State of California
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Department of Fish and Wildlife

Instream Flow Evaluation
Steelhead Spawning and Rearing
BIG SUR RIVER, Monterey County

STREAM EVALUATION REPORT 14-2
July 2014

Department of Fish and Game
Stream Evaluation Report
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Secretary for Resources	Governor	Director
Natural Resources Agency	State of California	Department of Fish and Game

Instream Flow Evaluation
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Robert W. Holmes and William Cowan

ABSTRACT

Steelhead spawning and rearing flows were evaluated in the Big Sur River, Monterey County from 2009 – 2011. A stratified random design was used to identify sample sites and corresponding transect locations for mesohabitat sampling of hydraulic and physical habitat data spanning the anadromous zone of the river (~ 7.5 miles) at each of three flow levels. One-dimensional (1D) hydraulic habitat models were then developed using the site-specific data for each of three river reaches and used to evaluate flow and habitat relationships for steelhead lifestages using a median habitat duration approach and time series analyses. Flows identified by the 1D models incorporate water availability and the natural flow regime of the Big Sur River, and are presented by monthly hydrologic condition type (i.e., critical dry, dry, below median, above median, wet, and extremely wet). Significant flow losses (- 8 cfs) were observed between USGS 11143000 and USGS 11143010, which must be factored into future stream flow requirements for protection of steelhead spawning and rearing in the Lower Molera Reach of the Big Sur River. A low-flow threshold analysis was also conducted using empirical data (i.e., water surface elevations, bed profiles, water depths, etc.) collected from three distinct flows from randomly identified fixed, cross-channel, riffle transects and Manning's equation to evaluate wetted perimeter and discharge relationships. The low-flow threshold analysis, which is recognized as a necessary and important component of an overall stream flow regime assessment, indicated 22 cfs as the low-flow threshold necessary to conserve and protect the Big Sur River steelhead fishery. Flow criteria were developed using the above instream flow evaluation information and are recommended to promote the continued viability of the Big Sur River steelhead population.

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[1] Stream Evaluation Report No. 14-2, July 2014. Water Branch Instream Flow Program.

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ABBREVIATIONS, ACRONYMS, AND CONVERSIONS

1D	one-dimensional hydraulic model (PHABSIM, RHABSIM)
7DADM	seven day average of daily maximum temperature
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
cm	centimeter
DPS	Distinct Population Segment
°F	degrees Fahrenheit
ft	foot (feet) (30.5 centimeters)
HSC	Habitat Suitability Criteria
IFIM	Instream Flow Incremental Methodology
in	inch
km	kilometer
km^2	square kilometer
log-log	a regression analysis expressed using logarithmic scales
mm	millimeter
m	meter
MANSQ	manning’s stage discharge
NMFS	National Marine Fisheries Service
PHABSIM	Physical Habitat Simulation Model
PRC	Public Resources Code
RHABSIM	Riverine Habitat Simulation Model
RM	river mile
SZF	stage of zero
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VAF	velocity adjustment factor
WSEL	water surface elevation
WSP	Water Surface Profile Model
WUA	weighted usable area

FOREWORD

California's south-central coast steelhead (*Oncorhynchus mykiss*) populations have declined from about 25,000 spawning adults per year to fewer than 500 (NMFS, 2007). Consequently, the south-central steelhead Distinct Population Segment 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). All of the watersheds in the south-central coast DPS are impacted by a variety of anthropogenic stressors, but the most frequent source of threat stems from water management activities, such as agricultural and urban diversions (NMFS, 2008).

The Department's policy is that the federal Instream Flow Incremental Methodology (IFIM) will be used to evaluate and develop instream flow criteria and recommendations for projects which may affect the state’s aquatic resources. The policy indicates that the IFIM approach will be used to assess the relationship between flows and habitat because of its benefits and defensibility. The Public Resources Code (PRC) §10000-10005 outline the Department’s responsibilities for developing and transmitting flow recommendations to the State Water Resources Control Board (State Board) for consideration as set forth in 1257.5 of the Water Code. Consistent with the PRC, the 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 those resources. The results from this study component of an overall IFIM on the Big Sur River are intended to be used, along with other supporting information and data, to identify stream flow requirements for the Big Sur River pursuant to CDFW’s PRC mandate.

INTRODUCTION

The unregulated, free-flowing, Big Sur River is a steelhead (*Oncorhynchus mykiss*) stronghold (Wild Salmon Center, 2010) and supports one of the most important wild steelhead populations on California's Central Coast. Unlike other steelhead populations to the north (i.e., Carmel River, San Lorenzo River), the Big Sur River steelhead population is not dependent upon hatchery production or rearing activities for maintenance of the population. However, the Big Sur River steelhead population has declined from historical levels with estimations of fewer than 100 adults in recent decades (Nehlsen et al. 1991), a population level that could be even lower today.

Because of its' high resource value and presence of south-central steelhead, the Big Sur River was identified as one of the California Department of Fish and Wildlife's (Department) priority streams in 2008 for future instream flow assessments (CDFW, 2008a). In 2009, the Department initiated an Instream Flow Incremental Methodology (IFIM; Bovee 1982; Bovee et al. 1998) study on the Big Sur River as part of its responsibility to implement Public Resources Code (PRC) §10000-10005 through the Department's Instream Flow Program. The Big Sur River IFIM study was comprised of investigation elements specifically designed to identify instream flow needs and to provide the basis for flow requirements.

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 (i.e., hydrology, biology, water quality, connectivity, and geomorphology). Study elements of the Big Sur River IFIM investigations included: a lagoon study (Allen and Riley 2012); steelhead spawning surveys (CDFW, 2014); a steelhead passage and habitat connectivity study (Holmes et al. 2014a); and a site-specific habitat suitability criteria (HSC) study for juvenile steelhead rearing (Holmes et al. 2014b).

The goal of the current study was to quantify or characterize south-central steelhead habitat as a function of flow in the Big Sur River using modeling, hydrologic, and empirical methods. Objectives of this study included to estimate the habitat index versus flow relationships using one-dimensional (1D) hydraulic habitat (Riverine Habitat Simulation: RHABSIM) models, and use habitat index versus flow relationships to develop habitat duration and time series analyses of steelhead habitat in the Big Sur River under alternative flow scenarios. The current study report also incorporates other components of the IFIM study, including the mesohabitat habitat mapping data, water quality (temperature) monitoring data, hydrological analyses, low-flow threshold analyses, and a geomorphology (i.e., channel forming flow) analyses.

DESCRIPTION OF STUDY AREA

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 (Figure 1). It 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. Significant tributaries include Pfeiffer-Redwood Creek, Juan Higuera Creek, Post Creek and Pheneger Creek (Figure 1).

The Big Sur River is among the larger central coast watersheds supporting south-central steelhead south of San Francisco Bay (Titus et al. 2010). The Big Sur River has a watershed of approximately 60 square miles (150 km^2) with no major dams, diversions, or reservoirs. However, only the lower 7.5 miles of the river (lower Big Sur River) are accessible to steelhead, with upstream fish migration blocked either by a partial or complete bedrock barrier, depending on stream flow conditions.

The lower Big Sur River is situated in what is referred to as the Big Sur River Valley. The Big Sur River Valley 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.

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 wettest year on record was 1983 with 88.85 inches (2,257 mm) and the driest year was 1990 with 17.90 inches (455 mm). More than 70% of the rainfall falls from December through March.

Human population density in the Big Sur area is low, with about 1,000 year-round inhabitants, according to the 2000 U.S. Census. The Pacific Ocean is located on the western base of the mountains and offers motorists many vistas and views varying from at sea level to an over six hundred foot sheer cliff from Highway 1. The section of Highway 1 through Big Sur is one of, if not the, most scenic driving routes in the United States.

Figure 1. Map of lower Big Sur River Watershed.

The hydrology of the Big Sur River is typical of many coastal California streams, with high winter flows, low summer flows, and variable annual discharges. Most of the flow occurs in the winter with stream discharge reflecting local and watershed-wide rainfall patterns. Flows in winter may raise and recede rapidly associated with rainfall events, while flows in the summer tend to be more stable and predictable as they recede into the fall months.

Two U.S. Geological Survey (USGS) stream flow gages were in operation during the study: 1) USGS stream flow gage 11143000, located in Pfeiffer State Park and 2) USGS gage 11143010 located approximately 7 river miles downstream (of USGS gage 11143000) in Molera State Park. Gage 11143000 has been in operation since March of 1950 and is located upstream all known diversions. Although, Gage 11143000 does not reflect accretion of flow from several lower river tributaries including Post, Pfeiffer-Redwood, Juan Higuera, and Pheneger Creeks, and is assumed to reflect the natural flow conditions. Gage 11143010 began operation in 2010 and is located downstream of all river tributaries.

Fishery Resource

The Big Sur River is home to approximately 5 native species of freshwater fishes, including the anadromous steelhead, Table 1. There does not appear to be any introduced freshwater fishes in the study area. Steelhead use the area year-round for migration, spawning, incubation, rearing, and/or emigration (Figure 2).

Table 1. A partial list of fish species in the Big Sur River.

Scientific Name	**Common Name**
Lampetra tridentata	Pacific Lamprey
Oncorhynchus mykiss	Steelhead
Cottus asper	Prickly Sculpin
Cottus aleuticus	Coast Range Sculpin
Gasterosteus aculeatus	Threespine Stickleback

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

Figure 2. Life stage periodicity for south-central steelhead in the Big Sur River.

METHODS

Identification of Sampling Sites and Sampling Strategy

The study area spans approximately 7.5 miles (12 km) in length and is divided into three reaches representing homologous stream segments based upon gradient, geomorphology, hydrology, riparian zone types, flow accretion, diversion influence, and channel metrics (Figure 3). The reaches include: 1) the Lower Molera Reach, which extends from the lower-most part of the river at the lagoon/river transition to the Molera campground parking lot; 2) the Molera Reach, which extends from the Molera campground parking lot through Molera State Park boundary; and 3) the Campground Reach, which extends from the Molera State Park boundary into Pfeiffer Big Sur State Park near the USGS stream flow gage (Station 11143000) and the upper end of steelhead anadromy.

Mesohabitat types were numbered sequentially, beginning at the first habitat unit at the lower end of the Molera Reach and working upstream. Mesohabitat classification consisted of partitioning the river channel into two main channel types: main and split channel. There was one split channel section of the river located approximately 1310 feet (400 m) upstream of the Lower Molera and Molera Reach boundary. The split channel was 620 feet (189 m) long, constituted less than 2% of the river channel, and was therefore not included in the study because it was considered atypical in the study area.

The channel types were further subdivided into low gradient riffle, pool, glide, run, and shallow run mesohabitat types. Mesohabitat type classifications were consistent with Flosi et al. (2010) with the exception of the shallow runs. Shallow runs, unlike the run mesohabitat type, were characterized by a preponderance of surface agitation and typically included flow obstructions. For the remainder of this report, mesohabitat data collected make reference to the habitat type and unit number to apportion sampling effort (Table 2).

Study sites for 1D model sampling were selected using a stratified random sampling design in each of the three reaches. First, each study reach was partitioned into three approximately equal sub-reaches based upon the number of mesohabitat units (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, Table 3. Units 167-194 were omitted from the random draw of sites because of the significant amount of anthropogenic activity (camping, swimming, etc.) in this segment of river. Three transects per unit were selected using the same stratified random sampling design in each reach (Figure 4, Figure 5, and Figure 6).

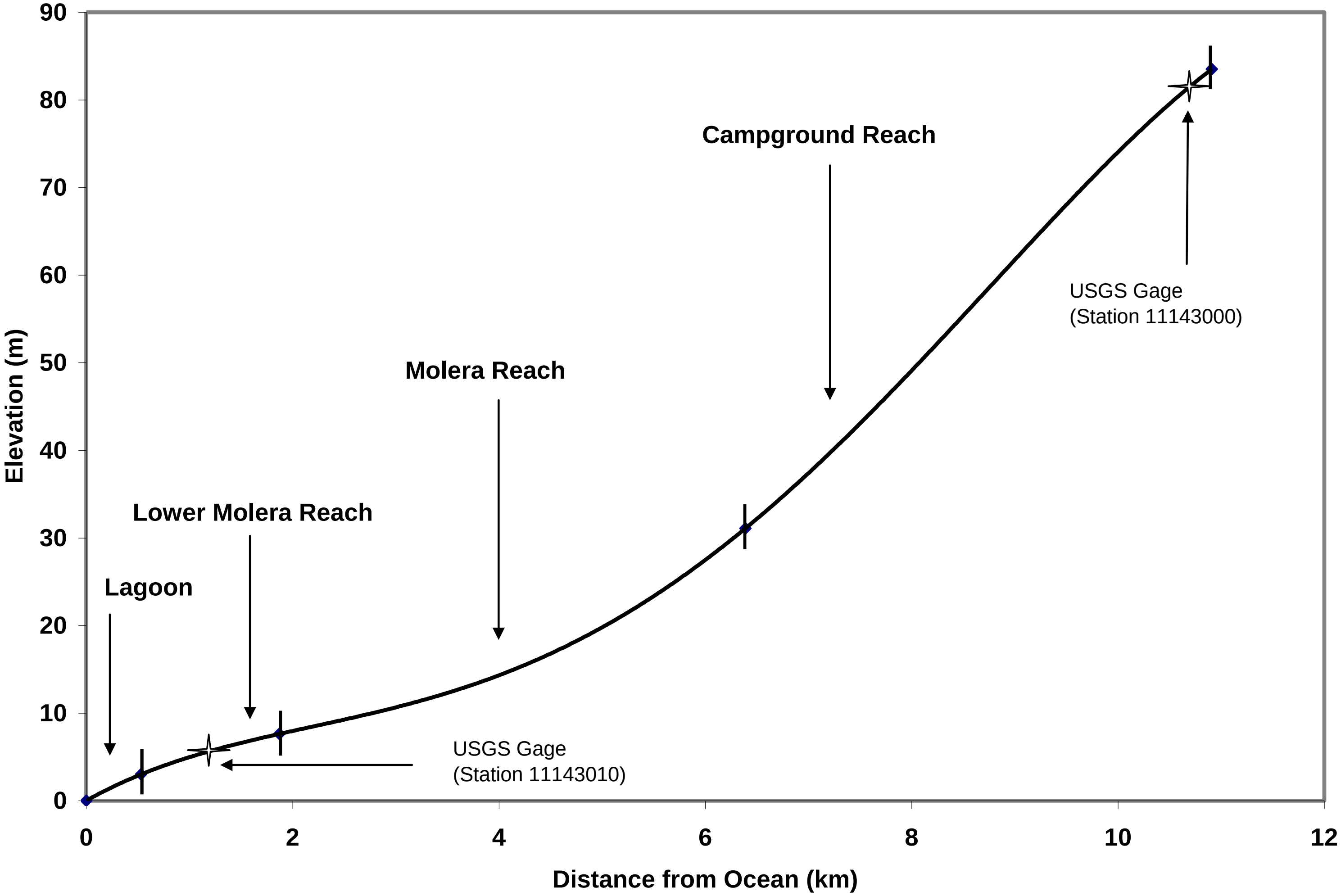

Figure 3. Gradient profile for the Big Sur River from ocean through study area.

Table 2. Summary of mesohabitat types in Big Sur River study area.

	Mesohabitat Unit Type				
	Low Gradient Riffle (LGR)	POOL	Glide (GLD)	RUN	Shallow Run RUN(S)
LOWER MOLERA					
# Units	11	11	3	8	0
Total Length (ft)	735	2362	341	974	0
Average Length (ft)	66	217	115	121	0
MOLERA					
# Units	43	30	17	31	4
Total Length (ft)	3615	3219	2641	3478	522
Average Length (ft)	85	108	154	112	131
CAMPGROUND					
# Units	70	44	15	32	16
Total Length (ft)	8225	5102	2024	3343	2418
Average Length (ft)	118	115	135	105	151

Table 3. Sampling sites and corresponding mesohabitat types in Lower Molera, Molera, and Campgrounds Reaches.

LOWER MOLERA		MOLERA		CAMPGROUND	
Sampling Unit	Mesohabitat Type	Sampling Unit	Mesohabitat Type	Sampling Unit	Mesohabitat Type
14	RUN	55	POOL	195	LGR
16	GLD	62	LGR	205	GLD
17	POOL	73	GLD	211	RUN(S)
18	LGR	77	RUN	217	RUN
25	RUN	102	POOL	219	POOL
26	LGR	110	RUN	244	POOL
27	POOL	111	LGR	245	RUN
28	GLD	112	GLD	258	GLD
31	POOL	148	POOL	260	LGR
35	LGR	152	GLD	274	RUN(S)
36	RUN	154	LGR	300	LGR
37	GLD	161	RUN	301	POOL
				324	GLD
				330	RUN
				333	RUN(S)

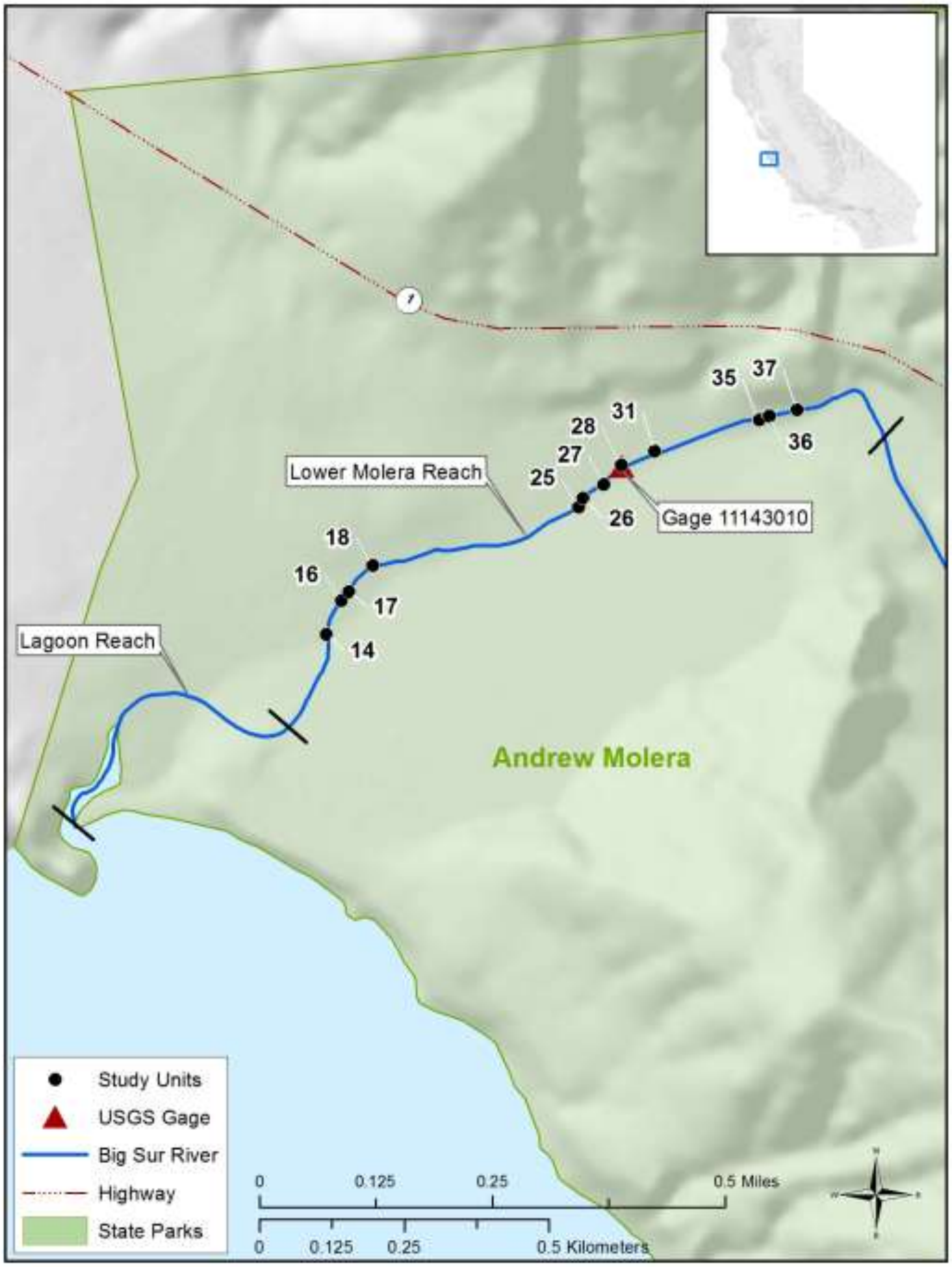

Figure 4. Lower Molera Reach study site locations.

Figure 5. Molera Reach study site locations.

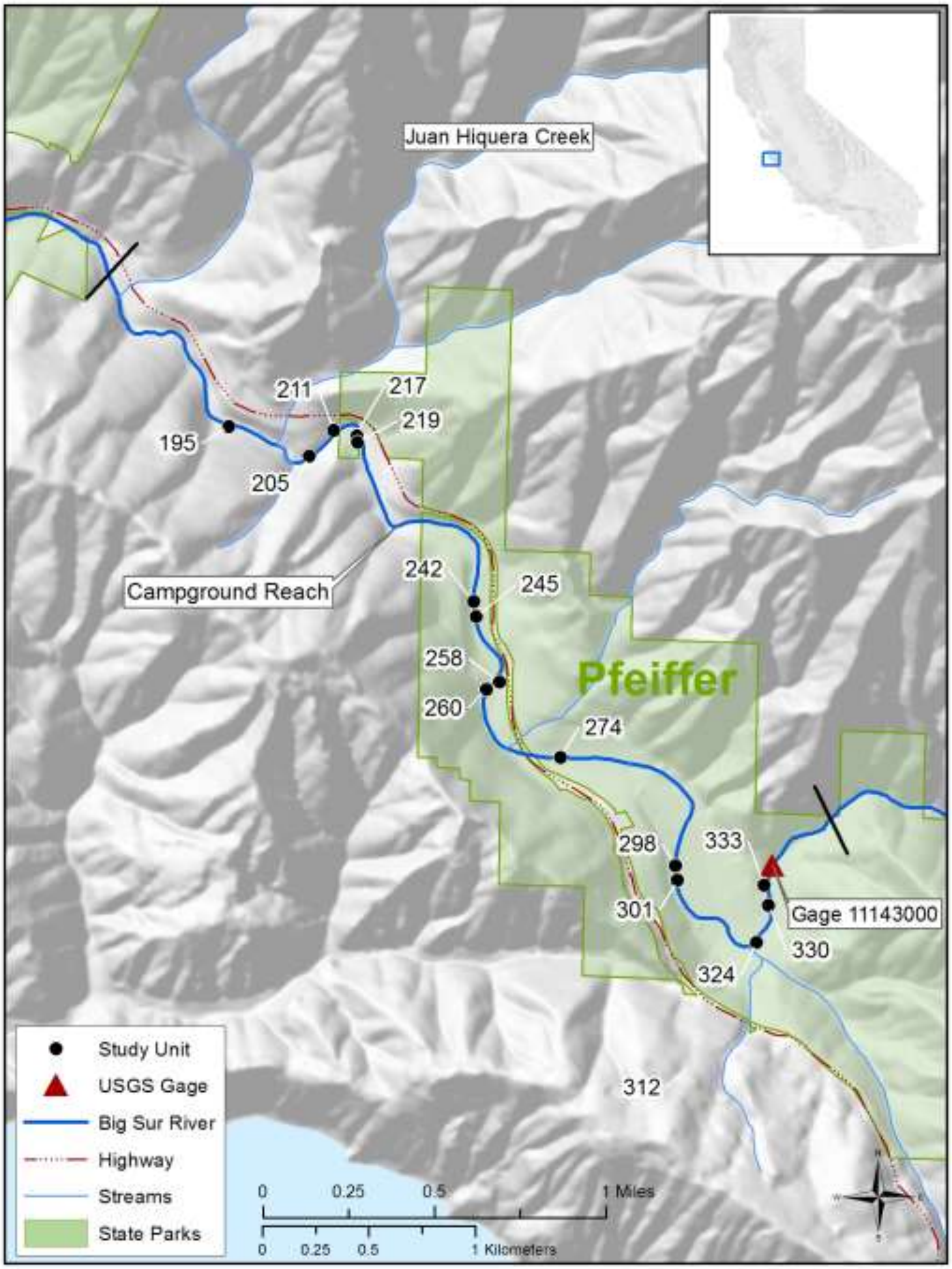

Figure 6. Campground Reach study site locations.

Identification of Target Flows for Sampling

Mean daily flows and percent exceedance flows for the Big Sur River at USGS gage 11143000 are presented in Figure 7 and Figure 8, respectively. Since there are no diversions or dams upstream of USGS gage 11143000, the hydrology patterns reported at USGS gage 11143000 reflect the natural unimpaired flow regime. Target sampling flows for hydraulic and habitat data collection were based upon the 20, 50, and 80 percent exceedance flows of USGS gage 11143000. Percent exceedance flows are typically used as a guideline for describing the watershed hydrology, as well as for making informed decisions about water resources planning and management. The percent exceedance flows between 20 and 80 percent reflect the most commonly observed flows in the stream, with the 50 percent exceedance flow reflecting the stream's natural benchmark. The 80, 50, and 20 percent exceedance flows for the Big Sur River are 14, 30, and 105 cfs, respectively. Monthly exceedance flows are presented in Appendix 1.

Structural and Hydraulic Data Collection

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 (WSELs), 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 2013); 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 (Table 4) at these same locations and also where dry ground elevations were surveyed.

Elevational benchmarks were established at each site and we referenced all elevations 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. WSELs were collected in each channel at split channel sites. A top-setting wading rod and Marsh-McBirney model 2000 water velocity meter were used to measure water depth and velocities at specific intervals along each transect. Onsite discharge measurements were made following procedures of Rantz (1982). The stage of zero flow (SZF), 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.

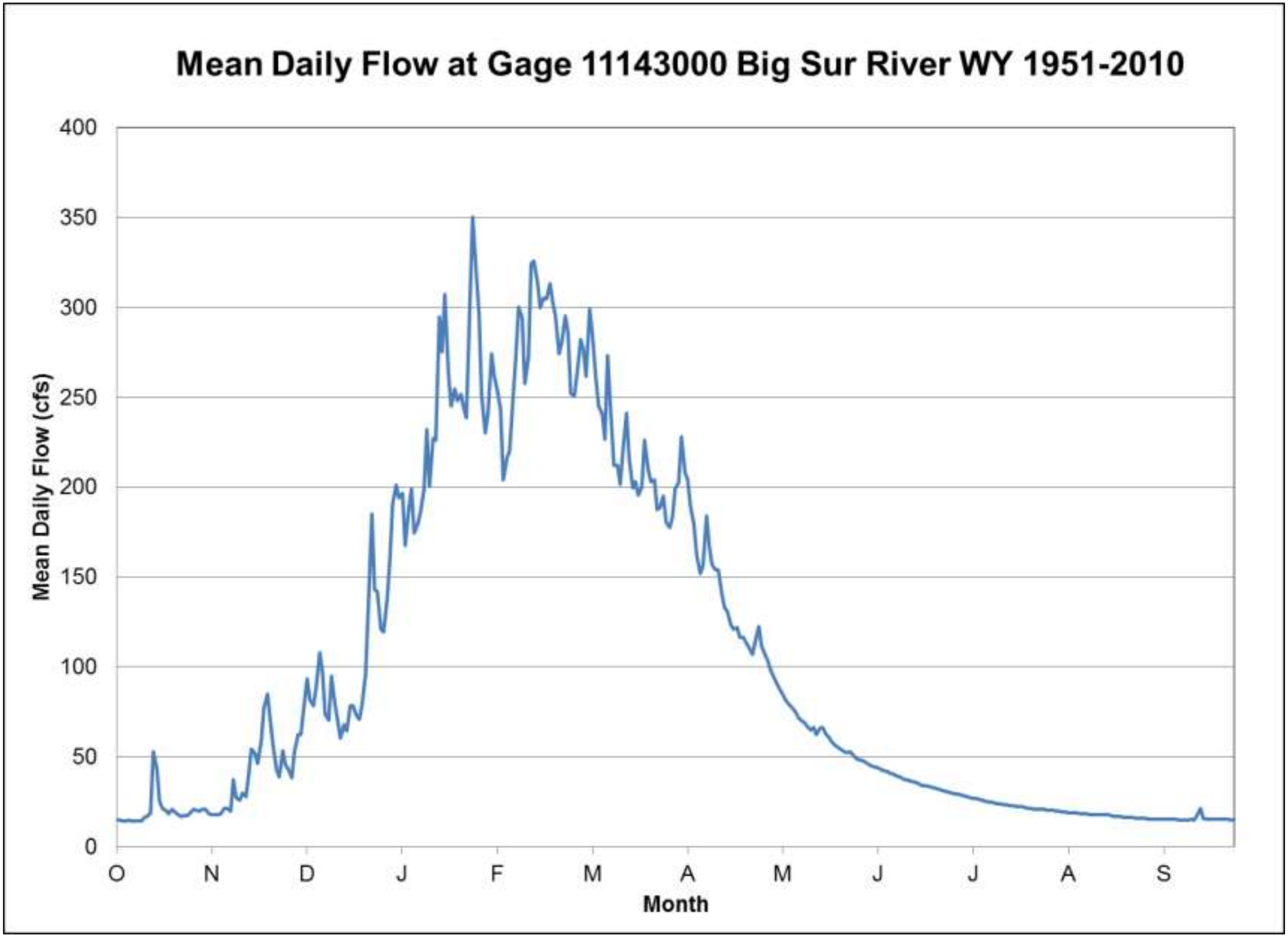

Figure 7. Mean daily flow at USGS gage 11143000 on the Big Sur River for water years 1951 through 2010.

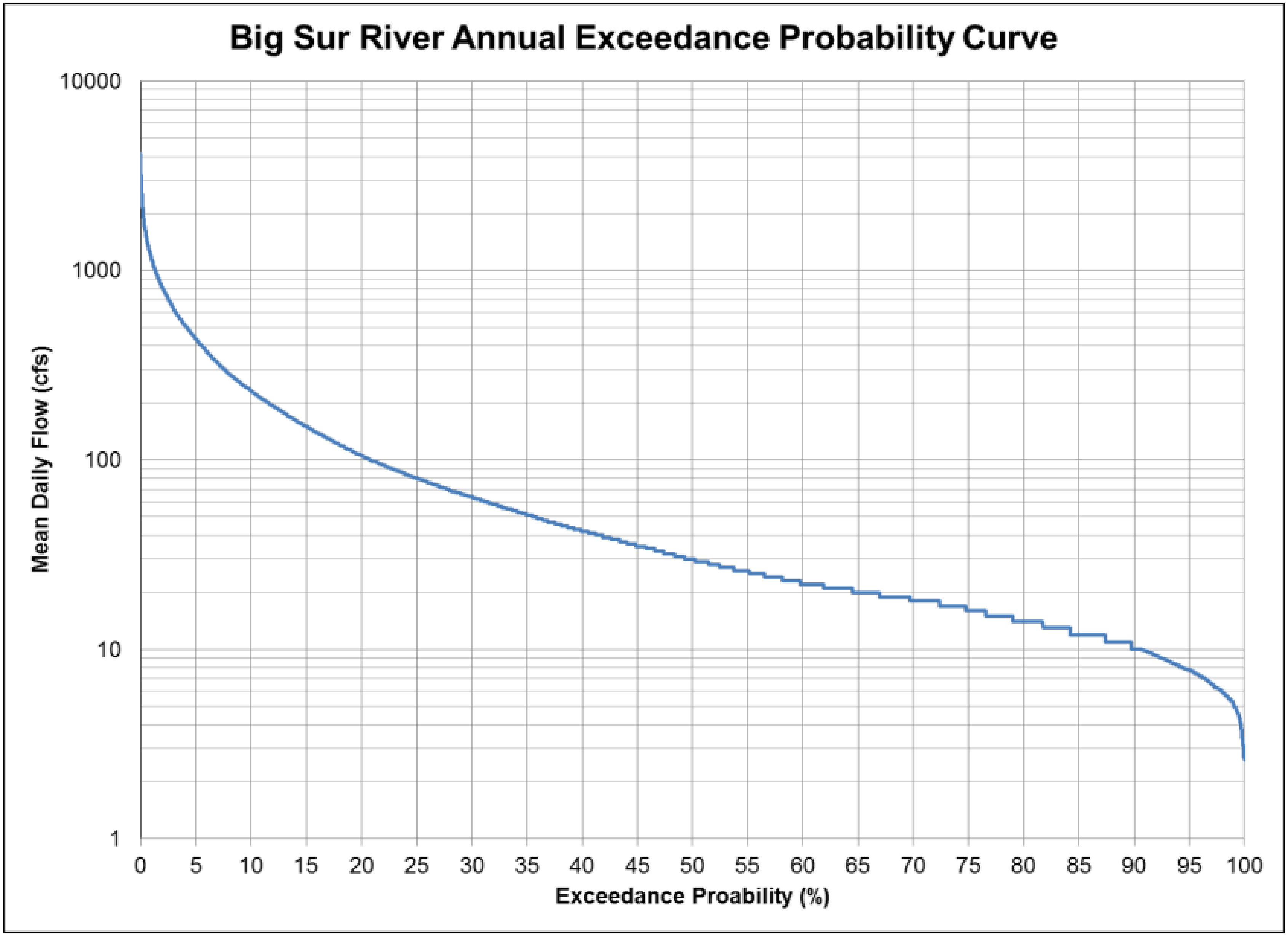

Figure 8. Big Sur River annual exceedance probability curve using mean daily flows from USGS gage 11143000 for water years 1951 through 2010.

Table 4. Vegetative and substrate codes.

Vegetative Codes		Substrate Codes		Size (in)
0	None	20	None	
1	Filamentous algae	21	Clay	
2	Non-emergent rooted aquatic vegetation	22	Sand or silt/sand	< 0.1
3	Emergent rooted aquatic vegetation	23	Coarse sand/DG	0.1-0.2
4	Grass	24	Small gravel	0.2-1
5	Sedges/rushes	25	Medium gravel	1-2
6	Vines/ poison oak	26	Large gravel	2-3
7	Branches &/or small vegetation < 4 inches, IW	27	Gravel/cobble	3-4
8	Branches &/or small vegetation < 4 inches, OW	28	Small cobble	4-6
9	Branches > 4 inches, IW	29	Medium cobble	6-9
10	Branches > 4 inches, OW	30	Large cobble	9-12
11	Tree trunks < 4 inches, IW	31	Small boulder	12-24
12	Tree trunks < 4 inches, OW	32	Medium boulder	24-48
13	Tree trunks > 4 inches, IW	33	Large boulder	>48
14	Tree trunks > 4 inches, OW	34	Bedrock	
15	Roots and root-wads	35	Undercut bank	
16	Shrubs < 4 inches			
17	Duff, leaf litter, organic debris			
18	Small woody debris (< 4 inches), dead			
19	Large woody debris (> 4 inches), dead			

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 unit.

Hydraulic Model Development, Calibration, and Simulation

In general, hydraulic models were developed using the structural and hydraulic data in the Field Data Entry (FIELDAT) module of RHABSIM[2] and then data were processed in the Hydraulic Calibration (HYDSIM) module. The data were then used to simulate WSELs and velocities over a range of simulation flows. Once the hydraulic simulations were completed, habitat suitability data for each steelhead lifestage were input into the Criteria Curves (CRITERIA) module. Finally, the Habitat Simulation (HABSIM) module presents the results generated using the HYDSIM and CRITERIA modules and the results are presented by way of habitat index (weighted usable area (WUA)) curves.

The following are the calibration criteria (Waddle 2001) used to evaluate the performance of each of the models:

- The mean error of predicted versus measured discharge does not exceed 10%;
- The maximum variance of any one predicted discharge compared to a measured discharge does not exceed 25%; and
- The difference between measured and predicted WSELs does not exceed 0.1 foot at a given calibration flow.

Transect weighting factors were calculated and used in each model to ensure representativeness of available habitats in each reach (Table 5). Run and shallow run (RUN(S)) transect numbers in the Campground Reach were combined to determine transect weighting. The one velocity calibration method (Payne 1998) was used to develop simulation flows using the mid flow velocity profiles from the field data. For more information, a hydraulic calibration report was prepared (Cowan 2014) which outlines the calibration flows for each reach-specific model, the process of developing the bed profiles for each model, velocity adjustment factor results, and overall calibration summary results.

Water surface elevations were simulated in RHABSIM using the following rating curve methods: 1) Log-log regression (REG); 2) Manning's formula (MANSQ); and/or a step backwater model (WSP). REG was run for all transects. MANSQ was run for all transects except pool transects. WSP was run for pool transects where the stage of zero flow for a particular transect was controlled by a downstream point. The method with the best fit of stage/discharge compared to the user-defined calibration points was selected as outlined in Cowan (2014).

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[2] 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.

Table 5. Transect weighting factors (percent) by reach.

Reach	Mesohabitat Type	Weight of Meso Type Sampled (%)	Number of Transects	Transect Weights (%)
Lower Molera	LGR	16.7%	6	2.78%
	POOL	53.5%	8	6.69%
	GLD	7.7%	8	0.97%
	RUN	22.1%	7	3.15%
	Total	100.0%	29	
Molera	LGR	26.8%	6	4.47%
	POOL	23.9%	9	2.66%
	GLD	19.6%	9	2.18%
	RUN	29.7%	9	3.30%
	Total	100.0%	33	
Campground	LGR	39.0%	8	4.87%
	POOL	24.2%	6	4.03%
	GLD	9.6%	9	1.07%
	RUN AND RUN(S)	27.3%	18	1.52%
	Total	100.0%	41	
Total Number of Transects:			103	

Habitat Suitability Criteria

Habitat Suitability Criteria for four steelhead lifestages were developed for use in the hydraulic modeling: <6 cm juvenile rearing, 6-9 cm juvenile rearing, 10-15 cm juvenile rearing, and adult spawning. The juvenile rearing HSC were developed from a site-specific study on the Big Sur River during three important rearing seasons: spring, summer, and fall using a stratified random and equal area sampling design for water depth and water velocity (Holmes et al. 2014b). The adult spawning HSC were developed from the literature (Dettman and Kelley 1986; Hampton 1997), and verified for appropriateness using observations from Big Sur River steelhead spawner surveys (CDFW 2014).

Habitat Duration and Time Series

The 60-year unimpaired flow record 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. 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 2008b) based upon the monthly water types. Monthly habitat duration values were determined by computing daily habitat index (WUA) 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 results ensures corresponding flow criteria and recommendations are consistent with natural water availability.

A total of nine habitat time series were developed using each steelhead lifestage and reach. Mean daily discharge values from USGS gage 11143000 were converted to habitat values using linear interpolation. Each habitat time series was then partitioned by monthly water type and the median habitat duration value for each water month category and lifestage was calculated. The flow corresponding to the median habitat value was identified from each WUA curve. The peak of the WUA curve was used as an upper boundary for flow duration analysis in the wet and extremely wet month types. The WUA curves for the <6 cm steelhead lifestage peaked at the minimum simulation value for each reach, which precluded calculation of habitat values using the time series method. CDFW (2008b) recommends 1D habitat index vs discharge relationships be compared with the river's unimpaired flow time series to identify flow regimes that address intra- and inter-annual riverine needs, an analyses that may be useful for evaluating project impacts and potential tradeoffs. Since USGS gage 11143000 is upstream of all known diversions it is considered to represent natural unimpaired flow conditions.

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 (when 11143010 was also in operation). USGS 11143010 has since been taken off-line due to lack of funding, although the equipment remains in place at time of this report.

Low-Flow Threshold

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 (WSELs), 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.

Temperature Monitoring

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 (Lower River), the Molera Reach (Middle River), and Campground Reach (Upper River) using digital data thermographs (Figure 9). HOBO® thermographs were used at the lower 6 sites and TidbiT® thermographs were used at the upper 3 sites where water depths were anticipated 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 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. The 7DADM provides a good representation of the typical maximum temperatures encountered by aquatic species without allowing one abnormally high daily value to skew results. Because 7DADM is an average of maximums, it can be used to evaluate acute effects like lethality and blockage, while still being used to evaluate non-lethal effects like growth limitations, disease, competition, and smoltification.

Figure 9. Water temperature digital data thermograph locations.

RESULTS

Structural and hydraulic data were collected from a total of 117 transects in the study area. One-hundred and three transects were used in development of the 1D models. The transects represent the variability of steelhead habitat throughout the study area (Figures 10-14), and are consistent with number of transects needed for robust modeling (CDFW 2008b; Gard 2005; Payne et al. 2004) of flow and habitat relationships. Flow levels as measured by staff gages remained constant during all transect measurements and therefore did not affect the quality of the data. A summary of the model calibration results for each reach are presented in Table 6. Model stage/discharge calibration was measured by comparing CalSet WSELs with WSELs predicted using a specified stage/discharge method and the variance of velocity adjustment factors VAFs about unity for each transect and flow regime. Predictive model results were within tolerances of recommended guidelines for PHABSIM hydraulic calibration. See Cowan (2014) for an overview of the transects omitted from the model calibration data sets and the overall calibration results. Transects are typically omitted from model calibration data sets if the difference between measured and predicted WSELs exceeded ±0.10 ft.

Table 6. Summary of discharge, WSEL, and VAF Results.

<table>
<tr><th colspan="5">Lower Molera Reach</th></tr>
<tr><td>Parameter</td><td>Range</td><td>Min.</td><td>Max.</td><td>Avg.</td></tr>
<tr><td>WSEL (Error)</td><td>< 0.1</td><td>0.00</td><td>0.09</td><td>0.02</td></tr>
<tr><td>VAF</td><td>0.75-1.25 (Avg <0.10)</td><td>0.82</td><td>1.21</td><td>0.98</td></tr>
<tr><th colspan="5">Molera Reach</th></tr>
<tr><td>Parameter</td><td>Range</td><td>Min.</td><td>Max.</td><td>Avg.</td></tr>
<tr><td>WSEL (Error)</td><td>< 0.1</td><td>0.00</td><td>0.09</td><td>0.01</td></tr>
<tr><td>VAF</td><td>0.75-1.25 (Avg <0.10)</td><td>0.85</td><td>1.16</td><td>1.02</td></tr>
<tr><th colspan="5">Campground Reach</th></tr>
<tr><td>Parameter</td><td>Range</td><td>Min.</td><td>Max.</td><td>Avg.</td></tr>
<tr><td>WSEL (Error)</td><td>< 0.1</td><td>0.00</td><td>0.07</td><td>0.01</td></tr>
<tr><td>VAF</td><td>0.75-1.25 (Avg <0.10)</td><td>0.84</td><td>1.25</td><td>0.99</td></tr>
</table>

Flow and Habitat Relationships

Estimated weighted useable habitat for steelhead lifestages in the Big Sur River varies considerable with change in discharge. Available steelhead spawning habitat slowly increases at lower flows and then begins to rapidly increase as flows increase.

Figure 10. IFIM Site 14 in Lower Molera Reach at 26 cfs (above) and 163 cfs (below).

Figure11. IFIM Site 36 in Lower Molera Reach at 26 cfs (above) and 89 cfs (below).

Figure 12. IFIM site 148 in Molera Reach at 47 cfs.

Figure13. IFIM site 195 (Campground Reach) at 27 cfs (above) and 91 cfs (below).

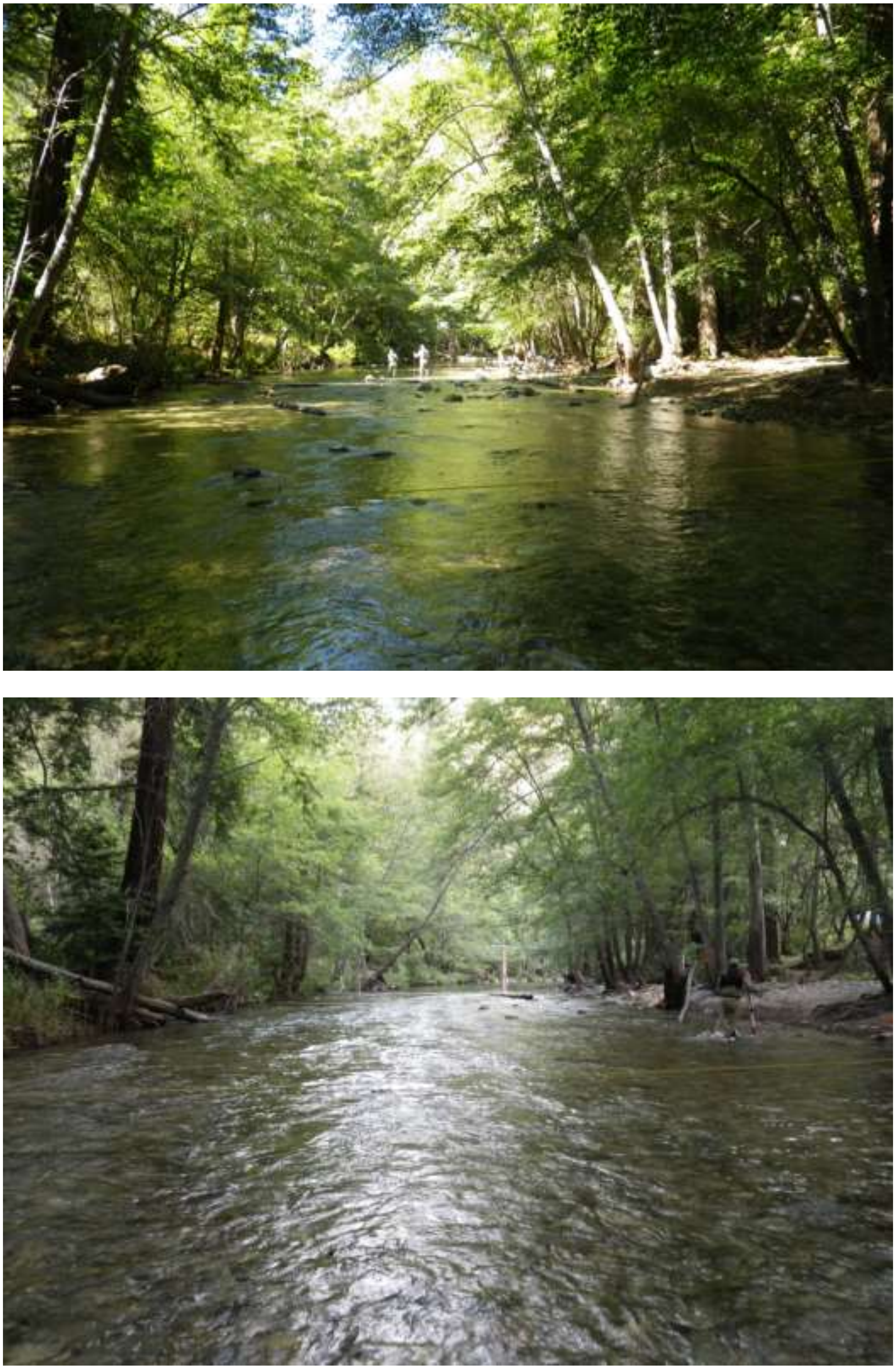

Figure 14. IFIM site 333 (Campground Reach) at 29 cfs (above) and 108 cfs (below).

After reaching maximum habitat index results, available habitat generally decreases from the peak as flows continue to increase. Rate of increase and curve inflection points usually are different for individual lifestages and in individual reaches. Therefore, it is necessary to evaluate steelhead flow needs for each lifestage simultaneously, and to develop a flow regime which balances the needs of each of the species' lifestages.

Available steelhead spawning habitat generally increases slowly in all reaches until discharge reaches 64 cfs in the Lower Molera Reach, 80 cfs in the Molera Reach, and 90 cfs in the Campground Reach, respectively (Table 7, Table 8, Table 9, Figure 15, Figure 16, Figure 17). As discharge increases above 64 cfs in the Lower Molera Reach, 80 cfs in Molera Reach, and 90 in the Campground Reach spawning habitat slowly decreases.

Steelhead fry (<6 cm) habitat peaks at the lowest simulation flow in all three reaches at approximately 10 cfs. On the other hand juvenile 6-9 cm steelhead habitat steadily increases moving upstream from 50 cfs, 60 cfs, and 66 cfs flows having the most abundant habitat in the Lower Molera, Molera, and Campground Reaches, respectively. The larger 10-15 cm juvenile steelhead habitat had a similar pattern in the Molera and Campground Reaches, increasing as going upstream from 72 cfs and 79 cfs flows as having the most abundant habitat in the Molera, and Campground Reaches, respectively. In the Lower Molera Reach steelhead habitat peaked at 64 cfs, although was relatively constant between 61 and 69 cfs.

Table 7. Steelhead habitat/streamflow relationship, Lower Molera Reach, Big Sur River.

Lower Molera Reach				
Flow	WUA (sf)			
Simulated Discharge (cfs)	Adult Spawning	Juvenile (6-9 cm) Rearing	Juvenile (10-15 cm) Rearing	Fry (0-5 cm) Rearing
10	433	11796	8218	**13569**
15	910	14150	10306	12882
20	1424	15795	11984	12369
25	1912	16990	13198	11857
27	2095	17319	13601	11515
29	2271	17635	13973	11192
30	2354	17793	14126	11050
32	2512	18111	14396	10832
35	2729	18461	14788	10478
40	3045	18919	15235	9833
45	3292	19248	15471	9323
50	3470	**19252**	15536	9051
55	3601	19154	15554	8749
61	3679	18989	15595	8457
63	3690	18890	15599	8375
64	**3693**	18844	**15600**	8332
69	3690	18574	15596	8100
75	3640	18202	15451	7809
81	3554	17771	15164	7570
88	3416	17222	14728	7338
95	3269	16723	14351	7196
104	3051	16130	13881	6944
110	2895	15764	13561	6864
114	2803	15526	13347	6838
147	2103	13708	11776	6517
157	1920	13275	11408	6396
158	1904	13234	11381	6386
161	1855	13100	11301	6369
165	1789	12922	11181	6350
200	1328	11704	10199	5846

*Peak WUA values for each lifestage highlighted in bold.

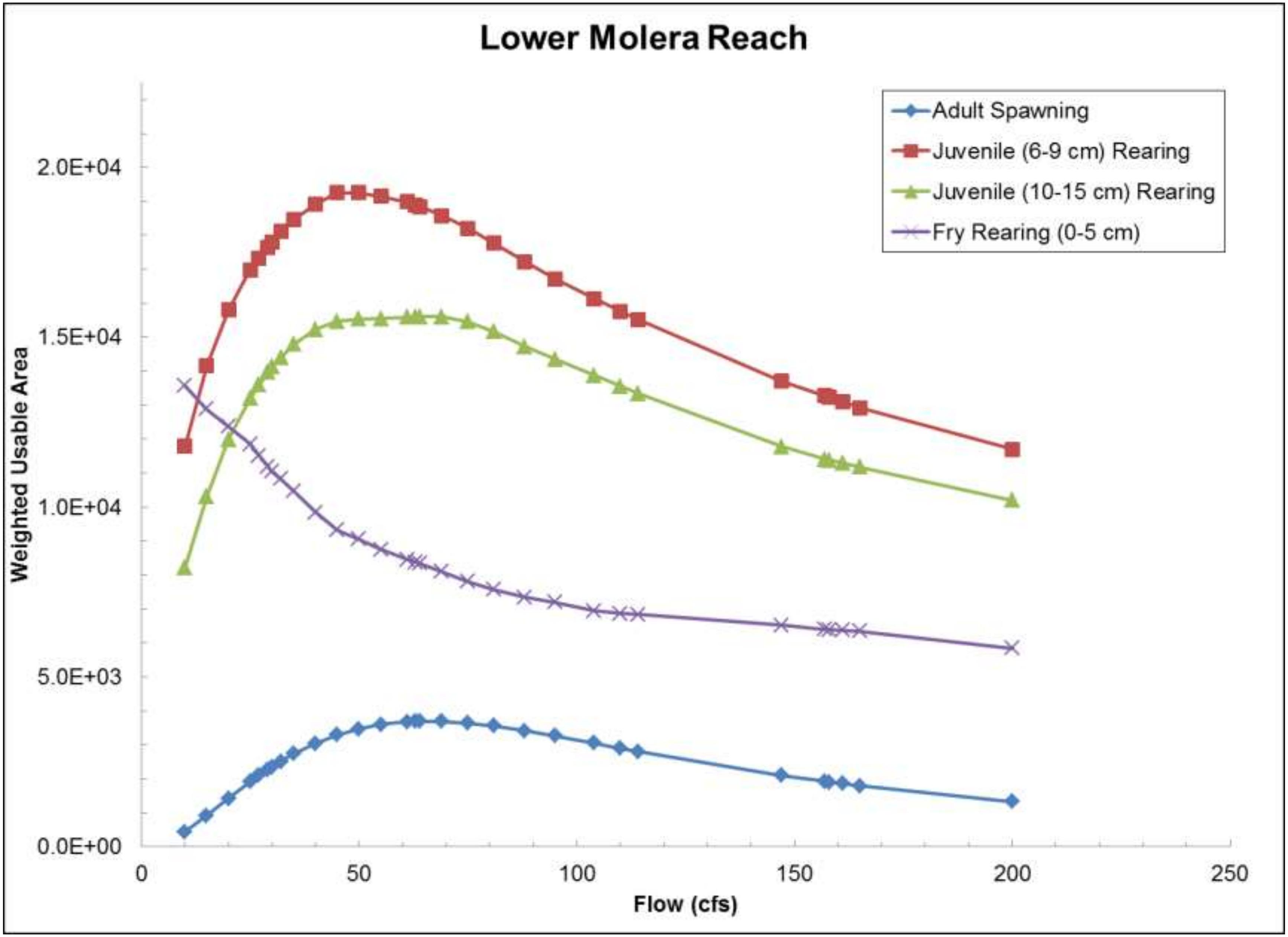

Figure 15. Steelhead habitat/streamflow relationship, Lower Molera Reach, Big Sur River.

Table 8. Steelhead habitat/streamflow relationship, Molera Reach, Big Sur River.

Molera Reach				
Flow	WUA (sf)			
Simulated Discharge (cfs)	Adult Spawning	Juvenile (6-9 cm) Rearing	Juvenile (10-15 cm) Rearing	Fry (0-5 cm) Rearing
12	104	19124	15198	**22685**
15	343	20964	17478	21436
20	806	23194	20068	19693
25	1306	24829	22044	17674
29	1683	25895	23295	16417
32	1941	26553	24086	15539
33	2021	26779	24314	15230
35	2173	27208	24725	14682
40	2526	28096	25731	13369
45	2829	28748	26547	12219
50	3080	29190	27202	11264
55	3285	29395	27696	10460
60	3443	**29453**	27966	9820
67	3599	29386	28187	9034
72	3665	29196	**28267**	8555
77	3698	28852	28221	8153
80	**3703**	28607	28124	7967
83	3696	28331	27971	7773
84	3692	28230	27913	7710
90	3643	27565	27454	7360
95	3570	26928	26981	7104
100	3474	26267	26436	6903
104	3379	25712	25963	6757
110	3216	24845	25215	6566
118	2966	23680	24198	6329
123	2799	22952	23561	6204
128	2626	22259	22962	6103
135	2372	21266	22073	5974
150	1822	19326	20228	5752
375	35	8966	9276	4757

*Peak WUA values for each lifestage highlighted in bold.

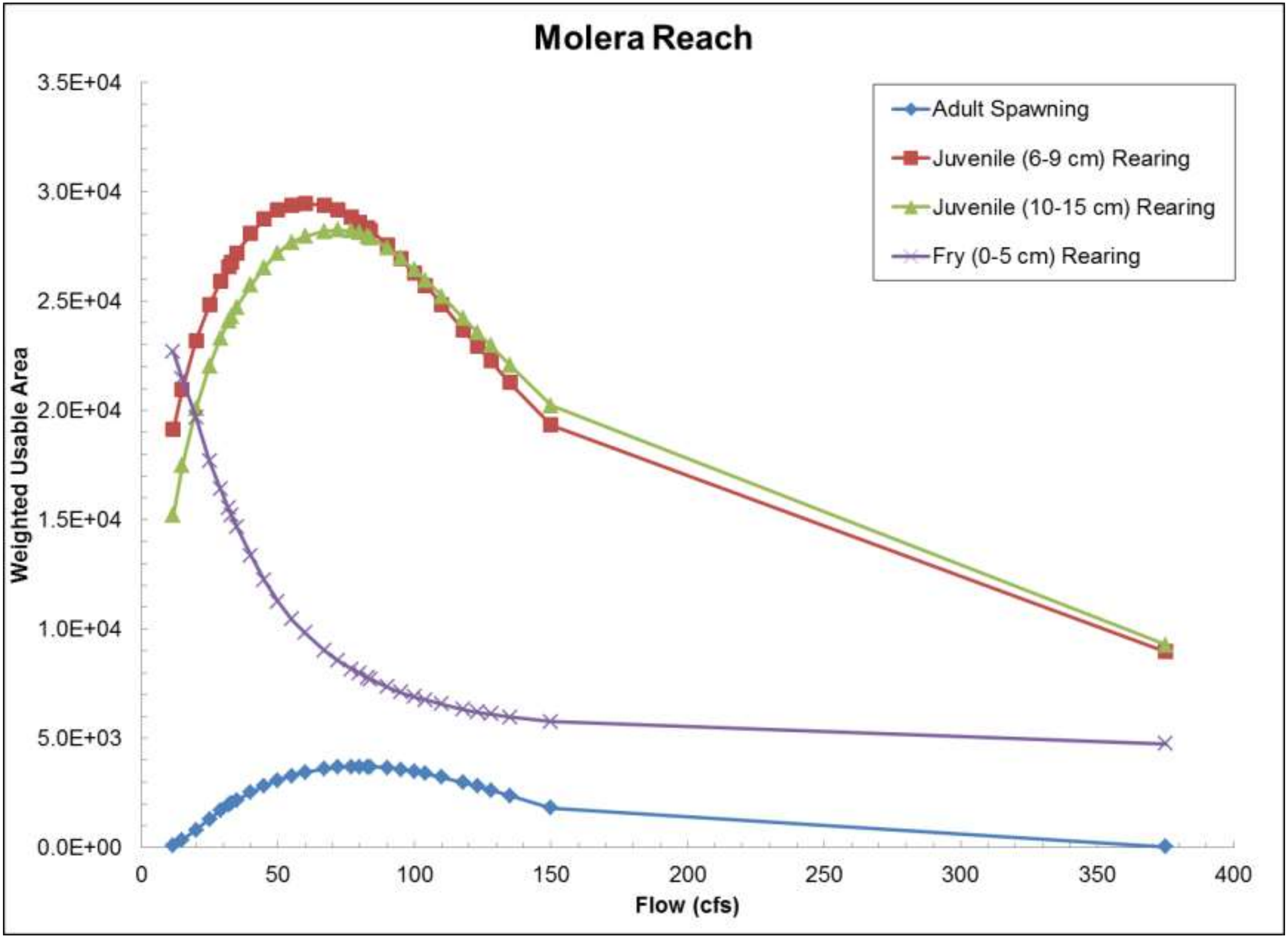

Figure 16. Steelhead habitat/streamflow relationship, Molera Reach, Big Sur River.

Table 9. Steelhead habitat/streamflow relationship, Campground Reach, Big Sur River.

Campground Reach				
Flow	WUA (sf)			
Simulated Discharge (cfs)	Adult Spawning	Juvenile (6-9 cm) Rearing	Juvenile (10-15 cm) Rearing	Fry (0-5 cm) Rearing
11	443	14461	9012	**21039**
15	775	17413	11350	20957
20	1190	19915	13656	20740
25	1600	21996	15819	19605
27	1753	22677	16604	19059
28	1828	23012	16962	18809
29	1903	23326	17298	18549
30	1978	23615	17608	18310
35	2334	24965	19046	17143
40	2651	26178	20234	16184
45	2920	27030	21230	15244
50	3148	27435	21954	14497
55	3337	27676	22549	13838
62	3543	27834	23104	12989
66	3637	**27839**	23305	12624
68	3674	27805	23405	12482
69	3692	27783	23452	12421
70	3707	27746	23486	12355
71	3722	27712	23525	12302
79	3800	27361	**23703**	11763
90	**3831**	26687	23637	11107
91	3829	26626	23617	11057
93	3820	26505	23568	10956
94	3815	26443	23540	10907
101	3764	25959	23284	10622
105	3719	25675	23104	10449
108	3682	25451	22939	10328
111	3640	25223	22763	10216
112	3625	25145	22705	10183
280	1389	15502	14820	7851

*Peak WUA values for each lifestage highlighted in bold.

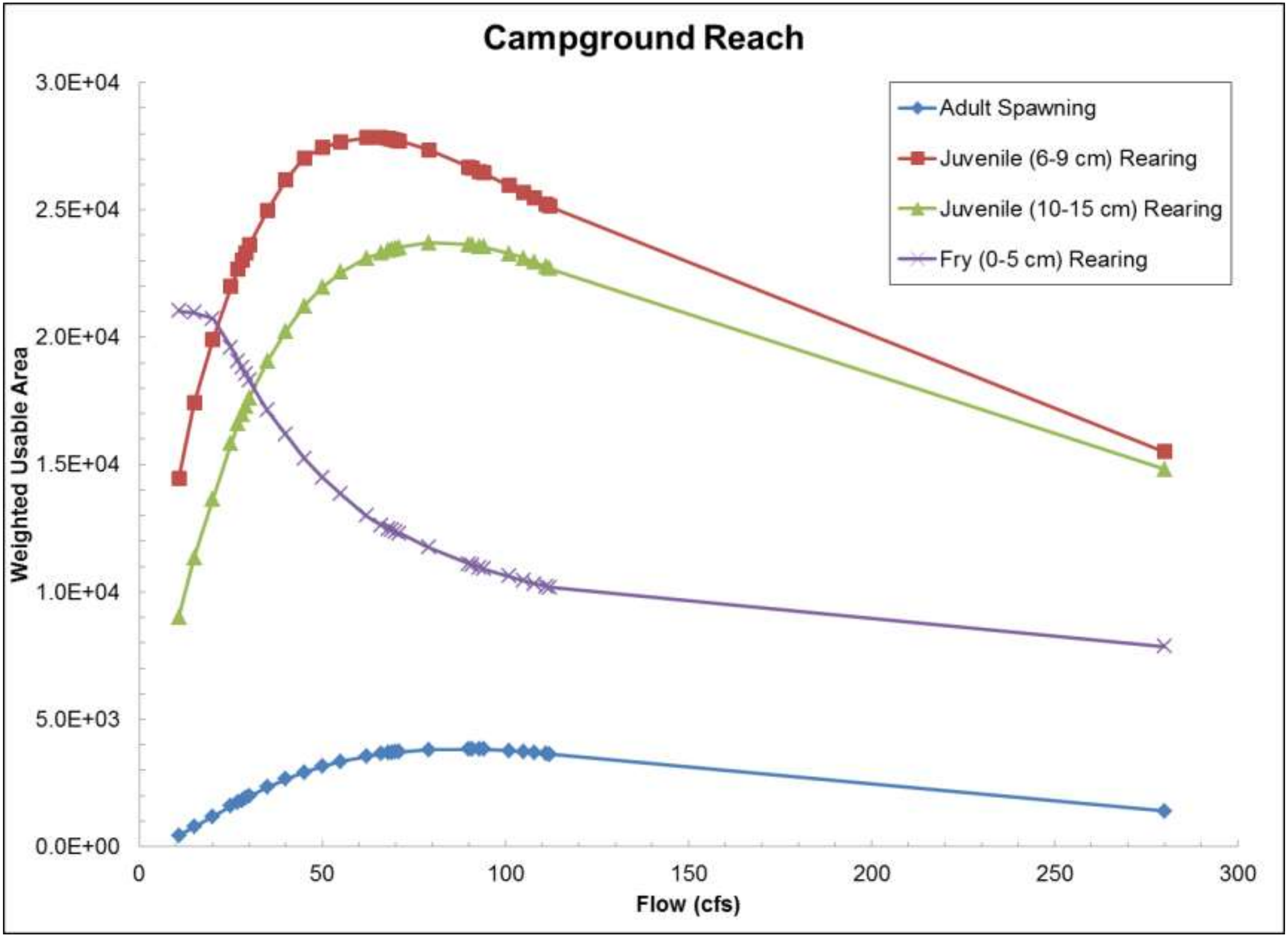

Figure 17. Steelhead habitat/streamflow relationship, Campground Reach, Big Sur River.

Habitat Duration and Time Series

Steelhead rearing and spawning streamflows derived by habitat duration and time series analyses are presented by monthly water type for the Lower Molera, Molera, and Campground Reaches in Table 10, Table 11, and Table 12, respectively. Since the flows identified by the habitat duration and habitat time series analyses were derived for each month from the lifestage WUA curves and local unimpaired hydrology, the median habitat values (and associated flows) generally increased in wetter months, and decreased in drier months.

Table 10. Steelhead rearing and spawning streamflows (cfs) by monthly water type, Lower Molera Reach, Big Sur River.

Month	Target Species/ life stage	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
January	Adult Spawning	19	30	30	64	64	64
	Juvenile Rearing	18	30	50	64	64	64
	Fry Rearing	10	10	10	10	10	10
February	Adult Spawning	24	36	64	64	64	64
	Juvenile Rearing	24	50	64	64	64	64
	Fry Rearing	10	10	10	10	10	10
March	Adult Spawning	24	44	64	64	64	64
	Juvenile Rearing	23	50	64	64	64	64
	Fry Rearing	10	10	10	10	10	10
April	Adult Spawning	19	36	64	64	64	64
	Juvenile Rearing	19	35	64	64	64	64
	Fry Rearing	10	10	10	10	10	10
May	Adult Spawning	14	26	40	64	64	64
	Juvenile Rearing	14	26	39	64	64	64
	Fry Rearing	10	10	10	10	10	10
June	Juvenile Rearing	10	16	26	44	50	64
	Fry Rearing	10	10	10	10	10	10
July	Juvenile Rearing	6	12	18	28	34	44
August	Juvenile Rearing	6	10	13	22	23	32
September	Juvenile Rearing	7	9	12	18	20	26
October	Juvenile Rearing	9	14	14	19	19	19
November	Adult Spawning	16	16	19	19	19	19
	Juvenile Rearing	16	16	18	21	21	21
December	Adult Spawning	21	21	22	24	33	64
	Juvenile Rearing	21	21	21	50	50	64

Table 11. Steelhead rearing and spawning streamflows (cfs) by monthly water type, Molera Reach, Big Sur River.

Month	Target Species/ life stage	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
January	Adult Spawning	20	31	31	80	80	80
	Juvenile	19	30	60	72	72	72
	Fry	12	12	12	12	12	12
February	Adult Spawning	24	39	80	80	80	80
	Juvenile	24	35	72	72	72	72
	Fry	12	12	12	12	12	12
March	Adult Spawning	24	48	80	80	80	80
	Juvenile	24	45	72	72	72	72
	Fry	12	12	12	12	12	12
April	Adult Spawning	19	37	54	80	80	80
	Juvenile	19	36	60	72	72	72
	Fry	12	12	12	12	12	12
May	Adult Spawning	14	26	40	59	80	80
	Juvenile	14	26	40	72	72	72
	Fry	12	12	12	12	12	12
June	Juvenile	10	16	26	45	54	60
	Fry	12	12	12	12	12	12
July	Juvenile	6	12	18	28	34	45
August	Juvenile	6	10	13	22	23	32
September	Juvenile	7	9	12	18	20	26
October	Juvenile	9	14	14	19	19	19
November	Adult Spawning	16	16	19	22	22	22
	Juvenile	16	16	19	21	21	21
December	Adult Spawning	21	21	22	26	35	35
	Juvenile	21	21	21	21	33	72

Table 12. Steelhead rearing and spawning streamflows (cfs) by monthly water type, Campground Reach, Big Sur River.

Month	Target Species/ life stage	Critically Dry	Dry	Below Median	Above Median	Wet	Extremely Wet
January	Adult Spawning	20	32	37	90	90	90
	Juvenile	20	32	35	79	79	79
	Fry	11	11	11	11	11	11
February	Adult Spawning	25	44	90	90	90	90
	Juvenile	25	42	79	79	79	79
	Fry	11	11	11	11	11	11
March	Adult Spawning	24	50	90	90	90	90
	Juvenile	24	49	79	79	79	79
	Fry	11	11	11	11	11	11
April	Adult Spawning	19	37	57	90	90	90
	Juvenile	19	37	66	79	79	79
	Fry	11	11	11	11	11	11
May	Adult Spawning	14	26	40	64	90	90
	Juvenile	14	26	40	66	79	79
	Fry	11	11	11	11	11	11
June	Juvenile	10	16	26	45	56	66
	Fry	11	11	11	11	11	11
July	Juvenile	6	12	18	28	34	45
August	Juvenile	6	10	13	22	23	32
September	Juvenile	7	9	12	18	20	26
October	Juvenile	9	14	14	19	19	19
November	Adult Spawning	16	16	19	22	22	22
	Juvenile	16	16	19	22	22	22
December	Adult Spawning	21	21	23	28	40	40
	Juvenile	21	21	23	28	38	66

Low-Flow Threshold

The flows associated with the wetted perimeter breakpoints, slope at breakpoints, and incipient asymptotes from each riffle transect are presented in Table 13. Breakpoint and incipient asymptote flows reflected the variability in the natural channel conditions of the Big Sur River's steelhead habitat and ranged between 4–64 cfs and 34–201 cfs, respectively. A flow of 22 cfs, based upon the average breakpoint flow from the riffle transects, was identified as the low-flow threshold flow for protection of the Big Sur River steelhead fishery. Flows between 22 and 69 cfs were identified as the range of flows that are critically important to aquatic food production in riffles. The model calibrated very well with the differences between measured and predicted WSELs all being well below USFWS (1994) physical habitat simulation guidelines of 0.10 ft except the high flow at unit 18 transect 2, which only marginally exceeded the criteria with 0.15 ft difference (Appendix 2). The cross-channel transect profiles and wetted perimeter discharge curves are located in Appendix 3.

Table 13. Wetted perimeter breakpoint, slope at breakpoint, and incipient asymptote flows (cfs).

Riffle Unit	Transect	Breakpoint flow (cfs)	Slope at Breakpoint	Incipient Asymptote flow (cfs)
18	1	12	2.563	201
	2	28	1.179	65
	3	64	2.635	85
26	1	4	1.335	44
	2	11	1.958	34
	3	23	1.118	61
35	1	33	2.570	51
	2	8	2.810	34
	3	19	1.090	47
	Average	22		69

Temperature Monitoring

The highest temperatures observed in the Big Sur River during 2011 occurred in the upper river section (corresponding with the Campground Reach) during late June and early July (Figure 18, Table 14). A similar pattern was observed at the downstream sections of river with peak temperatures occurring in late June and early July, when flow levels were relatively high (~50 cfs). Interestingly, the peak temperatures observed during summer and fall 2011 did not coincide with the lowest flows observed which instead occurred in late October.

Table 14. Summary of water temperature statistics from Big Sur River temperature monitoring during summer and fall 2011.

Temperature (^{0}F)	June	July	August	September	October
Lower River					
N-value	6720	7440	7440	7200	7680
Minimum	53.2	56.0	56.0	53.9	51.8
Maximum	65.6	67.7	64.9	65.6	63.5
Average	58.7	61.1	60.0	58.9	56.9
Standard Deviation	2.7	2.2	1.9	1.8	2.1
Average 7DADM*	62.3	65.1	63.7	62.7	60.5
Maximum 7DADM*	64.7	67.1	64.4	63.6	62.5
Middle River					
N-value	2686	2976	2976	2880	3072
Minimum	53.2	56.0	56.7	54.6	51.8
Maximum	64.9	67.8	64.3	64.4	61.6
Average	58.7	61.1	60.0	58.9	57.1
Standard Deviation	2.7	2.2	1.9	1.8	2.3
Average 7DADM*	61.7	64.3	62.9	61.7	59.2
Maximum 7DADM*	63.3	66.9	63.5	62.6	61.6
Upper River					
N-value	2684	2976	2976	2880	3072
Minimum	52.9	57.2	56.8	55.5	51.9
Maximum	67.0	69.8	65.8	65.1	61.3
Average	59.4	62.7	61.5	60.6	57.1
Standard Deviation	3.1	2.6	1.9	1.6	2.2
Average 7DADM*	63.2	66.1	64.3	62.4	58.9
Maximum 7DADM*	65.6	69.2	65.0	63.5	61.7

7DADM = seven day average of daily maximums.

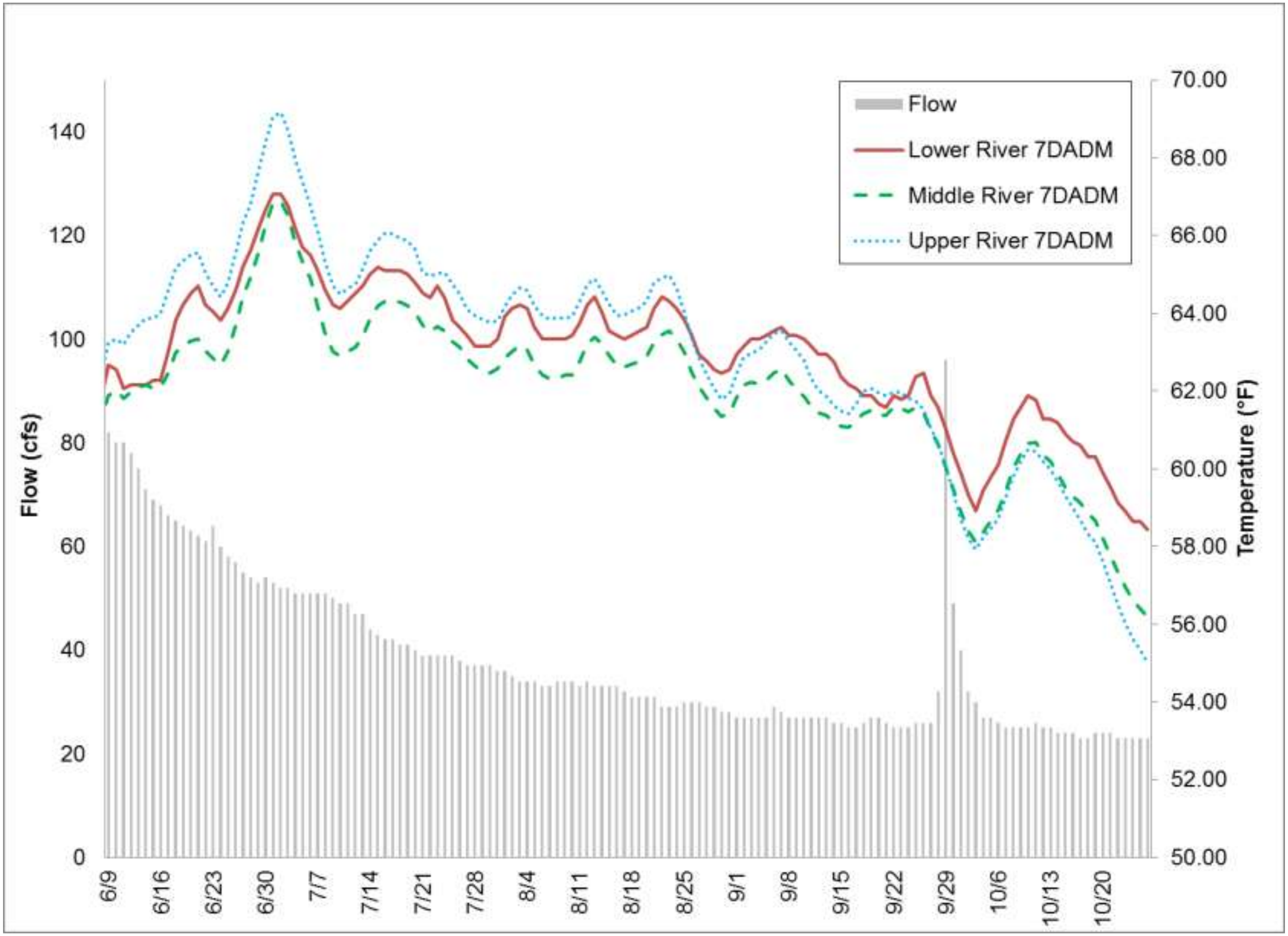

Figure 18. The seven day average of daily temperature maximums compared to flow in three reaches of Big Sur River during summer and fall 2011.

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 (Table 15; Figure 19), and an approximate maximum loss of 7 cfs during November through April (Table 16; Figure 19) between USGS 11143000 in the Campground Reach and USGS 11143010 the Lower Molera Reach. This is an important consideration that must be addressed to provide for a margin of safety when establishing flow requirements for protection of steelhead in the Lower Molera Reach. Furthermore, the pattern of flow losses is relatively consistent among seasons although flow losses May through October are cumulatively greater than flow losses November through April (Figure 20).

Table 15. Big Sur River gage differences statistics May through October.

Gage Difference (cfs)	No. of Days	Percent of days	Total
Total days	562		
X>0	93	16.5%	
X=0	14	2.5%	19.0%
0<=X>-1	21	3.7%	22.8%
-1<=X>-2	29	5.2%	27.9%
-2<=X>-3	68	12.1%	40.0%
-3<=X>-4	79	14.1%	54.1%
-4<=X>-5	127	22.6%	76.7%
-5<=X>-6	89	15.8%	92.5%
-6<=X>-7	40	7.1%	99.6%
-7<=X>-8	1	0.2%	99.8%
-8<=X>-9	0	0.0%	99.8%
-9<=X>-10	0	0.0%	99.8%
-10<=X>-11	0	0.0%	99.8%
-11<=X>-12	0	0.0%	99.8%
-12<=X>-13	0	0.0%	99.8%
-13<=X>-14	0	0.0%	99.8%
X<=-14	1	0.2%	100.0%
No data @ Gage #3010 =	1	0.2%	

Table 16. Big Sur River gage differences statistics November through April.

Gage Difference (cfs)	No. of Days	Percent of days	Total
Total days	695		
X>0	257	37.0%	
X=0	23	3.3%	40.3%
0<=X>-1	47	6.8%	47.1%
-1<=X>-2	55	7.9%	55.0%
-2<=X>-3	49	7.1%	62.0%
-3<=X>-4	54	7.8%	69.8%
-4<=X>-5	43	6.2%	76.0%
-5<=X>-6	77	11.1%	87.1%
-6<=X>-7	27	3.9%	90.9%
-7<=X>-8	3	0.4%	91.4%
-8<=X>-9	3	0.4%	91.8%
-9<=X>-10	1	0.1%	91.9%
-10<=X>-11	1	0.1%	92.1%
-11<=X>-12	1	0.1%	92.2%
-12<=X>-13	0	0.0%	92.2%
-13<=X>-14	1	0.1%	92.4%
X<=-14	53	7.6%	100.0%
No data @ Gage #3010 =	48	6.9%	

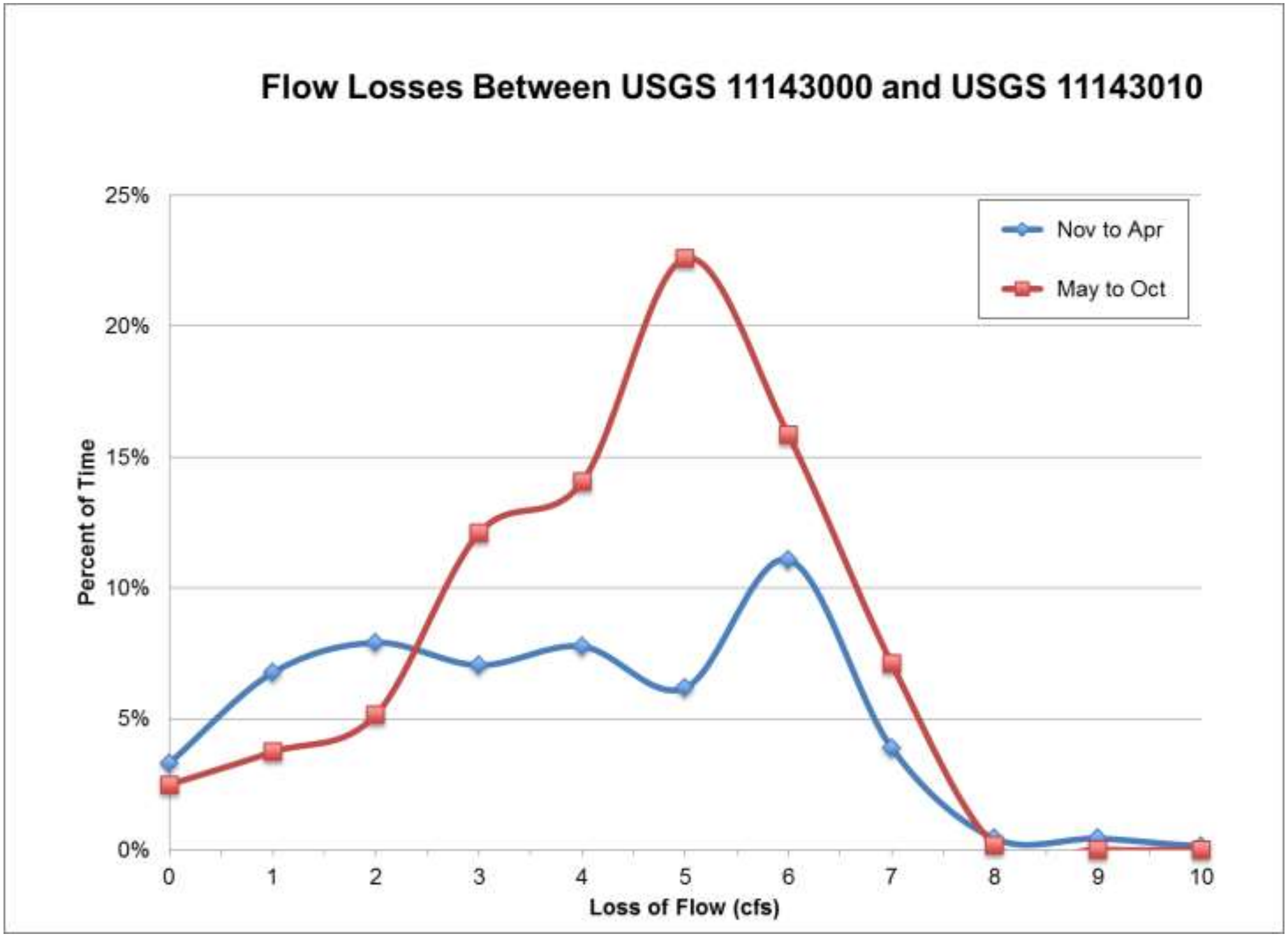

Figure 19. Flow losses between USGS 11143000 and USGS 11143010.

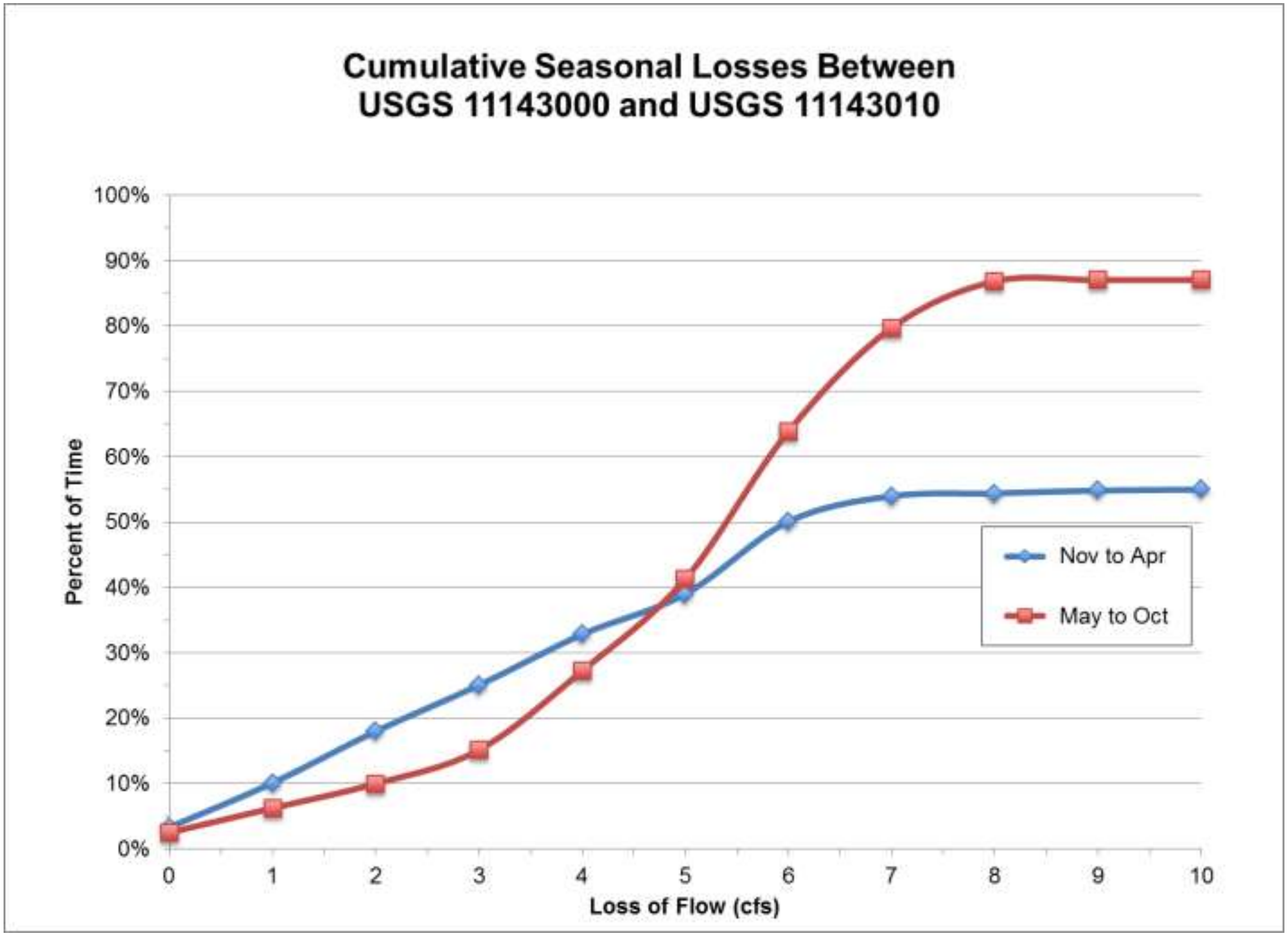

Figure 20. Cumulative seasonal flow losses between USGS 11143000 and USGS 11143010.

DISCUSSION

When performing an IFIM instream flow evaluation, it is necessary to balance the needs of the target species and lifestages. Since the Big Sur River is predominately a single-salmonid species system, the focus of the hydraulic habitat models developed in this report are on steelhead flows. The Big Sur River supports several steelhead lifestages, and it is necessary to develop flow regimes which consider each steelhead lifestage. Although steelhead spawning and fry lifestages occur at generally the same time with some overlap, the juvenile lifestage occurs year-round overlapping with both the spawning and fry lifestages. 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 values (i.e., 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.

The flows identified for steelhead spawning and rearing using WUA incorporated the 60-year unimpaired flow record partitioned into six monthly water type categories. 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 2008b) 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 results ensures corresponding flow criteria and recommendations are consistent with natural water availability.

Mean daily discharge values from USGS gage 11143000 were converted to habitat values using linear interpolation. Each habitat time series was then partitioned by monthly water type and the median habitat duration value for each water month category and life stage was calculated. The flow corresponding to the median habitat value was identified from each WUA curve. The peak of the WUA curve was used as an upper boundary for flow duration analysis in the wet and extremely wet month types. CDFW (2008b) recommends 1D habitat index vs discharge relationships be compared with the river's unimpaired flow time series to identify flow regimes that address intra- and inter-annual riverine needs, an analyses that may be useful for evaluating project impacts and potential tradeoffs. Since USGS gage 11143000 is upstream of all known diversions it is considered to represent natural unimpaired flow conditions.

Low-flow thresholds are applied to conserve and protect fisheries, and it is widely recognized that having such a threshold floor value can preserve ecosystem structure and function in riverine ecosystems that support fisheries (DFO 2013). Establishing a low-flow threshold should include careful consideration of any cumulative flow alterations that could result in instantaneous flows < 30% of the mean annual discharge (MAD), which DFO (2013) reports to have a “heightened risk” to fisheries. Thirty percent of the MAD on the Big Sur River equates to approximately 30 cfs, meaning instantaneous discharges below this value are within the zone of highest risk to fisheries and any flow alterations from the natural flow regime below 30 cfs should be carefully evaluated. Based upon our analysis, a low-flow threshold of 22 cfs would provide a protective lower threshold for the Big Sur River steelhead fishery. DFO (2013) and Richter et al. (2011) further recommend instantaneous daily flow alterations of no greater than 10% based upon the natural annual hydrograph, to maintain a high level of ecological protection on a year-round basis. 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.

This report does not identify flows for protecting passage and habitat connectivity for each steelhead lifestage. Optimizing passage and habitat connectivity flows within the realm of natural water availability is an important management objective, and is anticipated to be a necessary component of an overall stream flow requirements regime for protection of steelhead in the Big Sur River. Without adequate consideration of steelhead passage and habitat connectivity flows for rearing juvenile fish, maintenance of spawning and fry habitats would not produce the expected number of returning adults. Of equal importance, is the fact that the Big Sur River is likely an important source population within the South-Central Coast Distinct Population Segment (DPS), that may help maintain some of the other very small steelhead populations that occur throughout the Big Sur Coast. Thus, maintenance of juvenile habitat is paramount to the existence of the species within the DPS, and any flow regime developed for the Big Sur River must fully consider juvenile lifestage needs.

Flow gains and 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. USGS 11143010 has since been taken off-line due to lack of funding, although the equipment remains in place at time of this report. 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 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 in the criteria section of this report include an adjustment of +8 cfs during May through October, and an adjustment of +7 cfs during November through April for protection of steelhead spawning and rearing in the lower reach of the Big Sur River.

Water temperature is a critical component affecting the suitability of steelhead habitat, especially on the Central California Coast. The results of the water temperature monitoring conducted in the summer and fall 2011 indicated that the peak temperatures occurred during the early summer, when streamflows are relatively higher as compared to the fall. This observation may be related to the orientation of the south-to-north flowing lower (below the gorge) river channel which may receive the most direct sunlight in early summer. Further, the Campground Reach had the highest temperatures in early and mid-summer presumably due to the wider, more exposed channel, and generally shallower river conditions when compared to the two lower reaches. It is also common to encounter coastal fog in the lower reaches during summer which may also help to cool temperatures in the lower reaches. Although we observed exceedances of the USEPA (2003) criteria (i.e.,18^{o}C) for juvenile rearing in the early summer when flows were higher, there was not a direct flow and temperature relationship in our data set.

Channel maintenance and flushing streamflows 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). 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.

FLOW CRITERIA

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 criteria presented in Table 17, Table 18, and Table 19 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 criteria for the Big Sur River considers 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 criteria for upstream reaches must also consider and meet downstream reach criteria.

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 17), 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 17. Flow regime criteria 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 18), 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 18. Flow regime criteria 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 19), 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 19. Flow regime criteria 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 streamflows 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 criteria for the Big Sur River as the science and understanding of climate change evolves.

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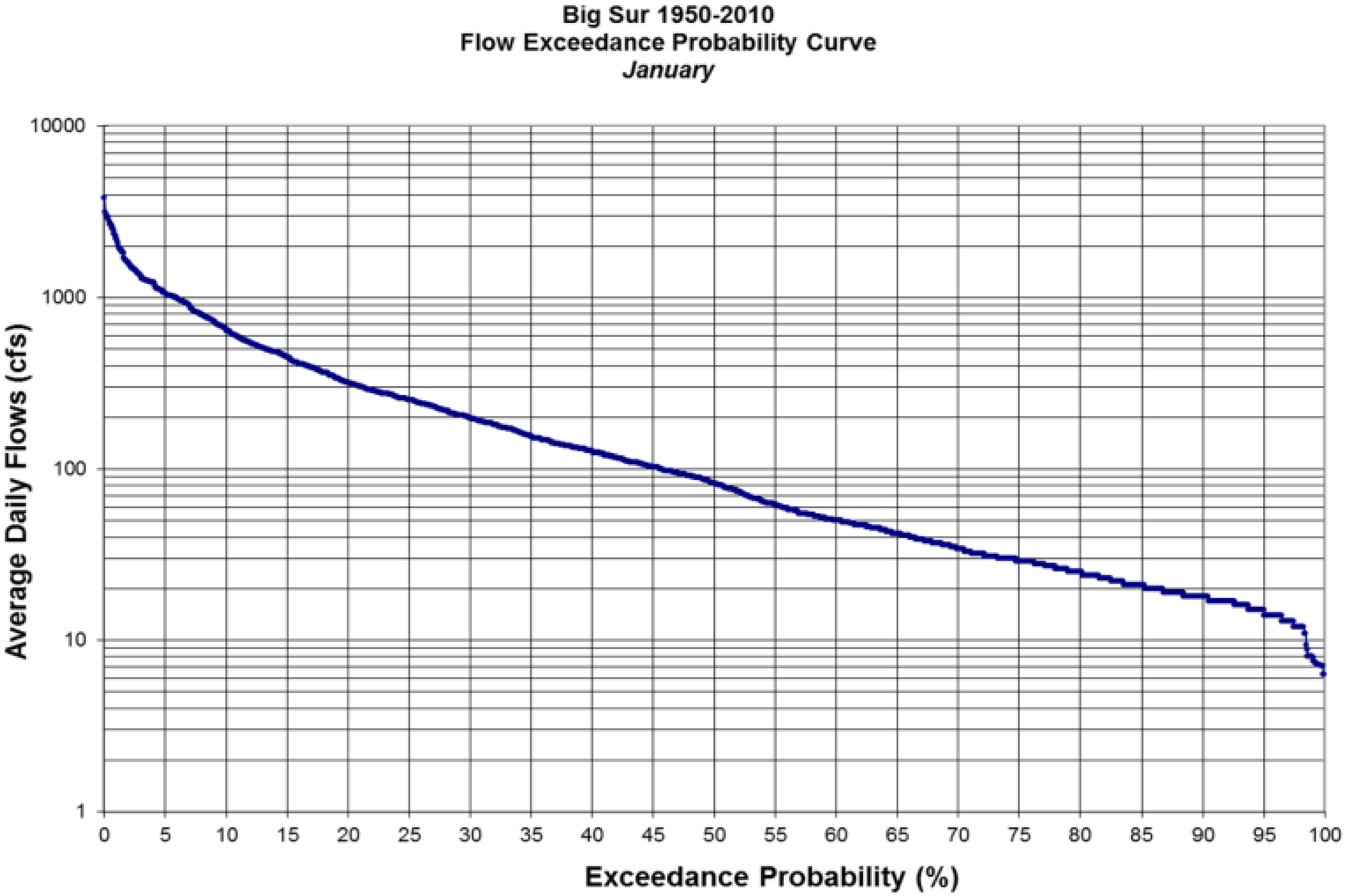
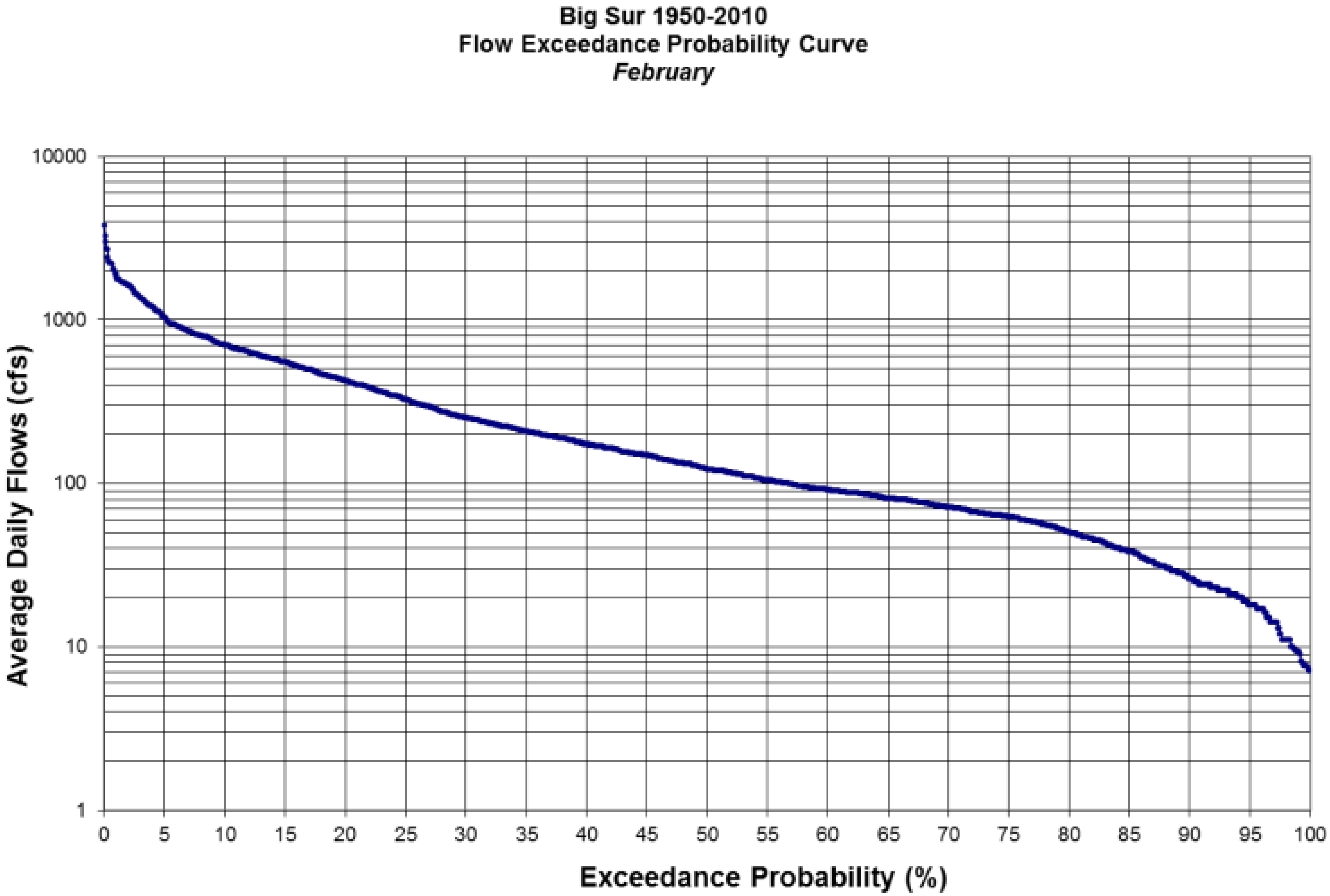
APPENDIX 1. Flow exceedance probability curves.



Flow exceedence probability curve for Big Sur River in January using USGS gage #1114300 data from 1950-2010.



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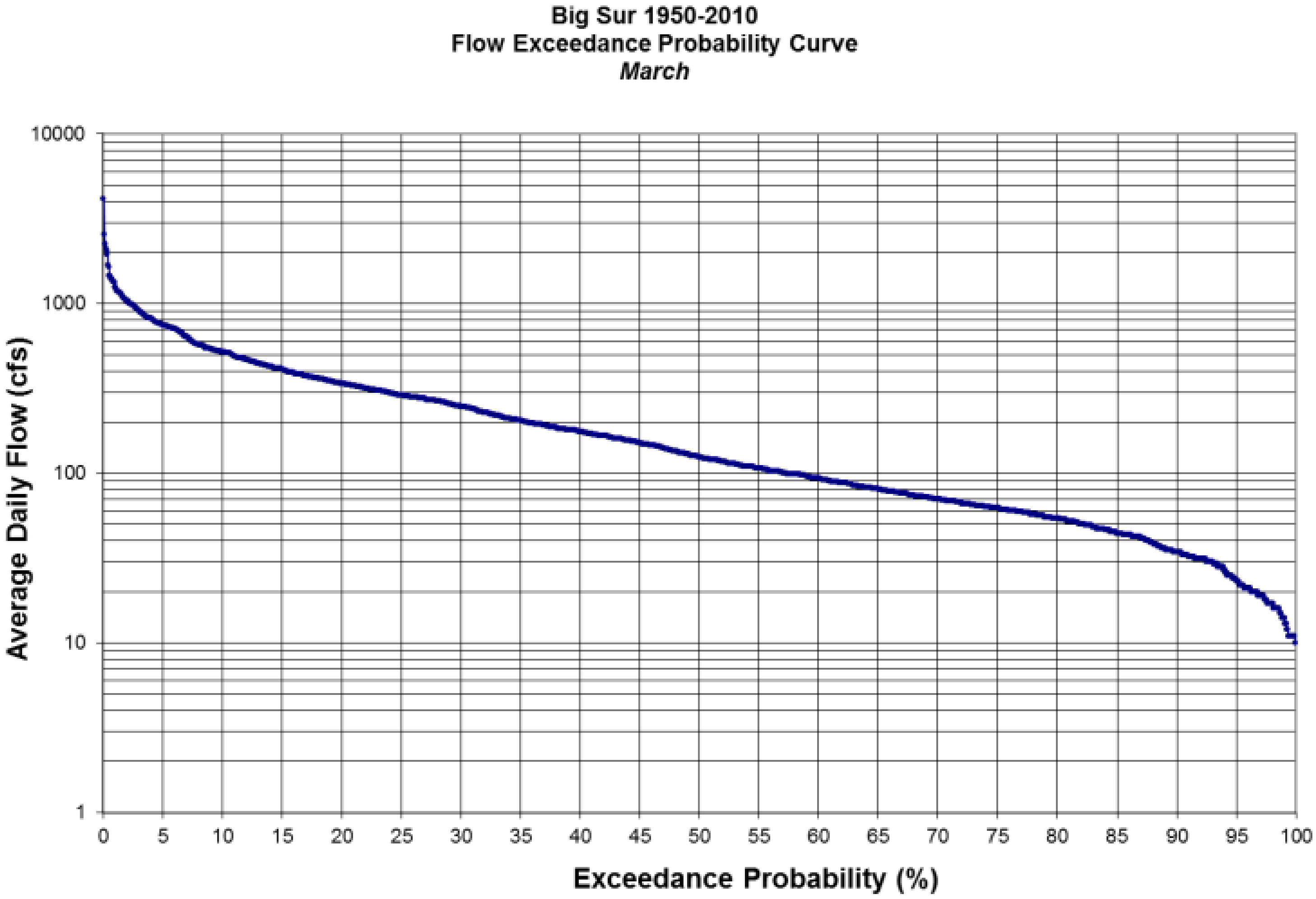

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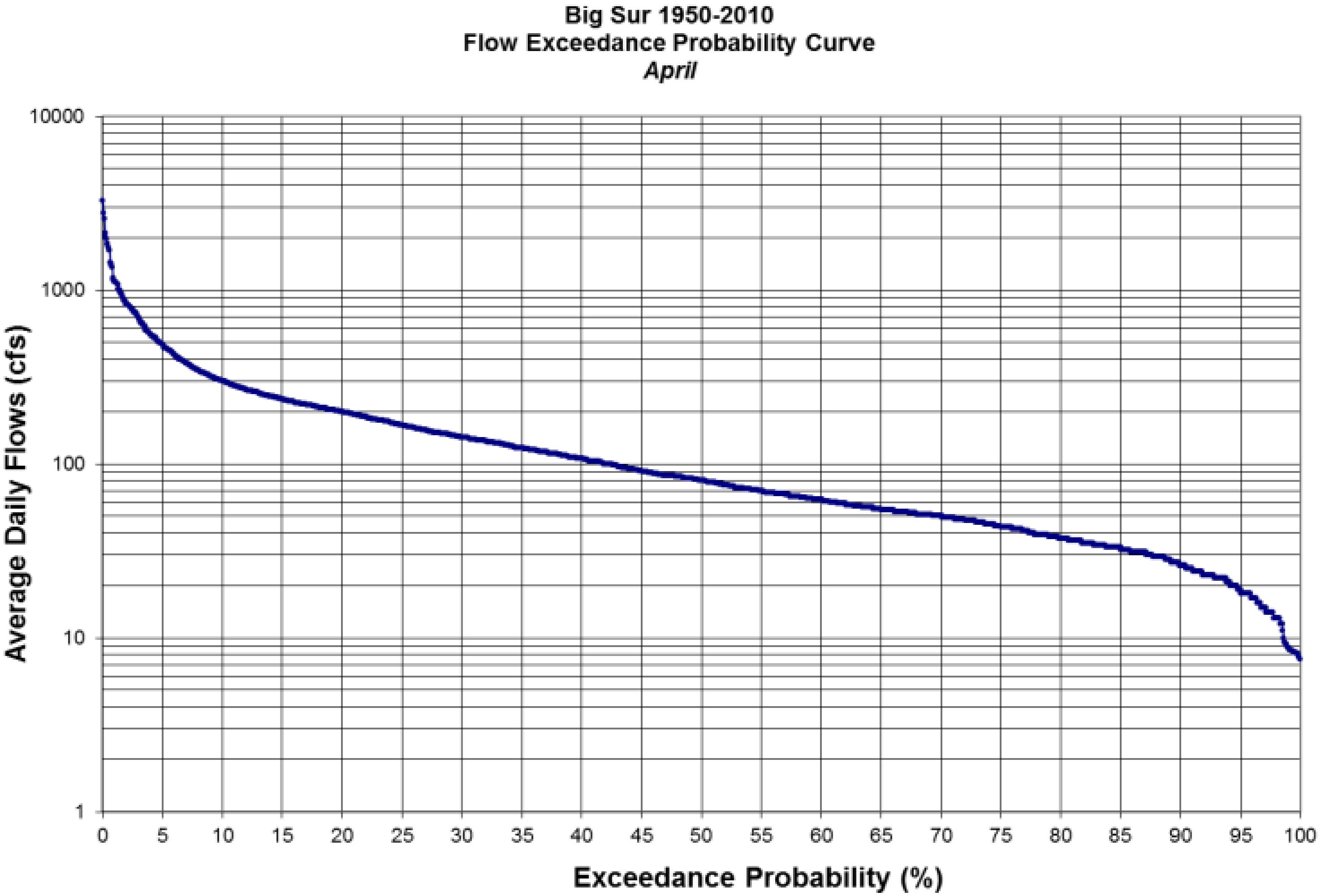

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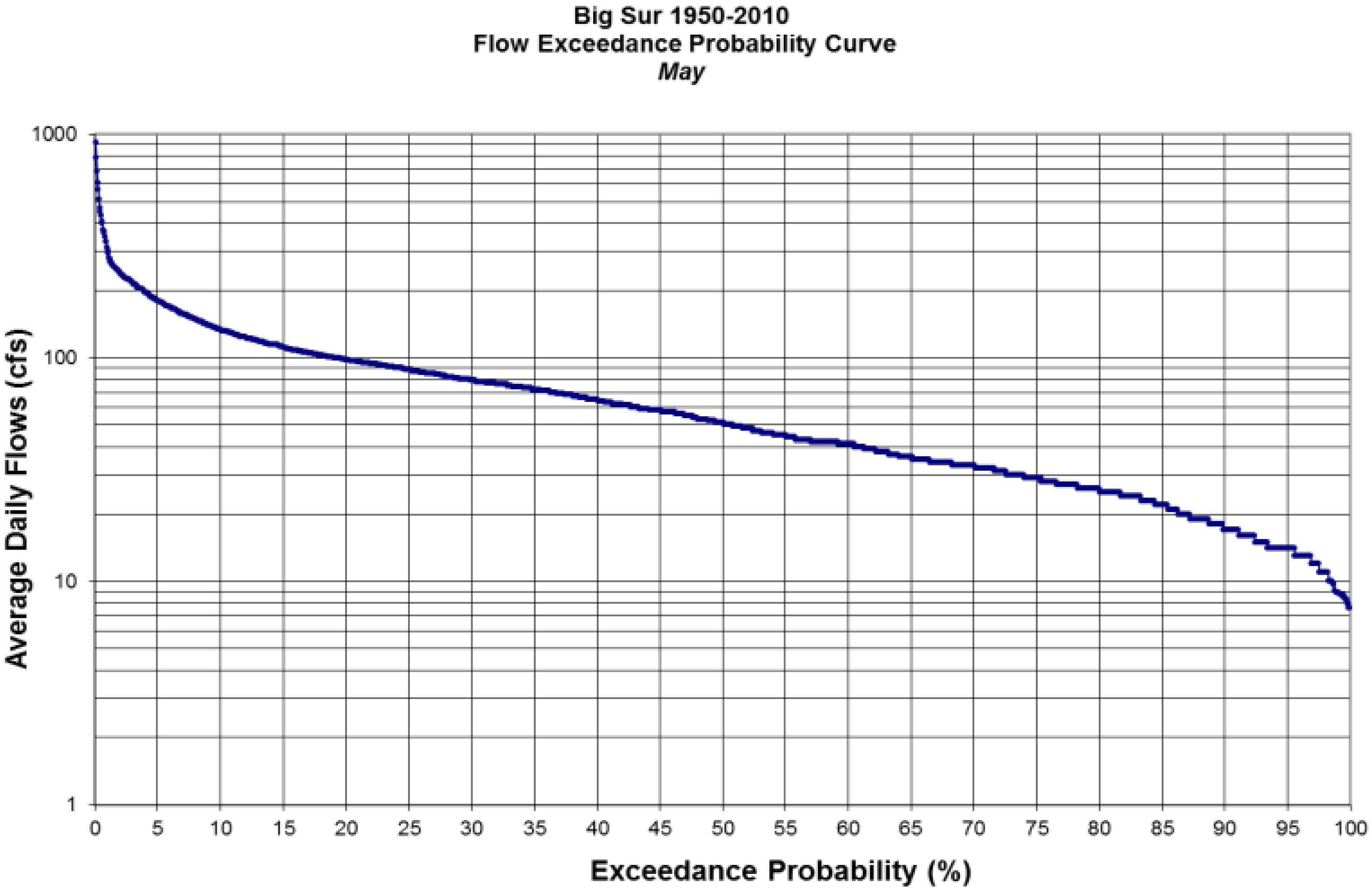

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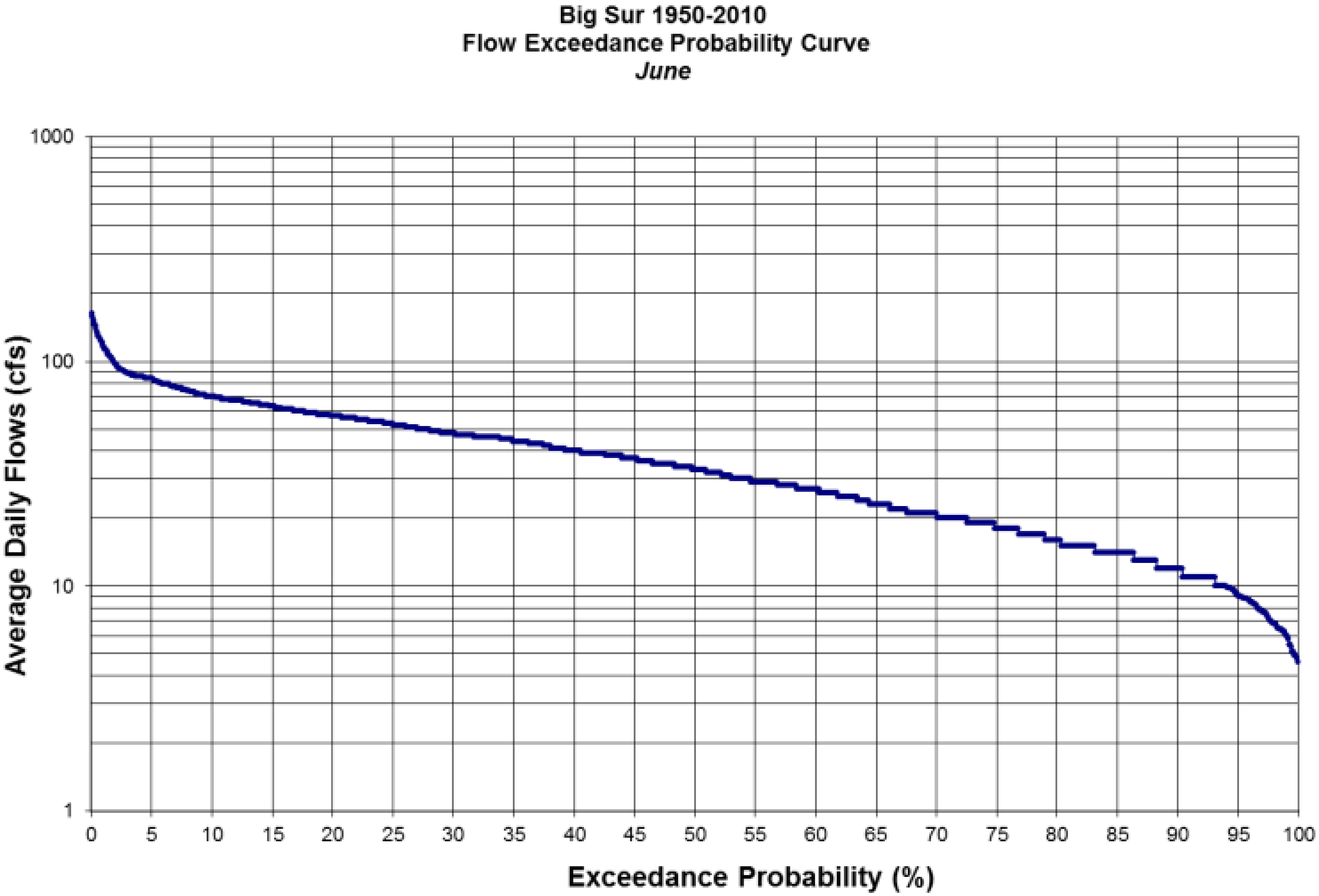

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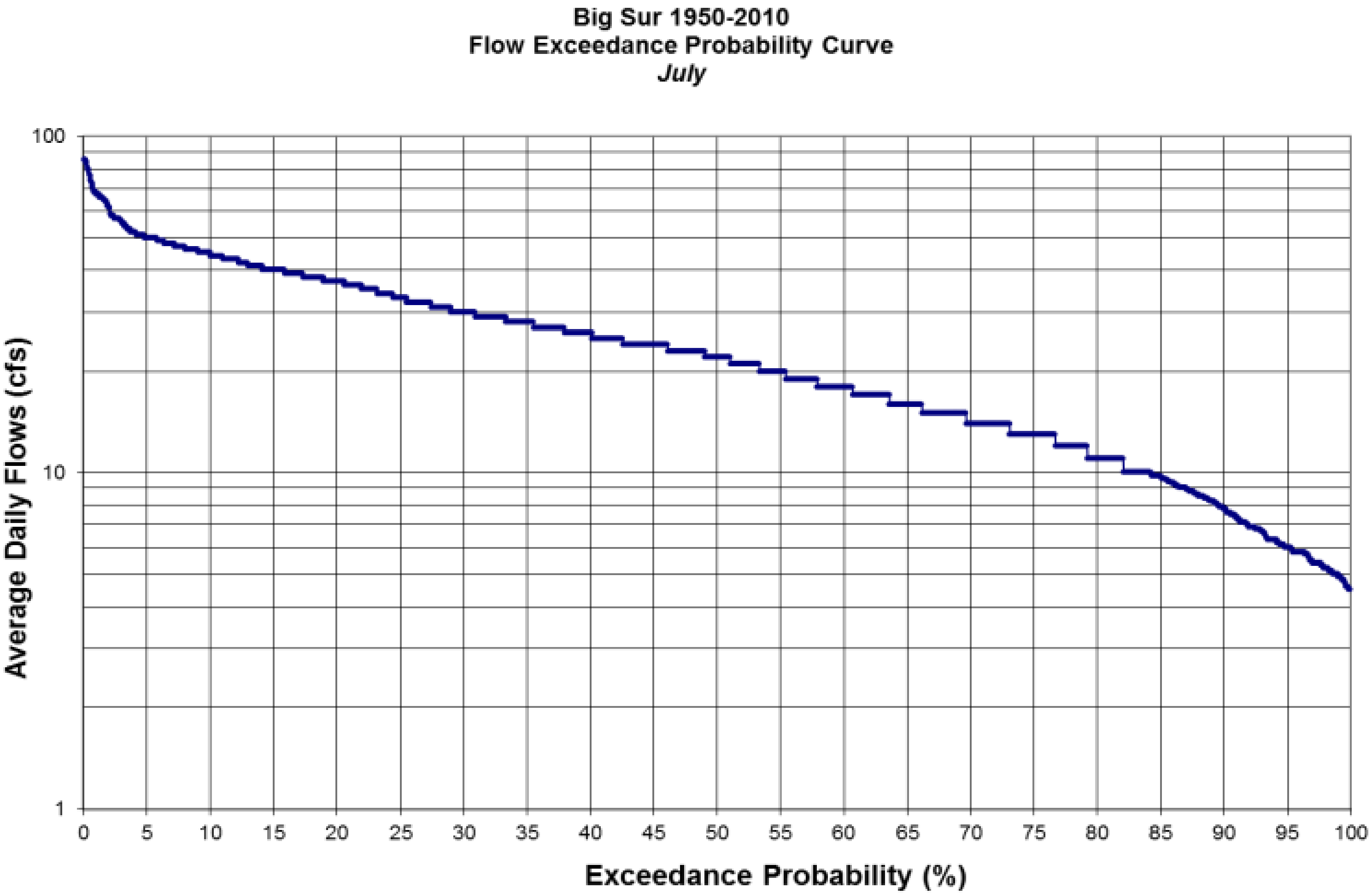

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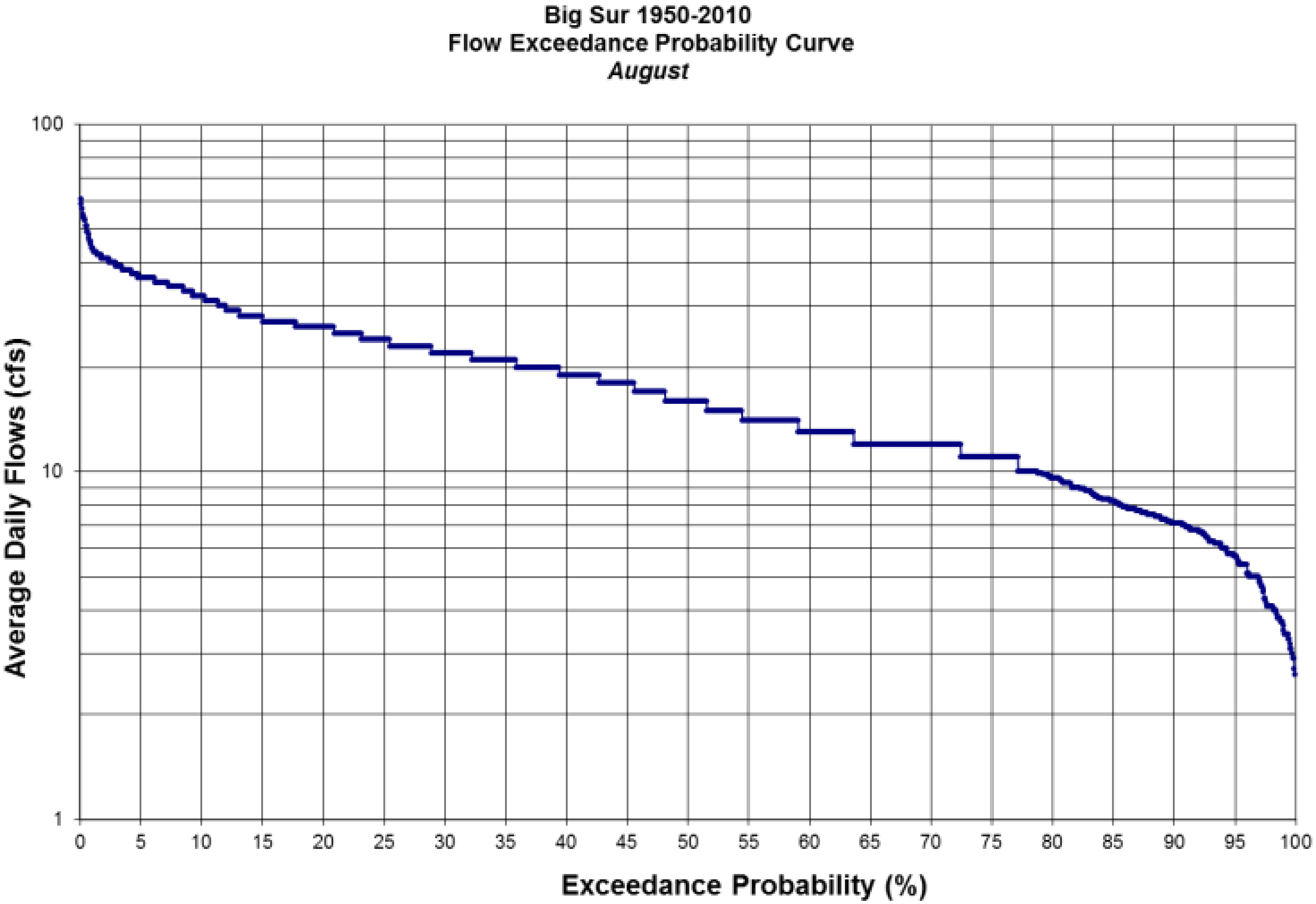
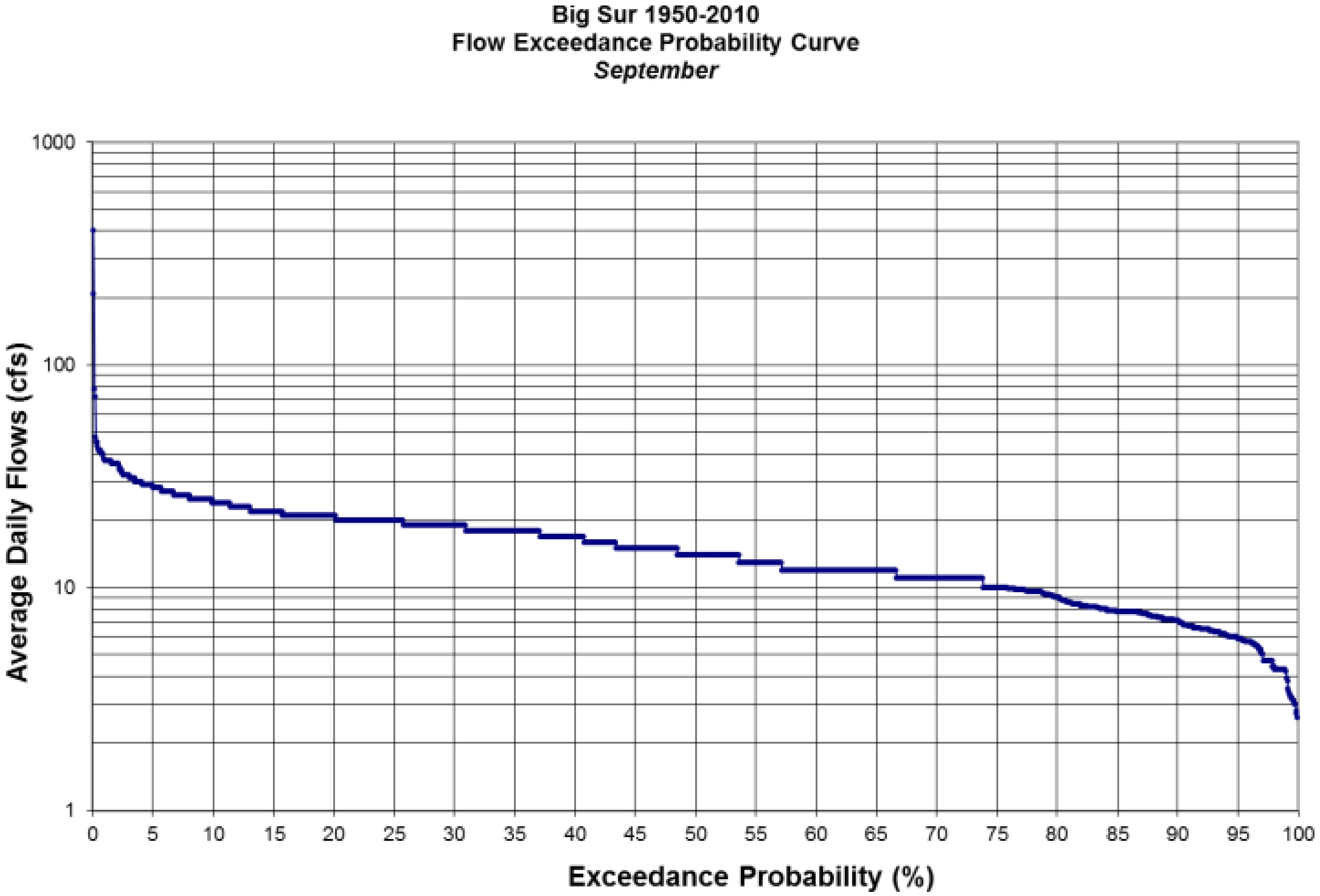


Flow exceedence probability curve for Big Sur River in August using USGS gage #1114300 data from 1950-2010.



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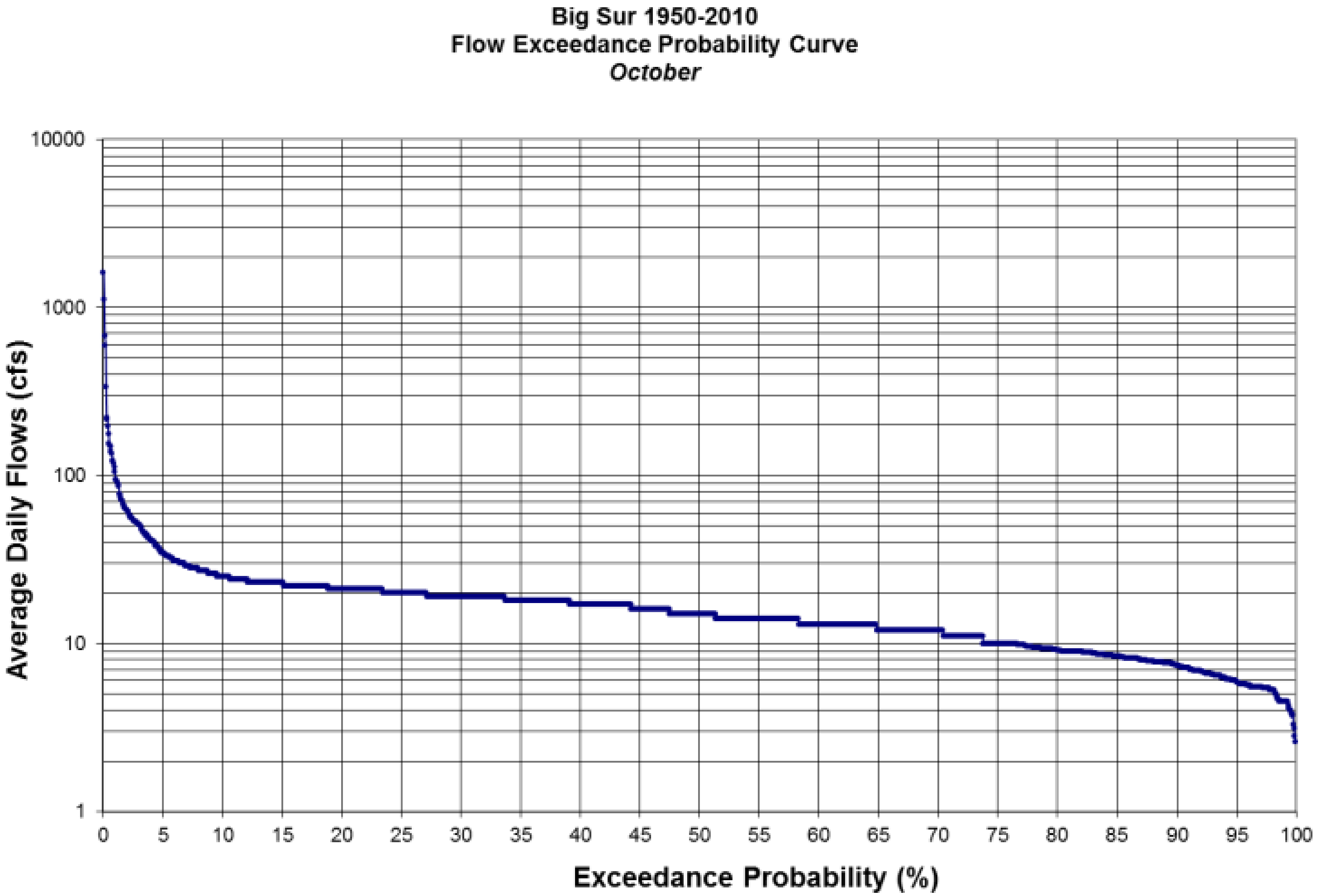

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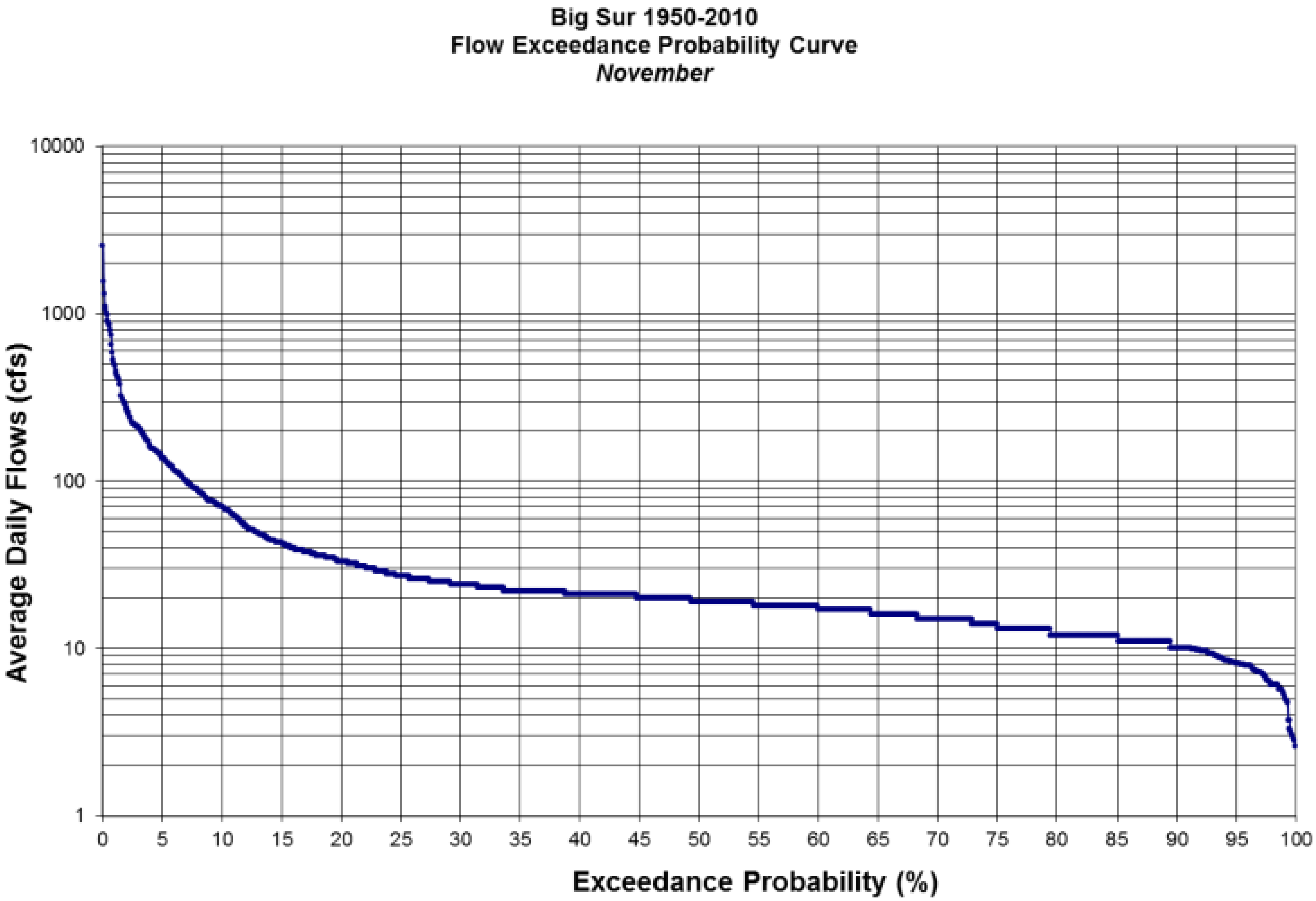

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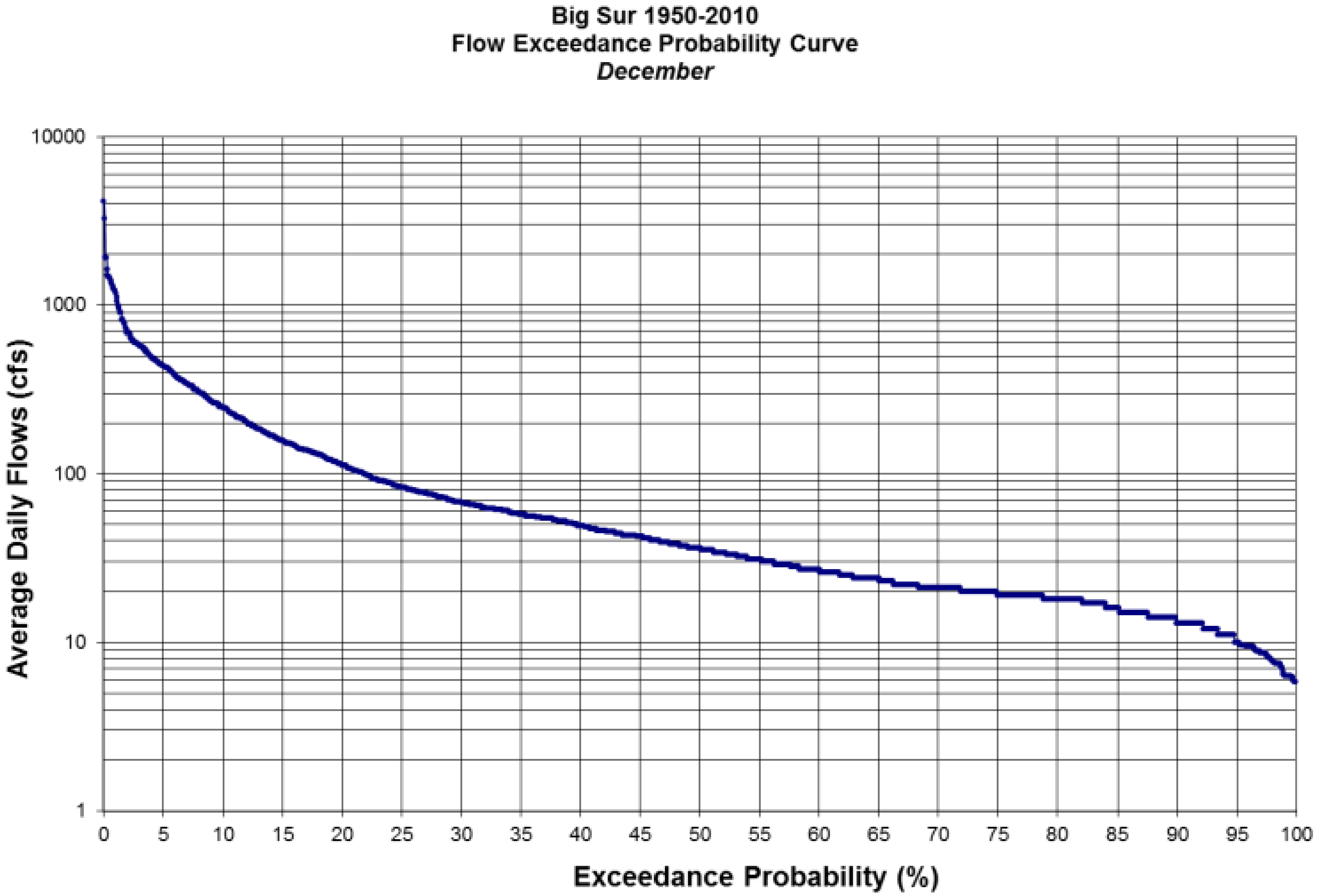
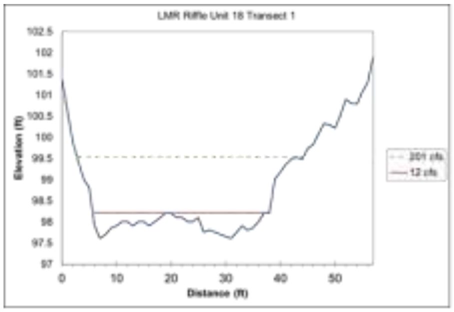


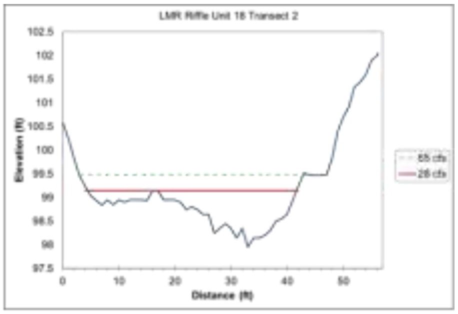
Flow exceedence probability curve for Big Sur River in December using USGS gage #1114300 data from 1950-2010.

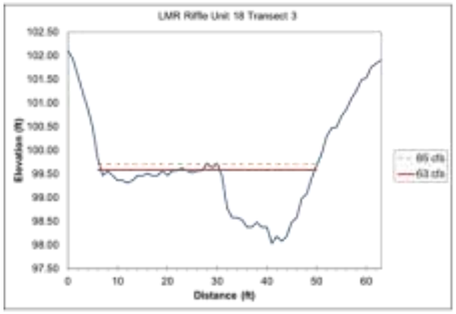
APPENDIX 2. Calibration results of wetted perimeter hydraulic model.

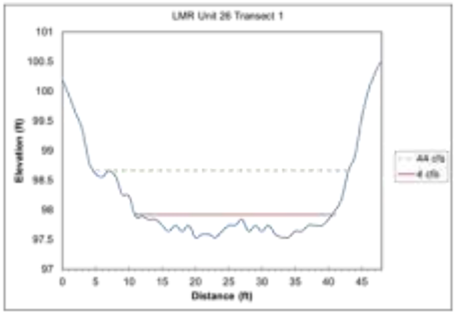
			WSEL (ft)		
Unit	Calibration Flow (cfs)	Transect	Measured	Predicted	Difference
Low Flow					
18	29	1	98.41	98.42	0.01
		2	99.15	99.15	0.00
		3	99.38	99.39	0.01
26	29	1	98.44	99.45	0.01
		2	98.56	98.57	0.01
		3	98.85	98.86	0.01
35	30	1	98.75	98.60	0.03
		2	99.15	99.16	0.01
		3	99.26	99.26	0.00
				Average	0.01
Mid Flow					
18	88	1	98.75	98.73	0.02
		2	99.44	99.44	0.01
		3	99.76	99.73	0.03
26	64	1	98.56	98.58	0.02
		2	98.81	98.78	0.03
		3	99.07	99.09	0.02
35	104	1	99.01	98.96	0.05
		2	99.40	99.45	0.05
		3	99.63	99.61	0.02
				Average	0.03
High Flow					
18	161	1	99.21	99.15	0.06
		2	99.67	99.82	0.15
		3	100.12	100.09	0.03
26	158	1	99.01	98.99	0.02
		2	99.19	99.20	0.01
		3	99.54	99.51	0.03
35	165	1	99.40	99.37	0.04
		2	99.82	99.81	0.01
		3	99.95	99.94	0.01
				Average	0.04

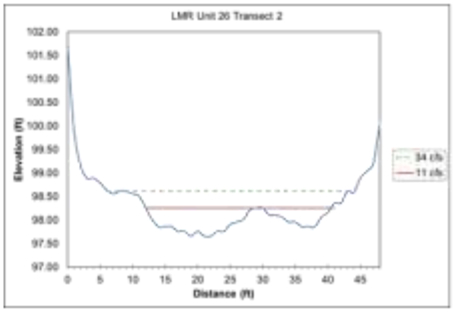
APPENDIX 3. Wetted perimeter cross-channel transect bed profiles and wetted perimeter versus discharge curves[3].

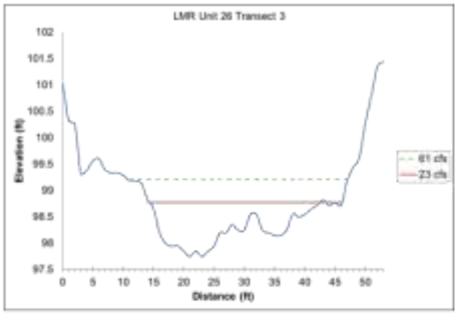


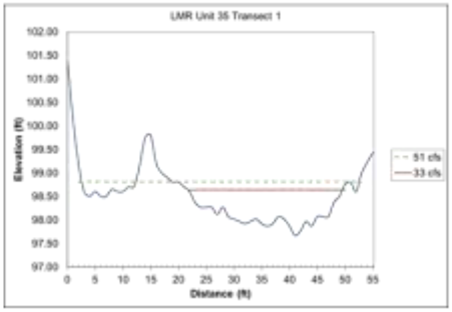


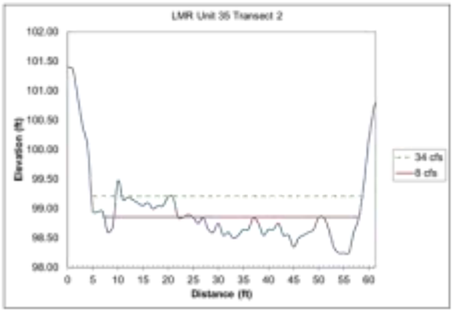


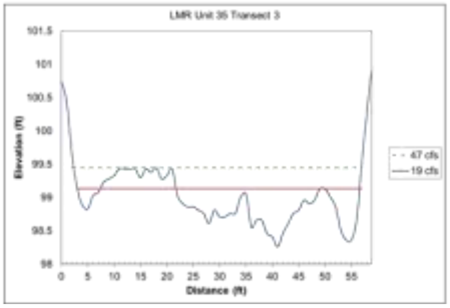












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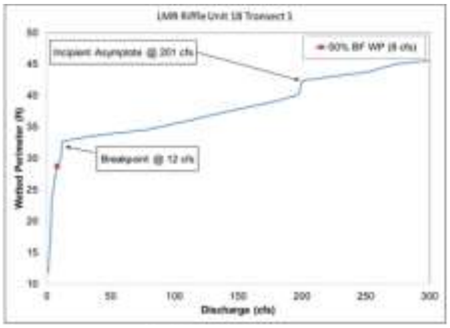
[3] Solid red line = breakpoint flow; dashed green line = incipient asymptote flow.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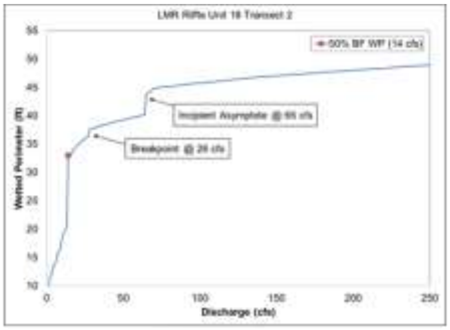
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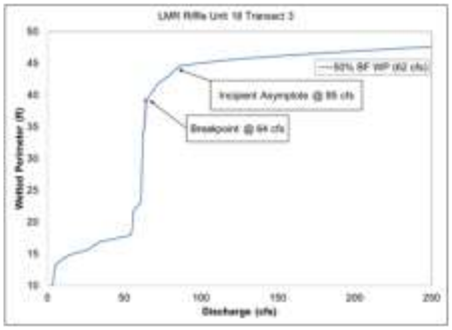
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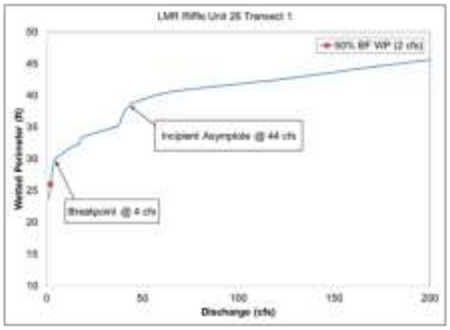
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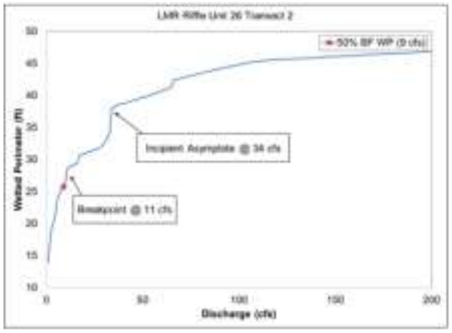
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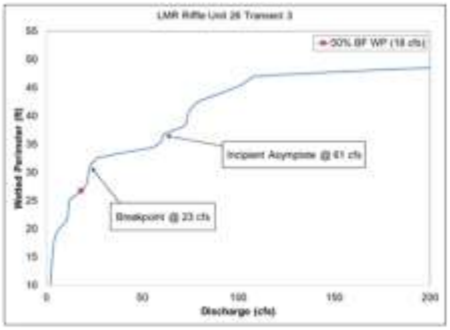
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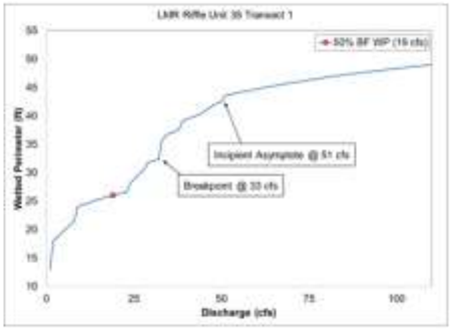
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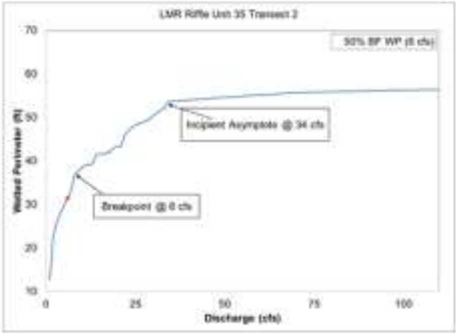
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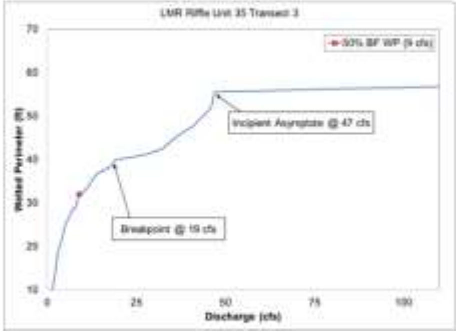
LMR Riffle Unit 35 Transect 3

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