DFG-T-22

Interim Minimum Flow Recommendation for Maintenance of Juvenile Steelhead Rearing Habitat on the Big Sur River, Monterey County, California

California Department of Fish and Game
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INTRODUCTION

The purpose of this assessment was to determine an interim minimum flow for maintenance of juvenile steelhead (*Oncorhynchus mykiss*) rearing habitat during the summer-to-fall low-flow period on the Big Sur River, Monterey County, California. The assessment tool used was the wetted perimeter method. This method was selected to develop an interim minimum flow using existing data in anticipation of more comprehensive flow recommendations for steelhead that will result from a Physical Habitat Simulation Model (PHABSIM) study currently being conducted on the Big Sur River by the California Department of Fish and Game (DFG).

The prescribed application of the wetted perimeter method (Stalnaker et al. 1995; Annear et al. 2004) relates the distance along the contour of the stream bottom from one wetted edge of the stream to the other to the associated stream discharge. When done over a range of flows of interest, the paired values of wetted perimeter and stream flow are then plotted on an *x-y* graph to determine the breakpoint[1] where steep gains in wetted perimeter begin to slope off toward an asymptote (Figure 1). The primary assumption with the method is that the flow represented by the breakpoint will protect aquatic life in food producing riffle habitats at a level sufficient to maintain an existing fish population at an acceptable level of production (Annear et al. 2004). It is further assumed that protection of riffle habitats will also confer a minimal level of protection to deeper water habitats such as runs and pools (Stalnaker et al. 1995), although perhaps to a lesser degree than for riffles.

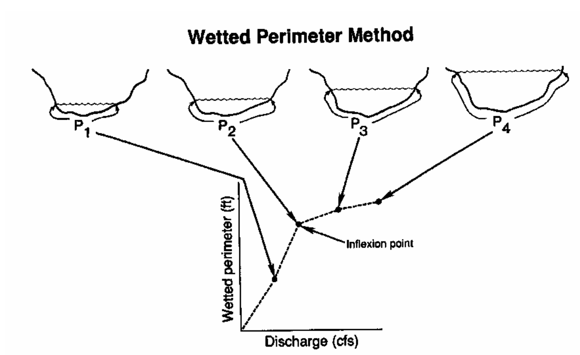

Figure 1. Graphical depiction of the wetted perimeter method. See text for further explanation. Graphic copied from Stalnaker et al. (1995).

The wetted perimeter method should be restricted to use on streams with well-defined riffle and pool sequences, and with cross sections that are wide, shallow, and relatively rectangular (Stalnaker et al. 1995). It should also only be used to address flow conditions during the typical low-flow period on a stream, usually summer and fall (Annear et al. 2004). The geomorphology of the lower Big Sur River and time period of interest generally fit these criteria, and so application of the method here was deemed appropriate.

The minimum flow determined from standard application of the wetted perimeter method appears to correspond to a minimal level of protection for aquatic resources dependent upon stream flow. For example, Collings (1974, as cited in Annear et al. 2004) found that the stream flow associated with the breakpoint on the wetted perimeter

[1] The breakpoint on the wetted perimeter-discharge graph is often referred to as the inflection point, although apparently in error. See Gippel and Stewardson (1998) in this regard.

graph protected 50% to 80% of the maximum available wetted perimeter of the stream, thus possibly falling short of even a fully wetted channel. Dunbar et al. (1998, as cited in Annear et al. 2004) concluded that the stream flow determined by the breakpoint still significantly reduces invertebrate production. This point is particularly significant as arrested growth in juvenile steelhead during the summer-fall low-flow period in California coastal streams (Sogard et al. 2009; Sogard et al., submitted.; R.G. Titus, DFG, unpubl. data for the Big Sur River) is associated with reduced densities of drifting food items (Collins et al., in prep.), a consequence of reduced stream flow.

While the breakpoint flow may correspond to a less-than-desired level of habitat protection in some cases, a greater level of protection for aquatic resources can still be obtained using the wetted perimeter method for determining minimum flows. For example, the incipient flow at which wetted perimeter reaches an asymptote should provide a level of protection that is more consistent with maintaining habitat conditions to support a typical density of juvenile steelhead occupying a mosaic of feeding territories (sensu Kalleberg 1958) in a given habitat area. Assuming a roughly rectangular channel morphology, the incipient asymptotic flow should minimally provide a fully wetted stream channel, or nearly so. While this flow condition is likely below that associated with a maximum measure of habitat quality and quantity for juvenile steelhead – for example, maximum weighted useable area from a PHABSIM study – it should be more protective for both aquatic macroinvertebrate and salmonid production than the lower breakpoint flow.

Determination of the incipient asymptotic flow from the wetted perimeter-discharge graph for use as an interim minimum flow may be especially appropriate in a case such as the Big Sur River. Since 1997, steelhead in the Big Sur River have been federally listed as threatened under the U.S. Endangered Species Act (ESA) as part of the South-Central California Coast Evolutionary Significant Unit (ESU). Within this ESU, the Big Sur River, along with the nearby Little Sur River and San Jose Creek, has been identified as a California steelhead stronghold (Wild Salmon Center 2010). In addition, the Big Sur River is one of the DFG's top priority streams for determination of instream flow requirements in its obligation to do so per California Public Resources Code 10000 (Unpubl. memo. of 12 August 2008 from C. Wilcox, DFG to V. Whitney, State Water Resources Control Board). The high conservation value of the Big Sur River, its importance to the eventual recovery of steelhead, in addition to the State of California's obligation to protect public trust fishery resources in a manner that aids steelhead recovery, supports application of the more conservative incipient asymptotic flow in determining an interim protective minimum flow for the river. Thus, the wetted-perimeter assessment that follows includes use of the incipient asymptotic flow on the wetted perimeter-discharge graph for minimum flow setting on the Big Sur River.

METHODS

The data used in this analysis were collected during 1992–1995 when DFG conducted a multi-year investigation of juvenile steelhead habitat use on the Big Sur River. Replicate mesohabitat units were selected for study in each of three river reaches (Figure 2 – at end of report). Distinct riffles and runs were present in the Campground and Molera reaches of the river, referring to the campground in Pfeiffer Big Sur State Park in the upstream portion of the study area and Andrew Molera State Park in the downstream portion of the study area, respectively. Riffles and runs dominated these river reaches both in terms of frequency (66%–71%) and by stream length (76%–79%), based on DFG habitat typing data collected in 1989, and both were used extensively as rearing habitat by juvenile steelhead (Titus 1994). Physical habitat data were collected on each occasion a given habitat unit was sampled for juvenile steelhead. Transects were placed at five equidistant points from the top to the bottom of each habitat unit (or the sub-sampled length of the unit). Wetted width (0.1 ft), thalweg depth (0.1 ft), and mean thalweg current velocity (ft/s) were measured at each transect. Measurements for each attribute were averaged over the five transects for each habitat unit and sampling date.

Wetted perimeter of a habitat unit was estimated by summing the mean width with twice the mean thalweg depth to approximate the distance from one wetted edge of the stream to the other, following the contour of the stream bottom. Use of mean thalweg depth was a slight departure from convention of using mean cross-sectional depth. However, the difference here was likely minimized by using the average of five thalweg depth measurements to include some degree of depth variation in each habitat unit. In addition, because of the mostly rectangular shape of the stream channel, mean thalweg depth likely did not depart greatly from average cross-sectional depth, especially in riffles and runs (see Results and Discussion below).

Big Sur River stream flow data were obtained from U.S. Geological Survey (USGS) gage 11143000 (http://waterdata.usgs.gov/nwis/uv?11143000), which is located near the upstream boundary of Pfeiffer Big Sur State Park. This location is above all diversions on the stream. Additionally, flow at the gage does not include accretion of flow from several lower river tributaries, including Post, Pfeiffer-Redwood, Juan Higuera, and Pheneger creeks. For graphical analyses, wetted perimeter estimates made on a given day were paired with the mean daily stream gage flow for that day.

Wetted perimeter was then plotted as a function of stream flow for each of five riffles and runs spanning the Campground and Molera reaches (Table 1). Trend lines were fitted by eye, beginning from the origin where it was assumed that a flow of 0 cfs would yield a wetted perimeter of 0 ft. Stream flows associated with the breakpoint and incipient asymptote were determined for each habitat unit. Values for riffles and runs were averaged separately to facilitate comparisons between the two habitat types, since riffles are the prescribed habitat type for the wetted perimeter method (Stalnaker et al. 1995; Annear et al. 2004). Mean breakpoint and incipient asymptotic flows between both river reaches (Campground vs. Molera) and habitat types (riffles vs. runs) were compared with a multifactor analysis of variance (MANOVA) to determine if results among reaches and habitat types could be combined.

Table 1. Habitat unit code, location, and length of five low-gradient riffles and five runs at which wetted perimeter was estimated on the Big Sur River, Monterey Co., California. See Figure 2 for map.

Habitat unit	Habitat type	General location	Length (ft)
C7	Low-gradient riffle	Pfeiffer Big Sur State Park at day use area	164
C9	Run	Pfeiffer Big Sur State Park at day use area	127
C14	Low-gradient riffle	Confluence with Juan Higuera Creek	78
C15	Run	Confluence with Juan Higuera Creek	85
M16	Low-gradient riffle	Upper Andrew Molera State Park at access gate 9	108
M17	Run	Upper Andrew Molera State Park at access gate 9	121
M18	Low-gradient riffle	Lower Andrew Molera State Park at access gate 4	114
M20	Low-gradient riffle	Lower Andrew Molera State Park near parking lot	74
M23	Run	Lower Andrew Molera State Park below parking lot	136
M25	Run	Lower Andrew Molera State Park adjacent campground	147

RESULTS

The wetted perimeter-discharge relationship for all five low-gradient riffles (Figure 3) showed a well-defined breakpoint and/or asymptote. The stream flow associated with the breakpoint ranged from 6 to 11 cfs and averaged 8 cfs (Table 2). In habitat unit M20, data to estimate wetted perimeter were not available for flows less than about 20 cfs. In this case, the breakpoint flow was undeterminable.

Incipient asymptotic flows in low-gradient riffles ranged from 8 to 20 cfs and averaged 15 cfs (Table 2). In four of five riffles (C7, C14, M18, and M20), there was little additional gain in wetted perimeter at flows above the incipient asymptotic flow. In habitat unit M16, though, wetted perimeter increased substantially to 51 ft at 37 cfs following an initial asymptote at about 30 ft and 9 cfs. This riffle apparently had a secondary terrace that became wetted at flows in excess of 21 cfs, providing additional area for food production and juvenile steelhead rearing.

Table 2. Summary of the breakpoint and incipient asymptotic flows from an analysis of the wetted perimeter-discharge relationship at five low-gradient riffles on the Big Sur River during 1992 – 1995.

Habitat unit	Breakpoint flow (cfs)	Incipient asymptotic flow (cfs)
C7	6	8
C14	9	19
M16	6	9
M18	11	19
M20	–	20
Mean	8	15
SD	2.4	6.0
cv (%)	30	40

Patterns in the wetted perimeter-discharge relationship for runs (Figure 4) were very similar to those observed for low-gradient riffles. Stream flows associated with the breakpoint were very similar to those for riffles, and ranged from 6 to 11 cfs and averaged 8 cfs (Table 3). Incipient asymptotic flows, though, tended to be higher than those for riffles, and ranged from 17 to 23 cfs and averaged 19 cfs. There was little additional gain in wetted perimeter at flows above the incipient asymptotic flow, especially in habitat units C9, C15, M17, and M25. In habitat unit M23, there was a gain in wetted perimeter of 6 ft (20%) from an incipient asymptotic flow of about 19 cfs to a maximum perimeter flow of about 38 cfs (Figure 4). Outlier values of wetted perimeter in habitat units C9 and M17 were based on measurements made in early August 1995, following two exceptional peaks in flow the previous winter: 5,970 cfs on 10 January 1995 and 6,690 cfs on 10 March 1995 (Figure 5). These values were not included in line fitting for the wetted perimeter-discharge relationship for these two habitat units (Figure 4).

Table 3. Summary of the breakpoint and incipient asymptotic flows from an analysis of the wetted perimeter-discharge relationship at five runs on the Big Sur River during 1992 – 1995.

Habitat unit	Breakpoint flow (cfs)	Incipient asymptotic flow (cfs)
C9	6	18
C15	9	17
M17	8	23
M23	11	19
M25	6	18
Mean	8	19
SD	2.1	2.3
cv (%)	26	12

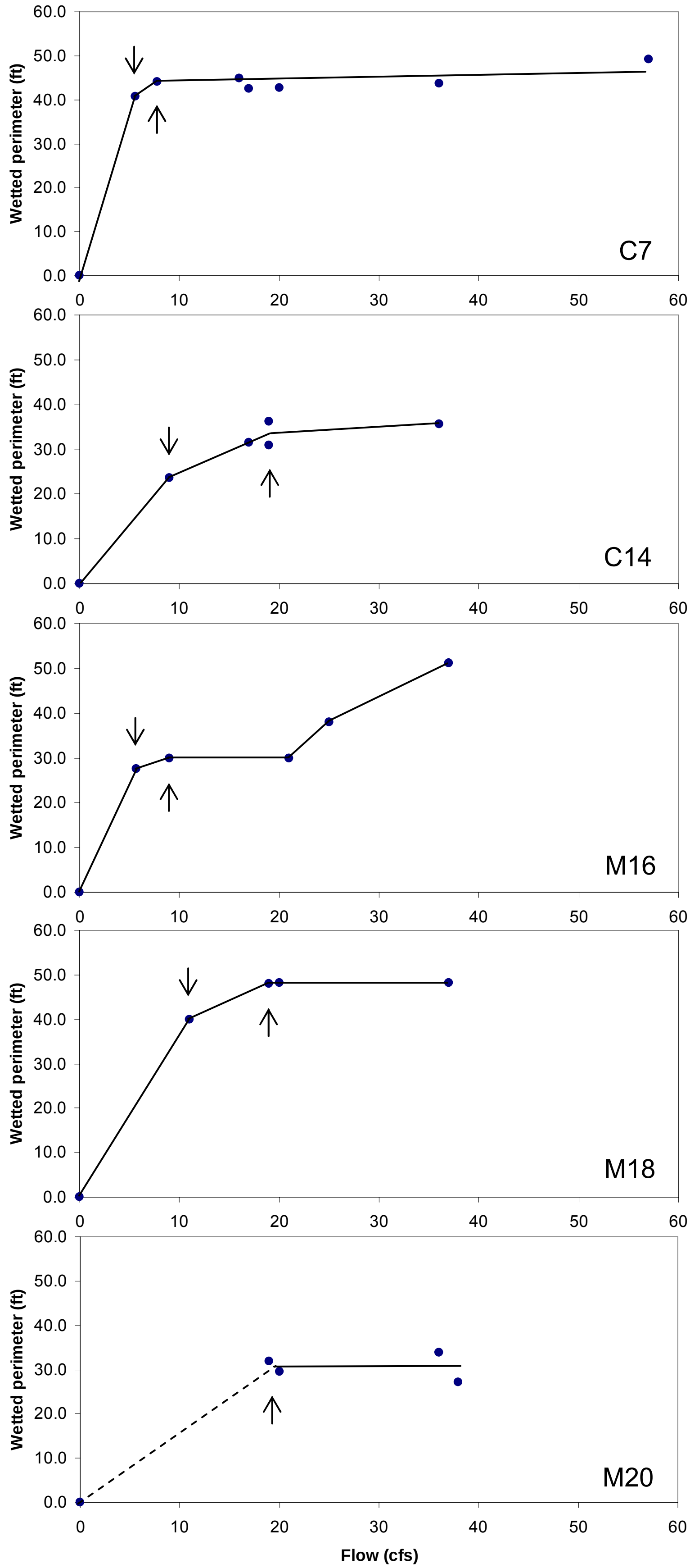

Figure 3. Wetted perimeter as a function of stream flow at low-gradient riffles on the Big Sur River from Pfeiffer Big Sur State Park to lower Andrew Molera State Park. See Table 1 for site descriptions. ↓ indicates the breakpoint, ↑ indicates the incipient asymptote. See the text for the breakpoint in M20.

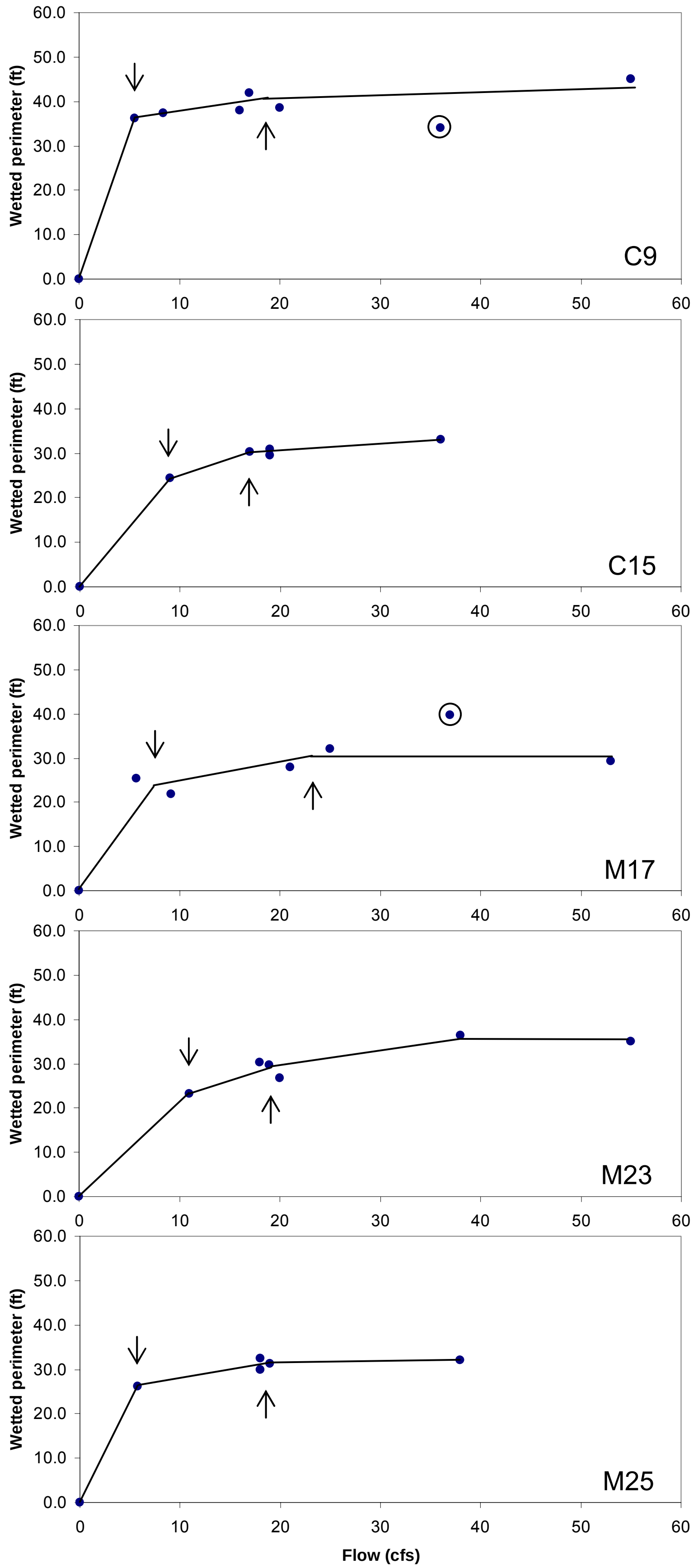

Figure 4. Wetted perimeter as a function of stream flow at runs on the Big Sur River from Pfeiffer Big Sur State Park to lower Andrew Molera State Park. See Table 1 for site descriptions. Outliers are circled. ↓ indicates the breakpoint, ↑ indicates the incipient asymptote.

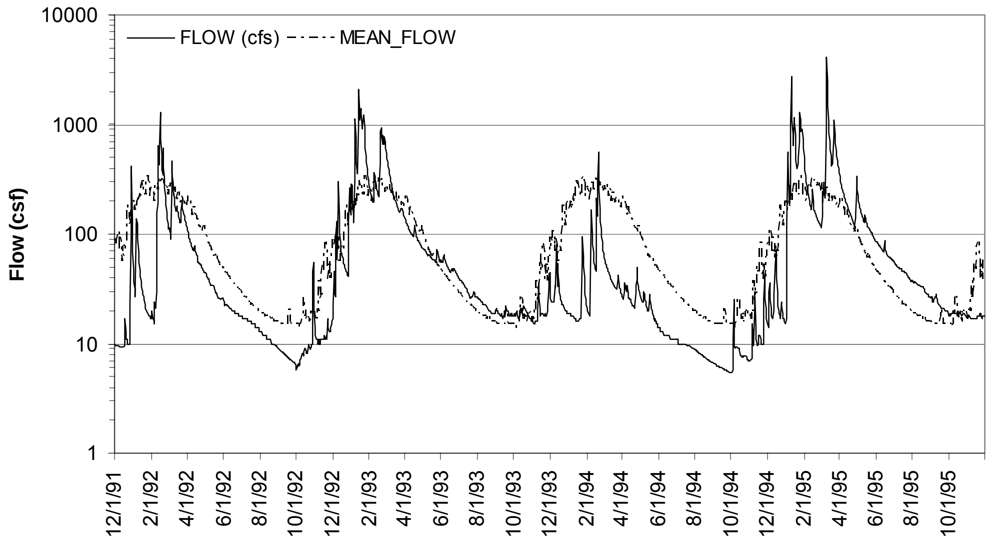

Figure 5. Daily mean flow (solid line) during the 1992 – 1995 study period, and mean of daily mean flow (dashed line) over the entire period of record for stream flow on the Big Sur River.

Mean breakpoint and incipient asymptotic flows did not differ significantly between reaches (MANOVA, $p > 0.62$ for breakpoint flows, $p > 0.46$ for incipient asymptotic flows) nor between habitat types (MANOVA, $p > 0.96$ for breakpoint flows, $p > 0.26$ for incipient asymptotic flows). In addition, there was no significant interaction term between reach and habitat type in either case ($p > 0.96$). Thus, datasets for riffles and runs were combined for final estimation of mean breakpoint and incipient asymptotic flows (Table 4).

Table 4. Summary statistics for breakpoint and incipient asymptotic flows in an analysis of the wetted perimeter-discharge relationship on the Big Sur River. Data from low-gradient riffles and runs are combined.

Statistic	Breakpoint flow (cfs)	Incipient asymptotic flow (cfs)
Range	6–11	8–23
Mean	8.0	17.0
SD	2.1	4.8
cv (%)	26	28
95% CI	6.4–9.6	13.6–20.4
n	9	10

Using the mean incipient asymptotic flow determined for the five low-gradient riffles and five runs, the interim minimum flow recommendation for maintenance of juvenile steelhead rearing habitat is 17 cfs (Table 4). In comparison, the mean breakpoint flow for all 10 habitat units was 8 cfs (Table 4), or less than half the mean incipient asymptotic flow.

DISCUSSION

Data quality

The data used for the wetted perimeter analysis were generally well-suited for this purpose. The range of flows over which wetted perimeter was measured (5.5 to 57 cfs, overall) was great enough to illustrate how wetted perimeter increased as a function of stream flow in each of the 10 habitat units investigated, riffles and runs alike (Figures 3 and 4, respectively). Channel stability and repeatability of measurements were evident in that there was good correspondence in wetted perimeter values measured at similar flows, but on disparate dates, in a given habitat unit (e.g., habitat unit M25 at 18 to 19 cfs; Figure 4). The strongly asymptotic relationship in all cases emphasized the rectangularity of the river channel. That is, once the incipient asymptotic flow was reached, there was little or no increase in wetted perimeter. Exceptions included riffle unit M16 in which wetted perimeter reached an asymptote at 9 cfs, but where a secondary terrace became wetted beginning at a flow of 21 cfs and wetted perimeter increased sharply up to an observed flow of 37 cfs (Figure 3). In run unit M23, wetted perimeter increased by about 20% beyond an asymptote reached at 19 cfs. Overall, though, the nature of the wetted perimeter-discharge relationship was well-defined and indicative of largely rectangular channel morphology, the latter being a preferred criterion for application of the method (Stalnaker et al. 1995).

The sampling design that served as the basis for collecting the data used in this analysis was relatively robust for estimating an average minimum flow condition for juvenile steelhead on a river reach scale. Variation in wetted perimeter parameters within a habitat unit was captured by making measurements at multiple transects, thus providing the basis for estimating the average wetted perimeter condition for the entire unit at a given flow. Stalnaker et al. (1995) did not specify sampling design criteria for application of the wetted perimeter method, but Annear et al. (2004) indicated that the most common practice was to establish only one transect across the stream, typically at the high point of a riffle. However, averaging measurements among multiple transects within a habitat unit, as was done in the present study, should provide a more integrated representation of width and depth in a habitat unit than that provided by using a single transect alone.

Spatial variation in the wetted perimeter-discharge relationship was addressed by systematically selecting dispersed low-gradient riffle and run habitats throughout the Campground and Molera reaches of the lower Big Sur River for habitat measurements. This aspect of the design not only captured variability in wetted perimeter throughout the majority of the juvenile steelhead rearing area on the lower river, but also allowed for comparison in wetted perimeter results between riffles and runs, the two most common habitat types. Because mean incipient asymptotic flow did not differ significantly between habitat types, the results for riffles and runs could be combined to estimate an overall mean using a doubled sample size (n = 10 with each of five riffles and runs combined) for a statistically more robust result. Having 10 sets of replicate wetted perimeter measurements was beneficial given apparent variation in channel morphology as suggested by the profiles of wetted perimeter-discharge graphs among habitat units (Figures 3 and 4). Depending upon the wetted perimeter-discharge relationship at a single point for determination of a minimum flow for the entire lower river could lead to a highly misinformed flow decision.

Degree of protection

The interim minimum flow recommendation for maintenance of juvenile steelhead rearing habitat during the summer-to-fall low-flow period was 17 cfs. This flow was the mean incipient asymptotic flow associated with providing a fully wetted channel as determined from the wetted perimeter-discharge graph for each habitat unit (Figures 3 and 4). This flow was slightly more than twice the mean breakpoint flow of 8 cfs (Table 4). The incipient asymptotic flow should provide a fully wetted channel, while the flow associated with the breakpoint may protect only 50% to 80% of the maximum wetted perimeter of the stream (Collings 1974). Maintenance of a fully wetted channel is more appropriate than only a portion of the available primary channel perimeter for protection and recovery of a listed species such as steelhead. In addition, it is anticipated that this level of flow would provide for a greater level of aquatic invertebrate production than at the breakpoint flow, and also minimum conditions for protection of riparian vegetation.

Implementation of the 17 cfs interim minimum flow recommendation would provide a varying degree of protection of aquatic habitat throughout the lower river, given variation in incipient asymptotic flow among habitat units (Figures 3 and 4). Use of the mean incipient asymptotic flow provides a conservative minimum flow recommendation, given that seven of 10 habitat units assessed for wetted perimeter had incipient asymptotic flows above 17 cfs (Tables 2 and 3). However, it also likely averages uncertainty in actual stream flow at specific habitat units, relative to the daily mean flow reported from the USGS gage. Flow from the USGS gage to the mouth of the stream is affected seasonally by several factors, including gains from tributaries, losses from diversions, and losses from evapotranspiration. That there can be relatively great discrepancies between daily mean flow reported from the USGS gage and the actual instantaneous flow measured in a given habitat unit is illustrated by discharge measurements made at 16 habitat units on the Big Sur River during July 1994 (Table 5). In 14 of 16 cases, measured flow in a habitat unit was less than that reported from the gage. Losses of flow were greatest within Pfeiffer Big Sur State Park (C7 through C11, mean loss of 38%) while greatest gains occurred with inputs from Pfeiffer-Redwood Creek (unknown volume between C11 and C12, relative gain of 23%), Juan Higuera Creek (1 cfs in the vicinity of C15 increasing river flow to 5.6% above that at the gage), and Pheneger Creek (unknown volume between C15 and M16), ameliorating losses from Big Sur community diversions as reflected in a discharge estimate at M16 that was nearly identical to that reported at the gage. Losses increased sharply again in the vicinity of the walk-in campground and the El Sur Ranch pumps in lower Andrew Molera State Park (M20 through M25, mean loss of 30%).

The recommended interim minimum flow of 17 cfs is based on flow at the USGS gage and assumes an average condition for flow losses and gains that occur downstream of the gage to the Molera campground during the low-flow period. In lieu of there being a streamflow gage downstream from all existing diversions on the Big Sur River, a complete bypass flow recommendation that would maintain an average minimum flow of 17 cfs throughout the lower Big Sur River would need to include additional flow at the USGS gage to offset downstream losses occurring at their maximum rates, including both diversions and natural losses such as evapotranspiration. Losses between the USGS gage and the Molera campground have an estimated maximum rate of 9 cfs, and average about 3 cfs. Assuming the 17 cfs minimum flow includes average diversion conditions in this reach, an additional 6 cfs would be needed to offset the maximum diversion condition. In addition, the El Sur Ranch pumps have a maximum diversion capacity of 5.84 cfs, and so this amount would also need to be added to complete the minimum bypass flow recommendation. In total, the complete interim minimum bypass flow recommendation for instream rearing of juvenile steelhead on the Big Sur River during the summer-fall low-flow period is 29 cfs[2], as measured at the USGS gage.

Table 5. Stream flow on the Big Sur River during July 1994 as measured from replicate transect measurements (mean *n* = 5; range 3–13) within each of 16 habitat units, from Pfeiffer Big Sur State Park downstream to Andrew Molera State Park. Date refers to the day in July 1994 on which stream flow was measured. The corresponding daily mean flow from the USGS streamflow gage on the Big Sur River is provided for comparison. Difference in flow is the net loss or gain between the gage and the habitat unit in which flow was measured, expressed in both cfs and as a percentage of the gage flow.

Habitat unit	Date	Measured flow (cfs)	USGS gage flow (cfs)	Difference (cfs)	Difference (%)
C7	18	6.0	9.7	-3.7	-38.1
C8	19	6.5	9.7	-3.2	-32.6
C9	19	5.6	9.7	-4.1	-41.9
C11	27	5.5	9.2	-3.7	-40.2
Inflow of Pfeiffer-Redwood Creek, volume not determined					
C12	19	8.0	9.7	-1.7	-17.2
C13	26	7.5	9.3	-1.8	-19.6
C13.5	27	8.1	9.2	-1.1	-12.2
C14	22	8.8	9.5	-0.7	-7.4
Inflow of Juan Higuera Creek, 1 cfs, estimated on 21–22 July 1994					
C15	20	10.1	9.6	0.5	5.6
Inflow of Pheneger Creek, volume not determined					
M16	20	9.5	9.6	-0.1	-0.7
M17	20	9.0	9.6	-0.6	-6.2
M18	20	8.9	9.6	-0.7	-7.6
M19	20	9.8	9.6	0.2	2.4
M20	21	7.6	9.6	-2.0	-21.2
M23	21	6.4	9.6	-3.2	-33.3
M25	21	6.3	9.6	-3.3	-34.4

It should be noted that the *minimum* flow recommended here should not be interpreted as being the *optimal* flow for production of juvenile steelhead in the Big Sur River. Rather, 17 cfs at the USGS gage, plus any additional flow to offset maximum diversion and natural loss rates downstream, should be regarded as the lowest flow that confers an acceptable temporary and short-term minimum condition for protection of juvenile steelhead, their physical instream habitat, and their invertebrate food source in years when runoff is insufficient to provide a flow nearer an as-of-yet undetermined optimum. A fully wetted channel should provide a minimum level of protection for associated riparian resources, as well. Finally, it is uncertain what level of protection 17 cfs provides for lagoon habitat. A complicating factor in this regard is the El Sur Ranch pumps, which divert subsurface flow of the Big Sur River between the Molera parking lot and the lagoon. Further study is needed to determine instream flow requirements for maintenance of lagoon habitat, including water quality.

Comparison with earlier flow recommendation

During the mid-1980s, Monterey County and the State of California adopted the Big Sur River Protected Waterway Management Plan (Monterey County 1986). This document was prepared in response to the California Protected Waterways Plan of 1971, which recognized the Big Sur River as an important steelhead stream. The Big

[2] Note that this interim minimum flow recommendation does not address flow needed for upstream passage of adult steelhead, steelhead spawning, or protection of lagoon habitat.

Sur River waterway plan included an interim minimum flow recommendation of 19.6 cfs based on guidelines provided by DFG. The guidelines suggested that the minimum flow be the mean of mean monthly flows for the June–October low flow period, using all available historic USGS streamflow data available for the Big Sur River at that time.

Although determined using a different method, the protected waterway flow recommendation of 19.6 cfs was very similar to the mean incipient asymptotic flow of 19 cfs determined for runs in the current analysis (Table 3). In addition, the earlier recommendation was 15% greater than, but still within the 95% confidence interval for, the 17 cfs proposed as an interim minimum flow in the current analysis (Table 4). While never proposed by DFG as an instream flow recommendation per Public Resources Code 10000, the protected waterway flow recommendation would provide the target level of aquatic habitat protection (fully wetted stream channel) in a higher frequency of habitat units than the 17 cfs minimum flow. For example, incipient asymptotic flow would be maintained or exceeded in four each of the five riffle and run habitats assessed in the current analysis, as opposed to only two riffles and one run with 17 cfs (Tables 2 and 3).

Minimum flow relative to the hydrograph

The seasonal hydrograph for the Big Sur River (Figure 6) is typical of central California coastal streams: following the winter rainy season when flow is high, the hydrograph decreases rapidly through the spring and continues to decline gradually from June until it hits bottom in September. Low flow conditions prevail until the rainy season begins again, typically during the latter half of November or December. In some years, the low-flow period may extend into January of the following year (USGS stream flow data for the Big Sur River, 1952–2011). The average lowest flow of the year on both a daily (Figure 5) and monthly (Figure 6) basis is 15 cfs.

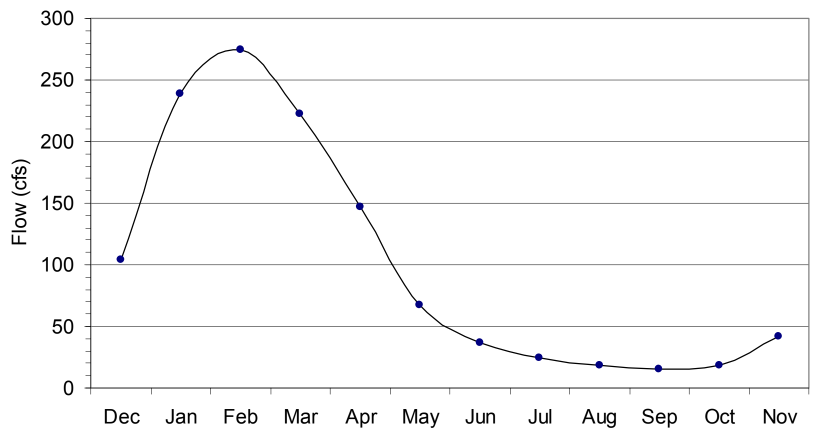

Figure 6. Mean of monthly mean flow on the Big Sur River, 1952–2010. Data are from USGS gage 11143000.

Under average water year conditions or drier, the Big Sur River watershed does not produce enough water to maintain the recommended interim minimum flow of 17 cfs throughout the entire low-flow period. The mean of daily mean flow drops below 17 cfs at the USGS gage during 44 days from 25 August through 9 October (Figure 5). Over the 60 year period of record, there have been 16 years (27%) when daily mean flow at the USGS gage has remained at or above 17 cfs throughout the year, or very nearly so (four or fewer inconsecutive days < 17 cfs). A minimum bypass flow incorporating additional flow to offset maximum diversion rates both within and below the current study area would be supported at an even lower frequency. These statistics suggest that little or no flow should be diverted from the Big Sur River during the low-flow period in most years if at least minimum flow conditions for juvenile steelhead rearing are to be maintained, per the criteria established in this analysis.

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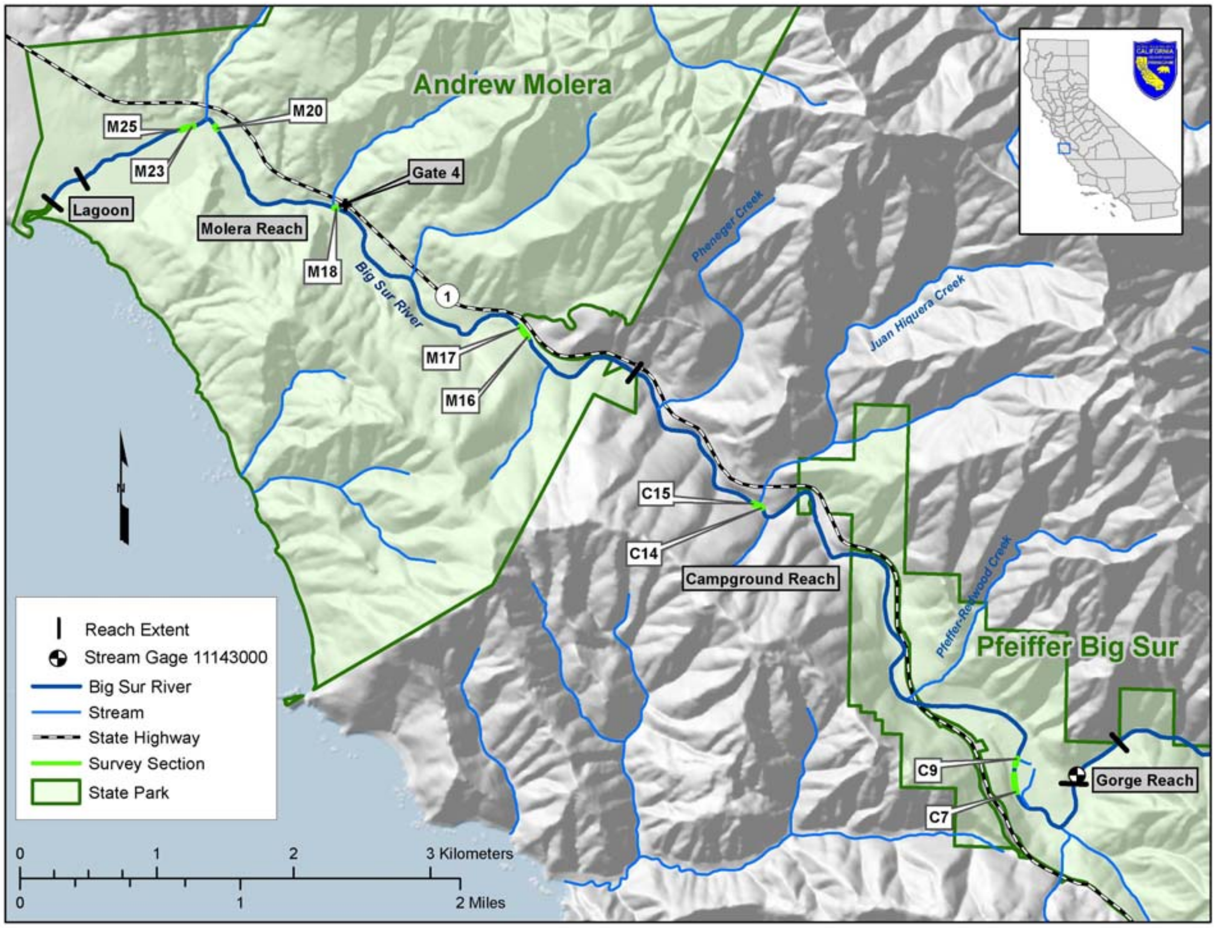

Figure 2. Map of the study area in which data were collected for the wetted perimeter analysis.