
R = hydraulic radius, where
R = A/P
P = wetted perimeter in feet (ft)
S = slope in feet per feet (ft/ft)

A minimum of 50% wetted perimeter was used as the lower threshold (Annear et al. 2004) for identifying the breakpoint (i.e., first point of maximum curvature). Maximum curvature was assessed on each transect by computing the slope inflection at each point (e.g., flow) on the wetted perimeter versus discharge curve and subtracting the slope of the flow from the slope of the preceding flow. The flow with the maximum positive slope inflection, above the 50% minimum wetted perimeter, was identified as the breakpoint (Annear et al. 2004). The breakpoint is the lower ecosystem threshold flow, which below this level is indicative of rapidly declining aquatic invertebrate food production. The incipient asymptote was identified using the wetted perimeter discharge curve as the upper point of maximum curvature (i.e., upper ecosystem threshold flow which is at or near optimum food production for the riffle). Flow levels between the breakpoint and the incipient asymptote are critically important to aquatic ecosystem productivity (CDFW 2013c).

Water Month Types

The 60-year unimpaired flow record from USGS 11143000 was partitioned into six monthly water type categories as follows: critically dry, dry, below median, above median, wet, and extremely wet based upon monthly exceedance percentage as follows: 99-90, 89-70, 69-50, 49-30, 29-10, 9-0%, respectively (Table 2). The monthly water types were used to guide evaluation of flow losses between the Lower Molera Reach and the Campground Reach, and guide development of the flow recommendations for protection of steelhead in the Big Sur River. Since the hydrology from USGS 11143000 represents unimpaired flow conditions, it is an appropriate baseline for determining flow/habitat conditions in the Big Sur River. Table 3 contains monthly flow exceedance probabilities for the Big Sur River.

Table 2. Monthly water type categories and associated exceedance percentages.

	Monthly Water Category					
	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
Exceedance Percentage	99-90	89-70	69-50	49-30	29-10	9-0

Table 3. Monthly flow exceedance probability for the Big Sur River[2].

	Flow Exceedance Probability (cfs)									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
January	654	315	197	126	83	50	34	24	18	6.3
February	698	423	250	173	122	91	71	50	26	7.1
March	518	337	246	175	123	93	70	54	34	10
April	300	199	142	107	80	62	50	37	26	7.5
May	134	98	79	65	50	41	33	25	17	7.6
June	70	57	30	40	33	27	20	16	12	4.6
July	45	37	30	26	22	18	14	11	7.8	4.5
August	32	26	22	19	16	13	12	9.6	7.1	2.6
September	24	21	19	17	14	12	11	9	7.1	2.6
October	25	21	19	17	15	13	12	9.1	7.4	2.6
November	70	33	24	21	19	17	15	12	10	2.6
December	246	112	68	49	35	27	21	18	13	5.8

Low-flow Threshold

Low-flow thresholds 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). Furthermore, flow levels less than 30% of the Mean Annual Discharge (MAD) for the river being assessed are identified as the "zone of highest risk" to the fishery using the strictly hydrology-based approach (DFO 2013). Applying the 30% MAD low-flow threshold on the Big Sur River equates to approximately 30 cfs. To further refine the hydrological low-flow assessment, the Department also assessed ecological habitat flow needs using site-specific data from the Big Sur River. The site-specific low-flow threshold analysis identified 22 cfs as the ecological flow necessary to conserve and protect the Big Sur River steelhead fishery (Holmes and Cowan 2014), which is reflected in the instream flow regime recommendations presented in this report as a threshold floor value. Furthermore, flow levels between 22 and 69 cfs were identified as those flows critically important to the benthic ecology and productivity in the Big Sur River.

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. The ecological low-flow threshold for the Big Sur River presents an important ecological benchmark for the river, and flows below this value result in conditions that are high risk to the steelhead fishery. Since the low-flow threshold value (i.e., 22 cfs) is not always naturally available on the Big Sur River,

[2] Data based upon mean daily values from October 1, 1949 through September 30, 2012 from USGS 11143000.

especially in the late summer or fall, it deserves special consideration when making flow management decisions. For example, Richter et al. (2011) recommends daily flow alterations of no greater than 10% from the natural flow regime on a year-round basis to maintain a high level of ecological protection. Although steelhead populations near the southern extent of their distribution, such as in the Big Sur River, may have adapted to cycles of natural high water years and natural dry water years, flow alterations that may result in managed flows below the 22 cfs ecological threshold would not promote the continued viability of the Big Sur River steelhead population.

Flow Losses Evaluation

Flow losses in the Big Sur River were examined by comparison of USGS gage 11143000 in Pfeiffer State Park and USGS gage 11143010 in Molera State Park from October 22, 2010 through March 22, 2014. Examination of the flow losses between USGS 11143000 and USGS 11143010 indicated an approximate maximum loss of 8 cfs during May through October, and an approximate maximum loss of 7 cfs during November through April (Holmes and Cowan 2014) between USGS 11143000 in the Campground Reach and USGS 11143010 in the Lower Molera Reach. As a result, and to provide for an appropriate margin of safety, the flow recommendations for the Lower Molera Reach outlined below include an adjustment of +8 cfs during May through October, and an adjustment of +7 cfs during November through April. See Holmes and Cowan (2014) for the flow losses evaluation in the Lower Molera Reach.

Instream Flow Regime Recommendations

An objective of the Department is to manage steelhead populations for optimum production of naturally spawning sea-run adult fish. To increase production of steelhead in the Big Sur River requires fish to have both full access to optimum spawning habitats for adults, in addition to full access to optimum rearing habitats for YOY and juvenile lifestages throughout and between lagoon and river habitats. Since survival to adult spawning fish is largely related to size of smolts at emigration to the ocean (Ward et al. 1989), a primary objective for steelhead nursery streams is to optimize production of large juvenile, or pre-smolt fish. This objective is pertinent in the Big Sur River, as well as other coastal California rivers and streams, where rearing YOY and juvenile steelhead are dependent upon adequate rearing, passage, and habitat connectivity flows within and between riverine and lagoon habitats.

Based upon the steelhead lifestage habitat/streamflow relationships and integration of individual lifestage needs, the instream flow regime recommendations presented in Table 4, Table 5, and Table 6 provide substantial benefits to the steelhead resource. Spawning and rearing habitat should be sufficient to fully seed the river with fry, and ample habitat is available so sufficient numbers of fry should survive to become juveniles. The development of instream flow regime recommendations for the Big Sur River also considers steelhead passage and habitat connectivity flows, natural water availability, the unregulated free-flowing natural flow regime of the Big Sur River, and maintenance of desirable physical habitat conditions for steelhead. Since fish population levels may exhibit variability over time in response to various environmental influences, numbers of fish are not necessarily consistent indices of a stream's ability to support fish. However, use of a habitat index (i.e., weighted useable area or WUA) provides a more consistent measure of physical habitat potentially available to fish under various flow regimes, which can be evaluated on an incremental basis.

Water month types and percent exceedance flow probabilities for the monthly period of record are determined by CDFW on the 1st of each preceding month. The monthly criteria should be implemented and continued until exceeded. Instream flow regime recommendations for upstream reaches must also consider and meet downstream reach recommendations.

The California Nevada River Forecast Center provides a monthly forecast for the Big Sur, which could be useful for determining water year and month types: http://www.cnrfc.noaa.gov/water_resources_update.php?image=43&stn_id=BSRC1&stn_id2=BSRC1&region=all&graphics=1&text=0&mode=default

Lower Molera Reach

The following flow regime (Table 4) in cfs, measured at USGS 11143000 in Pfeifer State Park, should be implemented for the Lower Molera Reach (including the lagoon upstream to RM 1.16 (Molera State Park parking lot)).

Table 4. Flow regime recommendations (cfs) for the Lower Molera Reach of the Big Sur River.

Month	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
January	29	37	57	71	71	71
February	31	57	71	71	71	71
March	31	57	71	71	71	71
April	29	43	71	71	71	71
May	30	34	48	72	72	72
June	30	30	34	52	58	72
July	30	30	30	36	42	52
August	30	30	30	30	31	40
September	30	30	30	30	30	34
October	30	30	30	30	30	30
November	29	29	29	29	29	29
December	29	29	29	57	57	71

Molera Reach

The following flow regime (Table 5) in cfs, measured at USGS 1114300 in Pfeifer State Park, should be implemented for the Molera Reach (RM 1.16 (Molera State Park parking lot) to RM 4.8 (Juan Higuera Creek)).

Table 5. Flow regime recommendations (cfs) for the Molera Reach of the Big Sur River.

Month	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
January	22	31	60	80	80	80
February	24	39	80	80	80	80
March	24	48	80	80	80	80
April	22	37	60	80	80	80
May	22	26	40	72	80	80
June	22	22	26	45	54	60
July	22	22	22	28	34	45
August	22	22	22	22	23	32
September	22	22	22	22	22	26
October	22	22	22	22	22	22
November	22	22	22	22	22	22
December	22	22	22	26	35	72

Campground Reach

The following flow regime (Table 6) in cfs, measured at USGS 1114300 in Pfeifer State Park should be implemented for the Campground Reach ((RM 4.8 (Juan Higuera Creek) to approximately RM 7.5 (USGS 11143000)).

Table 6. Flow regime recommendations (cfs) for the Campground Reach of the Big Sur River.

Month	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
January	22	32	37	90	90	90
February	25	44	90	90	90	90
March	24	50	90	90	90	90
April	22	37	66	90	90	90
May	22	26	40	66	90	90
June	22	22	26	45	56	66
July	22	22	22	28	34	45
August	22	22	22	22	23	32
September	22	22	22	22	22	26
October	22	22	22	22	22	22
November	22	22	22	22	22	22
December	22	22	23	28	40	66

Channel Maintenance and Flushing Flows

Channel maintenance and flushing flows 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 steelhead lifestages. The 1.5 year recurrence flood (Leopold 1994) was determined using a peaks-over-thresholds method (SWRCB 2014) which estimates flood magnitudes using a frequency analysis. This flow level (i.e., 1644 cfs) is considerably higher than the flows needed for steelhead spawning, fry, and rearing lifestages, however should be considered in an overall stream management plan for channel maintenance and flushing streamflows in the Big Sur River.

Climate Change

The Department is committed to minimizing to the maximum extent practical the effects of climate change on the state's natural resources. Changes in temperature and precipitation could result in alteration to existing fresh water systems and an overall reduced availability of water for fish and wildlife species. In addition, these changes may impact groundwater recharge and over drafting as well as impacting hydropower and hatchery project operations, fish populations' passage issues, and water diversion projects. Given the uncertainty associated with climate change impacts, the Department reserves the right to modify the instream flow regime recommendations for the Big Sur River as the science and understanding of climate change evolves.

Literature Cited

Allen, M.A. 2000. Seasonal microhabitat use by juvenile spring chinook salmon in the Yakima River Basin, Washington. *Rivers* 7(4):314-332.

Allen, M. A., and S. Riley. 2012. Fisheries and Habitat Assessment of the Big Sur River Lagoon, California. Report of Normandeau and Associates, Inc. Arcata, California.

Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other coauthors. 2004. Instream Flows for Riverine Resource Stewardship, Revised Edition. Instream Flow Council, Cheyenne, Wyoming.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. 131pp.

CDFW (California Department of Fish and Wildlife). 2008. Guidelines to the Application and Use of the Physical Habitat Simulation System. Sacramento, CA. 16pp.

CDFW (California Department of Fish and Wildlife). 2012. Critical Riffle Analysis for Fish Passage in California. California Department of Fish and Wildlife Instream Flow Program Standard Operating Procedure DFG-IFP-001, 24 pp. Available: http://www.dfg.ca.gov/water/instream_flow_docs.html .

CDFW (California Department of Fish and Wildlife). 2013a. Standard Operating Procedure for Flow Duration Analysis in California. CDFW-IFP-005, August 2013. 17 pp. Accessed online at: http://www.dfg.ca.gov/water/instream_flow.html

CDFW (California Department of Fish and Wildlife). 2013b. Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California. CDFW-IFP-003, August 2013. 24 pp. Accessed online at: http://www.dfg.ca.gov/water/instream_flow.html

CDFW (California Department of Fish and Wildlife). 2013c. Standard Operating Procedure for Wetted Perimeter Method in California. CDFW-IFP-004, August 2013. 19 pp. Accessed online at: http://www.dfg.ca.gov/water/instream_flow.html

CDFW (California Department of Fish and Wildlife). 2014. Big Sur River Steelhead Spawner Survey Report, 2012. Region 4 office report, Monterey, California. 18 pp.

DFO, 2013. Framework for Assessing the Ecological Flow Requirements to Support Fisheries in Canada. DFO Can. Sci. Advis. Rep. 2013/017.

Dunham, J., Chandler, G., Reiman, B., Martin, D. 2005. Measuring Stream Temperature with Digital Data Loggers: a User’s Guide. Gen. Tech. Rep. RMRS-GTR-150WWW. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15pp.

Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins. 2010. California Salmonid Stream Habitat Restoration Manual, 4th ed. California Department of Fish and Game. Available on-line at: http://www.dfg.ca.gov/fish/resources/habitatmanual

Gallagher, S. P, P. K. Hahn, and D. H. Johnson. 2007. Redd Counts. Pages 197–234 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Holmes, R.W., and W. Cowan. 2014. Instream Flow Evaluation: Steelhead Spawning and Rearing, Big Sur River, Monterey County. California Department of Fish and Wildlife, Water Branch Instream Flow Program Technical Report 14-2. 66pp.

Holmes, R.W., D.E. Rankin, M. Gard, and E. Ballard. 2014a. Instream Flow Evaluation: Steelhead Passage and Connectivity of Riverine and Lagoon Habitats Big Sur River, Monterey County. California Department of Fish and Wildlife, Water Branch Instream Flow Program Technical Report 14-3. 84pp.

Holmes, R.W., M.A. Allen, and S. Bros-Seeman. 2014b. Habitat Suitability Criteria Juvenile Steelhead in the Big Sur River, Monterey County. California Department of Fish and Wildlife, Water Branch Instream Flow Program Technical Report 14-1. 181 pp.

Jowett, I.G. and A.J.H. Davey. 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence-habitat availability. *Transactions of the American Fisheries Society* 136:428-444.

Leopold, L.B. 1994. A View of the River. Harvard University Press Cambridge.

Manly, B. F. J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second Edition. Kluwer Academic Publishers, Netherlands. 221pp.

Milhous, R. T., M. A. Updike, and D. M. Schneider. 1989. Physical habitat simulation system reference manual. Version II. Instream Flow Information Paper No. 26 U.S. Fish and Wildlife Service Biological Report 89(16).

Molls, T. 2000. NCH Hydraulic Calculator (HydroCalc), Version 2.0. Northwest Hydraulic Consultants, Inc. West Sacramento, CA.

Moyle, P.B. 2002. Inland Fishes of California, Second Edition, Berkeley, CA. University of California Press.

Moyle, P.B., and D. M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: Developing criteria for instream flow determinations. *Transactions of the American Fisheries Society* 114:695-704.

NOAA (National Oceanic and Atmospheric Administration). 2012. NOAA Tide Predictions for Carmel Cove, Carmel Bay, California Station 9413375. Available: http://tidesandcurrents.noaa.gov/noaatidepredictions/NOAATidesFacade.jsp?Stationid=9413375http://tidesandcurrents.noaa.gov/noaatidepredictions/NOAATidesFacade.jsp?Stationid=9413375

NMFS (National Marine Fisheries Service). 1997. Endangered and Threatened Species: Listing of Several Evolutionary Significant Units (ESUs) of West Coast Steelhead. Federal Register 62(159):43937-43935.

NMFS (National Marine Fisheries Service). 2006. Endangered and Threatened Species: Final Listing Determinations for 10 Distinct Population Segments of West Coast Steelhead. Federal Register 71(3):834-862.

NMFS (National Marine Fisheries Service). 2007. Recovery outline for the distinct population segment of the south-central California coast steelhead. National Marine Fisheries Service, Southwest Regional Office.

NMFS (National Marine Fisheries Service). 2011. Endangered and Threatened Species; 5-Year Reviews for 4 Distinct Population Segments of Steelhead in California. Federal Register 76(235):76386.

NMFS (National Marine Fisheries Service). 2013. South-Central California Coast Steelhead Recovery Plan. West Coast Region, California Coastal Area Office, Long Beach, California. Available: http://www.westcoast.fisheries.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/south_central_southern_california/2013_scccs_recoveryplan_final.pdf

Payne, T.R, and I.G. Jowett. 2012. SEFA – Computer Software: System for Environmental Flow Analysis based upon the Instream Flow Incremental Methodology (IFIM). Paper presented to Ninth International Symposium on Ecohydraulics, Vienna, Austria.

Rantz, S. E. 1982. Measurement and computation of streamflow, Volume 1, Measurement of stage and discharge, U.S. Geological Survey. Water Supply Paper 2175.

Richter, B.D., M.M. Davis, C. Apse, and C. Konrad. 2011. A presumptive standard for environmental flow protection. *River Research and Applications* 18(8):1312-1321.DOI: 10.1002/rra.1511.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Game, Fish Bulletin No. 98.

Steffler, P. and J. Blackburn. 2002. River2D: Two-dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat. Introduction to Depth Averaged Modeling and

User's Manual. University of Alberta, Edmonton, Alberta. Available: http://www.River2D.ualberta.ca/download.htm

SWRCB (State Water Resources Control Board), 2014. Policy for Maintaining Instream Flows in Northern California Streams. Division of Water Rights. California Environmental Protection Agency. Sacramento, CA. 33 pp. plus appendices.

Thomas, J.A., and K.D. Bovee. 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. *Regulated Rivers: Research & Management* 8:285-294.

Titus, R. G., D. C. Erman, and W. M. Snider. 2010. History and status of steelhead in California coastal drainages south of San Francisco Bay. *In* draft for publication in *California Department of Fish and Game Fish Bulletin*.

U.S. EPA (U.S. Environmental Protection Agency). 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

U.S. Fish and Wildlife Service. 2011. Sacramento Fish and Wildlife Office: Standards for Physical Habitat Simulation Studies. U.S. Fish and Wildlife Service, Sacramento, California. Available: http://www.fws.gov/sacramento/fisheries/Instream-Flow/fisheries_instream-flow.htm

Wales., J.H. 1941. Development of steelhead trout eggs. *California Fish and Game* 27(4) 250-261.

Ward, B. R., Slaney, P. A., Facchin, A. R., and R. W. Land. 1989. Size-biased survival in steelhead trout (*Onchorhynchus mykiss*): back calculated lengths from adult scales compared to migrating smolts at the Keogh River, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1853-1858.

Wild Salmon Center. 2010. North American Salmon Stronghold Partnership, North American Salmon Stronghold Partnership Charter. Portland, Oregon.