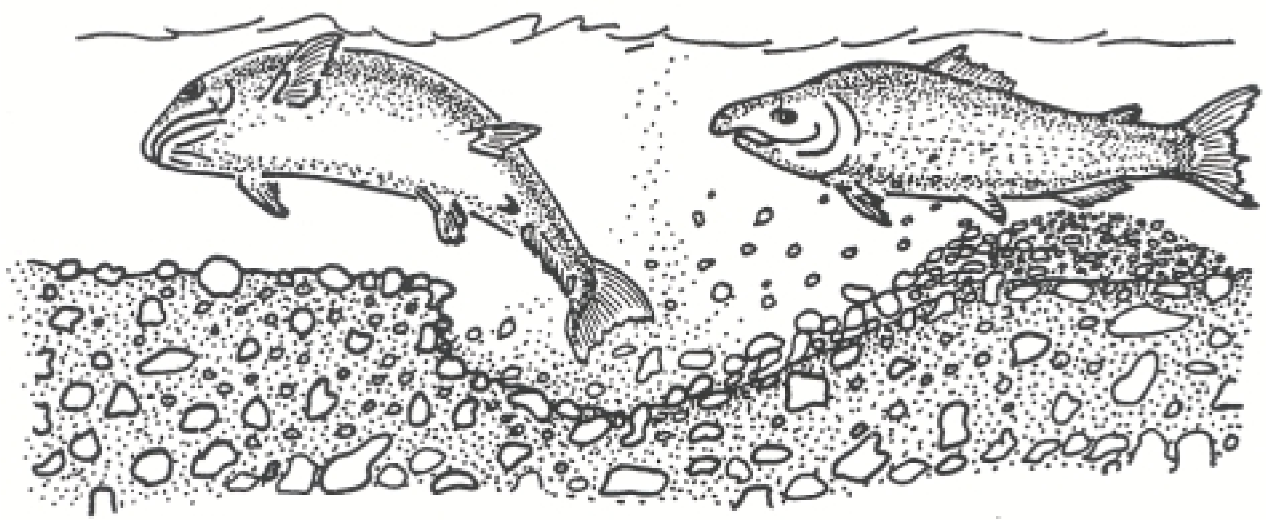
PREFERRED STREAM DISCHARGES FOR SALMON SPAWNING AND REARING IN WASHINGTON



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Open-File Report 77-422

Prepared in Cooperation with
State of Washington Department of Fisheries

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREFERRED STREAM DISCHARGES FOR SALMON SPAWNING AND REARING IN WASHINGTON

By C. H. Swift III

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Tacoma, Washington
1979

For further information on this investigation and on
other water-resources studies in Washington carried
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METRIC CONVERSION TABLE

Multiply	By	To obtain
Feet (-ft)	0.3048	meters (m)
Miles (mi)	1.609	kilometers (lan)
Square feet (ft^2)	.09290	square meters (m2)
Square miles (mi^2)	2.590	square kilaneters (km2)
Feet per mile (ft/mi)	.1894	meters per kilometer (m/lcn)
Feet per second (ft/s)	.3048	meters per second (m/s)
Cubic feet per second (ft^3/s)	.02832	cubic meters per second (m3 /s)

PREFERRED STREAM DISCHARGES FOR SALMON SPAWNING AND REARING IN WASHINGTON

By C. H. Swift III

ABSTRACT

Stream discharges preferred by salmon for spawning were determined from relationships between discharge and spawnable area at 84 study reaches on 28 streams in Washington. Preferred discharges for spawning were found statistically equivalent for Chinook, pink and chum salmon. Regression equations developed for estimating discharges preferred by these species for spawning at other stream sites had standard errors of estimate of 40 percent where a relationship with toe-of-bank channel width was used, and 55 percent where as in drainage area was used. Similarly, equations for estimating the preferred discharge for spawning by sockeye and coho salmon (also statistically, equivalent) had standard errors of 48 percent using channel width and 61 percent using drainage area. In general, the discharges preferred for spawning by salmon ranged in magnitude from about 0.3 to 11 times the median monthly mean discharges for September and October and about 0.1 to 6 times the median monthly means for November and December-the four months when spawning is greatest.

Stream discharges preferred by salmon for rearing were determined from relationships between discharge and wetted perimeter at the study reaches. Those discharges ranged from about 0.7 to 4 times the median monthly mean discharge for September, when low flows are usually most limiting on the rearing capacity of streams. Equations developed for estimating preferred rearing discharges at other stream sites had standard errors of 57 percent using channel width and 81 percent using drainage area.

Peak-unit spawnable area, or maximum area per unit length of channel that has preferred water depths and velocities, was similar for the five salmon species. Equations developed for estimating that area at other sites had standard errors of 27 percent using channel width and 47 percent using drainage area. In general, reducing discharge below the preferred spawning discharge by 25, 50, and 75 percent had the effect of reducing spawnable area by about 5, 15, and 40 percent of the peak-unit spawnable area.

INTRODUCTION

Purpose and Scope

This study was conducted in cooperation with the State of Washington Department of Fisheries (1) to evaluate at study sites the stream discharges and streambed areas preferred by salmon for spawning, (2) to evaluate the stream discharges preferred for rearing, (3) to develop relationships for estimating the preferred discharges and areas at sites on any stream in the study area, and (4) to examine the relationship between the preferred discharges and selected streamflow characteristics. Such information has been needed since management of the salmon fishery first began, but that need has increased appreciably during the past few years.

Commercial and sport fishing for salmon in waters of western Washington is one of the State's major economic enterprises. Although some of these anadromous fish ace reproduced in hatcheries, most spawn naturally in the streams of Washington. Juvenile salmon, prior to becoming smolts and descending to the ocean, also rear in these same streams, and in lakes and estuaries connected with the streams. Hatcheries will probably play an increasingly important rote in supplementing this fish resource, but continuation of natural reproduction is necessary to preserve the physical and biological characteristics of the various salmon species.

The Washington State Legislature, recognizing a need to maintain stream conditions that would preserve natural salmon reproduction and growth, in 1967 provided a statute for the establishment of minimum water flows and levels to protect fish, among other resources. In the Water Resources Act of 1971, the State Legislature defined fish propagation as a beneficial water use and directed that the natural environment be protected and, where possible, be enhanced by providing sufficient base flows to reserve the fish resource. Requests for establishment of minimum flow could be made by the Department of Fisheries, but just what that magnitude of flow should be was unknown.

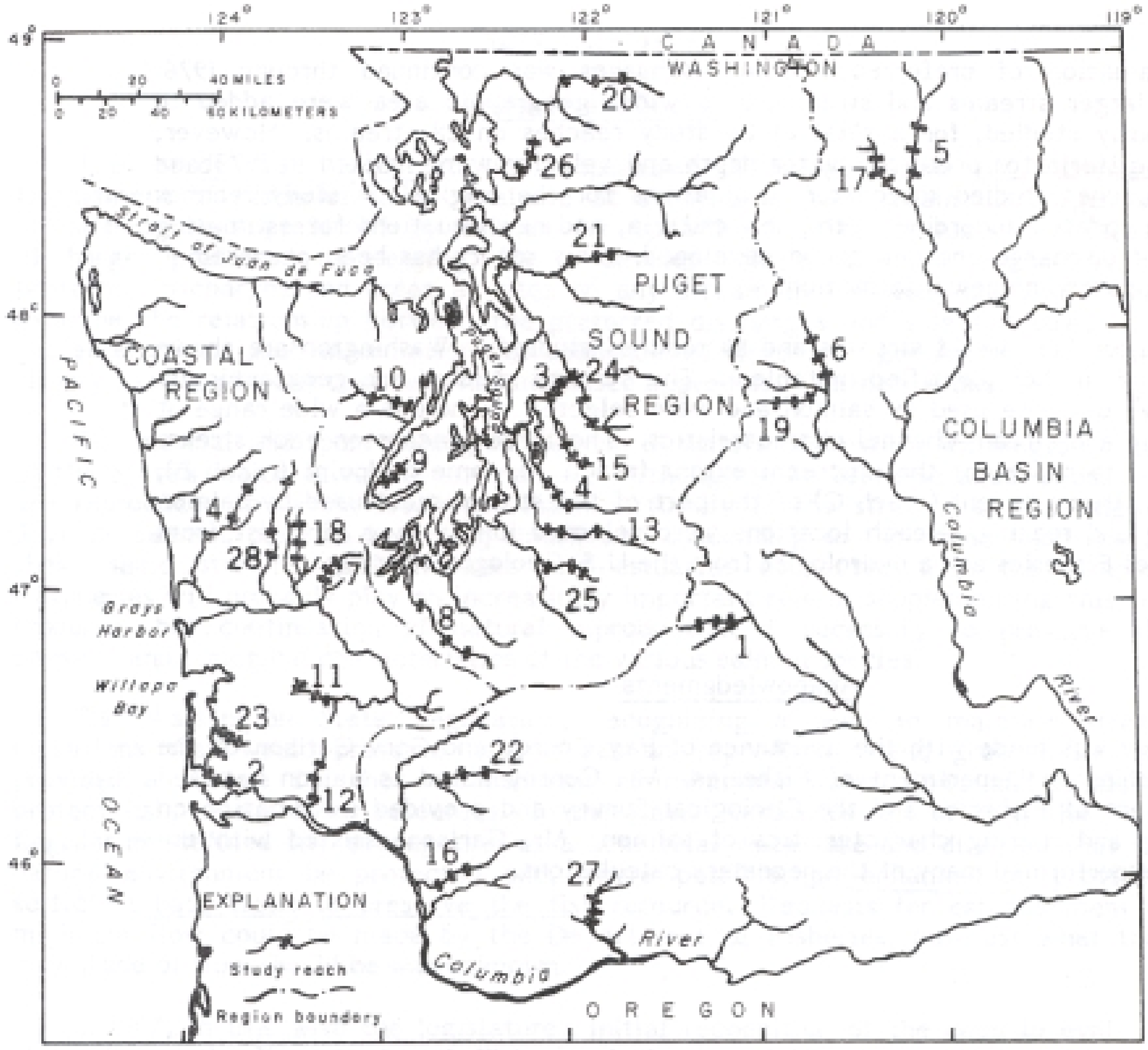
In 1967, in line with the legislature's initial recognition of the need to evaluate streamflows, the Department of Fisheries had entered into a cooperative program with the U.S. Geological Survey to develop a method of determining desirable streamflows for salmon spawning and rearing. Criteria for preferred water depths and velocities for spawning for each salmon species were provided by the Department of Fisheries. A method based on favorable water depths and velocities was developed for salmon spawning and a method based on wetted perimeter of the streambed was developed for salmon rearing at specific study reaches by Collings, Smith, and Higgins (1972a). The method for spawning was a modification of that developed by Rantz (1964). By 1973 these methods had been applied and discharges preferred for spawning and rearing evaluated for 54 study reaches, 3 on each of 18 streams in western Washington (Collings and others, l972a and 1972b; Collings and Hill, 1973). On the basis of the data for those 54 reaches, Collings (1974) also developed equations for estimating the preferred discharges at other reaches on other streams.

The evaluation of preferred stream discharges was continued through 1976. Reaches on larger streams and streams in a wider geographic area were added to those previously studied, for a total of 84 study reaches on 28 streams. However, because the criteria for preferred water depth and velocity were revised in 1973 and applied to reaches studied thereafter, evaluations for .the original 54 study reaches needed to be updated according to the new criteria, and new equations for estimating the preferred discharges needed to be developed. This report has been prepared to cover both updated and new information.

The locations of the 28 streams and 84 reaches studied in Washington are shown in figure 1 and further identified in table 1. The streams studied are geographically representative of those used by salmon and were selected to include a wide range of drainage-basin and stream-channel characteristics. The three reaches on each stream were selected to represent the upstream extent (reach A), some midpoint (reach B), and the downstream extent (reach C) of the part of the stream most used by salmon for spawning and rearing. Reach locations were selected jointly by a biologist from Department of Fisheries and a hydrologist from the U.S. Geological Survey.

Acknowledgments

This study was made with the assistance of Fay Conroy and Gary Carlson of the State of Washington Department of Fisheries. Mr. Conroy acted as liaison between the Department of Fisheries and the Geological Survey and provided information on the spawning and rearing characteristics of salmon. Mr. Carlson assisted with the fieldwork and performed many of the necessary calculations.



1 American River
2 Bear Branch
3 Bear Creek
4 Cedar River
5 Chewack River
6 Chiwawa River
7 Cloquallum Creek
8 Deschutes River
9 Dewatto River
10 Dosewallips River
11 Elk Creek and Smith Creek
12 Elochoman River
13 Green River
14 Humptulips River
15 Issaquah Creek
16 Kalama River
17 Methow River
18 Middle Fork Satsop River
19 Nason Creek
20 North Fork Nooksack River
21 North Fork Stillaguamish River
22 North Fork Toutle River
23 North Nemah River
24 Snohomish River and Snoqualmie River
25 South Prairie Creek
26 Samish River
27 Wind River
28 Wynoochee River

FIGURE 1.--Location of streams and reaches studied in Washington. Cross bars on streams indicate study reaches. Salmon species present and periods of spawning differ in the three regions shown.

TABLE 1.--Summary of locations of stream reaches studied

Study stream	Study reach	North Latitude	West Longitude	Township North	Range	Section and quarter	County	River mile above mouth
American River	A	46°55'33"	121°21'46"	17	12 E.	NW¼NW¼ sec. 33	Yakima	12.5
	B	46°56'46"	121°19'07"	17	12 E.	NW¼SW¼ sec. 23	Yakima	9.6
	C	46°57'57"	121°15'54"	17	13 E.	NW¼NE¼ sec. 18	Yakima	5.8
Bear Branch	A	46°18'47"	123°52'43"	10	10 W.	NW¼NE¼ sec. 35	Pacific	7.9
	B	46°19'13"	123°53'51"	10	10 W.	NW¼SE¼ sec. 27	Pacific	6.6
	C	46°19'48"	123°54'36"	10	10 W.	SE¼SE¼ sec. 21	Pacific	5.3
Bear Creek	A	47°49'10"	122°09'32"	27	5 E.	SW¼SW¼ sec. 15	Snohomish	5.6
	B	47°48'39"	122°09'28"	27	5 E.	NE¼SW¼ sec. 22	Snohomish	4.9
	C	47°47'36"	122°08'33"	27	5 E.	SE¼SE¼ sec. 27	Snohomish	3.4
Cedar River	A	47°25'07"	122°02'45"	22	6 E.	SW¼SE¼ sec. 4	King	13.2
	B	47°26'18"	122°03'54"	23	6 E.	SW¼NE¼ sec. 32	King	11.1
	C-1	47°28'09"	122°08'25"	23	5 E.	SW¼NW¼ sec. 23	King	5.2
Chewack River	A	48°42'27"	120°07'21"	37	22 E.	SE¼NE¼ sec. 18	Okanogan	19.6
	B	48°40'24"	120°08'06"	37	22 E.	SE¼SW¼ sec. 30	Okanogan	16.8
	C	48°35'32"	120°09'50"	36	21 E.	NE¼SE¼ sec. 26	Okanogan	10.3
Chiwawa River	A	48°02'48"	120°50'04"	29	16 E.	NE¼ sec. 3	Chelan	28.5
	B	47°59'49"	120°48'59"	29	16 E.	NE¼SW¼ sec. 23	Chelan	24.3
	C	47°57'34"	120°47'16"	28	16 E.	NW¼NE¼ sec. 1	Chelan	20.8
Cloquallum Creek	A	47°05'03"	123°22'13"	19	6 W.	SE¼SE¼ sec. 36	Mason	8.9
	B	47°02'03"	123°22'11"	18	6 W.	SE¼NE¼ sec. 24	Grays Harbor	5.0
	C	47°00'56"	123°21'44"	18	5 W.	NE¼SW¼ sec. 30	Grays Harbor	3.5
Deschutes River	A	46°47'53"	122°29'02"	15	3 E.	NW¼SW¼ sec. 7	Thurston	37.4
	B	46°50'42"	122°36'00"	16	2 E.	SW¼NE¼ sec. 30	Thurston	29.5
	C	46°57'27"	122°52'00"	17	2 W.	NE¼SE¼ sec. 13	Thurston	9.4
Dewatto River	A	47°28'10"	123°01'33"	23	3 W.	NE¼SW¼ sec. 23	Mason	1.9
	A-1	47°27'42"	123°01'54"	23	3 W.	NW¼SW¼ sec. 26	Mason	1.4
	B	47°27'21"	123°02'33"	23	3 W.	SW¼NE¼ sec. 27	Mason	0.5
Dosewallips River	A	47°43'42"	123°00'52"	26	3 W.	NE¼SE¼ sec. 23	Jefferson	7.2
	B	47°43'05"	122°56'50"	26	2 W.	NE¼NE¼ sec. 29	Jefferson	3.9
	C	47°41'44"	122°54'33"	26	2 W.	SE¼SE¼ sec. 34	Jefferson	0.8
Smith Creek (A) and Elk Creek (B & C)	A	46°39'04"	123°23'38"	13	5 W.	SW¼SE¼ sec. 35	Pacific	0.3 Smith Cr.
								7.1 Elk Cr.
	B	46°37'42"	123°19'50"	13	5 W.	SE¼NE¼ sec. 8	Lewis	2.5
	C	46°38'02"	123°17'41"	13	5 W.	NE¼NW¼ sec. 10	Lewis	0.7
Elochoman River	A	46°15'37"	123°18'05"	9	5 W.	NE¼SE¼ sec. 16	Wahkiakum	9.2
	B	46°13'36"	123°19'55"	9	5 W.	NE¼NW¼ sec. 32	Wahkiakum	5.8
	C	46°13'13"	123°21'11"	9	5 W.	NE¼SW¼ sec. 31	Wahkiakum	4.2
Green River	A	47°17'00"	122°03'24"	21	6 E.	NW¼NW¼ sec. 28	King	41.9
	B	47°16'42"	122°07'18"	21	5 E.	NW¼SW¼ sec. 25	King	37.2
	C	47°17'12"	122°09'16"	21	5 E.	SE¼SW¼ sec. 22	King	35.3
Humptulips River	A	47°19'44"	123°49'57"	21	9 W.	NE¼SW¼ sec. 9	Grays Harbor	40.7
	B	47°17'52"	123°50'19"	21	9 W.	NE¼NE¼ sec. 20	Grays Harbor	37.0
	C	47°13'45"	123°57'28"	20	10 W.	SW¼SW¼ sec. 8	Grays Harbor	23.6
Issaquah Creek	A	47°27'28"	122°00'13"	23	6 E.	NE¼SW¼ sec. 26	King	10.6
	B	47°28'55"	122°02'10"	24	6 E.	SW¼NW¼ sec. 15	King	7.4
	C	47°31'00"	122°01'58"	24	6 E.	SW¼SW¼ sec. 34	King	4.2
Kalama River	A	46°02'43"	122°38'17"	7	1 E.	SW¼SW¼ sec. 36	Cowlitz	18.7
	B	46°02'02"	122°39'27"	6	1 E.	SW¼NW¼ sec. 2	Cowlitz	16.7
	C	46°00'43"	122°41'15"	6	1 E.	SW¼SE¼ sec. 9	Cowlitz	14.3

TABLE 1.--Summary of locations of stream reaches studied--cont.

Study stream	Study reach	North Latitude	West Longitude	Township North	Range	Section and quarter	County	River mile above mouth
Methow River	A	48°35'23"	120°23'43"	36	19 E.	NE¼SE¼ sec. 25	Okanogan	65.3
	B	48°34'31"	120°22'28"	36	20 E.	NE¼SW¼ sec. 32	Okanogan	63.3
	C	48°32'48"	120°19'34"	35	20 E.	NW¼SE¼ sec. 10	Okanogan	59.9
Middle Fork Satsop River	A	47°13'30"	123°30'40"	20	7 W.	NE¼NE¼ sec. 14	Grays Harbor	25.4
	B	47°11'03"	123°30'53"	20	7 W.	SW¼SE¼ sec. 26	Grays Harbor	21.6
	C	47°06'42"	123°30'15"	19	7 W.	NW¼NW¼ sec. 25	Grays Harbor	14.5
Nason Creek	A	47°46'37"	120°54'22"	26	16 E.	SW¼SW¼ sec. 6	Chelan	14.8
	B	47°47'12"	120°51'23"	26	16 E.	NE¼NW¼ sec. 4	Chelan	12.2
	C	47°47'26"	120°42'55"	27	17 E.	SE¼SE¼ sec. 33	Chelan	1.6
North Fork Nooksack River	A	48°54'22"	121°50'38"	40	7 E.	SE¼SW¼ sec. 36	Whatcom	63.1
	B	48°54'16"	121°59'25"	39	6 E.	NW¼NE¼ sec. 2	Whatcom	54.9
	C	48°52'32"	122°09'02"	39	5 E.	NW¼NW¼ sec. 15	Whatcom	44.1
North Fork Stillaguamish River	A	48°16'33"	121°38'38"	32	9 E.	NE¼SE¼ sec. 9	Snohomish	34.0
	B	48°16'52"	121°42'52"	32	8 E.	NW¼NE¼ sec. 12	Snohomish	29.0
	C	48°16'37"	121°54'31"	32	7 E.	SW¼NE¼ sec. 9	Snohomish	16.1
North Fork Toutle River	A	46°22'23"	122°34'57"	10	2 E.	NW¼NE¼ sec. 8	Cowlitz	11.2
	B	46°21'19"	122°39'06"	10	1 E.	NW¼NW¼ sec. 14	Cowlitz	5.3
	C	46°20'22"	122°42'28"	10	1 E.	SW¼NE¼ sec. 20	Cowlitz	1.2
North Nemah River	A	46°28'00"	123°45'51"	11	9 W.	SW¼NW¼ sec. 2	Pacific	10.8
	B	46°30'12"	123°50'30"	12	10 W.	SW¼SW¼ sec. 19	Pacific	4.8
	C	46°30'27"	123°50'37"	12	10 W.	NE¼SE¼ sec. 24	Pacific	4.4
Snoqualmie River (A&B) and Snohomish River (C)	A	47°34'27"	121°53'35"	24	7 E.	SW¼SE¼ sec. 10	King	56.1
	B	47°39'55"	121°55'30"	25	7 E.	NW¼SW¼ sec. 9	King	43.5
	C	47°49'50"	122°02'55"	27	6 E.	SW¼SW¼ sec. 9	Snohomish	19.7
South Prairie Creek	A	47°07'58"	122°01'11"	19	6 E.	S½SE¼ sec. 15	Pierce	10.3
	B	47°07'25"	122°03'16"	19	6 E.	SW¼SW¼ sec. 16	Pierce	8.0
	C	47°07'13"	122°07'13"	19	5 E.	NE¼NE¼ sec. 23	Pierce	2.6
Samish River	A	48°35'20"	122°14'00"	36	4 E.	SW¼SE¼ sec. 24	Skagit	20.7
	B	48°33'27"	122°17'25"	35	4 E.	SW¼NW¼ sec. 3	Skagit	13.8
	C	48°32'44"	122°20'19"	35	4 E.	SE¼SE¼ sec. 6	Skagit	10.4
Wind River	A	45°54'17"	121°56'58"	5	7 E.	SW¼ sec. 21	Skamania	21.6
	B	45°52'50"	121°58'38"	5	7 E.	NE¼ sec. 31	Skamania	19.1
	C	45°51'36"	121°57'46"	4	7 E.	NW¼SW¼ sec. 4	Skamania	17.0
Wynoochee River	A	47°25'58"	123°33'02"	23	7 W.	SE¼SE¼ sec. 27	Grays Harbor	58.3
	B	47°17'54"	123°39'09"	21	8 W.	NE¼NE¼ sec. 23	Grays Harbor	40.6
	C	47°08'19"	123°38'23"	19	8 W.	SW¼SE¼ sec. 11	Grays Harbor	20.6

DEFINITIONS

Salmon Species, Distribution, and Periods of Spawning and Rearing

The five species of salmon found in Washington streams and the subject of this evaluation of their preferred spawning and rearing discharges include the following:

Chinook (Oncorhynchus tshawytscha)
Sockeye (0. nerka)
Coho (O. kisutch
Pink k (0. gorbuscha)
Chum (0. keta)

Pink and chum salmon were combined in the analyses for this report because they have the same criteria of preferred water velocities and depths for spawning. Chinook salmon are a single species, although two races (fall and spring Chinook) were treated separately in the study by Collings (1974) which gave equations for estimating preferred discharges,

For the streams studied, table 2 lists the distribution of the five salmon species (with pink and chum being combined). As in similar tables in this report, the streams are listed alphabetically.

The time of year when spawning and rearing usually occur is given in table 3. Differences in the distribution of species and their periods of spawning activity can be used to distinguish three geographic regions-Coastal, Puget Sound, and Columbia Basin-shown by boundaries in figure 1. Names of the regions are arbitrary, and the boundaries are only generally defined on the basis of the streams studied.

Generally, spawning activities begin earliest in late summer in the Puget Sound and Columbia Basin regions, but extend through the longest period in the Coastal region. Chinook, coho, and sockeye salmon occur in all three regions, but among the study streams sockeye have been observed only in the Puget Sound region. The occurrence of pink salmon is significant only in the Puget Sound region,. and chum salmon are seldom observed in the Columbia Basin region.

Coho salmon rear in streams for approximately a year. The rearing period of various races of Chinook salmon varies from 5 months to a year in streams. Sockeye salmon usually rear in lakes for approximately a year. Pink and chum salmon do not rear in freshwater but go to sea immediately upon emergence from spawning areas in the streams.

The period of spawning and rearing activity can be an important factor when the stream discharges preferred for spawning and rearing by a particular species are examined in relationship to the flow characteristics of streams. Relationships for spawning are studied herein only for the months of greatest activity-September through December. For rearing, relationships are studied for the month of September when streamflow is lowest. The rearing capacities of streams are generally considered to be controlled by the lowest flows during a year, which limit food production and shelter from predators.

TABLE 2.--Salmon species observed in streams studied[1]

Study stream	Salmon species			
	Chinook	Sockeye	Coho	Pink and/or chum
American River	X			
Bear Branch	X		X	X
Bear Creek	X	X	X	
Cedar River	X	X	X	
Chewack River	X			
Chiwawa River	X			
Cloquallum Creek	X		X	X
Deschutes River	X		X	
Dewatto River	X		X	X
Dosewallips River	X		X	X
Elk Creek and Smith Creek	X		X	
Elochoman River	X		X	X
Green River	X		X	X
Humptulips River	X		X	X
Issaquah Creek	X	X	X	
Kalama River	X		X	
Methow River	X		X	
Middle Fork Satsop River	X		X	X
Nason Creek	X		X	
North Fork Nooksack River	X		X	X
North Fork Stillaguamish River	X		X	X
North Fork Toutle River	X		X	
North Nemah River	X		X	X
Snohomish River and Snoqualmie River	X		X	X
South Prairie Creek	X		X	X
Samish River	X		X	X
Wind River	X		X	
Wynoochee River	X		X	X

[1]Fay Conroy of State of Washington Department of Fisheries (written commun., December 4, 1975).

TABLE 3.--General periods of salmon spawning and rearing[1]

Activity, region,[2] and species of salmon	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
	Months of activity											
SPAWNING:												
Puget Sound region:												
Chinook	X	X									X	X
Sockeye	X	X	X								X	X
Coho	X	X	X	X								
Pink and chum	X	X	X	X							X	X
Coastal region:												
Chinook	X	X	X	X							X	X
Sockeye	X	X	X	X	X	X						
Coho	X	X	X	X	X	X						
Chum	X	X	X									
Columbia Basin region:												
Chinook	X	X									X	X
Sockeye	X	X										X
Coho	X	X	X									X
REARING:												
All regions named above:												
Chinook	X	X	X	X	X	X	X	X	X	X	X	X
Sockeye	X	X	X	X	X	X	X	X	X	X	X	X
Coho	X	X	X	X	X	X	X	X	X	X	X	X
Pink and chum			X	X	X	X	X	X				

[1] From Fay Conroy of State of Washington Department of Fisheries (written commun., December 4, 1975).

[2] Regions are as outlined on the location map, figure 1.

Spawning and Rearing Criteria for Salmon

The water depths and velocities preferred by spawning salmon are shown for the five species yin table 4. these values are based on recent reanalyses of available data by the Department of Fisheries and have been used since 1973 as criteria for determining areas of the streambed preferred for spawning at study reaches. The primary differences from criteria formerly used (Collings, 1974) are reduction of the minimum depths, removal of a maximum depth, and a greater range in preferred velocities for all species, except for pink and chum, which were changed only slightly from formerly used velocities by rounding to the nearest 0.25 unit. The preferred maximum velocity for spawning is now similar for Chinook, pink, and chum salmon and the same for sockeye and coho salmon.

The criteria for the preferred rearing discharge is based on the assumption that the survival and growth rate of young salmon is proportional to food production in the stream and that food production, in turn, is proportional to the wetted perimeter of water in the stream. The assumption of proportionality between food production and wetted perimeter is based on the conclusion by Bell (1973) that aquatic insects, which serve as the major source of food for salmon during their rearing period, 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. As the water level of a stream nay rise without limit, however, so also may the wetted perimeter increase without limit. For rearing, a limit was set where wetted perimeter covers the streambed from near the bottom of. one bank of the stream channel to near the bottom of the other bank. In most channels wetted perimeter increases little for water level increases from the bottom to top of the banks. The preferred rearing discharge is thus that which provides a wetted perimeter across the entire streambed.

TABLE 4.--Depths and velocities preferred by spawning salmon[1]

Salmon species	minimum depth (ft)	Velocity[2] (ft/s)
Chinook	1.0	1.00-3.00
Sockeye	.5	1.00-2.50
Coho	.5	.25-2.50
Pink and chum	.5	.75-3.25

[1]From Fay Conroy of Sate of Washington Department of Fisheries (written commun., June 29,1973).

[2]Measured 0.4 ft (0.1 m) above streambed.

Special Terms and Abbreviations

Some special terms and abbreviations used in this report are defined as follows:

Terms

Study reach is a length of stream channel, usually 1 to l½ times the width of the channel and extending upstream from a riffle into a pool, at which stream discharge and other data are collected over a period of several months. Reaches studied for this report were selected with the onsite advice of fisheries biologists and are known to be used by salmon for spawning.

Spawnable area is that part of the streambed having water depths and velocities preferred by salmon for spawning. Spawnable areas for the five species vary because of differences in preferred water depths and velocities.

Unit spawnable area is the spawnable area at a study reach divided by the length of the reach. It is the area per unit length of channel.

Preferred spawning discharge is the stream discharge at which the water depths and velocities most favored by salmon for spawning occur over the greatest area of the streambed upstream of a riffle. This discharge is determined at study reaches from spawnable area-discharge relationships, and differs among salmon species.

Preferred rearing discharge is the minimum stream discharge that provides maximum wetted area of the streambed. This discharge is determined at study reaches from wetted perimeter-discharge relationships, taken as the center point of greatest curvature in the relationships, and is the same for all salmon species that rear in streams.

Streambed is that part of a stream channel, usually not occupied by perennial plantlife, between the toe of each defined side or bank of the channel. Streambed area and width are measured in a horizontal plane.

Abbreviations

Qch, Qso, Qco, Qpc	Stream discharges preferred for spawning by chinook, sockeye, coho, and pink and chum salmon, respectively.
Qcc, Qsc	Average of the stream discharges preferred for spawning by chinook, pink, and chum salmon, and by sockeye and coho salmon, respectively.
Qr	Stream discharge preferred by salmon for rearing.
Apk	Average of unit spawnable areas at the stream discharges preferred for spawning by the five salmon species.
A25, A50, A75	Average of unit spawnable areas at 25-, 50-, and 75-percent reductions, respectively, of the stream discharges preferred for spawning by the five salmon species.
DA	Drainage area of a river basin.
TW	Average of four channel widths at a study reach at a toe-of-bank river stage.
Qa	Average annual discharge of a stream.
7Q2	Median annual value (2-year recurrence interval) of the 7-day mean low flow of a stream.
Qoc	Median annual value (50-percent probability of annual exceedance) of the October monthly mean discharge.
Qno, Qde, Qja, Qfe, Qmr, Qap, Qmy, Qjn, Qjl, Qau, Qse	Same as Qoc, but for each of the remaining consecutive 11 months of the year, respectively.

EVALUATION OF PREFERRED DISCHARGES, SPAWNABLE AREAS, AND RELATED INFORMATION

Preferred Discharges and Areas for Spawning

Stream discharge, depth, and velocity were measured at each study reach during the period of recession from seasonal high flows to low flows. Usually, measurements were made about 10 times during a period of several months. About 5 years were required to obtain the measured data for the 84 study reaches.

An example of the analytic results of one measurement at one study reach to determine spawnable area for one species, chinook salmon, is shown in figure 2. The measurement at the reach, previously mapped by a plane-table survey, consisted of obtaining water depths and water velocities at each of four marked cross sections. Velocities were measured at 0.4 ft (0.1 m) above the streambed, which is approximately the height where spawning salmon position themselves. The distributions of depths and velocities at the four cross sections were analyzed by a computer program, especially developed for this study, to determine the total streambed area having preferred depths, preferred velocities, and the combination of both for a species of salmon. Total spawnable area of the streambed is the summation of small trapezoidal areas (fig. 2) for which interpolated values of both depth and velocity are within the range of those preferred by the species. The stream discharge associated with the spawnable area was either measured at the reach or obtained from records for a nearby gaging station.

Examples of the spawnable area-discharge relationships defined by about !0 measurements at one study reach are shown in figures 3 and 4 for each of the five salmon species (pink and chum being combined). The curves defined by the spawnable areas have their peaks at a particular discharge for each species, which is defined as the preferred spawning discharge. The peak area is correspondingly called the preferred spawnable area. At lower or higher discharges the spawnable area is reduced and so is the potential salmon productivity of the stream at that study reach. To produce results of uniform quality, the preferred spawnable area and discharge were determined from equations representing the curve of best fit for the measured areas and discharges. However, the results should be interpreted only as best estimates, rather than exact solutions, because the true mathematic-11 relationship is unknown and there are measurement errors in the data.

The preferred spawning discharge and unit spawnable area are summarized for the five species and the 84 study reaches in table 5. The table is incomplete for some species and reaches where the data did not adequately define a relationship. Estimates are indicated in the table where extrapolations of the curves were made. Unit spawnable areas (area divided by reach length) are listed in table 5 to allow rational comparisons of spawnable areas among the reaches.

The unit spawnable areas summarized in table 6 for the 84 study reaches apply to selected percentage reductions (25, 50, and 75 percent) in the preferred spawning discharge. These reduced areas document the effect of reducing stream discharges to less than preferred for spawning.

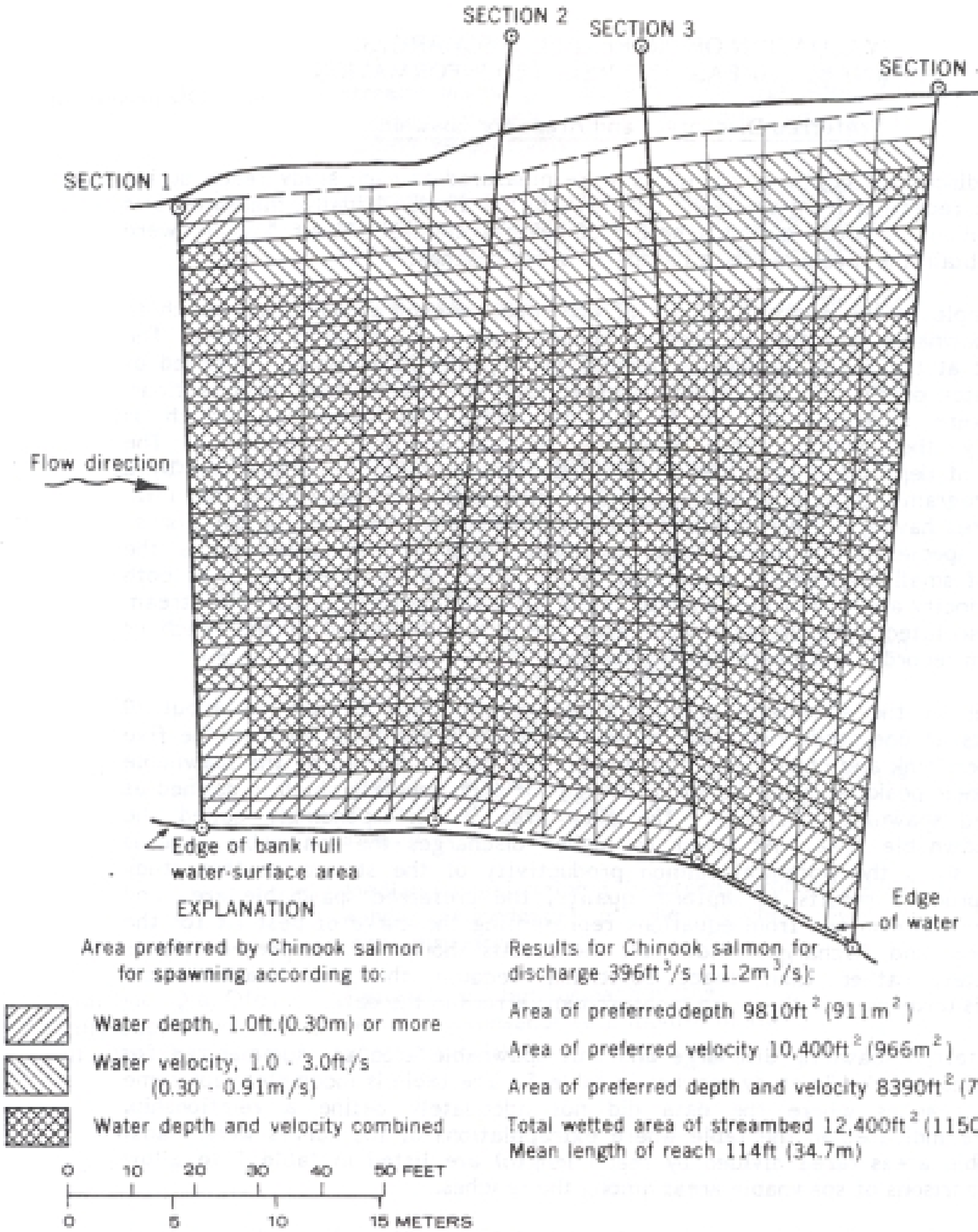


FIGURE 2.--Plan view of reach A on Dosewallips River, an example showing areas of reach that have water depths and velocities preferred by chinook salmon for spawning at one value of stream discharge.

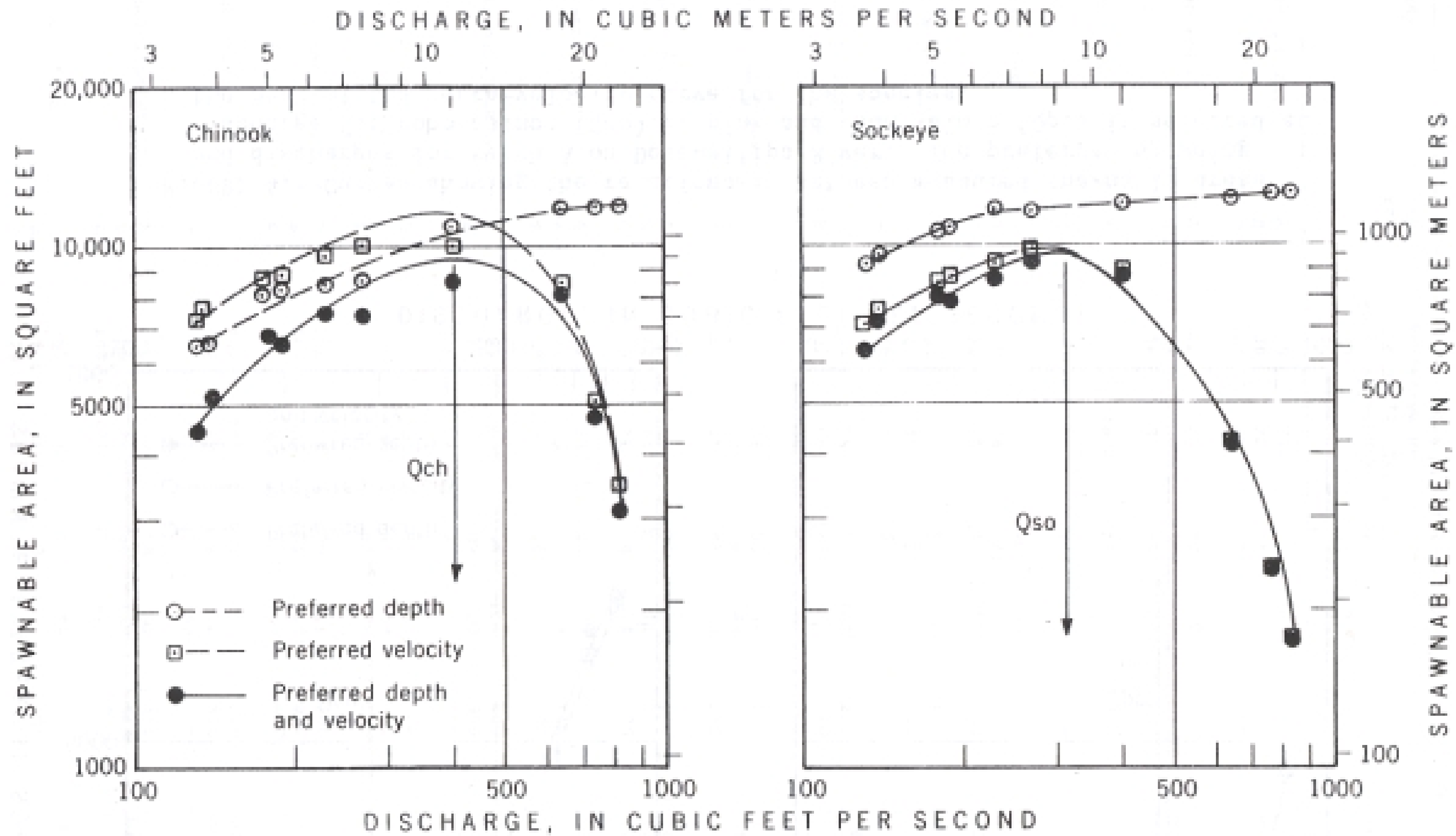


FIGURE 3.--Curves showing the relationship between measured spawnable areas and discharges for reach A on Dosewallips River. The preferred spawning discharge for chinook salmon (Qch) or sockeye salmon (Qso) is selected at the peak of the depth-velocity curve for the species.

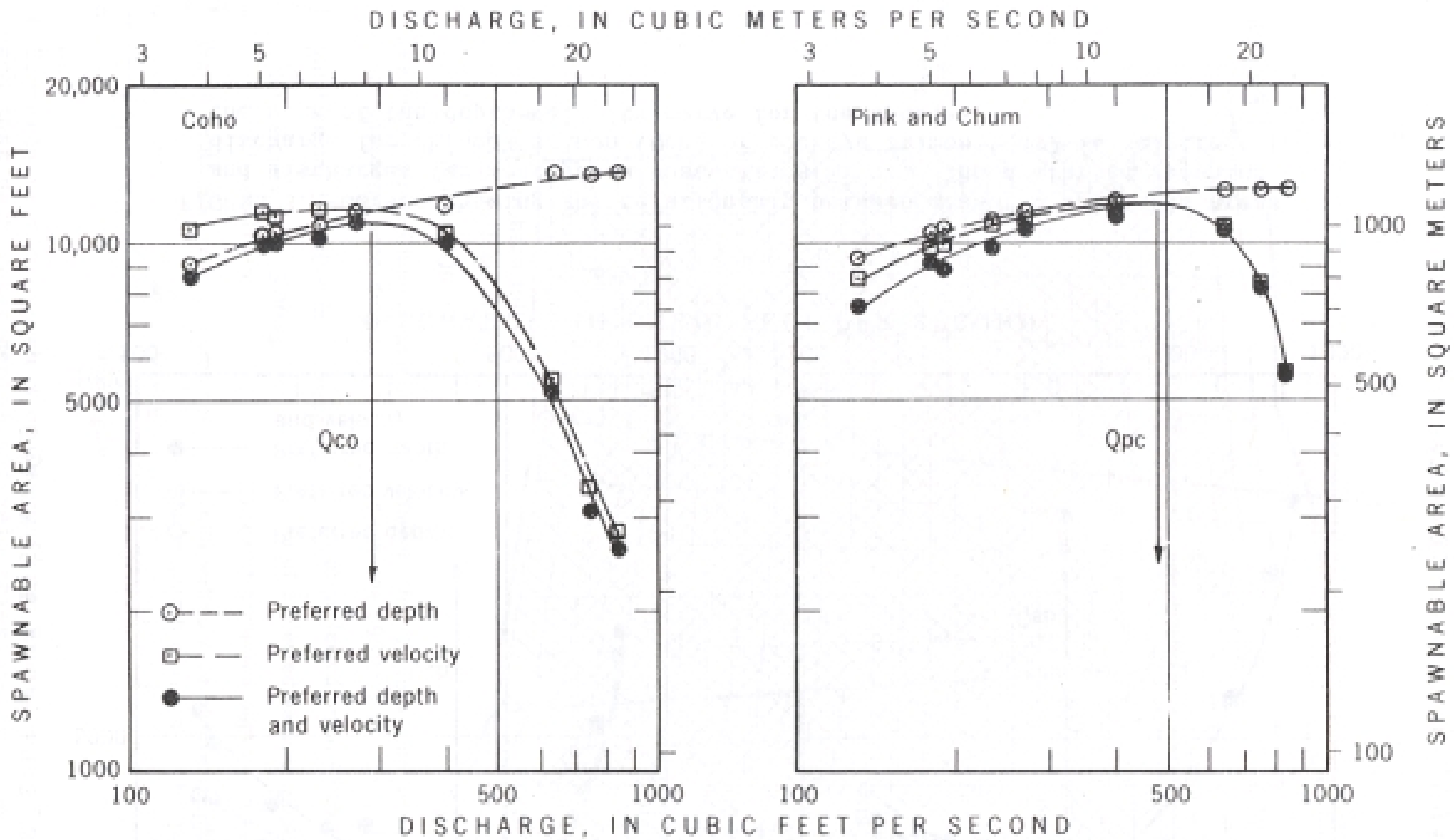


FIGURE 4.--Curves showing the relationship between measured spawnable areas and discharges for reach A on Dosewallips River. The preferred spawning discharge for coho salmon (Qco) or pink and chum salmon (Qpc) is selected at the peak of the depth-velocity curve for the species.

TABLE 5.--Summary of preferred unit spawnable areas and discharges for salmon at stream reaches studied[1]

Study stream	Study reach	Preferred unit spawnable area ft^2/ft, for: Chinook	Sockeye	Coho	Pink and chum	Preferred spawning discharge, ft^3/s, for: Chinook	Sockeye	Coho	Pink and chum
American River	A	38	35	42	40	160	93	86	160
	B	30	28	35	40	140	87	69	240
	C	63	61	64	73	310	160	140	260
Bear Branch	A	26	29	30	30	93	90	84	100
	B	31	30	(35)	(32)	100	93	(120)	(130)
	C	34	33	38	(36)	130	92	84	(150)
Bear Creek	A	--	(8.4)	(12)	(9.7)	--	(25)	(19)	(31)
	B	--	7.1	8.5	8.7	--	10	11	14
	C	--	8.2	8.6	14	--	13	13	24
Cedar River	A	44	43	46	58	180	120	110	210
	B	(19)	24	(27)	44	(220)	330	(330)	200
	C-1	51	51	43	65	350	230	280	270
Chewack River	A	53	47	52	59	310	200	150	350
	B	47	42	48	51	310	180	200	380
	C	(76)	79	80	(88)	(510)	390	400	(610)
Chiwawa River	A	(39)	55	57	(68)	(200)	140	120	(180)
	B	61	68	(73)	(70)	210	210	(280)	(280)
	C	(90)	108	111	107	(350)	230	210	200
Cloquallum Creek	A	22	29	30	34	110	43	47	86
	B	23	29	29	48	120	53	61	160
	C	40	41	45	48	150	89	86	140
Deschutes River	A	61	59	62	70	360	140	120	220
	B	41	54	63	74	210	140	100	170
	C	75	71	74	74	270	220	180	260
Dewatto River	A	31	25	30	34	170	87	84	200
	A-1	27	25	31	29	110	39	42	130
	B	39	36	40	48	240	95	89	220
Dosewallips River	A	83	84	96	104	400	310	290	480
	B	78	76	89	100	500	300	270	440
	C	94	87	97	112	450	220	220	460
Smith Creek (A) and Elk Creek (B&C)	A	--	2.4	3.9	5.6	--	13	14	19
	B	36	36	40	48	220	120	110	180
	C	21	22	29	36	240	120	100	180
Elochoman River	A	101	105	109	111	480	390	300	470
	B	(69)	57	65	(108)	(800)	260	270	(710)
	C	65	69	75	83	430	220	200	290
Green River	A	249	229	255	254	870	520	430	620
	B	52	58	58	88	520	350	340	540
	C	--	103	115	166	--	410	440	1000
Humptulips River	A	75	76	78	92	410	190	200	500
	B	60	86	90	113	510	170	160	300
	C	148	151	157	157	740	740	750	720
Issaquah Creek	A	8.0	20	21	29	86	34	35	59
	B	7.1	29	33	40	140	47	46	79
	C	29	--	--	42	130	--	--	86
Kalama River	A	139	140	149	146	640	590	680	600
	B	(91)	--	(101)	(99)	(520)	--	(320)	(600)
	C	(125)	120	142	137	(850)	700	560	780

TABLE 5.--Summary of preferred unit spawnable areas and discharges for salmon at stream reaches studied[1]--cont.

Study stream	Study reach	Preferred unit spawnable area ft^2/ft, for:				Preferred spawning discharge, ft^3/s, for:			
		Chinook	Sockeye	Coho	Pink and chum	Chinook	Sockeye	Coho	Pink and chum
Methow River	A	157	161	166	166	660	650	420	540
	B	(70)	77	84	107	(650)	390	370	500
	C	153	140	158	161	930	480	450	610
Middle Fork Satsop River	A	75	(71)	84	83	320	(480)	280	300
	B	46	46	48	(74)	270	180	200	(590)
	C	48	43	47	72	440	260	260	420
Nason River	A	68	66	70	71	390	220	210	340
	B	46	40	49	58	380	260	270	360
	C	75	71	81	78	360	290	220	340
North Fork Nooksack River	A	76	74	--	87	410	180	--	420
	B	--	--	--	--	--	--	--	--
	C	121	--	--	150	870	--	--	900
North Fork Stillaguamish River	A	57	58	66	(69)	320	260	240	(360)
	B	52	59	69	105	380	210	200	530
	C	143	131	154	162	760	390	370	780
North Fork Toutle River	A	(138)	127	141	(152)	(1100)	630	590	(1100)
	B	105	99	105	(108)	750	450	410	(940)
	C	201	180	186	204	1000	730	720	930
North Nemah River	A	12	18	21	23	80	57	39	72
	B	34	32	39	40	260	150	150	220
	C	(31)	23	33	(35)	(340)	180	110	(330)
Snoqualmie River (A&B) and Snohomish River (C)	A	161	134	156	211	3000	1500	1300	2600
	B	140	110	135	225	4000	1100	860	4100
	C	527	481	520	556	7100	4500	4600	8200
South Prairie Creek	A	31	31	38	41	160	89	67	130
	B	27	20	21	(47)	190	92	72	(390)
	C	64	55	57	71	270	110	94	240
Samish River	A	8.2	13	13	20	79	34	30	68
	B	16	20	19	30	190	62	67	110
	C	52	52	59	57	260	230	210	280
Wind River	A	(47)	(57)	(58)	49	(210)	(200)	(370)	170
	B	(52)	(59)	(67)	(59)	(300)	(280)	(560)	(280)
	C	52	50	59	(77)	380	320	340	(430)
Wynoochee River	A	37	41	41	64	320	160	150	270
	B	166	171	178	167	550	320	320	350
	C	108	98	105	--	720	190	200	--

[1]Dashes indicate insufficient data and parentheses enclose estimated data.

TABLE 6.--Unit spawnable areas corresponding to selected percentage reductions of the preferred spawning discharge at stream reaches studied

Study stream	Study reach	Unit spawnable areas (ft^2/ft) for 25-percent reduction of preferred spawning discharge for:				Unit spawnable areas (ft^2/ft) for 50-percent reduction of preferred spawning discharge for:				Unit spawnable areas (ft^2/ft) for 75-percent reduction of preferred spawning discharge for:			
		Chinook	Sockeye	Coho	Pink and chum	Chinook	Sockeye	Coho	Pink and chum	Chinook	Sockeye	Coho	Pink and chum
American River	A	37	34	42	40	29	29	40	38	10	(16)	(34)	35
	B	29	26	35	39	24	23	30	36	20	13	(26)	28
	C	58	58	61	72	42	48	51	67	20	(30)	(27)	46
Bear Branch	A	23	26	29	29	16	20	28	26	4.0	9.6	24	18
	B	25	30	(34)	(31)	14	27	(33)	(30)	--	--	(29)	(26)
	C	27	32	37	(35)	14	27	34	(33)	0.3	(16)	(25)	(27)
Bear Creek	A	--	(8.1)	(10)	(9.4)	--	(6.5)	(7.8)	(8.6)	--	(3.6)	(4.7)	(5.5)
	B	--	6.5	7.9	7.8	--	(4.1)	6.5	6.5	--	--	--	(5.1)
	C	--	6.1	6.9	12	--	(2.0)	--	7.9	--	--	--	--
Cedar River	A	39	41	42	54	26	--	--	48	--	--	--	--
	B	(17)	23	(27)	41	(14)	21	(24)	35	--	--	--	--
	C	49	35	40	65	39	(27)	(31)	(60)	--	--	--	--
Chewack River	A	50	44	51	57	41	36	48	52	24	17	42	41
	B	42	40	46	51	33	29	43	47	24	9.2	37	36
	C	(70)	73	79	(86)	(57)	60	74	(80)	(39)	38	63	(63)
Chiwawa River	A	(33)	49	54	(61)	(21)	35	45	(47)	--	--	--	--
	B	56	65	(72)	(68)	40	54	(70)	(65)	--	--	(58)	(57)
	C	(72)	100	110	99	(40)	80	85	78	--	--	--	--
Cloquallum River	A	18	26	27	33	4.1	(17)	20	29	--	--	--	(19)
	B	19	27	28	43	8.6	(21)	25	39	--	--	--	28
	C	35	37	42	45	19	(31)	(37)	40	--	--	--	--
Deschutes River	A	59	52	61	69	48	45	52	63	21	24	34	44
	B	36	52	61	71	23	39	53	58	3.8	15	(37)	31
	C	70	69	71	73	50	62	70	71	(9.5)	--	--	(55)
Dewatto River	A	28	25	29	33	22	22	27	30	11	15	21	26
	A-1	23	23	29	28	13	15	21	27	3.1	--	--	26
	B	36	34	38	48	30	27	32	43	13	15	23	31
Dosewallips River	A	75	76	90	96	57	62	81	86	--	--	--	(63)
	B	70	70	83	90	52	58	70	79	(30)	--	--	(50)
	C	84	85	97	110	51	(77)	(90)	93	(19)	--	--	--
Smith Creek (A) and Elk Creek (B&C)	A	--	1.8	2.7	3.8	--	(0.2)	0.5	2.8	--	--	--	0.1
	B	34	33	39	47	29	26	33	40	12	17	--	26
	C	21	21	29	35	18	19	26	32	11	11	21	22
Elochoman River	A	96	97	110	110	73	74	99	97	31	32	79	64
	B	(69)	53	62	(110)	(59)	44	56	(97)	(36)	26	41	(73)
	C	64	67	73	82	54	54	68	76	25	23	53	51
Green River	A	220	220	250	250	140	170	170	230	28	--	--	--
	B	50	52	52	84	41	(35)	(35)	72	--	--	--	--
	C	--	99	110	160	--	(80)	(99)	140	--	--	--	99
Humptulips River	A	70	72	76	90	53	61	63	84	24	--	--	69
	B	54	81	84	110	43	57	60	98	23	--	--	(55)
	C	140	140	150	150	99	110	150	130	32	45	131	85
Issaquah Creek	A	5.7	(16)	(17)	27	(1.8)	--	--	20	--	--	--	--
	B	5.2	(18)	(17)	36	2.2	--	--	28	(0.5)	--	--	--
	C	17	--	--	(38)	3.9	--	--	--	--	--	--	--
Kalama River	A	130	130	150	140	95	94	150	130	--	--	--	--
	B	(74)	--	(97)	(95)	(49)	--	--	(84)	--	--	--	--
	C	(110)	110	140	130	(82)	69	130	100	--	--	--	--

TABLE 6.--Unit spawnable areas corresponding to selected percentage reductions of the preferred spawning discharge at stream reaches studied--cont.

Study stream	Study reach	Unit spawnable areas (ft^2/ft) for 25-percent reduction of preferred spawning discharge for:				Unit spawnable areas (ft^2/ft) for 50-percent reduction of preferred spawning discharge for:				Unit spawnable areas (ft^2/ft) for 75-percent reduction of preferred spawning discharge for:			
		Chinook	Sockeye	Coho	Pink and chum	Chinook	Sockeye	Coho	Pink and chum	Chinook	Sockeye	Coho	Pink and chum
Methow River	A	140	150	160	160	98	100	160	130	19	34	150	66
	B	--	69	74	96	--	49	55	69	--	35	41	42
	C	140	130	150	150	110	100	110	130	57	63	68	79
Middle Fork Satsop River	A	59	(69)	76	77	29	(57)	66	59	--	(26)	59	23
	B	44	43	47	(74)	37	33	44	(63)	16	13	38	(47)
	C	43	41	46	69	33	35	40	62	20	28	31	45
Nason Creek	A	64	61	66	69	53	52	56	66	25	31	46	52
	B	43	38	46	55	38	33	39	47	25	28	32	36
	C	70	69	79	76	57	66	75	73	21	47	54	61
North Fork Nooksack River	A	74	(67)	--	84	66	--	--	79	--	--	--	--
	B	--	--	--	--	--	--	--	--	--	--	--	--
	C	110	--	--	140	--	--	--	--	--	--	--	--
North Fork Stillaguamish River	A	52	51	65	(68)	39	36	63	(62)	14	23	52	(43)
	B	50	57	66	100	35	50	51	94	8.2	34	41	70
	C	130	120	150	160	90	(99)	(130)	150	(29)	--	--	(120)
North Fork Toutle River	A	130	120	130	(150)	120	110	130	(140)	(96)	--	--	(120)
	B	98	92	100	(110)	85	--	--	(100)	--	--	--	(88)
	C	170	180	180	200	130	170	180	190	--	--	--	--
North Nemah River	A	12	17	18	23	9.1	14	17	19	2.5	6.1	14	12
	B	33	30	36	38	28	25	31	33	16	16	24	23
	C	(30)	23	31	(34)	(26)	20	28	(27)	(17)	12	23	(23)
Snoqualmie River (A&B) and Snohomish River (C)	A	150	120	140	200	150	64	96	170	65	--	--	78
	B	140	(100)	--	220	120	--	--	190	110	--	--	160
	C	510	430	500	540	430	230	490	500	--	--	--	(440)
South Prairie Creek	A	29	30	36	40	20	26	(31)	35	7.4	--	--	(25)
	B	25	20	21	(44)	18	19	(19)	(41)	4.4	--	--	(34)
	C	53	52	54	61	20	47	(46)	65	2.0	--	--	50
Samish River	A	7.6	12	13	19	5.2	9.8	11	16	--	--	--	11
	B	15	18	18	29	13	13	16	25	8.2	--	--	14
	C	49	50	57	56	40	43	53	50	18	19	48	43
Wind River	A	(44)	(45)	(56)	48	(33)	(35)	(55)	43	(6.4)	(11)	(52)	19
	B	(47)	(54)	(66)	(55)	(39)	(44)	(62)	(48)	(27)	(31)	(52)	(37)
	C	50	49	56	(71)	41	42	49	(59)	21	27	41	(44)
Wynoochee River	A	30	39	40	61	26	32	34	52	17	21	24	33
	B	150	160	180	160	66	140	150	150	4.5	--	--	--
	C	110	(86)	(96)	--	91	--	--	--	37	--	--	--

[1]Dashes indicate insufficient data, and parentheses enclose estimated data.

Similarities of Spawning Discharges and Areas Preferred by Different Species

Examination of the spawnable area-discharge curves and comparison of the water-depth and velocity criteria among the five species indicated a possible similarity in preferred spawning discharges for chinook, pink and churn salm, and also for sockeye and coho salmon. This similarity was tested statistically with covariance analysis at a 95-percent-confidence level, using basin drainage area as a control variable in one trial and toe-of-bank width of the channel as a control variable in a second trial. Both trials resulted in the conclusion that the previously mentioned discharges were statistically similar and could be combined. Averaging the discharges that are statistically similar for different species should improve the accuracy of the value for each of those species by reducing the errors represented by individually high or low values. Thus, for the purpose of developing equations for making estimates of preferred discharges at other sites, the preferred spawning discharges for chinook, pink and chum salmon have been averaged, as have those for sockeye and coho salmon.

Examination of the unit spawnable areas listed in tables 5 and 6 for all five species indicates few consistent differences among the species for the different study reaches, although the preferred unit spawnable areas for pink and chum salmon tend to be the largest and those for chinook the smallest. Therefore, even though not statistically tested, the averages of the unit areas for all five species were used to develop equations for estimating unit areas at other sites.

The average preferred spawning discharges and unit spawnable areas used hereafter in this report are given in table 7. Although the averaging process resulted in the loss of some information, the results given in table 7 and used later to develop relationships with other parameters are based on measured data, not estimates. Additional statistical tests for similarity of discharges between reaches, discussed later in this report, resulted in the conclusion that preferred spawning and rearing discharges for 13 reaches also should not be used for developing relationships with other. parameters.

TABLE 7.--Preferred spawning discharges, unit spawnable areas, and preferred rearing discharges for salmon at stream reaches studied

Study stream	Study reach	Average preferred spawning discharges for: Chinook, pink and chum salmon (ft^3/s)	Average preferred spawning discharges for: Sockeye and coho salmon (ft^3/s)	Average of unit spawnable areas [ft^2/ft] for all salmon species: Preferred unit spawnable area	Unit spawnable area for indicated percentage reduction of preferred spawning discharge: 25%	50%	75%	Preferred rearing discharge (ft^3/s)
American River	A	160	90	39	38	34	--	60
	B	190	78	33	32	28	--	100
	C	280	150	65	62	52	--	100
Bear Branch	A	96	87	29	27	22	14	25
	B[1]	--	--	--	--	--	--	25
	C	--	88	--	--	--	--	40
Bear Creek	A	--	--	--	--	--	--	5
	B	--	10	--	--	--	--	7
	C	--	13	8.3	6.7	--	--	8
Cedar River	A	200	120	48	44	--	--	75
	B[1]	--	--	--	--	--	--	90
	C-1	310	260	52	47	--	--	80
Chewack River	A	330	175	53	50	44	31	25
	B	340	190	47	45	38	27	30
	C	--	400	--	--	--	--	50
Chiwawa River	A	--	130	--	--	--	--	80
	B	--	--	--	--	--	--	50
	C	--	220	--	--	--	--	120
Cloquallum Creek	A	98	45	29	26	--	--	25
	B	140	57	32	29	--	--	75
	C	140	88	44	40	--	--	30
Deschutes River	A	290	130	63	60	52	31	40
	B	190	120	58	55	43	--	60
	C	260	200	74	71	63	--	70
Dewatto River	A	180	86	30	29	25	18	20
	A-1[1]	120	40	28	26	19	--	20
	B	230	92	41	39	33	20	40
Dosewallips River	A	440	300	92	84	72	--	180
	B[1]	470	280	86	78	65	--	300
	C[1]	460	220	98	94	--	--	220
Elk Creek (B&C) and Smith Creek (A)	A	--	14	--	--	--	--	2.5
	B	200	120	40	38	32	--	60
	C	210	110	27	26	24	16	40
Elochoman River	A	480	340	106	100	86	52	40
	B	--	260	--	--	--	--	100
	C	360	210	73	72	63	38	60
Green River	A	740	480	247	240	180	--	200
	B	530	340	64	60	--	--	250
	C	--	420	--	--	--	--	250
Humptulips River	A	460	200	80	77	65	--	100
	B	400	160	87	82	64	--	150
	C	730	740	153	140	120	73	150
Issaquah Creek	A	72	34	20	--	--	--	25
	B	110	46	27	--	--	--	35
	C	110	--	--	--	--	--	40

TABLE 7.--Preferred spawning discharges, unit spawnable areas, and preferred rearing discharges for salmon at stream reaches studied--continued

Study stream	Study reach	Average preferred spawning discharges for: Chinook, pink and chum salmon (ft^3/s)	Average preferred spawning discharges for: Sockeye and coho salmon (ft^3/s)	Average of unit spawnable areas (ft^2/ft) for all salmon species: Preferred unit spawnable area	Unit spawnable area for indicated percentage reduction of preferred spawning discharge: 25%	50%	75%	Preferred rearing discharge (ft^3/s)
Kalama River	A[1]	620	640	144	140	120	--	300
	B[1]	--	--	--	--	--	--	320
	C	--	630	--	--	--	--	330
Methow River	A	600	540	162	150	120	67	160
	B	--	380	--	--	--	--	200
	C	770	460	153	140	110	67	250
Middle Fork Satsop River	A	310	--	--	--	--	--	110
	B[1]	--	190	--	--	--	--	70
	C	430	260	52	50	42	31	110
Nason Creek	A	360	220	69	65	57	38	80
	B	370	260	48	46	39	30	50
	C	350	260	76	74	68	46	80
North Fork Nooksack	A	420	--	--	--	--	--	200
	B	--	--	--	--	--	--	560
	C	880	--	--	--	--	--	570
North Fork Stillaguamish River	A	--	250	--	--	--	--	110
	B	460	200	71	68	58	38	150
	C	770	380	148	140	--	--	200
North Fork Toutle River	A[1]	--	610	--	--	--	--	300
	B[1]	--	430	--	--	--	--	350
	C	970	720	193	180	170	--	400
North Nemah River	A	76	48	18	18	15	8.6	15
	B	240	150	36	34	29	20	50
	C[1]	--	140	--	--	--	--	45
Snohomish River (C) and Snoqualmie River (A&B)	A	2800	1400	166	150	120	--	1200
	B	4000	980	152	--	--	--	860
	C	7600	4600	521	500	410	--	2800
South Prairie Creek	A[1]	140	78	35	34	--	--	80
	B	--	82	--	--	--	--	100
	C	260	100	62	55	--	--	100
Samish River	A	74	32	14	13	10	--	25
	B	150	64	21	20	17	--	50
	C	270	220	55	53	46	32	30
Wind River	A	--	--	--	--	--	--	20
	B	--	--	--	--	--	--	20
	C	--	330	--	--	--	--	60
Wynoochee River	A	300	160	46	42	36	24	100
	B	450	320	170	160	130	--	125
	C	--	200	--	--	--	--	130

[1] Data for this reach was not used in regression analysis because statistical tests indicated streamflow there to be the same as that at one or more of the other reaches on the same stream.

Preferred Discharges for Rearing

The preferred discharge for rearing, or the discharge that provides the maximum wetted area of the streambed, is determined from the relationship between the average wetted perimeter and the discharge at a study reach. The wetted perimeter of the streambed, shown schematically in figure 5, was determined by surveys at each of the four cross sections at a reach ; for several different water stages and corresponding stream discharges. Wetted perimeters for the four cross sections then were averaged for each discharge at the reach.

An example of the relationship between average wetted perimeter and discharge is shown by the curve in figure 6. Typically, as discharge increases from zero, wetted perimeter increases rapidly as the streambed becomes increasingly covered with water until the steep banks of the channel are encountered. At that point the rate of increase in wetted perimeter is greatly reduced by further increases in discharge. The preferred rearing discharge is selected at the center point of greatest curvature in the wetted perimeter-discharge relationship.

Selection of the center point of greatest curvature is a matter of judgment and subject to error. Every attempt was made to be as consistent as possible in the selection process, but accuracy should be expected to be somewhat less for rearing discharges than for spawning discharges. Preferred rearing discharges, as selected and used in this report, are given in table 7 for the 84 study reaches.

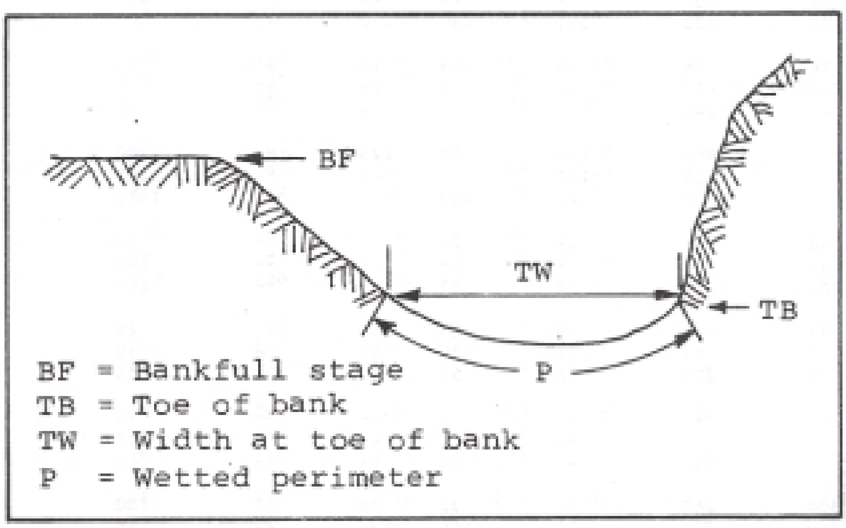


FIGURE 5.--Cross section of a stream, showing selected channel parameters.

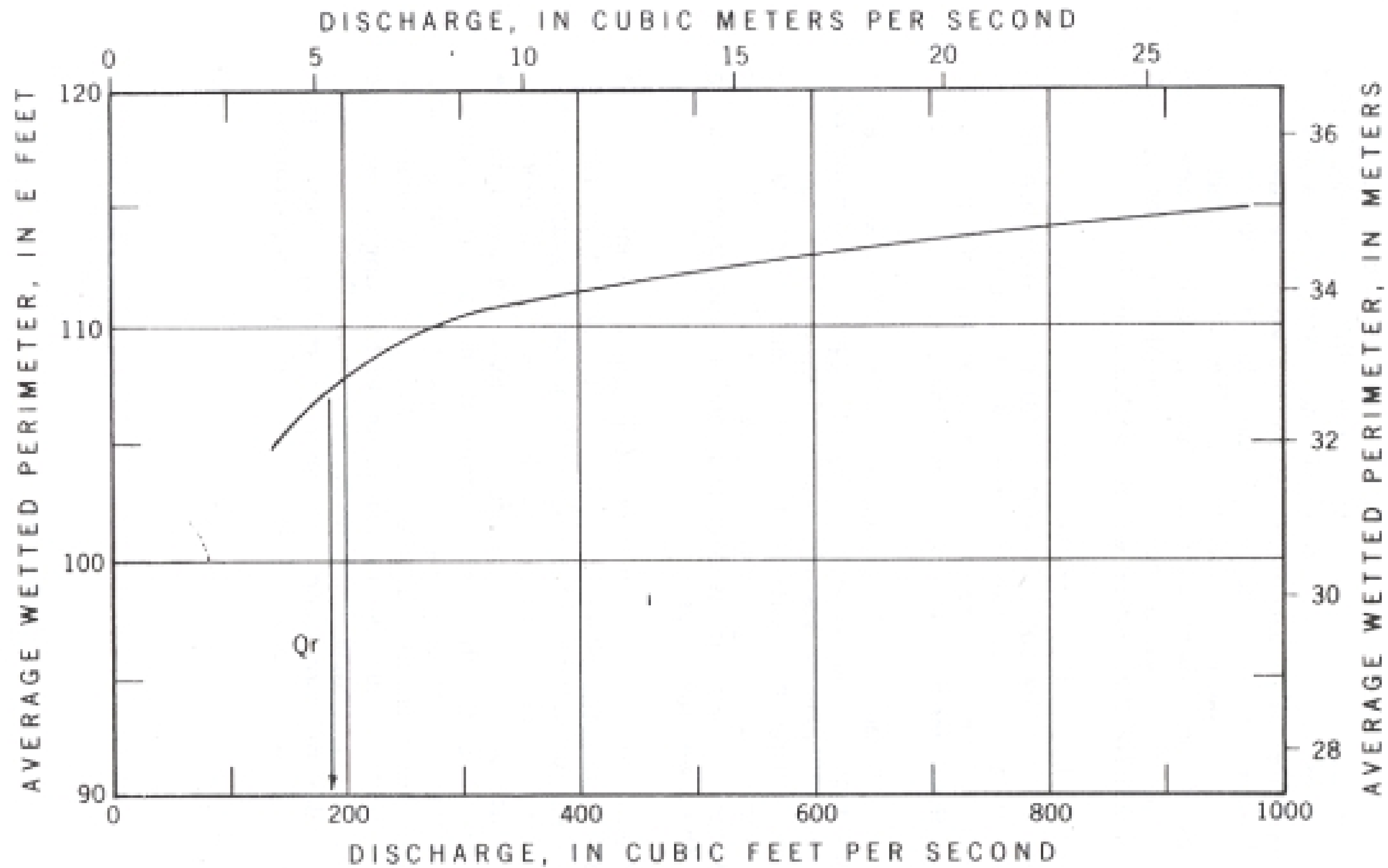


FIGURE 6.--Curve showing the relationship between average wetted perimeter and discharge. The preferred rearing discharge (Qr) is selected at the center point of greatest curvature in this example for reach A on the Dosewallips River.

Drainage-Basin and Stream-Channel Parameters

For each study reach five parameters peculiar to the drainage basin upstream and five peculiar to the stream channel were examined for possible use in describing variations among the study reaches in preferred spawning and rearing discharges and unit spawnable areas. The drainage-basin parameters examined were drainage area, mean basin altitude, reach altitude, main channel length, and channel slope upstream of the reach for one-tenth of the main channel length. The channel parameters examined were average values of toe-of-bank width of channel, water-surface slope within the reach, maximum depth of water below the toe-of-bank, top-of-bank channel width, and hydraulic radius for the channel within the top of banks.

Of the basin parameters, drainage area accounted for appreciably more of the variation among the discharges and spawnable areas than did the other parameters, and of the channel parameters, the toe-of-bank channel width accounted for the greatest variation. Neither of those two descriptive relationships were usefully improved by addition of any of the other basin or channel parameters.

The drainage areas and toe-of-bank widths for each of the reaches are given in table 8. Toe-of-bank channel width, shown schematically in figure 5, is the average of the widths of the four cross sections at a study reach. The width of each cross section is determined by measuring horizontally from the elevation where the streambed and one bank join (point TB in fig. 5), to the ground surface on the other bank. The width of gravel bars, if present, is included, and if the channel has a distinctive toe at each bank, the lower toe is used.

Selection of a toe-of-bank elevation is a matter of judgment, complicated at some cross sections by boulders or other bank materials that have fallen into the stream. Such complications were usually overcome by examination of graphs for the other cross sections and by using a water-surface profile connecting all four cross sections. Measurements of width at four or more cross sections and averaging the results are recommended to reduce the error inherent in a single-section measurement. Experience indicates that differences in average widths at a reach, whether due to mistaken elevations or the judgment of different individuals, are usually a matter of only a few feet and quite small in relation to the range of average widths (several hundreds of feet) among the study reaches. Even so, it is recommended that for the sake of consistency guidance in making these width measurements be obtained from personnel of the State of Washington Department of Fisheries or U.S. Geological Survey.

TABLE 8.--Summary of drainage areas and channel widths at stream reaches studied

Study stream	Study reach	Total basin drainage area (mi^2)	Average channel width at toe-of-bank river stage (ft)	Study stream	Study reach	Total basin drainage area (mi^2)	Average channel width at toe-of-bank river stage (ft)
American River	A	35.4	44	Deschutes River	A	56.2	66
	B	58.1	40		B	76.0	88
	C	70.2	82		C	139	77
Bear Branch	A	8.89	33	Dewatto River	A	18.4	31
	B	9.64	35		A-1	19.1	31
	C	11.7	45		B	21.7	32
Bear Creek	A	4.39	15	Dosewallips River	A	91.9	105
	B	5.85	11		B	99.9	100
	C	10.8	16		C	114.8	123
Cedar River	A	160	111	Smith Creek (A) and Elk Creek (B&C)	A	3.48	15
	B	169	96		B	46.7	50
	C-1	177	67		C	57.6	83
Chewack River	A	240	77	Elochoman River	A	47.1	117
	B	294	62		B	56.2	126
	C	382	98		C	66.2	102
Chiwawa River	A	50.0	78	Green River	A	285	262
	B	64.4	91		B	325	121
	C	95.3	108		C	327	174
Cloquallum Creek	A	23.5	39	Humptulips River	A	48.9	116
	B	30.4	60		B	61.4	149
	C	60.2	48		C	132	163
Issaquah Creek	A	17.6	31	North Fork Toutle River	A	277	158
	B	27.0	42		B	286	110
	C	38.1	40		C	291	208
Kalama River	A	142	153	North Nemah River	A	6.7	24
	B	154	106		B	18.8	45
	C	157	147		C	19.1	40
Methow River	A	363	162	Snoqualmie River (A&B) and Snohomish River (C)	A	450	238
	B	411	114		B	603	290
	C	423	157		C	1537	547
Middle Fork Satsop River	A	38.2	94	South Prairie Creek	A	67.5	46
	B	42.5	65		B	69.7	78
	C	56.7	74		C	87.2	76
Nason Creek	A	61.6	67	Samish River	A	27.0	30
	B	69.9	66		B	40.3	39
	C	107	85		C	87.8	52
North Fork Nooksack River	A	105	130	Wind River	A	56.4	55
	B	193	130		B	79.0	53
	C	282	176		C	95.3	84
North Fork Stillaguamish River	A	51.5	108	Wynoochee River	A	16.4	77
	B	89.7	173		B	74.1	178
	C	162	196		C	112	214

Selected Streamflow Characteristics

Several streamflow characteristics were selected for examination of their relationship to the preferred spawning and rearing discharges at the study reaches. Because the primary purpose of determining the preferred discharges is allocation of streamflow for salmon, it is helpful to know if the preferred discharges are available when spawning occurs or when rearing conditions are most critical.

The streamflow characteristics selected were the average annual discharge, the median monthly mean discharges during the 4 months September-December, and the 7-day mean low-flow at a 2-year recurrence interval. All these characteristics can be determined from records collected at stream-gaging stations. All values for these characteristics are average or median values because these are more confidently established than extreme values and because they can be more reliably transferred to the study reaches and other sites than can extreme values.

To develop relationships by which comparisons may be made, the streamflow characteristics must first be transferred to the study reaches. Transfer of the characteristics from gaging stations to study reaches was accomplished through a relationship between discharges measured at a study reach and the concurrent discharges at a stream-gaging station. The regression equations representing those relationships are of the form:

$$\text{Discharge at reach A (or B or C)} = a\,(\text{discharge at gage})^{b} \pm SE,$$

where a and b are coefficients, and SE is the average standard error of estimate in percentage of the discharge at A (or B or C). Table 9 gives the values of a, b, and SE for those relationships, the U.S. Geological Survey identification number of the stream-gaging station used for the transfer, and the range of measured discharges at each study reach. The standard error of estimate is a statistical measure of the accuracy of each equation. About two-thirds of the solutions to the equations are expected to be within one standard error of the correct value, and about 95 percent of the solutions are expected to be within two standard errors of the correct value. The gaging stations used for transfer purposes were selected as those nearest the study reaches, and their general proximity to the study reaches is indicated in table 9.

The streamflow characteristics determined for the gaging stations are listed in table 10. The average annual discharges for the period of record at gaging stations were obtained from publications of surface-water records for 1974 or earlier by the U.S. Geological Survey. The median, or 2-year recurrence interval, values of 7-day mean low flow were obtained from low-flow frequency curves of annual minimum 7-day mean discharges recorded prior to 1975 at the gaging stations. Median monthly mean discharges, or the monthly mean discharges having a 50-percent probability of being exceeded annually, were obtained from probability curves prepared manually for each month of the year, such as those shown in figure 7 for one gaging station.

TABLE 9.--Summary of relationships of discharge at the study reaches to discharge at the nearest stream-gaging station

Study stream	Study reach	Nearest stream-gaging station: At reach	Nearest stream-gaging station: Near reach	Nearest stream-gaging station: On a nearby stream	Nearest stream-gaging station: U.S.G.S. National identification number for QG	Coefficients, a and b, and standard error of estimate, SE, for equation on p. 28: a	b	SE	Range of discharges studied: Lowest (ft^3/s)	Highest (ft^3/s)
American River	A	--	--	--	--	0.52	1.05	12	24	337
	B	--	--	--	--	.16	1.31	18	15.5	441
	C		X		12488500	1.16	.97	9	41	459
Bear Branch	A	--	--	--	--	.68	1.03	4	9.4	121
	B	--	--	--	--	.75	1.03	5	9.4	118
	C	X	--	--	12009500	1.00	1.00	0	24	143
Bear Creek	A	--	--	--	--	.55	.86	7	4.8	21
	B	--	--	--	--	.45	.97	8	5.4	30
	C	--	X	--	12125500	.39	1.17	5	7.4	56
Cedar River	A	--	--	--	--	.45	1.10	9	76	1050
	B	--	--	--	--	.59	1.07	4	89	1540
	C-1	--	X	--	12119000	.78	1.03	3	200	900
Chewack River	A	--	--	--	--	.083	1.05	13	24	395
	B	--	--	--	--	.11	1.02	15	29	428
	C	--	--	X	12449950	.38	.89	14	50	503
Chiwawa River	A	--	--	--	--	.033	1.16	16	61.2	176
	B	--	--	--	--	.038	1.18	14	79.2	230
	C	--	--	X	12457000	.080	1.11	13	108	277
Cloquallum Creek	A	--	--	--	--	.69	.90	9	24.4	170
	B	--	--	--	--	.68	.95	3	30.4	205
	C	--	X	--	12032500	1.00	1.00	4	55.3	390
Deschutes River	A	--	--	--	--	.41	1.09	2	22	186
	B	--	X	--	12079000	.39	1.16	3	26	250
	C	--	--	--	--	2.75	.88	4	68	397
Dewatto River	A	X	--	--	12068500	1.00	1.00	0	19	225
	A-1	---	--	--	--	.99	1.00	2	19	247
	B	--	--	--	--	1.33	.97	5	22	274
Dosewallips River	A	--	X	--	12053000	1.00	1.00	4	131	830
	B	--	--	--	--	1.17	1.00	4	128	778
	C	--	--	--	--	1.17	1.00	4	129	775
Smith Creek (A) and Elk Creek (B&C)	A	--	--	--	--	.040	1.09	11	2.4	52
	B	X	--	--	12020500	1.00	1.00	0	24	680
	C	--	--	--	--	.73	1.10	4	24	950
Elochoman River	A	--	--	--	--	.88	.99	5	32	468
	B	--	--	--	--	1.14	.96	4	37	494
	C	--	X	--	14247500	1.00	1.00	4	37	549
Green River	A	--	--	--	--	.47	1.08	4	188	2030
	B	--	--	--	--	.70	1.03	3	232	948
	C	--	X	--	12113000	.70	1.03	3	225	1770
Humptulips River	A	---	--	--	--	.26	1.11	5	70	534
	B	--	--	--	--	.34	1.09	5	80	622
	C	--	X	--	12039000	1.00	1.00	3	148	974
Issaquah Creek	A	--	--	--	--	.32	1.02	10	27	169
	B	--	--	--	--	.56	.97	6	37	194
	C	--	X	--	12121600	.92	.95	5	57	283
Kalama River	A	--	--	--	--	1.59	.91	8	270	1280
	B	--	--	--	--	1.11	.97	8	287	1690
	C	--	X	--	14223500	1.08	.98	7	264	1660

TABLE 9.--Summary of relationships of discharges at the study reaches to discharges at the nearest stream-gaging station--cont.

Study stream	Study reach	Nearest stream-gaging station: At reach	Near reach	On a nearby stream	U.S.G.S. National identi-fication number for QG	Coefficients, a and b, and standard error of estimate, SE, for equation on p. 28: a	b	SE	Range of discharges studied: Lowest (ft^3/s)	Highest (ft^3/s)
Methow River	A	--	--	--	--	0.0012	1.75	18	64	863
	B	--	--	--	--	.0000068	2.49	30	32	522
	C	--	X	--	12449950	.0039	1.61	14	88	843
Middle Fork Satsop River	A	--	--	--	--	.050	1.14	24	37.6	406
	B	--	--	--	--	.0083	1.42	7	35.5	400
	C	--	--	X	12035000	.082	1 12	18	43.5	431
Nason Creek	A	--	--	--	--	.0064	1.33	28	33.7	409
	B	--	--	--	--	.034	1.13	35	32	390
	C	--	--	X	12457000	.026	1.19	36	36	424
North Fork Nooksack River	A	X	--	--	12205000	1.00	1.00	0	185	1800
	B	--	--	--	--	4.84	.85	4	342	2160
	C	--	--	--	--	22.0	.64	30	585	2700
North Fork Stillaguamish River	A	--	--	--	--	.0040	1.49	17	15	347
	B	--	--	--	--	.13	1.12	19	47	642
	C	--	X	--	12167000	3.44	.75	13	203	1200
North Fork Toutle River	A	--	--	--	--	.94	.98	8	293	900
	B	--	--	--	--	.94	.98	8	271	820
	C	--	--	X	14242500	.94	.98	8	282	1050
North Nemah River	A	--	--	--	--	.38	.99	7	8.1	118
	B	--	X	--	12011000	1.00	1.00	4	21	296
	C	--	--	--	--	1.00	1.00	10	21	316
Snoqualmie River (A&B) and Snohomish River (C)	A	--	--	--	--	.55	1.05	10	624	7250
	B	X	--	--	12149000	1.00	1.00	0	934	8470
	C	--	--	--	--	1.62	1.06	7	2200	20,860
South Prairie Creek	A	--	--	--	--	1.57	.86	11	35	265
	B	--	X	--	12095000	1.57	.86	11	39	268
	C	--	--	--	--	1.62	.93	4	55	370
Samish River	A	--	--	--	--	.78	.87	13	12.6	148
	B	--	--	--	--	1.24	.85	10	19.4	212
	C	X	--	--	12201500	1.00	1.00	0	25.2	455
Wind River	A	--	--	--	--	.037	1.26	11	18.7	174
	B	--	--	--	--	.0041	1.65	17	14.0	248
	C	--	X	--	14128500	.21	1.11	7	53.9	391
Wynoochee River	A	--	--	--	--	.020	1.53	4	31	494
	B	X	--	--	12036000	1.00	1.00	0	131	838
	C	--	--	--	--	1.38	.97	5	156	896

The streamflow characteristics for the study reaches, obtained by transferring the characteristics at the gaging stations through the equations in table 9, are given in table 11. Al! of the values in this table are estimates having certain standard errors that are associated with the transfer process. The least reliable values, whether due to a short length of record at a gaging station or due to being beyond the range of measured discharges given in table 9, are enclosed in parentheses.

Median monthly mean discharges, even though compared in this report with preferred spawning and rearing discharges only for the more important months September-December, are given for all 12 months of the year in tables 10 and 11. That is done in case similar comparisons might be necessary for other months.

The 12 median monthly mean discharges should not be interpreted on an annual basis as a consecutive series of events that have a 50-percent probability of being exceeded. The reason is that the monthly mean discharges for any one month were treated as random annual events for the purpose of probability analysis. In reality, monthly means are serially correlated from one month to the next, and the true probability of a monthly mean discharge being exceeded in any sane month is somewhat dependent on the mean for the previous month.

TABLE 10.--Average annual discharges, median 7-day mean low flows, and median monthly-mean discharges at stream-gaging stations[1]

Gaging-station name	USGS gaging station number	Average annual discharge (ft³/s)	7-day, 2-year mean low flow, ft³/s	Monthly-mean discharge, ft³/s, exceeded 50 percent of the time for the month of: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
American River near Nile, Wash.	12488500	248	41	65	100	150	120	110	110	300	660	670	250	78	54
Bear Branch near Naselle, Wash.	12009500	84	7	63	130	180	190	130	83	54	36	17	12	8.8	16
Bear Creek at Woodinville, Wash.	12125500	(23)	(6)	(14)	(18)	(43)	(53)	(34)	(31)	(22)	(15)	(11)	(8)	(7)	(8)
Cedar River at Renton, Wash.	12119000	711	100	260	810	810	1000	980	870	830	830	440	440	160	190
Chewack River Methow River near Pateros, Wash.	12449950	1,660	300	450	410	360	350	380	460	1300	4600	6400	1900	630	410
Chiwawa River Wenatchee River at Plain, Wash.	12457000	2,260	410	760	1000	1000	880	770	970	2700	5700	6400	2900	1000	600
Cloquallum Creek at Elma, Wash.	12032500	274	24	100	340	560	600	540	360	250	120	69	42	32	31
Deschutes River near Rainier, Wash.	12079000	270	32	120	310	470	580	500	360	290	140	88	52	39	38
Dewatto River near Dewatto, Wash.	12068500	71	12	18	70	70	110	98	68	41	41	20	20	15	14
Dosewallips River near Brinnon, Wash.	12053000	445	110	200	340	450	420	370	340	440	710	770	480	220	160
Elk Creek near Doty, Wash.	12020500	(160)	(13)	(63)	(250)	(380)	(330)	(370)	(230)	(160)	(81)	(45)	(26)	(16)	(25)
Elochoman River near Cathlamet, Wash.	14247500	375	29	120	480	480	520	540	420	220	220	70	70	38	39
Green River near Auburn, Wash.	12113000	1,370	180	390	1000	1800	1500	1500	1400	1900	1800	1000	450	260	230
Humptulips River near Humptulips, Wash.	12039000	1,360	140	660	1800	1800	1700	1600	1300	860	860	300	300	180	200

TABLE 10.--Average annual discharges, median 7-day mean low flows, and median monthly-mean discharges at stream-gaging stations[1]--cont.

Gaging-station name	USGS gaging station number	Average annual discharge (ft^3/s)	7-day, 2-year mean low flow, ft^3/s	Monthly-mean discharge, ft^3/s, exceeded 50 percent of the time for the month of: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
Issaquah Creek near mouth, near Issaquah, Wash.	12121600	150	15	52	110	280	350	230	180	160	99	62	37	32	44
Kalama River below Italian Creek, near Kalama, Wash.	14223500	1,260	230	490	1500	1500	1600	1700	1400	1200	1200	460	460	280	250
Methow River near Pateros, Wash.	12449950	1,660	300	450	410	360	350	380	460	1300	4600	6400	1900	630	410
Middle Fork Satsop River near Satsop, Wash.	12035000	2,030	230	980	2700	4000	4100	3400	2800	2000	1000	580	400	300	330
Nason Creek Wenatchee River at Plain, Wash.	12457000	2,260	410	760	1000	1000	880	770	970	2700	5700	6400	2900	1000	600
North Fork Nooksack River below Cascade Creek, near Glacier, Wash.	12205000	780	190	530	520	520	370	330	390	700	700	1300	1300	710	490
North Fork Stillaguamish River near Arlington, Wash.	12167000	1,900	250	2100	2700	3300	2900	2900	1800	2100	2200	1600	760	440	520
North Fork Toutle River near Silver Lake, Wash.	14242500	2,070	360	1000	2300	3400	3400	2700	2200	2600	2100	1600	800	520	470
North Nemah River near South Bend, Wash.	12011000	122	9	75	170	270	280	210	150	74	45	26	16	13	14
Snoqualmie River near Carnation, Wash.	12149000	3,820	570	2700	4400	5300	5100	4300	3500	4600	5200	4500	2100	940	1100
South Prairie Creek at South Prairie, Wash.	12095000	243	38	140	270	360	380	340	230	300	260	200	92	56	55
Samish River near Burlington, Wash.	12201500	243	26	120	300	420	490	430	320	270	170	91	48	35	39
Wind River near Carson, Wash.	14128500	1,210	180	310	1200	1800	1700	1800	1600	1700	1200	590	330	230	200
Wynoochee River above Save Creek, near Aberdeen, Wash.	12036000	826	130	490	1100	1100	1100	1000	750	640	640	330	330	170	170

[1] Parentheses indicate an estimate from a short record (less than 10 years).

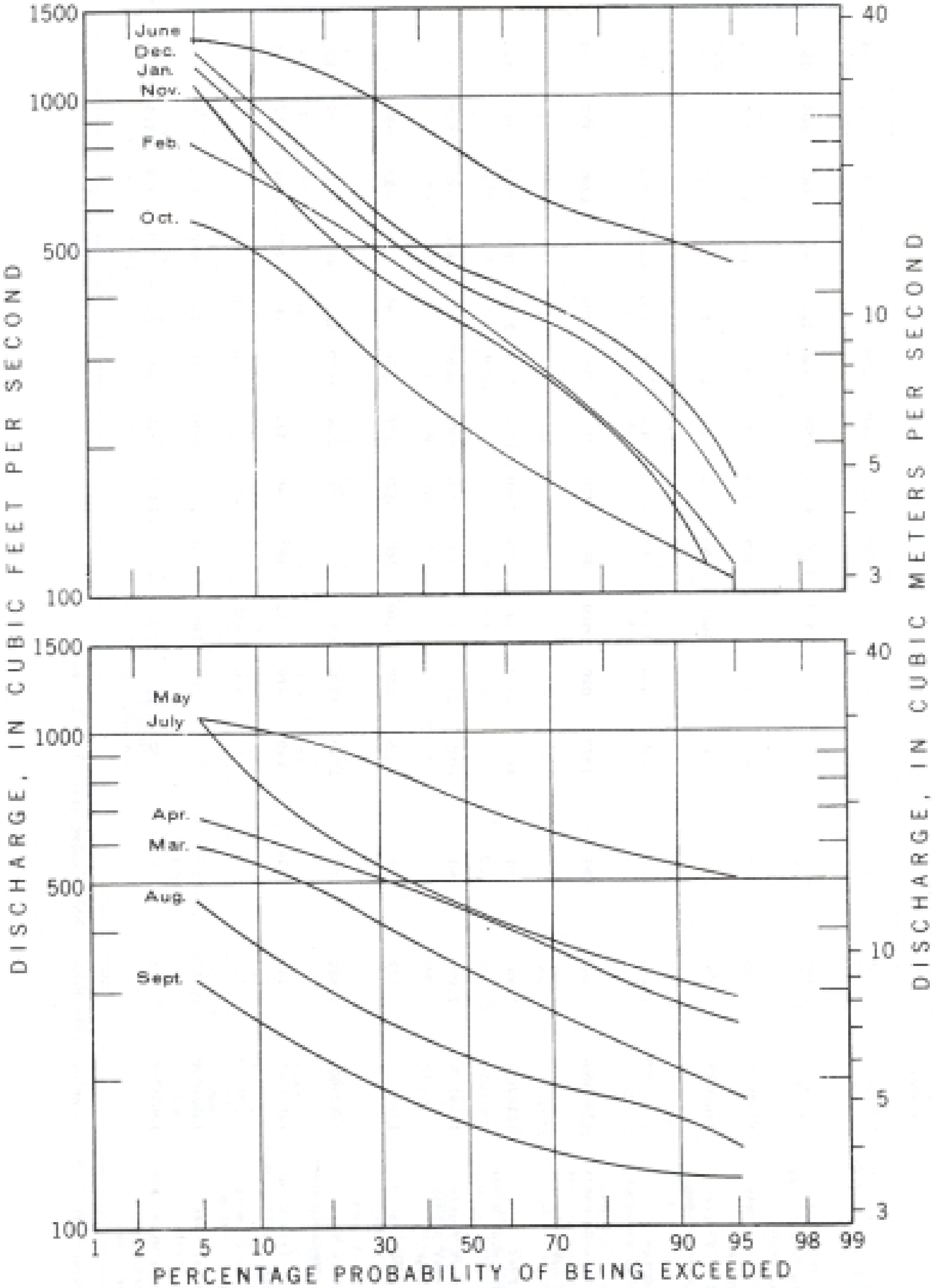


FIGURE 7.--Probability distributions of monthly mean discharges during the period 1930-49, Dosewallips River near Brinnon, Washington (12053000).

TABLE 11.--Average annual discharges, median 7-day mean low flows, and median monthly-mean discharges at stream reaches studied[1]

Study stream	Study reach[2, 3]	Average annual discharge (ft^3/s)	7-day, 2 year mean low flow (ft^3/s)	Monthly-mean discharge (ft^3/s) exceeded 50 percent of the time for the month of: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
American River	A	170	26	42	66	100	80	73	73	210	(480)	(490)	170	51	34
	B	220	21	37	66	110	84	75	75	280	(780)	(800)	220	48	29
	C	240	43	67	100	150	120	110	110	290	(630)	(640)	250	80	56
Bear Branch	A	65	(5)	49	100	(140)	(150)	100	64	41	27	13	(9)	(6)	12
	B[3]	72	(5)	54	110	(160)	(170)	110	71	46	30	14	10	(7)	13
	C[2]	84	7	63	130	180	190	130	83	54	36	17	12	9	16
Bear Creek	A	(8)	(3)	(5)	(7)	(14)	(17)	(11)	(11)	(8)	(6)	(4)	(3)	(3)	(3)
	B	(9)	(3)	(6)	(7)	(17)	(21)	(14)	(13)	(9)	(6)	(5)	(3)	(3)	(3)
	C	(15)	(3)	(9)	(11)	(32)	(41)	(24)	(22)	(15)	(9)	(6)	(4)	(4)	(4)
Cedar River	A	620	(71)	200	710	710	900	880	770	730	730	360	360	120	140
	B[3]	660	(81)	230	760	760	960	940	820	780	780	400	400	130	160
	C-1	680	(90)	(240)	770	770	(960)	(940)	830	790	790	410	410	(150)	(170)
Chewack River	A	200	33	51	46	40	39	42	52	150	(580)	(820)	230	72	46
	B	210	37	54	49	43	42	46	56	160	(580)	(820)	240	77	49
	C	280	61	87	80	72	70	75	89	220	(690)	(920)	310	120	80
Chiwawa River	A	(260)	(35)	72	100	100	86	74	96	(320)	(750)	(860)	(340)	100	(55)
	B	(340)	(46)	95	130	130	110	97	133	(430)	(1000)	(1200)	(460)	130	(72)
	C	(420)	(64)	130	170	170	150	130	170	(520)	(1200)	(1300)	(560)	170	(97)
Cloquallum Creek	A	110	(12)	44	130	(210)	(220)	(200)	140	100	52	31	(20)	(16)	(15)
	B	140	(14)	53	170	(270)	(290)	(260)	180	130	63	37	(23)	(18)	(18)
	C	270	(24)	100	340	(560)	(600)	(540)	360	250	120	69	(42)	(32)	(31)
Deschutes River	A	180	(18)	76	(210)	(340)	(420)	(360)	(250)	(200)	90	54	30	22	22
	B	(260)	(22)	100	(300)	(490)	(630)	(530)	(360)	(280)	120	70	38	27	27
	C	330	(58)	186	(430)	(620)	(740)	(650)	(490)	(400)	210	140	89	69	63
Dewatto River	A[2]	71	12	18	70	70	110	98	68	41	41	20	20	15	14
	A-1[3]	70	(12)	18	69	69	110	97	67	41	41	20	20	(15)	(14)
	B	83	(15)	22	82	82	130	110	80	49	49	24	24	(18)	(17)
Dosewallips River	A	440	110	200	340	450	420	370	340	440	710	770	480	220	160
	B[3]	520	130	230	400	530	490	430	400	510	(830)	(900)	560	260	190
	C[3]	520	130	230	400	530	490	430	400	510	(830)	(900)	560	260	190

TABLE 11.--Average annual discharges, median 7-day mean low flows, and median monthly-mean discharges at stream reaches studied[1]--cont.

Study stream	Study reach[2,3]	Average annual discharge (ft^3/s)	7-day, 2-year mean low flow (ft^3/s)	Monthly-mean discharge (ft^3/s) exceeded 50 percent of the time for the month of: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
Smith Creek (A) and Elk Creek (B&C)	A	(10)	(1)	(4)	(16)	(26)	(22)	(25)	(15)	(10)	(5)	(2)	(1)	(1)	(1)
	B[2]	(160)	(13)	(63)	(250)	(380)	(330)	(370)	(230)	(160)	(81)	(45)	(26)	(16)	(25)
	C	(190)	(12)	(70)	(320)	(500)	(430)	(490)	(290)	(190)	(92)	(48)	(26)	(15)	(25)
Elochoman River	A	310	(25)	100	400	400	430	450	350	180	180	59	59	32	33
	B	340	(29)	110	430	430	460	480	380	200	200	67	67	37	38
	C	380	(29)	120	480	480	520	540	420	220	220	70	70	38	39
Green River	A	1100	(130)	300	820	1500	1300	1300	1200	1600	1500	820	340	190	(170)
	B[3]	(1200)	(150)	330	860	(1600)	(1300)	(1300)	(1200)	(1700)	(1600)	860	380	(220)	(190)
	C	1200	(150)	330	860	1600	1300	1300	1200	1700	1600	860	380	(220)	(190)
Humptulips River	A	(780)	(63)	350	(1100)	(1100)	(1000)	(940)	(740)	470	470	150	150	83	93
	B	(890)	(74)	400	(1200)	(1200)	(1100)	(1100)	(840)	540	540	170	170	98	110
	C	(1400)	(140)	660	(1800)	(1800)	(1700)	(1600)	(1300)	860	860	300	300	180	200
Issaquah Creek	A	53	(5)	(18)	39	100	130	82	64	57	35	(22)	(13)	(11)	(15)
	B	72	(8)	(26)	53	130	160	110	86	77	48	(31)	(19)	(16)	(22)
	C	110	(12)	(39)	80	190	240	160	130	110	72	(46)	(28)	(25)	(34)
Kalama River	A[3]	1100	(220)	450	1200	1200	(1300)	(1400)	1200	1000	1000	420	420	270	(240)
	B[3]	1100	(220)	450	1300	1300	1400	1500	1300	1100	1100	420	420	(260)	(240)
	C	1200	(220)	470	1400	1400	1500	1600	1300	1100	1100	440	440	270	(240)
Methow River	A	520	(26)	(53)	(45)	(36)	(34)	(39)	(55)	340	(3100)	(5500)	660	95	(45)
	B	(710)	(10)	(27)	(22)	(16)	(15)	(18)	(29)	380	(8900)	(20000)	(990)	63	(22)
	C	600	(38)	(73)	(62)	(51)	(48)	(55)	(75)	400	(3100)	(5200)	740	120	(62)
Middle Fork Satsop River	A	290	(25)	130	(410)	(640)	(660)	(530)	(430)	290	130	71	46	(33)	37
	B[3]	(410)	(19)	150	(620)	(1100)	(1100)	(850)	(650)	400	150	69	41	(27)	(31)
	C	420	(36)	180	570	(890)	(910)	(740)	600	410	190	100	67	49	54
Mason Creek	A 14.2	180	(19)	43	62	62	52	44	60	230	(630)	(730)	260	62	(32)
	B 12.7	210	(30)	61	83	83	72	62	80	250	(590)	(680)	280	83	47
	C 6.6	250	(33)	70	97	97	83	71	93	310	(770)	(880)	340	97	53
North Fork Nooksack River	A[2]	780	190	530	520	520	370	330	290	700	700	1300	1300	710	490
	B	1400	420	1000	990	990	740	670	600	1300	1300	2100	2100	1300	940
	C	1600	630	1200	1200	1200	970	900	830	1500	1500	2200	2200	1500	1200
North Fork Stillaguamish River	A	310	15	(360)	(520)	(700)	(580)	(580)	280	(360)	(380)	240	78	35	45
	B	610	63	(680)	(910)	(1100)	(980)	(980)	580	(680)	(720)	500	220	120	140
	C	990	220	1100	(1300)	(1500)	(1400)	(1400)	950	1100	1100	870	500	330	370

TABLE 11.--Average annual discharges, median 7-day mean low flows, and median monthly-mean discharges at stream reaches studied[1]--cont.

Study stream	Study reach[2] [3]	Average annual discharge (ft^3/s)	7-day, 2-year mean low flow (ft^3/s)	Monthly-mean discharge (ft^3/s) exceeded 50 percent of the time for the month of: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
North Fork Toutle River	A[3]	(1700)	300	820	(1900)	(2700)	(2700)	(2200)	(1800)	(2100)	(1700)	(1300)	660	430	390
	B[3]	(1700)	300	820	(1900)	(2700)	(2700)	(2200)	(1800)	(2100)	(1700)	(1300)	660	430	390
	C	(1700)	300	820	(1900)	(2700)	(2700)	(2200)	(1800)	(2100)	(1700)	(1300)	660	430	390
North Nemah River	A	44	(3)	27	61	97	100	76	54	27	16	10	(6)	(5)	(5)
	B	120	(9)	75	170	270	280	210	150	74	45	26	(16)	(13)	(14)
	C[3]	120	(9)	75	170	270	280	210	150	74	45	26	(16)	(13)	(14)
Snoqualmie River (A&B) and Snohomish River (C)	A	3200	(430)	2200	3700	4500	4300	3600	2900	3900	4400	3800	1700	730	860
	B[2]	3800	570	2700	4400	5300	5100	4300	3500	4600	5200	4500	2100	940	1100
	C	10000	(1400)	7000	12000	14000	14000	12000	9300	12000	14000	12000	5400	2300	2700
South Prairie Creek	A[3]	180	36	110	190	250	260	240	170	210	190	150	77	50	49
	B	180	(36)	110	190	250	260	240	170	210	190	150	77	50	49
	C	270	(48)	160	300	(390)	(410)	370	250	330	290	220	110	68	67
Samish River	A	93	13	50	110	(150)	(170)	(150)	120	100	68	39	23	17	19
	B	130	20	73	160	210	(240)	210	170	140	98	57	33	25	28
	C[2]	240	26	120	300	420	490	430	320	270	170	91	48	35	39
Wind River	A	(280)	26	51	(280)	(470)	(440)	(470)	(400)	(440)	(280)	110	55	35	29
	B	(500)	22	53	(490)	(970)	(880)	(970)	(880)	(880)	(490)	150	59	32	26
	C	(550)	67	120	(550)	(860)	(810)	(860)	(760)	(810)	(550)	250	130	88	75
Wynoochee River	A	(580)	34	260	(900)	(900)	(900)	(780)	(500)	390	390	140	140	52	52
	B[2]	830	130	490	1100	1100	1100	1000	750	640	640	330	330	170	170
	C	(930)	160	560	(1200)	(1200)	(1200)	(1100)	850	730	730	380	380	200	200

[1]Values in parentheses are estimates beyond the range of discharges measured at the reach or based on a short length of gaging-station record.

[2]A study reach located at a U.S.G.S. stream-gaging station.

[3]Data for this reach is not used in the regression analyses.

RELATIONSHIPS FOR ESTIMATING PREFERRED DISCHARGES AND SPAWNABLE AREAS

Tests for Differences in Discharges Among Reaches and Streams

Two separate sets of statistical tests were made on discharge data from the study reaches to determine if any of the data should not be used to develop relationships for making estimates, and to determine if separate relationships should be developed for streams of eastern and western Washington.

The first set of tests were analyses of covariance on the discharges measured at the three reaches on each stream. These tests are necessary because reaches on some- streams are close together, and discharges at one, two, or all three reaches might possibly be virtually equal. Such replicates might cause a bias in a generalization, and are best not used. The first analysis was 'a test at a 95-percent-confidence level for differences in concurrent discharges at reaches A and 13, adjusted or controlled by the concurrent discharges at reach C. The second I analysis was similar except that discharges at reaches B and C were compared, using the discharges at reach A for adjustment or control. This system of testing resulted in the conclusion that streamflow at 13 of the reaches was not different from streamflow at one or another of the 71 remaining reaches. The 13 reaches for which data were not used in development of estimating relationships are identified by footnotes to tables 7 and 1t. The choice of which reach to delete from an adjacent similar pair is partly a matter of familiarity with various difficulties encountered in obtaining data from some of the reaches, but mostly reach B's were deleted to provide as much difference as possible among the remaining reaches.

The second set of tests were analyses of covariance on preferred spawning and rearing discharges at reaches on eastern and western Washington streams. For the purpose of these tests, coastal and Puget Sound streams were classified as western, and Columbia Basin streams as eastern. The adjustment or control variables were drainage area in some tests and toe-of-bank channel width in other tests. The conclusions from each of six separate ~ analyses of covariance were the same; there is no difference at the 95-percent-confidence level in preferred spawning and rearing discharges between the eastern and western streams studied.

Relationships for Estimating Spawning and Rearing Discharges from Channel Widths and Drainage Areas

Two sets of relationships with physiographic parameters are provided for making estimates of preferred spawning and rearing discharges at stream sites other than the stream reaches studied. The first set, shown in figure 8, uses toe-of-bank width of channel as the parameter for obtaining an estimate, and the second set, shown in figure 9, uses drainage area similarly. Both sets of relationships were developed by standard methods of linear regression between the logarithms of the discharges for the study reaches and the logarithms of either toe-of-bank width or drainage area for the same reaches.

Figures 8 and 9 also show the regression equation representing each relationship and the average percentage standard error of estimate. These equations, and all others in this report, have been defined only for certain ranges of data, which may be determined from the various tables. The accuracy of extrapolations beyond the limits of those ranges has not been determined, and the results of extrapolation should be regarded as questionable.

The regression equations in this report are appropriate only for use with English units of measurement. The use of metric units for the independent parameter in the equations will not produce correct solutions unless the multiplier in each of the equations is suitably changed. Exponents in the equations are unaffected by the use of metric units.

The standard error of estimate has been previously defined in the discussion of selected streamflow characteristics (p. 28). Notably, the standard errors for estimating spawning and rearing discharges are appreciably less from toe-of-bank width than from drainage area regressions. Toe-of-bank width, therefore, is recommended as the parameter for making the estimates whenever possible. Drainage area is provided as an alternative parameter because it can be determined from maps, whereas toe-of-bank width is necessarily measured at stream sites, and that may not always be practical.

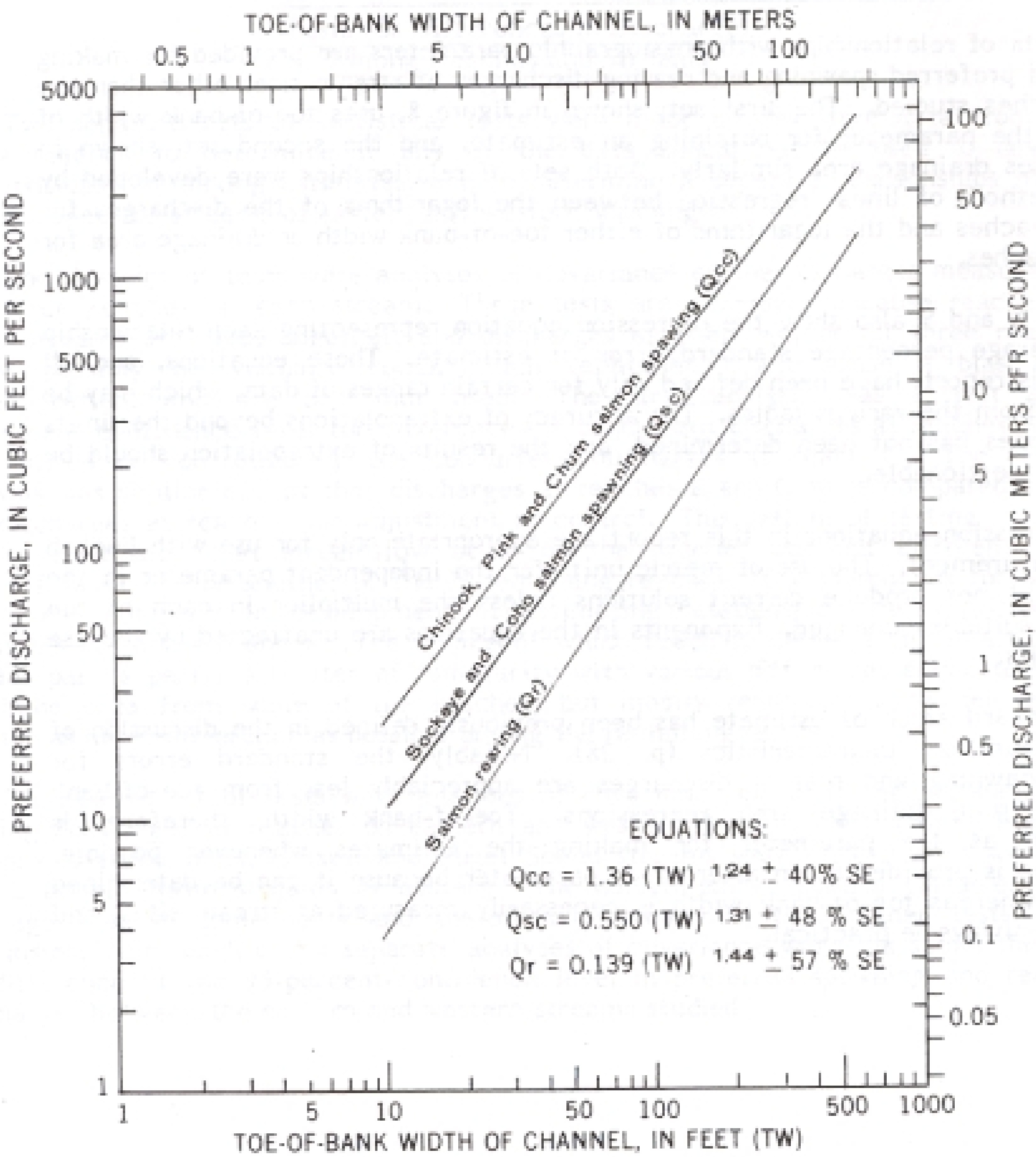


FIGURE 8.--Relationships for estimating from channel width the stream discharges preferred by salmon for spawning and rearing.

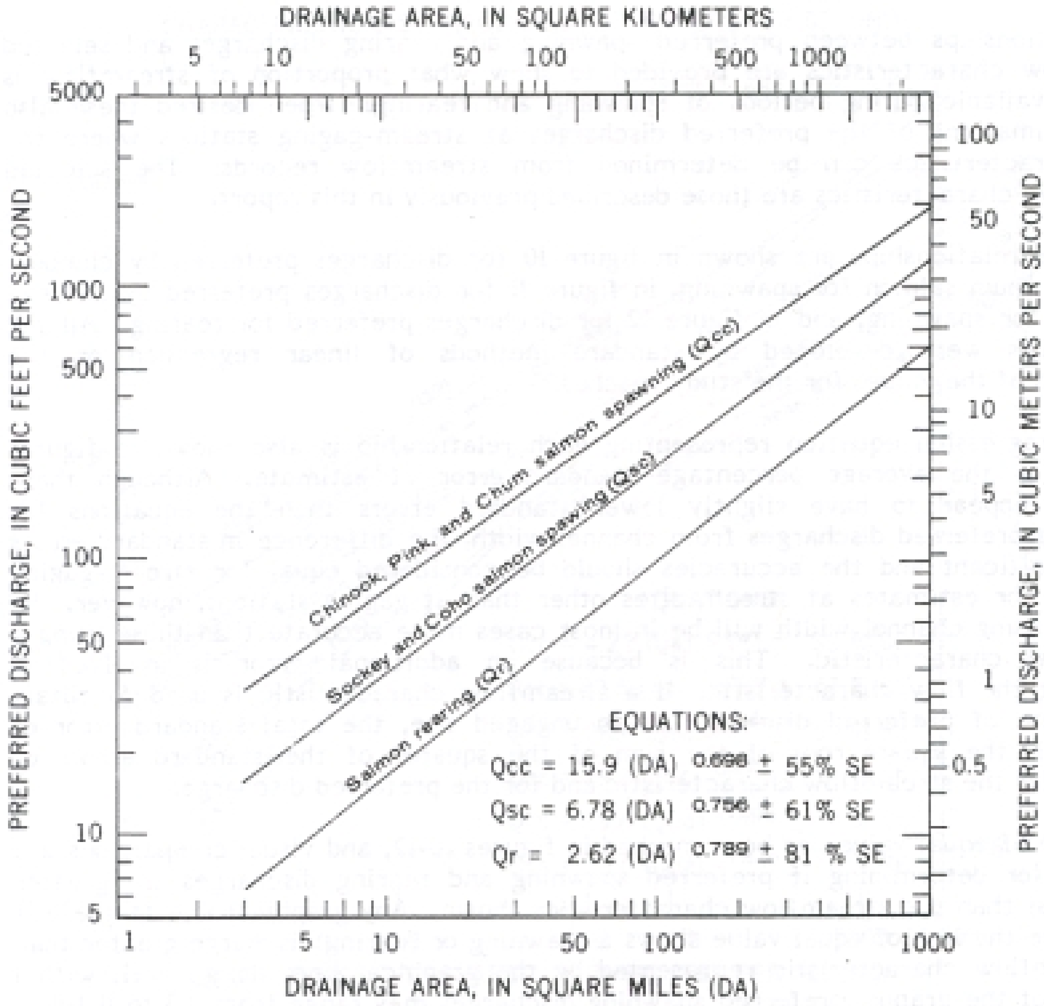


FIGURE 9.--Relationships for estimating from basin drainage area the stream discharges preferred by salmon for spawning and rearing.

Relationships for Estimating Spawning and Rearm Discharges from Selected Streamflow Characteristics

Relationships between preferred spawning and rearing discharges and selected streamflow characteristics are provided to show what proportion of streamflow is usually available during periods of spawning and rearing. When desired these also allow estimations of the preferred discharges at stream-gaging stations where the flow characteristics can be determined from streamflow records. The selected streamflow characteristics are those described previously in this report.

Those relationships are shown in figure 10 for discharges preferred by Chinook, pink, and chum salmon for spawning, in figure 11 for discharges preferred by sockeye and coho for spawning, and in figure 12 for discharges preferred for rearing. All the relationships were developed by standard methods of linear regression on the logarithms of the values for the study reaches.

The regression equation representing each relationship is also shown in figures 10-12, as is the average percentage standard error of estimate. Although these equations appear to have slightly lower standard errors than the equations for estimating preferred discharges from channel width, the difference in standard errors is not significant and the accuracies should be considered equal for stream-gaging stations. For estimates at stream sites other than at gaging stations, however, the equations using channel width will be in most cases more accurate than those using a streamflow characteristic. This is because an additional error is involved in estimating the flow characteristic. If a streamflow characteristic is used to obtain an estimate of preferred discharge at an engaged site, the total standard error of estimate is the square root of the sum of the squares of the standard errors of estimate for the streamflow characteristic and for the preferred discharge.

A line of equal value has been marked in figures 10-12, and visual comparisons are adequate for determining if preferred spawning and rearing discharges are greater than or less than the streamflow characteristics shown. Any graphical line to the left of or. above the line of equal value shows a spawning or rearing discharge greater than the streamflow characteristic represented by the graphical line. In general, within the scale of the graphs, preferred spawning discharges may range from 0.3 to 11 times the median monthly mean discharges for September and October and from 0.1 to 6 times the median for November and December-the four months when spawning activity is greatest. Also, preferred spawning discharges may range from 0.3 to 2 times the average annual discharge and 0.8 to 14 times the median 7-day low flow.

Similarly to the above observations, preferred rearing discharges may range from 0.7 to 4 times the median monthly-mean discharges for September, from 0.9 to 5 times the median 7-day low flow, and from 0.2 to 2 times the average annual discharge.

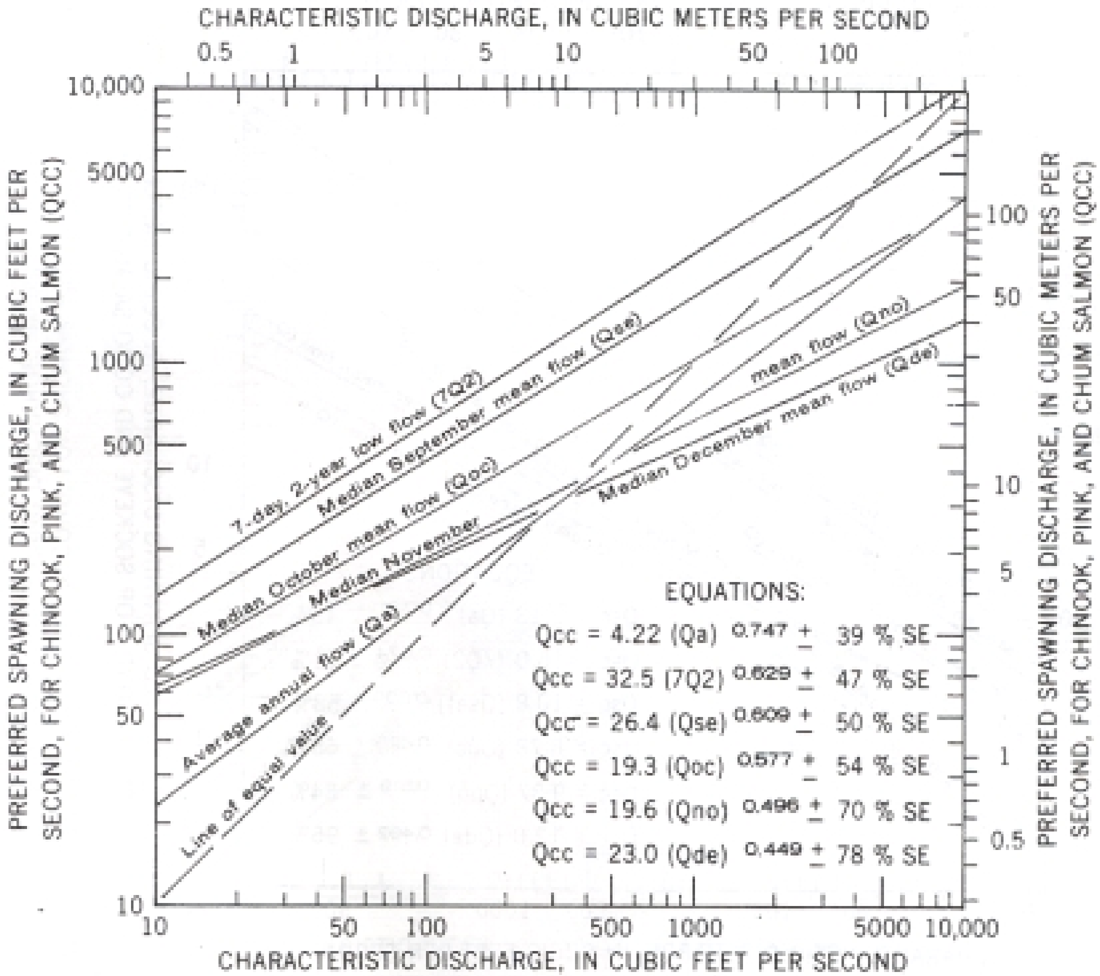


FIGURE 10.--Relationships for estimating from selected streamflow characteristics the average discharge preferred by chinook, pink, and chum salmon for spawning.

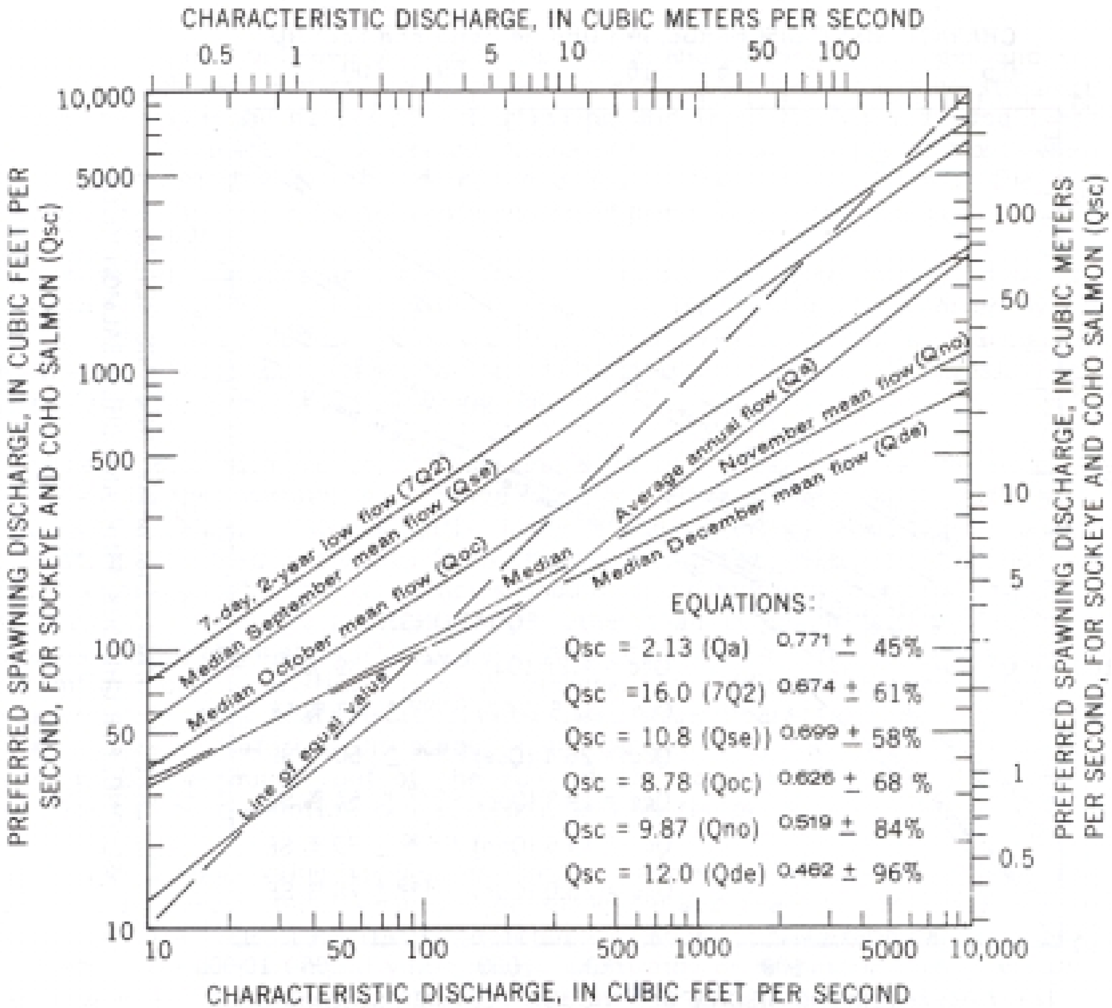


FIGURE 11.--Relationships for estimating from selected streamflow characteristics the average discharge preferred by sockeye and coho salmon for spawning.

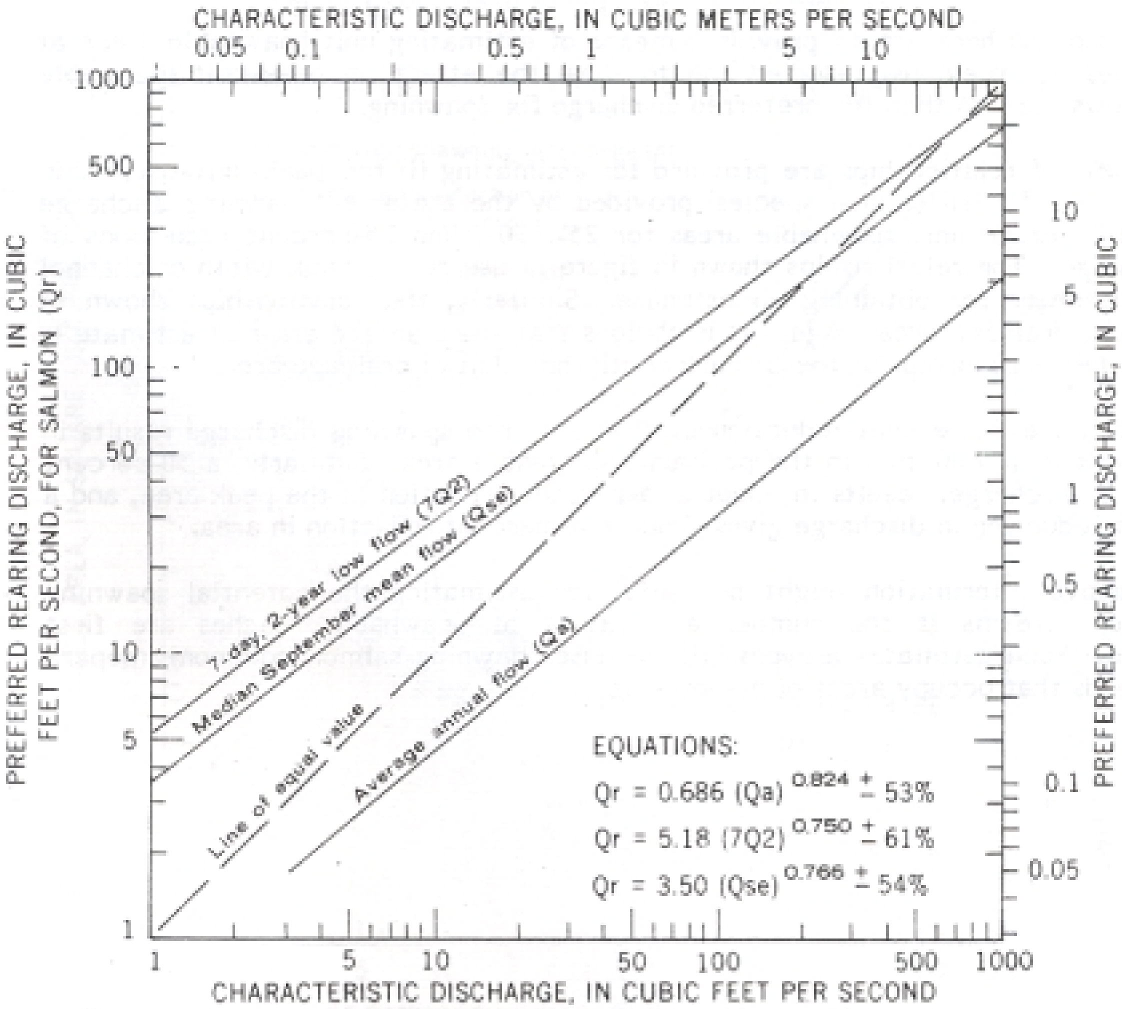


FIGURE 12.--Relationships for estimating from selected streamflow characteristics the discharge preferred by salmon for rearing.

Relationships for Estimating Unit Spawnable Area from Channel Width and Drainage Area

The purposes here are to provide a means of estimating unit spawnable areas at stream sites not previously studied and to show the effect on peak-unit-spawnable areas if flows are less than the preferred discharge for spawning.

Two sets of relationships are provided for estimating (1) the peak-unit-spawnable area (averaged for all salmon species) provided by the preferred spawning discharge and (2) the average unit spawnable areas for 25-, 50-, and 75-percent reductions of that discharge. The relationships shown in figure 13 use toe-of-bank width of channel as the parameter for obtaining an estimate. Similarly, the relationships shown in figure 14 use drainage area. Again it is obvious that the standard error of estimate is less using the relationships of toe-of-bank width than that of drainage area.

Generally, a 25-percent reduction of the preferred spawning discharge results in about a 5-percent reduction in the peak-unit-spawnable area. Similarly, a 50-percent reduction in discharge, results in about a 15-percent reduction in the peak area, and a 75-percent reduction in discharge gives about a 40-percent reduction in area.

The above information might be useful for estimating the potential spawning capacity of streams if the number and extent of spawnable reaches are first determined. Such estimates are possible because spawning salmon commonly prepare nests or redds that occupy areas of a known size.

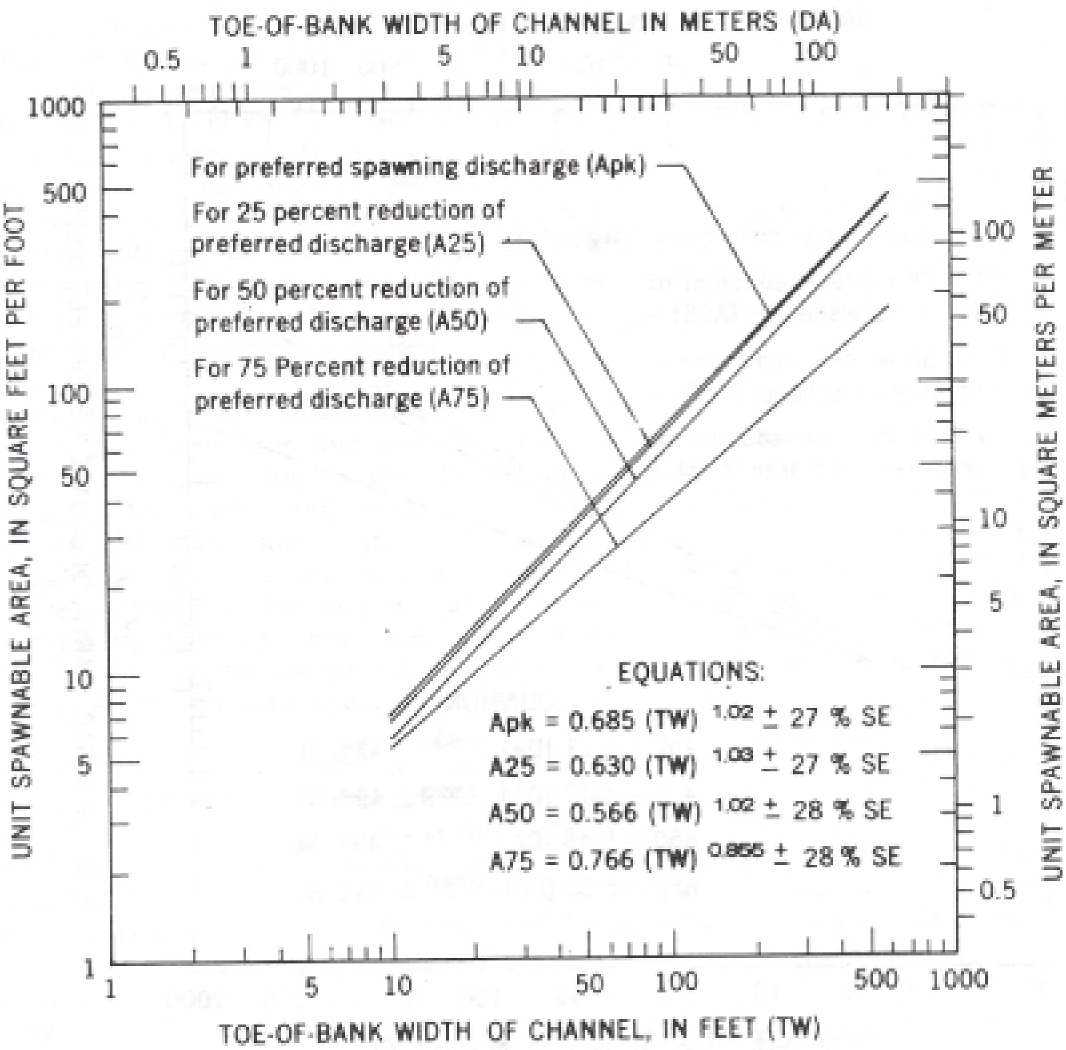


FIGURE 13.--Relationships for estimating unit spawnable areas from channel width.

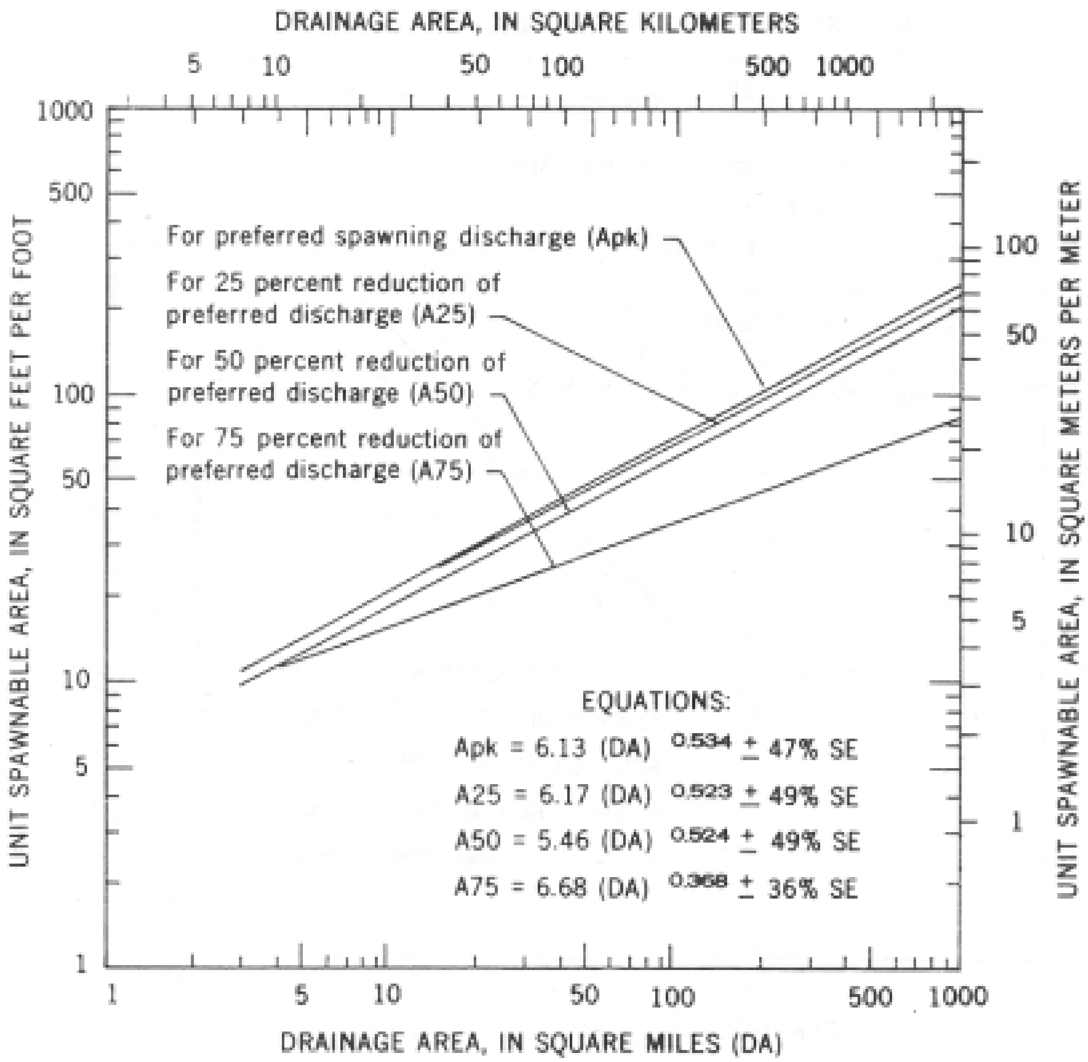


FIGURE 14.--Relationships for estimating unit spawnable areas from basin drainage area.

SUMMARY AND CONCLUSIONS

The objectives of this study were to evaluate at study reaches on streams in Washington the discharges and streambed areas preferred by salmon for spawning and rearing, to develop relationships for estimating those discharges and areas at ungaged sites, and to examine the relationship between the preferred discharges and the discharges that characteristically occur during periods of spawning and rearing. Preferred spawning discharge is defined as the stream discharge that provides the greatest spawnable area. Spawnable area is that part of the streambed at a study reach having water depths and velocities preferred by salmon for spawning. Preferred rearing discharge is the stream discharge that provides maximum wetted area of the streambed, as determined from the relationship between discharge and wetted perimeter of the stream channel.

Preferred spawning discharges and unit spawnable areas (areas divided by reach length) were determined for five species of salmon at 84 study reaches on 28 streams in Washington. Examination of the discharges revealed that they could be averaged as two values for each study reach according to two groups of salmon species; Chinook, pink, and chum salmon in one group and sockeye and coho salmon in a second group. Examination of the unit spawnable areas indicates that they could be averaged for all five salmon species as one value for each study reach. A single value of preferred rearing discharge was determined for each of the study reaches because, in the definition of that discharge, no distinction is made between the different species of salmon, even though some species do not rear in streams.

Relationships are provided for obtaining estimates of the average preferred spawning and rearing discharges and unit spawnable area from either toe-of-bank channel width or drainage area. The relationships using channel width are recommended for use over drainage area whenever practical, because they have lower standard errors of estimate--40 to 48 percent for spawning discharges, 57 percent for rearing discharges, and 27 percent for greatest unit spawnable area.

Additional relationships, using the same two parameters, are provided for estimating the effect on unit spawnable areas if flows are reduced below the preferred spawning discharge by 25, 50, and 75 percent. The average corresponding reductions .from greatest unit spawnable area are approximately 5, !5, and 40 percent, respectively.

Comparison of the relationships between preferred spawning discharges and selected stream flow characteristics indicates that the preferred discharges range from about 0.8 to !4 times the median 7-day mean low flows, about 0.3 to 11 times the median monthly mean discharges during September arid October, about 0.1 to 6 times the median monthly mean discharge for November and December, and about 0.3 to 2 times the average annual discharge. Similar comparisons for preferred rearing discharges indicate that these preferred discharges may range from 0.9 to 5 times the median 7-day mean low flows, from 0.7 to 4 times the median September monthly mean discharge, and .from 0.2 to 2 times the average annual discharge.

COMMENTS FROM THE COOPERATOR

By Fay Conroy
State of Washington Department of Fisheries

The reader and potential user of the methodology presented in this report is cautioned that there are factors beyond the scope of this study influencing flows necessary for salmon propagation.

Rearing is dependent upon food supply, physical habitat and water quality. The relationship of stream flow to salmon rearing is undoubtedly much more complex than indicated by a plotting of wetted perimeter against discharge. More data must be collected relating salmon to their freshwater environment before a comprehensive rearing methodology can be developed.

Redds near the center of a stream are more likely to be disturbed by high autumn and winter flows than those nearer the edges. Greater discharges during spawning may increase survival by shifting the spawnable area toward the edges even though the total area spawnable is reduced.

Preferred flows determined by the methodology tend to be less than historically available in the larger streams and greater than historically available in the smaller streams. The first has caused criticism by biologists who feel the salmon have adjusted to existing flow regimes. The second causes criticism from those having potential out-of-stream uses for the water who claim that, since the flows have not been normally available, they are unjustifiably high. It is not claimed that preferred flows will always be available, but that any reduction below those levels will reduce fish production capacity and that man should do nothing to cause flows to. drop below, or further below, those levels.

After flows necessary for salmon propagation are determined, it is still necessary to get them legally established and defend them in an adversary system. To justify retaining any level of stream flow it may be necessary to establish that sufficient numbers, existing or potential, of salmon are available to utilize the habitat provided. The State of Washington is well advanced in having statutes protecting instream flow needs and is progressing in the establishment of minimum and base flows and in enforcing them once established.

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