California Department of Fish and Game
Environmental Services Division
Stream Flow and Habitat Evaluation Program

THE RELATIONSHIP BETWEEN INSTREAM FLOW AND COHO SALMON AND STEELHEAD HABITAT AVAILABILITY IN SCOTT CREEK, SANTA CRUZ COUNTY, CALIFORNIA

Prepared by

Bill Snider [1]

Kevan A. F. Urquhart [1]

and

Dean Marston [2]

April 1995

1/ Environmental Services Division, Stream Flow and Habitat Evaluation Program
2/ Region 3, Inland Fisheries, Monterey

Surface and subsurface diversion within the critical lower 0.5 mile reach exacerbate the low flow conditions by further reducing surface flow during the spawning and rearing periods (Marston 1992). The most significant deficiencies in the present flow conditions occur between June and November.

Currently there are no formal instream flow requirements for the lowermost 0.5 mile reach of Scott Creek, and no measurement of the agriculture diversions is required. An interim bypass flow requirement of 2 cubic feet per second (cfs) was agreed to by DFG and local landowners and incorporated into a Streambed Alteration Agreement, in August 1992 (Nelson 1994), but this goal is periodically unmet.

In December 1992, a water right application was filed with the State Water Resources Control Board to appropriate water via subsurface diversions adjacent to lower Scott Creek. DFG protested the application based upon the impacts on Scott Creek's anadromous fish populations attributed to existing diversions. The results of the instream flow study presented in this report are intended to be used to develop dismissal terms in the form of flow requirements.

Coho Salmon and Steelhead Life History

The following description of the life history of coho salmon and steelhead trout in Scott Creek is based largely on the work of Shapovalov and Taft (1954). They conducted intensive investigations of these two species in Waddell Creek, located about 5 miles north of Scott Creek, in Santa Cruz County. They also used information collected from the Scott Creek egg taking facility to describe life history characteristics of coho salmon and steelhead.

Coho Salmon

Coho salmon are anadromous fish which means they grow and mature in the ocean and reproduce in fresh water streams. They are fall and winter run fish, meaning they generally enter fresh water during the fall and early winter and spawn from late fall through winter. The young salmon usually hatch and emerge from the gravel to the flowing stream by spring. They then typically spend over a year in fresh water before migrating to sea towards the end of the second spring. They remain in the ocean for typically two years before reentering their natal streams and starting the cycle again.

In Scott Creek, the reproduction cycle begins with the entry of salmon into fresh water soon after fall rains open the sand bar at the mouth of the lagoon and connect the stream with the ocean. This event usually occurs by December, but may be as early as September or as late as February. Some salmon enter Scott Creek immediately following breaching of the bar with the remainder of the spawning population entering on successive storms, until the entire season's run is completed. In Waddell Creek, the earliest that fish entered the stream was during the week ending November 25, and the latest during the week ending March 24 (Shapovalov and Taft 1954). Most of the fish (96%) entered between December 10 and January 20.

Spawning in Scott Creek can take place anytime from late November through mid-March but generally occurs from mid-December through February. Coho salmon generally spawn in the lower portion of a stream, where stream gradient is low (< 2%). Shapovalov and Taft (1954) observed most coho salmon spawning in Waddell Creek within the first two miles upstream of the lagoon. Spawning in Scott Creek drainage occurs throughout the accessible portion drainage, but is largely confined to the lower 6 miles of Scott Creek and the lower reaches of Mill and Big creeks. Spawning typically occurs where a pool transitions into a riffle, in an area containing medium to small sized gravel. This area, called a glide, or riffle, is located where smooth surface water becomes turbulent and water flows through as well as over the gravel. The female salmon selects a site in this area where water depth and velocity are suitable and begins to build a series of depressions, collectively called a redd, or egg nest. The female digs the first depression then deposits a portion of her eggs into the depression where they are fertilized by the male. A second depression is built immediately above the first; the gravel excavated from the second depression flows into the first depression, burying the eggs, protecting them from predation, sunlight, etc. This activity is continued as depressions are successively built until all the eggs are deposited and buried.

Spawning habitat conditions are selected to accommodate spawning, egg incubation and eventually the emergence of young fish from the redd. Water depth and velocity must be sufficient to allow the salmon access to the site and assist gravel movement during digging. The redd site must be in an area that remains covered with water even as flow typically rises and falls during the fall and winter months. The gravel must be clean, small to medium sized (between 0.5 and 2.5 inches in diameter) and located in an area where water moves both through and over the gravel. Gravel must be small enough to allow the female salmon to dig the depressions, and large enough to allow free movement of water through the redd to provide oxygen and remove waste products produced during incubation. The areas between the gravel must be large enough to allow young fish to emerge from the redd. Silt is one of the greatest threats to egg survival. Extremely high flows can scour redds, killing eggs and pre-emergent fish. One reason coho salmon may choose the lower reaches of streams is that an unaltered channel in these reaches is typically well connected to its flood plain allowing higher flows to spill over the bank before sufficient scour occurs within the preferred spawning habitat areas.

Incubation lasts from 35 to 50 or more days depending upon water temperature. Optimum incubation temperatures range from 42 to 56 °F. Eggs incubated at 48 °F hatch in 48 days; eggs incubated at 52 °F hatch in about 35 days. Egg incubation in Scott Creek may extend from late-November through mid-April. Eggs incubating under optimum conditions can expect to attain over 95% survival to hatching.

Newly hatched fish remain in the gravel and are nourished by absorbing nutrients from a yolk sac. Under normal conditions, the young fish rarely emerge until the yolk sac is absorbed. Time of emergence can be influenced by: 1) water temperature, which affects the rate of development, 2) redd or burial depth and gravel size which can either expose the fish early if the redd is shallow or the gravel is loose, or retard emergence if gravel is tight or the redd is deep, and 3) silt which can force the fish out due to unfavorable conditions resulting from poor water quality. Under normal conditions, emergence typically starts two to three weeks after hatching, with the peak of emergence occurring within three weeks of hatching. However, it may take up to an additional seven weeks before the last fish emerges, owing to individual differences among fish even in the same redd. The emergence period in Scott Creek can extend from January through May. Shapovalov and Taft (1954) estimated that 65% to 85% of eggs deposited in redds in Waddell Creek resulted in successful fry emergence.

Upon emergence, the young salmon, now called fry, seek out shallow, relatively low velocity areas, usually associated with overhead cover along the stream margins. These recently emerged fry, generally less than 35 mm long, appear to remain in groups for several weeks. Eventually, as the fry grow, they become more aggressive and move into more open, faster, deeper water typically in pools, but also in riffles and runs depending upon cover availability. Here some fish take up and actively defend feeding stations, while others are forced into the slower, deeper areas of the pools. Competition from larger coho and other salmonid species, such as steelhead, dictate the distribution of coho fry in both pool and riffle-like habitats.

The abundance of coho in Scott Creek is probably limited by the availability of suitable spawning habitat as well as fry territories and food. More structurally complex streams that contain larger substrate, woody debris and overhanging vegetation support more fry. Likewise, streams producing an abundance of benthic organisms also support more fry. Significant depletions in fry numbers, in spite of low spawning population numbers, are likely indicators of a relative lack of suitable territories and food production in Waddell and Scott creeks (Shapovalov and Taft 1954).

By late summer and early fall, as flow recedes, temperature increases, and food availability decreases, most of the now juvenile-sized fish (> 50 mm) move into deeper pools. Fish seem to remain in the pools until the following spring, generally in March, when feeding activity increases concurrent with increased food availability. Toward the end of March, fish begin to accumulate in schools and begin downstream migration. It is during this period that the fish begin to smolt, a process involving physiological and behavioral changes that prepares the fish to enter the marine environment.

During the nine years of sampling in Waddell Creek, only 106 out of 18,352 downstream migrants were age 0 - the rest were age 1. Nearly all downstream migration occurred during April and May. The peak of migration never occurred before April 22, and always occurred before May 20.

Steelhead

Steelhead are also anadromous fish. Steelhead life history categories are much more variable than coho salmon. Unlike coho salmon, steelhead migrate to sea at various ages and over a longer period within a season, spend varying amounts of time in the ocean and return over a longer period during a season. They do not always die after spawning. A mean of 17% (up to 36%) of spawning migrants collected in Waddell Creek were repeat spawners.

Steelhead migrate into Scott Creek from immediately following breaching of the bar (typically November) through May. The timing of migration is somewhat related to size which is associated with previous life history. Typically, smaller 2/1 fish (2/1 indicates that the fish spent two growing seasons in fresh water and one year in the ocean) enter the stream early, numbers peaking before the end of February. Larger 2/1 fish and 2/2 fish enter the stream later, peaking in late February or March.

Spawning can occur from November through May, but appears to peak from January through March. Steelhead typically occupy the entire, accessible portion of the Scott Creek drainage. Spawning takes place in both the low gradient, lower drainage and in the higher gradient, upper drainage. Spawning habitat and behavior are similar to that of coho salmon, discussed above.

The protracted steelhead spawning period results in significant variation in incubation and emergence. Eggs of early spawning steelhead exhibit incubation periods similar to coho salmon. Eggs of later spawning steelhead experience substantially warmer temperatures, increasing the rate of incubation. At the temperatures prevailing in Scott Creek, the usual hatching time is 25 to 35 days. Steelhead emergence begins within two to three weeks of hatching, and may last another two to three weeks.

After emergence, steelhead fry behavior is comparable to that described above for coho salmon. The primary difference is a greater within-cohort variability in the size of steelhead present in the stream, due to the protracted spawning and emergence period. As with coho salmon, fry begin to move into deeper, faster water as they grow. It is during this transition that a large number of steelhead are lost, either through displacement or mortality.

A substantial difference between steelhead and coho salmon behavior occurs during the late summer period. Unlike salmon that move to the deeper pools and reduce feeding, steelhead remain in the faster areas of the stream and continue to feed throughout late-summer and fall. During winter, when temperatures decline below 50 °F, steelhead juveniles seek areas with suitable overhead cover, often in the form of cobble as well as woody debris and undercut banks. Steelhead juvenile appear to continue to feed during the winter, exhibiting a distinct diurnal switch in feeding. Almost all activity occurs at night (coho salmon may also exhibit this shift).

Unlike coho salmon, steelhead migrate downstream at various ages and during various times within a season. The majority of downstream migration occurs during spring and summer, followed by a secondary migration in late fall and winter. Few fish migrate downstream during January and February. Steelhead migrate downstream as young-of-the-year, yearling, two, three and four year old fish. Shapovalov and Taft (1954) noted comparable numbers of young of the year and yearling downstream migrants, about half as many two year old migrants and very few older migrants.

Not all downstream migrants enter the ocean. Shapovalov and Taft noted yearling and older fish returning upstream, from below their traps, after rearing in the lower creek and lagoon, without emigrating to the ocean. Survival to mature adults also varied significantly with age at ocean entry. Even though the majority of downstream migrants in Waddell Creek were age 0 and age 1, the majority of adults returning to spawn in Waddell Creek had spent two years in fresh water before entering the ocean. The significance of the lower stream reach and the lagoon in providing the younger (< age 2) fish freshwater rearing is unknown. The relatively small proportion of age 2 fish encountered at the Waddell Creek trap during out migration compared with the large proportion of age 2/n fish returning to spawn combined with the noted occurrence of steelhead using the lagoon for rearing suggests that these lower stream reaches and lagoon may be very important to steelhead survival.

METHODS

General Site Description

Scott Creek is located in Santa Cruz County in the central coast region of California. It originates in the Santa Cruz Mountains within the Coast Range and flows westward 11 miles, entering directly into the Pacific Ocean about 17.5 miles north of Santa Cruz (Figure 1). A lagoon exists at its mouth. The Scott Creek watershed drains approximately 25 square miles including three major tributaries: Little Creek, Big Creek, and Mill Creek. Little Creek enters Scott Creek at stream mile 1.8, Big Creek at stream mile 3.2, and Mill Creek at stream mile 4.1. Unimpaired flow is perennial throughout Scott Creek and most of its major tributaries; unimpaired flow is discussed in detail in a later section.

The Scott Creek watershed supports two anadromous salmonid species, coho salmon[1] and steelhead trout, two sculpin species, (*Cottus* spps.), threespine stickleback (*Gasterosteus aculeatus*) and tidewater goby (*Eucyclogobius newberryi*). Anadromous salmonid spawning and rearing habitat occurs throughout the accessible portions of Scott Creek and its major tributaries. A 19+ foot high waterfall restricts anadromous fish to the lower 7.5 stream miles of Scott Creek. Similarly, barriers restrict access to the lower 1.5 miles of Little Creek, the lower 2.5 miles of Big Creek, and the lower 2.6 miles of Mill Creek.

The majority of coho salmon spawn in the 6-mile reach of the main stem of Scott Creek from stream mile 1.5 to the area just below the falls, and in the lower sections of Big (first 2.5 miles) and Mill creeks (first 2.6 miles). Steelhead also use these areas, as well as the lower 1.5 miles of Little Creek and the lower 1.5 miles of Scott Creek. The lower 0.25 miles of Little Creek and the lower 1.5 miles of Scott Creek also likely support coho salmon spawning habitat, but such use has not been documented (J. Nelson, DFG Region 3, pers. comm.).

Rearing habitat for both species extends from the spawning reaches downstream to the mouth of Scott Creek and into the lagoon/estuary. Suitable flow to accommodate fish passage, rearing and spawning throughout Scott Creek's anadromous reach, including the lowermost 0.5 miles presently affected by diversions, is essential to the maintenance of viable, anadromous fish populations.

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[1] The coho salmon populations occurring south of San Francisco Bay are candidates for possible listing as threatened or endangered pursuant to the California Endangered Species Act. Both the coho salmon and steelhead trout populations, coast wide , are under status review for possible listing pursuant to the federal Endangered Species Act. The tidewater goby is listed under both the federal and state endangered species acts.

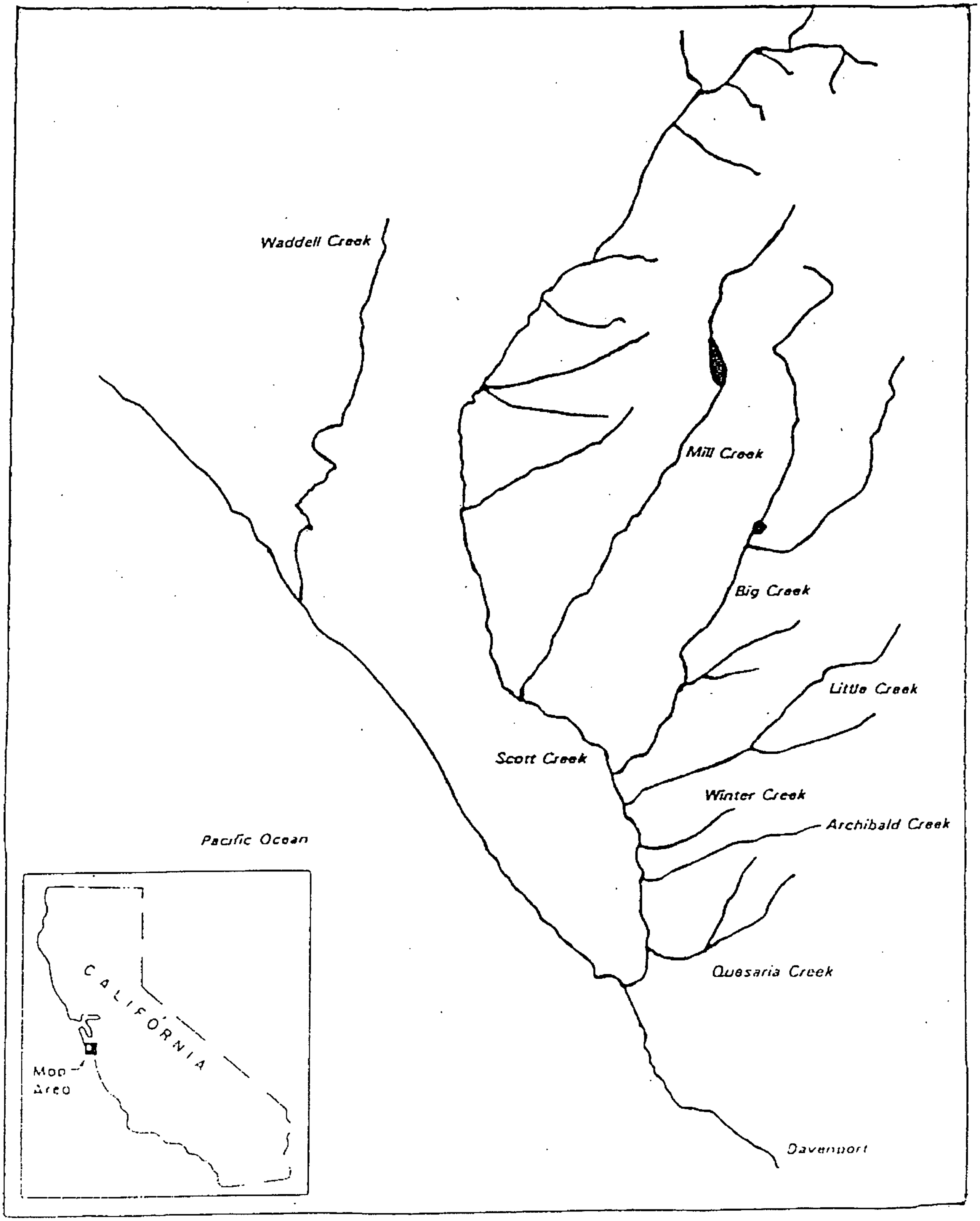


FIGURE 1. The Scott Creek drainage, Santa Cruz County, California.

Study Reach

The study reach is characterized by the following:

- It extends from stream mile (SM) 0.3 on California Polytechnic University - San Luis Obispo's (Cal-Poly) property, near the lowermost road crossing, upstream to SM 0.9, near the upper road crossing and the Cal-Poly well house, about 0.6 SMs.
- It encompasses the area affected by the subsurface well diversions and the one surface diversion. It extends from just upstream of the first well, operated by Cal-Poly, to downstream of the well operated by Mr Bontadellii.
- It contains all the major fish habitat types: pools, runs, riffles, and glides.
- It has a low gradient, sand, gravel, and cobble bed channel, and no tidal influence.

General Approach

The relationship between flow and habitat availability was developed using the physical habitat simulation model (PHABSIM) developed by the U.S. Fish and Wildlife Service (FWS) Instream Flow Group (Bovee 1982). Our approach was to collect hydraulic and physical modeling data at transects located across representative habitats to define habitat availability for the entire study area. We identified the representative transect sites by: 1) classifying habitat types within the study reach to identify dominant and critical habitat types, 2) selecting three replicate habitat types to represent the dominant and critical types, and 3) systematically establishing transects across the selected sites to collect the required data. Data were collected at each transect at three distinct flows. Transect data were then entered into the PHABSIM model (segregated by habitat type), calibrated, then modeled to identify flow versus habitat relationships for each habitat type. The model results were then weighted to represent the proportion of the represented habitat type within the study reach, then combined using a spreadsheet to identify flow versus habitat relationships for the entire study reach.

Field Methods

Habitat Classification

The habitat classification system outlined in Flossi and Reynolds (1991) was used to delineate aquatic habitat types in the study reach. Habitat classification was based on channel morphology and gradient, substrate composition, and hydraulic characteristics. Habitats were classified as riffle, run, glide, or pool. Pools were further classified as either lateral-scour pools, lateral-scour/rootwad-influenced pools, or main-channel pools.

Personnel from DFG Region 3 surveyed the study reach by foot on 22-23 June 1992 to identify habitat types. The boundaries of each habitat type were marked using surveyors flagging tape. Flows during the survey averaged 6.5 cfs.

Transect Selection and Placement

Three representatives each of the dominant habitat types located in the study reach (i.e., run, riffle, main-channel-pool, and glide) were selected as flow study sites. We also selected three study sites to represent lateral-scour pools; two were lateral-scour/rootwad-influenced pools. A total of fifteen IFIM study sites were selected. These study sites were termed Transect Areas (TA) one through fifteen. Study transects were located at each study site to develop flow-habitat relationships. One transect was used to represent the more uniform habitat types (i.e., run, riffle, and glide). Pools were represented by three transects. Transect areas were numbered sequentially with a single number (e.g., TA1) for sites with one transect and with a single decimal place number for a second or third transect in a series within a pool (e.g., TA2.3). Twenty-seven study transects were established representing 15 study sites: three transects each representing runs, riffles, and glides; nine representing main-channel pools; three representing lateral scour pools; and six representing lateral-scour/rootwad-influenced pools.

Data Acquisition

The hydraulic data required for PHABSIM modeling was measured at three nominal flows (Table 1). The high-flow measurements were made 6-8 April 1993; the mid-flow measurements 15-16 June 1993; and the low-flow measurements during 9-11 August 1993. Water depth, water velocity, water surface elevations (WSL), water surface elevations at the stage of zero flow (SZF), and bed elevation profile were measured at low and high flow per Trihey and Wegner (1981). The SZF is the water surface elevation when the flow equals zero. This is the elevation of either the deepest point of the cross section (thalweg) or the downstream hydraulic control. Only WSL's were collected during the mid-flow.

TABLE 1. Target and measured flows for PHABSIM data collection, Scott Creek, Santa Cruz County.

Nominal Flow Level	Target Flows (cfs)	Measured Flow (cfs) (mean & [range])	Type of data measured	
			Velocity & stage/discharge	Stage/discharge only
Low	< 5	3.2 [2.0-4.3]	X	
Mid	15	12 [11.4-12.4]		X
High	45	43.3 [37.7-48.0]	X	

Hydraulic data acquisition and recording procedures followed FWS guidelines (Trihey and Wegner 1981; Milhous *et al.* 1981). Discharge was measured per guidelines outlined in the U.S. Geological Survey Water Supply Paper No. 2175 (Rantz *et al.* 1982). A semi-permanent benchmark was mounted in concrete, and semi-permanent head-stakes were installed for all transects. Temporary working pins were used to string transect tapes to minimize disturbing transect headpins. A minimum of 20 vertical cell measurements were made between the waters edges at high flow. The cell boundaries along each transect were typically distributed incrementally, except where substantial changes in water velocity or depth required additional cells. Cells defined during high flow were used during low flow measurements.

Total water depth was measured to the nearest 0.1 ft with a top-setting rod. Marsh McBirney Flowmate Model 2000 digital electromagnetic velocity meters (capable of providing both instantaneous readout of positive and negative water velocity values) and Marsh McBirney Model 201 analog electromagnetic velocity meters, were used to measure water velocity to the nearest 0.01 ft/second. Mean column velocity was measured at 0.6 depth from the water surface in depths less than 2.0 ft, and at proportional 0.2 and 0.8 depths from the water surface in depths between 2.0 and 4.0 ft (Buchanan and Somers 1969). Water velocities at three proportional depths (0.2, 0.6, and 0.8) were measured when total water depth exceeded 4 ft, and when water velocity distribution in the water column was highly variable (Bovee and Milhous 1978).

Temporary staff gages were installed and monitored for stream discharge changes (water surface elevation) during transect data collection. Flow remained constant during transect measurements. Headpin, tailpin, dry bed elevations and WSLs were measured to the nearest 0.01 foot using an auto level and stadia rod.

Substrate, object cover, and overhead cover were identified for each cell of each transect using a scoring system based on methods developed by the FWS and U.S. Forest Service (Appendix 1 & 2). Substrate was characterized by dominant and subdominant particle size using a two digit code from 1 to 15 (Appendix 1). Object and overhead cover were characterized by type and size. We used ten cover types and three cover sizes to define cover (Appendix 2).

Analytical Techniques

Data Proofing & Quality Control

Field data were proofed by the field crew leader at the end of each field day, or on the first available work day immediately following field work. Field data (dry-land elevations, velocity/depth data, and WSL data) were transcribed onto one data entry sheet per transect per flow in the office, and cross-checked immediately by the transcriber. As such, two data decks (one for low-flow data and one for high-flow data) were created for each individual transect using IFG4IN. Decks were proofed for data entry errors during the data entry process. Discharge calculated by IFG4IN was compared with field discharge calculations. If discharge differed by more than 5%, the field computations were recalculated and the entered data were rechecked and corrected, as needed.

Data Screening & Adjustments

Each data deck was run through TREVI4, (i.e., subroutines CKI4 and REVI4) to detect formatting errors (in CKI4) and for aberrant results (in REVI4) including: 1) trends in velocity with depth, 2) trends in roughness with depth, 3) channel profiles, such as mid-channel points above the WSL, 4) velocity distributions across the channel, and 5) trends in WSL with discharge. Anomalies were noted and the raw data and data entry sheets were rechecked for errors that could have caused any observed aberration. Errors were corrected on all paper and computer records, as necessary.

Stage - Discharge Calibrations & WSL Modeling

Stage-discharge calibrations and predictions of WSL's at modeled flows were made using IFG4 for each individual transect. The tolerances used for modeling decisions were as follows:

Residual Error Levels in IFG4

The mean square error term (MSE) from REVI4 and IFG4 were reviewed to determine how well transects with three sets of stage-discharge data fit the IFG4 model for WSL prediction. Standard FWS criteria suggests that transects with MSE's greater than 10% be recalibrated with MANSQ.

The MSE from REVI4 and IFG4 averaged 10.7% (range 0.4% to 27.0%, s.d. ± 8.0%). Thirteen transect's MSE's were within the suggested criteria. Fourteen of the 27 transects calibrated with IFG4 had MSE's greater than 10% (mean = 16.7%, s.d. ± 5.5%, range 10.6-27.0%). Four of these transects had MSE's which were barely out of the acceptable range (< +2%), and ten had MSE's which were further out of range (+3.5% to +17%). Ten of these fourteen transects were in pools, thus only four of the transects had any potential for improved WSL calibrations using MANSQ.

WSL Predicted versus Measured in IFG4

Standard FWS criteria suggest that each transect's WSL-predicted should differ from its WSL-measured by less than or equal to 0.1 ft.

All transects were calibrated to within ≤0.15 ft of measured WSL, with WSL-predicted differing from WSL-measured by an average of 0.03 ft (s.d± 0.03 ft., range 0.00-0.15 ft.). WSL-predicted versus WSL-measured varied by more than 0.05 ft in only 10 transects, and varied by more than 0.10 ft in only three of those 10 transects. WSLs calibrated quite well in spite of some high MSEs. Since all transects had predicted WSLs which were close to their measured WSLs, we used IFG4 for all WSL calibration.

Velocity Calibrations

Velocity calibration comprised two general screening and evaluation approaches. First we reviewed the pattern and magnitude of the velocity values and Manning's N (roughness) values produced during the calibration and production runs of IFG4. Excessive roughness values along any portion of the transect, except the shallow water edges, are a potential problem and should be modified, as needed. Excessive roughness values are defined as N values that greatly exceed the common level of roughness values seen in areas other than very shallow, channel-edge cells. Velocity distributions were also reviewed for any abnormal or inconsistent patterns. If anomalies are detected, the raw data is cross-checked for accuracy and N values are rechecked to see if they were consistent with the range of N's in the rest of the transect, a potential cause of abnormal velocity.

No anomalous trends were observed in the velocities predicted by IFG4. Adjacent cells had relatively similar but gradually changing velocities. Rapid changes in velocity and roughness only occurred where there were abrupt changes in substrate elevation, as expected.

Highly elevated N values only occurred in shallow water over mid-channel bars or in lateral, shallow-water habitats, as is expected. Thus, no attempt was made to limit N values. Artificially restricting the magnitude of N values (roughness) in lateral, shallow-water habitats has the effect of accelerating modeled water velocities in the habitat areas most valuable to juvenile fish, and functions to depress the value the model assigns to these areas for the juvenile life stage.

For the second part of a velocity calibration, velocity data sets (e.g., low, mid- and high-flow) are compared by transect. If the pattern and magnitude of the predicted velocities are not similar to the measured values (using each velocity data set to predict values at the discharge measured in the complementary data set) then the appropriate approach to velocity modeling is to split the range of flows to be modeled into two ranges. Separate ranges of flows would then be modeled with each low- or high-flow data set.

In our evaluation, we modeled habitat conditions independently using the high and low flow decks to describe requirements as appropriate. The range of flows that are of primary concern for coho salmon and steelhead fry (0-10 cfs), for example, were most appropriately modeled with the low-flow velocity data set (mean measured flow of 3.2 cfs), upon which our results are based. It is possible that model output based on the high-flow data set might alter the results in the 23-50 cfs range to some slight degree. These flows are outside the range of concern, eliminating the need to use the high flow data deck results. If the pattern and magnitude of the predicted velocities were similar to the measured values, using either low- or high-flow velocity data set to predict values at the discharge measured in the complementary data set is appropriate. If pattern and magnitude differed, the use of the low flow data set to model through the mid-flow levels (12 cfs), and at least half way (23 cfs) to the high-flow level would be appropriate.

Velocity Adjustment Factors (VAFs)

The FWS' guidelines recommend that VAFs range between 0.6 and 1.4 for calibrations using a single velocity set. However, these guidelines <u>are not</u> binding rules or fixed assumptions. Some PHABSIM/IFIM practitioners advocate a wider range of acceptable VAFs (0.1 to 1.9), and are only truly concerned with VAFs greater than 3.0. Our modeling produced Velocity Adjustment Factors (VAFs) between 0.283 and 12.886, which indicates that some of the flows we modeled were somewhat out of the range best predicted with the low-flow data set

Production runs of the low flow velocity data sets generated VAFs out of the FWS' recommended range at some flow for all 27 transects (Figure 2, Table 2). Most of the 27 transects had a VAF greater than the FWS' recommended range at flows between 5 to 8 cfs. When less stringent criteria (VAF's > 3) is used, only 20 of 27 transects had a VAF > 3, and then only after flows exceeded 12 cfs.

The few, small, negative velocities we measured were changed to positive numbers for the IFG4 calibration and production runs. As a result, Q-calculated from the data on the VEL lines in the IFG4 data set might not exactly match Q-given on the CAL line. The velocities across each transect may therefore, have been dampened slightly by the PHABSIM model to get Q-calculated to match Q-given in the production runs of IFG4, possibly causing a slight dampening of the predicted velocities at modeled flows for a few transects.

IFG4 Production Runs

Actual habitat lengths measured for each transect in the field were used on the XSEC line for each IFG4 run, except in the case of pools (Table 2). Since pools typically had three transects for each habitat unit, the length of the habitat unit was apportioned equally (1/3) to each sub-transect in that pool habitat.

We used IOC codes 5=1 and 8=0 for production runs to produce the TAPE3 and TP4 files necessary for our HABTAT modeling runs, since our data decks had their WSL's calibrated and predicted via IFG4. We set IOC code numbers 1, 2, & 13 equal to 1 during the calibration phases to get expanded model output and VAFs to use in the screening process. All other IOC codes were left at their default values.

We selected flows for the QARD cards during production runs that represented the range of flows which we could model appropriately with our field data (1-50 cfs). We modeled WUA versus flow at 1 cfs intervals from 1 cfs to 10 cfs, and at 2 cfs intervals from 10 to 20 cfs, since these were the flow ranges of primary concern, and the ranges where the model output was most likely to change rapidly. Flows from 20 to 50 cfs were modeled every 5 cfs.

Habitat Suitability Curve Selection

Site specific habitat suitability curves for coho salmon and steelhead are not available for Scott Creek. Therefore, we used curves from the FWS (Bovee 1978). These curves are Category Two curves, as defined by the FWS, representing habitat utilization curves developed from frequency analysis of field data. However, the steelhead juvenile and fry curves were based on density rather than frequency data.

The depth and velocity suitability curves for coho salmon spawning and fry, and steelhead spawning, fry, and juveniles which were available for our use are plotted in Figures 3-8. Juvenile coho salmon suitability curves are not available. Substrate and cover data were not yet available when the PHABSIM modeling was completed, thus suitability curves for these features were not used as part of the HABTAT modeling process. Such criteria would likely increase the flows required to maximize habitats. If necessary, they can be provided and the model re-run.

Habitat Modeling Runs

We used HABTAT to produce models of Weighted Usable Area (WUA) We ran HABTAT with ZHABIN IOC Code numbers 2, 3, 8, 10, and 19 = 1.

Conservative Cut-off at 1.4 to 1.9, Liberal Cut-off at 3.0

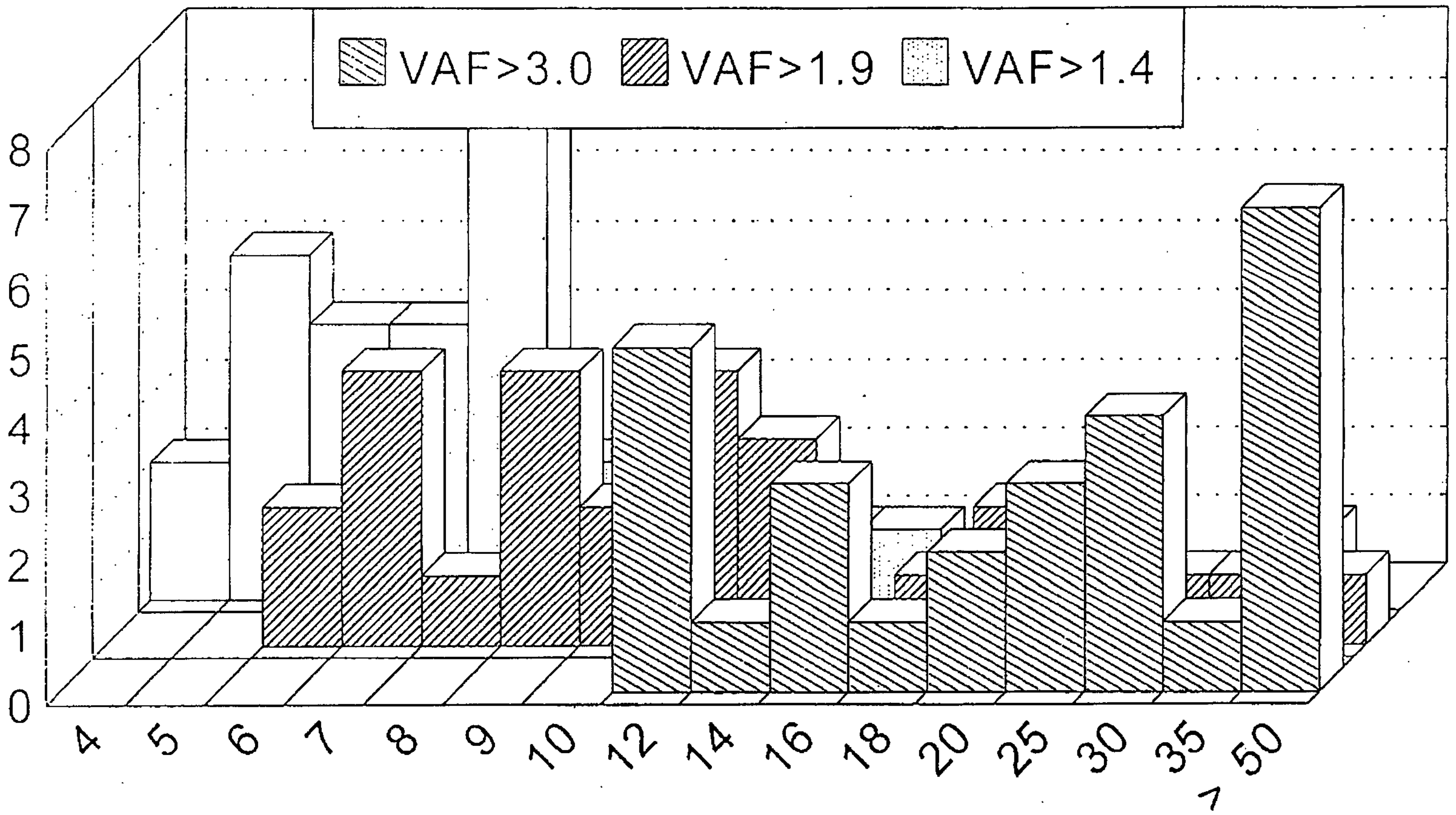


Figure 2. Distribution of flows at which Velocity Adjustment Factors (VAFs) exceeded generally accepted guidelines for the PHABSIM model of the critical reach of Scott Creek, Santa Cruz County, CA.

TABLE 2. Transects measured for the PHABSIM analysis of the instream flow needs of coho salmon and steelhead in the critical reach of Scott Creek, Santa Cruz Co., Ca., during 1993.

Transect ID #	Meso-Habitat Type[1/]	Habitat Length (ft)	Range of VAFs[2/]	QARDs[3/] with VAFs ≥0.6 or ≤1.4	QARDs[3/] with VAFs ≥0.1 or ≤1.9	QARDs[3/] with VAFs ≥3.0
T1	RIFFLE	63	0.75-2.63	1-7	1-16	none
T2A	L.S.-POOL	34.33	0.68-2.77	1-8	1-18	none
T2B	L.S.-POOL	34.33	0.4-8.56	2-4	1-6	12-50
T2C	L.S.-POOL	34.33	0.42-5.31	2-5	1-9	20-50
T3	RUN	67.4	1.02-1.59	2-30	1-50	none
T4A	M.C.-POOL	35.33	0.56-3.60	2-7	1-12	35-50
T4B	M.C.-POOL	35.33	0.52-7.17	2-4	1-6	14-50
T4C	M.C.-POOL	35.33	0.34-4.66	3-7	1-12	25-50
T5A	L.S.R.-POOL	31.17	0.36-4.93	3-6	1-10	25-50
T5B	L.S.R.-POOL	31.17	0.42-9.04	2-4	1-6	12-50
T5C	L.S.R.-POOL	31.17	0.41-12.89	2-3	1-5	10-50
T6A	M.C.-POOL	26	0.53-4.75	2-5	1-9	25-50
T6B	M.C.-POOL	26	0.43-4.37	2-7	1-12	30-50
T6C	M.C.-POOL	26	0.46-4.12	2-6	1-12	30-50
T7	RIFFLE	101	0.50-4.29	2-6	1-10	30-50
T8	GLIDE	215.5	1.02-2.42	1-12	1-25	none
T9	GLIDE	115	0.46-6.54	2-5	1-8	18-50
T10A	M.C.-POOL	25.6	0.36-11.22	2-4	1-6	12-50
T10B	M.C.-POOL	25.6	0.28-8.89	3-6	1-8	19-50
T10C	M.C.-POOL	25.6	0.34-8.44	2-5	1-8	16-50
T11A	L.S.R.-POOL	22.77	0.63-8.29	1-3	1-5	12-50
T11B	L.S.R.-POOL	22.77	0.66-4.09	1-6	1-10	30-50
T11C	L.S.R.-POOL	22.77	0.49-5.72	2-5	1-8	20-50
T12	RUN	171	0.90-2.45	1-8	1-20	none
T13	RIFFLE	111	0.86-2.72	1-7	1-18	none
-T14	RUN	153.5	1.05-2.17	1-12	1-30	none
T15	GLIDE	218	0.55-6.78	2-4	1-7	16-50

[1/] L.S. - POOL= lateral scour-pool; L.S.R.-POOL = lateral-scour rootwad-influenced pool; M.C.-POOL = mid-channel pool.

[2/] VAF's = velocity adjustment factors.

[3/] QARDs = modelled flows entered on QARD cards in the IFG4 data deck, for which HABTAT produced predictions of weighted-useable-area.

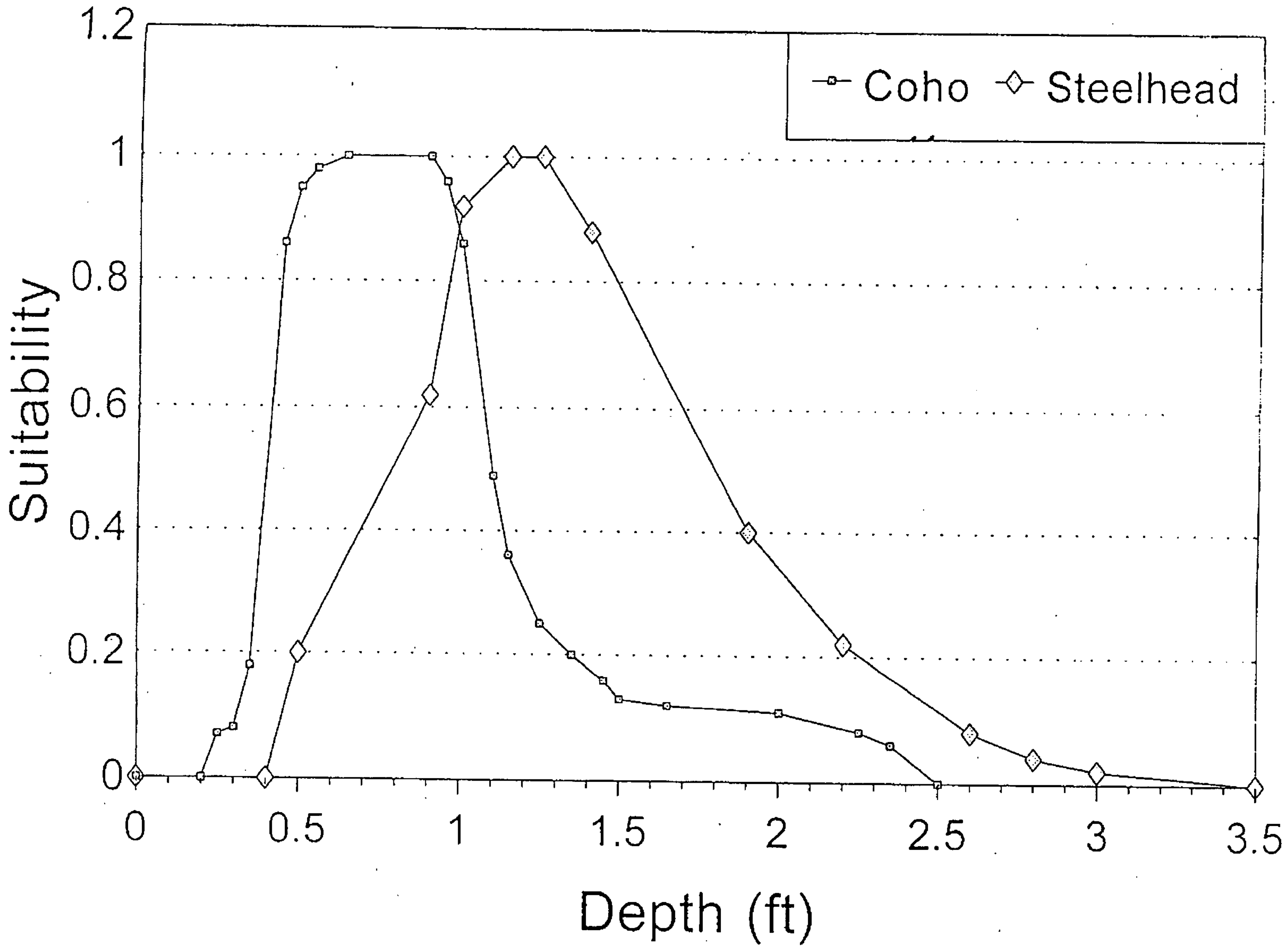


Figure 3. Spawning depth suitability curves for coho salmon and steelhead used in the PHABSIM model of the critical reach of Scott Creek, Santa Cruz County, CA.

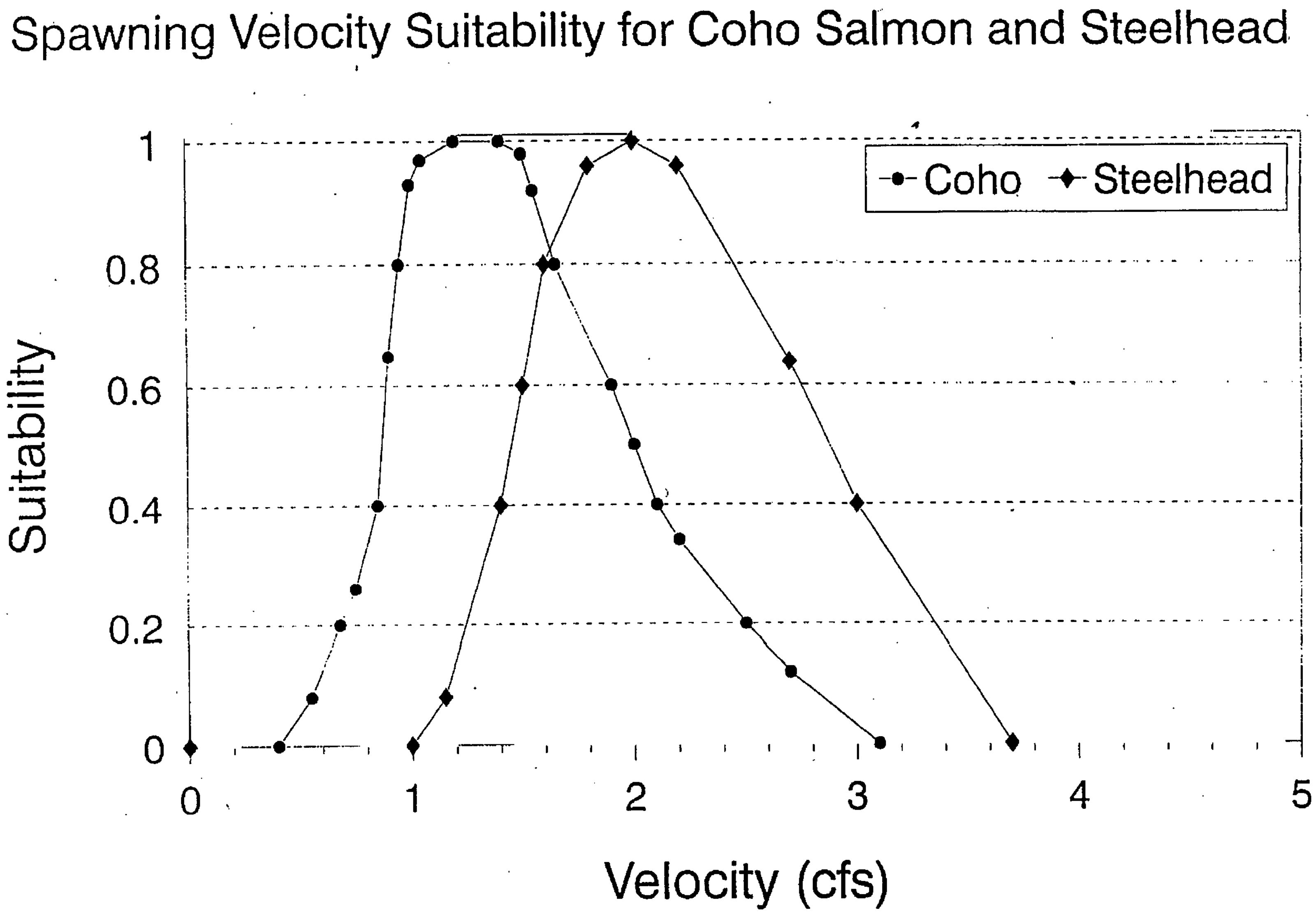


Figure 4. Spawning velocity suitability criteria for coho salmon and steelhead used in PHABSIM to model spawning habitat availability in Scott Creek, Santa Cruz County, CA.

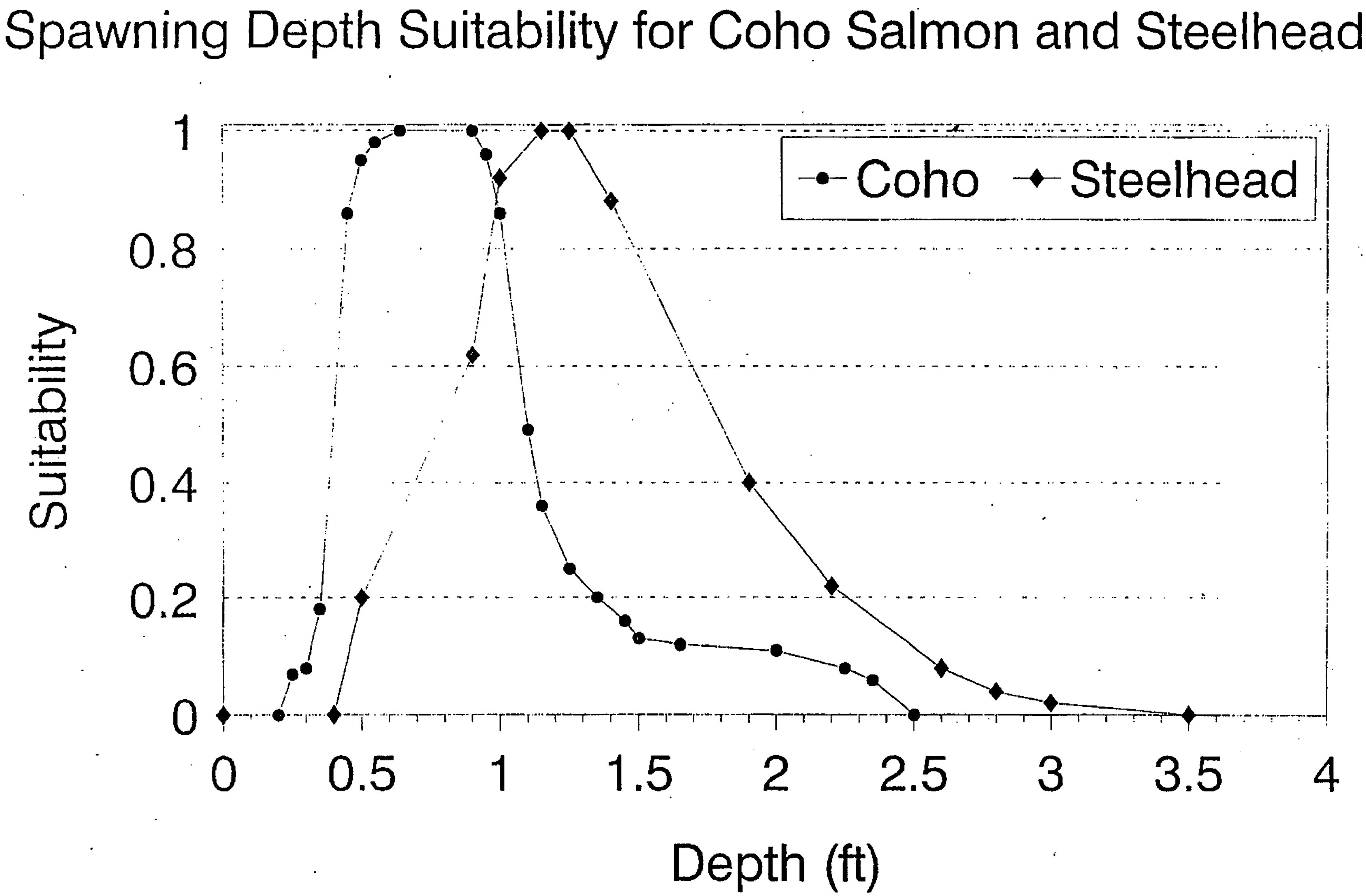


Figure 5. Spawning depth suitability curves for coho salmon and steelhead used in PHABSIM to model spawning habitat availability in Scott Creek, Santa Cruz County, CA.

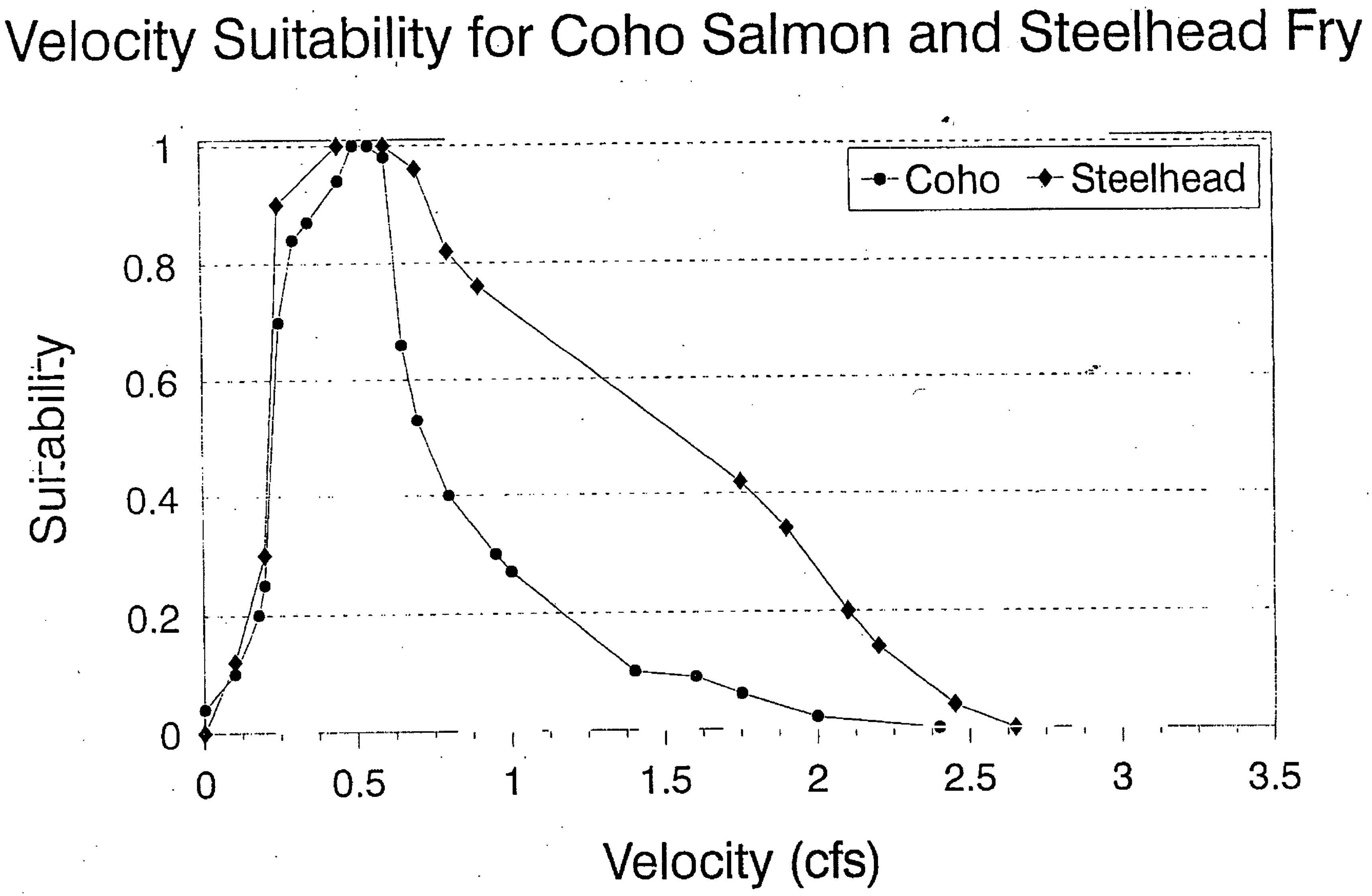


Figure 6. Velocity suitability curves for coho salmon and steelhead fry used in PHABSIM to model fry habitat availbility in Scott Creek, Santa Cruz County, CA.

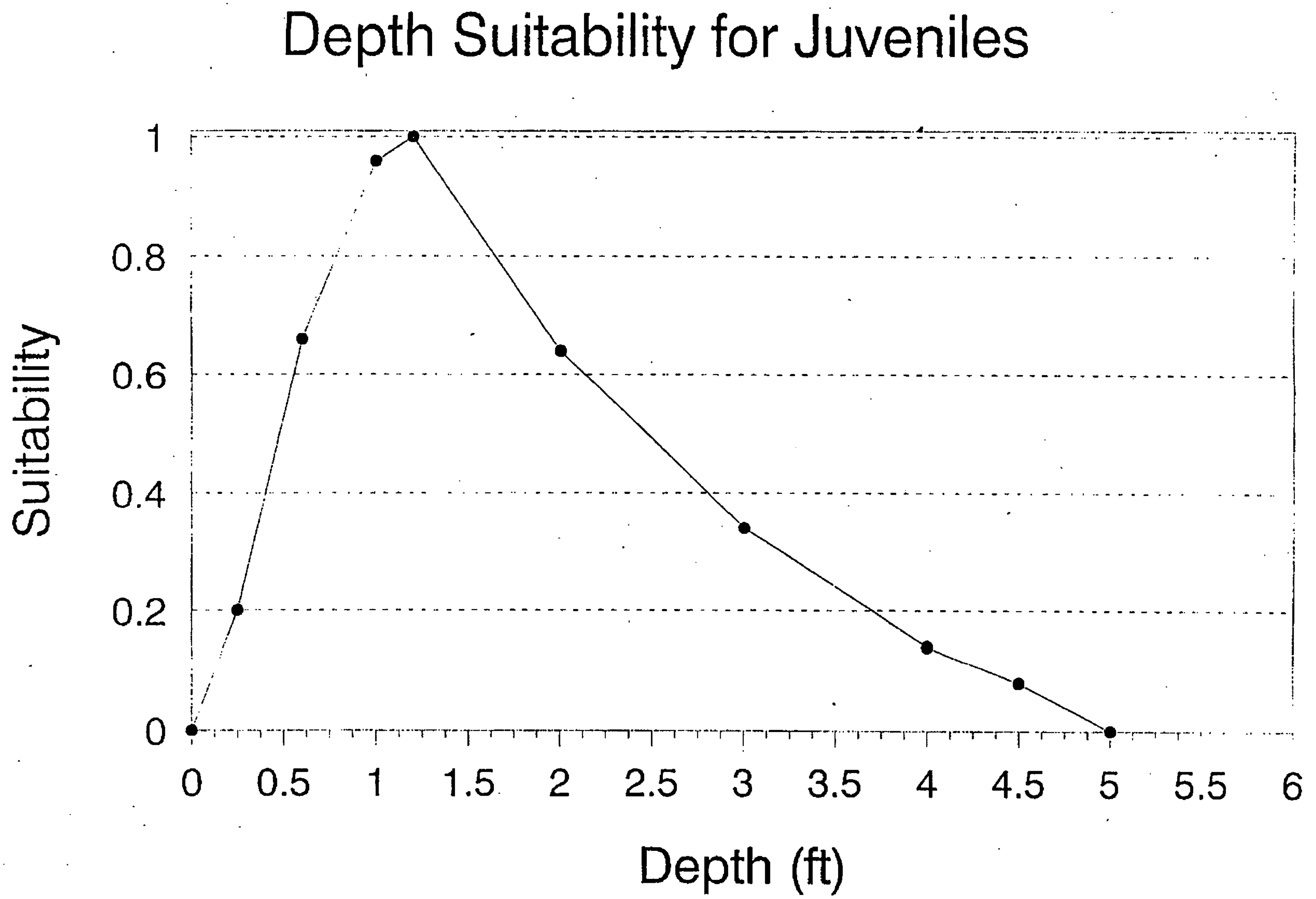


Figure 7. Depth suitability criteria used in PHABSIM to model juvenile coho salmon and steelhead habitat availability in Scott Creek, Santa Cruz County, CA.

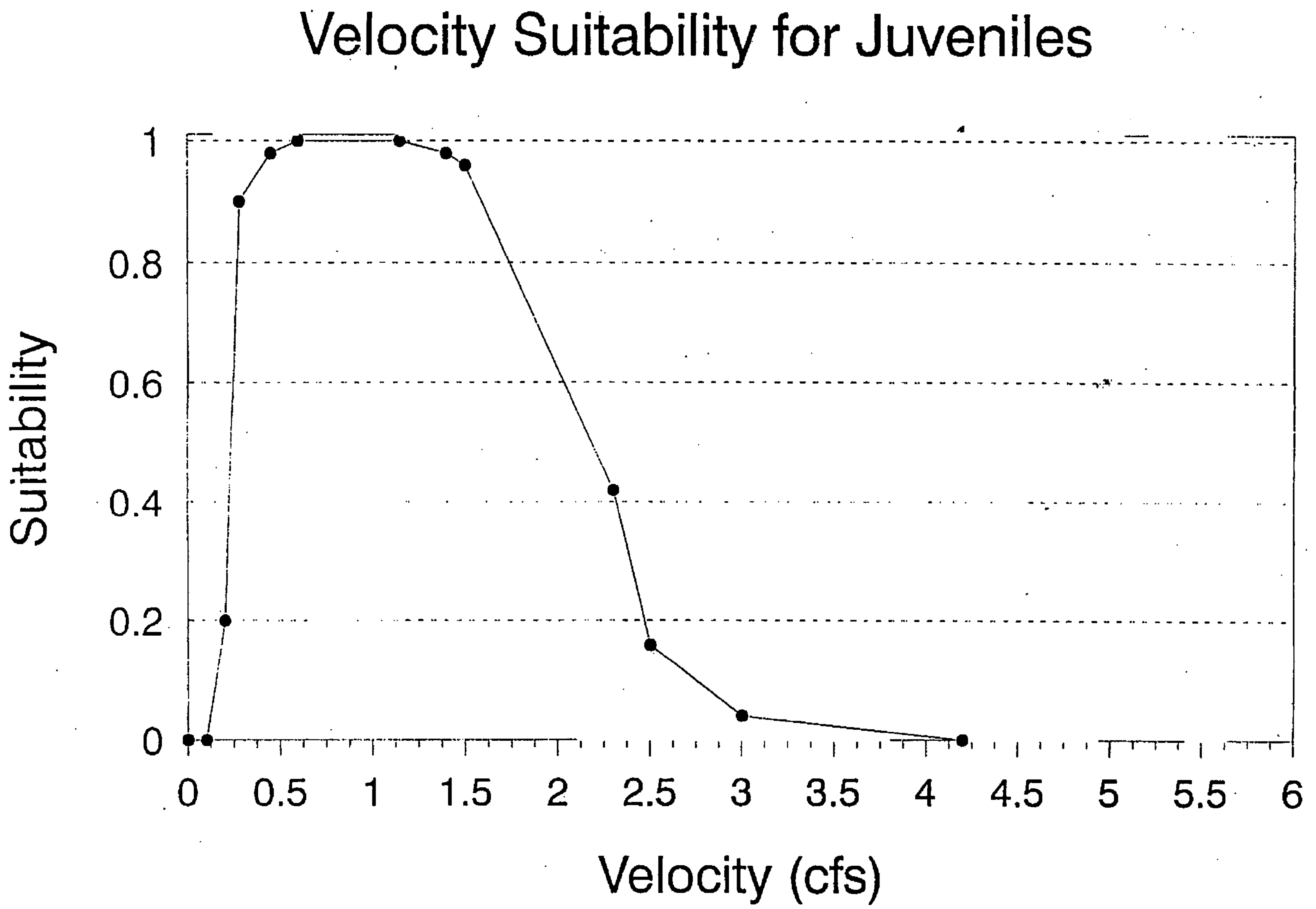


Figure 8. Velocity suitability criteria used in PHABSIM to model juvenile coho salmon and steelhead habitat availability in Scott Creek, Santa Cruz County, CA.

RESULTS

Habitat Availability versus Flow

Coho Salmon

Spawning

The PHABSIM modeling results show that coho salmon spawning habitat curves for all habitats, combined according to the habitat ratios measured by Marston (1992), is maximized between 30-50 cfs, (40 cfs is optimum) and decreases rapidly below 12 cfs (Figure 10). Only about half of the predicted, maximum habitat available for spawning remains at 7-8 cfs.

Coho salmon spawning habitat availability peaks in riffles at 12 cfs and is maximized between 10-18 cfs (Figure 9). Spawning habitat in runs also peaks at 12 cfs and is maximized between 9-14 cfs. However, spawning habitat availability in glides peaks at 40 cfs and is maximized above 35 cfs (Figure 9). There is a precipitous decline in coho salmon spawning habitat in runs and riffles when flows are below 9 cfs. Almost half the habitat available at 9 cfs is lost at 3.5-4 cfs. Essentially no spawning habitat is available in glides or pools at these low flows (< 4 cfs). Typically, there is little spawning in pools due primarily to inappropriate substrate composition. Our results developed without substrate input shows that pools had very little appropriate combinations of depth and velocity at any flow.

Fry

Combining the curves for coho salmon fry in all habitats, according to the ratios in Marston (1992), shows that habitat availability is maximized between 16-25 cfs, and declines rapidly below 10 cfs (Figure 10). Only about half of the maximum, predicted fry habitat availability remains at 5 cfs.

Fry rearing habitat availability in pools peaks at 16-20 cfs and is maximized between 12-25 cfs (Figure 11). It peaks in glides at 20 cfs and is maximized between 18-30 cfs. There is a precipitous drop in fry rearing habitat in both pools and glides when flows are below 10 cfs (Figure 11). Almost half the habitat available at 10 cfs is lost at 4.5-5.25 cfs, and there is very little habitat available in riffles or runs at these low flows. Fry rearing habitat continuously improves in runs with increasing flow, but runs have a smaller proportion of fry habitat at any flow compared to pools and glides (Figure 11). Riffle habitat lacks appropriate combinations of depth and velocity for fry at any flow, with no net improvement above 4 cfs.

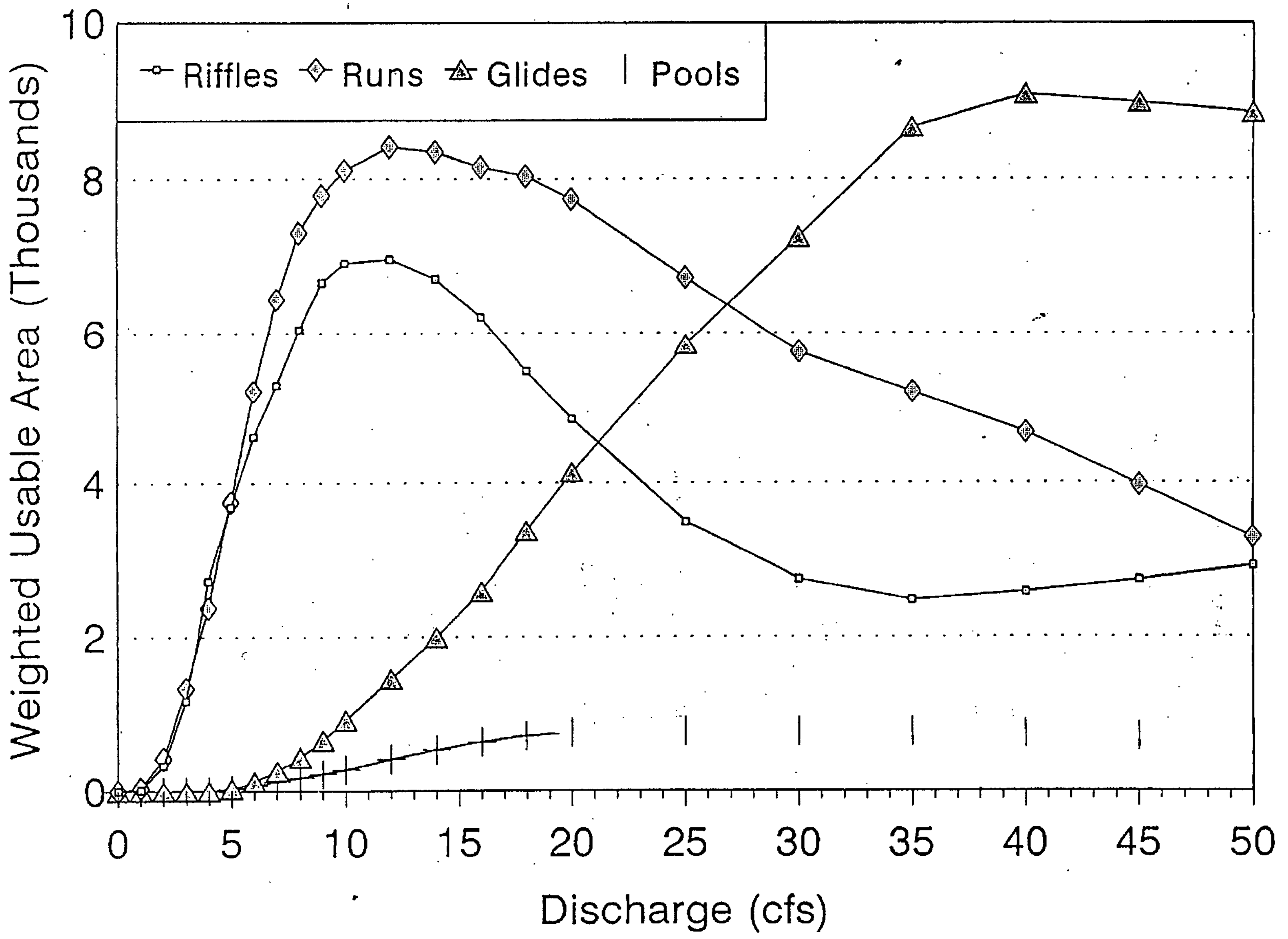


Figure 9. Curves showing the Weighted Usable Area (WUA) for spawning available to coho salmon in each of the four habitat types found in Scott Creek, as predicted by the PHABSIM model HABTAT.

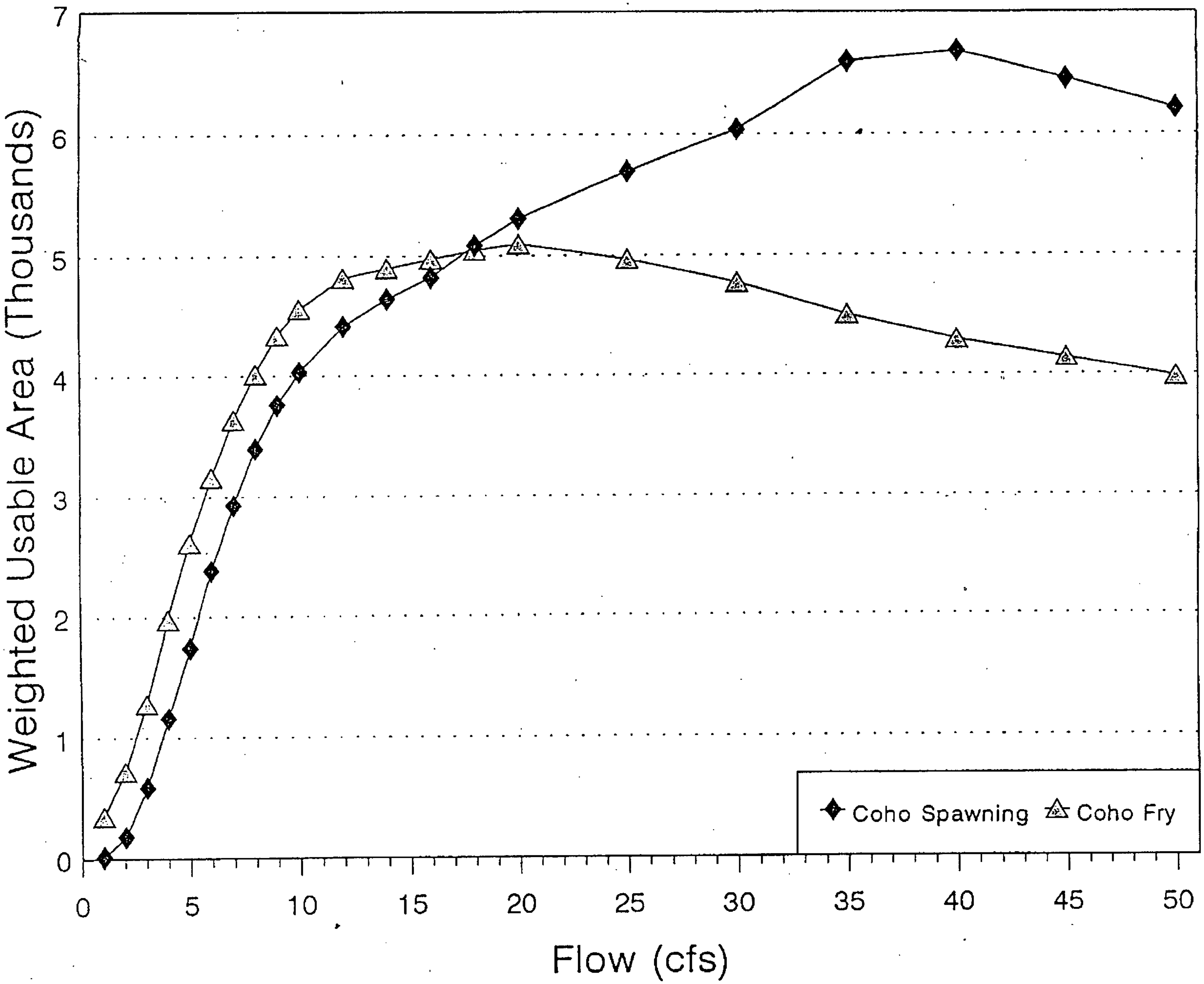


Figure 10. Curves showing the combined Weighted Usable Area (WUA) for spawning and fry life stages available to coho salmon in Scott Creek, as predicted by the PHABSIM model HABTAT, based on the ratio of habitat types measured by Marston (1992).

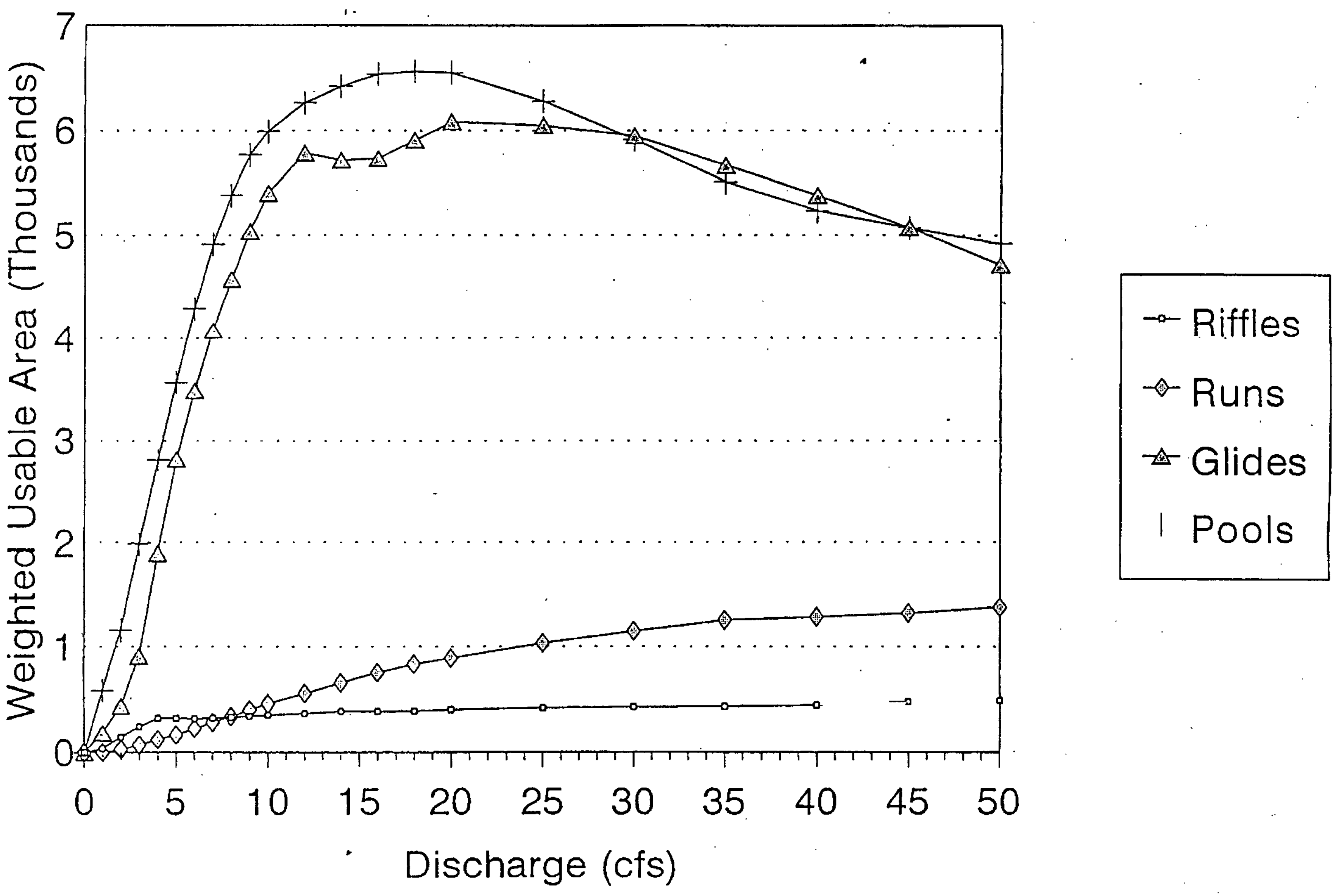


Figure 11. Curves showing the Weighted Usable Area (WUA) for rearing habitat available to coho salmon fry in each of the four habitat types found in Scott Creek, as predicted by the PHABSIM model HABTAT.

Juvenile rearing habitat was not directly modeled due to the lack of suitability curves. Juvenile **steelhead** rearing habitat curves, provided below, are used as a **surrogate for coho salmon juvenile.**

Steelhead

Spawning

The steelhead spawning habitat availability curves combined for all habitats, according to the ratios in Marston (1992), shows spawning habitat availability increases continuously with flow up to the maximum modeled flow, 50 cfs (Figure 13). Flows greater than 30 cfs provide ≥50% of predicted potential spawning habitat; target spawning flows should be above these levels.

Steelhead spawning habitat availability peaks at 40 cfs in runs and is maximized at flows above 25 cfs (Figure 12). Spawning habitat in riffles peaks at 25 cfs and is maximized at flows between 20-35 cfs. There is a gradual decline in spawning habitat in runs and riffles below 20 cfs. Less than half of the maximum habitat available (at 20-35 cfs) in runs and riffles remains at 13-16 cfs, and it declines to near zero at 5 cfs (Figure 12). Sufficient depths and velocities for spawning do not occur in glides until flows exceed 20 cfs, but spawning habitat availability increases rapidly above 20 cfs. As with coho salmon, little spawning habitat is typically available in pools due to poor substrate composition. Pools provided very little suitable spawning habitat at any of the modeled flows due to a lack of appropriate combinations of depth and velocity. Essentially no spawning habitat was available in pools below 20 cfs.

Fry

Steelhead fry habitat curves for all habitats combined according to the ratios in Marston (1992) shows fry habitat is maximized between 8-14 cfs, and diminishes rapidly below 7 cfs (Figure 13). Only about half of the maximum predicted fry habitat is available at 2 cfs.

Steelhead fry rearing habitat peaks in runs at 12 cfs, is maximized between 10-16 cfs, and decreases rapidly below 7 cfs (Figure 14). Fry habitat in glides peaks at 10 cfs, is maximized between 5-12 cfs, and decreases rapidly below 4 cfs. In riffles, it peaks at 4 cfs, is maximized between 3-6 cfs and decreases rapidly below 3 cfs. However, it is only slightly reduced at flows between 7 and 14 cfs and remains a fairly constant proportion of total linear habitat at higher flows Only about half of the maximum fry habitat remains in glides, runs, and riffles when flows are reduced to 1-3 cfs. Fry habitat in pools is maximized after 4-6 cfs, and does not change much in availability thereafter (Figure 14). Pools have less fry habitat at any flow than the other habitat types.

Juvenile

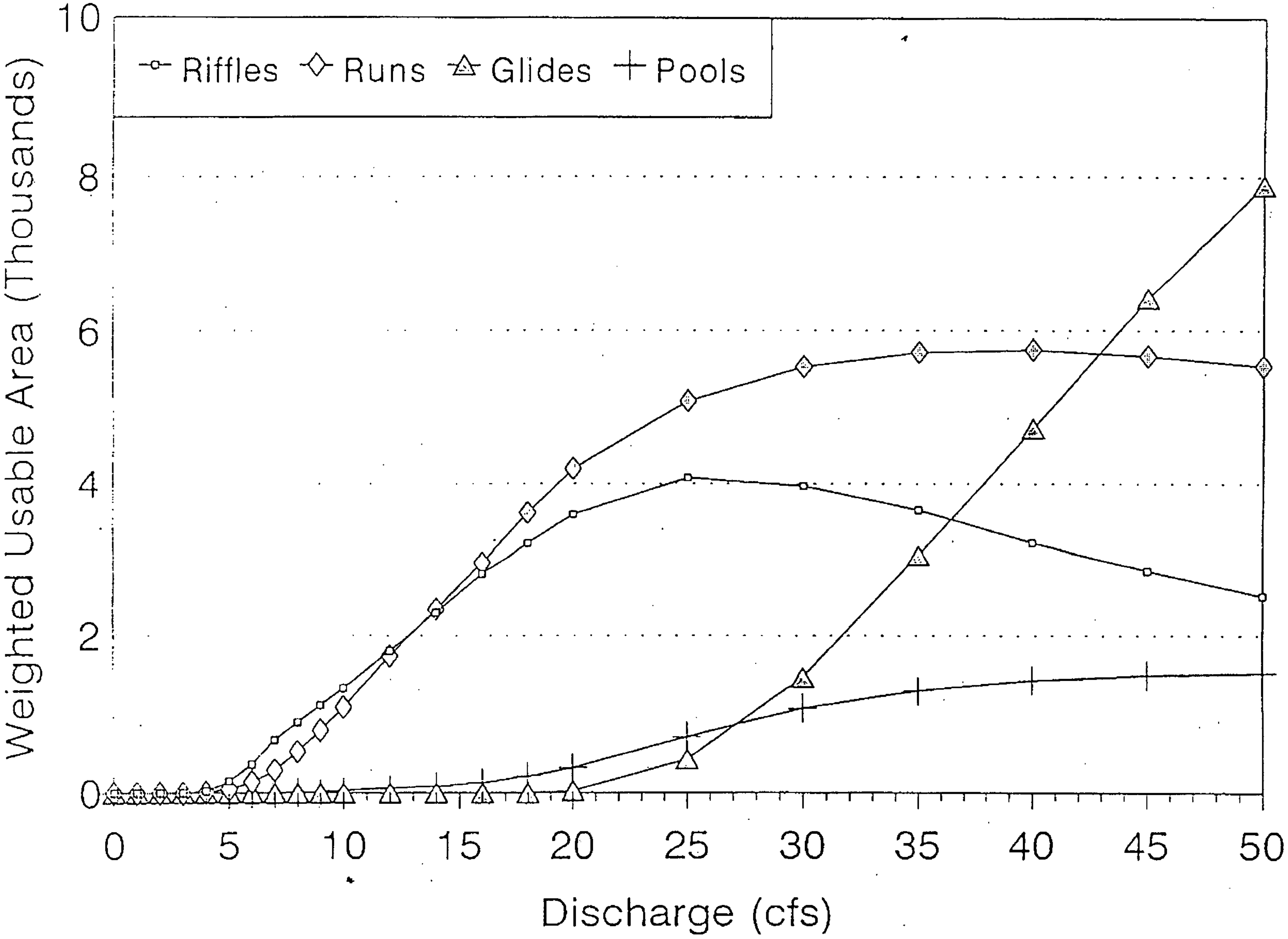
Steelhead juvenile habitat curves for all habitat types combined according to the ratios in Marston (1992) shows juvenile steelhead habitat availability is maximized between 18-35 cfs, and diminishes rapidly below 8 cfs (Figure 15). Only about half of the maximum predicted juvenile habitat remains at 5-6 cfs.

Steelhead juvenile habitat in glides peaks at 25-30 cfs, and is maximized between 20-40 cfs (Figure 15). Juvenile habitat in runs peaks at 16 cfs, and is maximized between 12-25 cfs. In riffles it peaks at 12 cfs and is maximized between 8-25 cfs. Juvenile habitat in pools is maximized above 12-16 cfs, but does not increase much above 16 cfs. Available juvenile habitat in all four macro-habitat types starts to decline at 10 cfs, and is reduced by about half when flows drop to between 2.5 and 5.5 cfs.

Natural Flow Patterns

It is necessary to consider unimpaired flow patterns when using PHABSIM habitat availability curves to set flow recommendations for target species and life stages. Unimpaired flow in the Scott Creek drainage is often less than the flow levels predicted to maximize habitat for each life stage of steelhead and coho salmon (Figures 16 and 17). Mean daily flows remain above minimal levels (>10 cfs) from mid-November through mid-June. Critically low flows (≤2 cfs) occur from late August through early October. Late October through early November, and mid-July through mid-August are transitional periods when flow transitions between very low and moderate levels.

Monthly exceedence curves were developed for March through December to further evaluate flow availability (Figures 18-29). Critically low flows (≤2 cfs) can occur a significant fraction of the time (>25%) as early as July (Figure 24). These critically low flows become relatively common (>50% occurrence) by August (Figure 25), in spite of mean flows remaining above 2 cfs through most of the month (Figure 17). This means that just maintaining suboptimal flows (≤10 cfs) for coho salmon and steelhead fry, and juvenile steelhead may require unimpaired flow conditions (no diversion) in some years from mid-June through early November.



[illegible] showing the Weighted Usable Area (WUA) for spawning available to steelhead in each of the four habitat types found in Scott Creek, as predicted by the PHABSIM model HABTAT.

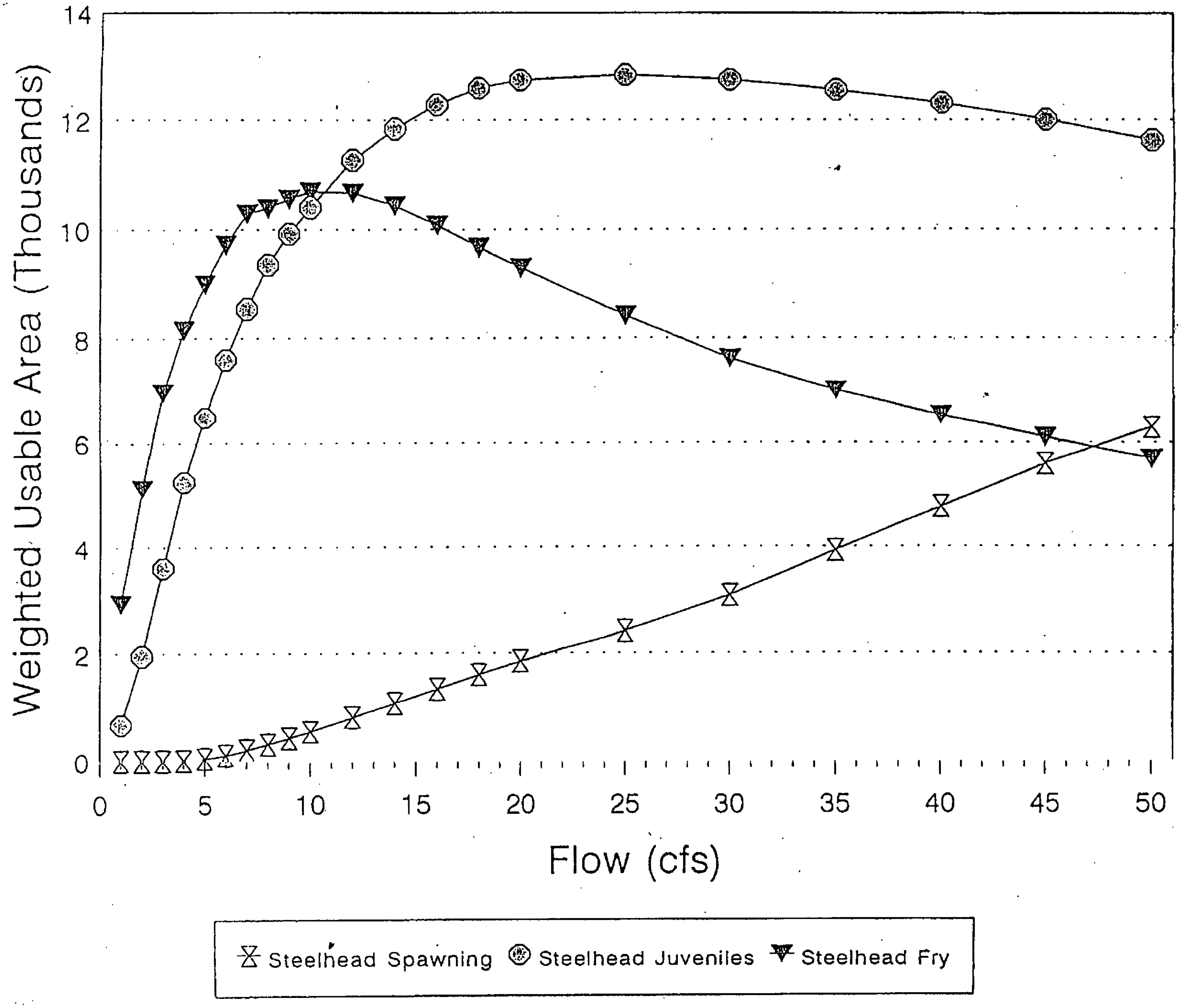


Figure 13. Curves showing the combined Weighted Usable Area (WUA) for spawning, fry, and juvenile life stages available to steelhead in Scott Creek, as predicted by the PHABSIM model HABTAT, based on the ratio of habitat types measured by Marston (1992).

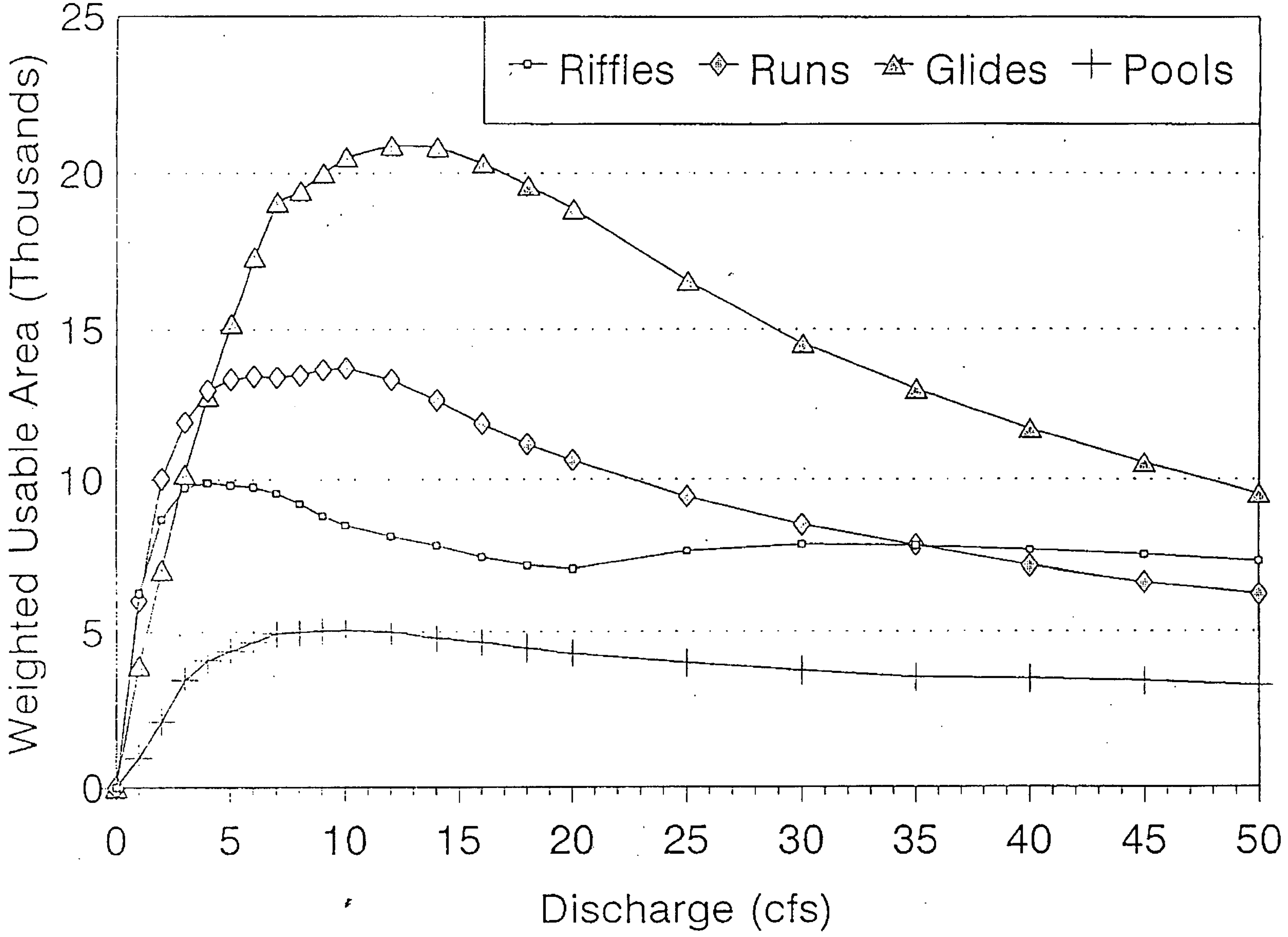


Figure 14. Curves showing the Weighted Usable Area (WUA) for rearing available to steelhead fry in each of the four habitat types found in Scott Creek, as predicted by the PHABSIM model HABTAT.

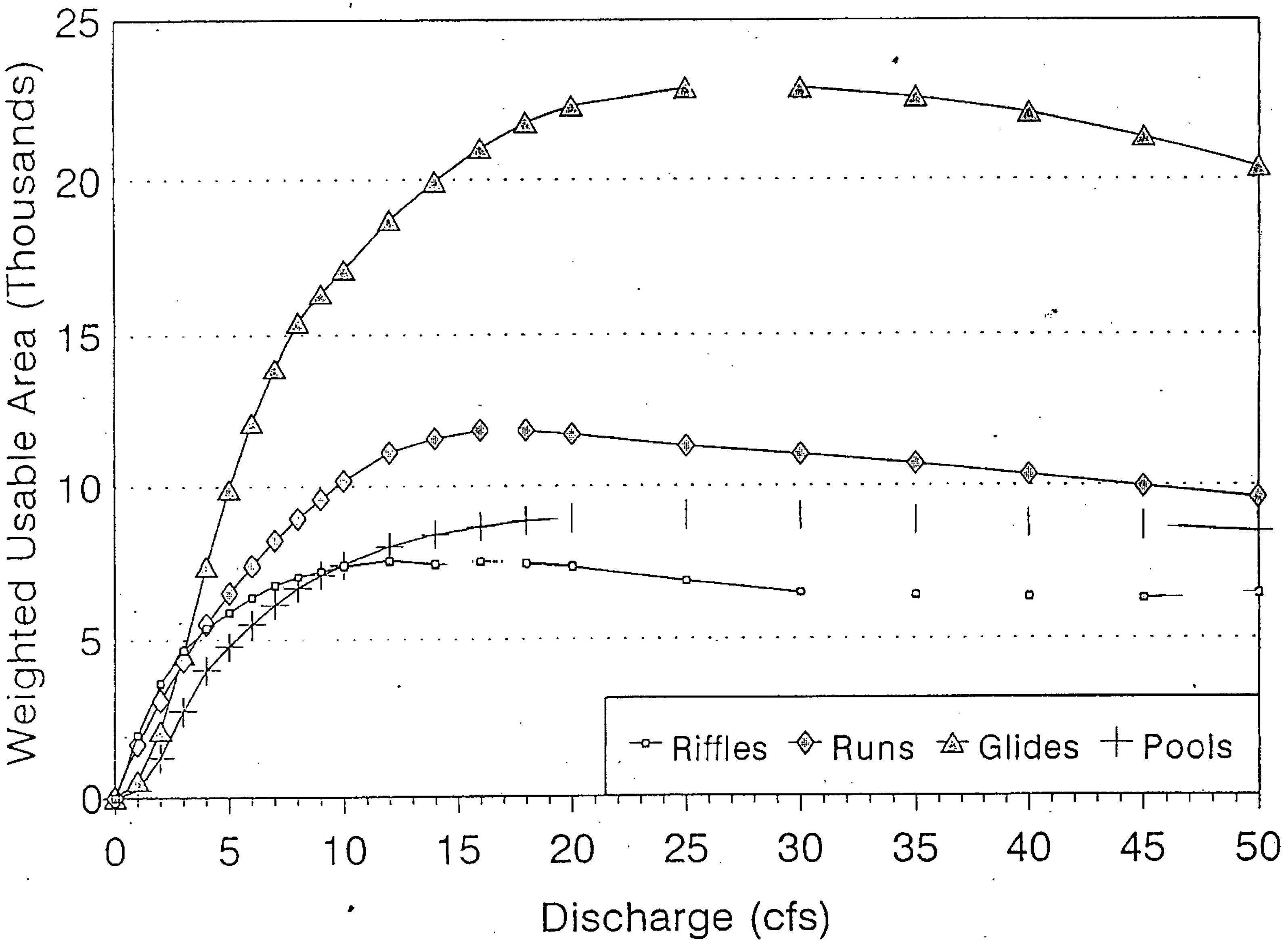


Figure 15. Curves showing the Weighted Usable Area (WUA) for rearing available to steelhead juveniles in each of the four habitat types found in Scott Creek, as predicted by the PHABSIM model HABTAT.

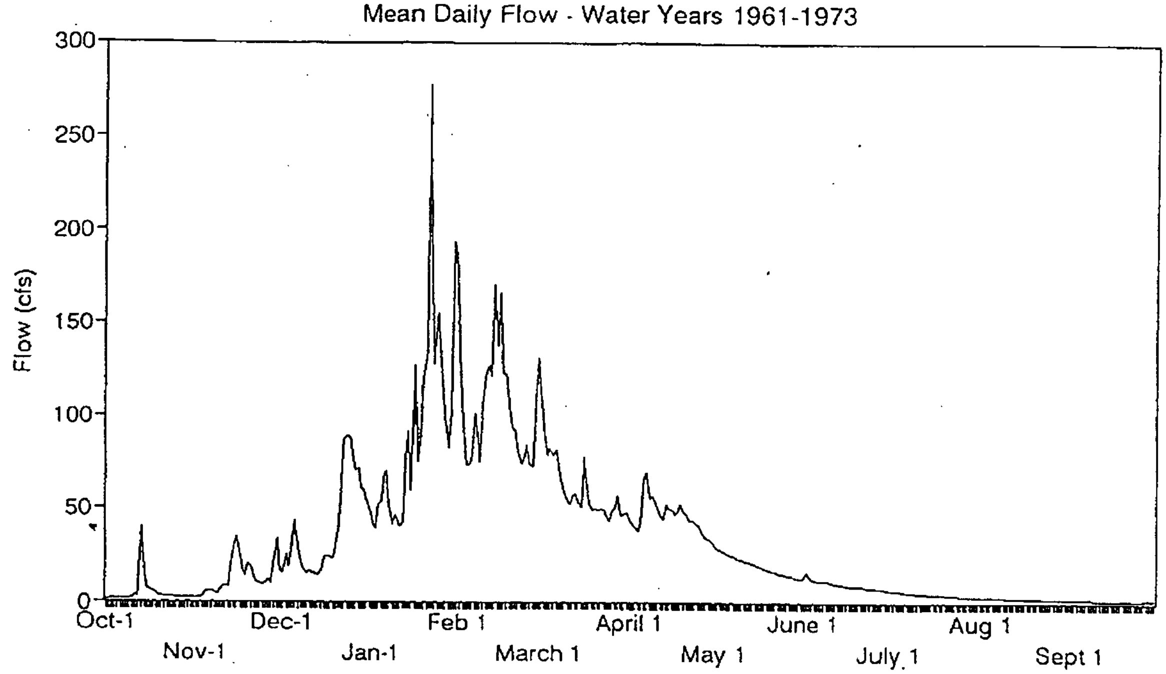


Figure 16. Mean daily flow in Scott Creek, Santa Cruz County, CA, measured at USGS gage.

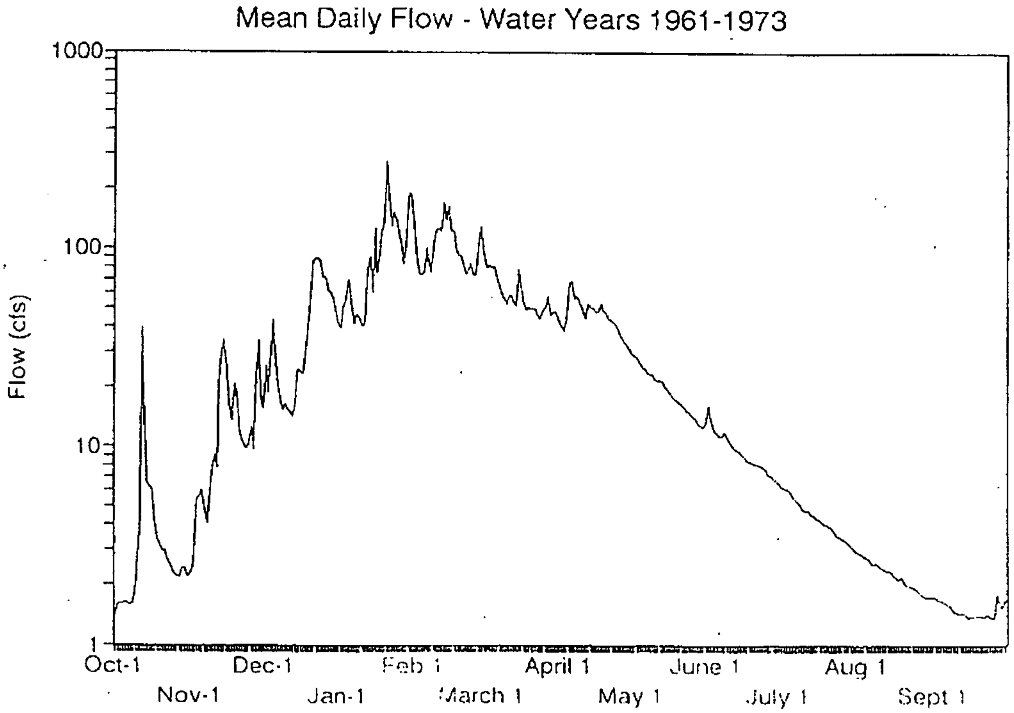


Figure 17. Mean daily flow (1961-1973) in Scott Creek, Santa Cruz County, CA, measured at US plotted on log scale.

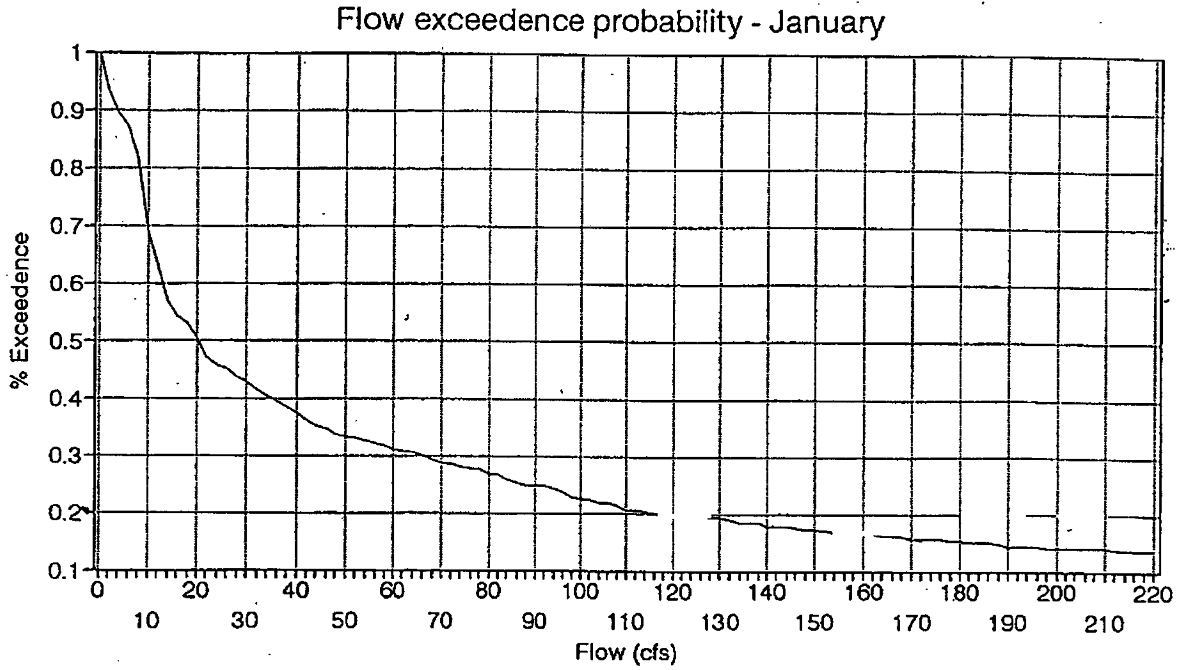


Figure 18. Flow exceedence probabilities (%) during water years 1961 - 1973 for January in Scott Creek, Santa Cruz County, CA.

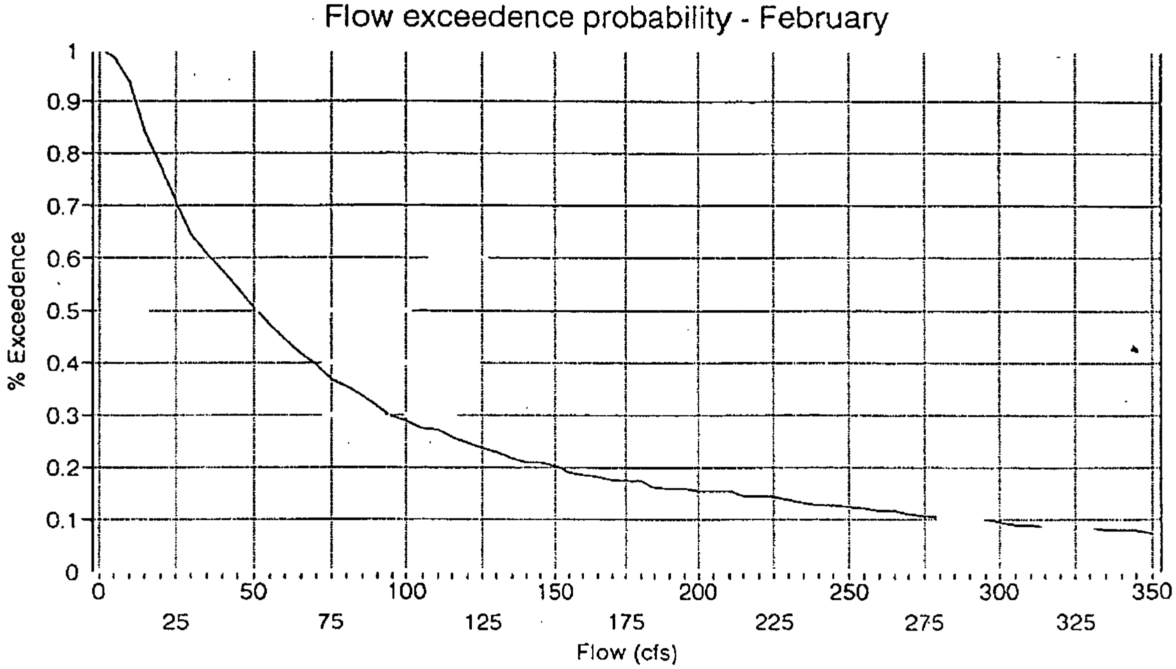


Figure 19. Flow exceedence probabilities (%) during water years 1961 - 1973 for February in Scott Creek, Santa Cruz County, CA.

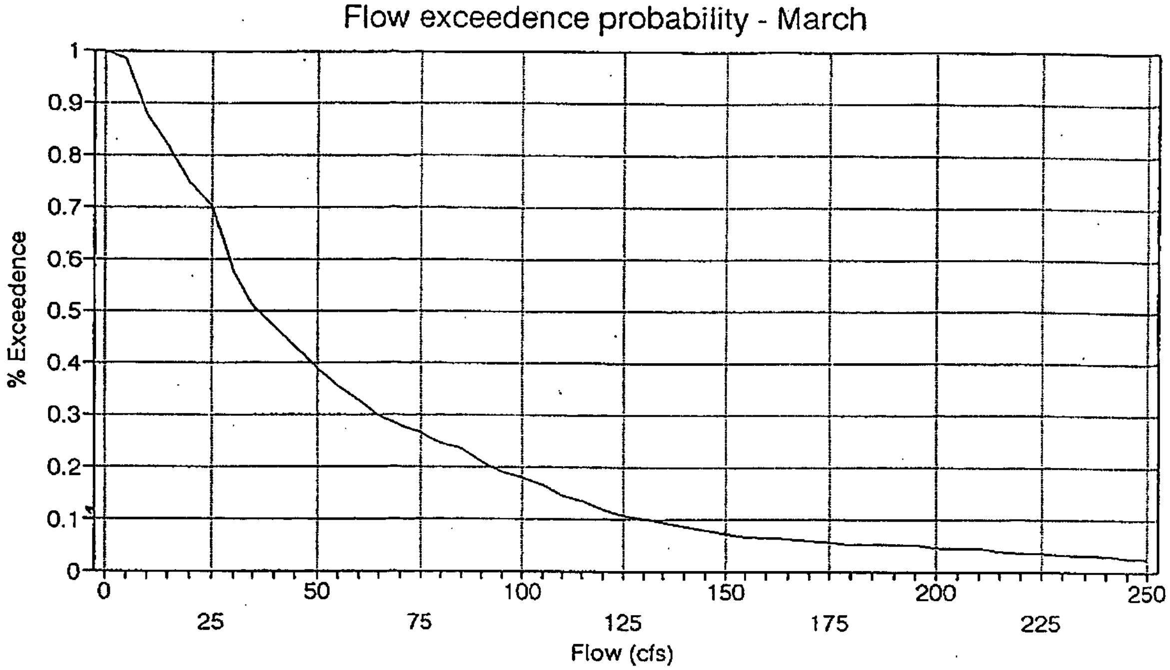


Figure 20. Flow exceedence probabilities (%) during water years 1961 - 1973 for March in Scott Creek, Santa Cruz County, CA.

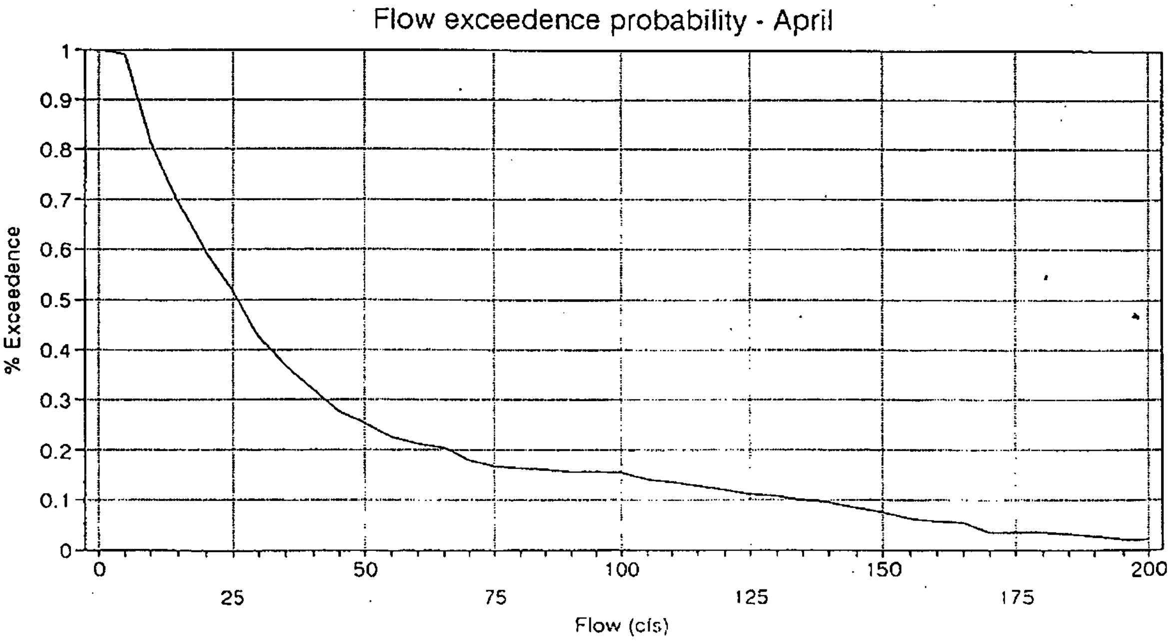


Figure 21. Flow exceedence probabilities (%) during water years 1961 - 1973 for April in Scott Creek, Santa Cruz County, CA.

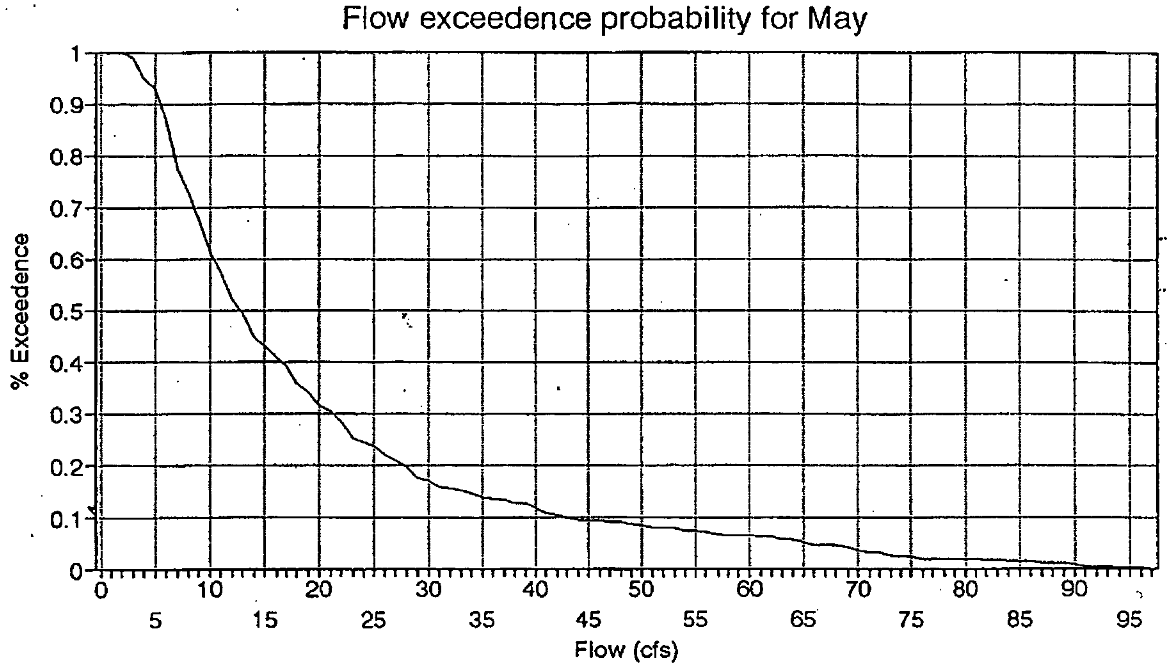


Figure 22. Flow exceedence probabilities (%) during water years 1961 - 1973 for May in Scott Creek, Santa Cruz County, CA.

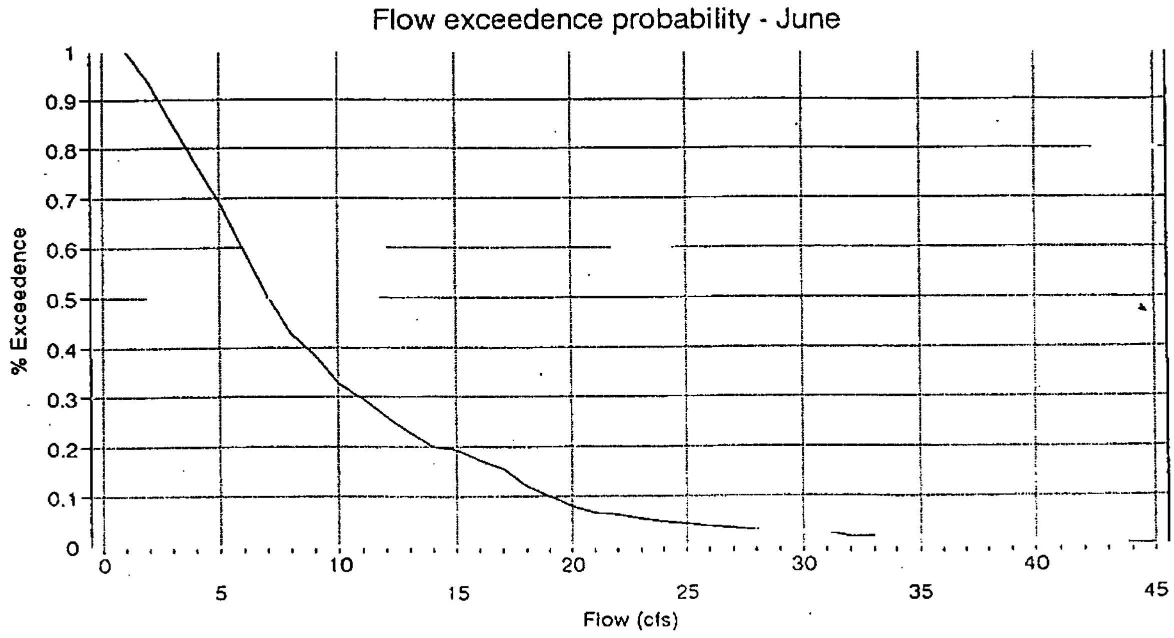


Figure 23. Flow exceedence probabilities (%) during water years 1961 - 1973 for June in Scott Creek, Santa Cruz County, CA.

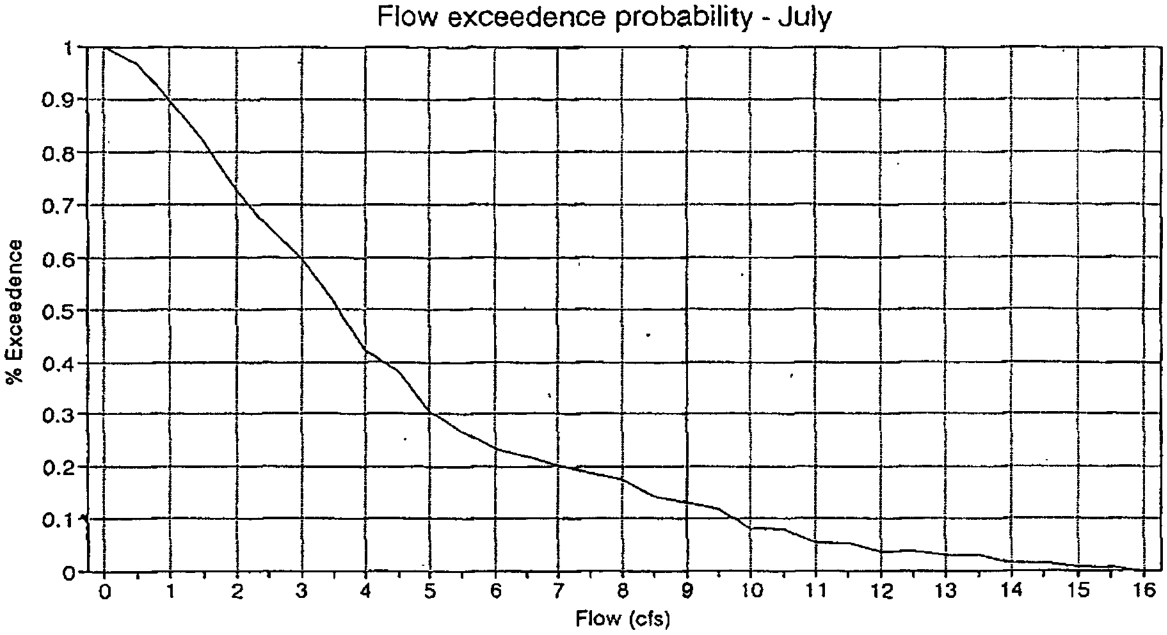


Figure 24. Flow exceedence probabilities (%) during water years 1961 - 1973 for July in Scott Creek, Santa Cruz County, CA.

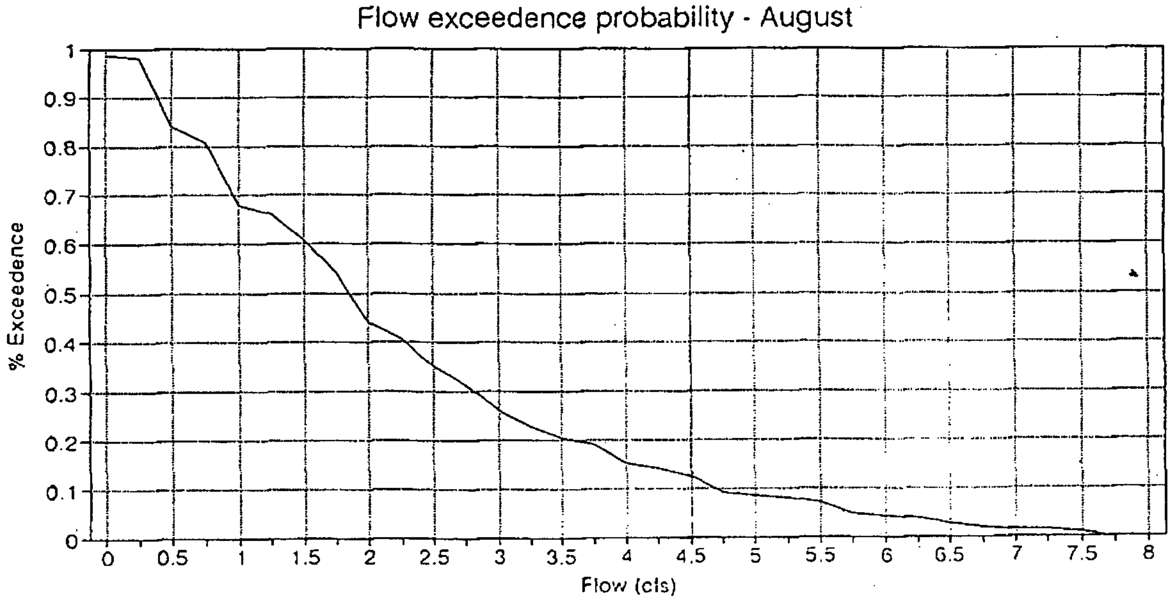


Figure 25. Flow exceedence probabilities (%) during water years 1961 - 1973 for August in Scott Creek, Santa Cruz County, CA.

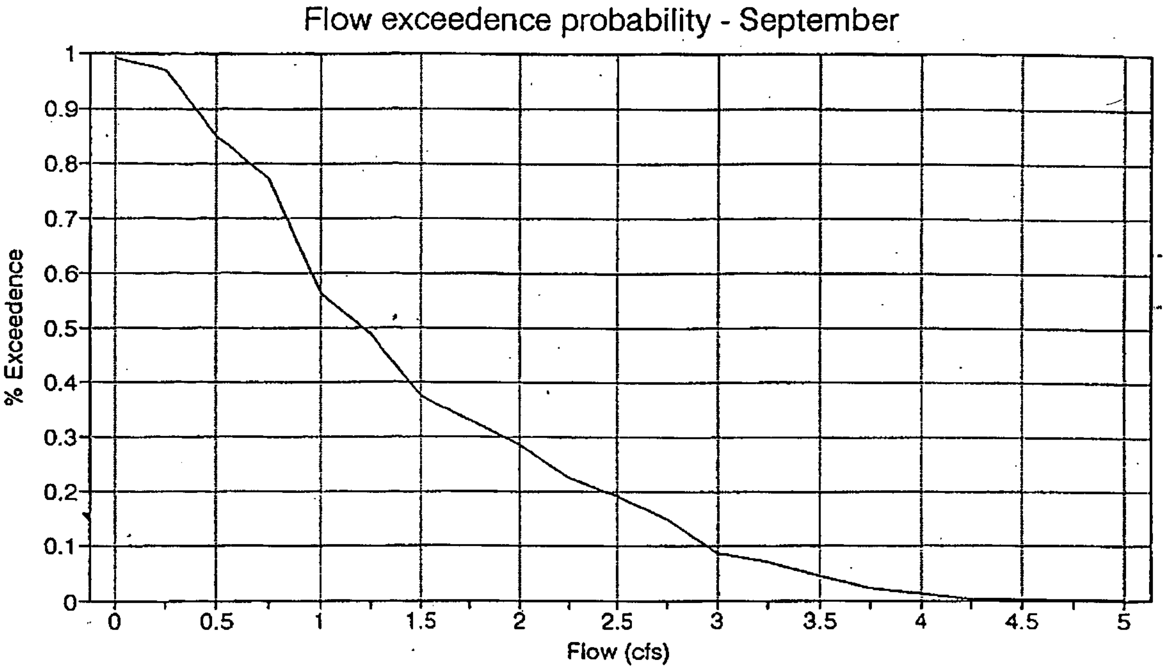


Figure 26. Flow exceedence probabilities (%) during water years 1961 - 1973 for September in Scott Creek, Santa Cruz County, CA.

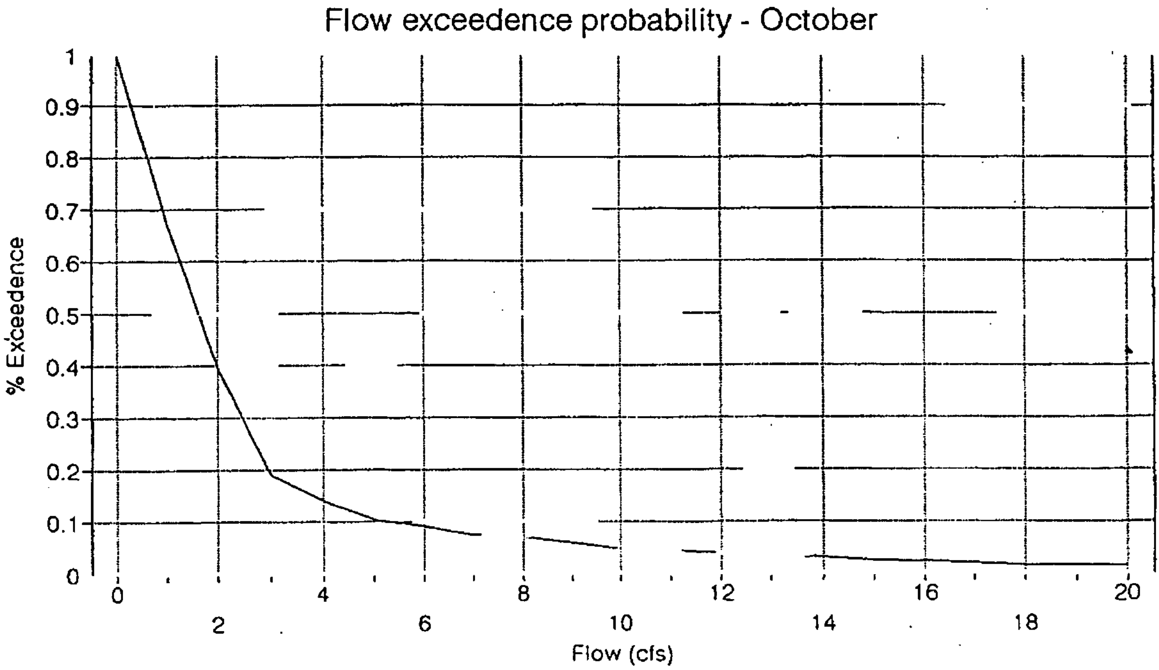


Figure 27. Flow exceedence probabilities (%) during water years 1961 - 1973 for October in Scott Creek, Santa Cruz County, CA.

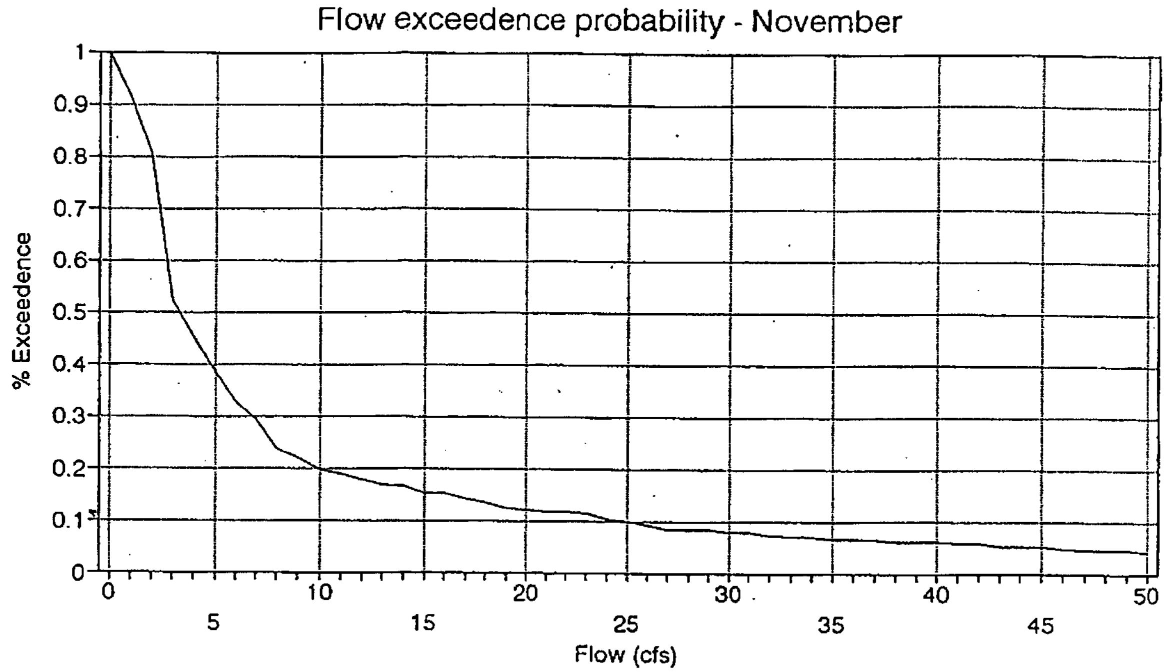


Figure 28. Flow exceedence probabilities (%) during water years 1961 - 1973 for November in Scott Creek, Santa Cruz County, CA.

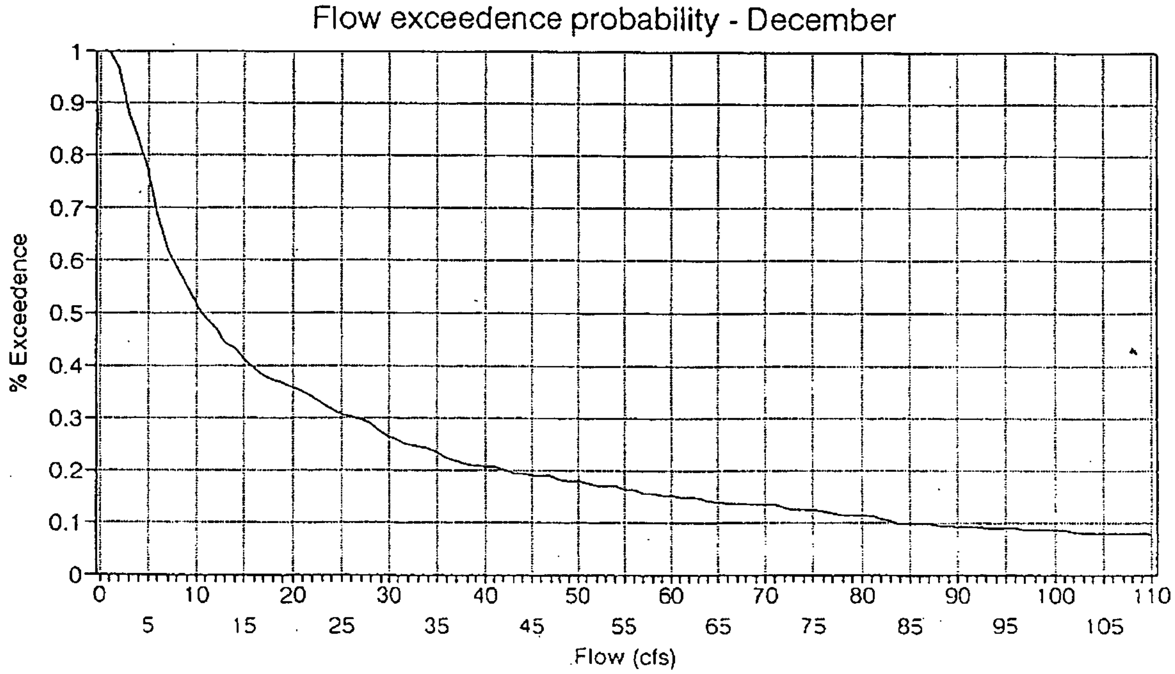


Figure 29. Flow exceedence probabilities (%) during water years 1961 - 1973 for December in Scott Creek, Santa Cruz County, CA.

DISCUSSION

Timing and Feasibility of Flows to Optimize Habitat for Coho Salmon and Steelhead Trout

Coho Salmon Spawning

Coho salmon spawning in Scott Creek can take place anywhere from late-November through mid-March (Table 3) but typically occurs from mid-December through February. Coho salmon spawning habitat availability is maximized at flows above 30 cfs (40 cfs is optimum), and rapidly decreases below 12 cfs. As such, the preferred flow during the coho spawning period (November 21 through March 15) should be 40 cfs; the minimum flow should be 12 cfs.

Based upon flow exceedence data for water years 1961 through 1973, minimum spawning flow conditions (12 cfs) are not likely to occur until December, but preferred flow conditions are generally available January through April. In November, flows rarely exceed preferred (40 cfs) and only occasionally exceed minimum (20% of the time); marginal flows (7-8 cfs) are exceeded only 20-30% of the time (Figure 28). In December, marginal spawning flows are exceeded more than 50% of the time and minimum flow conditions occurred more than 40% of the time; preferred flow occurred less than 30% of the time (Figure 29). From January into April, mean flows exceed 40 cfs, and preferred spawning flow conditions could be achieved even with existing levels of diversion.

Coho Salmon Fry

Coho fry may appear in the Scott Creek as early as January and on through May. Coho salmon fry habitat availability is optimum at 20 cfs, while flows below 10 cfs rapidly deplete habitat availability for fry.

Optimum flow can easily be accommodated with existing levels of diversion through April (Figure 21). In May these flows will only be available approximately 30% of the time; minimum flows (10 cfs) are likely to occur more than 60% of the time (Figure 22). In June 10 cfs flows will likely occur less than 35% of the time, though marginal flows (> 5 cfs) are likely to occur nearly 70% of the time (Figure 23).

Coho Salmon Juveniles

Coho salmon juveniles occur in Scott Creek year-round, and may remain in fresh water up to two years before smolting and migrating to the ocean. No

TABLE 3. Life stage periodicity for coho salmon and steelhead in Scott Creek, Santa Cruz County.

Life stage	January	February	March	April	May	June	July	August	September	October	November	December
Coho spawning	■	■	◧								◨	■
Coho fry	■	■	■	■	■							
Coho juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Steelhead spawning	■	■	■	■	■						◨	■
Steelhead fry	■	■	■	■	■	■	■					
Steelhead juvenile	■	■	■	■	■	■	■	■	■	■	■	■

microhabitat criteria were available for juvenile coho salmon; we therefore assumed it appropriate to use juvenile steelhead criteria, discussed below.

Steelhead Spawning

Steelhead spawning in Scott Creek may occur as early as November and extend through May. Flows greater than 50 cfs are needed to optimize steelhead spawning.

Optimum conditions rarely occur during December when flows above 30 cfs are expected to occur less than 30% of the time (Figure 29). Even without any diversion, adequate flows for spawning are not likely to occur in most years until the last half of December or in January (Figure 19). By January, however, mean flows exceed 40 cfs, and suitable spawning habitat could be provided even with existing levels of diversion. Average flows exceed 40 cfs through April.

Steelhead Fry

Steelhead fry may occur in Scott Creek as early as January and as late as July. Flows of 10 cfs optimize steelhead fry habitat, while flows below 7 cfs rapidly deplete the habitat available for this life stage.

Optimum fry flows can easily be accommodated with existing levels of diversion through early May (Figure 19). However, in May optimum flows have occurred only 45% of the time Flows of 7 cfs are likely to occur more than 75% of the time (Figure 22). In June flows of 7 cfs are likely to occur about 50% of the time, though marginal flows of at least 2 cfs are likely to occur more than 90% of the time (Figure 23).

Steelhead Juveniles

Steelhead juveniles occur in Scott Creek year round, and may remain in fresh water three to four years before smolting and migrating to the ocean. Optimum coho and steelhead juvenile habitat conditions are provided at 20 cfs, while juvenile habitat availability is rapidly depleted as flow falls below 8 cfs, and only half of the maximum WUA remains at 5-6 cfs. Juvenile conditions are necessary year-round, however unimpeded flow conditions from June through October are so low that they maximize habitat for the juvenile life stage less than 10% of the time. Marginal flow conditions (5-8 cfs) are uncommon in July, August, and October, and almost non-existent in September.

RECOMMENDATIONS

Flow recommendations are based upon PHABSIM model results, unimpaired flow exceedence data, and the timing of various steelhead and coho salmon life stages in Scott Creek, as discussed in the previous section. Critical life stages were defined to prioritize flow allocation when life stage occurrence overlapped and optimum flow requirements conflicted. The critical life stage flow requirements were then compared, by month, with potential flow availability to identify flow conditions that could be reasonably expected to accommodate that life stage's needs. Critical life stages were defined as spawning during the late November through April period, fry during May and juvenile the remainder of the year (Table 4). The following summarizes the results of this approach.

Spawning Flow Recommendations

Minimum flows of 12 cfs are recommended for December and 40 cfs from January through March before any diversion can occur. Flow requirements are reduced to 25 cfs in April to attempt to optimize steelhead spawning habitat availability relative to expected, lower flow conditions; flows below 20 cfs would only provide minimal steelhead spawning habitat.

Fry Rearing Flow Requirements

Spawning flow requirements were used to define flows needed during most of the fry rearing period (through April). Fry flow requirements were prioritized to define flow conditions required during May. We recommend minimum flows of 10 cfs in May before any diversion occurs in order to reasonably maximize rearing habitat for steelhead fry in Scott Creek relative to flow availability.

Juvenile Rearing Flow Requirements

Flow minimums previously recommended for other life stages will meet the needs of juvenile steelhead and coho salmon from January through April. Previous recommendations for minimum flows in November, December, and May will provide marginally adequate habitat for juvenile life stages. Since flows greater than 5-6 cfs are needed, but can rarely be achieved from June through October with unimpaired flow conditions, our recommendation is for no diversions to occur unless flow exceeds 6 cfs. Therefore, during these low flow periods, all flow needs to be allocated to the maintenance of juvenile steelhead and coho salmon habitat.

In any month where unimpaired natural flows do not meet the minimum flow requirements, run-of-the-river, unimpeded natural flows should be maintained.

TABLE 4 Summary of flow recommendations by month for Scott Creek anadromous fish resources based upon critical life stage requirements and flow availability.

Month	Target Species/life stage[1]	Optimum Flow	50% exceedence flow[2]	Recommended Flow
January	Coho spawning	40	> 40	40
	Steelhead spawning	≥ 50		
February	Coho spawning	40	>40	40
	Steelhead spawning	≥ 50		
March	Coho spawning	40	~40	40
	Steelhead spawning	≥ 50		
April	Steelhead spawning	≥ 50	~30	25
May	Coho fry	20	13	10
	Steelhead fry	10		
June	Coho juvenile	20	7	6
	Steelhead juvenile	20		
July	Coho juvenile	20	3.5	6
	Steelhead juvenile	20		
August	Coho juvenile	20	1.8	6
	Steelhead juvenile	20		
September	Coho juvenile	20	1.5	6
	Steelhead juvenile	20		
October	Coho juvenile	20	2	6
	Steelhead juvenile	20		
November	Coho juvenile	40	~5	8
December	Coho spawning	40	~12	12

[1] Life stage considered most critical during the month and used as basis for determining required flow conditions.

[2] Flow exceeded at least 50% of the time during the base flow period, 1961-1973.

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Appendix 1. Substrate codes used to type the substrates along each transect for potential use in the PHABSIM model HABTAT.

Code	Substrate catagory description	Size class (inches)
1	Organic debris	-
2	Clay	<0.002
3	Silt	<0.002
4	Sand	0.002-0.100
5	Course sand	0.10-0.25
6	Small gravel	0.25-1
7	Medium gravel	1-2
8	Large gravel	2-3
9	Small cobble	3-6
10	medium cobble	6-9
11	Large cobble	9-12
12	Small boulder	12-24
13	Medium boulder	24-79
14	Large boulder	>79
15	Bedrock (hardpan/clay)	-

Appendix 2. Cover codes used to type and size the object (instream) or overhead cover along each transect for potential use in the PHABSIM model HABTAT.

Cover type (instream-object or overhead)		Cover size (for each type identified other than "0")	
Type code	Type description	Size code	Size class (inches)
0	No cover	1	<6
1	Boulders	2	6-12
2	Submerged logs or woody debris	3	>12
3	Overhanging vegetation[1/]		
4	Undercut banks		
5	Root wads		
6	Aquatic vegetation		
7	Turbidity		
8	Water depth (>3 ft)		
9	Surface turbulence		

[1/] The vegetation must be immediately above the water's surface providing shade and visual screeneing; vegetative canopy does not qualify.