AVAILABLE HABITAT FOR SALMON AND STEELHEAD TROUT IN THE LOWER PUYALLUP, WHITE, AND CARBON RIVERS IN WESTERN WASHINGTON

By S. S. Embrey

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Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
square foot (ft^2)	0.09294	square meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Instream Flow Incremental Methodology was used to determine available habitat for anadromous fish in 1984 and 1985 in the lower Puyallup, White, and Carbon Rivers in western Washington. Computer simulated stream discharge-habitat relations were used to identify maximum habitat and corresponding discharge for different life stages and species of fish. Habitat available during median discharge for each month that a particular fish is present in the river at a study site was identified. These habitat areas at median discharges were averaged for the period of time the fish was present at a site, and were used to rank the six sites from greatest average habitat through least average habitat.

For adult steelhead trout, maximum habitat determined from simulated discharge-habitat curves ranged from 15,000 ft^2/1,000 ft (square feet per 1,000 feet of stream) at a simulated discharge of 600 ft^3/s (cubic feet per second) to 2,300 ft^2/1,000 ft at 250 ft^3/s. For adult chinook salmon, maximum habitat ranged from 8,400 ft^2/1,000 ft at a discharge of 16,000 ft^3/s to 4 ft^2/1,000 ft at 2,800 ft^3/s. Maximum habitat for spawning ranged from to 34,700 ft^2/1,000 ft for chinook salmon at a discharge of 1,200 ft^3/s to 4,100 ft^2/1,000 ft for pink and chum salmon at 1,500 ft^3/s. Maximum habitat for the rearing life stages ranged from 85,900 ft^2/1,000 ft for juvenile salmon at a discharge of 390 ft^3/s to 14,400 ft^2/1,000 ft for juvenile salmon at 3,200 ft^3/s. In some instances, simulated discharges associated with maximum habitat are exceeded less than 10 percent of the time at these sites.

Habitat at median discharges generally was larger for steelhead trout juveniles and fry and for salmon juveniles than for other life stages. The least amount of available habitat at all six sites was for adult chinook salmon. There was no available habitat for adult chinook salmon in the White River near Auburn and Carbon River near Orting at the median discharges for the months of July through November. At median discharges, habitat for spawning was greater for chinook salmon than for other species in the Puyallup River near Orting, the Puyallup River at Alderton, the White River near Dieringer, and the Carbon River. In the White River near Auburn, more habitat was available for chum salmon spawning than for other species. The least amount of available spawning habitat was for coho salmon in the Puyallup River at Alderton and in the Carbon River. In the White River near Dieringer, there was less spawning habitat for chum salmon than for other species, and in the White River near Auburn, there was less habitat for chinook salmon.

On the basis of average habitat associated with median discharges for the period a fish is present in the rivers, the Puyallup River near Puyallup ranked number 1 in habitat for adult steelhead trout and Puyallup River at Alderton ranked number 1 in habitat for adult chinook salmon. Habitat for adult chinook salmon was absent at median discharges in the Carbon River and in the White River near Auburn. The White River near Auburn ranked number 1 for the rearing of steelhead trout fry, steelhead trout juveniles, and juvenile chinook and coho salmon. Puyallup River near Orting ranked number 1 in average habitat for chinook spawning and pink salmon spawning. White River near Auburn ranked number 1 in spawning habitat for steelhead trout, coho salmon, and chum salmon. The Carbon River near Orting site generally ranked fifth or sixth as having the least average habitat available for all species and life stages except steelhead trout fry and chinook spawning.

On the basis of fish-preference criteria, the abundance of sand in the streambed composition limits habitat for spawning in the Puyallup River near Puyallup. In the Carbon River, velocities exceeding 1.5 feet per second appear to limit habitat for juvenile life stages and velocities greater than 3.0 feet per second limit habitat for adult and spawning life stages. The habitat for adult chinook salmon at all the study sites was limited by depths less than 4.0 feet; however, habitat was limited also by velocities exceeding 3.0 feet per second at large discharges having water depths greater than 4.0 feet.

INTRODUCTION

The lower Puyallup River and its two largest tributaries, the White and Carbon Rivers, flow through a region where much of the land adjacent to these rivers and in their flood plains is developed. Present types of development include single family homes, mobile homes on individual lots, mobile-home parks, cultivated land and farm buildings, and some commercial buildings.

Inundation of developed property along some reaches of these rivers appears to some land owners to occur more frequently than in the past. It has been suggested that either the flood-carrying capacity of the channels has been reduced, possibly due to sediment aggradation in river channel bottoms between raised levees or banks, or that the hydraulic roughness of the channels has increased due to bushes and trees growing on the channel sides.

Pierce County Public Works Department, through the Pierce County River Improvement and Inter-County River Improvement agencies, is responsible for maintaining levees, banks, and river channels in the lower Puyallup River basin. Typical maintenance consists of repairing levees and riprapped banks to maintain their structural integrity, and attempting to maintain the flood-carrying capacities of the channels by removing tops of gravel bars and by cutting trees and bushes from stream banks. Several groups, including the Puyallup and Muckleshoot Indian Tribes, the State of Washington Department of Wildlife and the Department of Fisheries, and the U.S. Fish and Wildlife Service, wishing to maintain suitable habitat in the rivers for the migration, spawning, and rearing of salmon and steelhead trout, have expressed concern regarding some of these channel-maintenance activities. An overall study of the lower Puyallup River basin was begun because of apparent conflict between the needs for flood protection and preservation of fish habitat.

Purpose and Scope

In 1983, Pierce County Public Works Department began discussions to study the lower Puyallup River basin. The purpose of the study was to investigate ways for maintaining and improving flood protection along the lower Puyallup, White, and Carbon Rivers and yet protect and enhance the habitat in these rivers for the migration, spawning, and rearing of salmon and steelhead trout. Investigations began in June 1984 with parts to be done by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the Pierce County Public Works Department, giving due consideration to the advice of fish-habitat specialists from the fisheries groups with interests in the Puyallup River basin (Prych, 1987).

The purpose of this report is to assess the available habitat for salmon and steelhead trout in the lower Puyallup, White, and Carbon River channels under current conditions. The assessment was made on the basis of information collected by the U.S. Geological Survey during one phase of the study of the lower Puyallup River basin. During 1984 and 1985, stream-discharge data and descriptions of substrate composition were collected at each of six study sites to determine habitat area. Data-collection sites were located in three segments of the Puyallup River, two segments of the White River, and one segment of the Carbon River. Discussions of habitat are approached in two

ways: (1) a maximum available habitat for each species and life stage was identified from the computer-simulated relations between stream discharge and habitat and is referred to as maximum habitat, and (2) the available habitat for each species and life stage was calculated for the median discharges of the months when the fish is actually present in the river at a study site.

Description of the Study Area and Fishery

The Puyallup River basin (fig. 1), most of which lies within Pierce County in western Washington, drains an area of about 1,000 square miles and includes about 1,280 miles of rivers and streams (Williams and others, 1975). The boundaries of the study area extend to approximately RM (river mile) 26 of the Puyallup River, RM 8 of the White River, and RM 6 of the Carbon River and include a total of six habitat study sites (see table below). The Puyallup, White, and Carbon Rivers originate at glaciers on the slopes of Mount Rainier and flow generally west and north to Puget Sound. More than half of the mean annual precipitation of 37 to 59 inches per year falls from October through February when rainfall runoff and snowmelt occasionally cause flooding (Prych, 1987). In summer, glacial meltwater and ground water are the principal sources of river discharge. Turbidity of the river water from glacial-flour or silt is typical from late spring to early fall and prohibits observations or documentation of certain fish life stages or activities in these rivers.

Study site	Site and segment number	Segment location (River Mile)	Approximate site location (River Mile)	Number of cross sections
Puyallup River near Puyallup	1	6.0 to 10.4	7	5
Puyallup River at Alderton	2	10.4 to 17.9	14	8
Puyallup River near Orting	3	17.9 to 26.0	20	12
White River near Dieringer	4	0.0 to 3.5	3	6
White River near Auburn	5	3.5 to 8.0	5	7
Carbon River near Orting	6	0.0 to 5.9	2	7

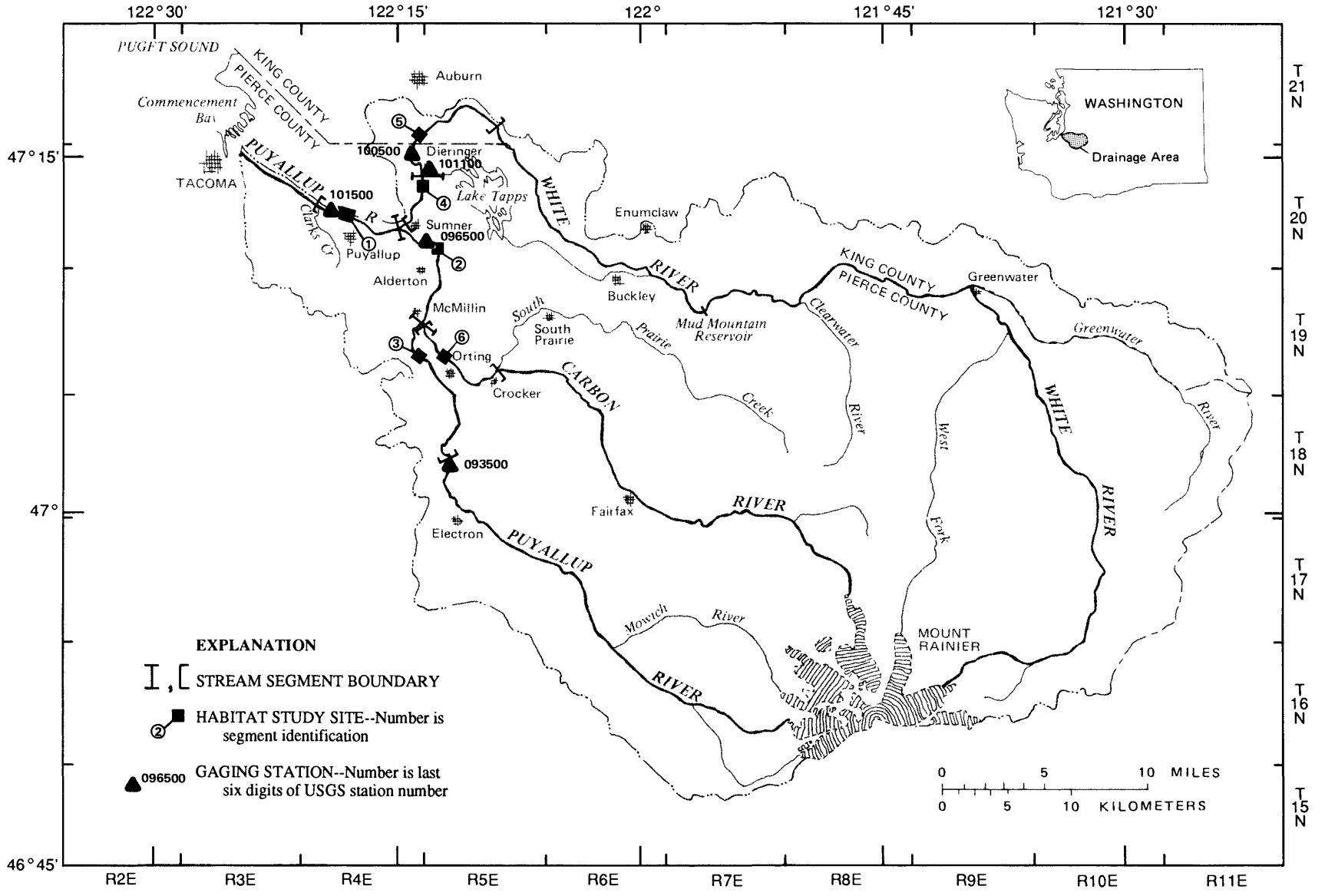


Figure 1.--Puyallup River basin showing location of study area and selected stream-gaging stations.

Flood-protection levees stabilized by rock riprap form the banks on one or both sides of the rivers along most of the study reaches. Widths between the levees or banks range from greater than 1,000 feet to less than 150 feet. Along most of the Puyallup River and the White River downstream from Auburn, streamflow is confined within a relatively narrow space between levees or banks. In the upper reaches of the study area, widths between levees and banks are sufficiently wide that the low-flow river channel is braided or meanders between the levees.

In general, the bottoms of the study rivers are predominantly gravel and cobble, with boulder-sized riprap or deposits of sand along some stream edges. Gravel bars are abundant in the Carbon River study segment, the Puyallup River upstream from the White River, and the White River upstream from the Lake Tapps inflow near Dieringer. Vegetation on most of the streambanks and levees is large enough in places to form some overhanging protective cover for fish, particularly in the segment of the White River downstream from the Lake Tapps inflow and the Puyallup River at Alderton.

The rivers and streams of the Puyallup River basin provide migration, spawning, and rearing habitat for four species of Pacific salmon--coho (Oncorhynchus kisutch), pink (O. gorbuscha), chum (O. keta), and two subspecies or races of chinook (O. tshawytscha)--and two subspecies of steelhead trout (Salmo gairdneri). Downstream from its confluence with the White River, the Puyallup River provides some spawning for pink and chum salmon to about RM 6 near the mouth of Clark's Creek. It is not known if this segment is used for spawning by other salmon species or steelhead trout; however, it does provide for the migration and rearing of all the salmon and steelhead trout species that utilize the upstream reaches of the Puyallup River basin. Vegetation on the banks and levees provides some overhanging protection for fish. Deposits of sand are common along the banks and cover much of the stream bottom downstream from Clark's Creek where the river is affected by tides in Puget Sound. From the mouth of the White River upstream to the study area boundary, the Puyallup River flows in a pool-riffle-run pattern between confining levees. The many gravel bars are composed of medium to large gravels and some small cobbles. This segment provides habitat for migration, spawning, and rearing for all four salmon species and winter steelhead trout. It is unknown if spring chinook spawn in this segment, or if summer steelhead spawn in the segment between the mouth of the White River and the mouth of the Carbon River.

The 3.5-mile segment of the White River, from its confluence with the Puyallup River to the Lake Tapps inflow near Dieringer, flows through a relatively narrow and straight channel between levees. Overhanging vegetation grows along both levees throughout this segment. Streambed material is mostly gravel and small cobble with sand deposits along the stream edges. Upstream of the inflow near Dieringer, the White River meanders through a wider channel with numerous gravel bars. The White River provides habitat for the migration, spawning, and rearing of all four salmon species and steelhead trout including the subspecies or races.

Carbon River, between its confluence with the Puyallup River and the mouth of South Prairie Creek, is similar to the White River upstream from the Lake Tapps inflow in channel configuration and streambed material. The channel is braided in some parts of this segment, and the river generally flows in a

pool-riffle pattern. Numerous bars are composed of gravels and small to large cobbles. All four salmon species and winter steelhead use the Carbon River for migration, spawning, and rearing. It is unknown if summer steelhead or spring chinook spawn in this segment.

Salmon and steelhead that are native to the Puyallup River basin or are raised in the basin's hatcheries are caught by commercial and sport fishermen throughout Puget Sound and the Pacific Ocean. From 1978 to 1985, an annual average of 206,000 wild or hatchery-produced salmon and steelhead from the Puyallup River basin were counted by fisheries biologists at trap locations or caught by commercial and sport fishermen in Puget Sound (Washington Department of Fisheries, written commun., 1986). Of these 206,000 fish, an average of about 59,000 salmon and steelhead were commercially caught by the area's Indian Tribes within Commencement Bay or in the Puyallup River. On the basis of general market values ranging from about $1.75 per fish (pink salmon) to $20.00 or more per fish (steelhead trout and chinook salmon) (J. Miyamoto, Puyallup Tribe of Indians, written commun., 1986), the average annual catch represented approximately $430,000 income to the Tribes.

Coho salmon, the most numerous fish of the anadromous species in the catch, averaged about 45,000 fish during this period, with annual catches ranging from about 26,000 to 70,000 fish. Commercially, coho salmon made up about 75 percent or about $320,000 of the average annual tribal income from the fishery. Considering only odd-numbered years from 1978 through 1985, pink salmon numbered second to coho in the catches, averaging about 6,500 fish and ranging from 1,500 to 21,000 fish. Monetarily, the most valuable species to the fisherman on a dollar-per-pound basis (about $2.00) are steelhead trout and chinook salmon. The numbers of winter steelhead trout and chinook salmon in the catches averaged 2,000 and 2,100 fish, respectively. Annual catches ranged from about 200 to 6,000 steelhead (J. Miyamoto, Puyallup Tribe of Indians, written commun., 1986) and from about 700 to 5,500 chinook. Chum salmon catches were similar to the numbers of steelhead trout catches, averaging about 1,700 fish and ranging from 100 to 6,200 fish.

Other Studies

Studies by D. W. Chapman Consultants, Inc., begun in 1980, have determined the instream-flow requirements for steelhead trout, and coho, chinook, sockeye, pink, and chum salmon in the White River, Washington, and have developed streamflow hydrographs for this river (Chapman, 1981 and 1984). Other studies of fish habitat include a study of the White River begun about 1985 by Hosey and Associates (Phil Hilgert, Hosey and Associates, oral commun., 1985) and a study of the lower Puyallup River basin by the University of Washington (Pauley and others, 1989).

Acknowledgments

The following agencies provided suggestions and technical assistance: the Puyallup Tribe of Indians, the Muckleshoot Indian Tribe, the State of Washington Department of Fisheries, and the State of Washington Department of Wildlife.

METHODS

The techniques of Instream Flow Incremental Methodology (IFIM) and the computer programs of the Physical Habitat Simulation system (PHABSIM) developed by the U.S. Fish and Wildlife Service (Bovee, 1978 and 1982) were used in this study to estimate the habitat available to salmon and steelhead trout in the lower Puyallup, White, and Carbon Rivers. In IFIM, fish habitat is defined as the streambed area over which water depth, water velocity, and substrate particle size are within the ranges preferred by fish.

Instream Flow Incremental Methodology

IFIM for the investigation of fish habitat is expressed in an assemblage of computer programs named PHABSIM, for the Physical Habitat Simulation system (Milhous and others, 1984). The programs are used to determine fish habitat available over a range of stream discharges at study sites within selected reaches of a river. The necessary data for the programs, including water depths and velocities, and streambed composition, are collected at specific cross sections at study sites. The PHABSIM programs used in this study are the WSP (Water Surface Profile) program (also known as IFG-2) and the HABTAT program. The WSP program is a hydraulic simulation model that uses the concept of mass balance (continuity) and energy balance between a succession of channel cross sections to simulate water depths and velocities at each of the cross sections that represent a study site. The data required to calibrate the WSP model are obtained from one or more measurements of water-surface elevation, stream discharge, water depths, and velocities at each cross section. The model develops relations among these measured parameters to simulate the hydraulic characteristics in individual cells (verticals in the cross section) of each cross section for a particular discharge.

The HABTAT program compares the biological preferences of fish to the physical habitat available in the stream. The fish preferences applied in this study are the specific water depths, velocities, and sizes of substrate material or protective cover that are preferred by different species during different life stages. Fisheries biologists commonly express fish preferences graphically in preference weighting factor curves. The inclusion of protective cover for adult and juvenile fish as a parameter is accomplished using a modification to the substrate preference curves proposed by Hal Beecher (Washington Department of Wildlife, written commun., 1984). Protective cover, which cannot be quantified, has been incorporated by biologists in varying degrees into some of the depth and substrate preference curves. The descriptors of physical habitat are the water depths and velocities simulated by the WSP program and the observed substrate particle sizes and cover types at each site. The comparison of preference-curve values to the physical habitat is made in each cell of each cross section at a study site. The HABTAT program determines habitat amount by summing the weighted streambed areas (areas multiplied by preference factors) over all the cells. These computations are performed for different discharges to produce a continuous relation between discharge and weighted streambed area that is unique to each life stage of individual fish species at a study site.

Data Collection and Compilation

The three rivers included in this study were divided into six segments according to IFIM guidelines (Bovee, 1982). Segments were characterized by similarities in flow quantities; channel pattern, slope, and shape; sediment transport and water quality; fish-passage barriers; and intensity of use by fish. The downstream limit of segment 1, on the Puyallup River, was established at the confluence of Clark's Creek. The division between segments 1 and 2 and between segments 2 and 3 on the Puyallup River were defined by streamflow and slope at the confluences of the White and Carbon Rivers. Segments 4 and 5 on the White River were defined by the Lake Tapps inflow near Dieringer and changes in channel slope. Segment 6 on the Carbon River was defined by the confluence of South Prairie Creek.

A habitat-study site for each segment was randomly selected according to IFIM guidelines from among all possible sites reflecting the similarities within each segment. Each habitat-study site was verified on-site by representatives of State, Federal, and Tribal agencies to typify the stream segment.

Field Procedures

A habitat-study site is a short reach of stream channel in a segment and is described by several cross sections positioned to represent most of the different hydraulic and biologic characteristics of the reach. In this study, the sites were represented by 5 to 12 cross sections. In general, reach length at habitat sites ranged from about 8 to 12 times the channel width as recommended by Bovee (1982). At each study site, the ends of each cross section were marked with long-term reference points, and the locations, dimensions, and elevations of each cross section were documented by transit survey.

Water-surface elevation, total stream discharge, and water depths and velocities were measured at 20 to 40 verticals in each cross section during low, medium, and high stream discharges which approximated the 90-, 50-, and 10-percent exceedence discharges at each site (table 1). These data were used to calibrate the WSP hydraulic model. At habitat-study site 2, Puyallup River at Alderton, depth and velocity data for the largest discharge were obtained at five of the eight cross sections before hazardous conditions on the river forced the termination of measurements. The methods used for these hydraulic measurements followed U.S. Geological Survey's procedures outlined by Rantz and others (1982, Volumes I and II). Substrate particle sizes were estimated once at each habitat cross section using procedures described by Trihey and Wegner (1981).

TABLE 1.--Stream discharge and related characteristics at the six study sites at three different streamflows approximating the 90-, 50-, and 10-percent exceedence discharges estimated for the sites

[Stream discharge is in cubic feet per second; water depth is in feet; water velocity is in feet per second]

Site number	Study site	Low flow	Medium flow	High flow
1	Puyallup River near Puyallup			
	measurement date	10/19/84	12/11/84	6/13/85
	discharge	977	2,290	5,570
	average depth range[1]	1.8 to 3.9	2.1 to 4.6	3.9 to 6.8
	maximum depth[2]	6.8	7.7	11.4
	average velocity range[1]	1.8 to 2.7	3.0 to 4.0	4.7 to 5.3
	maximum velocity[2]	3.14	5.75	7.37
2	Puyallup River at Alderton			
	measurement date	10/04/85	7/11/85	6/08/85
	discharge	583	1,620	6,460
	average depth range[1]	1.3 to 4.2	2.4 to 6.3	4.9 to 8.8[3]
	maximum depth[2]	7.8	13.0	18.5[3]
	average velocity range[1]	1.7 to 3.4	2.9 to 4.5	6.0 to 6.6[3]
	maximum velocity[2]	5.20	6.32	8.71
3	Puyallup River near Orting			
	measurement date	10/10/85	9/04/85	6/11/85
	discharge	184	396	1,090
	average depth range[1]	0.5 to 2.1	0.8 to 2.1	1.4 to 2.6
	maximum depth[2]	4.3	4.7	5.5
	average velocity range[1]	1.0 to 3.3	1.9 to 4.5	3.3 to 6.0
	maximum velocity[2]	5.32	5.84	7.97
4	White River near Dieringer			
	measurement date	10/18/84	1/09/85	5/24/85
	discharge	458	1,610	2,760
	average depth range[1]	1.5 to 2.6	3.0 to 4.1	4.2 to 5.2
	maximum depth[2]	4.7	6.4	7.8
	average velocity range[1]	1.4 to 2.5	3.2 to 4.0	4.1 to 4.7
	maximum velocity[2]	3.72	5.25	6.28
5	White River near Auburn			
	measurement date	7/22/85	10/24/85	5/30/85
	discharge	122	497	749
	average depth range[1]	0.4 to 1.3	0.8 to 1.6	1.3 to 2.2
	maximum depth[2]	2.3	3.4	4.1
	average velocity range[1]	1.0 to 1.5	2.1 to 3.4	2.1 to 2.9
	maximum velocity[2]	4.19	4.72	4.21

TABLE 1.--Stream discharge and related characteristics at the six study sites at three different streamflows approximating the 90-, 50-, and 10-percent exceedence discharges estimated for the sites--continued

Site number	Study site	Low flow	Medium flow	High flow
6	Carbon River near Orting			
	measurement date	10/09/85	7/17/85	6/14/85
	discharge	191	488	1,280
	average depth range[1]	0.8 to 1.4	1.1 to 2.0	1.6 to 2.8
	maximum depth[2]	2.6	3.6	4.4
	average velocity range[1]	1.7 to 4.0	2.2 to 5.8	4.0 to 5.9
	maximum velocity[2]	6.17	9.33	8.89

[1] Cross-sectional averages for the study site.
[2] Maximum for the study site.
[3] For five cross sections.

Habitat Preference

A habitat-preference factor is an expression on a scale of 0 to 1 of the relative degree of preference for a particular combination of substrate sizes and cover, or for water depth or velocity. The preference-factor curves for water depths, velocities, substrate, and cover used in this study (Appendix A) were obtained from a number of sources and were agreed upon for use in this study at a meeting of fisheries biologists on June 3, 1986. Agencies represented at the meeting were the Puyallup Tribe of Indians, the Muckleshoot Indian Tribe, the Washington State Departments of Fisheries and Ecology, and the U.S. Geological Survey.

Each preference curve is unique to individual species and life stages in the Puyallup, White, and Carbon Rivers and represents current understanding of fish behavior and the physical conditions preferred by fish. Adult steelhead trout prefer water depths that are greater than about 2 feet with moderate velocities (between about 1.5 and 2.0 ft/s (feet per second)). Adult chinook salmon prefer deep water (greater than 5.0 feet) with moderate velocities; depths less than 4.0 feet will not support adult chinook. Depths greater than about 1 foot and moderate to slow velocities (less than 2.0 ft/s) provide favorable habitat for juvenile salmon and steelhead trout. For spawning, chinook salmon prefer deeper (between 1.5 and 4.5 feet) and faster (1.5 to 3.5 ft/s) water than the smaller salmon and steelhead trout. The smaller fish prefer depths between about 1.0 and 3.0 feet and velocities between about 1.0 and 3.0 ft/s (see Appendix A).

For the purpose of IFIM studies, substrate is defined as the material that lies on or near the surface of the streambed. Substrate of gravels and cobbles is the primary material in which adult salmon and steelhead trout lay their eggs and the primary habitat for newly hatched fish (alevins).

Preference-factor curves for substrate in Washington State are generated by a three-digit substrate code that expresses the size range of the dominant substrate particles, the size range of subdominant particles, and the percentage of abundance of dominant particles. A description of the substrate-code numbers for particle-size range is given in Appendix B, along with an example of the three-digit code that employs these numbers. The method of incorporating the description of types of cover into the substrate code is also shown in Appendix B.

Water Discharges

Flow-duration values, giving expected values of mean daily discharges that are exceeded for various percentages of the time in each month and for a year, were calculated for each of the six river segments. These flow-duration values calculated for a river segment were then used for the particular habitat study site located in that segment. Different methods were used in calculating the flow-duration values, depending on available stream-discharge data.

For the three segments on the Puyallup River, stream discharge records collected at gaging stations were used for calculating flow-duration values. These stations were: station 12101500 with record for water years 1942 to 1982; station 12096500 with record for water years 1915 to 1927 and 1944 to 1957; and station 12093500 with record for water years 1932 to 1982.

Gaging station 12100500 on the White River, upstream from the Lake Tapps inflow, with record for water years 1945 to 1970 was used to calculate flow-duration values for segment 5 on the White River. To estimate the values in segment 4 on the White River, daily discharges for water years 1944 to 1957 at station 12096500 on the Puyallup River were subtracted from daily discharges at station 12101500 on the Puyallup River; and for water years 1959 to 1970, daily discharges at station 12100500 on the White River were added to daily discharges at station 12101100, the gage located on the Lake Tapps inflow near Dieringer.

Flow-duration values for segment 6 on the Carbon River were estimated by subtracting daily discharges at station 12093500 on the Puyallup River from discharges at station 12096500 on the Puyallup River. The period of record common to these two stations, water years 1945 to 1957, was used for discharge estimation.

SALMON AND STEELHEAD TROUT HABITAT IN THE LOWER PUYALLUP, WHITE, AND CARBON RIVERS

In this section, the available habitat for different species and life stages of salmon and steelhead trout is discussed. Graphs of the simulated stream discharge and habitat relations are shown for each of the six study sites. The data used to generate the discharge-habitat graphs are available in U.S. Geological Survey computer files. Tables of discharge-exceedence statistics for each study site are provided and may be used to relate available habitat for different species and life stages to median discharge (50-percent exceedence) or other exceedence values. Planimetric maps show cross-section locations within each study site reach, and the width of the river and the extent of gravel bars or islands at the time of the low and high flow measurements made during the study. Graphs of two cross sections accompany each planimetric map and show the streambed and water-surface elevations at the time of the three discharge measurements. At the end of this section are charts showing the time of year when different life stages and species are present in the segments of the Puyallup, White, and Carbon Rivers (figs. 16-20, end of section). These charts supplement the discharge-habitat curves.

Puyallup River near Puyallup - Site 1

On the basis of discharge-habitat relations (fig. 2), habitat is generally greater for all the species and life stages of interest (except adult chinook salmon) when stream discharge is less than about 3,000 ft^3/s than it is at larger streamflows. Habitat for adult chinook salmon increases with discharge from about 200 ft^2/1,000 ft (square feet per 1,000 feet of stream) to a maximum of about 7,000 ft^2/1,000 ft at the largest discharge (13,900 ft^3/s) simulated with PHABSIM. Discharges greater than 8,300 ft^3/s in the Puyallup River near Puyallup are exceeded less than 10 percent of the time (table 2).

Habitat available at the median discharges for the months when the particular fish is present at the site tends to be greater for juvenile steelhead trout and salmon than for other species or life stages, ranging from 15,800 to 28,500 ft^2/1,000 ft for steelhead trout and from 16,600 to 23,500 ft^2/1,000 ft for salmon (table 3). The least amount of habitat is available for adult chinook salmon, ranging from 161 ft^2/1,000 ft in July to 558 ft^2/1,000 ft in October. Only two species are known to spawn in this section of the Puyallup River--pink and chum salmon. Habitat area for pink salmon spawning ranges from 3,120 ft^2/1,000 ft in December to 4,120 ft^2/1,000 ft in October and November; for chum salmon, habitat ranges from 1,060 ft^2/1,000 ft in December to 3,020 ft^2/1,000 ft in November.

Cross-sectional averaged water depths ranged from 1.8 to 3.9 feet at low flow and from 3.9 to 6.8 feet at high flow (see table 1). Cross-sectional averaged velocities ranged from 1.8 to 2.7 ft/s at low flow and from 4.7 to 5.3 ft/s at high flow. According to preference criteria (Appendix A), depths greater than about 1 foot and velocities between about 0.3 and 2.0 ft/s would favor habitat for juvenile salmon and steelhead trout. Habitat available for spawning may be limited, in part, to depths greater than about 4.0 feet and velocities greater than about 4.0 ft/s at discharges greater than the median. Depths less than 4.0 feet also limit the habitat for adult chinook salmon.

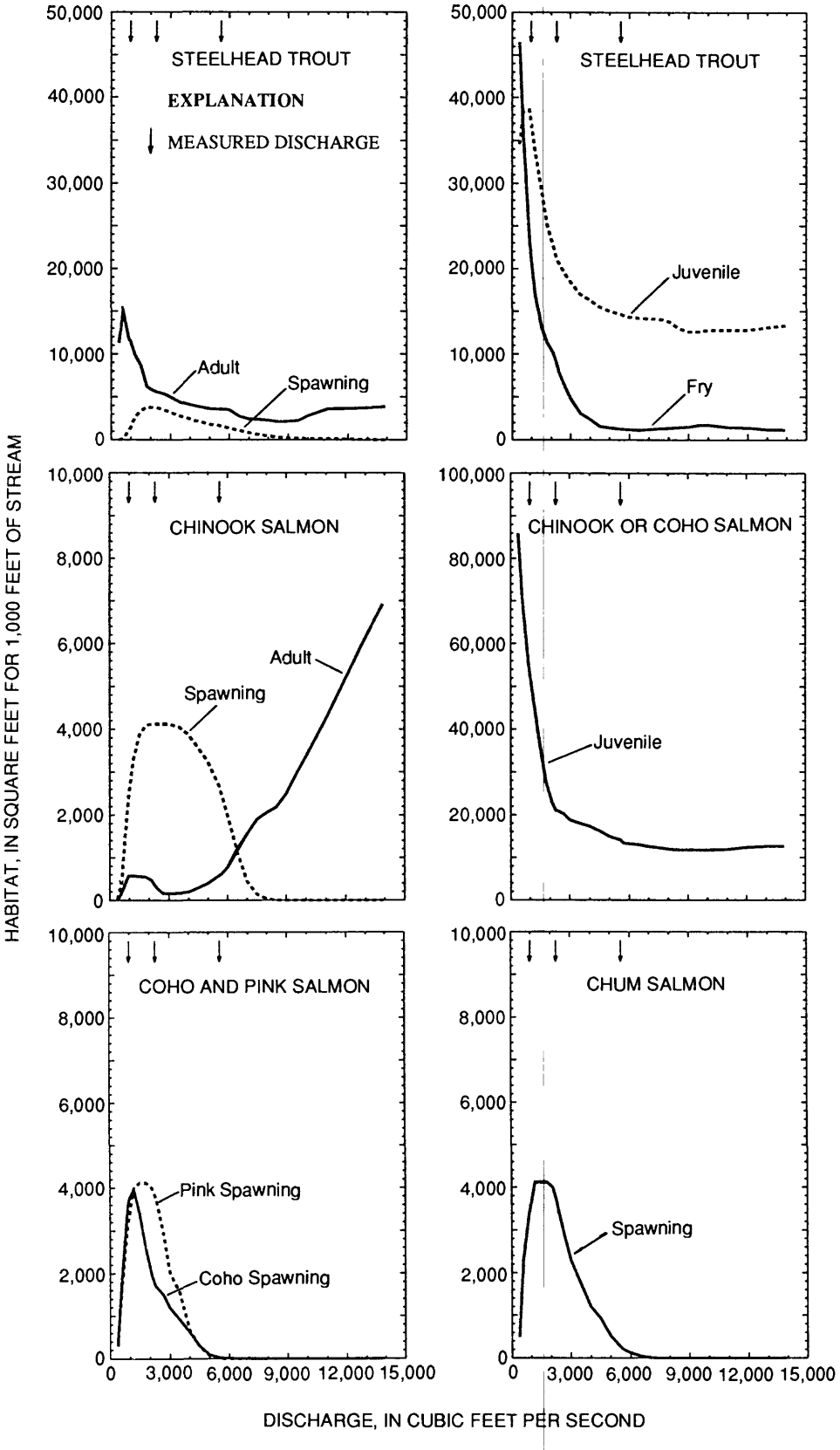


Figure 2.--Relations between stream discharge and habitat at site 1, Puyallup River near Puyallup.

Table 2.--Mean daily discharge that is exceeded various percentages of time in each month and the entire year for site 1, Puyallup River near Puyallup, from stream discharge records for water years 1942 to 1982

Percent of time the mean daily discharge is exceeded	Mean daily discharge, in cubic feet per second												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
95	1,590	1,600	1,720	1,650	2,070	2,730	1,790	1,220	987	836	925	1,360	1,200
90	1,910	1,900	1,970	1,980	2,400	2,950	1,980	1,410	1,130	970	1,210	1,850	1,430
75	2,510	2,540	2,350	2,570	3,040	3,480	2,390	1,710	1,370	1,200	1,710	2,650	2,020
70	2,690	2,740	2,460	2,730	3,200	3,640	2,510	1,790	1,430	1,270	1,870	2,890	2,190
50	3,480	3,460	2,900	3,220	3,910	4,340	3,070	2,060	1,640	1,560	2,600	3,750	2,950
25	5,400	4,830	3,590	3,960	5,040	5,760	3,900	2,440	2,010	2,350	4,170	5,390	4,180
10	8,040	7,110	4,690	4,990	6,120	7,120	4,970	2,940	2,560	3,420	6,500	8,270	5,890

Table 3.--Median discharge and corresponding habitat area for each species and life stage during each month that the fish is present in the Puyallup River near Puyallup (site 1)

Month	Median discharge, in cubic feet per second	HABITAT AREA, in square feet per 1,000 feet of stream									
		Steelhead trout				Chinook salmon		Chinook and coho salmon	Coho salmon	Pink salmon	Chum salmon
		Adult	Spawning	Fry	Juvenile	Adult	Spawning	Juvenile	Spawning	Spawning	Spawning
January	3,480	4,420		3,180	17,100						1,220
February	3,460	4,450		3,250	17,100						1,240
March	2,900	5,120		5,330	18,800			19,300			2,470
April	3,220	4,740		4,080	17,800			18,400			
May	3,910			2,540	16,400			17,400			
June	4,340			1,860	15,800			16,600			
July	3,070			4,610	18,300	161		18,700			
August	2,060			10,300	23,100	492		23,500			
September	1,640			12,300	27,400	556				4,120	
October	1,560			12,800	28,500	558				4,120	
November	2,600	5,420		6,830	19,900					3,120	3,020
December	3,750	4,250		2,760	16,600						1,060

Streambed elevations at the cross sections were relatively constant over the three discharge measurements (fig. 3). Gravel and sand bars less than 75 feet wide along the channel sides were exposed at a discharge of about 1,000 ft^3/s. Streambed materials at all the cross sections were observed to be mixtures of sand and large gravel in nearly equal proportions or with the amount of sand exceeding 50 percent of the material. The limitation on habitat for spawning is due mostly to the abundance of sand in the substrate composition.

Puyallup River at Alderton - Site 2

On the basis of discharge-habitat relations (fig. 4), habitat is generally greater for the spawning life stage of steelhead trout and salmon, and the rearing of juvenile salmon and steelhead trout fry, when stream discharge is less than about 1,000 ft^3/s than at larger streamflows. Habitat for adult chinook salmon increases with discharge from 80 ft^2/1,000 ft to a maximum of about 8,000 ft^2/1,000 ft at the largest discharge (16,150 ft^3/s) simulated with PHABSIM. The habitat curves for steelhead trout adults, fry, and juveniles and for juvenile chinook and coho salmon show two peaks of maximum habitat; one associated with discharge less than 1,000 ft^3/s, and one with discharge greater than 5,000 ft^3/s. Discharges greater than 4,900 ft^3/s in the Puyallup River at Alderton are exceeded less than 10 percent of the time (table 4).

Habitat available at the median discharges for the months when the particular fish is present at the site tends to be greater for juvenile steelhead trout and salmon than for other species or life stages, ranging from 9,620 to 14,900 ft^2/1,000 ft for trout, and from 9,460 to 13,000 ft^2/1,000 ft for salmon (table 5). The least amount of habitat is available for adult chinook salmon, ranging from 356 ft^2/1,000 ft in July to 858 ft^2/1,000 ft in October. Habitat for spawning is most abundant for chinook salmon with a maximum of 10,100 ft^2/1,000 ft with September and October median discharges, followed by maximum areas of 8,640 ft^2/1,000 ft for pink salmon in September; 6,850 ft^2/1,000 ft for steelhead trout in March; 5,420 ft^2/1,000 ft for chum salmon in November; and 4,370 ft^2/1,000 ft for coho salmon in October.

Cross-sectional averaged water depths ranged from 1.3 to 4.2 feet at low flow and from 4.9 to 8.8 feet at high flow (see table 1). Cross-sectional averaged velocities ranged from 1.7 to 3.4 ft/s at low flow and from 6.0 to 6.6 ft/s at high flow. According to preference criteria (Appendix A), depths greater than 1.0 foot and velocities between about 0.3 and 2.0 ft/s would favor habitat for juvenile salmon and steelhead trout. Water depths greater than 4.0 feet and velocities less than 2.0 ft/s provide favorable conditions for adult chinook salmon; depths less than 4 feet do not provide any habitat.

Streambed elevations between the left bank and the deeper parts of the representative cross sections were relatively constant over the three discharge measurements (fig. 5). Near the right bank, however, elevations at the time of the high-flow measurement made in early June 1985 were about 4 feet higher than the elevations measured in July 1985. Gravel bars up to about 100 feet wide along the channel sides were exposed at discharges less than 1,600 ft^3/s, but were submerged at a discharge of about 6,500 ft^3/s.

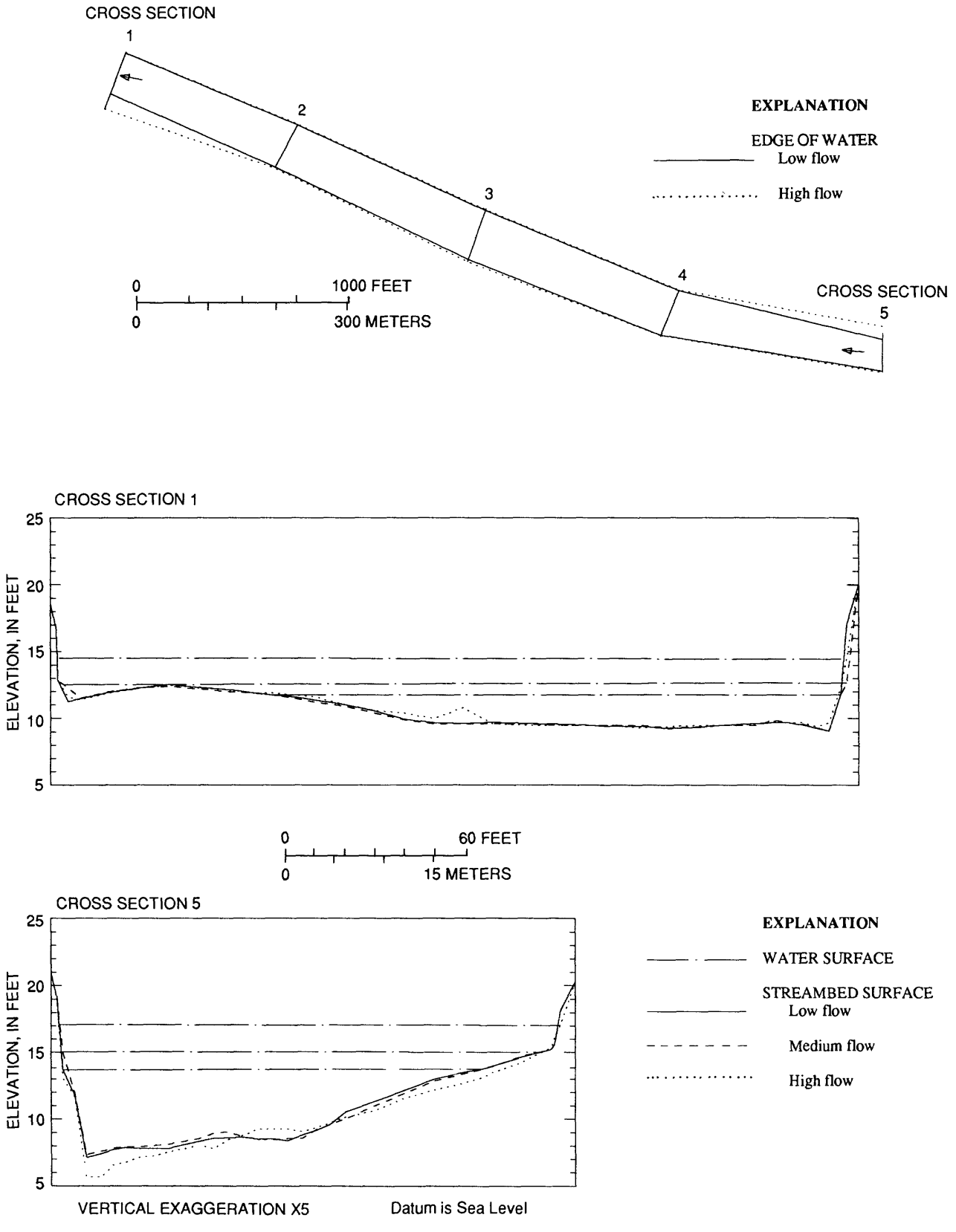


Figure 3.--(a) A planimetric sketch of the Puyallup River near Puyallup, Washington, study site 1, showing cross section locations within the study reach and the edges of water at two stream discharge; and (b) two cross sections showing water surface and streambed elevations at three discharges.

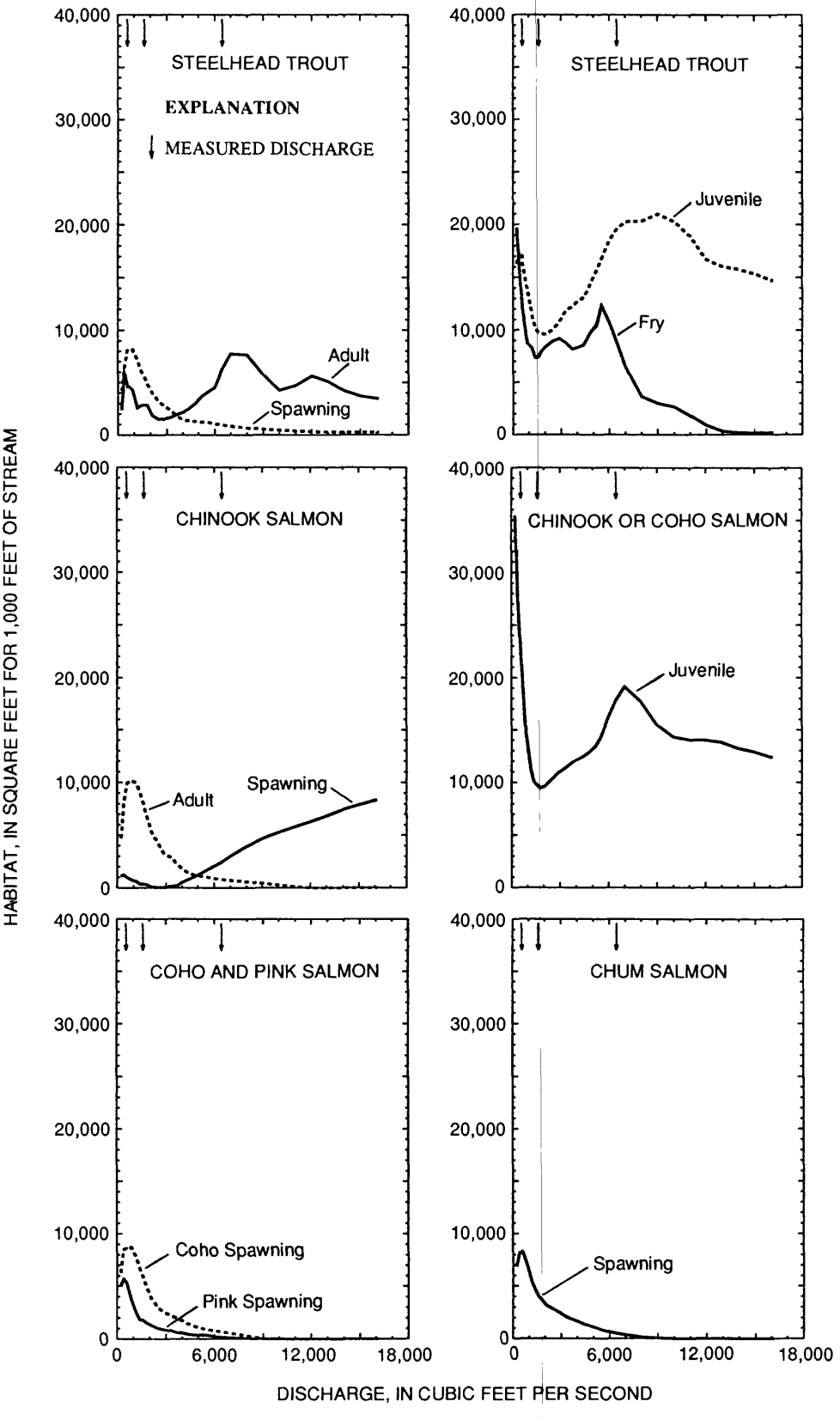


Figure 4.--Relations between stream discharge and habitat at site 2, Puyallup River at Alderton.

Table 4.--Mean daily discharge that is exceeded various percentages of time in each month and the entire year for site 2, Puyallup River at Alderton, from stream discharge records for water years 1915 to 1927 and 1944 to 1957

Percent of time the mean daily discharge is exceeded	Mean daily discharge, in cubic feet per second												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
95	625	646	667	815	890	978	941	663	477	396	372	444	542
90	696	772	763	915	1,080	1,090	1,020	739	529	441	506	636	658
75	962	1,090	968	1,130	1,340	1,400	1,200	875	633	551	694	1,050	926
70	1,600	1,160	1,020	1,190	1,420	1,460	1,260	910	667	590	767	1,150	1,010
50	1,470	1,480	1,270	1,470	1,730	1,810	1,460	1,050	792	768	1,180	1,650	1,330
25	2,440	2,260	1,680	1,880	2,170	2,400	1,880	1,240	975	1,330	2,020	2,640	1,950
10	3,920	3,660	2,320	2,310	2,710	3,020	2,410	1,440	1,210	2,110	3,180	4,890	2,800

Table 5.--Median discharge and corresponding habitat area for each species and life stage during each month that the fish is present in the Puyallup River at Alderton (site 2)

Month	Median discharge, in cubic feet per second	HABITAT AREA, in square feet per 1,000 feet of stream										
		Steelhead trout				Chinook salmon		Chinook and coho salmon	Coho salmon	Pink salmon	Chum salmon	
		Adult	Spawning	Fry	Juvenile	Adult	Spawning	Juvenile	Spawning	Spawning	Spawning	
January	1,470	2,840	6,030	7,360	9,870				1,860		4,370	
February	1,480	2,840	6,000	7,360	9,840						4,330	
March	1,270	2,680	6,850	7,940	10,900			10,800			5,070	
April	1,470	2,840	6,030	7,360	9,870			9,920				
May	1,730		5,130	7,760	9,650			9,550				
June	1,810			7,990	9,620			9,460				
July	1,460			7,350	9,910	356	8,720	9,940				
August	1,050			8,490	12,500	674	10,000	13,000				
September	792			9,880	14,700	839	10,100			8,640		
October	768			10,100	14,900	858	10,100		4,370	8,620		
November	1,180	2,710		8,290	11,500		9,900		2,510	7,740	5,420	
December	1,650	2,880		7,500	9,680				1,780		3,930	

Streambed materials were observed to be mixtures of large gravel and sand at five out of eight cross sections including cross-section 3, with the percentage of gravel predominating within the main channel. At the three other cross sections, including cross-section 6, the streambed materials were mostly sand. The amount of habitat for salmon and steelhead trout spawning is limited because of the abundance of sand in the substrate and because of depths exceeding 3.0 feet.

Puyallup River near Orting - Site 3

On the basis of discharge-habitat relations (fig. 6), habitat is generally greater for all species and life stages except adult chinook salmon when stream discharge is less than about 600 ft^3/s than at larger streamflows. The peak of the habitat curves (maximum habitat) for pink and chinook salmon spawning and for steelhead trout spawning also extends to discharges between 600 ft^3/s and 800 ft^3/s. Habitat for adult chinook and for juvenile chinook and coho salmon increases with discharge for streamflows greater than about 2,000 ft^3/s. Adult chinook habitat increases from 3 to 1,000 $ft^2/1,000$ ft and juvenile salmon habitat increases from 10,200 to 22,500 $ft^2/1,000$ ft at the largest discharge (2,720 ft^3/s) simulated with PHABSIM. Discharges greater than 1,900 ft^3/s in the Puyallup River near Orting are exceeded less than 10 percent of the time (table 6).

Habitat available at the median discharges for the months when the particular fish is present at the site tends to be greater for the rearing of steelhead trout fry than for other species and life stages, ranging from 16,700 $ft^2/1,000$ ft in June to 24,500 $ft^2/1,000$ ft in October (table 7). Habitat available for the rearing of juvenile fish ranges from 14,500 to 16,500 $ft^2/1,000$ ft for salmon, and from 11,800 to 14,600 for steelhead trout. The least amount of habitat is available for adult chinook salmon, ranging from 3 $ft^2/1,000$ ft in July to 11 $ft^2/1,000$ ft in September. Habitat for spawning is most abundant for chinook salmon with a maximum of 16,200 $ft^2/1,000$ ft with the median discharge in September, followed by maximum areas of 15,800 $ft^2/1,000$ ft for pink salmon in November; 14,200 $ft^2/1,000$ ft for steelhead trout in March; 12,500 $ft^2/1,000$ ft for chum salmon in March; and 9,060 $ft^2/1,000$ ft for coho salmon in October.

Cross-sectional averaged water depths ranged from 0.5 to 2.1 feet at low flow and from 1.4 to 2.6 feet at high flow (see table 1). Cross-sectional averaged velocities ranged from 1.0 to 3.3 ft/s at low flow and from 3.3 to 6.0 ft/s at high flow. According to preference criteria (Appendix A), the abundant habitat for steelhead trout fry is because of depths less than 2.0 feet and velocities less than 2.0 ft/s. Water depths between 1.5 and 4.5 feet and velocities between 1.5 and 3.5 ft/s with suitable substrate composition would provide favorable spawning habitat for chinook salmon. The limited adult chinook habitat is due to depths less than 4.0 feet.

Streambed elevations at the cross sections were relatively constant over the three discharge measurements. Gravel bars along the channel sides and portions of the streambed upstream from cross-section 6 were exposed (fig. 7) at discharges up to about 1,100 ft^3/s. Streambed materials at all the cross sections were observed to be mixtures of gravel and sand, with the percentage of gravel predominating over sand within the main channel.

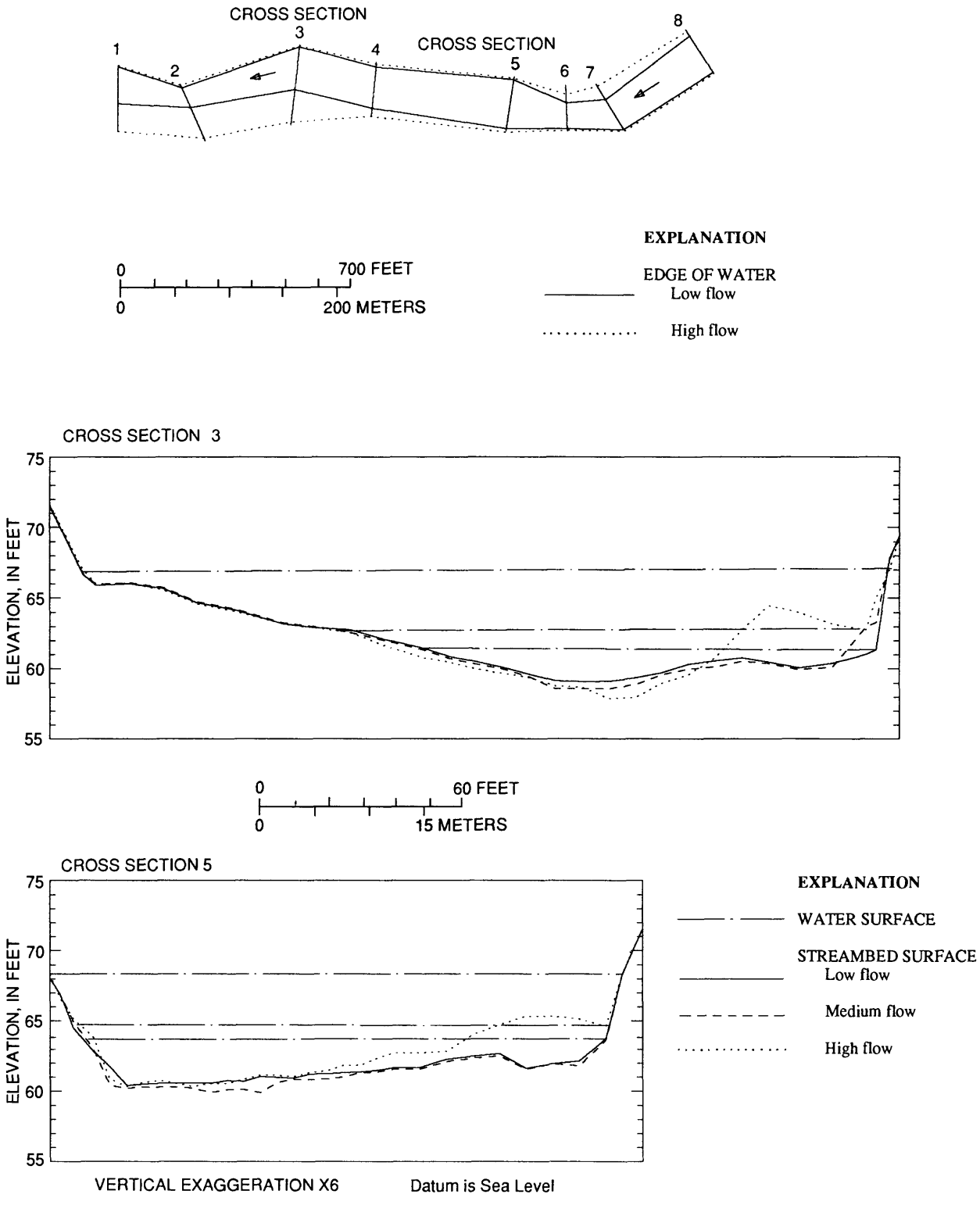


Figure 5.--(a) A planimetric sketch of the Puyallup River at Alderton, Washington, study site 2, showing cross section locations within the study reach and the edges of water at two stream discharge; and (b) two cross sections showing water surface and streambed elevations at three discharges.

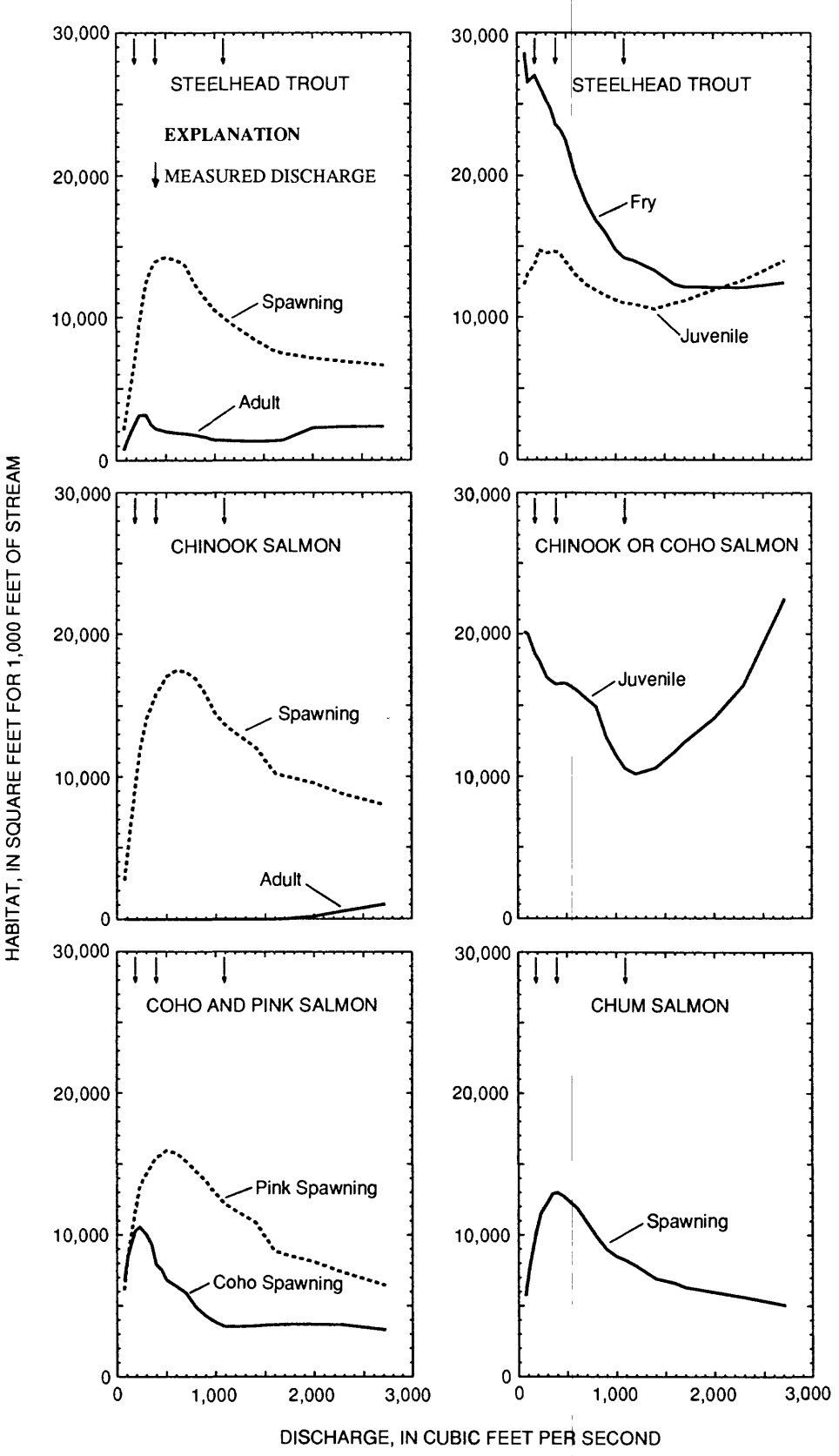


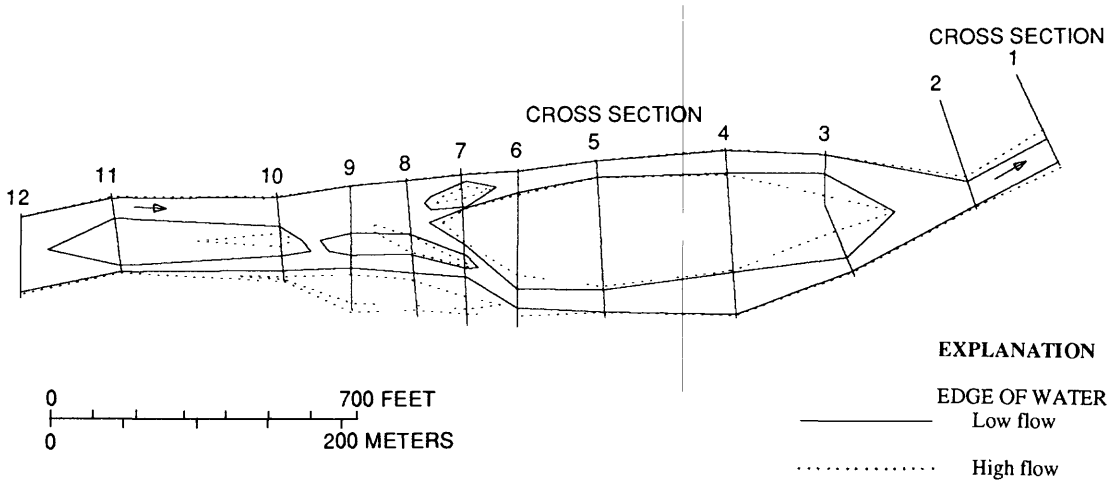
Figure 6.--Relations between stream discharge and habitat at site 3, Puyallup River near Orting.

Table 6.--Mean daily discharge that is exceeded various percentages of time in each month and the entire year for site 3, Puyallup River near Orting, from stream discharge records for water years 1932 to 1982

Percent of time the mean daily discharge is exceeded	Mean daily discharge, in cubic feet per second												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
95	258	263	281	319	430	455	449	332	247	190	178	264	258
90	299	299	319	361	470	519	491	376	282	213	236	329	309
75	401	394	393	453	578	649	564	450	346	263	347	471	422
70	439	426	415	478	608	685	588	468	364	281	380	514	454
50	622	564	506	578	729	818	683	538	427	358	556	734	584
25	1,050	888	688	756	933	1,070	840	643	522	554	930	1,120	832
10	1,820	1,410	1,000	958	1,190	1,380	1,040	761	648	854	1,490	1,880	1,210

Table 7.--Median discharge and corresponding habitat area for each species and life stage during each month that the fish is present in the Puyallup River near Orting (site 3)

Month	Median discharge, in cubic feet per second	HABITAT AREA, in square feet per 1,000 feet of stream									
		Steelhead trout				Chinook salmon		Chinook and coho salmon	Coho salmon	Pink salmon	Chum salmon
		Adult	Spawning	Fry	Juvenile	Adult	Spawning	Juvenile	Spawning	Spawning	Spawning
January	622	1,890	14,000	19,600	12,800				6,270		11,700
February	564	1,940	14,100	20,900	13,300						12,100
March	506	1,990	14,200	22,300	13,800			16,500			12,500
April	578	1,920	14,100	20,500	13,200			16,200			
May	729		13,300	17,800	12,200			15,300			
June	818			16,700	11,800			14,500			
July	683			18,500	12,400	3.1		16,200			
August	538			21,500	13,600	4.5		16,400			
September	427			23,300	14,500	11.1	16,200			15,600	
October	358			24,500	14,600	3.6	15,100		9,060	15,000	
November	556	1,950		21,100	13,400	4.4	17,300		6,580	15,800	12,200
December	734	1,820		17,800	12,200				5,560		10,500



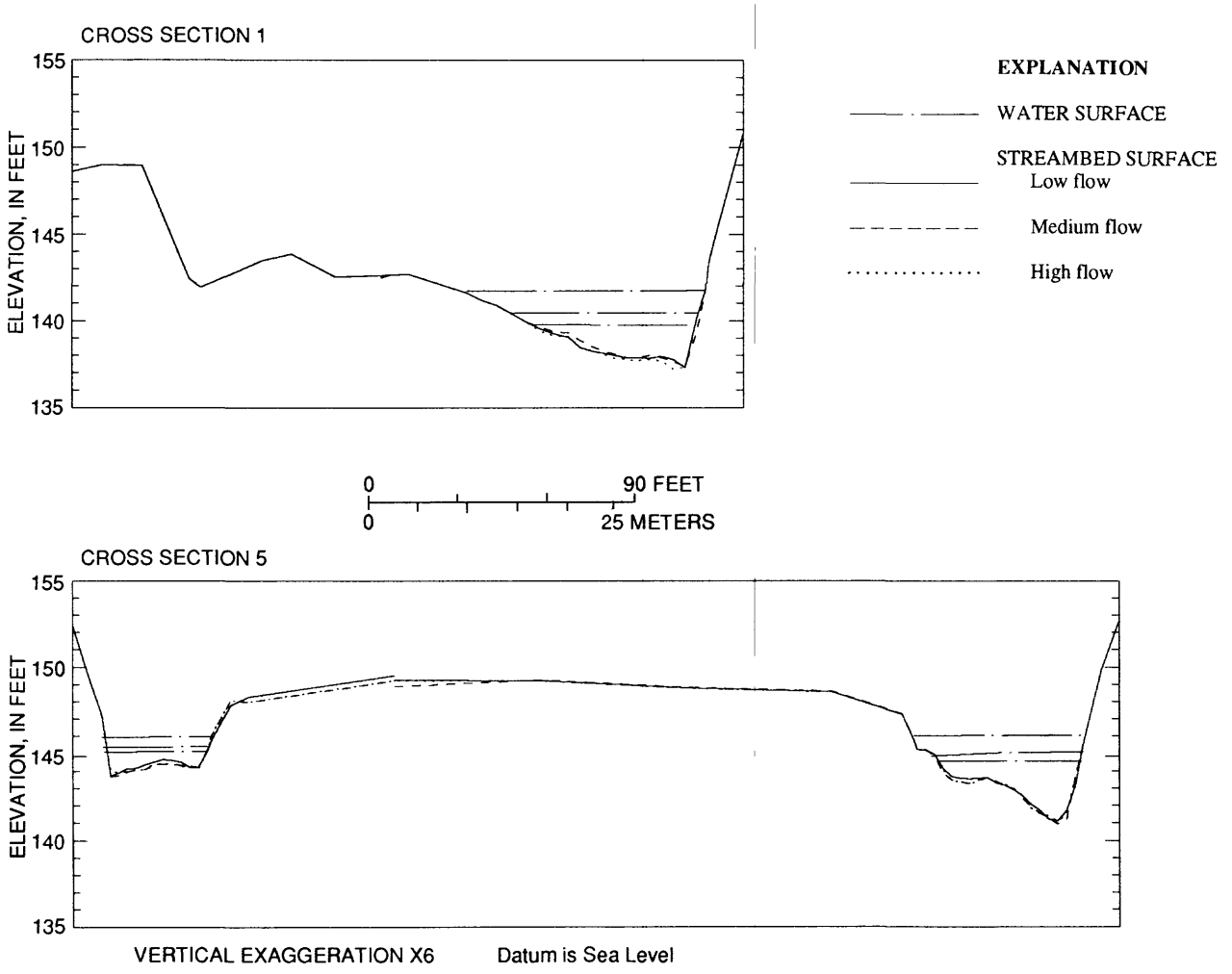


Figure 7.--(a) A planimetric sketch of the Puyallup River near Orting, Washington, study site 3, showing cross section locations within the study reach and the edges of water at two stream discharge; and (b) two cross sections showing water surface and streambed elevations at three discharges.

White River near Dieringer - Site 4

On the basis of discharge-habitat relations (fig. 8), habitat is generally greater for species and life stages, except for the spawning and adult life stages of chinook salmon, when stream discharge is less than about 700 ft^3/s than at larger streamflows. The peak of the habitat curves (maximum habitat) for pink and chinook salmon spawning and for steelhead trout spawning extends also to discharges between 700 ft^3/s and about 1,100 ft^3/s. Habitat for adult chinook salmon increases with discharge for streamflows greater than about 2,000 ft^3/s. Adult chinook habitat increases from 22 $ft^2/1{,}000$ ft to a maximum of about 1,600 $ft^2/1{,}000$ ft at the largest discharge (6,900 ft^3/s) simulated with PHABSIM. Discharges greater than 4,300 ft^3/s in the White River near Dieringer are exceeded less than 10 percent of the time (table 8).

Habitat available at the median discharges for the months when the particular fish is present at the site tends to be greater for juvenile chinook and coho salmon than for other species and life stages, ranging from 14,800 $ft^2/1{,}000$ ft in June to 17,600 $ft^2/1{,}000$ ft in August (table 9). Habitat for the rearing of steelhead trout ranges from 480 to 3,010 $ft^2/1{,}000$ ft for fry and from 3,370 to 12,700 $ft^2/1{,}000$ ft for juveniles. The least amount of habitat is available for adult chinook salmon, ranging from 0 to 161 $ft^2/1{,}000$ ft. Habitat for spawning is most abundant for chinook salmon with a maximum of 16,100 $ft^2/1{,}000$ ft with the median discharge in August, followed by maximum areas of 13,600 $ft^2/1{,}000$ ft for pink salmon in September; 7,570 $ft^2/1{,}000$ ft for steelhead trout in March; 4,710 $ft^2/1{,}000$ ft for coho salmon in October; and 3,840 $ft^2/1{,}000$ ft for chum salmon in November.

Cross-sectional averaged water depths ranged from 1.5 to 2.6 feet at low flow and from 4.2 to 5.2 feet at high flow (see table 1). Cross-sectional averaged velocities ranged from 1.4 to 2.5 ft/s at low flow and from 4.1 to 4.7 ft/s at high flow. According to preference criteria (Appendix A), water depths greater than about 2.0 feet and velocities ranging from 0.3 to 1.5 ft/s would favor habitat for juvenile chinook and coho salmon. The limited adult chinook habitat is due to depths less than 4.0 feet. Also, it is limited by velocities greater than 3.0 ft/s at discharges larger than about 1,600 ft^3/s.

Streambed elevations at the representative cross sections were relatively constant over the three discharge measurements (fig. 9). A narrow gravel bar less than 10 feet wide along the right bank near cross-section 6 was exposed at the low-flow discharge of 460 ft^3/s. Streambed materials were observed to be mixtures of large gravel and sand, with the percentage of gravel predominating within the main channel.

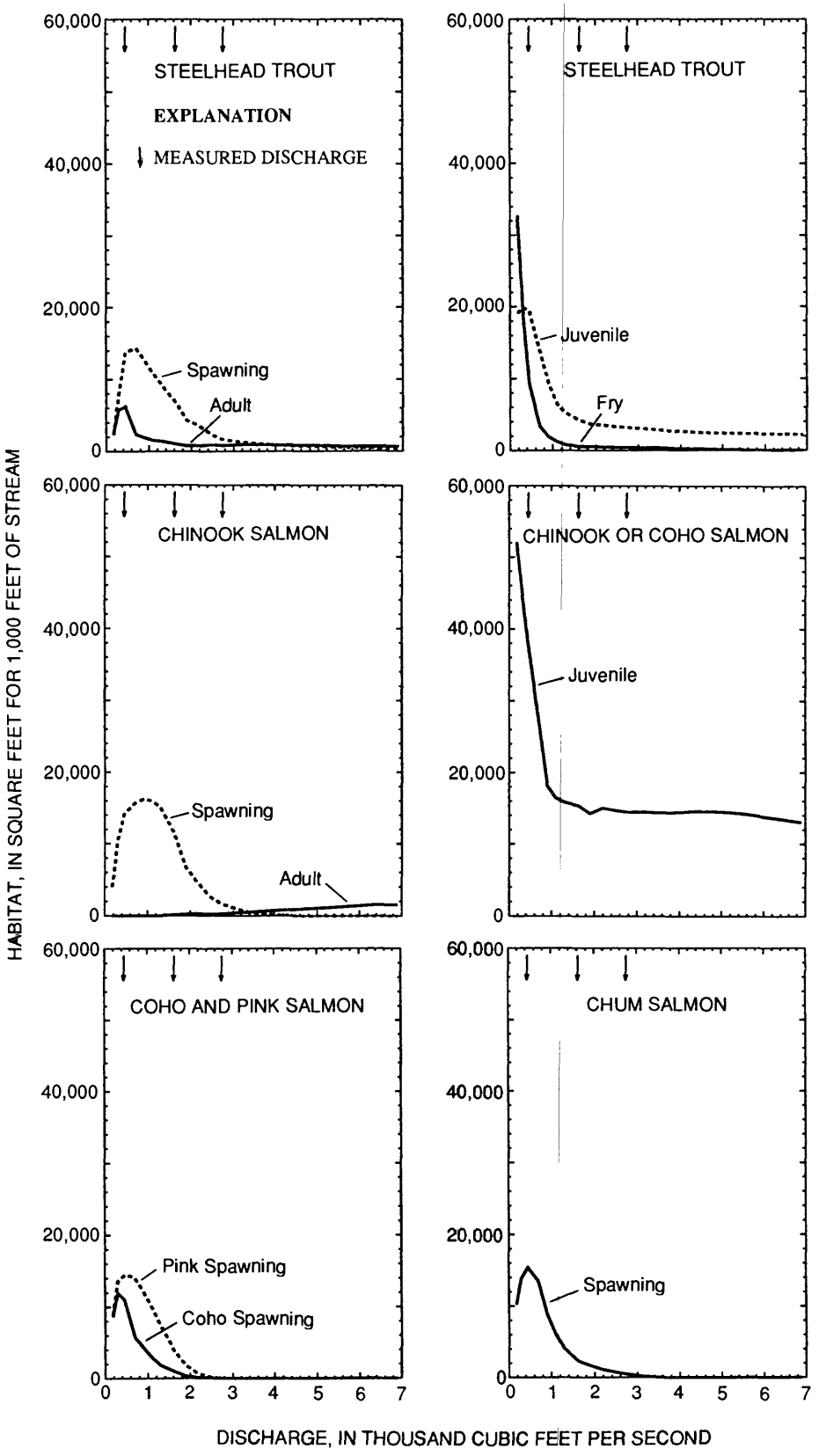


Figure 8.--Relations between stream discharge and habitat at site 4, White River near Dieringer.

Table 8.--Mean daily discharge that is exceeded various percentages of time in each month and the entire year for site 4, White River near Dieringer, from stream discharge records for water years 1944 to 1957 and 1959 to 1970

Percent of time the mean daily discharge is exceeded	Mean daily discharge, in cubic feet per second												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
95	689	595	670	788	830	1,290	644	259	176	228	385	609	432
90	913	815	855	973	1,090	1,540	877	444	352	356	511	816	609
75	1,290	1,280	1,140	1,350	1,570	1,960	1,170	720	544	589	791	1,250	959
70	1,400	1,380	1,220	1,430	1,690	2,070	1,250	784	588	647	888	1,380	1,070
50	1,820	1,770	1,530	1,740	2,160	2,450	1,600	967	755	847	1,350	1,800	1,520
25	2,680	2,390	1,960	2,180	2,950	3,440	2,060	1,250	969	1,260	2,180	2,630	2,220
10	3,850	3,440	2,430	2,770	3,720	4,330	2,760	1,550	1,220	1,780	3,600	3,920	3,240

Table 9.--Median discharge and corresponding habitat area for each species and life stage during each month that the fish is present in the White River near Dieringer (site 4)

Month	Median discharge, in cubic feet per second	HABITAT AREA, in square feet per 1,000 feet of stream										
		Steelhead trout				Chinook salmon		Chinook and coho salmon	Coho salmon	Pink salmon	Chum salmon	
		Adult	Spawning	Fry	Juvenile	Adult	Spawning	Juvenile	Spawning	Spawning	Spawning	
January	1,820	877	5,070	570	3,830				553		1,860	
February	1,770	926	5,540	576	3,930						1,980	
March	1,530	1,180	7,570	657	4,520			15,500			2,850	
April	1,740	955	5,820	580	3,990			14,900				
May	2,160		3,650	515	3,560			14,900				
June	2,450			480	3,370			14,800				
July	1,600			612	4,300	161	11,700	15,400				
August	967			1,710	8,390	1.8	16,100	17,600				
September	755			3,010	12,700	0	15,700			13,600		
October	847			2,340	10,600	0	16,000		4,710	12,600		
November	1,350	1,390		773	5,080	45.4	14,500		1,710	6,860	3,840	
December	1,800	897		572	3,870				598		1,910	

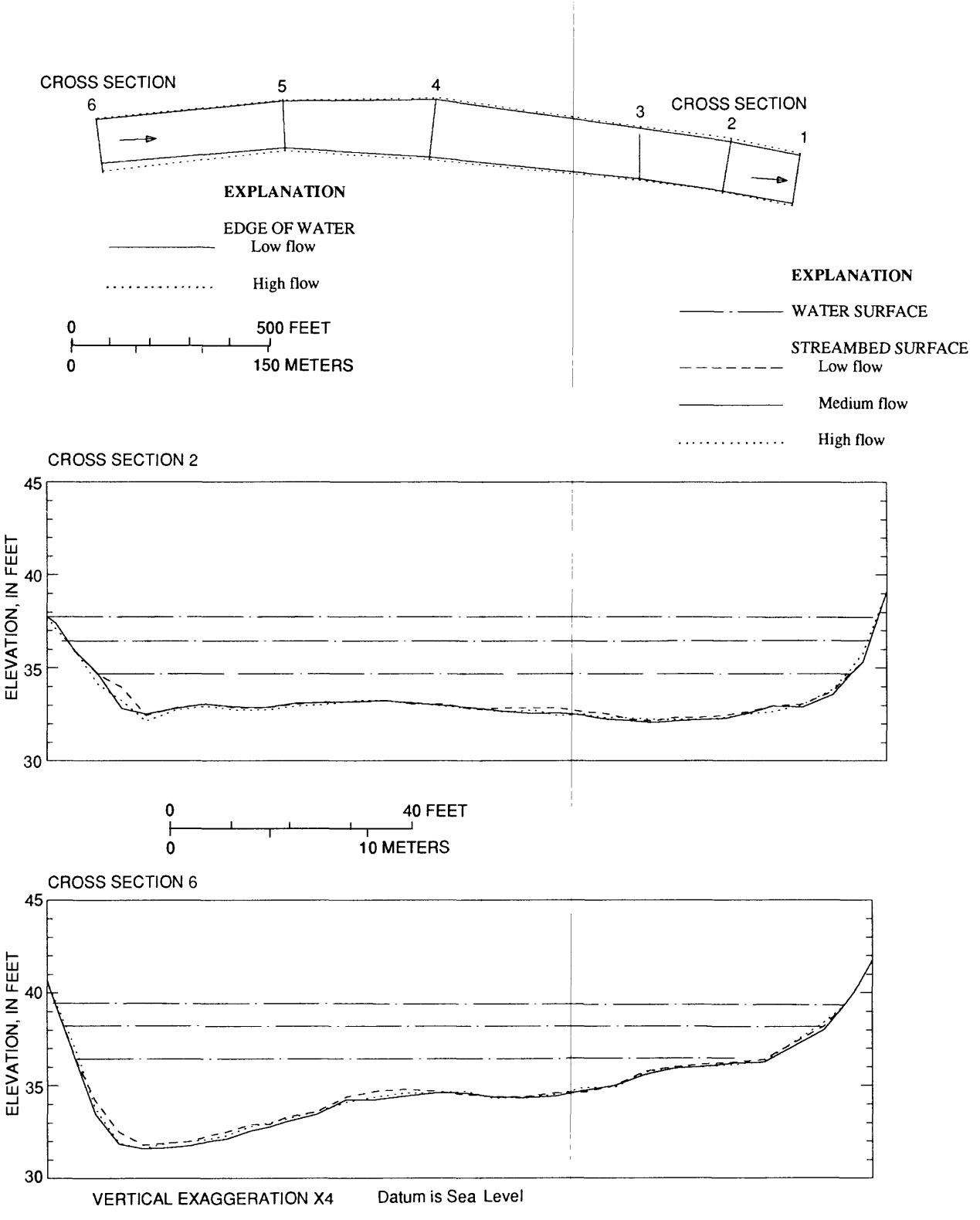


Figure 9.--(a) A planimetric sketch of the White River near Dieringer, Washington, study site 4, showing cross section locations within the study reach and the edges of water at two stream discharge; and (b) two cross sections showing water surface and streambed elevations at three discharges.

White River near Auburn - Site 5

On the basis of discharge-habitat relations (fig. 10), habitat is generally abundant for all species and life stages, except steelhead trout fry, when stream discharge is greater than about 700 ft^3/s. The peak of the habitat curves also extends to discharges as large as 1,400 ft^3/s. Maximum habitat for steelhead fry is associated with small discharges less than 700 ft^3/s. No habitat is available for adult chinook salmon at flows less than 1,300 ft^3/s. Habitat for adult chinook salmon increases from 1 ft^2/1,000 ft at a discharge of 1,400 ft^3/s to a maximum of 20 ft^2/1,000 ft at a discharge of 1,870 ft^3/s, the largest discharge simulated with PHABSIM. Discharges greater than 2,000 ft^3/s during any given month in the White River near Auburn are exceeded less than 25 percent of the time (table 10).

Habitat available at the median discharges for the months when the particular fish is present at the site tends to be greater for the rearing life stages of steelhead trout and salmon than for other species and life stages (table 11). Habitat available for rearing steelhead trout fry ranges from 26,100 to 46,800 ft^2/1,000 ft; habitat for juvenile salmon ranges from 24,300 to 45,100 ft^2/1,000 ft; and habitat for juvenile steelhead trout ranges from 16,400 to 32,400 ft^2/1,000 ft. No habitat is available for adult chinook salmon at the median flows for July through November. Habitat for spawning is most abundant for chum salmon with a maximum of 22,900 ft^2/1,000 ft with the median discharge in January, followed by maximum areas of 27,300 ft^2/1,000 ft for steelhead trout in May; 16,100 ft^2/1,000 ft for coho salmon in December and January; 15,300 ft^2/1,000 ft for pink salmon in November; and 10,800 ft^2/1,000 ft for chinook salmon in July.

Cross-sectional averaged water depths ranged from 0.4 to 1.3 feet at low flow and from 1.3 to 2.2 feet at high flow. Cross-sectional averaged velocities ranged from 1.0 to 1.5 ft/s at low flow and from 2.1 to 2.9 ft/s at high flow. According to preference criteria (Appendix A), water depths greater than about 2.0 feet and velocities ranging from 0.3 to 1.5 ft/s provide favorable conditions for juvenile chinook and coho salmon. Depths greater than about 1.0 foot and velocities less than 1.0 ft/s provide favorable habitat for juvenile trout and salmon. The limited adult chinook habitat is due to depths less than 4.0 feet.

Near the center of the channel at cross-section 2, streambed elevations were about 1.5 feet higher at the time of the first measurement during high flow than when the next two measurements were made (fig. 11). Elevations at cross-section 5 were about 0.5 to 1 foot higher at the time of the first measurement during high flow than at the last measurement during low flow. Cross-section 2 is located about 200 feet upstream from gravel-removal activities that occurred in summer 1984. Both cross sections 5 and 2 represent the changing characteristics of the channel within this reach of the White River. Gravel bars up to about 120 feet wide along the left and right banks, and an island, were exposed at discharges less than about 120 ft^3/s. The bars were submerged at a discharge of about 750 ft^3/s. Streambed materials at all the cross sections were observed to be mixtures of large gravel or small cobble and sand with the percentage of gravel or cobble predominating within the main channel.

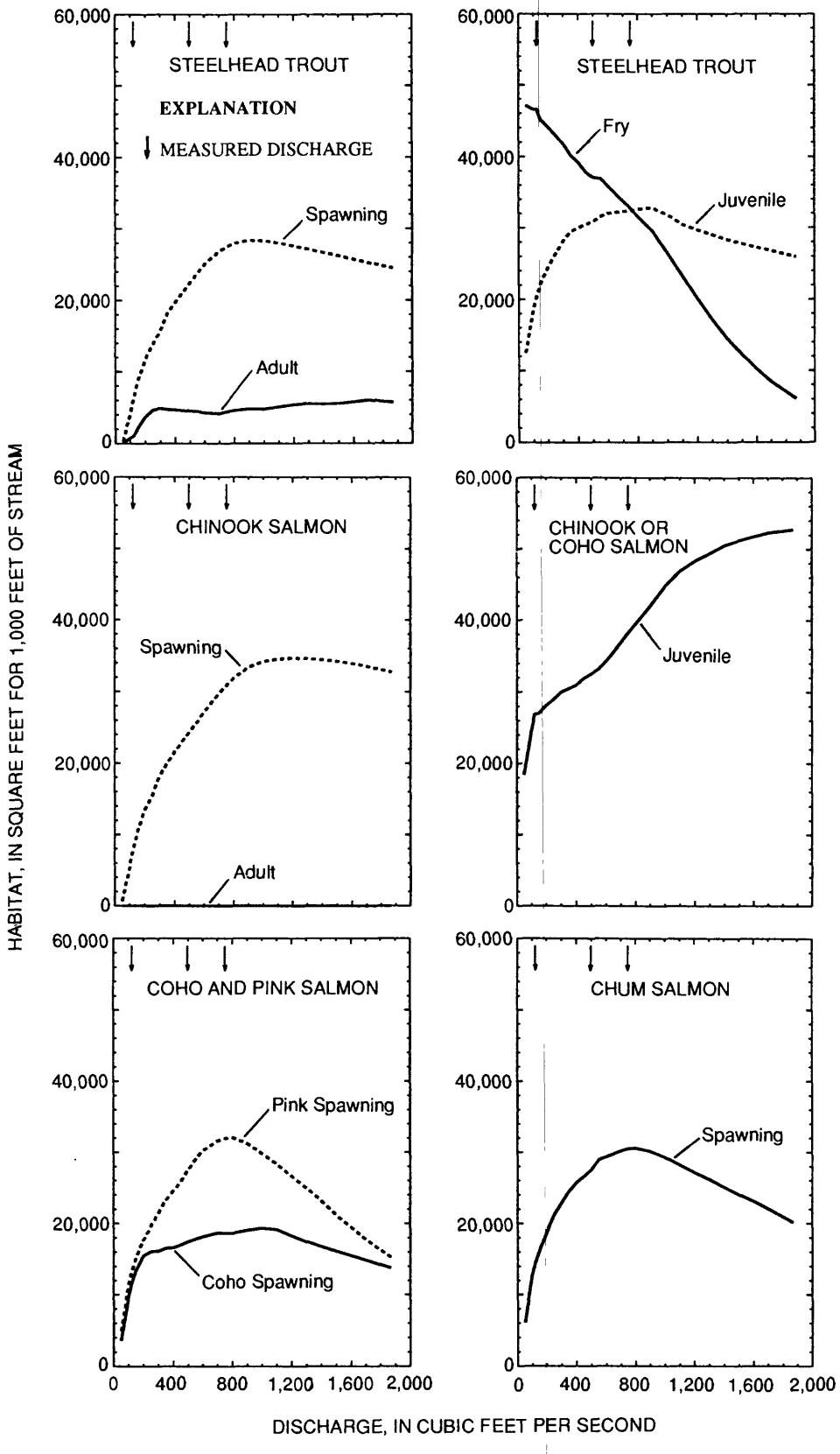


Figure 10.--Relations between stream discharge and habitat at site 5, White River near Auburn.

Table 10.--Mean daily discharge that is exceeded various percentages of time in each month and the entire year for site 5, White River near Auburn, from stream discharge records for water years 1945 to 1970

Percent of time the mean daily discharge is exceeded	Mean daily discharge, in cubic feet per second												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
95	110	119	122	118	143	133	66.0	56.9	56.1	55.0	54.2	84.4	64.9
90	128	144	132	140	165	167	76.0	62.4	59.0	62.5	74.5	106	77.2
75	167	186	157	167	271	362	108	76.9	67.7	81.3	103	158	113
70	186	201	164	176	362	456	116	81.2	70.3	86.1	110	179	127
50	300	275	204	230	736	1,010	158	96.5	80.9	108	153	282	197
25	975	715	283	561	1,650	2,000	430	124	102	167	474	1,210	621
10	1,970	1,970	609	1,360	2,450	2,850	993	186	133	484	2,040	2,570	1,800

Table 11.--Median discharge and corresponding habitat area for each species and life stage during each month that the fish is present in the White River near Auburn (site 5)

Month	Median discharge, in cubic feet per second	HABITAT AREA, in square feet per 1,000 feet of stream										
		Steelhead trout				Chinook salmon		Chinook and coho salmon	Coho salmon	Pink salmon	Chum salmon	
		Adult	Spawning	Fry	Juvenile	Adult	Spawning	Juvenile	Spawning	Spawning	Spawning	
January	300	4,880	15,700	41,800	28,200				16,100		22,900	
February	275	4,780	14,800	42,400	27,300						22,100	
March	204	3,810	11,900	44,000	24,700			28,200			19,000	
April	230	4,300	13,000	43,400	25,700			28,600				
May	736		27,300	33,100	32,400			37,900				
June	1,010			26,100	31,600			45,100				
July	158			45,000	22,600	0	10,800	27,200				
August	96.5			46,600	18,400	0	5,160	24,300				
September	80.9			46,800	16,400	0	3,670			8,880		
October	108			46,600	19,400	0	6,340		10,300	12,000		
November	153	2,220		45,000	22,400	0	10,500		13,500	15,300	16,400	
December	282	4,810		42,200	27,600				16,100		22,300	

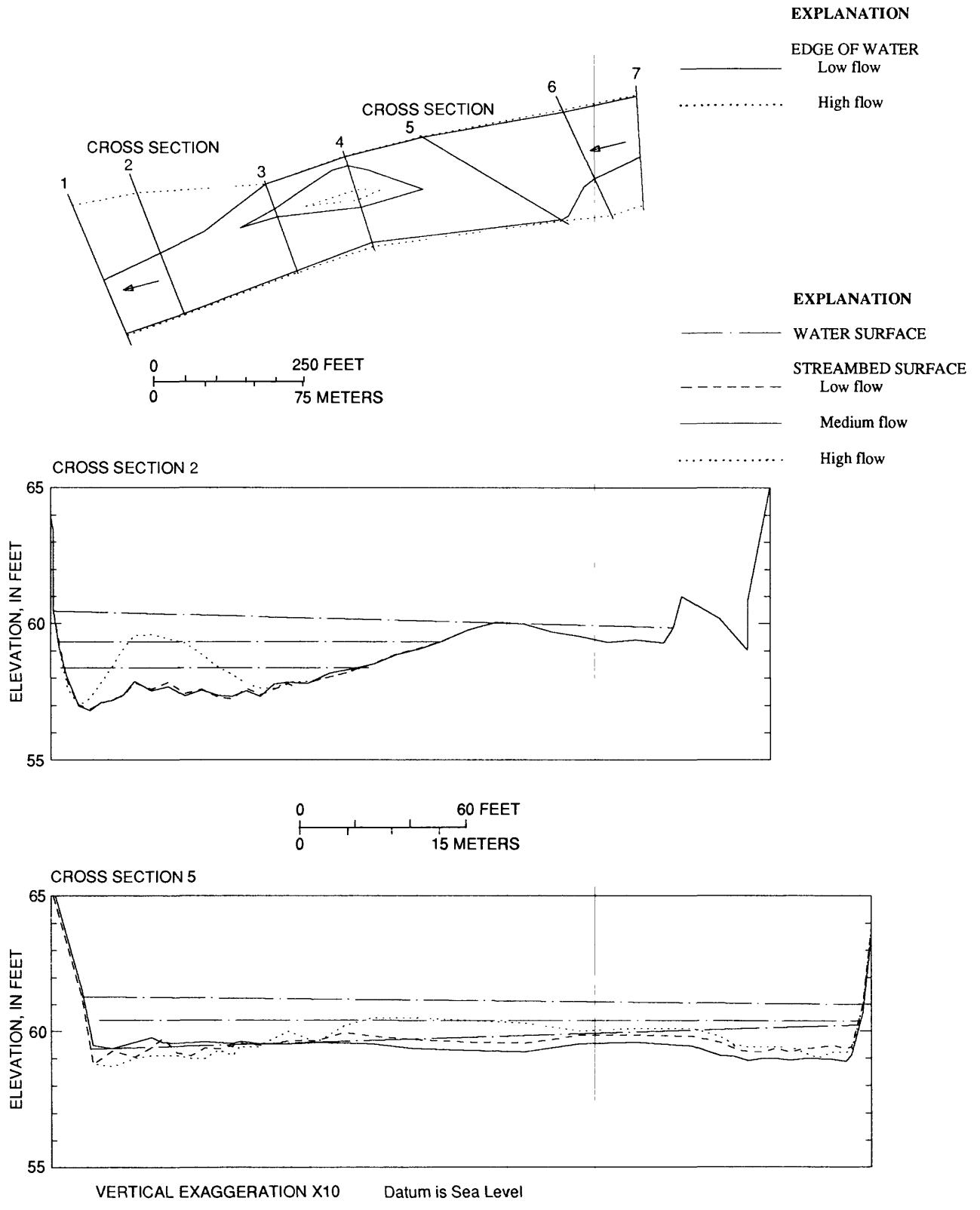


Figure 11.--(a) A planimetric sketch of the White River near Auburn, Washington, study site 5, showing cross section locations within the study reach and the edges of water at two stream discharge; and (b) two cross sections showing water surface and streambed elevations at three discharges.

Carbon River near Orting - Site 6

On the basis of discharge-habitat relations (fig. 12), habitat is generally greater for species and life stages when stream discharge is less than about 400 ft^3/s than at larger streamflows. The habitat curves for steelhead adults, juveniles, and fry, and juvenile salmon show two peaks of habitat (maximum habitat); one associated with discharges less than 400 ft^3/s, and one with discharges greater than about 2,500 ft^3/s. No adult chinook habitat is available at discharges less than 2,500 ft^3/s. At 2,800 ft^3/s adult chinook habitat is only 4 $ft^2/1{,}000$ ft. Discharges greater than 2,700 ft^3/s during any given month in the Carbon River near Orting are exceeded less than 10 percent of the time (table 12).

Habitat available at the median discharges for the months when the particular fish is present at the site tends to be greater for juvenile steelhead trout than for other species and life stages, ranging from 6,300 to 10,400 $ft^2/1{,}000$ ft (table 13). Habitat for the rearing of steelhead trout fry ranges from 6,900 to 9,600 $ft^2/1{,}000$ ft and for rearing of juvenile salmon, habitat ranges from 3,700 to 6,100 $ft^2/1{,}000$ ft. No habitat is available for adult chinook salmon at the median flows for July through November. Habitat for spawning is most abundant for chinook salmon with a maximum of 9,170 $ft^2/1{,}000$ ft in September, followed by maximum areas of 8,830 $ft^2/1{,}000$ ft for pink salmon in September; 3,640 $ft^2/1{,}000$ ft for steelhead trout in March; 2,580 $ft^2/1{,}000$ ft for chum salmon in November; and 2,300 $ft^2/1{,}000$ ft for coho salmon in October.

Cross-sectional averaged water depths ranged from 0.8 to 1.4 feet at low flow and from 1.6 to 2.8 feet at high flow. Cross-sectional averaged velocities ranged from 1.7 to 4.0 ft/s at low flow and from 4.0 to 5.9 ft/s at high flow (see table 1). According to preference criteria (Appendix A), velocities between 1.0 and 2.0 ft/s and depths between about 1.0 and 3.0 feet provide favorable habitat for spawning. The limited adult chinook habitat is due to depths less than 4.0 feet and by velocities greater than 3.0 ft/s.

Streambed elevations at cross-section 2 between the left bank and the 75-foot width were relatively constant over the three discharge measurements. From the 75-foot width to the right bank, the streambed was about 1 foot higher at the time of the low-flow measurement in October 1985 than the June and July 1985 measurements (fig. 13). At cross-section 4, the elevations increased over time by as much as 0.5 foot between the time of the high-flow measurement in June 1985 and the low-flow measurement in October 1985. The gravel bar along the right channel side remained exposed at discharges as large as 1,300 ft^3/s. Streambed materials at all cross sections were estimated to be mixtures of gravel, cobble, and sand with the percentage of gravel and cobble predominating within the main channel.

In the lower Puyallup, White, and Carbon Rivers, habitat was generally more abundant in area for the rearing life stages of steelhead trout and salmon than for other life stages, particularly for juvenile chinook and coho salmon, and steelhead trout fry. Figure 14 summarizes the maximum habitat available at the six study sites in the basin for the different life stages and species of fish as defined by the simulated discharge-habitat relations.

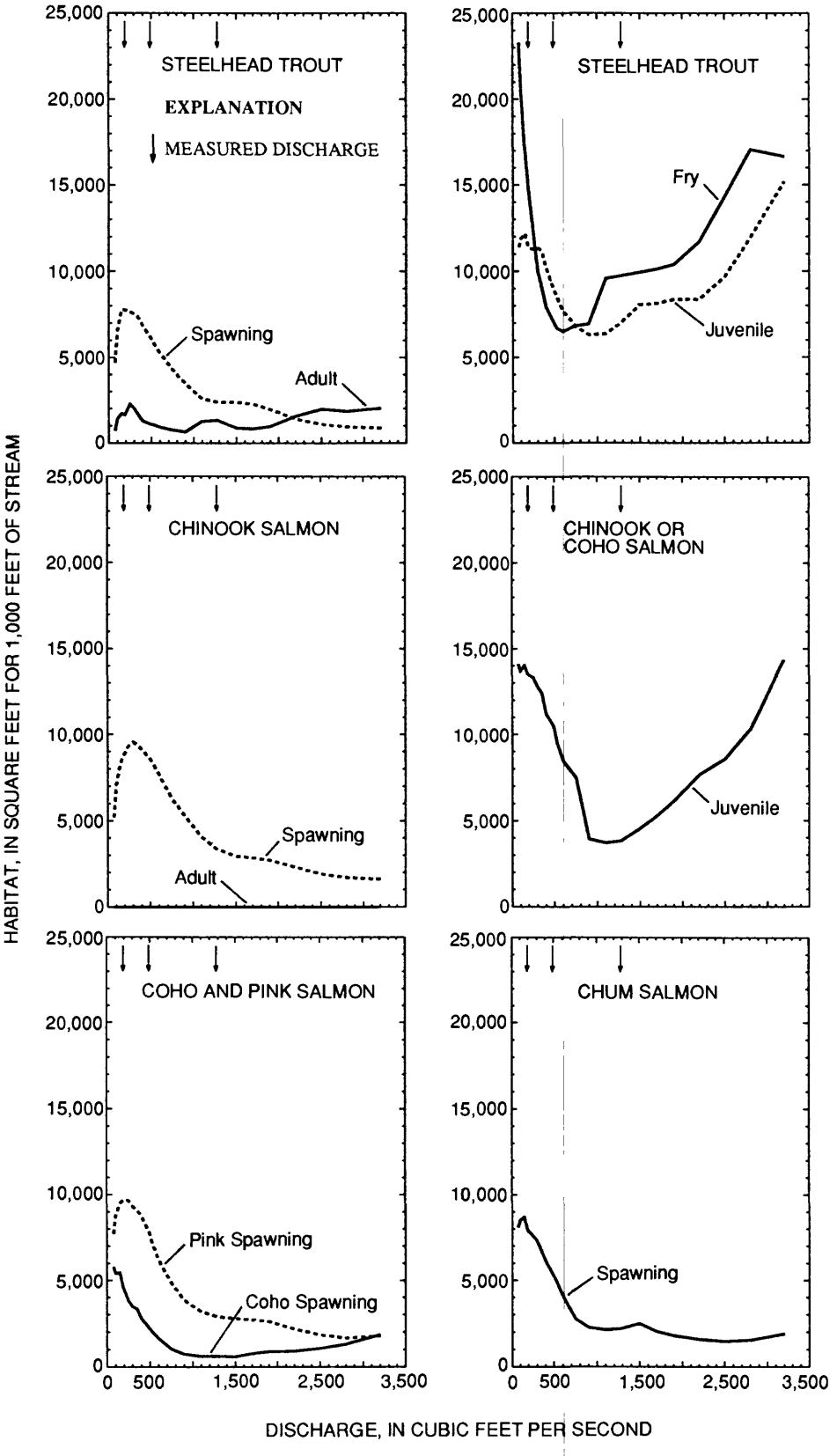


Figure 12.--Relations between stream discharge and habitat at site 6, Carbon River near Orting.

Table 12.--Mean daily discharge that is exceeded various percentages of time in each month and the entire year for site 6, Carbon River near Orting, from stream discharge records for water years 1945 to 1957

Percent of time the mean daily discharge is exceeded	Mean daily discharge, in cubic feet per second												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
95	346	434	461	551	634	598	434	274	188	161	135	172	246
90	402	522	515	622	706	670	481	301	212	191	270	294	336
75	576	679	637	770	869	831	601	368	278	298	483	638	516
70	627	723	681	810	916	876	638	387	299	325	549	694	575
50	873	901	868	977	1,110	1,120	807	463	388	482	805	1,000	808
25	1,400	1,370	1,150	1,230	1,380	1,430	1,080	585	508	838	1,350	1,610	1,210
10	2,130	2,190	1,540	1,530	1,690	1,820	1,340	738	696	1,280	1,990	2,710	1,660

Table 13.--Median discharge and corresponding habitat area for each species and life stage during each month that the fish is present in the Carbon River near Orting (site 6)

Month	Median discharge, in cubic feet per second	HABITAT AREA, in square feet per 1,000 feet of stream										
		Steelhead trout				Chinook salmon		Chinook and coho salmon	Coho salmon	Pink salmon	Chum salmon
		Adult	Spawning	Fry	Juvenile	Adult	Spawning	Juvenile	Spawning	Spawning	Spawning
January	873	674	3,610	6,910	6,390				798		2,360
February	901	657	3,460	6,940	6,310						2,270
March	868	677	3,640	6,910	6,410			4,680			2,380
April	977	894	3,130	7,950	6,330			3,850			
May	1,110		2,570	9,580	6,400			3,720			
June	1,120			9,590	6,430			3,730			
July	807			6,860	6,590	0		6,110			
August	463			7,310	9,350	0					
September	388			8,190	10,400	0	9,170			8,830	
October	482			7,120	9,090	0	8,650		2,300	7,880	
November	805	723		6,860	6,600	0	5,930		933	4,480	2,580
December	1,000	965		8,250	6,340				678		2,210

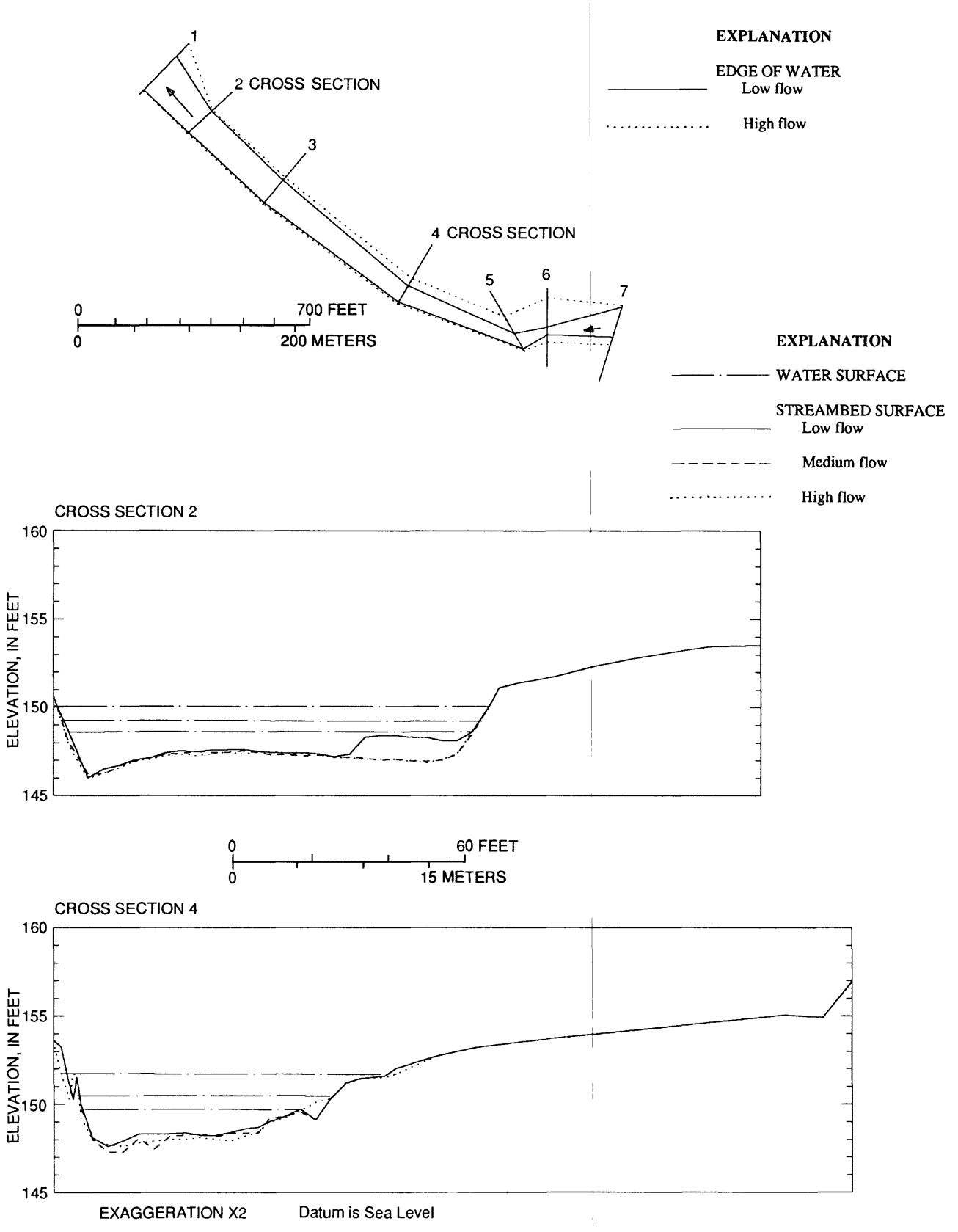


Figure 13.--(a) A planimetric sketch of the Carbon River near Orting, Washington, study site 6, showing cross section locations within the study reach and the edges of water at two stream discharge; and (b) two cross sections showing water surface and streambed elevations at three discharges.

Figure 15 shows the simulated discharges that correspond to the maximum habitat areas summarized in figure 14. For juvenile salmon, maximum habitat ranged from 85,900 ft^2/1,000 ft at a simulated discharge of 390 ft^3/s in the Puyallup River near Puyallup (site 1) to 14,400 ft^2/1,000 ft at 3,200 ft^3/s in the Carbon River (site 6). For steelhead trout fry, maximum habitat ranged from 47,100 ft^2/1,000 ft at a discharge of 50 ft^3/s in the White River near Auburn (site 5) to 19,700 ft^2/1,000 ft at 230 ft^3/s in the Puyallup River at Alderton (site 2). For juvenile steelhead trout, maximum habitat ranged from 38,600 ft^2/1,000 ft at 600 ft^3/s in the Puyallup River near Puyallup (site 1) to 14,800 ft^2/1,000 ft at 2,700 ft^3/s in the Puyallup River near Orting (site 3).

Maximum habitat available for adult chinook salmon and adult steelhead trout was less than the maximum habitat available for other life stages. For adult chinook salmon, maximum habitat ranged from 8,400 ft^2/1,000 ft at a discharge of 16,000 ft^3/s in the Puyallup River at Alderton (site 2) to 4 ft^2/1,000 ft at 2,800 ft^3/s in the Carbon River (site 6). For adult steelhead trout, maximum habitat ranged from 15,000 ft^2/1,000 ft at 600 ft^3/s in the Puyallup River near Puyallup (site 1) to 2,300 ft^2/1,000 ft at 250 ft^3/s in the Carbon River (site 6).

Maximum habitat available for the spawning life stage was greater for chinook salmon and less for coho salmon than for the other species. For chinook salmon, maximum habitat for spawning ranged from 34,700 ft^2/1,000 ft in the White River near Auburn (site 5) at a discharge of 1,200 ft^3/s to 9,500 ft^2/1,000 ft in the Carbon River (site 6) at 300 ft^3/s. Maximum habitat for coho spawning ranged from 19,300 ft^2/1,000 ft at 1,000 ft^3/s in the White River near Auburn (site 5) to 5,700 ft^2/1,000 ft at 400 ft^3/s in the Puyallup River at Alderton (site 2). Maximum habitat for pink and chum salmon was greatest in the White River near Auburn (site 5) with 32,100 and 30,600 ft^2/1,000 ft, respectively, at 800 ft^3/s. Habitat for pink and chum spawning, 4,100 ft^2/1,000 ft at a discharge of 1,500 ft^3/s was less in the Puyallup River near Puyallup (site 1) than at other sites. For steelhead trout, maximum habitat for spawning ranged from 28,400 ft^2/1,000 ft at a discharge of 900 ft^3/s in the White River near Auburn (site 6) to 7,800 ft^2/1,000 ft at a discharge of 150 ft^3/s in the Carbon River (site 6).

Habitat areas computed for each median discharge or each month when a species and life stage is in the river at a site were averaged to form an index in order to compare sites for their quantity of habitat available for the same fish. The six study sites were ranked from number 1, the site with the greatest average habitat on the basis of median discharges, to number 6, the site with the least amount of average habitat for a particular species or life stage (table 14). Puyallup River near Puyallup (site 1) ranked number 1 in the habitat available for adult steelhead trout with 4,730 ft^2/1,000 ft, and number 2 in habitat for adult chinook salmon with 442 ft^2/1,000 ft. Puyallup River at Alderton (site 2) ranked number 1 in habitat available for adult chinook salmon with 682 ft^2/1,000 ft. Site 6 on the Carbon River had the least amount of habitat for adult fish and ranked sixth with 765 ft^2/1,000 ft available for adult steelhead trout and 0 ft^2/1,000 ft available for adult chinook salmon. Habitat for adult chinook salmon was also 0 ft^2/1,000 ft in the White River near Auburn (site 5).

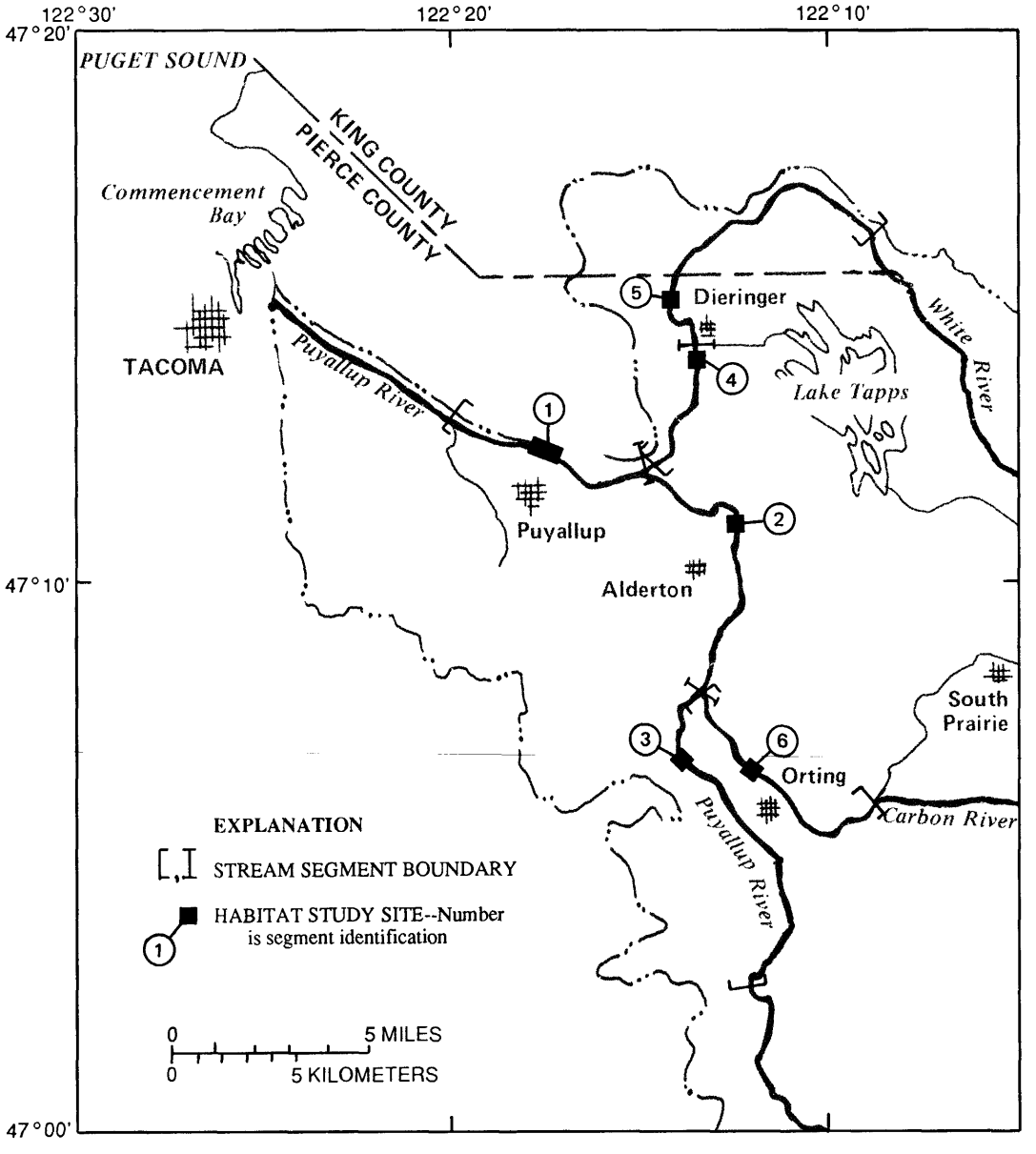


Figure 14.--Maximum habitat available for different life stages of steelhead trout and salmon at study sites in the lower Puyallup, White, and Carbon Rivers.

Species	Stream discharges providing maximum habitat, in square feet per 1,000 feet of stream, for each discharge-habitat relation			
	Adult	Spawning	Fry	Juvenile
Site 1--Puyallup River near Puyallup				
Steelhead trout	15,000	--	46,500	38,600
Chinook salmon	6,900	--	--	85,900
Coho salmon	--	--	--	85,900
Pink salmon	--	4,100	--	--
Chum salmon	--	4,100	--	--
Site 2--Puyallup River near Alderton				
Steelhead trout	7,700	8,200	19,700	21,000
Chinook salmon	8,400	10,200	--	35,400
Coho salmon	--	5,700	--	35,400
Pink salmon	--	8,700	--	--
Chum salmon	--	8,300	--	--
Site 3--Puyallup River near Orting				
Steelhead trout	3,200	14,200	28,600	14,800
Chinook salmon	1,000	17,500	--	22,500
Coho salmon	--	10,600	--	22,500
Pink salmon	--	15,900	--	--
Chum salmon	--	13,000	--	--
Site 4--White River near Dieringer				
Steelhead trout	6,300	14,300	32,800	19,900
Chinook salmon	1,600	16,200	--	52,100
Coho salmon	--	11,900	--	52,100
Pink salmon	--	14,500	--	--
Chum salmon	--	15,400	--	--
Site 5--White River near Auburn				
Steelhead trout	6,000	28,400	47,100	32,800
Chinook salmon	20	34,700	--	52,700
Coho salmon	--	19,300	--	52,700
Pink salmon	--	32,100	--	--
Chum salmon	--	30,600	--	--
Site 6--Carbon River near Orting				
Steelhead trout	2,300	7,800	23,300	15,200
Chinook salmon	4	9,500	--	14,400
Coho salmon	--	5,800	--	14,400
Pink salmon	--	9,700	--	--
Chum salmon	--	8,700	--	--

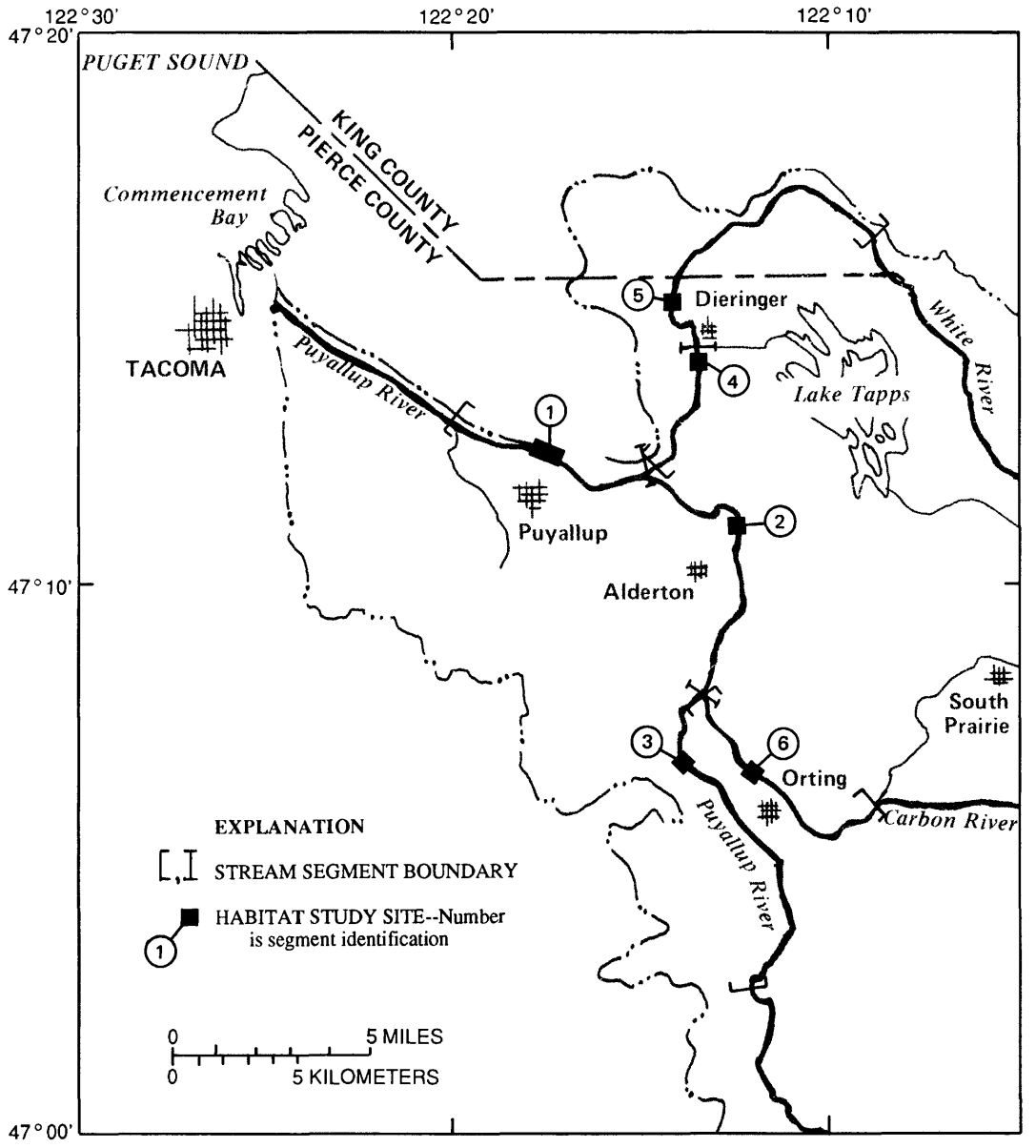


Figure 15.--Stream discharges providing maximum habitat for different life stages of steelhead trout and salmon at study sites in the lower Puyallup, White, and Carbon Rivers.

Species	Stream discharges providing maximum habitat, in square feet per 1,000 feet of stream, for each discharge-habitat relation			
	Adult	Spawning	Fry	Juvenile
Site 1--Puyallup River near Puyallup				
Steelhead trout	600	--	390	600
Chinook salmon	>13,000	--	--	390
Coho salmon	--	--	--	390
Pink salmon	--	1,500	--	--
Chum salmon	--	1,500	--	--
Site 2--Puyallup River at Alderton				
Steelhead trout	7,000	600	230	9,000
Chinook salmon	≥16,000	900	--	230
Coho salmon	--	400	--	230
Pink salmon	--	900	--	--
Chum salmon	--	600	--	--
Site 3--Puyallup River near Orting				
Steelhead trout	300	500	75	230
Chinook salmon	≥2,700	600	--	≥2,700
Coho salmon	--	230	--	≥2,700
Pink salmon	--	500	--	--
Chum salmon	--	400	--	--
Site 4--White River near Dieringer				
Steelhead trout	450	700	180	300
Chinook salmon	≥6,900	900	--	180
Coho salmon	--	300	--	180
Pink salmon	--	450	--	--
Chum salmon	--	450	--	--
Site 5--White River near Auburn				
Steelhead trout	1,700	900	50	900
Chinook salmon	>1,800	1,200	--	>1,800
Coho salmon	--	1,000	--	>1,800
Pink salmon	--	800	--	--
Chum salmon	--	800	--	--
Site 6--Carbon River near Orting				
Steelhead trout	250	150	76	≥3,200
Chinook salmon	2,800	300	--	≥3,200
Coho salmon	--	76	--	≥3,200
Pink salmon	--	190	--	--
Chum salmon	--	150	--	--

Table 14.--Ranking of the six study sites from greatest (1) to least (6) average habitat area available for each life stage and species. The habitat used for comparison is the average of habitat areas for each median discharge for each month that the fish is present at the site

[NA = Not applicable]

	Ranking number (average habitat in square feet per 1000 feet of stream)									
	ADULT		SPAWNING					JUVENILE		FRY
STUDY SITE	STEELHEAD	CHINOOK	STEELHEAD	CHINOOK	COHO	PINK	CHUM	CHINOOK/ COHO	STEELHEAD	STEELHEAD
1 Puyallup River near Puyallup	1 (4,730)	2 (442)	NA	NA	NA	6 (3,790)	6 (1,800)	2 (19,000)	2 (19,700)	5 (5,820)
2 Puyallup River at Alderton	3 (2,800)	1 (682)	3 (6,010)	3 (9,760)	3 (2,630)	4 (8,330)	3 (4,620)	5 (10,500)	4 (11,100)	3 (8,120)
3 Puyallup River near Orting	4 (1,920)	4 (5)	2 (13,900)	1 (16,200)	2 (6,870)	1 (15,500)	2 (11,800)	3 (15,900)	3 (13,200)	2 (20,400)
4 White River near Dieringer	5 (1,040)	3 (42)	4 (5,530)	2 (14,800)	4 (1,890)	3 (11,000)	4 (2,490)	4 (15,500)	6 (5,680)	6 (1,030)
5 White River near Auburn	2 (4,130)	6 (0)	1 (16,500)	5 (7,280)	1 (14,000)	2 (12,100)	1 (20,500)	1 (31,900)	1 (24,700)	1 (41,900)
6 Carbon River near Orting	6 (765)	6 (0)	5 (3,280)	4 (7,920)	5 (1,180)	5 (7,060)	5 (2,360)	6 (4,420)	5 (7,220)	4 (7,710)

For the rearing of juveniles and steelhead trout fry, the White River near Auburn (site 5) ranked number 1 in average habitat, with 31,900 ft^2/1,000 ft for juvenile salmon, 24,700 ft^2/1,000 ft for juvenile steelhead trout, and 41,900 ft^2/1,000 ft for steelhead trout fry. The next site downstream, White River near Dieringer (site 4), ranked sixth in habitat for both steelhead trout juveniles with 5,680 ft^2/1,000 ft, and fry with 1,030 ft^2/1,000 ft. Carbon River (site 6) ranked sixth in average habitat available for juvenile salmon with 4,420 ft^2/1,000 ft.

Puyallup River near Orting (site 3) generally ranked 1 or 2 in the amounts of average habitat for the spawning life stage of all five species of fish. This site ranked number 1 in habitat for chinook salmon and pink salmon with 16,200 ft^2/1,000 ft and 15,500 ft^2/1,000 ft, respectively, and number 2 in habitat for steelhead trout, coho salmon, and chum salmon with 13,900 ft^2/1,000 ft, 6,870 ft^2/1,000 ft, and 11,800 ft^2/1,000 ft, respectively. White River near Auburn (site 5) was the next best site in average habitat available for spawning and ranked number 1 in habitat for steelhead trout, coho salmon, and chum salmon with 16,500 ft^2/1,000 ft, 14,000 ft^2/1,000 ft, and 20,500 ft^2/1,000 ft, respectively. This site ranked number 2 in habitat for pink salmon with 12,100 ft^2/1,000 ft; however, it was fifth in habitat for chinook salmon with only 7,280 ft^2/1,000 ft available for spawning. Two sites, the Puyallup River near Puyallup (site 1) and the Carbon River (site 6), generally ranked as having the least habitat for spawning. Puyallup River near Puyallup (site 1) ranked sixth for pink and chum salmon spawning with 3,790 ft^2/1,000 ft and 1,800 ft^2/1,000 ft, respectively. Carbon River (site 6) ranked fifth in habitat for steelhead trout (3,280 ft^2/1,000 ft), coho salmon (1,180 ft^2/1,000 ft), pink salmon (7,060 ft^2/1,000 ft), and chum salmon (2,360 ft^2/1,000 ft).

On the basis of fish-preference criteria (Appendix A), the limited spawning habitat for salmon and steelhead trout in the Puyallup River near Puyallup (site 1) is due primarily to the abundance of sand in the substrate composition; however, spawning habitat may be further reduced by depths greater than about 4 feet and velocities greater than about 4.0 ft/s. The minimum habitat in the Carbon River near Orting (site 6) for nearly all the species and life stages appears to be due to velocities that exceed preference criteria. Habitat for juvenile salmon and steelhead trout in the Carbon River is limited by velocities exceeding 1.5 ft/s even at low flows (less than about 250 ft^3/s). Habitat in the Carbon River for adult steelhead trout is limited by velocities greater than about 3 ft/s and for spawning is limited by velocities exceeding about 4.0 ft/s at flows greater than about 500 ft^3/s. The minimal habitat for adult chinook salmon at all the study sites is generally due to depths less than 4 feet. At some sites, however, the limited habitat is also caused by velocities exceeding 3.0 ft/s at discharges large enough to have water-surface elevations that provide depths greater than 4 feet.

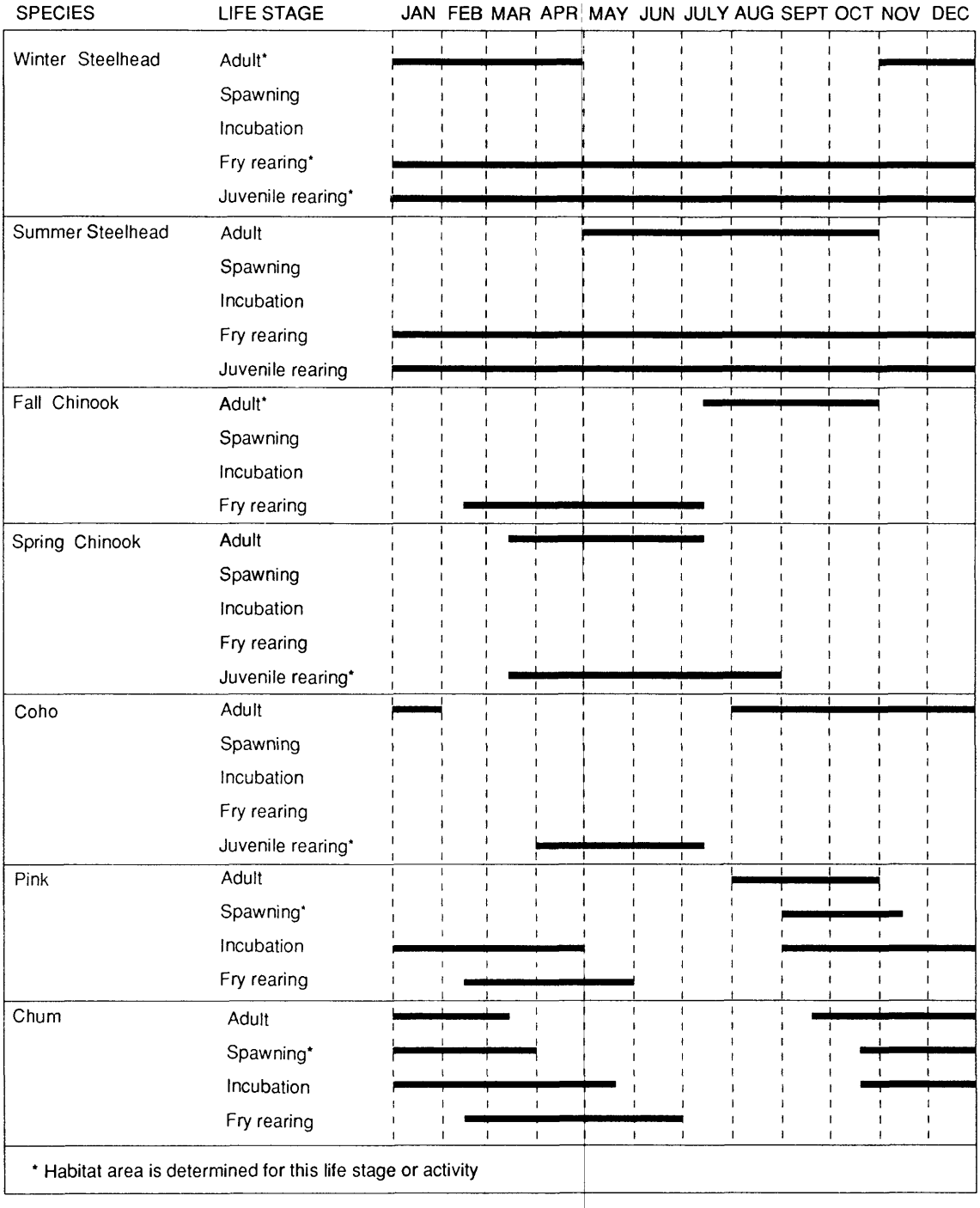


Figure 16.--Times of the year that different life stages of steelhead trout and salmon typically are present at site 1, Puyallup River near Puyallup. (Sources: Williams and others (1975); Tom Deming, Puyallup Tribe of Indians, oral commun., 1985; Don Finney, Muckleshoot Indian Tribe, oral commun., 1986; Joe Miyamoto, Puyallup Tribe of Indians, oral commun., 1986.)

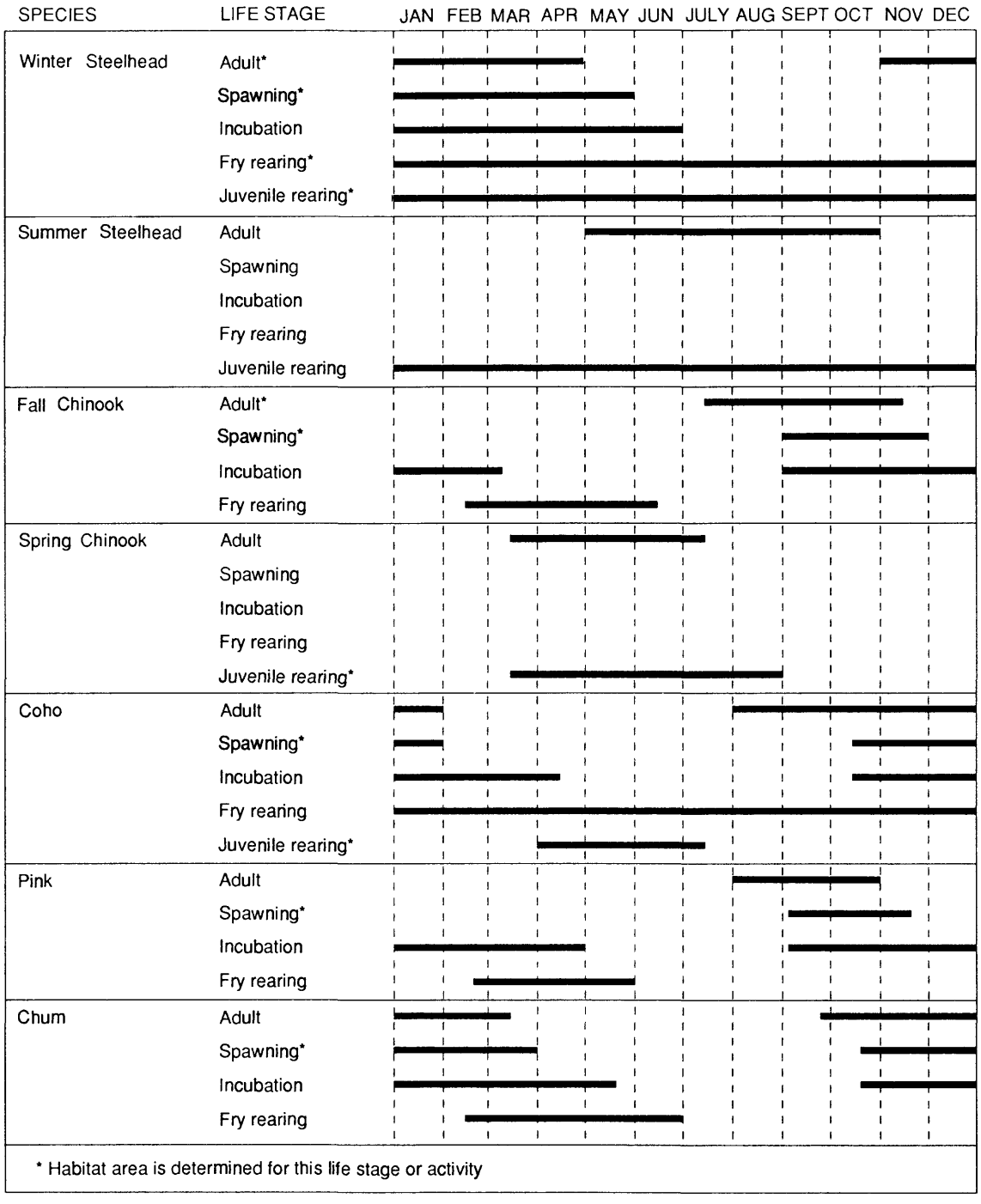


Figure 17.--Times of the year that different life stages of steelhead trout and salmon typically are present at site 1, Puyallup River near Puyallup. (Sources: Williams and others (1975); Tom Deming, Puyallup Tribe of Indians, oral commun., 1985; Don Finney, Muckleshoot Indian Tribe, oral commun., 1986; Joe Miyamoto, Puyallup Tribe of Indians, oral commun., 1986.)

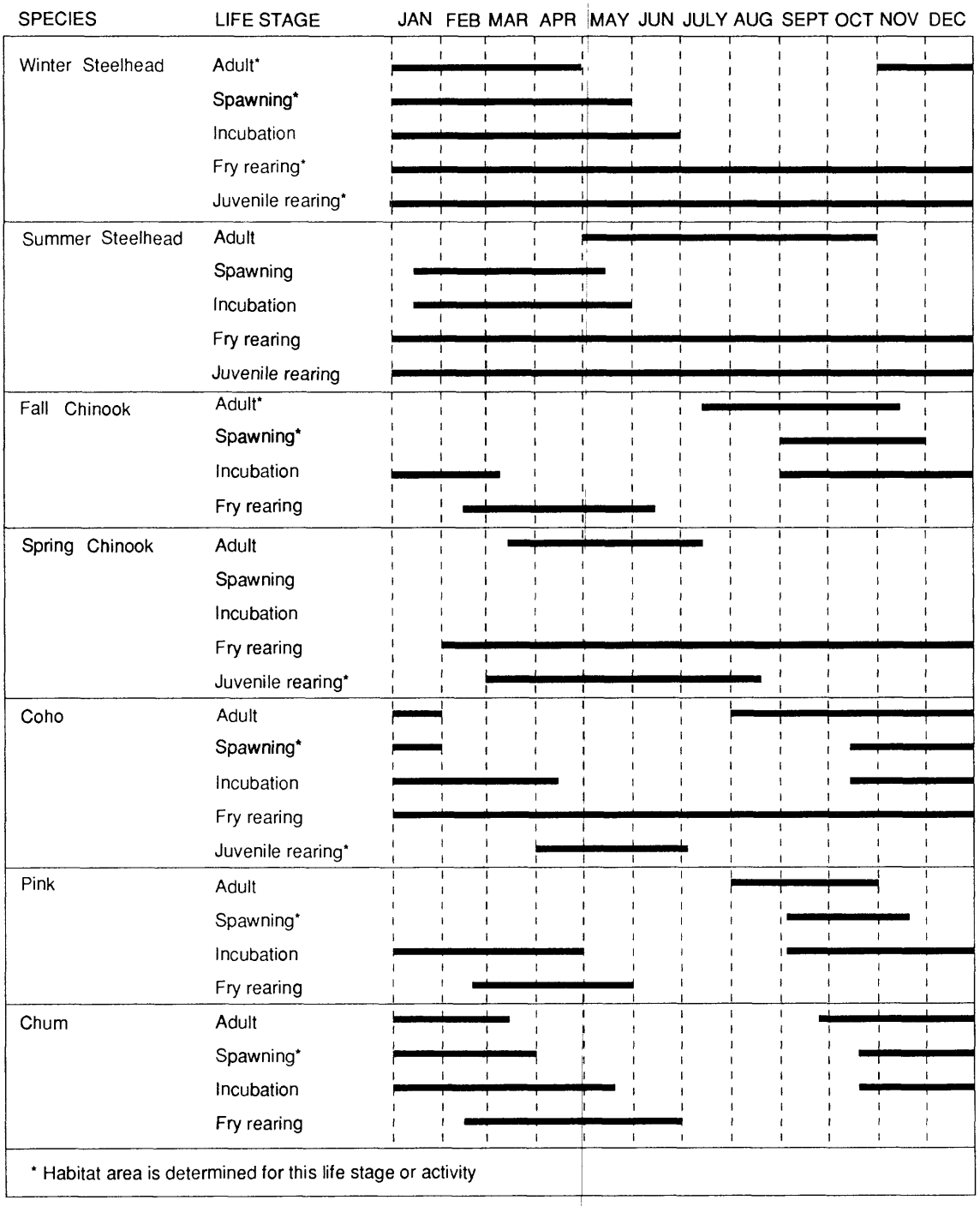


Figure 18.--Times of the year that different life stages of steelhead trout and salmon typically are present at site 1, Puyallup River near Puyallup. (Sources: Williams and others (1975); Tom Deming, Puyallup Tribe of Indians, oral commun., 1985; Don Finney, Muckleshoot Indian Tribe, oral commun., 1986; Joe Miyamoto, Puyallup Tribe of Indians, oral commun., 1986.)

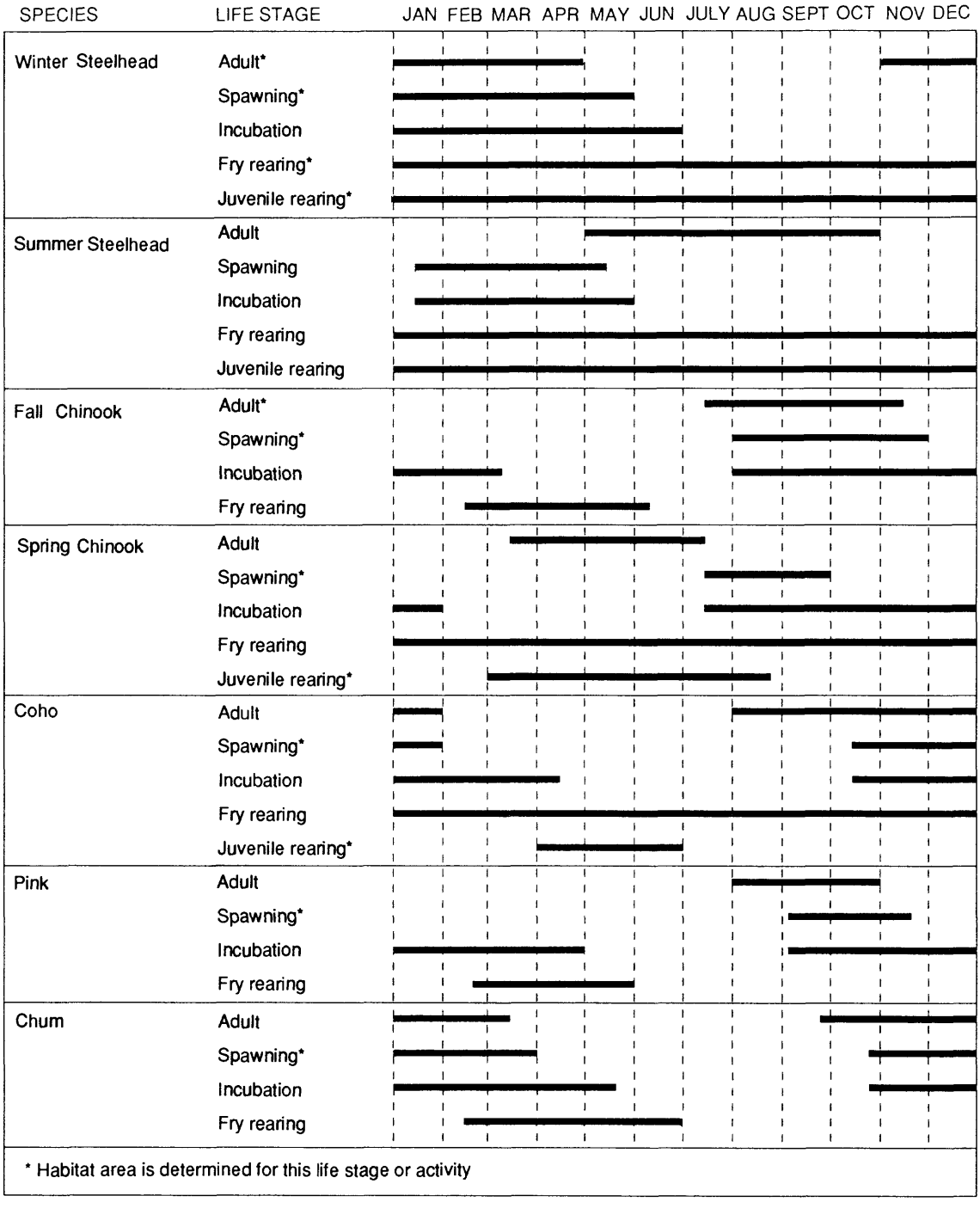


Figure 19.--Times of the year that different life stages of steelhead trout and salmon typically are present at site 1, Puyallup River near Puyallup. (Sources: Williams and others (1975); Tom Deming, Puyallup Tribe of Indians, oral commun., 1985; Don Finney, Muckleshoot Indian Tribe, oral commun., 1986; Joe Miyamoto, Puyallup Tribe of Indians, oral commun., 1986.)

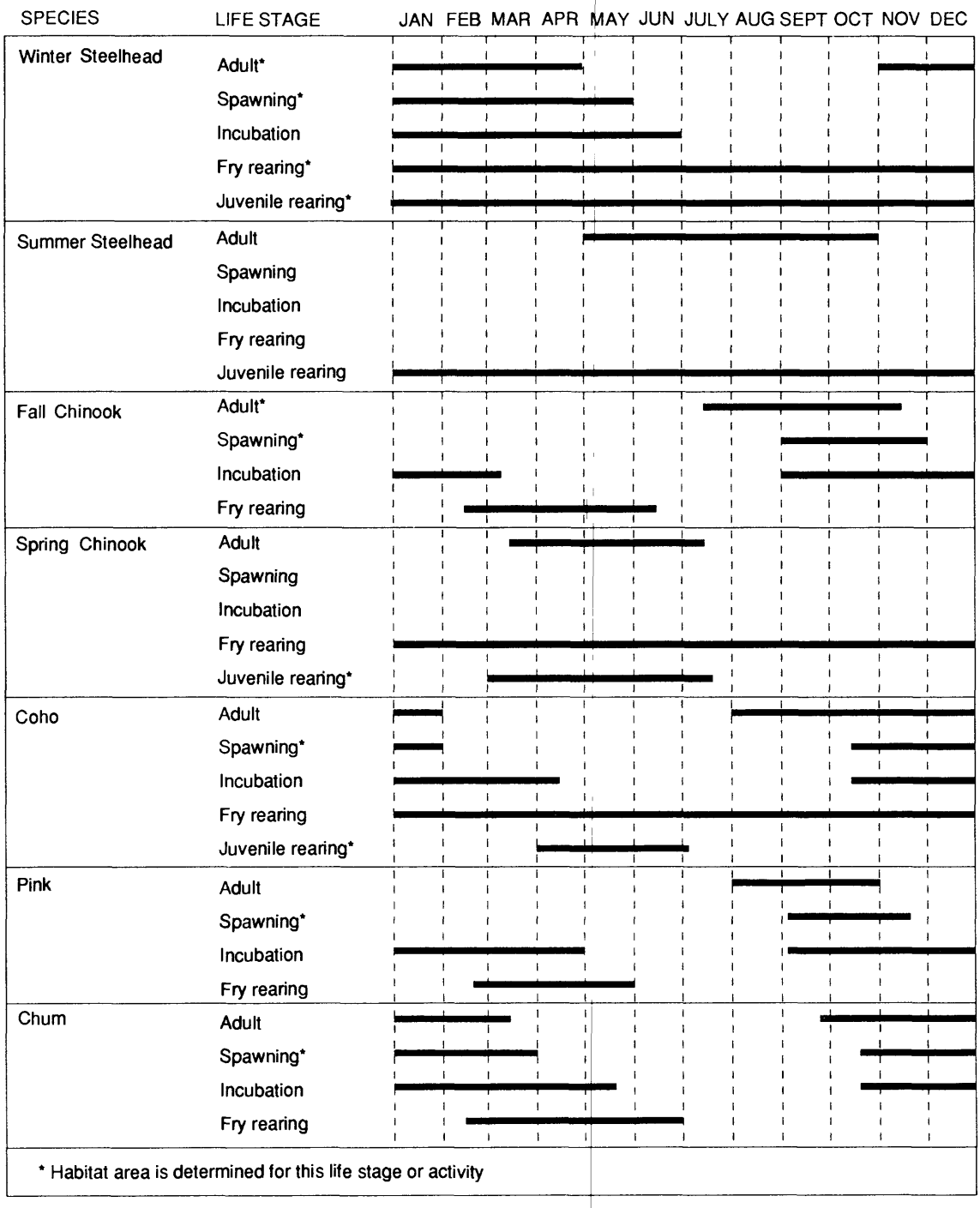


Figure 20.--Times of the year that different life stages of steelhead trout and salmon typically are present at site 1, Puyallup River near Puyallup. (Sources: Williams and others (1975); Tom Deming, Puyallup Tribe of Indians, oral commun., 1985; Don Finney, Muckleshoot Indian Tribe, oral commun., 1986; Joe Miyamoto, Puyallup Tribe of Indians, oral commun., 1986.)

SUMMARY

This report presents discharge-habitat relations that were developed for several life stages and species of salmon and steelhead trout and the available habitat for these fish that presently exists in the lower Puyallup, White, and Carbon Rivers in western Washington. The techniques of IFIM and the PHABSIM computer programs were used to determine the available habitat area at different streamflows at six study sites for four life stages of steelhead trout and four species of salmon. The WSP hydraulic simulation model of PHABSIM was used to develop the hydraulic data required by the HABTAT program to simulate habitat area available for a given life stage of fish.

At each study site the maximum habitat available for each species and life stage was determined from the discharge-habitat relations developed in the PHABSIM procedures. In some instances, the simulated discharge associated with maximum habitat area was a large discharge that is exceeded less than 10 percent of the time for any given month. For adult steelhead trout, maximum habitat ranged from 15,000 ft^2/1,000 ft at 600 ft^3/s in the Puyallup River near Puyallup to 2,300 ft^2/1,000 ft at a discharge of 250 ft^3/s in the Carbon River near Orting. For adult chinook salmon, maximum habitat ranged from 8,400 ft^2/1,000 ft at 16,000 ft^3/s in the Puyallup River at Alderton to 4 ft^2/1,000 ft at 2,800 ft^3/s in the Carbon River. For the spawning life stage of the salmon species, maximum habitat ranged from 34,700 ft^2/1,000 ft at a discharge of 1,200 ft^3/s for chinook salmon in the White River near Auburn to 4,100 ft^2/1,000 ft at a discharge of 1,500 ft^3/s for pink and chum salmon in the Puyallup River near Puyallup. For steelhead trout, maximum spawning habitat ranged from 28,400 ft^2/1,000 ft at a discharge of 900 ft^3/s in the White River near Auburn to 7,800 ft^2/1,000 ft at a discharge of 150 ft^3/s in the Carbon River. For juvenile chinook and coho salmon, maximum habitat ranged from 85,900 ft^2/1,000 ft at a discharge of 390 ft^3/s in the Puyallup River near Puyallup to 14,400 ft^2/1,000 ft at 3,200 ft^3/s in the Carbon River. For juvenile steelhead trout, maximum habitat ranged from 38,600 ft^2/1,000 ft at 600 ft^3/s in the Puyallup River near Puyallup to 14,800 ft^2/1,000 ft at 2,700 ft^3/s in the Puyallup River near Orting. For steelhead trout fry, maximum habitat ranged from 47,100 ft^2/1,000 ft at a discharge of 50 ft^3/s in the White River near Auburn to 19,700 ft^2/1,000 ft at 230 ft^3/s in the Puyallup River at Alderton.

Habitat area for each species and life stage was calculated for the median discharge of each month when the particular fish is present in the river at a study site. At median discharges available habitat was larger in area for the rearing life stages of steelhead trout and salmon juveniles than for other species or life stages. The least amount of available habitat area at all six sites was that for adult chinook salmon. At median discharges for the months of July through November, there was no available habitat for adult chinook salmon in the White River near Auburn or in the Carbon River near Orting. Habitat also was at a minimum for adult steelhead trout and ranged from 660 ft^2/1,000 ft in the Carbon River to 5,400 ft^2/1,000 ft in the Puyallup River near Puyallup. Habitat available for the spawning life stage at median discharges was more abundant for chinook salmon than for other species in the Puyallup River near Orting and at Alderton, the White River near Dieringer, and the Carbon River near Orting. In the Puyallup River at Alderton and in the Carbon River, the least amount of available habitat for spawning was for

coho salmon. At the White River near Dieringer site, less spawning habitat was available for chum salmon than the other species. In the White River near Auburn, available habitat for spawning was most abundant for chum salmon and least abundant for chinook salmon. Only pink and chum salmon spawn in the Puyallup River near Puyallup. Of these two, habitat was greater for pink salmon than for chum salmon.

Habitat areas corresponding to median discharges were averaged for the period of time that a particular fish is in the river. The six sites were ranked and compared for their general habitat quantity using these average habitat values. The site with the largest amount of average habitat ranked as number 1, and the site with the least amount of average habitat ranked as number 6. The Puyallup River near Puyallup site ranked number 1 in the amount of habitat for adult steelhead trout (4,730 ft^2/1,000 ft) and number 2 for adult chinook salmon (442 ft^2/1,000 ft). The next site upstream, Puyallup River at Alderton, ranked number 1 in habitat for adult chinook salmon with 682 ft^2/1,000 ft. The site on the Carbon River ranked sixth in the amount of adult habitat with 765 ft^2/1,000 ft available for steelhead trout and 0 ft^2/1,000 ft available for chinook salmon.

Average habitat for the rearing of juvenile salmon and steelhead trout and steelhead trout fry was greatest in the White River near Auburn, ranking number 1 with 31,900 ft^2/1,000 ft for juvenile salmon, 24,700 ft^2/1,000 ft for juvenile steelhead trout, and 41,900 ft^2/1,000 ft for steelhead trout fry. White River near Dieringer ranked sixth in habitat for steelhead trout fry (1,030 ft^2/1,000 ft) and juveniles (5,680 ft^2/1,000 ft), and Carbon River ranked sixth in habitat for juvenile salmon (4,420 ft^2/1,000 ft).

For spawning, the greatest amount of average habitat generally was found in the Puyallup River near Orting. This site ranked number 1 in habitat for chinook salmon (16,200 ft^2/1,000 ft) and pink salmon (15,500 ft^2/1,000 ft), and number 2 in habitat for steelhead trout (13,900 ft^2/1,000 ft), coho salmon (6,870 ft^2/1,000 ft), and chum salmon (11,800 ft^2/1,000 ft). White River near Auburn also ranked high in the amount of habitat available for spawning, being number 1 in habitat for steelhead trout, coho salmon, and chum salmon and number 2 in habitat for pink salmon, but ranking fifth in the amount of average habitat for chinook salmon spawning. The sites ranked as having the least habitat for spawning were the Puyallup River near Puyallup and the Carbon River.

Cross-sectional averaged depths at the Puyallup River near Puyallup site ranged from 1.8 feet at low flow to 6.8 feet at high flow; from 1.3 to 8.8 feet at the Puyallup River at Alderton site; from 0.5 to 2.6 feet at the Puyallup River near Orting site; from 1.5 to 5.2 feet at the White River near Dieringer site; from 0.4 to 2.2 feet at the White River near Auburn site; and from 0.8 to 2.8 feet at the Carbon River near Orting site. Cross-sectional averaged velocities ranged from 1.8 to 5.3 ft/s at the Puyallup River near Puyallup site; from 1.7 to 6.6 ft/s at the Puyallup River at Alderton site; from 1.0 to 6.0 ft/s at the Puyallup River near Orting site; from 1.4 to 4.7 ft/s at the White River near Dieringer site; from 1.0 to 2.9 ft/s at the White River near Auburn site; and from 1.7 to 5.9 ft/s at the Carbon River near Orting site.

The predominant streambed material at all the sites was some combination of gravel, cobbles, and sand. Within the main channel, the gravel and cobbles generally were present in greater percentages than sand. However, at Puyallup River near Puyallup and at three cross sections of the Puyallup River at Alderton, parts of the streambed consisted of sand and gravel in nearly equal proportions, or the percentage of sand exceeded 50 percent.

On the basis of fish-preference criteria, the abundance of sand in the streambed material limited the habitat available for spawning in the Puyallup River near Puyallup site. At high flows, spawning habitat may be further limited by depths greater than about 4 feet and velocities greater than about 4.0 ft/s. However, the greater adult chinook habitat at the Puyallup River at Alderton site than at other sites was due to water depths which exceeded 4 feet. The limited habitat in the Carbon River for all the life stages and species compared to the other sites was due to velocities exceeding preference criteria. Habitat for juvenile steelhead trout and salmon was limited by velocities exceeding 1.5 ft/s even at low flows (less than about 250 ft^3/s). Adult steelhead trout habitat was limited by velocities exceeding 3 ft/s and spawning habitat was limited at about 4.0 ft/s. The limited habitat for adult chinook salmon at all the study sites was generally due to depths less than 4 feet; however, at some sites, the habitat also was limited by velocities exceeding 3.0 ft/s at a stream discharge having water-surface elevations that provided water depths greater than 4 feet.

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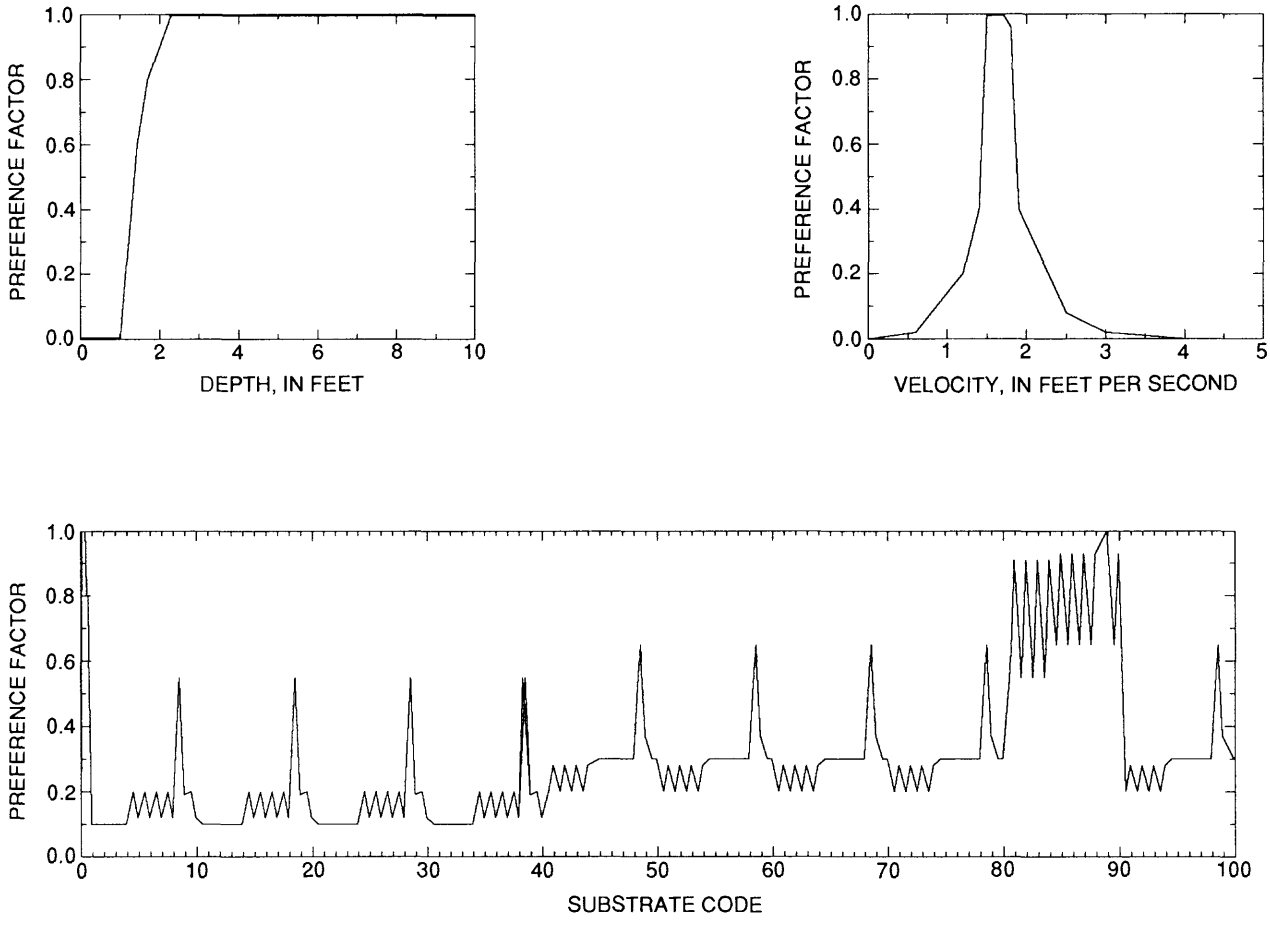
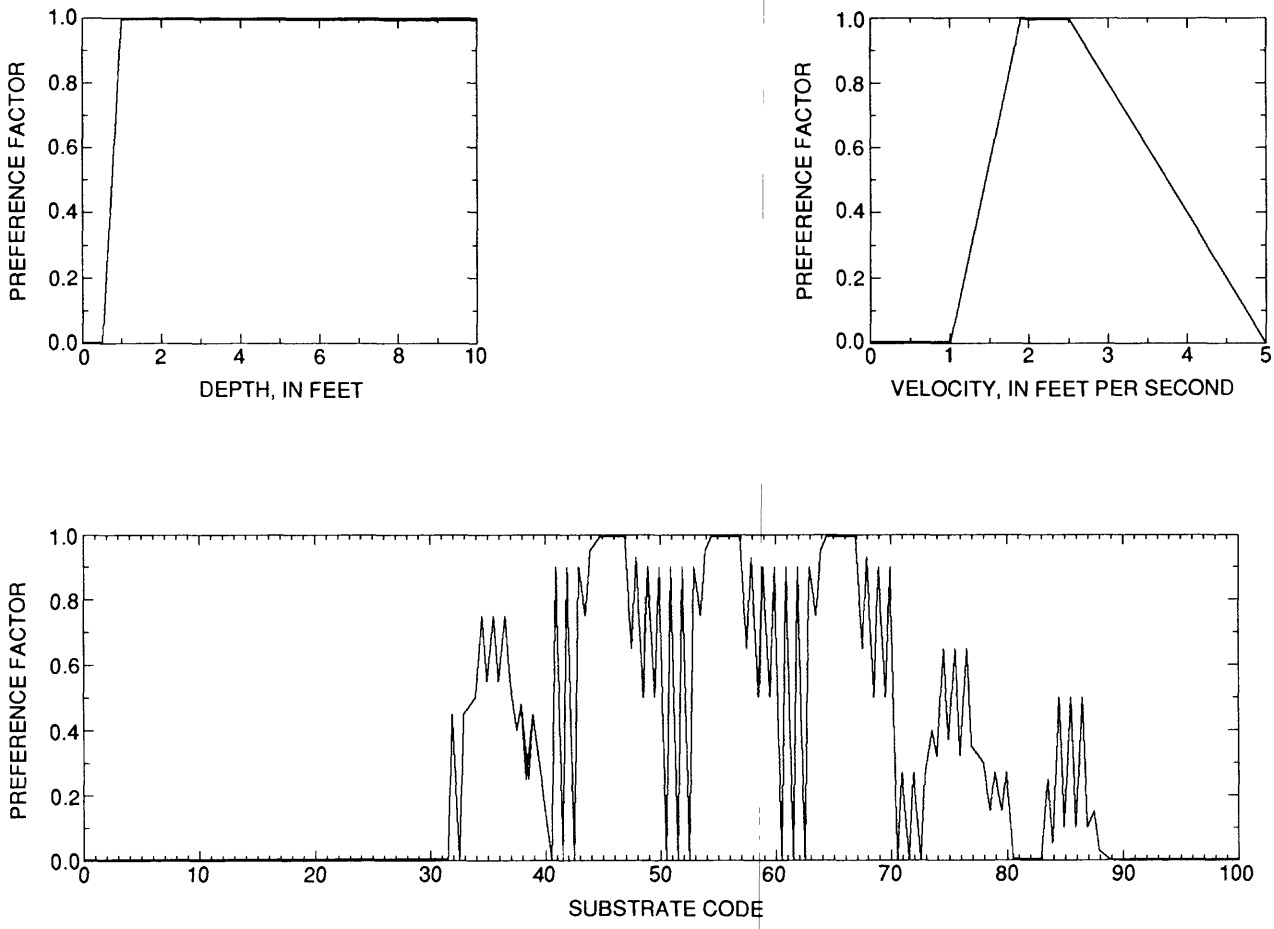
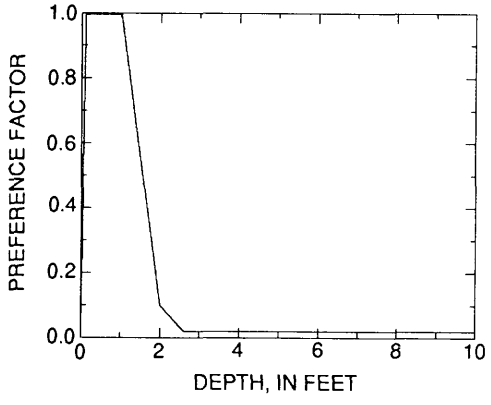
Appendix A.--Habitat preference curves for steelhead trout and salmon in the lower Puyallup, White, and Carbon Rivers.

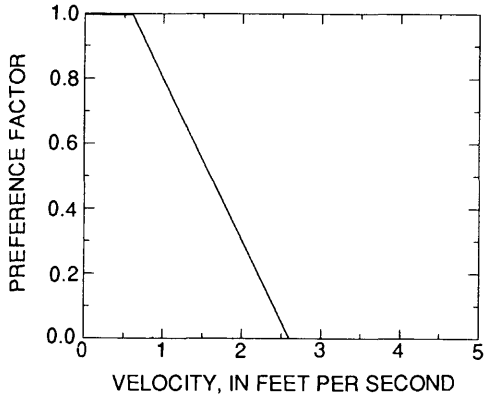


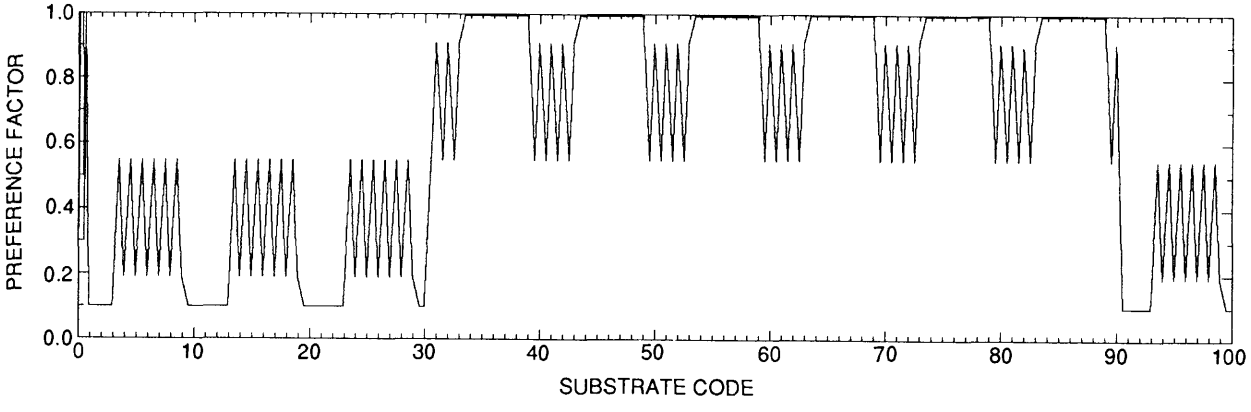
A.1.--Habitat preference curves for steelhead trout adults, for the Puyallup, White, and Carbon Rivers, Washington. (Source: H. Beecher, State of Washington Department of Game, written commun., 1983 and 1986.)



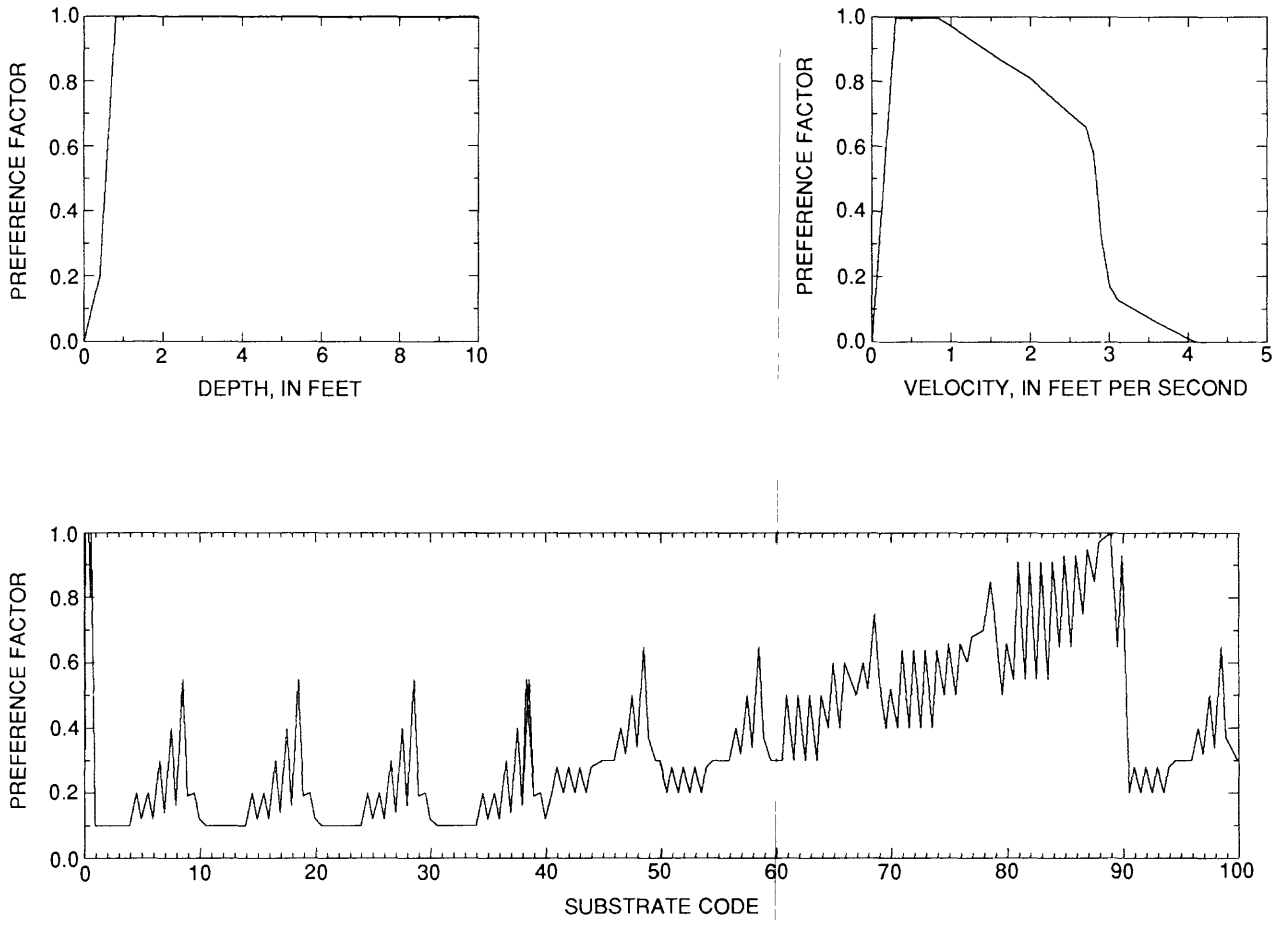
A.2.--Habitat preference curves for steelhead trout spawning, for the Puyallup, White, and Carbon Rivers, Washington, (Source: H. Beecher, State of Washington Department of Game, written commun., 1983, substrate and cover code from H. Beecher, written commun., 1986.)



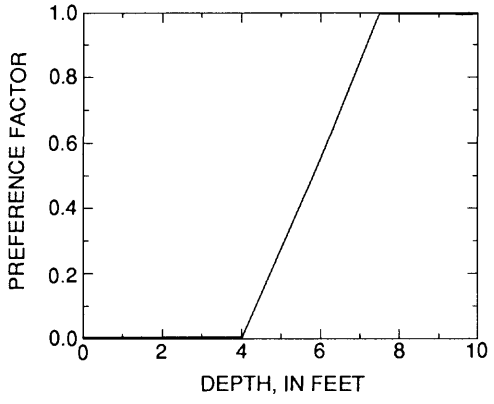


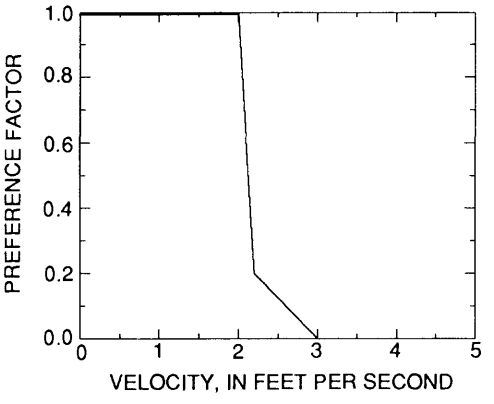


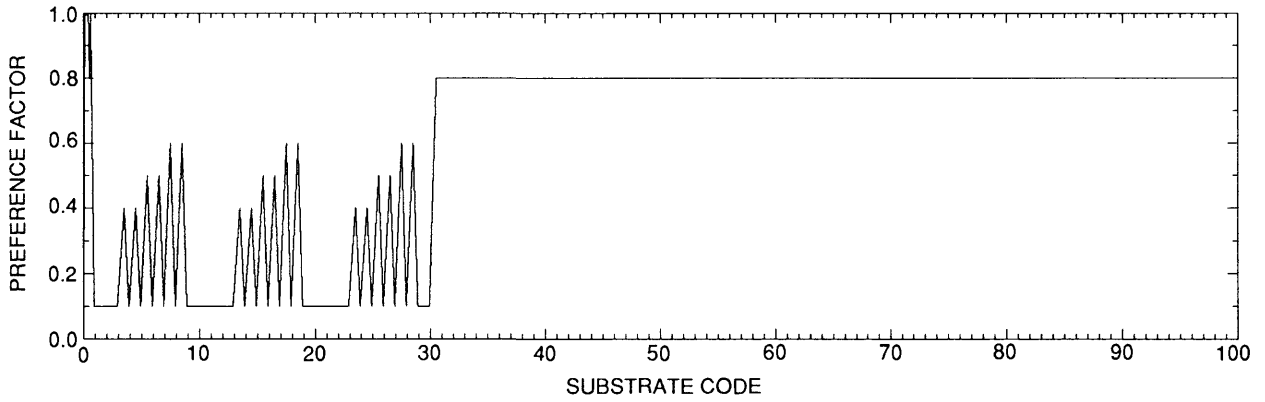
A.3.--Habitat preference curves for steelhead trout fry for the Puyallup, White, and Carbon Rivers, Washington. (Source: H. Beecher, State of Washington Department of Game, written commun., 1983 and 1986.)



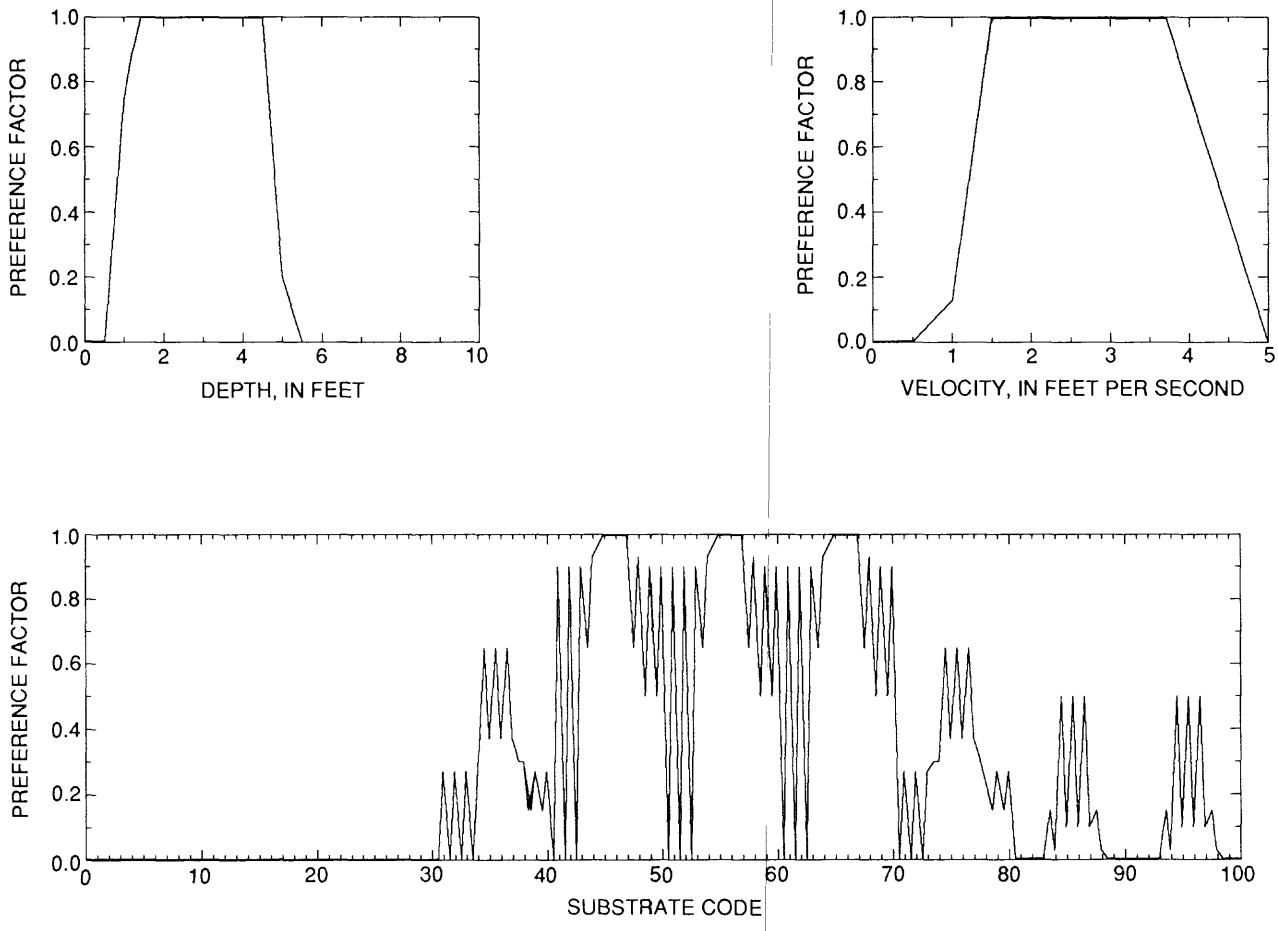
A.4.--Habitat preference curves for steelhead trout juveniles for the Puyallup, White, and Carbon Rivers, Washington. (Source: H. Beecher, State of Washington Department of Game, written commun., 1983 and 1986.)



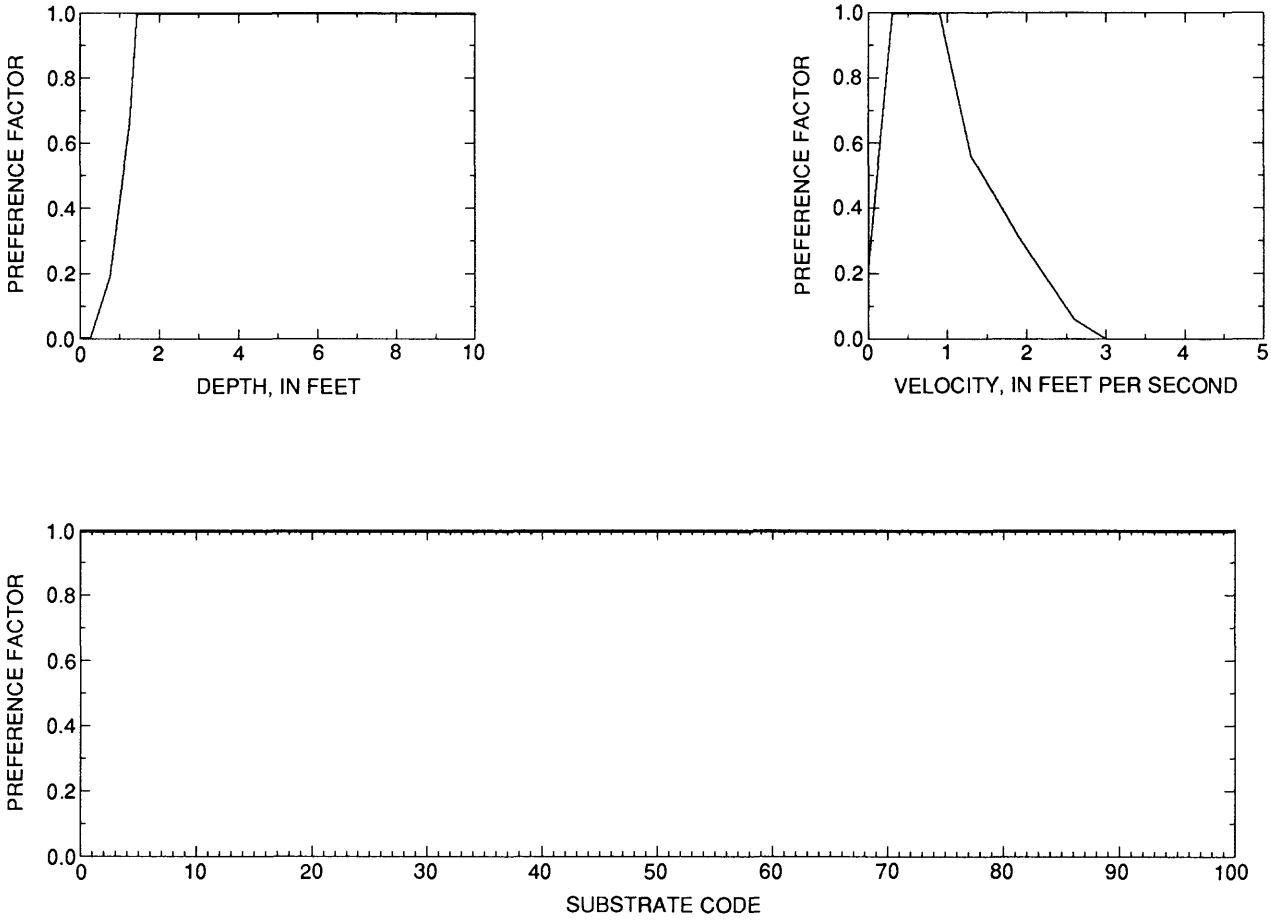




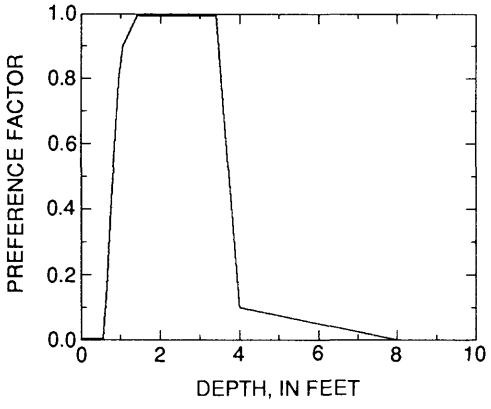
A.5.--Habitat preference curves for chinook salmon adults for the Puyallup, White, and Carbon Rivers, Washington. (Sources: depth and velocity curves from State of Washington Department of Fisheries, written commun., 1986; substrate curve form Dames and Moore Consultants, written commun., 1984; cover curve from H. Beecher, State of Washington Department of Game, written commun., 1986.)

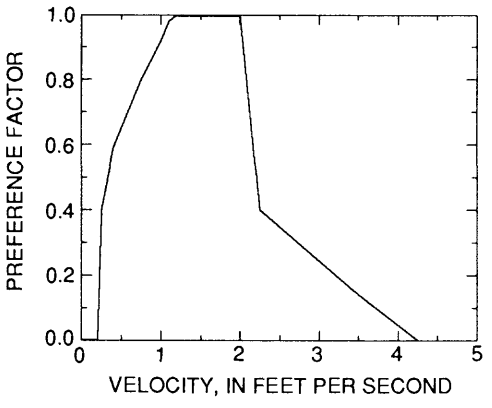


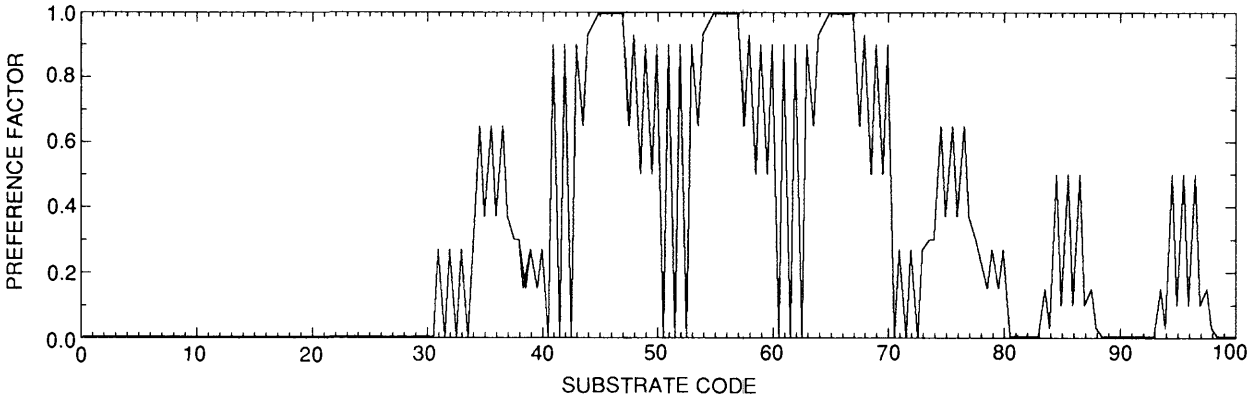
A.6.--Habitat preference curves for chinook salmon spawning for the Puyallup, White, and Carbon Rivers, Washington. (Sources: depth and velocity curves from State of Washington Department of Fisheries, written commun., 1986; substrate curve from Dames and Moore Consultants, written commun., 1984.)



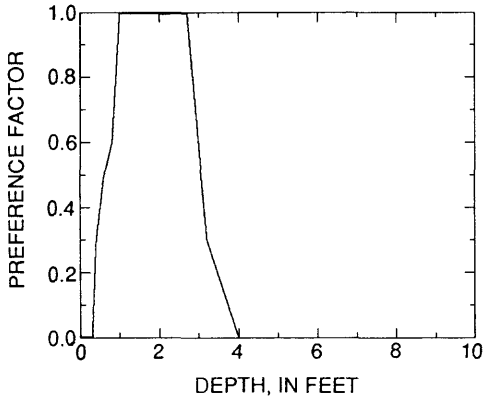
A.7.--Habitat preference curves for chinook and coho salmon juveniles for the Puyallup, White, and Carbon Rivers, Washington. (Sources: depth and velocity curves from State of Washington Department of Fisheries, written commun., 1986; substrate curve from Embrey, 1987, in preparation.)

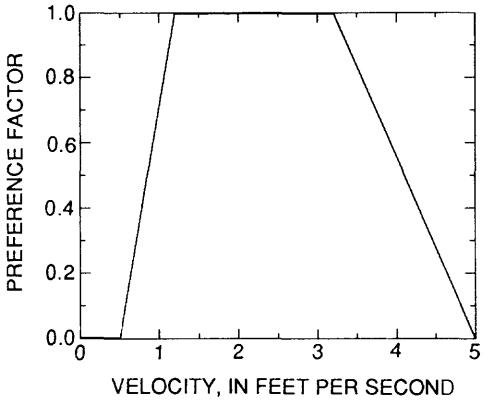


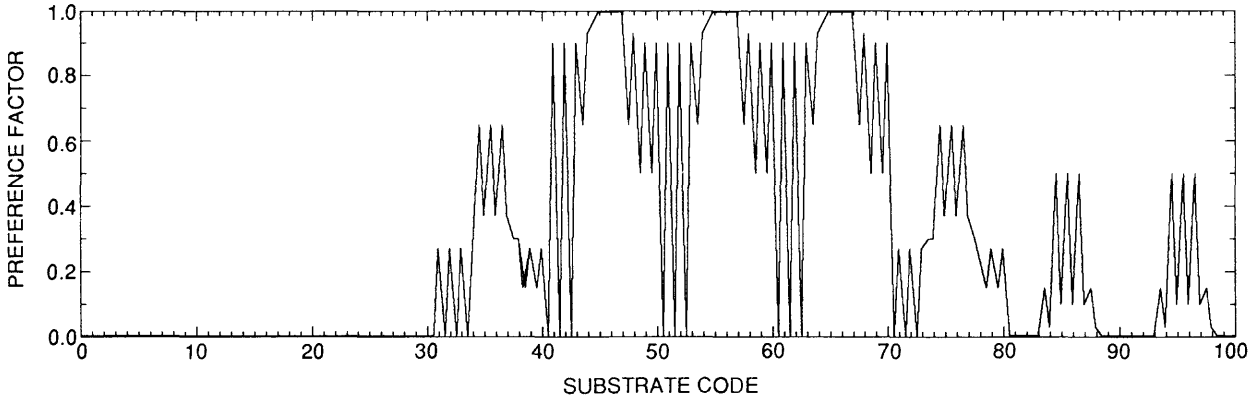




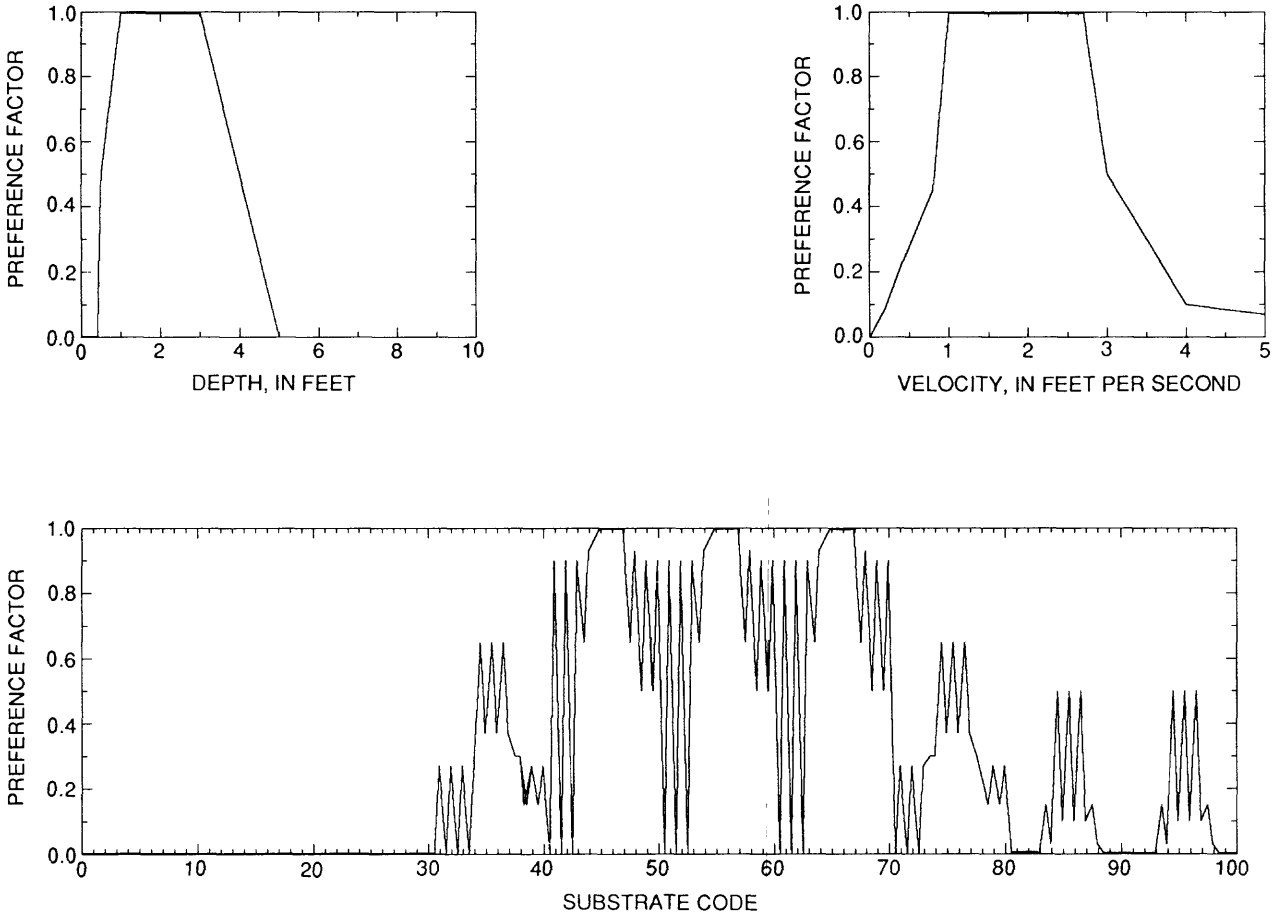
A.8.--Habitat preference curves for coho salmon spawning for the Puyallup, White, and Carbon Rivers, Washington. (Sources: depth and velocity curves from State of Washington Department of Fisheries, written commun., 1986; substrate curve from B. Caldwell, State of Washington Department of Ecology, written commun., 1984.)







A.9.--Habitat preference curves for pink salmon spawning for the Puyallup, White, and Carbon Rivers, Washington. (Sources: depth and velocity curves from State of Washington Department of Fisheries, written commun., 1986; substrate curve from B. Caldwell, State of Washington Department of Ecology, written commun., 1984.)



A.10.--Habitat preference curves for chum salmon spawning for the Puyallup, White, and Carbon Rivers, Washington. (Sources: depth and velocity curves from State of Washington Department of Fisheries, written commun., 1986; substrate curve from B. Caldwell, State of Washington Department of Ecology, written commun., 1984.)

Appendix B.--The size ranges of the substrate particles described by the substrate preference curves in Appendix A and the format of the substrate code as it is entered into the data files.

Substrate particle code number	Description	Diameter	
		millimeters	inches
0	organic detritus[1]		
1	silt, clay	<2	<0.1
2	sand[2]	<2	<0.1
3	small gravel	2 - 12	0.1 - 0.5
4	medium gravel	12 - 38	0.5 - 1.5
5	large gravel	38 - 76	1.5 - 3.0
6	small cobble	76 - 152	3.0 - 6.0
7	large cobble	152 - 305	6.0 - 12.0
8	boulder	>305	>12.0
9	bedrock	---	---

[1]Material smaller than that which will provide cover.
[2]Investigators use best judgement in the field to estimate whether small particles are sand or silt.

The substrate code is a 3-digit code as follows:

AB.C

where, A = dominant substrate particle code (from percent abundance),
B = subdominant substrate particle code (from percent abundance), and
C = percent of dominant particle (rounded to nearest 10 percent and last zero dropped).

Example: 53.9 where
5 = large gravel
3 = small gravel
0.9 = 90 percent large gravel

The substrate preference curves for spawning are constructed using the steps listed below.

1. The substrate coding will give a preference value for the substrate equal to zero when 50 percent or more of the substrate has a code equal to zero, one, or two. For example, 40.5 = zero preference, as does 41.5 and 14.6.

2. All other preference values are determined by using weighted averages. The value of the dominant substrate is multiplied by the percent of the dominant substrate, and that product is added to the product of the subdominant substrate times the percent of subdominant substrate.

Substrate Preference Value = [(Dominant Value) x (% Dominant)] +
[(Subdominant Value) x (% Subdominant)]

For example: the preference for Large Gravel (code 5) is assigned a value of 1.0, and Small Gravel (code 3) is assigned a value of 0.10 for a chinook salmon spawning curve. If the 3-digit code is 53.9 the Substrate Preference Value is computed as follows:

Substrate Preference Value = [(1.0) x (0.90)] + [(0.20) x (0.10)] = 0.92 = 0.9

The coordinate values for the plotting points entered into the computer are generally the 50 and 90 percent (AB.5 and AB.9) breaks in the preference value computations.