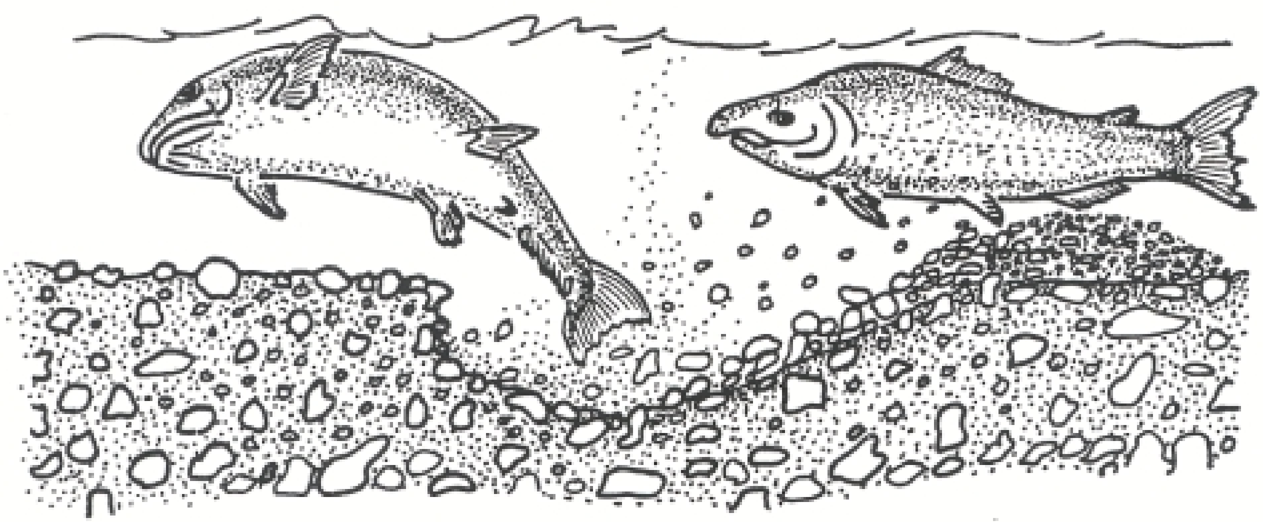
ESTIMATION OF STREAM DISCHARGES PREFERRED BY STEELHEAD TROUT FOR SPAWNING AND REARING IN WESTERN WASHINGTON



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Prepared in cooperation with the
State of Washington Department of Game
1976

OPEN-FILE REPORT 75-155

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By C. H. Swift III

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For further information on this investigation and on other water-resources studies in Washington carried out by the U.S. Geological Survey, contact the U.S. Geological Survey, Water Resources Division, 1305 Tacoma Avenue South, Tacoma, Wash. 98402

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The following factors are provided for conversion of English values used in this report to metric values:

Multiply	By	To obtain
Inches	25.4	millimetres (mm)
Feet (ft)	0.3048	metres (m)
Square feet (ft^2)	0.09290	square metres (m^2)
Square miles (mi^2)	2.590	square kilometres (km^2)
Feet per mile (ft/mi)	0.1894	metres per kilometre (m/km)
Feet per second (ft/s)	0.3048	metres per second (m/s)
Cubic feet per second (ft^3/s)	0.2832	cubic metres per second (m^3/s)
Pounds (lbs)	0.4536	kilograms (kg)

ESTIMATION OF STREAM DISCHARGES PREFERRED BY STEELHEAD TROUT FOR SPAWNING AND REARING IN WESTERN WASHINGTON

By C. H. Swift III

ABSTRACT

Determined during the study of selected stream reaches used for spawning and rearing by steelhead trout were (1) stream discharges that cover the greatest areas of the streambeds with water at both the depths and the velocities preferred by spawning steelhead; (2) discharges that cover selectively reduced streambed areas with water at both the depths and velocities preferred by spawning steelhead; (3) discharges that, cover the greatest streambed areas with water at velocities preferred by spawning steelhead; (4) rearing discharges that cover the streambed, but not the banks of the channel, with water; and (5) average wetted perimeters of the channels at water stages corresponding to the rearing discharges. These discharges and wetted perimeters were determined by measurements at 54 study reaches on 18 streams representative in size and 1ccation of those used by steelhead for spawning and rearing.

Using multiple-regression techniques and the measured discharges and wetted perimeters, equations were developed for estimating the spawning and rearing discharges and the wetted perimeter for rearing, at unmeasured stream sites. The independent parameters used were drainage area, mean altitude of the basin, reach altitude, reach slope, and average width of reach at toe of bank. Standard errors of estimate for the equations ranged from 26 to 50 percent for discharges corresponding to the greatest areas of preferred depths and velocities, from 32 to 46 percent for discharges corresponding to reduced areas of preferred depths and velocities, from 44 to 68 percent for discharges corresponding to the greatest areas of preferred velocities, from 46 to 57 percent for rearing discharges, and from 20 to 41 percent for the rearing wetted perimeter.

INTRODUCTION

Purpose and Scope

This study was conducted in cooperation with the Washington State Department of Game to develop equations for estimating discharges and wetted perimeters desired by steelhead trout in streams of western Washington.

The need for these data arose, when, in 1967, the Washington State legislature defined fish propagation as a beneficial water use. In effect, this placed fish propagation in competition for allocation of streamflow with other beneficial water uses, such as industrial, municipal and domestic supplies, irrigation, and hydroelectric power generation. Allocation of streamflow for a given water use is difficult, however, if the quantitative requirements for that use are not known.

Studies of several fish species have shown that most fish spawning in streams occurs within a certain range of water depths and, particularly, a certain range of water velocities. The Washington State Department of Game (Hunter, 1973) has established ranges of depths and velocities as "preferred" by steelhead for spawning. The upper and lower limits of those ranges serve to define the boundaries of the streambed area preferred for spawning at various stream discharges.

This report presents the results of studies made at 54 reaches on 18 streams in western Washington to (1) measure the stream discharges and spawnable areas corresponding to depths and velocities preferred by spawning steelhead, (2) measure the stream discharge and wetted perimeter of each stream channel corresponding to a water stage that covers the streambed but not the channel banks, as an evaluation of rearing conditions, and (3) develop equations relating the resulting stream discharges and wetted perimeters at the study reaches to drainage-basin and stream-channel parameters. Thus, estimates of discharges for the spawning and rearing characteristics preferred by steelhead trout can be derived from the equations presented herein. These equations, coupled with other requirements for steelhead propagation, can be used as a basis for allocating streamflows for steelhead at stream sites where measurements are not available.

The locations of streams and reaches studied are shown in figure 1, and the sizes of the reaches are listed in table 1. The streams included in this study of spawning and rearing conditions preferred by steelhead trout have been the subjects of similar studies for several species of salmon (Collings, 1974; Collings and Hill, 1973; and Collings and others, 1972a, 1972b). The streams were geographically representative of those in western Washington used by salmon and were selected to encompass a wide range of drainage-basin and stream-channel characteristics. The three reaches selected on each stream represent the upstream extent, downstream extent, and some midpoint of the part of the stream most used by salmon for spawning. The reaches were designated A, B, and C (not shown in fig. 1), with reach A as the farthest upstream of the three. Because the applicability of those same reaches for steelhead spawning and rearings was questionable, the Washington State Department of Game visited and investigated each of the reaches to insure their suitability to the steelhead-study criteria. The representatives of the study reaches for steelhead spawning and rearing was confirmed by J.W. Hunter (written commun., 1973).

Factors other than stream depth, velocity, and wetted perimeter also influence the spawning and rearing of steelhead. These may include water temperature, bankside and bottom cover or shelter, size distribution of bottom gravels and rocks, and supply of aquatic insects for food. Many of these factors are both interrelated and related to stream discharge, but evaluation of these relationships was beyond the scope of this study.

Acknowledgments

This study was made with the assistance of J.W. Hunter of the Washington State Department of Game who reviewed river study reaches and supplied information on spawning and rearing conditions for Steelhead. The constructive criticism and suggestions from W.L. Haushild, J.F. Turner and K.L. Wahl of the Geological Survey were of benefit to the final report.

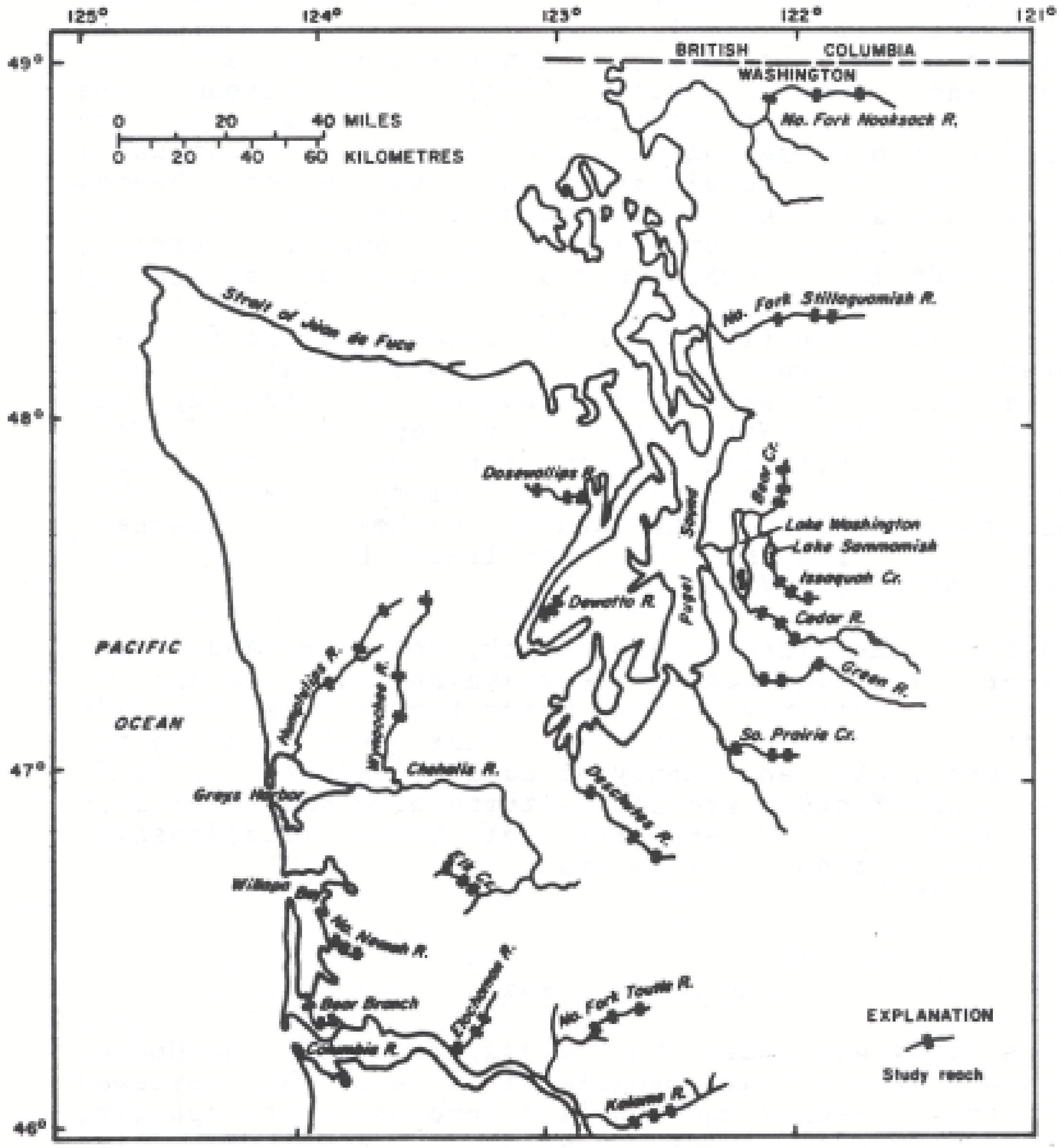

FIGURE 1.—Location of streams and reaches studied in western Washington. Cross bars on streams are study reaches.

TABLE 1.—Sizes of stream reaches studied

Stream name	Size of reach at bankfull river stage					
	Total streambed area (ft^2)			Average channel length (ft)		
	Reach[a]			Reach[a]		
	A	B	C	A	B	C
Cedar River--	22,200	23,400	17,600	162	189	164
Dewatto River--	7,690	2,920	8,250	158	78	143
Kalama River--	23,100	16,800	22,100	150	154	150
N.F. Nooksack River-----------------------------------	13,900	28,800	54,900	102	200	265
Elochoman River---------------------------------------	18,800	14,300	17,700	122	116	142
Humptulips River--------------------------------------	32,400	23,500	26,800	148	134	143
Green River--	42,500	40,300	40,300	162	173	203
Wynoochee River---------------------------------------	18,200	27,100	39,600	122	147	180
Deschutes River--	12,600	13,300	19,600	136	132	210
Dosewallips River--------------------------------------	12,500	15,600	19,300	114	145	156
N.F. Stillaguamish River------------------------------	14,100	24,800	37,400	113	136	191
N.F. Toutle River---------------------------------------	24,100	27,400	34,400	142	131	162
Bear Branch---	3,500	3,480	5,060	81	68	95
Bear Creek--	2,120	842	1,460	64	39	66
Elk Creek--	[b]1,200	7,610	9,820	47	126	106
Issaquah Creek---	3,840	4,300	7,480	96	88	126
North Nemah River-------------------------------------	2,540	3,930	3,820	58	78	89
South Prairie Creek------------------------------------	4,480	6,950	8,590	68	91	105

[a]Reaches designated in downstream order, with reach A the farthest upstream.
[b]On tributary Smith Creek.

Steelhead Trout

Description

Steelhead are sea-run rainbow trout of the same species of resident rainbow trout (Salmo gairdneri) and belong to the family Salmonidae, which includes all trout, char, salmon, whitefish, and grayling. Unlike resident rainbow trout, steelhead migrate to the ocean after spending usually their first 2 years in freshwater streams. At sea, they attain large size by feeding on other fish, squid, and amphipods. After spending usually 2 years in the ocean and reaching a weight of 7 to 9 lbs (3 to 4 kgs), steelhead may return to the streams to spawn. The larger returning fish, weighing up to 30 lbs (13 kgs), are those that have spent 3 or more years at sea.

Two races of steelhead occur in Washington streams. Winter steelhead travel upstream for spawning during November-June, whereas summer steelhead travel upstream during June-September. Most of those migrating in streams of western Washington are winter steelhead. Both races migrate to the ocean during February-June.

Spawning and Rearing Characteristics

According to Hunter (1973), certain conditions apply to steelhead spawning. The fish spawn in the early spring--winter steelhead immediately following their migration, and summer steelhead after remaining in deep pools during the winter following their migration. They spawn by laying clusters of eggs in redds (nests) they have dug with tail and body movements in the streambed gravels. Unlike salmon, steelhead may migrate and spawn more than once. Depending upon the availability of suitable gravels, the redds are commonly located just upstream from stream riffles, have gravel tailspills, are about 0.4 ft (0.1 m) deeper than the surrounding area, and may cover an area of about 27 ft^2 (3.4 m^2). Gravel sizes preferred range from ¼ to 4 inches (6 to 100 mm) and preferred water temperatures range from 40º to 55ºF (Fahrenheit) or 4.4º to 12.8ºC (Celsius).

From numerous measurements of spawning redds and from his review of literature, Hunter (1973) concluded that the preferred minimum depth of water for spawning was 0.7 ft (0.2 m) and that the preferred velocity range was 1.2 to 3.3 ft/s (0.37 to 1.0 m/s) at a point 0.4 ft (0.1 m) above the streambed. For the purpose of this study, Hunter (written commun., 1973) recommended the following criteria:

Depth range ---------- 0.7-2.3 ft (0.2-0.70 m)
Velocity range---------l.2-3.3 ft/s (0.37-1.0 m/s)

The rearing period is a general term referring to that part of the life cycle of anadromous fish from hatching through smolting. Survival of these fish during the 2 years of rearing after hatching depends on a number of factors, including the possibility of fry being either smothered by silt or lost to predators.

Criteria for the most suitable rearing conditions are not as well established as those for spawning, but a major factor in growth and survival of the young fish is the food supply. Aquatic insects that serve as the major source of food inhabit the part of the streambed that is always wetted, and do not readily reestablish in areas that are alternately wetted and dried each year (Bell, 1973). The concept of providing a maximum wetted streambed area for food production during periods of low flow was used in this study as the basis for determining rearing discharges.

Previous Studies

Four previous reports (Collings, 1974; Collings and Hill, 1973; and Collings and others, 1972a, 1972b) prepared in cooperation with the Washington State Department of Fisheries discuss the hydrology of streams relative to several species of salmon. The first report describes the methods used to determine spawning and rearing discharges for salmon and presents those discharges for 12 study reaches on four streams for each of four salmon species. The second and third reports use the same methods and include salmon spawning and rearing discharges for 12 study reaches on four streams and for 30 study reaches on 10 streams, respectively. The fourth report discusses a generalization of salmon spawning and rearing discharges for the 54 study reaches in the first three reports and includes spawning and rearing discharges for a fifth salmon species.

DETERMINATION OF SPAWNING AND REARING DISCHARGES AND REARING WETTED PERIMETERS

Discussion of Discharges and Wetted Perimeters

Determined during the study of selected stream reaches used for spawning and rearing by steelhead trout were (1) stream discharges that provide water that covers the greatest areas of the streambeds of both the depths and the velocities preferred by spawning steelhead; (2) discharges that provide water that covers selectively reduced streambed areas at both depths and velocities preferred by spawning steelhead; (3) discharges that provide water that covers the greatest streambed areas at velocities preferred by spawning steelhead; (4) rearing discharges that provide water that covers the streambed but not the banks of the channel; and (5) average wetted perimeters of the channels at water stages corresponding to the rearing discharges.

These discharges and wetted perimeters were determined by measurements at 54 study reaches on 18 streams selected to be representative in size and location of those used for steelhead spawning and rearing. The terms and symbols used for the discharges and wetted perimeters that were determined are described as follows:

1. Qdv is the discharge that provides water covering the greatest streambed area with ranges of depth and velocity preferred by spawning steelhead. It is the stream discharge most desired for steelhead propagation at the time of spawning, but is determined herein without regard to coincidence with the actual time of spawning. Whether or not Qdv is a feasible value for allocating streamflow depends upon the availability of streamflow in the spring at the time of spawning. Exceedence probabilities for discharge during the different months of the year are described in the three previous reports on salmon (Collings and others, 1972a, 1972b; Collings and Hill, 1973) for selected stream-gaging stations at or near the study reaches. Those reports also present a method of estimating flows for study reaches not at gaging stations.

2. Qs is the discharge at which the percentage rate of reduction in discharge equals the percentage rate of reduction in maximum spawnable area. It is determined by reducing the greatest area of preferred depths and velocities by 5, 10, 15, and 25 percent of that area, and comparing those percentages with the percentages corresponding to the associated discharge reductions. Usually, discharge and spawnable area reduce at different rates. If the reductions do not become equal before area is reduced by 25 percent, then Qs is the discharge that corresponds to 75 percent of the greatest area.

   The fundamental concept is that substantial reduction in Qdv discharge often produce relatively small reductions in spawnable area (to 75 percent of the greatest area). Thus, a stream discharge much less than 75 percent of Qdv may sustain spawning in 75 percent or more of the preferred area.

Where Qs is limited at one study reach to that corresponding to 75 percent of the greatest spawnable area, it is not necessarily comparable to values of Qs at the 75-percent limit at other reaches. Also, the availability of water in the spring at the time of spawning may determine whether or not Qs is a feasible value for allocating streamflow.

3. Qv is the discharge that provides water that covers the greatest streambed area with the velocities preferred by spawning steelhead. It differs from Qdv in that the depth criterion is omitted. Water velocity may, in some instances, be considered more important than depth as factors governing spawning, and Qv is provided in this report as an alternative value for allocating streamflow. However, it must be emphasized again that the availability of water in the stream at spawning time is very important in deciding whether or not Qv is a feasible value for allocating streamflow.

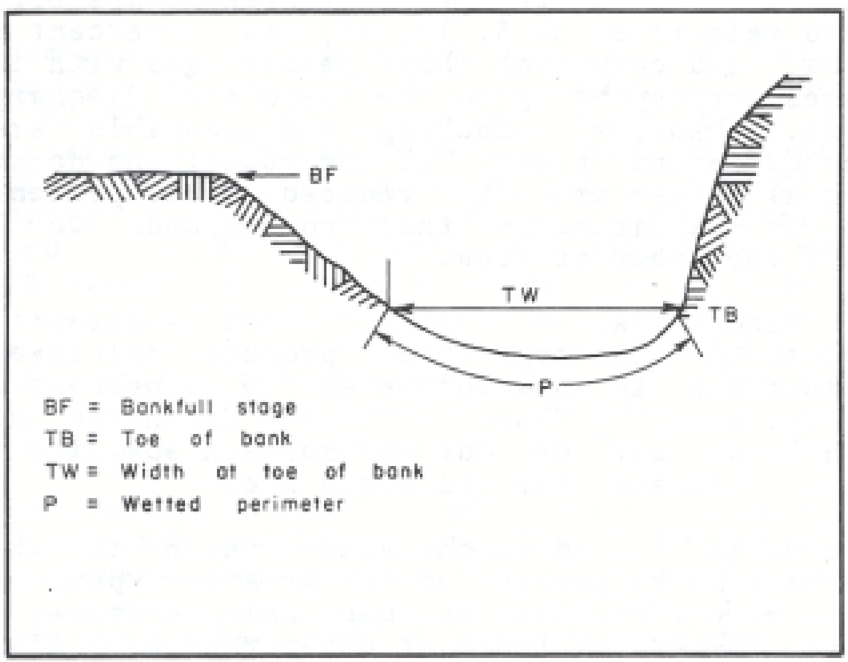

FIGURE 2.--Cross section of a stream, showing selected channel parameters.

4. Qr, the rearing discharge, is the discharge that provides water that just covers the streambed. It is related to the availability of aquatic insects serving as a food supply for fish. The rearing discharges determined in this report are much less than the spawning discharge, and flows of less than the rearing discharge would be critical at any time during the year. Thus, maintaining flows in excess of the rearing discharge would be of prime importance in allocating streamflow for steelhead rearing.

5. P is the average wetted perimeter of the streambed at the rearing discharge (fig.2). Like the rearing discharge, the importance of this wetted perimeter is related to food supply for rearing fish.

Methods of Determination

The methods used to determine spawning and rearing discharges in this study area a combination of those of Rantz (1964), Westgate (1958), and the State of Washington Department of Fisheries (Deschamps and others, 1966), with modifications by Collings, Smith, and Higgins (1972a).

Spawning Discharges

Three reaches were selected for study on each stream (fig.1) to obtain a representation of spawnable areas in the stream. This was done also to evaluate the variation of discharges both along and among the various streams studied. The reaches were studied at sites actually used for spawning and were usually located at the upstream end of a riffle. The sites were selected with the onsite advice of fisheries biologists.

Four cross sections were established on each reach, and base maps of the reach were prepared by plane-table methods. The sides of the reach are considered to be the water's edges when the stream is at bankfull stage--that water level where the stream is at the point of overflowing one, or both, banks of the reach. (See fig.2.)

At each study reach, about 10 visits were made over a period of several months to determine discharge through the reach and to obtain depths and velocities at each of the cross sections for a range of stages. Water depths and velocities were measured at 10 to 25 or more points along each cross section during each visit.

After each visit a map was drawn showing lines for equal values of the measured depths and velocities. Such a map is shown in figure 3 where the mapped values of depth and velocity correspond to the ranges preferred by spawning steelhead. The areas preferred on the basis of depth, velocity, and the combination of depth and velocity were determined in this way following each visit to the reach.

A graph, such as that shown in figure 4, was prepared from the maps by plotting the logarithms of spawnable areas for each criterion versus the logarithms of the associated discharges; curves were fitted by a parabolic-arc method (Whittaker and Robinson, 1932).

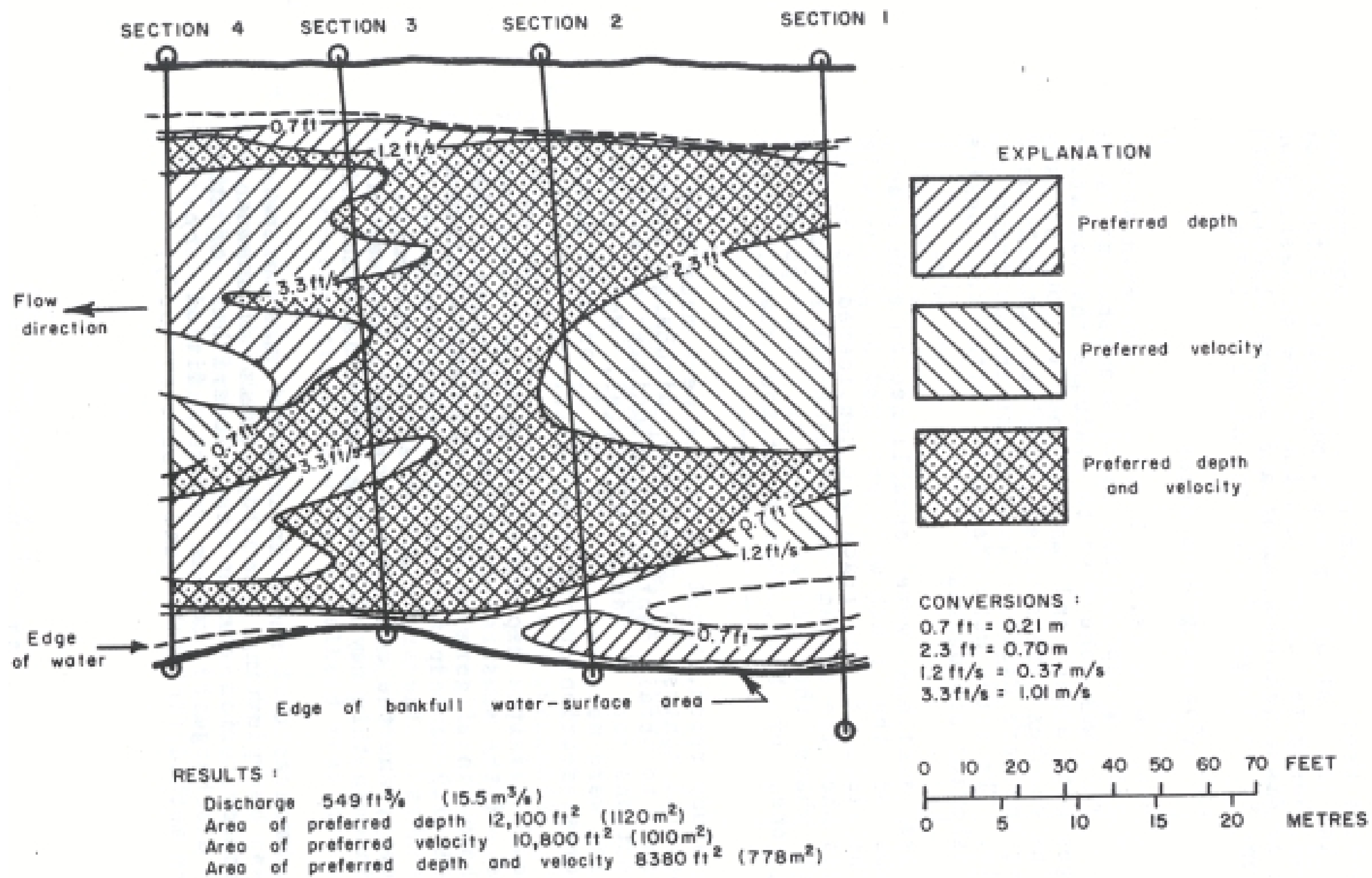

FIGURE 3.--Plan view of reach C on Elochoman River, an example showing areas of reach corresponding to spawning depths and velocities preferred by steelhead.

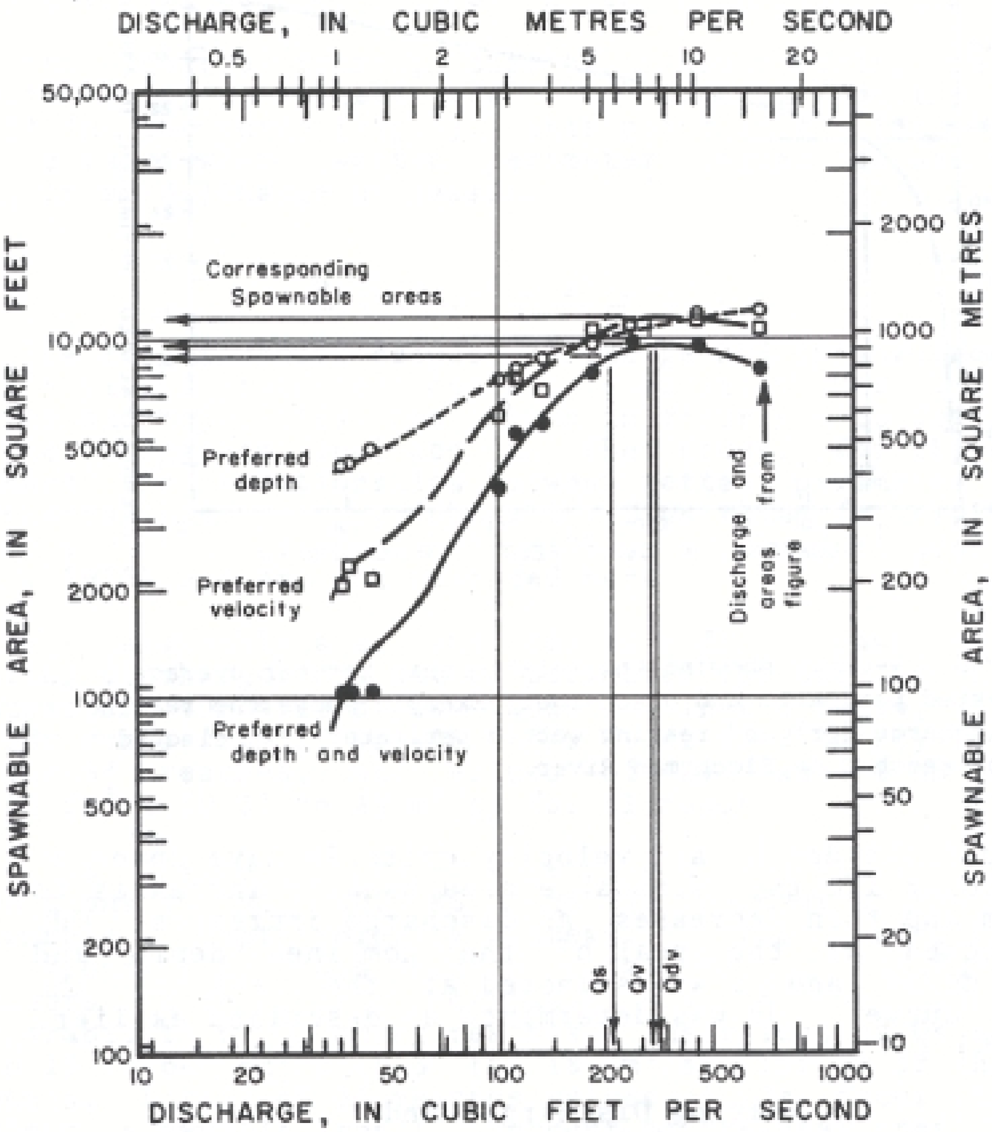

FIGURE 4.—Curves showing the relationship between measured spawnable areas and discharges. Example shows the selection of spawning discharges (Qdv, Qv, and Qs) for reach C on Elochoman River.

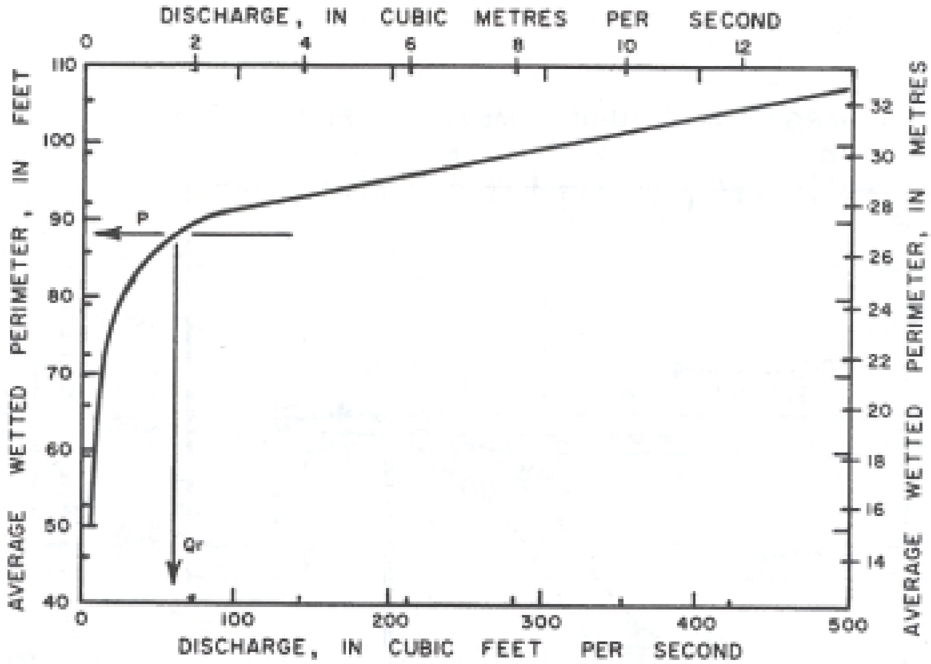

FIGURE 5.--Curve showing the relationship between average wetted perimeter and discharge. Example shows the rearing discharge (Qr) and rearing wetted perimeter (P) selected for reach C on Elochoman River.

Because the depth and velocity criteria have upper as well as lower limits, spawnable area usually increases to a maximum and then decreases as discharge increases. Qdv was selected at the peak of the combined depth and velocity curve, and Qv was selected at the peak of the velocity curve. Qs was determined as described earlier. (See p. 9.)

Rearing Discharges and Wetted Perimeters

Four cross sections were surveyed at each reach, and the wetted perimeter of each cross section was calculated for several different stages and corresponding discharges. Results were then averaged to obtain an average wetted perimeter for each discharge at the reach.

A relationship between average wetted perimeter and discharge was prepared for each reach, as shown by the example in figure 5. Typically, wetted perimeter increases rapidly as discharge increases and more of the streambed becomes covered with water. After the steep banks of the channel are encountered by the spreading water, however, the rate of increase in wetted perimeter is greatly reduced by further increases in discharge.

The desired rearing discharge and rearing wetted perimeter for steelhead are both selected from the same point on the curve (fig. 5). This point is the inflection of the curve where wetted perimeter begins to decrease rapidly as discharge decreases.

Results of Analyses

The relationships between discharge and spawnable area for steelhead-preferred depths, velocities, and combined depths and velocities are shown in figures 6-23 for each of the 54 reaches included in the study. For the same reaches the relationships between wetted perimeter and discharge have been graphically illustrated in previous reports (Collings and others, 1972a, 1972b; Collings and Hill, 1973) and are not repeated here.

The spawnable areas and corresponding spawning and rearing discharges and wetted perimeter for each of the 54 reaches are summarized in table 2. In the table, values of Qdv range from 15 to 940 ft^3/s (0.42 to 27 m^3/s) for 51 of the 54 reaches, and values of Qv range from 11 to 1,700 ft^3/s (0.31 to 48 m^3/s) for 51 reaches.

Also listed in the tables are discharges that give reductions to 95, 90, 85, and 75 percent of the peak spawnable depth-velocity areas. The discharges corresponding to those reduced areas may be useful to planners where Qs is unacceptable due to the lack of comparability of Qs among reaches. The values of Qs range from 13 to 640 ft^3/s (0.37 to 18m^3/s) for 51 of the 54 reaches. For 21 of 51 reaches values of Qs occur at the minimum spawnable area (75 percent of the peak area). A reduction to 75 percent of the peak spawnable area is the greatest reduction deemed desirable for steelhead propagation.

Qdv, Qs, and Qv were omitted in table 2 for 3 of the 51 reaches because the measurements did not adequately define the relationships. For some reaches, estimates of those spawning discharges were made on the basis of data trends and these estimates are denoted in the table. Spawning discharges that are based upon manually fitted curves are also denoted in the table. These hand-drawn curves were used where the parabolic-arc method fit the data incorrectly such as where only one or two discharge measurements were greater or less than Qdv.

Rearing discharges listed in table 2 range from 2.5 to 570 ft^3/s (0.071 to 16 $^{m3}/s$). Some of these discharges have been revised from those previously published (Collings and others, 1972a, 1972b; Collings and Hill, 1973) to achieve uniformity of selection from the wetted-perimeter curves, and these are so denoted in the table, Rearing wetted perimeters listed in the table range from 11 to 264 ft (3.3 to 80.5 m).

Table 2.—Summary of spawning and rearing discharges, spawnable areas, and rearing wetted perimeters, at stream reaches studied

		Spawnable areas and discharges for preferred spawning velocities and depths							
		Peak area		95 percent of peak area			90 percent of peak area		
Stream name	Study reach	Area (ft$_2$)	Discharge, (ft$_3$/s)	Area (ft$_2$)	Discharge (ft$_3$/s)	Percent of discharge at peak area	Area (ft$_2$)	Discharge (ft$_3$/s)	Percent of discharge at peak
Cedar River	A	8,700	280	8,260	220	79	7,830	200	71
	B	[a]5,800	[a]570	5,510	470	82	5,220	400	70
	C[b]	--	--	--	--	--	--	--	--
Dewatto River	A	4,050	91	3,850	75	82	3,640	69	76
	A$_{-1}$	2,100	94	2,000	79	84	1,890	65	69
	B[d]	5,700	210	5,420	170	81	5,130	135	64
Kalama River	A[d]	14,500	530	13,800	440	83	13,000	400	75
	B[d]	6,900	390	6,560	360	92	6,210	350	90
	C[d]	7,300	800	6,940	650	81	6,570	620	78
North Fork	A	7,900	360	7,500	320	89	7,110	270	75
Nooksack River	B[b]	--	--	--	--	--	--	--	--
	C	[a]32,000	[a]940	30,400	880	94	28,800	800	85
Elochoman River	A[d]	10,000	400	9,500	320	80	9,000	300	75
	B	[a]9,200	[a]500	8,740	430	86	8,280	380	76
	C	9,800	280	9,310	230	82	8,820	200	71
Humptulips River	A	12,800	420	12,200	360	86	11,500	270	64
	B	12,200	350	11,600	280	80	11,000	260	74
	C	11,700	500	11,100	420	84	10,500	390	78
Green River	A	38,000	860	36,100	620	72	34,200	450	52
	B	12,500	450	11,900	390	87	11,200	350	78
	C	22,200	940	21,100	640	68	20,000	520	55
Wynoochee River	A	6,200	270	5,890	235	87	5,580	210	78
	B	23,400	540	22,200	275	51	21,100	255	47
	C	22,600	630	21,500	400	63	20,300	330	52
Deschutes River	A	8,600	160	8,170	135	84	7,740	120	75
	B	[a]7,350	[a]250	6,980	220	88	6,620	200	80
	C	14,800	250	14,100	200	80	13,300	170	68
Dosewallips River	A	8,400	400	7,980	310	78	7,560	260	65
	B	10,100	400	9,600	340	85	9,100	280	70
	C	15,500	400	14,700	330	82	14,000	280	70
North Fork	A	5,200	225	4,940	175	78	4,680	165	73
Stillaguamish	B	[a]11,300	[a]600	10,700	400	67	10,200	335	56
River	C	25,700	650	24,400	400	62	23,100	340	52
North Fork	A	14,000	520	13,300	400	77	12,600	360	69
Toutle River	B	11,200	360	10,600	320	89	10,100	305	85
	C	29,600	650	28,100	560	86	26,600	500	77
Bear Branch	A	[a]2,100	[a]120	2,000	98	82	1,890	82	68
	B	[a]2,050	[a]130	1,950	95	73	1,840	75	58
	C	[a]3,000	[a]130	2,850	100	77	2,700	82	63
Bear Creek	A[b]	--	--	--	--	--	--	--	--
	B	270	15.0	256	13.3	89	243	13.0	87
	C	540	26.0	513	25.5	98	486	25.0	96
Smith Creek (A)	A[d]	125	25.0	119	23.5	94	112	22.5	90
Elk Creek (B,C)	B	5,100	190	4,840	160	84	4,590	140	74
	C	[a]2,000	[a]125	1,900	110	88	1,800	92	74
Issaquah Creek	A	2,600	85	2,470	80	94	2,340	70	82
	B	3,050	95	2,900	87	92	2,740	82	86
	C	4,900	120	4,660	105	88	4,410	92	77
North Nemah River	A	[a]1,100	[a]100	1,040	60	60	990	50	50
	B	2,300	160	2,180	130	81	2,070	120	75
	C[d]	1,400	160	1,330	135	84	1,260	100	62
South Prairie	A	2,700	165	2,560	140	85	2,430	125	76
Creek	B	[a]3,800	[a]270	3,610	220	81	3,420	200	74
	C	7,300	260	6,940	210	81	6,570	185	71

[a]Estimate based on data trend.
[b]Data inadequate to derive characteristic.
[c]Revised from previously published value.
[d]Spawning areas and discharges derived from manually fitted curve.

Spawnable areas and discharges for preferred spawning velocities and depths											
85 percent of peak area			75 percent of peak area			Sustaining area					
Area (ft^2)	Discharge (ft^3/s)	Percent of discharge at peak area	Area (ft^2)	Discharge (ft^3/s)	Percent of discharge at peak area	Area (ft^2)	Discharge, Qs (ft^3/s)	Percent of discharge at peak area	Discharge for peak area of preferred velocity, Qv (ft^3/s)	Rearing discharge, Qr (ft^3/s)	Rearing wetted perimeter, P (ft)
7,400	170	61	6,520	115	41	6,520	115	41	280	75	55
4,930	280	49	4,350	110	19	4,350	110	19	320	90	50
--	--	--	--	--	--	--	--	--	--	[c]150	54
3,440	66	73	3,040	56	62	3,600	68	75	[a]91	20	32
1,780	58	62	1,580	49	52	1,680	53	57	94	20	32
4,840	120	57	4,280	94	45	4,280	94	45	[a]210	40	47
12,300	385	73	10,900	345	65	12,800	392	74	[d]700	[c]300	153
5,860	340	87	5,180	320	82	6,560	360	92	[a]580	[c]320	108
6,200	580	72	5,480	500	62	6,790	640	80	[a]1,700	300	149
6,720	230	64	5,920	175	49	5,920	175	49	400	200	95
--	--	--	--	--	--	--	--	--	--	560	101
27,200	740	79	24,000	600	64	24,000	600	64	[a]900	570	172
8,500	275	69	7,500	230	58	9,200	310	78	[a]600	40	98
7,820	340	68	6,900	250	50	6,900	250	50	[a]540	[c]100	112
8,330	185	66	7,350	160	57	8,620	193	69	270	60	88
10,900	210	50	9,600	150	36	9,600	150	36	420	100	86
10,400	235	67	9,150	200	57	9,760	217	62	320	150	143
9,940	365	73	8,780	320	64	10,300	385	77	[a]1,000	150	158
32,300	420	49	28,500	375	44	33,800	440	51	1,200	200	264
10,600	300	67	9,380	240	53	9,380	240	53	[a]1,000	250	96
18,900	430	46	16,600	320	34	16,600	320	34	1,000	250	152
5,270	190	70	4,650	150	56	4,650	150	56	280	[c]100	70
19,900	245	45	17,600	220	41	22,000	270	50	800	125	180
19,200	285	45	17,000	240	38	18,100	265	42	[a]1,000	[c]150	133
7,310	115	72	6,450	101	63	7,740	120	75	160	40	69
6,250	185	74	5,510	155	62	5,510	155	62	[a]250	[c]60	88
12,600	140	56	11,100	115	46	11,800	125	50	320	[c]70	77
7,140	230	58	6,300	170	42	6,300	170	42	500	180	108
8,580	235	59	7,580	200	50	8,080	215	54	580	300	102
13,200	230	58	11,600	175	44	11,600	175	44	450	220	121
4,420	155	69	3,900	140	62	4,780	171	76	[a]400	110	93
9,600	270	45	8,480	175	29	8,480	175	29	450	[c]150	86
21,800	310	48	19,300	275	42	22,900	332	51	[a]1,200	[c]200	176
11,900	320	62	10,500	250	48	10,500	250	48	a800	[c]300	155
9,520	275	76	8,400	230	64	10,600	320	89	a800	350	114
25,200	475	73	22,200	400	62	26,600	500	77	[a]1,050	[c]400	206
1,780	73	61	1,580	60	50	1,580	60	50	[a]200	25	36
1,740	62	48	1,540	51	39	1,640	56	43	[a]130	25	35
2,550	72	55	2,250	57	44	2,250	57	44	[a]140	40	42
--	--	--	--	--	--	--	--	--	--	5	13
230	12.3	82	202	11.5	77	254	13.2	88	14	7	11
459	24.5	94	405	24.0	92	507	25.4	97	19	8	16
106	22.0	88	94	20.5	82	115	23.0	92	11	2.5	11
4,340	125	66	3,820	100	53	3,820	100	53	190	60	50
1,700	82	66	1,500	66	53	1,500	66	53	[a]140	40	51
2,210	65	76	1,950	57	67	2,080	61	72	80	25	31
2,590	79	83	2,290	74	78	2,710	81	85	60	35	42
4,160	84	70	3,680	72	60	3,920	78	65	120	[c]40	41
935	47	47	825	42	42	968	49	49	[a]110	[c]15	26
1,960	105	66	1,720	84	52	1,720	84	52	[a]300	50	42
1,190	80	50	1,050	65	41	1,120	74	46	[a]350	45	41
2,290	110	67	2,020	86	52	2,020	86	52	165	[c]40	48
3,320	165	61	2,850	115	43	2,850	115	43	[a]270	[c]50	43
6,200	165	63	5,480	140	54	5,840	151	58	250	100	74

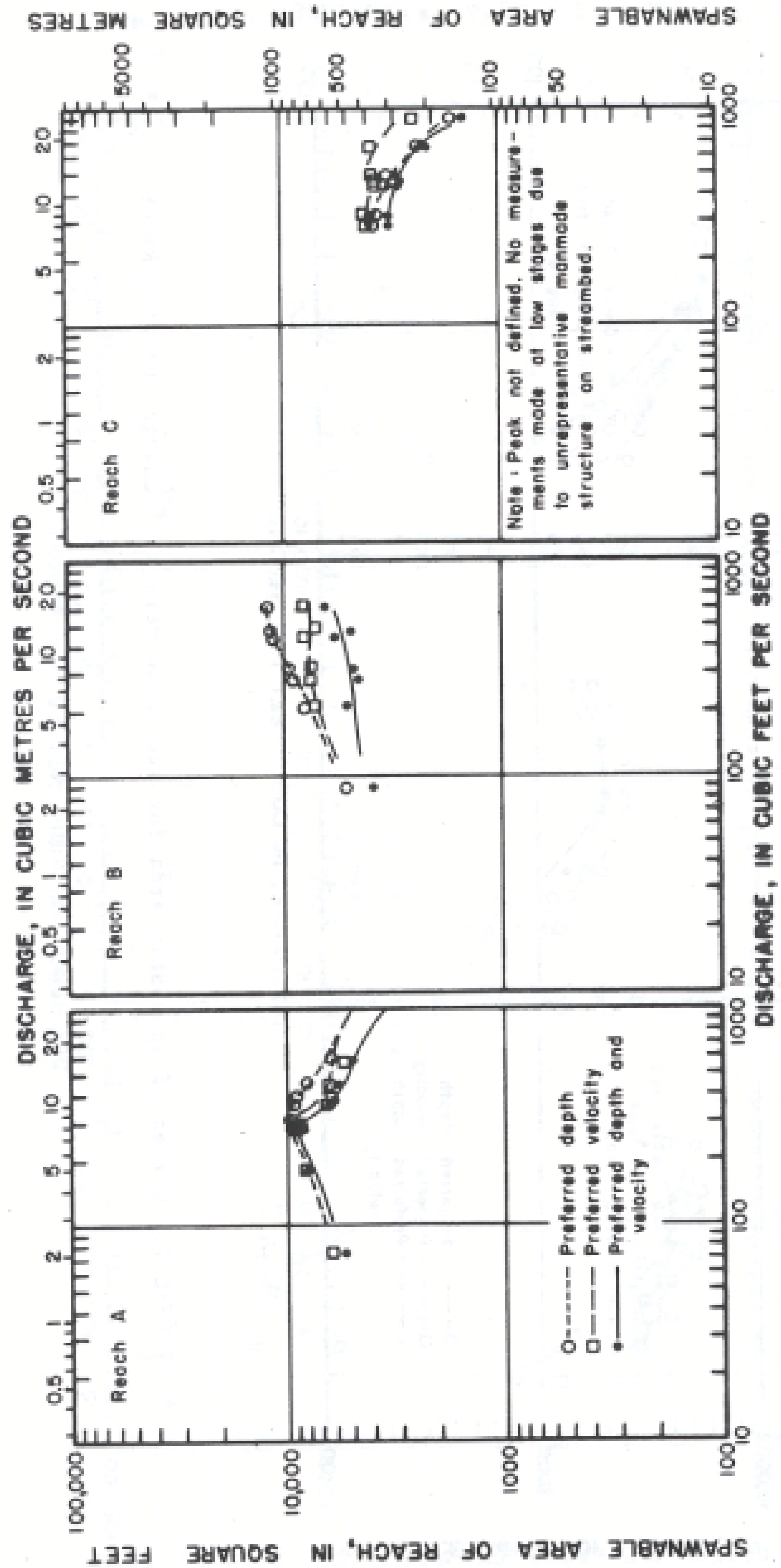

FIGURE 6.--Curves of spawnable area for steelhead versus discharge, Cedar River.

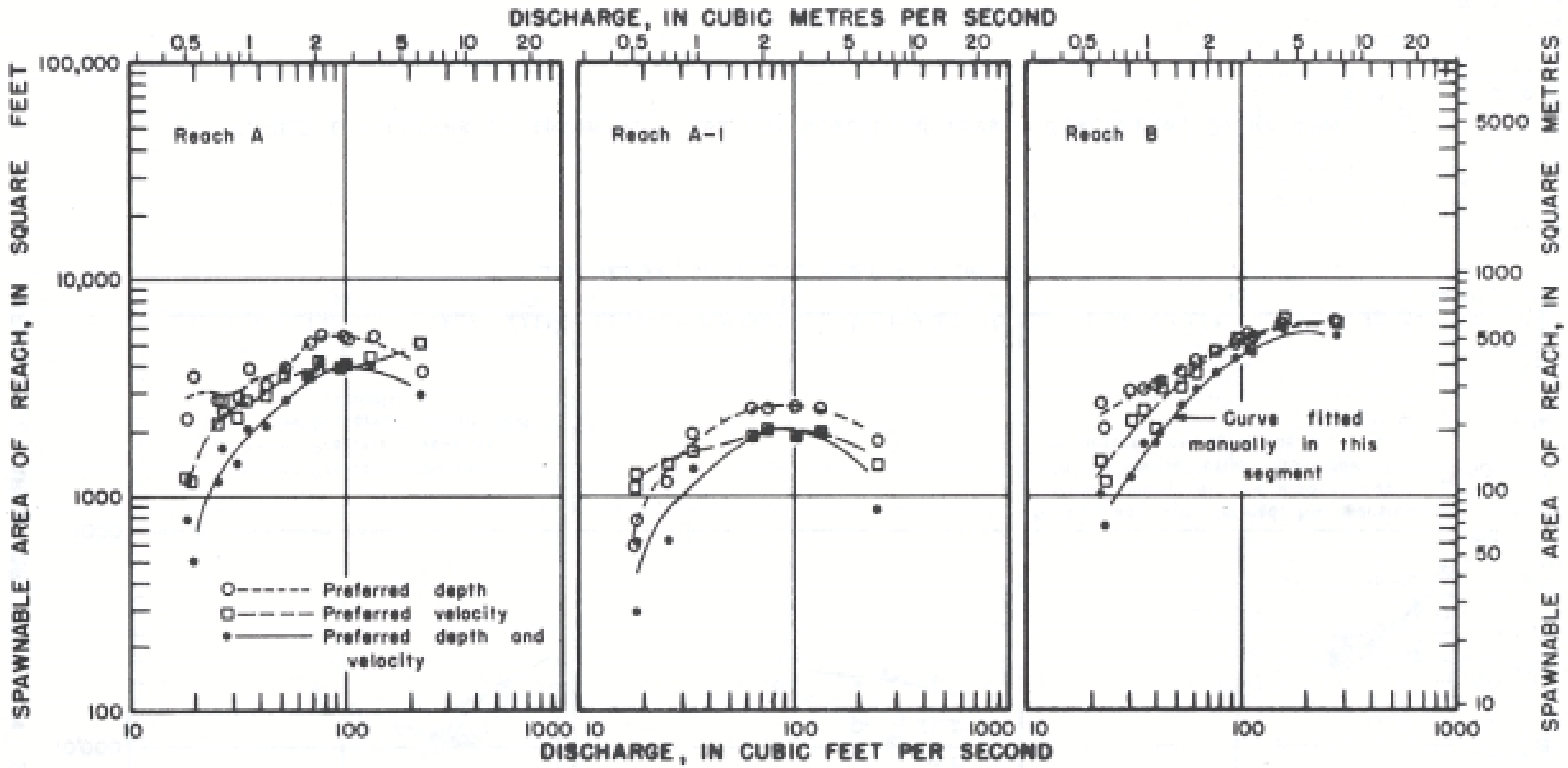

FIGURE 7.--Curves of spawnable area for steelhead versus discharge, Dewatto River.

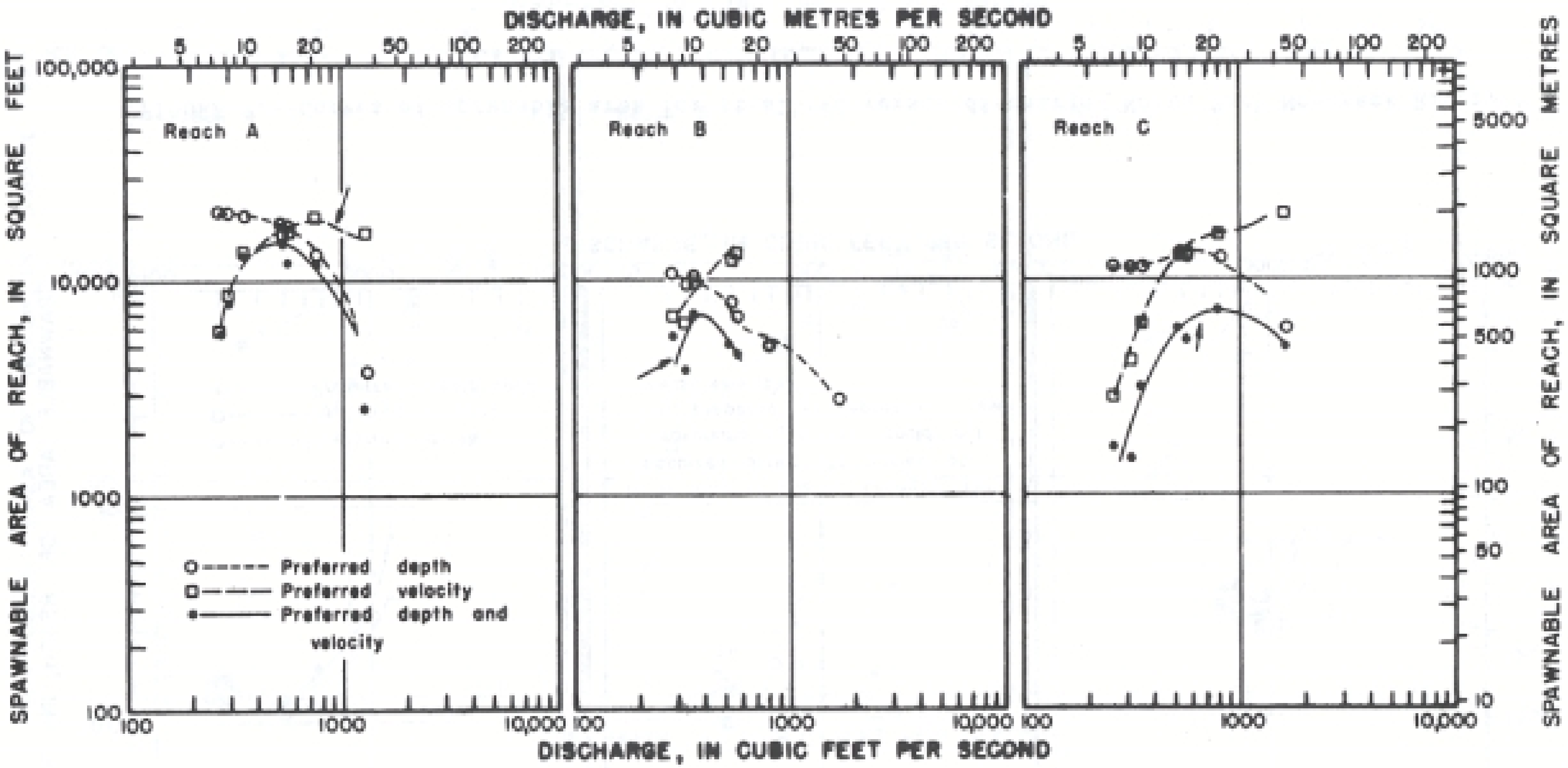

FIGURE 8.--Curves of spawnable area for steelhead versus discharge, Kalama River. Arrows indicate segments of curves fitted manually.

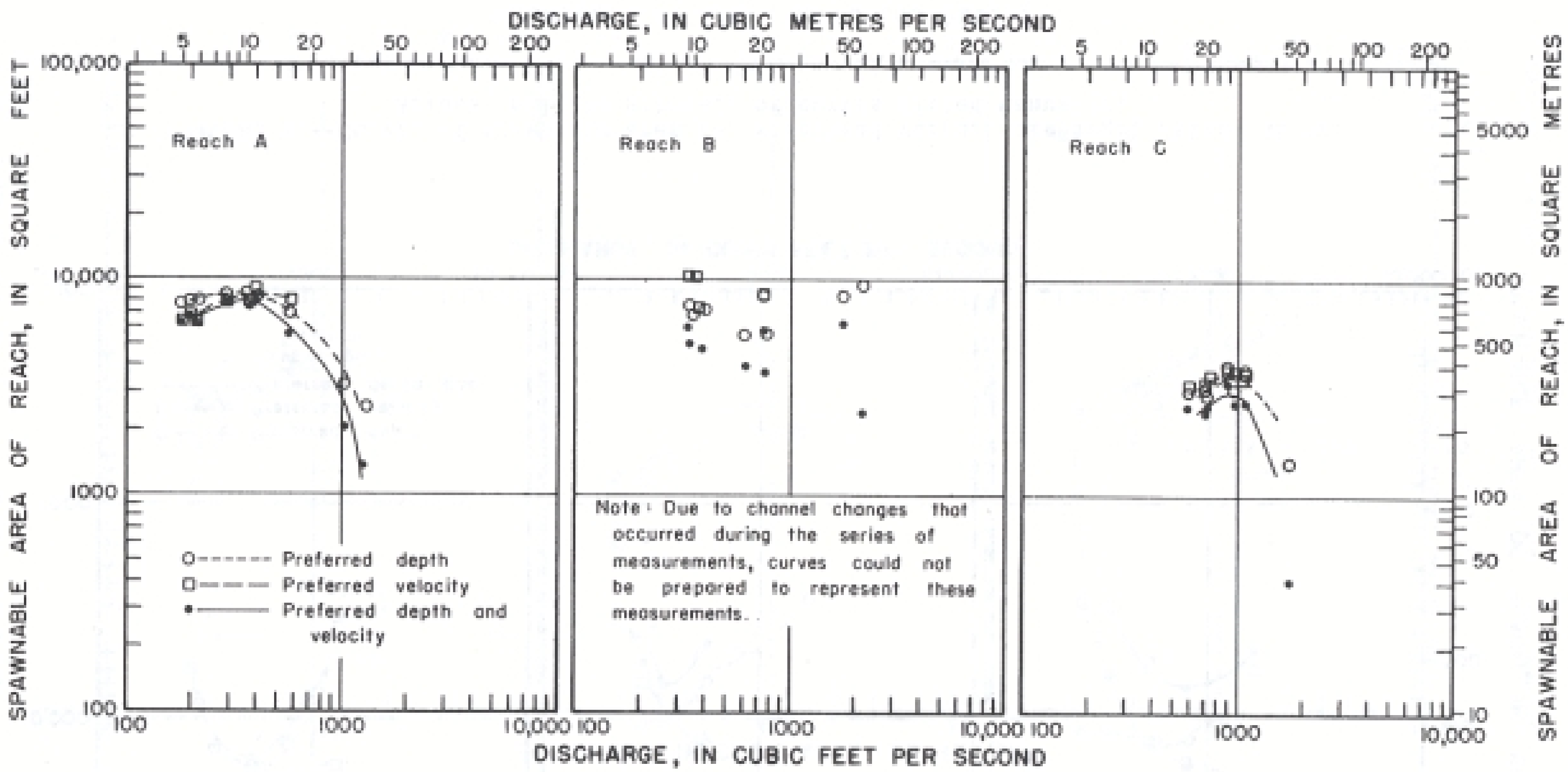

FIGURE 9.--Curves of spawnable area for steelhead versus discharge, North Fork Nooksack River.

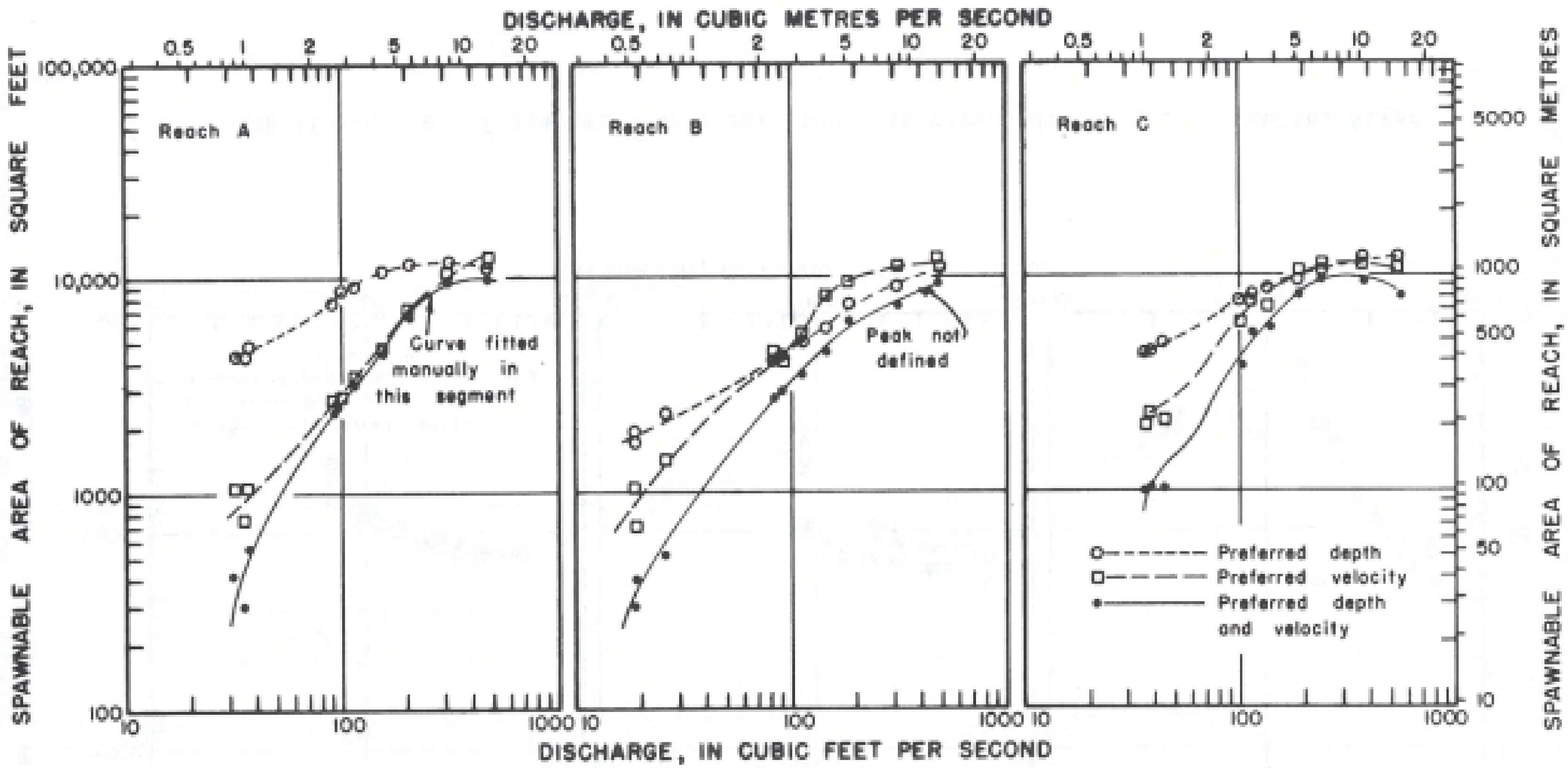

FIGURE 10.--Curves of spawnable area for steelhead versus discharge, Elochoman River.

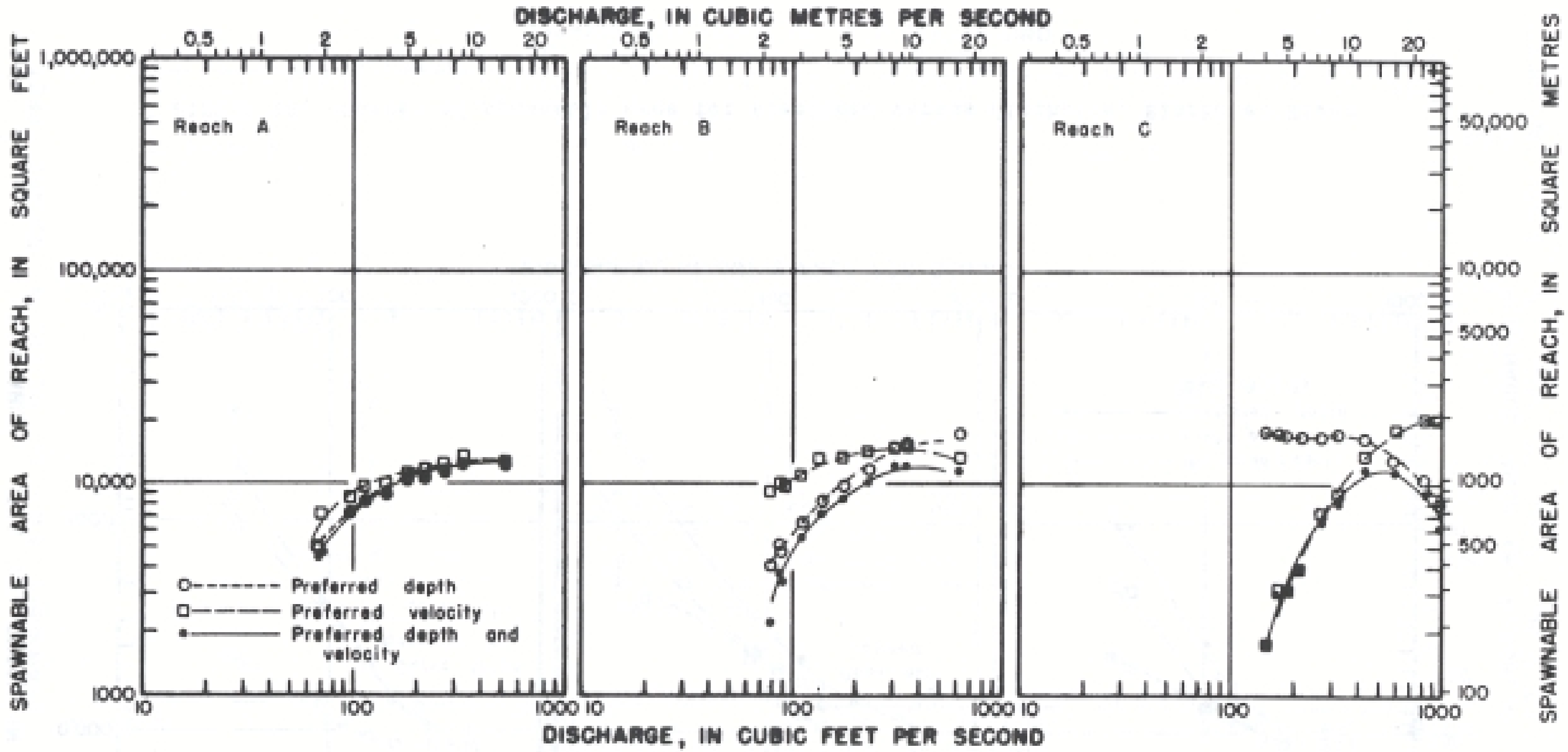

FIGURE 11.--Curves of spawnable area for steelhead versus discharge, Humptulips River.

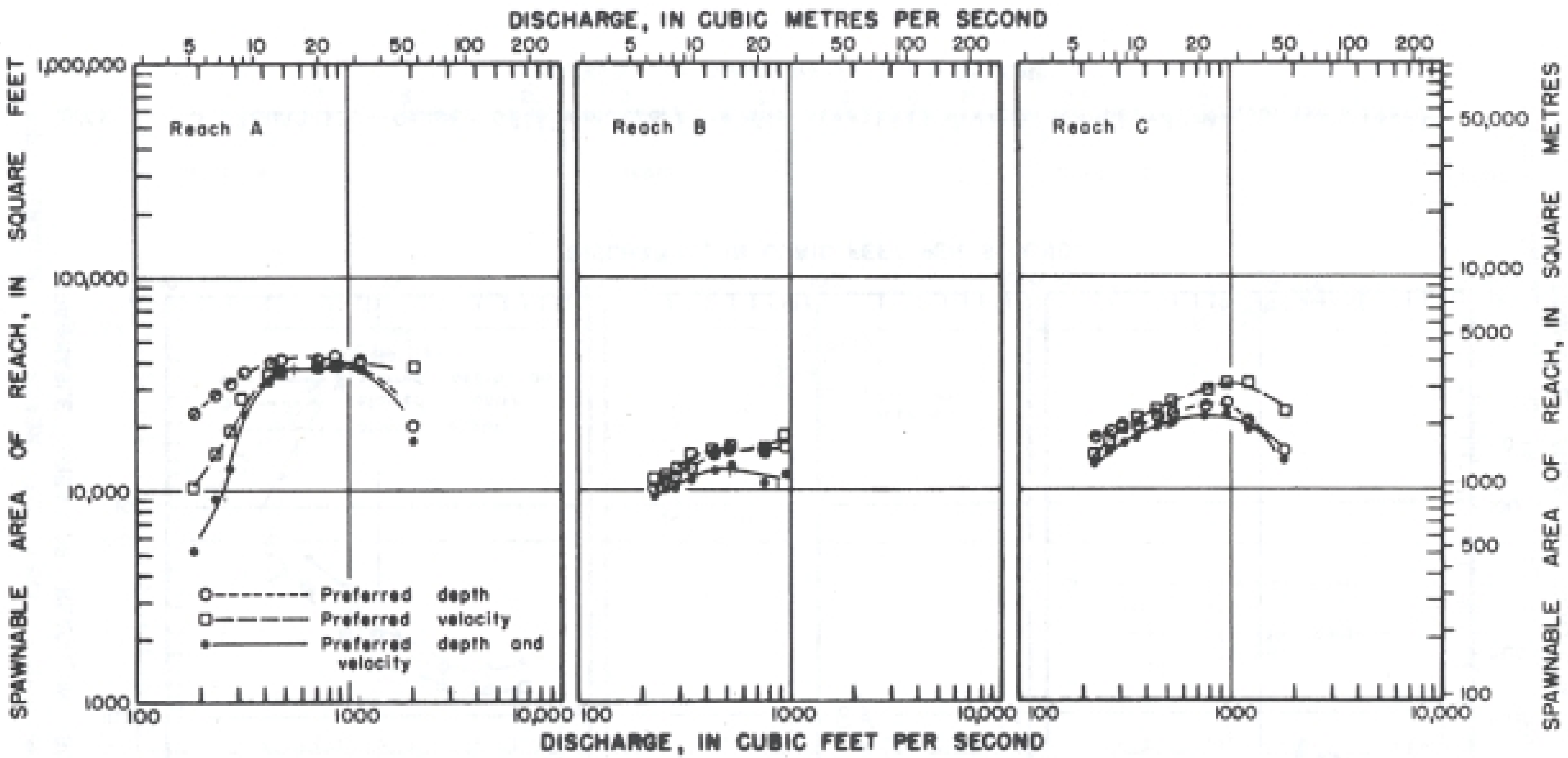

FIGURE 12.--Curves of spawnable area for steelhead versus discharge, Green River.

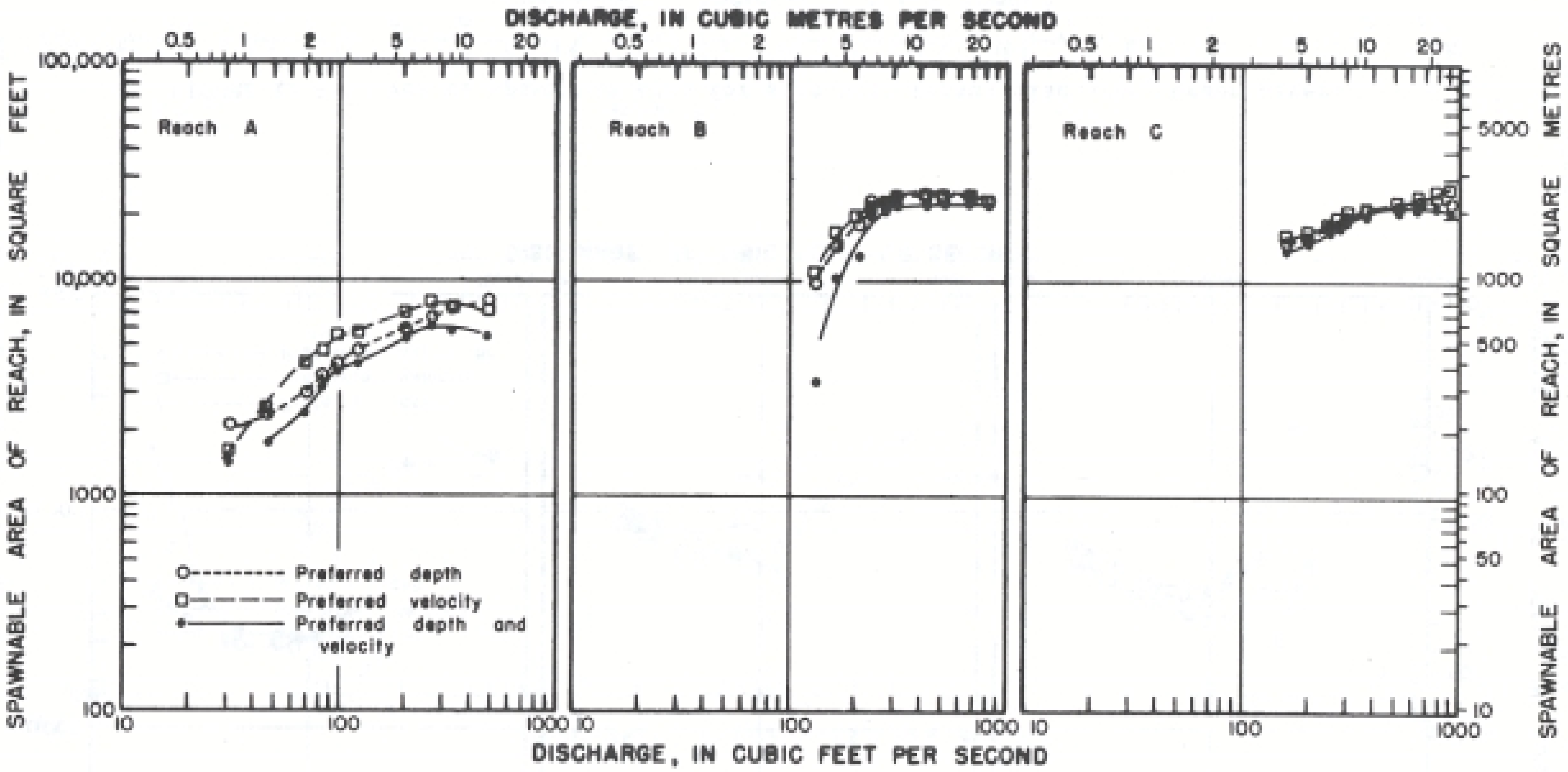

FIGURE 13.--Curves of spawnable area for steelhead versus discharge, Wynoochee River.

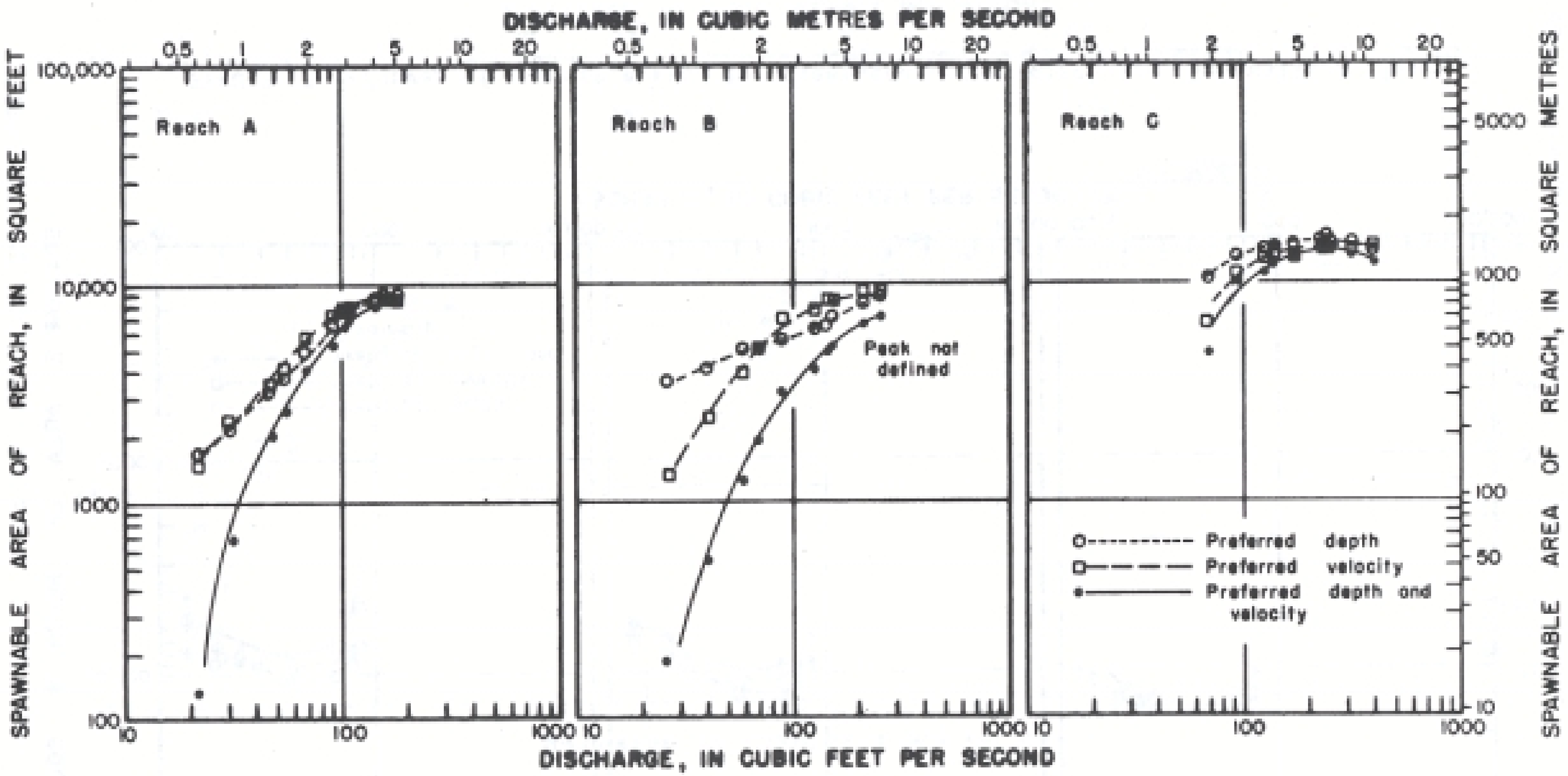

FIGURE 14.--Curves of spawnable area for steelhead versus discharge, Deschutes River.

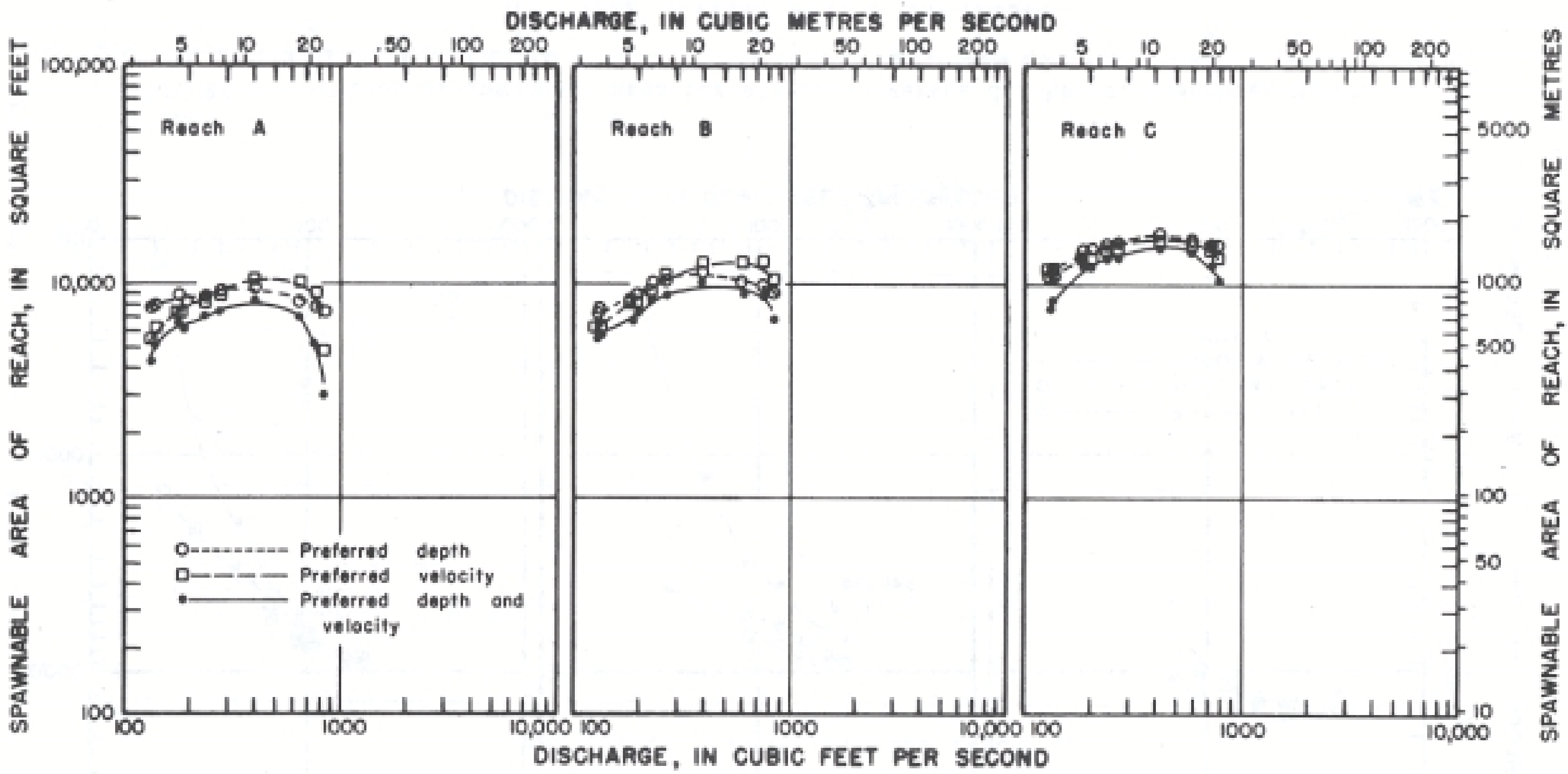

FIGURE 15.--Curves of spawnable area for steelhead versus discharge, Dosewallips River.

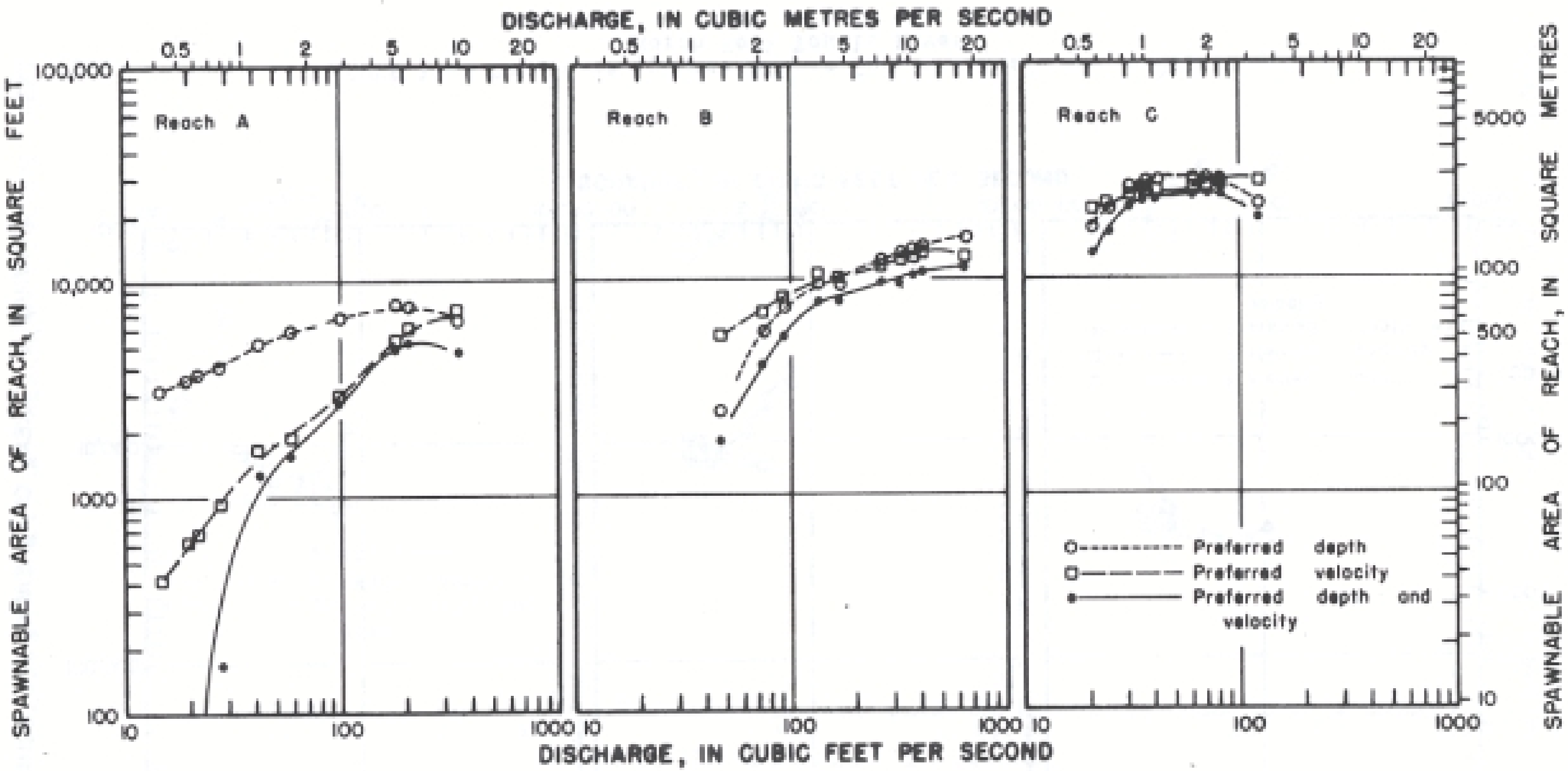

FIGURE 16.--Curves of spawnable area for steelhead versus discharge, North Fork Stillaquamish River.

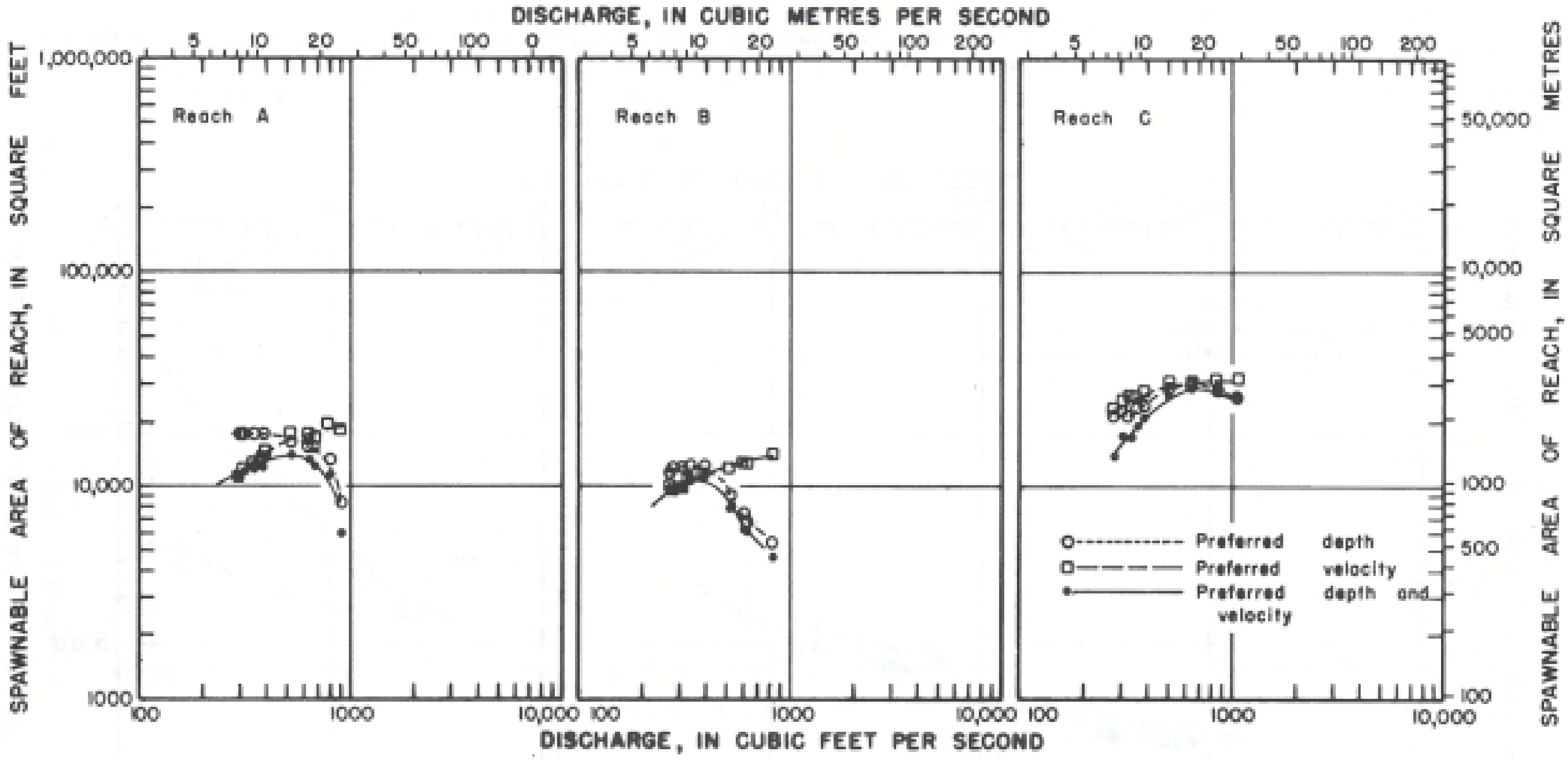

FIGURE 17.--Curves of spawnable area for steelhead versus discharge, North Fork Toutle River

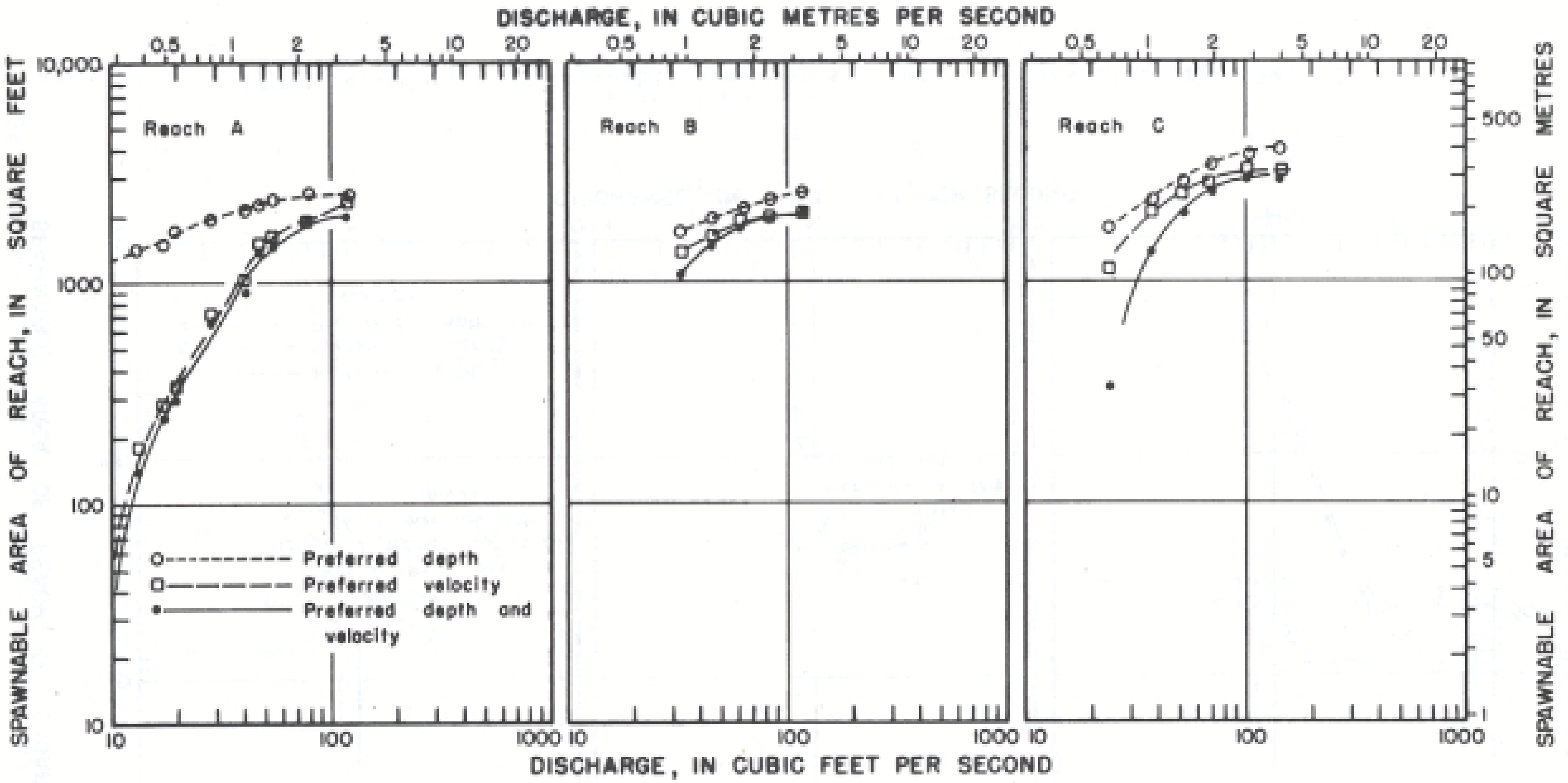

FIGURE 18.--Curves of spawnable area for steelhead versus discharge, Bear Branch.

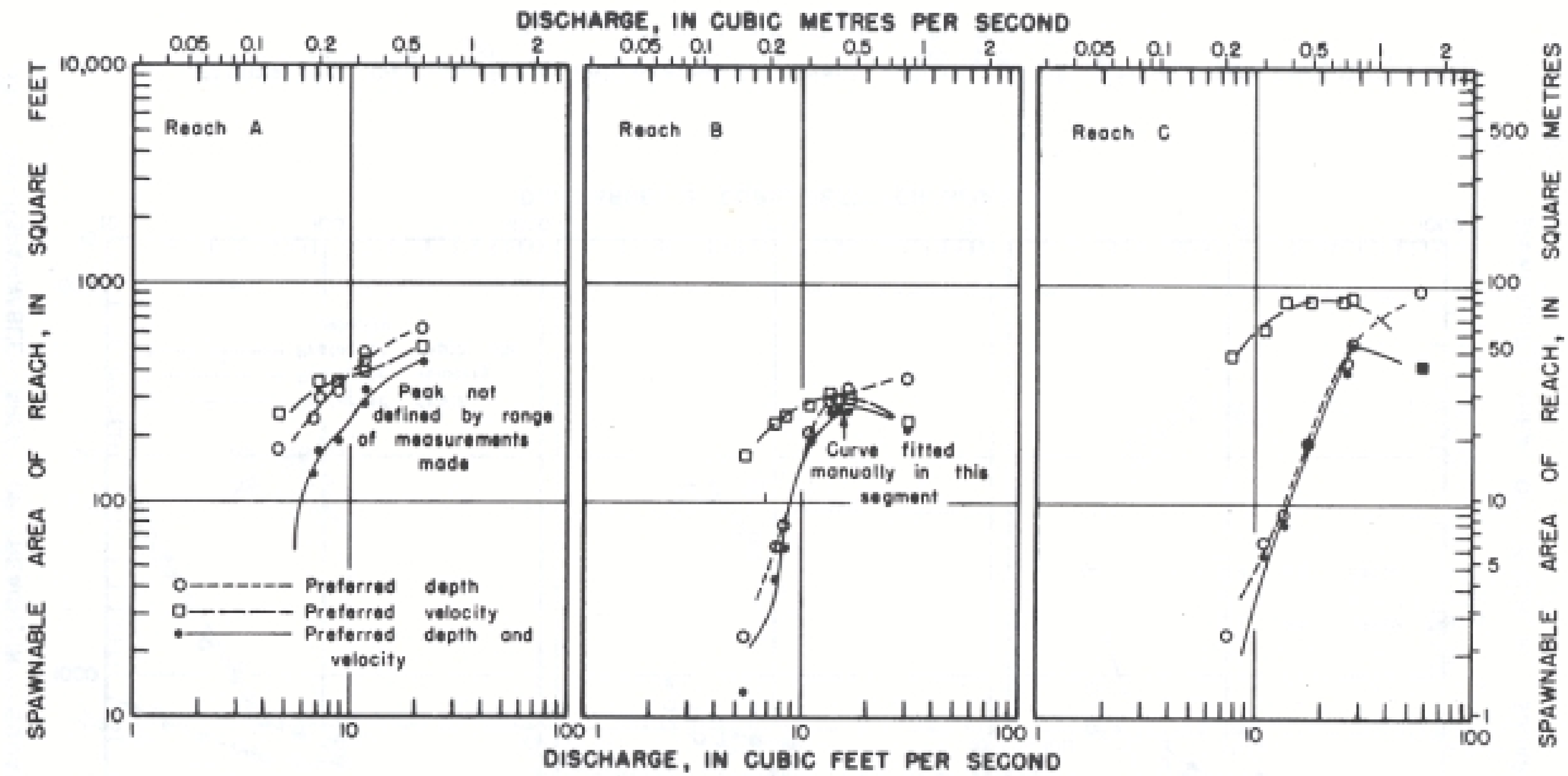

FIGURE 19.--Curves of spawnable area for steelhead versus discharge, Bear Creek.

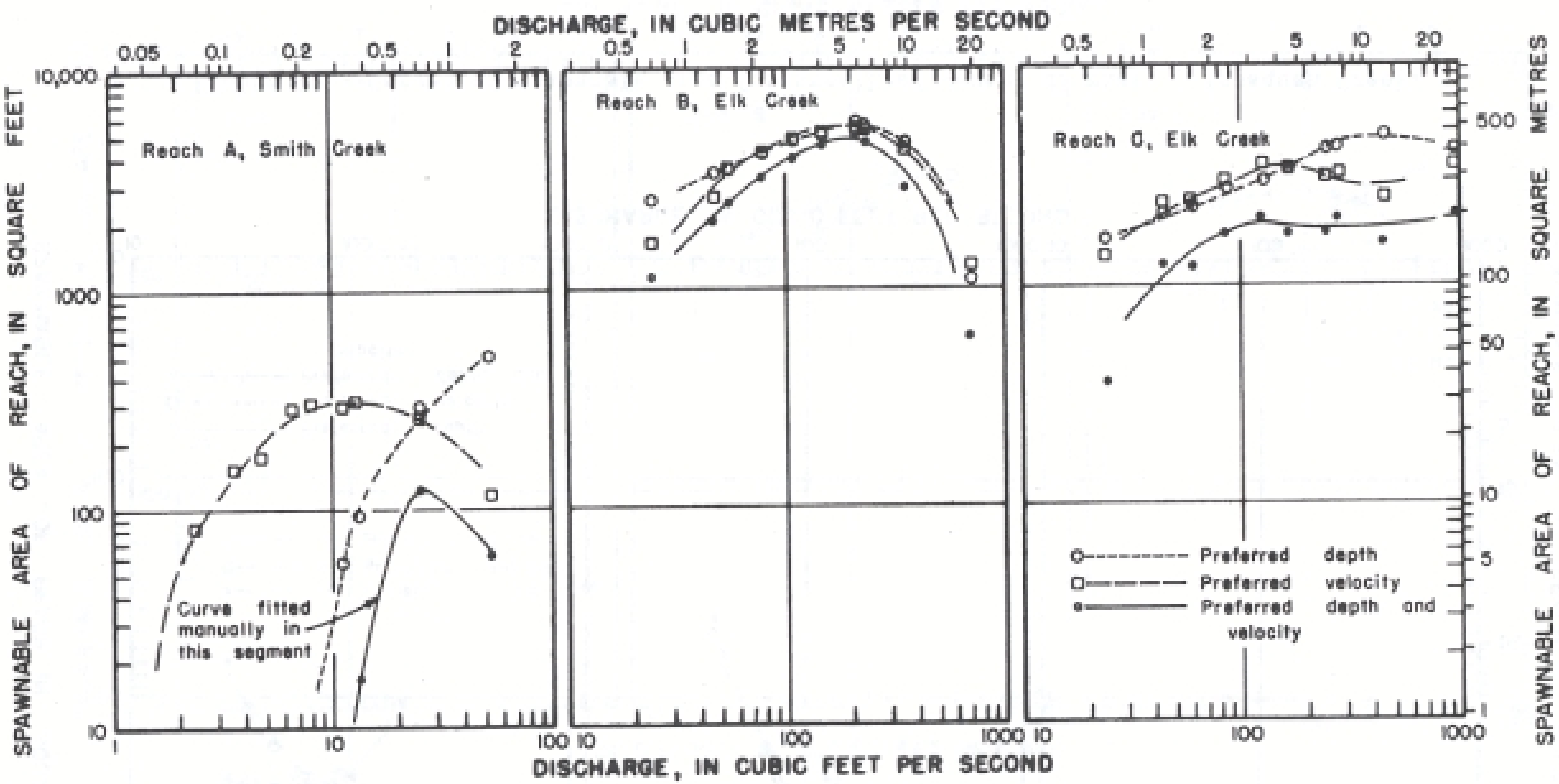

FIGURE 20.--Curves of spawnable area for steelhead versus discharge, Elk Creek and Smith Creek.

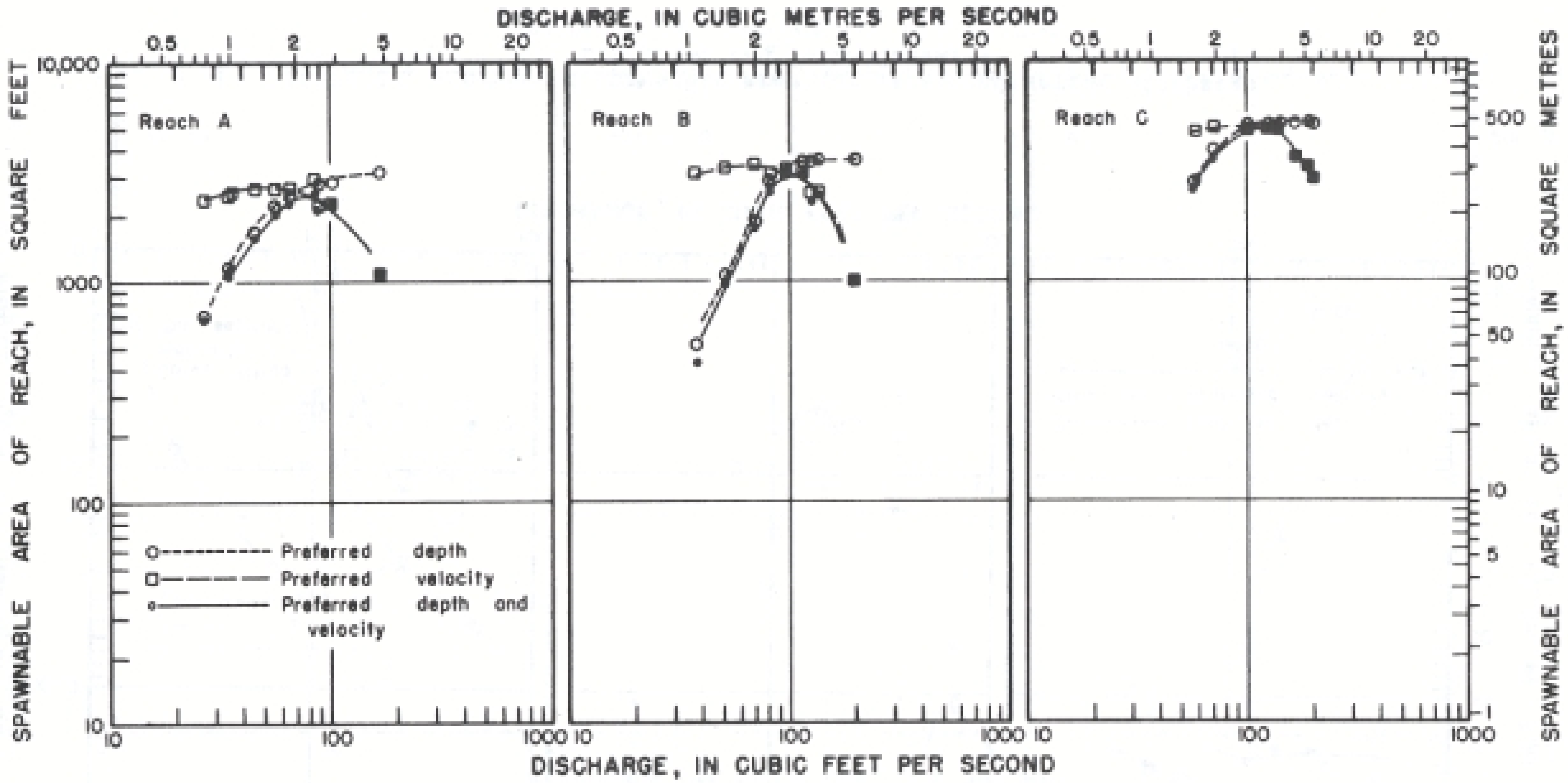

FIGURE 21.--Curves of spawnable area for steelhead versus discharge, Issaquah Creek.

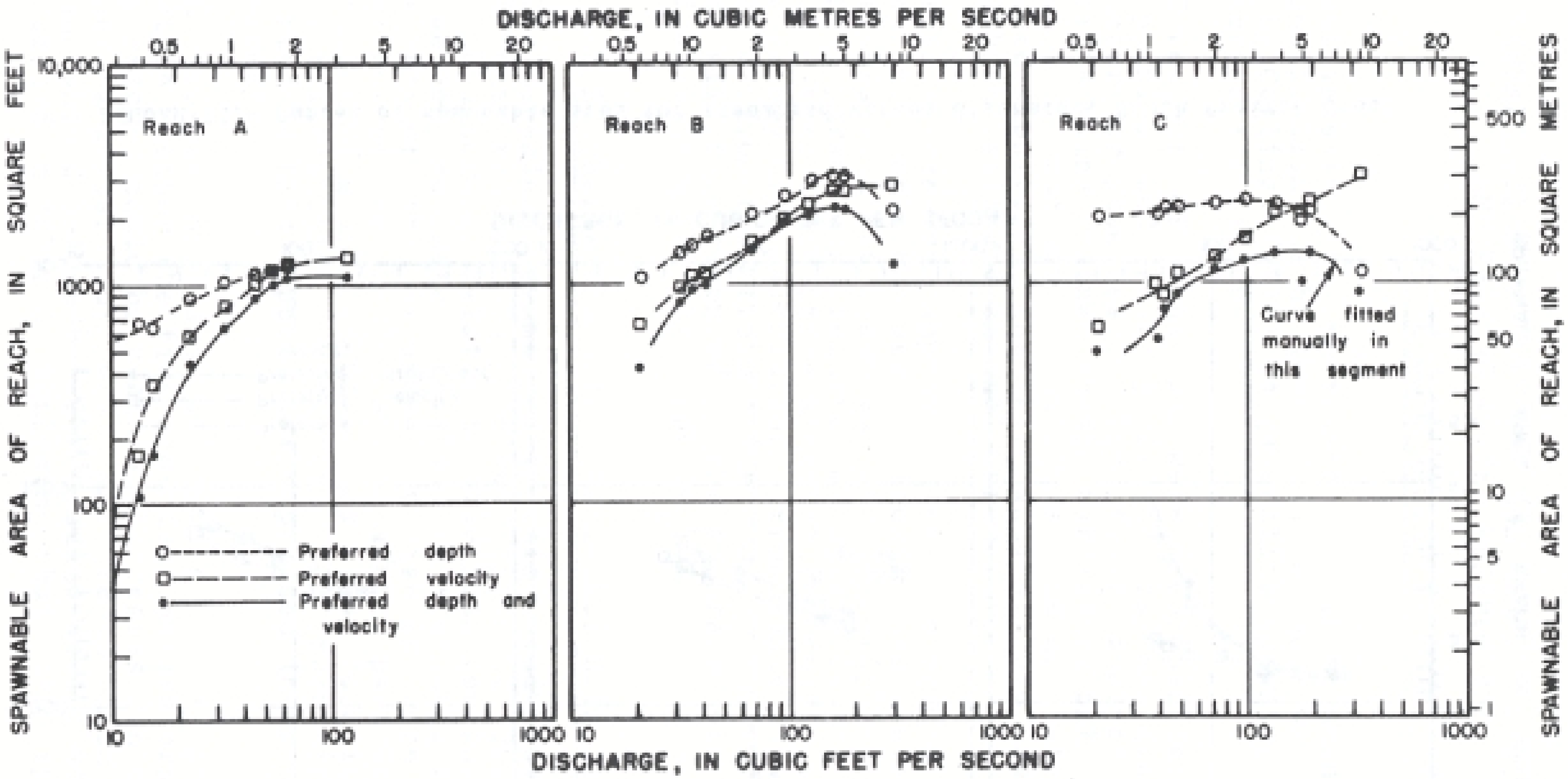

FIGURE 22.--Curves of spawnable area for steelhead versus discharge, North Nemah River.

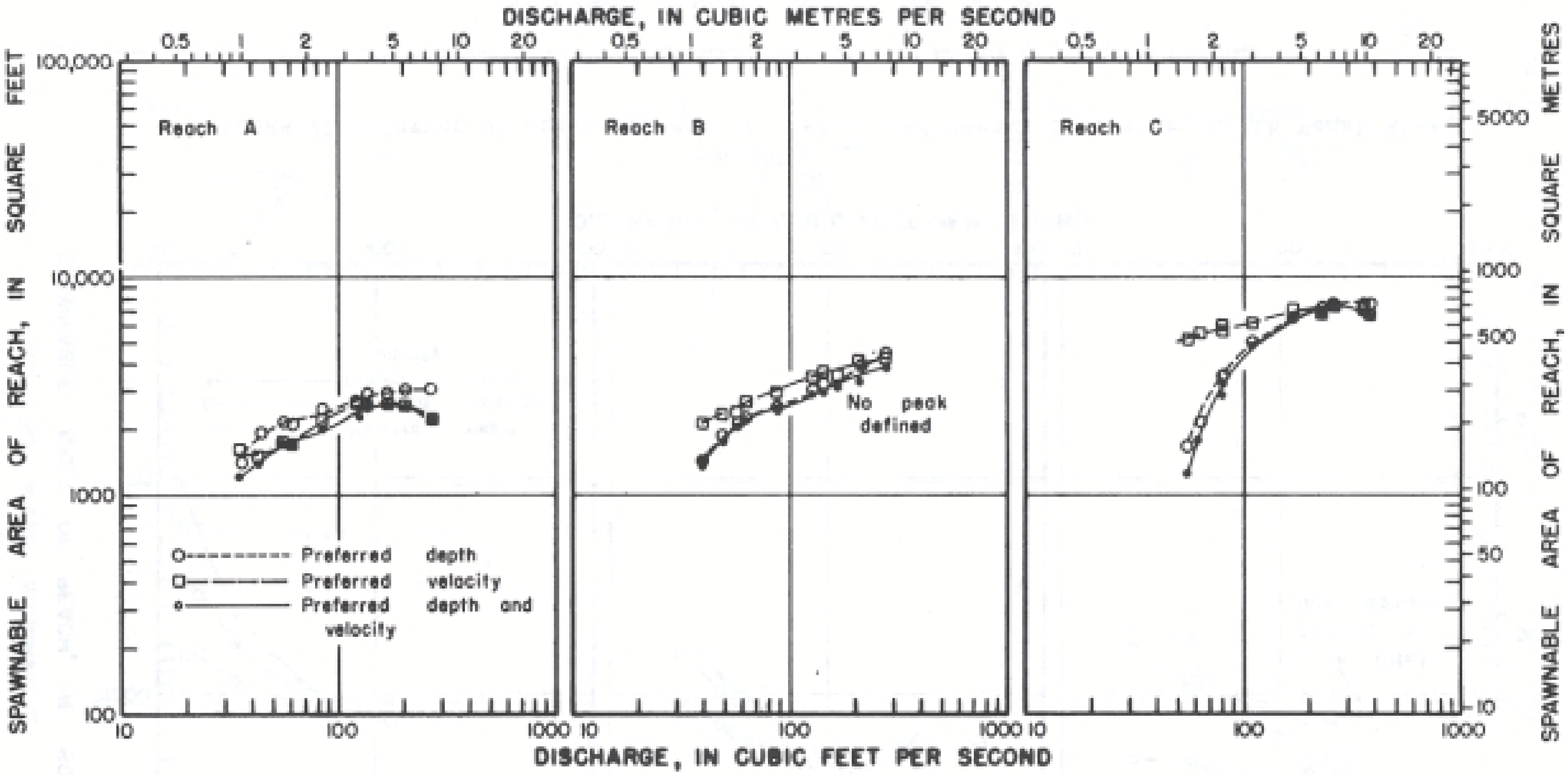

FIGURE 23.--Curves of spawnable area for steelhead versus discharge, South Prairie Creek.

GENERALIZATION OF SPAWNING AND REARING DISCHARGES AND REARING WETTED PERIMETERS

Method of Analysis

Multiple-linear regression was used as the regionalization technique. This method was previously used by Collings (1974) to generalize spawning and rearing discharges for salmon.

Three sets of equations were developed for estimating the spawning and rearing discharges and rearing wetted perimeter for steelhead. The first analysis developed equations using drainage-basin parameters only, the second analysis produced equations using stream-channel parameters only, and the third analysis produced equations using both basin and channel parameters.

This three-way approach was provided for the convenience of the user. Though most drainage-basin parameters can be measured on topographic maps, most channel parameters require measurements at the stream site. Thus, with three alternative equations available, the user may make calculations from data obtained in the office or from the stream site, or both. Of course the choice will be influenced by the accuracy of the results obtainable from the three approaches.

Discharge and Wetted-Perimeter Data Used

The dependent parameters in this study are the three discharges related to steelhead spawning (Qdv, Qs, and Qv), the discharge related to steelhead rearing (Qr), and the wetted perimeter related to steelhead rearing (P). Logarithms of the dependent variables were related to logarithms of the basin and channel parameters because inspection of graphical plots of the logarithms suggest linear relationships. However, the resulting equations presented in this report are expressed in actual units of measurement.

A two-way analysis of variance was performed to ascertain whether the five dependent parameters for all 54 study reaches could be used in the regression analysis, or whether parameters for only one reach on each of the 18 streams should be used. The results of the variance test (summarized in table 3) indicate that the spawning and rearing discharges and wetted perimeter for each reach may be considered independently. There is a 95-percent confidence that the values for different reaches on a stream are not related, or that the values for reaches on different streams are not related.

The general conclusion drawn from this variance analysis justifies the use of all the discharges and wetted perimeters in the generalization regression analysis. It must be noted, however, that spawning discharges for six reaches were excluded from the variance test due to a test requirement for three reaches on each stream. (Spawning discharges were indeterminate for one reach on each of three streams.) Therefore, spawning discharges for 51 reaches and rearing discharge and wetted perimeter for 54 reaches were included in the regression analysis.

TABLE 3.—Results of two-way analysis of variance for reaches and streams

Dependent parameter[2]	Source of variance[3]	Degrees of freedom	"F" statistic[1] Computed value	"F" statistic[1] Distribution4 value	Conclusion
Qdv	Reaches	2	4.94	3.35	Different
	Streams	14	9.65	2.04	Different
	Residual	28			
	Total-------	44			
Qs	Reaches	2	5.00	3.35	Different
	Streams	14	16.67	2.04	Different
	Residual	28			
	Total-------	44			
Qv	Reaches	2	4.94	3.35	Different
	Streams	14	8.57	2.04	Different
	Residual	28			
	Total-------	44			
Qr	Reaches	2	12.74	3.28	Different
	Streams	17	23.07	1.95	Different
	Residual	34			
	Total--------	53			
P	Reaches	2	4.99	3.28	Different
	Streams	17	15.79	1.95	Different
	Residual	34			
	Total--------	53			

[1]The testing level was 0.95 for all tests.

[2]Abbreviations are defined on p. 8-10 of report.

[3]Treatment is random throughout.

[4]"F" distribution values tabulated in statistical texts are dependent on the respective degrees of freedom of the specific and residual sources of variation.

Basin- and Channel-Parameter Data Used

The selection of independent parameters for use in regression analysis requires sound hydrologic experience and judgment. The independent parameters chosen must be hydrologically related to the dependent parameter and yet should be fairly easy to determine.

Several factors were considered in the selection of the independent parameters. The correlation coefficient was computed for all possible pairs of the dependent and independent parameters selected. Independent parameters that had a high correlation with the dependent parameter, but a low correlation with other similarly qualified independent parameters, were selected initially. Preliminary regressions using those initial independent parameters were then examined to determine which of the independent parameters had the greatest level of significance and produced the greatest reductions in the standard error of estimate. Seventeen drainage-basin and stream-channel parameters were examined and tested in that manner for this analysis; of these, four basin parameters and one channel parameter were selected in the final analysis.

The four drainage-basin parameters selected are described as follows:

1. Drainage area (DA), in square miles. This is gross horizontal area upstream from each study reach as delineated and measured from the latest U.S. Geological Survey topographic maps. This parameter represents the total surface from which precipitation and snowmelt may contribute to the flow of the stream at the reach.

2. Mean altitude of the basin (MA), in feet above mean sea level (msl). The mean altitude of the basin is determined by averaging elevations at points on a square grid overlying the drainage area on the topographic maps. This parameter is used to reflect differences among basins in the effects of weather and vegetation on the sources of water contributing to streamflow at the reaches.

3. Reach altitude (RA), in feet above mean sea level. This is the altitude of the streambed at the reach as determined from the topographic maps. This parameter often reflects differences in streamflow characteristics between mountain and lowland streams.

4. Reach slope (RS), in feet per mile. This is determined from topographic maps and is the average slope of the stream channel for the 10 percent of the total stream length immediately upstream from the reach, where stream length is measured along the main stem of the stream extended to the basin divide. This parameter is an approximate measure of the effect of gravity on the velocity of streamflow at the reach, and is the only independent parameter included both in the regression analysis using basin parameters and the regression analysis using channel parameters. It may be interpreted as a characteristic of both the drainage basin and the stream channel.

The stream-channel parameter included in the regression analyses is the width, in feet, of the stream at the toe of the bank, illustrated by TW in figure 2. It is the average width of the channel measured at the four cross sections of the study reach. The width is determined at each cross section by measuring horizontally from the point where the streambed and one bank join (point TB in fig.2), to the ground surface on the other bank. The width of gravel bars, if present, is included, and the lower toe of the two banks is used if a toe is found on both sides of the channel. This parameter is an indicator of the cross-section area in which flow can occur in the channel.

The basin and channel parameters described above are listed in table 4 for each of the 54 reaches.

The parameters examined and tested but not used in the final analyses include stream length, channel slope, bankfull width and wetted perimeter, bankfull average depth and maximum depth, three different ratios of width and depth, gravel size, cross-section area below the toe of bank, and maximum depth from toe of bank.

TABLE 4.—Drainage-basin and stream-channel parameters for stream reaches studied

Stream name	Drainage basin					Stream channel
	Study reach	Drainage area, DA (mi^2)	Mean basin altitude, MA (ft), msl	Reach altitude, RA (ft), msl	Reach slope, RS (ft/mi)	width at toe-of-bank stage,[a] TW (ft)
Cedar River---------------------------	A	160	2,010	260	29	111
	B	169	1,930	225	26	96
	C	177	1,860	90	22	87
Dewatto River------------------------	A	18.4	376	55	26	31
	A-1	19.1	372	40	31	31
	B	21.7	370	10	33	52
Kalama River-------------------------	A	142	2,350	400	34	153
	B	154	2,270	330	34	106
	C	157	2,240	260	30	147
North Fork Nooksack River--------	A	105	4,300	1,245	85	130
	B	193	4,000	720	59	130
	C	282	3,270	345	26	176
Elochoman River---------------------	A	47.1	1,270	140	30	117
	B	56.2	1,250	55	22	126
	C	66.2	1,180	25	20	102
Humptulips River--------------------	A	48.9	1,530	310	15	116
	B	61.4	1,370	260	13	149
	C	132	1,000	100	15	163
Green River---------------------------	A	285	2,900	160	24	262
	B	325	2,630	110	15	121
	C	327	2,620	75	16	174
Wynoochee River--------------------	A	16.4	2,640	840	35	77
	B	74.1	1,950	401	20	178
	C	112	1,490	155	11	214
Deschutes River----------------------	A	56.2	1,670	550	31	66
	B	76.0	1,460	415	12	88
	C	139	1,060	165	8	77
Dosewallips River--------------------	A	91.9	4,750	320	78	105
	B	99.9	4,480	130	46	100
	C	115	4,130	30	28	123
North Fork Stillaguamish River---	A	51.5	2,500	460	28	106
	B	89.7	2,340	385	18	173
	C	162	2,480	190	10	196

TABLE 4.—Drainage-basin and stream-channel parameters for stream reaches studied--Continued

Stream name	Drainage basin					Stream channel
	Study reach	Drainage area, DA (mi^2)	Mean basin altitude, MA (ft), msl	Reach altitude, RA (ft), msl	Reach slope, RS (ft/mi)	width at toe-of-bank stage,[a] TW (ft)
North Fork Toutle River-------------	A	277	2,790	720	40	158
	B	286	2,730	550	26	110
	C	291	2,690	440	26	208
Bear Branch---------------------------	A	8.8	557	138	20	33
	B	9.6	544	40	56	35
	C	11.7	546	15	7	45
Bear Creek-----------------------------	A	4.4	441	260	70	15
	B	5.8	420	210	56	11
	C	10.8	405	150	39	16
Smith Creek (A)----------------------	A	3.5	1,040	500	23	15
Elk Creek (B,C)-------------------	B	46.7	810	360	11	50
	C	57.6	817	310	32	83
Issaquah Creek-----------------------	A	17.6	1,130	300	68	31
	B	27.0	940	200	55	42
	C	38.1	996	95	39	40
North Nemah River------------------	A	6.7	822	245	59	24
	B	18.8	674	35	16	45
	C	19.1	666	30	15	40
South Prairie Creek------------------	A	[b]67.5	2,560	620	67	46
	B	69.7	2,500	510	50	78
	C	87.2	2,150	330	10	75

[a]Average of values at four channel cross sections.
[b]Revised from previously published value.

Results of Regression Analyses

The empirical equations and the regression coefficients derived through regression analysis are shown in tables 5-7. The equations using only basin parameters are shown in table 5, those using only channel parameters are in table 6, and those using both basin and channel parameters are in table 7.

All of the equations are of the general form,

$$Y = aX_1^{b_1} X_2^{b_2} \ldots\ldots X_n^{b_n} ,$$

where Y is the dependent parameter--the spawning or rearing discharge or rearing wetted-perimeter;

$$X_1, X_2 \ldots\ldots X_n$$

represent the drainage-basin and stream-channel independent parameters; a is a constant; and

$$b_1, b_2 \ldots\ldots b_n$$

are coefficients that represent the power to which the values of basin and channel parameters are to be raised.

It should be noted that basin and channel parameters used in the equations in metric units will not produce a correct solution in metric units unless the constant, a, is suitably changed also. Use of metric units does not affect values of the coefficient b.

The equations shown for each dependent parameter, Y, are those that include the single most effective independent parameter, the two most effective independent parameters, and up to as many as the four most effective parameters. The last equation shown for each dependent parameter is that with the lowest standard error. To permit the user a choice of accuracy and parameters, more than one equation is shown for most of the dependent parameters. Notably, the values in tables 6 and 7 for determining Qs and P are the same--none of the basin parameters were significant when combined with channel parameters.

The following is an example of the solution of the equation to determine Qdv for reach C on the Elochoman River, using both basin and channel parameters. The three equations shown in table 7 list coefficients for reach altitude, mean basin altitude, and width at toe of bank. The values for the independent parameters, found in table 4, are as follows: reach altitude, RA, 25 ft msl (7.6 m); mean basin altitude, MA, 1,180 ft msl (360 m); and width at toe of bank, TW, 102 ft (31.1 m). Substituting these values into the three equations yields:

$Y = Qdv_1 = 1.55(102)^{1.16} = 332$ ft^3/s(9.40 m^3/s) $\pm$28 percent.

$Y = Qdv_2 = 2.02(102)^{1.19}$ $(25^{)-0.068}$ = 399 ft^3/s(11.3 m^3/s)
$\pm$27 percent.

$Y = Qdv_3 = 1.12(102)^{1.08}$ $(25^{)-0.118}$ $(1,180)^{0.181}$

= 408 ft^3/s(11.6 m^3/s) $\pm$26 percent.

As noted in table 2, the peak discharge determined (Qdv) for reach C on the Elochoman River is 280 ft^3/s (7.9 M^3/s).

The average percentage standard error is listed for each equation in the last columns in tables 5-7 to indicate the range of accuracy that may be expected for about two-thirds of the solutions for each equation. In the example above, the standard errors from table 7 for those three equations are shown just following the three solutions. The difference of 52 ft^3/s (1.5 m^3/s) between Qdv from table 2 and the value computed from the first sample equation represents a departure of 19 percent from Qdv from table 2. This departure is within one standard error, $\pm$28 percent, for the first equation. Similarly, differences for the second and third equations represent departures of 42 and 46 percent, respectively. The departure of 42 percent for the second equation is within two standard errors ($\pm$54 percent) of the value from table 5, and the departure of 46 percent for the third solution is also within two standard errors ($\pm$52 percent). Thus, it is apparent that some solutions of the empirical equations may not fall within one standard error of the values determined for the study reaches. About one-third of the solutions are expected to depart by more than one standard error from the determined values, but only about 5 percent of the solutions are expected to depart by more than two standard errors.

The correlation coefficients listed for each equation in tables 5-7 indicate the degree of association among the parameters used in the equations. A value of $\pm$1.00 would indicate perfect correlation according to the assumption of a linear-logarithmic relationship among the parameters, and a value of 0.00 would indicate no correlation.

SUMMARY AND CONCLUSIONS

The purpose of this study was (1) to determine the stream discharges and wetted perimeters corresponding to spawning and rearing conditions preferred by steelhead trout at 54 reaches on 18 streams in western Washington, and (2) to develop empirical equations relating the discharges and wetted perimeters to easily measured drainage-basin and stream-channel parameters. Those objectives have been accomplished, and the results of the study are presented in this report.

Equations for estimating the spawning and rearing discharges and rearing wetted perimeter at unmeasured stream sites were developed by using multiple-regression techniques and measuring discharges and wetted perimeters. The independent parameters used were drainage area, mean altitude of the basin, reach altitude, reach slope, and average width of reach at toe of bank. Standard errors of estimate for the equations ranged from 26 to 50 percent for preferred discharges corresponding to the greatest areas of preferred spawning depths and velocities, from 32 to 46 percent for sustaining discharges corresponding to reduced areas of preferred spawning depths and velocities) from 44 to 68 percent for preferred discharges corresponding to the greatest areas of preferred spawning velocities, from 46 to 57 percent for rearing discharges, and from 20 to 41 percent for the rearing wetted perimeter.

Determination of stream discharges that are preferred during spawning and rearing of steelhead provides information from which the discharges best suited for fish propagation may be established. However, due to the amount of time and expense required to obtain the data, measurements to determine the discharges preferred at spawning and rearing sites on all streams in western Washington are neither practical nor desirable. Thus, the empirical equations presented in this report may be used to estimate the spawning and rearing discharges and rearing wetted perimeter for steelhead at many stream sites not studied. Measurements and determinations of relevant stream characteristics and parameters will probably be necessary for other streams where estimation errors, based on these equations, appear to be unacceptable to the user.

TABLE 5.—Constants and coefficients of equations used for estimating discharges and wetted perimeters from basin parameters

Model equation: $Y = a(DA)^{b1} (RA)^{b2} (MA)^{b3} (RS)^{b4} \pm SE$
(All units are English)

Discharge, Y, in ft^3/s or wetted perimeter Y, in feet[1]	Regression constant a	Regression coefficients, b, for: Drainage area, DA (mi^2) b_1	Reach altitude, RA (ft, msl) b_2	Mean basin altitude, MA (ft, msl) b_3	Reach slope, RS (ft/mi) b_4	Correlation coefficient	Standard error, SE (in percent of Y)
Discharge:2							
Preferred:							
Qdv_1---------------	16.8	0.666	--	--	--	0.85	50
Qdv_2---------------	31.4	.650	--	--	-0.172	0.86	50
Qdv_3---------------	7.30	.484	--	0.342	-.282	.87	48
Qdv_4---------------	4.64	.448	-0.182	.533	-.234	.89	45
Sustaining:							
Qs_1----------------	11.6	.614	--	--	--	.85	46
Qs_2----------------	4.65	.538	--	.168	--	.86	46
Qs_3----------------	5.49	.480	--	.258	-.179	.86	45
Velocity:							
Qv_1----------------	12.3	.783	--	--	--	.82	68
Qv_2----------------	24.0	.824	-.161	--	--	.84	66
Qv_3----------------	3.53	.653	-.268	.435	--	.85	64
Qv_4----------------	4.89	.569	-.240	.543	-.283	.86	62
Rearing:							
Qr_1-----------------	2.09	.892	--	--	--	.89	57
Qr_2-----------------	.217	.701	--	.418	--	.91	54
Qr_3-----------------	.146	.643	-.173	.628	--	.92	52
Wetted perimeter:							
Rearing:							
P_1------------------	8.25	0.523	--	--	--	.85	41
P_2------------------	14.4	.507	--	--	-.149	.86	40
P_3------------------	4.45	.307	--	.277	-.239	.87	38

[1]Abbreviations are defined on p. 8-10.
[2]The subscript numbers denote the number of independent parameters in the equation.

TABLE 6.—Constants and coefficients of equations used for estimating discharges and wetted perimeters from channel parameters

Model equation: $7 = a(TW)^{b_5} \pm SE$

[All units are English]

Discharge, Y, in ft^3/s or wetted perimeter Y, in feet[1]	Regression constant a	Regression coefficient for width at toe of bank, TW (ft) b_5	Correlation coefficient	Standard error, SE (in percent of Y)
Discharge:				
Preferred:				
Qdv------------------------	1.55	1.16	0.95	28
Sustaining:				
Qs-------------------------	1.45	1.05	.93	32
Velocity:				
Qv-------------------------	.773	1.36	.92	46
Rearing:				
Qr-------------------------	.164	1.42	.90	56
Wetted perimeter:				
Rearing:				
P---------------------------	1.17	.937	.96	20

[1]Abbreviations are defined on p. 8-10.

TABLE 7.—Constants and coefficients of equations used for estimating discharges and wetted perimeters from both basin and channel parameters

Model equation: $7 = a(DA)^{b1}\ (RA)^{b2}\ (MA)^{b3}\ (TW)^{b5} \pm SE$

[All units are English]

Discharge, Y, in ft³/s or wetted perimeter Y, in feet[1]	Regression constant a	Regression coefficients, b, for: Drainage area, DA (mi^2) b_1	Reach altitude, RA (ft, msl) b_2	Mean basin altitude, MA (ft, msl) b_3	Width at toe of bank, TW (ft) b_5	Correlation coefficient	Standard error, SE (in percent of Y)
Discharge:[2]							
Preferred:							
Qdv_1---------------	1.55	--	--	--	1.16	0.95	28
Qdv_2---------------	2.02	--	-0.068	--	1.19	.96	27
Qdv_3---------------	1.12	--	-.118	0.181	1.08	.96	26
Sustaining:							
Qs_1----------------	1.45	--	--	--	1.05	.93	32
Velocity:							
Qv_1----------------	.773	--	--	--	1.36	.92	46
Qv_2----------------	1.25	--	-.125	--	1.40	.93	44
Rearing:							
Qr_1-----------------	.164	--	--	--	1.42	.90	56
Qr_2-----------------	.410	0.459	--	--	.778	.92	49
Qr_3-----------------	.0991	.371	--	.295	.692	.93	47
Qr_4-----------------	.0809	.360	-.120	.452	.631	.94	46
Wetted perimeter:							
Rearing:							
P_1------------------	1.17	--	--	--	.937	.96	20

[1]Abbreviations are defined on p. 8-10.
[2]The subscript numbers denote the number of independent parameters in the equation.

REFERENCES CITED

Bell, M. C., 1973, Fisheries handbook of engineering requirements and biological criteria, Chapter 8, Food producing areas and their requirements: Fisheries-Engineering Research Program, Corps of Engineers, North Pacific Division, Portland, Oreg. (chapter unpaged).

Collings, M. R., 1974, Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington: U.S. Geol. Survey open-file report, 39 p.

Collings, M. R., Smith, R. W., and Higgins, G. T., 1972a, The hydrology of four streams in western Washington as related to several Pacific salmon species: U.S. Geol. Survey Water-Supply Paper 1968, 109 p.

--------1972b, Hydrology of four streams in western Washington as related to several Pacific salmon species, Humptulips, Elochoman, Green, and Wynoochee Rivers: U.S. Geol. Survey open-file report, 128 p.

Collings, M. R., and Hill, G. W., 1973, Hydrology of ten streams in western Washington as related to several Pacific salmon species: U.S. Geol. Survey Water-Resources Inv. 11-73, 149 p.

Deschamps, Gene, Wright, Sam, and Magee, J. K., 1966, Biological and engineering fisheries studies, Wynoochee Reservoir, Washington: Washington Dept. Fisheries, summ. rept., 40 p.

Hunter, J. W., 1973, A discussion of game fish in the State of Washington as related to water requirements: Washington State Dept. Game, dupl. rept., 66 p.

Rantz, S. E., 1964, Salmon hydrology related to the optimum discharge for king salmon spawning in the northern California coast ranges: U.S. Geol. Survey Water-Supply Paper 1779-AA, 15 p.

Westgate, John, 1958, The relationship between flow and usable salmon spawning gravel, Cosumnes River, region 2, Inland Fisheries: California Dept. Fish and Game, dupl. rept. no. 58-2, 8 p.

Whittaker, E. T., and Robinson, G., 1932, The calculus of observations: Blackie and Son, London, 295 p.