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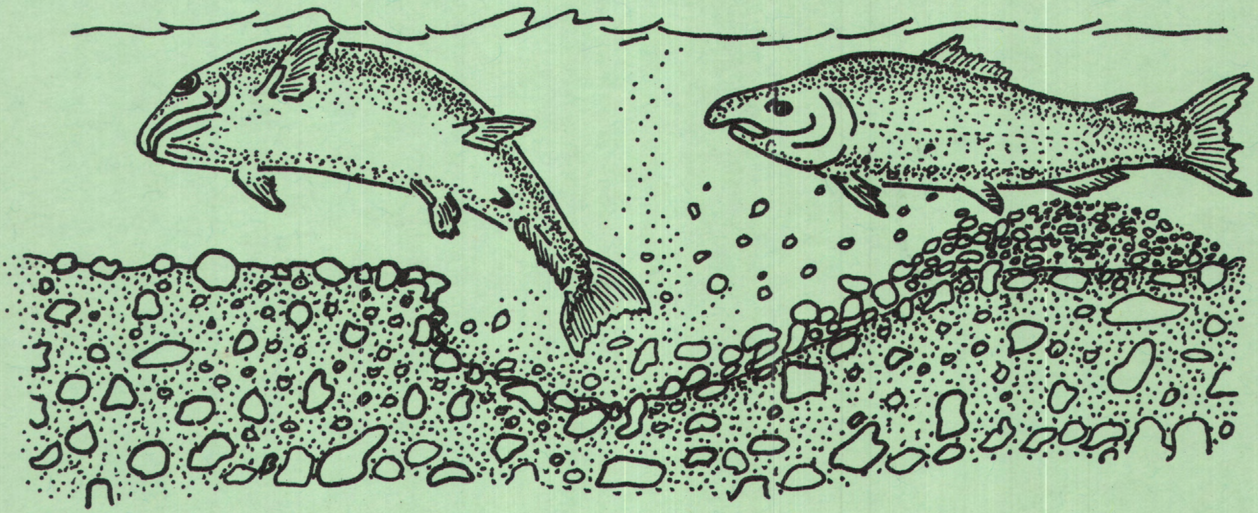
THE HYDROLOGY OF TEN STREAMS IN WESTERN WASHINGTON

AS RELATED TO THE PROPAGATION OF SEVERAL PACIFIC SALMON SPECIES



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Basic to all considerations related to the preservation and enhancement of the Pacific salmon runs in Washington are the quantitative and qualitative aspects of the streams utilized by the fish for spawning and rearing. The water must be of sufficient velocity and depth, and quality (with regard to temperature, suspended sediment, dissolved oxygen, and dissolved minerals) and the streambed must have satisfactory gravel conditions for spawning. This report is the third of several that describe such characteristics of streams in Washington, and covers 300 measurements of depths, velocities, and discharges obtained at 10 intervals at three study reaches on each of 10 streams. The ranges of preferred discharges for spawning and rearing for each of four salmon species are given for the 10 streams studied.

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THE HYDROLOGY OF TEN STREAMS IN WESTERN WASHINGTON AS RELATED TO SEVERAL PACIFIC SALMON SPECIES

By M. R. Collings and G. W. Hill

ABSTRACT

Basic to all other considerations related to the preservation and enhancement of the Pacific salmon runs in Washington are the quantitative and qualitative aspects of the streams utilized by the fish. First, there must be sufficient quantities of water for salmon propagation. Second, stream-hydraulic conditions of depth and velocity must be favorable for salmon spawning and rearing. Third, water quality must be favorable with regard to temperature, suspended sediment, dissolved oxygen, and the quantity of dissolved minerals.

This is the third in a series of reports that discuss the results of investigations to determine preferred spawning and rearing discharges on selected streams in western Washington. Using preferred depth and velocity criterion previously determined by anadromous-fish biologists, 300 sets of measurements of depth, velocity, and discharge were obtained during 10 visits to three study reaches on each of 10 streams. The data were evaluated to determine the preferred spawning and rearing flows for fall chinook, spring chinook, sockeye and coho salmon at the reaches studied. Documentation also was made, for each study reach, of streambed-gravel sizes, water temperatures, suspended-sediment concentrations, dissolved-oxygen concentrations, and specific conductance.

The range of preferred discharges on each stream investigated for fall chinook and coho (the most prevalent species in western Washington) are as follows: (1) For spawning--Bear Branch, 41-85 cfs (cubic feet per second); North Nemah River

31-95 cfs; Elk Creek, 6.5-250 cfs; North Fork Toutle River, 300-570 cfs; Deschutes River, 105-145 cfs; Dosewallips River, 125-330 cfs; North Fork Stillaguamish River, 125-410 cfs; South Prairie Creek, 67-128 cfs; Issaquah Creek, 82-140 cfs; and Bear Creek, 13-35 cfs; and (2) for rearing--Bear Branch, 25-40 cfs; North Nemah River, 25-50 cfs; Elk Creek, 2.5-60 cfs; North Fork Toutle River, 350-500 cfs; Deschutes River, 40-50 cfs; Dosewallips River, 180-300 cfs; North Fork Stillaguamish River, 110-400 cfs; South Prairie Creek, 8-100 cfs; Issaquah Creek, 25-50 cfs; and Bear Creek, 5.0-8.0 cfs.

INTRODUCTION

Status of Salmon Fisheries

Commercial and sports fishing for salmon in the Pacific Ocean and marine waters in and adjacent to western Washington are major economic enterprises. Commercial salmon fishing in the State is a multimillion-dollar industry, annually taking millions of pounds of salmon, most of which were naturally spawned and reared in the creeks and rivers of western Washington. In 1965 the retail value of the annual commercial catch of salmon in the State was $21.3 million (Puget Sound Task Force, 1970c). It was estimated that by 1967 more than $50 million was being expended annually for sports fishing for salmon in the State. Salmon fishing by charter boat, a sports enterprise along the Washington coast, is alone a multimillion-dollar business.

Projected future population figures for the State indicate an ever increasing demand for salmon as a food and sports fish (Puget Sound Task Force, 1970c). In the past two decades, the increase in number of salmon sports fishermen has been phenomenal; during the past several years the increase has been in direct proportion to the State's population. Each year since 1960, over 10 percent of Washington State residents have fished for salmon in the marine waters. Estimates indicate that the population of the Puget Sound area will more than triple in the next 50 years, and that there will be parallel threefold demand for Pacific salmon both as a sports and commercial fish. Some authorities say that the demand for fresh and frozen salmon should continue to rise at a rate even greater than the increase in population (Crutchfield and MacFarlane, 1968).

While predictions for the future inevitably show increasing demands on the Pacific salmon fisheries, one fact remains virtually the same--there will be no increase in the quantity of water available for natural salmon propagation in Washington State and no increase in the number of creeks and rivers available for salmon spawning and rearing; in fact, there could be a decrease in the number of usable streams. Yet, the availability of sufficient quantities of water suitable for propagation of Pacific salmon is the key to the future of commercial and sports salmon fisheries in the State. Other factors related and essential to salmon production--such as the stream environment, sound watershed management, and advanced technology--will still prove their contributions mainly on the basis of the availability of adequate water resources for salmon spawning and rearing.

Because of population growth, with its indigenous demands and effects on water supplies for various uses, water available for salmon propagation could face increasing competition in the future. In fact, competition on the part of other interests, which affect the water quantity and quality adversely relative to salmon propagation, already exist on certain streams and, in some cases, has existed for many years. Therefore, if natural propagation of Pacific salmon is to be maintained or, in the case of certain species, even preserved, careful planning and proper management will be necessary to insure the allocation of adequate streamflow.

In 1967, with modifications in 1969 and 1971, the State of Washington Department of Ecology received legislative authority to establish certain minimum flows on the State's streams for the protection of the interests of various water-user groups. Among these is the State of Washington Department of Fisheries whose interest is setting minimum flows on certain of the State's streams to ensure adequate discharge for optimum propagation of Pacific salmon.

Salmon Spawning and Rearing

Pacific salmon are anadromous fish which live in the sea but require the fresh waters of creeks and rivers accessible from the sea for the propagation phase of their life cycle. They spawn on the riffles of streambeds, then die. After hatching, the young salmon feed and grow (rear) in the pools and riffles of the streams and return to the sea where they spend the major part of their life cycle. The five species of Pacific salmon found in Washington streams are sockeye (*Oncorhynchus nerka*), chinook (*O. tswytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*), and chum (*O. keta*). This report will deal with sockeye, coho, and chinook (spring and fall). The two races of chinook will be referred to as spring chinook and fall chinook and treated as two separate species.

Pacific salmon use most of the streams in western Washington for reproduction purposes. Most spawning occurs on stream reaches where depth and velocity are favorable to the salmon and where streambed lithology is compatible to the egg-laying and incubation processes. Availability of cover and concealment in the form of overhanging trees, brush, and logs, either on the banks or in the stream, influences the spawning activities (Royce, 1959). Water temperature and the amount of suspended sediment, dissolved oxygen, and dissolved minerals in the water also affect spawning and rearing.

Salmon usually spawn in pool-and-riffle-type streams--streams characterized alternately by relatively level reaches (pools) and relatively steep reaches (riffles). The production of young salmon is highest in streams that have equal areas of pools and riffles (Ruggles, 1966). Pools serve as rearing areas for the young of some species, while riffles provide the spawning areas and can serve also for rearing. Sand is the major streambed material in the pools, and much coarser material makes up the streambed of the riffles.

Purpose and Scope of this Study

This is the third in a series of reports that discuss the most desirable streamflows for spawning and rearing of various salmon species that frequent western Washington streams. This report covers Bear Branch, North Nemah River, Elk Creek, Dosewallips River, Deschutes River, South Prairie Creek, Issaquah Creek, Bear Creek, North Fork Stillaguamish River, and North Fork Toutle River. Smith Creek, a short tributary of Elk Creek, is treated as part of the latter in this report.

Data from 300 sets of measurements of velocity, depth, discharge and water-quality parameters, made at 30 reaches on the 10 streams (fig. 1) were used to ascertain rearing and spawning flows for sockeye, coho, spring and fall chinook salmon.

Methods used for determination of spawning flows were a combination and integration of studies by Rantz (1964), Westgate (1958), and State of Washington Department of Fisheries (Deschamps and others, 1966), plus modifications described in the first report of this series on Washington streams (Collings and others, 1972a).

Previous Studies

Two reports in this series (Collings and others, 1972a and 1972b) have been published or released. The first report presents an analysis of the stream hydraulics as related to salmon spawning and rearing by each of four salmon species on 14 study reaches on four streams. With the same procedures applied as discussed in the first report, the second report covers four additional streams with a total of 12 study reaches. The total study to date (1972), including that discussed in this report, covers 18 streams, 56 study reaches, and 549 cross-section measurements, and required 5 years.

Pink and chum salmon are not discussed in the series of reports because the preferred spawning velocity and depths for these species were not defined until late in the study.

Acknowledgments

This study was made under a cooperative agreement between the U.S. Geological Survey and the State of Washington Department of Fisheries. The assistance of biologists from the Department of Fisheries in selecting river study reaches is gratefully acknowledged. The constructive criticism and suggestions from colleagues S. E. Rantz, research hydrologist, and J. E. Cummans, hydrologist, of the U.S. Geological Survey were of benefit to the final report.

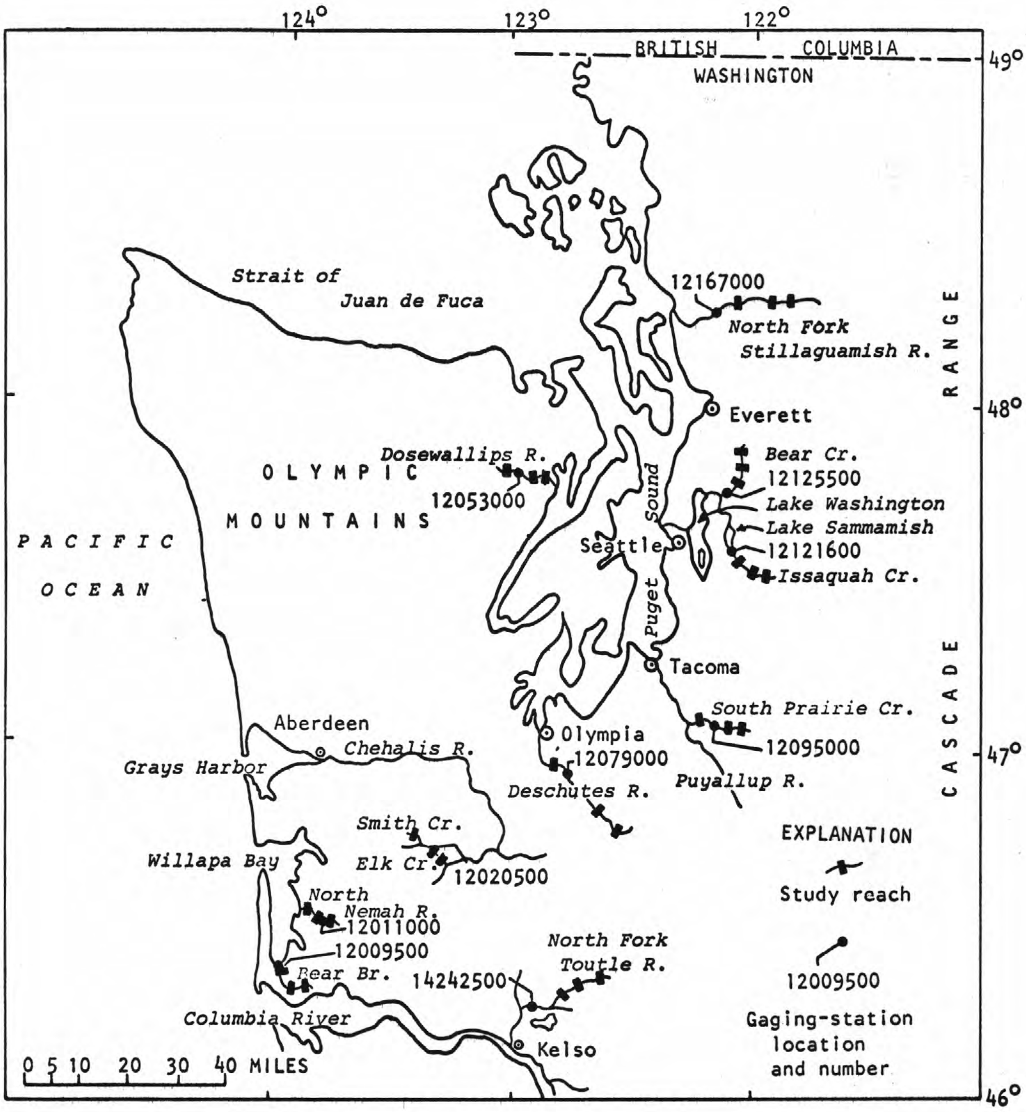


FIGURE 1.--Locations of streams and study reaches investigated in western Washington.

STREAM BASINS STUDIED

Flows required for the protection of salmon propagation are related to the physical and climatic features of stream basins. One objective in selecting the streams for this study was to broaden the representation--over that of the previous studies--of the physical and climatic areas of western Washington by increasing the number of streams sampled. The 10 streams selected represent most of the geographical areas of the State west of the Cascade Range, and range in size from very small creeks originating at low altitudes to large rivers flowing from the high altitudes of the Olympic Mountains and Cascade Range. Variations in forest cover, soils, geology, mean annual precipitation, and land-use patterns also are represented in this study.

The stream basins in western Washington are physiographically divided into three general groups with respect to their termination in the sea. The basin groups comprise streams and their tributaries which flow into (1) the Pacific Ocean, (2) Puget Sound, and (3) large fresh-water lakes adjacent to and accessible to Puget Sound. The streams discussed in this report are representative of all three groups and are discussed accordingly. The official U.S. Geological Survey identification numbers assigned to gaging stations on the streams are shown parenthetically wherever the station sites are mentioned in the report.

Pacific Slope and Lower Columbia River Basins

Bear Branch, North Nemah River, and Elk Creek originate in the Willapa Hills of southwestern Washington (fig. 1), and the North Fork Toutle River begins on the western slope of the Cascade Range. Bear Branch and North Nemah River flow into Willapa Bay, Elk Creek flows into the Chehalis River and North Fork Toutle River flows into the lower Columbia River.

The range of mean annual precipitation in these basins is from 60 to 120 inches, depending generally on altitude. Most precipitation and resulting high streamflows in these basins occur from fall to early spring, whereas the low-flow period occurs in late summer or early fall. The discharge of the North Fork Toutle River includes considerable water from melting snow during spring runoff.

The drainage basins of Bear Branch, North Nemah River and Elk Creek have a similar geology. The basins are underlain generally by marine and (or) nonmarine sedimentary rocks and some volcanic rocks. The upper part of the North Toutle River basin is underlain by volcanic rocks (basalt and breccia) and the lower slopes are underlain by nonmarine and volcanic rocks and some terrace deposits (Huntting and others, 1961).

The soils of these basins are medium to strongly acid, well drained to somewhat excessively drained, and moderately deep, with textures ranging from silty clay loam to stony loam. An imperfectly drained, strongly acid, silty clay loam is found in the lower part of the Bear Branch basin (U.S. Department of Agriculture, 1968).

Coniferous forests, interspersed with stands of deciduous trees--alder, big leaf maple and vine maple--cover more than 95 percent of these basins. The coniferous forests are mainly commercial timberlands where timber harvesting is likely to be perpetual in various parts of each basin; during the study period, logging was observed on the slopes of all four basins. The nonforested land in the downstream parts of each basin is mostly nonagricultural.

All four streams have runs of fall chinook and coho salmon, Bear Branch and North Nemah River have runs of chum, and only Elk Creek has a run of spring chinook. Artificial propagation of coho and chinook is facilitated at the State of Washington Department of Fisheries hatcheries on North Nemah River and the main stem of the Toutle River.

Basins Drained Directly to Puget Sound

The Deschutes, Dosewallips, and North Fork Stillaguamish Rivers and South Prairie Creek, all in the Puget Sound basin, flow either directly into Puget Sound or are tributaries to streams that flow directly to the Sound. Except the Dosewallips River, which flows from the Olympic Mountains, all have their sources on the western slope of the Cascade Range. Source altitudes for all four streams are above 3,000 feet.

The mean annual precipitation in the North Fork Stillaguamish and Dosewallips River basins ranges from about 40 to 50 inches at the lower altitudes to about 120 inches at the highest altitudes. The precipitation in the South Prairie

Creek and Deschutes River basins ranges from about 40 inches on the lower slopes to about 80 inches on the upper slopes. Most of the precipitation occurs from fall to early spring. The low-flow period is always in late summer or early fall. The discharge of each of the four streams, except that of the Deschutes River, consists partly of snow or glacial melt water during the spring and early summer. The Dosewallips River is partly fed by a glacier in the Olympic Mountains.

The mountainous parts of the basins of the North Fork Stillaguamish River, South Prairie Creek, and Deschutes River basins are underlain mainly by extrusive volcanic rocks, with the valley bottoms and lowlands being underlain by alluvium and glacial drift--till and advance and recessional outwash. The upper Dosewallips River basin is underlain by sedimentary rocks while the middle and lower parts of the basin are underlain mainly by extrusive volcanic rocks (Huntting and others, 1961).

Soils on the steeper slopes are shallow to deep, medium to extremely acid, stoney loams. Lower slopes have moderately deep to deep, somewhat excessively drained to imperfectly drained, medium to strongly acid soils. Texture ranges from clay loams to gravelly sandy loams (U.S. Department of Agriculture, 1968; Anderson and others, 1947).

With the exception of the Deschutes River basin, more than 90 percent of the land is covered by coniferous forests interspersed with deciduous alder and maple trees. The Deschutes basin has more open land than do the other basins, with about 78 percent forest land and about 22 percent cropland, rangeland, or nonagricultural land. Large parts of the forested areas are commercial timberlands.

The streams have some combination of two or more of the five species of Pacific salmon. The North Fork Stillaguamish River has spring and fall chinook, coho, pink, chum and a few sockeye; the Dosewallips River has runs of spring chinook, coho, pink and chum; South Prairie Creek has fall chinook, coho, pink and sockeye; and the Deschutes River has only fall chinook and coho to any degree. There are no fish hatcheries on any of these streams.

Basins Drained to Lakes Adjacent and Accessible to Puget Sound

Issaquah Creek and Bear Creek (fig. 1) are in the Sammamish River basin, and flow indirectly into Lake Washington, a fresh-water lake accessible to Puget Sound. Issaquah Creek flows into the south end of Lake Sammamish. Bear Creek flows into the Sammamish River about 1 mile upstream from the latter's entry into Lake Washington. The source of Issaquah Creek is in the foothills of the Cascade Range, while Bear Creek originates on the glacial drift plain below the mountains.

Mean annual precipitation ranges from 30 to 40 inches in the Bear Creek basin and from 50 to 80 inches in the Issaquah Creek basin. Most precipitation occurs from fall to early spring, and the low-flow period is from late summer to early fall.

Almost all of the Bear Creek basin and the lower part of the Issaquah Creek basin are underlain mainly by glacial drift consisting of till, sand and gravel, and some stratified clay and silt. The mountainous parts of the Issaquah Creek basin are underlain by volcanic rocks, mostly andesite flows, and breccia (Huntting and others, 1961).

Soils in both basins are moderately deep to deep, imperfectly drained to excessively drained, and medium in acidity. Soil texture consists of sandy loam and silt loam formed from glacial material. Soils on the upper slopes of the Issaquah Creek basin range in texture from gravelly sandy loam to stoney loam (Poulson and others, 1952).

Only about 44 percent of the Bear Creek basin is forested--mostly scattered stands of coniferous trees interspersed with deciduous alder and maple trees. About 25 percent of the basin is nonagricultural land and the remainder comprises urban and suburban developments, roads, and railroads. The Issaquah Creek basin is divided into the following approximate land-use proportions: 65 percent second-growth coniferous and deciduous forests, 10 percent crop and pasture land, 10 percent rural, nonagricultural land and 15 percent is culturally developed. There is very little commercial timber harvesting in either basin.

Fall chinook, coho, and sockeye salmon utilize both Issaquah Creek and Bear Creek. The State of Washington Department of Fisheries operates a salmon hatchery on Issaquah Creek at the town of Issaquah.

APPROACH, METHODS, AND DEFINITIONS

Selection of Sites

Time, budget, and manpower are constraints that limited the amount of data that could be collected and the number of rivers and study reaches that could be investigated. Therefore, the selection of streams for this study was based on (1) knowledge that the streams are currently natural habitats for salmon propagation; (2) geographic location of the stream--streams were selected so that an adequate spatial sample could be obtained; (3) stream size and flow characteristics--small, medium and large streams were selected; and (4) feasibility of future water-resources developments--streams on which water-related projects were potentially feasible or imminent were given priority.

For a more complete representation of each stream, to lessen the possibility of a selected site being unique, three study reaches were investigated on each of the 10 streams. The following rules were observed for the reach selections: (1) salmon spawning activity must have been observed in the reach, (2) the reach must have a fairly stable streambed to enable sampling over a range of flows without major streambed shifting, and (3) the environment of the streambanks and the channel and reach configurations must be representative of a much longer section of the stream.

With the aid of a biologist from the State of Washington Department of Fisheries, a reconnaissance was made of each stream and five to 15 potential sites usually were selected. Then, from a more intense additional investigation of these sites, three reaches were selected.

Physical Characteristics

The lengths of the reaches selected averaged about twice the width of the stream, and usually started in a pool and extended over a riffle. On each reach four equally spaced cross sections were established, and the reach, including some features of the littoral area, was mapped in detail by plane-table methods. The top of the channel sides at each reach was selected as representing the river stage at which the water first overflows the natural banks.

Basin and stream-channel indices, which are related to the flow characteristics of the stream and which partly describe the stream environment, were computed for each of the selected reaches. The basin indices include (1) drainage area, (2) length of the main stem of the channel from the source to the reach, (3) mean altitude of the basin upstream from the reach, and (4) slope of the main channel--computed from the distance and elevation between points on the river 10 and 85 percent of the total stream length above the reach. The stream-channel indices computed included (1) altitude of the reach, (2) wetted perimeter based on the average of four cross sections, (3) average channel width, (4) average channel depth, and (5) bank-full area--the area of the water surface of the reach at bank-full stage.

There are many physical characteristics of a stream channel that influence its potential and desirability for salmon rearing. These characteristics include (1) an adequate volume of water in the stream, (2) the depth and velocity of this water, (3) water temperature, (4) the rock and gravel sizes for habitats of bottom-dwelling organisms, (5) natural-food availability and production in the stream, and (6) the cover of the reach by brush, logs, and other material.

In studies of coho rearing in artificial test reaches, Ruggles (1966) concluded that fish prefer the pool environment but fish production is higher in the "riffle-like" environment. The most productive stream would be one with a channel having equal areas of pools and riffles. In his artificial test reaches, Ruggles found that the greatest number of coho were produced in a reach having water depths ranging from 0.8 to 2.5 feet and water velocities ranging from 0.2 to 0.6 fps (foot per second). Ruggles also found that the young fish tend to avoid shaded areas.

Kennedy (1967), in a study of fishfood abundance in a California stream, found that the greatest number of organisms occurred with water velocities between 1.0 and 1.2 fps and in depths between 0.25 and 0.5 foot. He also concluded that "apparently the combination of medium-sized and large rocks provided better niches for the small insects***[and] the substrata [streambed material] size was the critical factor."

Water-Quality Characteristics

Data on water temperature, DO (dissolved oxygen) concentration, suspended sediment, and specific conductance were collected during each visit to a study reach. These characteristics generally are significant factors related to the ability of salmon to propagate in the stream. The data are pertinent because they are measurements of conditions that existed in the stream when salmon were successfully utilizing the stream waters. Thus, by documenting water-quality information now, criteria are obtained to aid in possible future determination of water-quality standards for salmon.

Stream temperatures influence (1) the rate of food production for young salmon, (2) the amount of oxygen in the water, and (3) the length of time needed for salmon-egg hatching. Water temperature also is related to a salmon's resistance to disease and toxic materials in the water. Below are listed some water-temperature ranges desirable for Pacific salmon activities in streams, as defined by Burrows (1963):

Upstream migration:	7.2° to 15.6°C (45° to 60°F)
Spawning activity:	5.8° to 12.8°C (42.5° to 55°F)
Egg incubation:	0° to 12.8°C (32° to 55°F)
Development of the young:	10° to 15.6°C (50° to 60°F)

Thermographs were installed--usually at a gaging station--on each stream to obtain a continuous record of water temperatures. Water temperatures also were measured with hand-held thermometers at every reach during every visit. The thermograph record was evaluated by subjecting the data to a harmonic analysis (Collings, 1969); the results are shown by means of a time-temperature graph. (For an example, see fig. 8.) The type equation for the harmonic analysis is

$$T = \bar{T}+A[\sin(\underline{\underline{bx}}+C)] \quad ,$$

where T is the water temperature, $\bar{T}$ is mean temperature for the year, A is the amplitude of the curve measured above and below $\bar{T}$, x is the calendar-year day on which the temperature occurs, b is a constant equal to $2\pi/365$ or 0.0172 radians per day, and C is the phase coefficient in radians. The magnitude and day of occurrence of the highest and lowest temperatures for the year are where T is equal to $\bar{T}+A$ when x is equal to $[(3/2\pi-C)]/b$, and where T is equal to $\bar{T}-A$ when x is equal to $(\frac{1}{2}\pi-C)/b$, respectively.

DO in the water is necessary for the existence of all aquatic animals. Limited amounts of oxygen will limit migration, spawning, reproduction, hatching and survival of young salmon. The absence of DO would completely destroy salmon utilization of a stream. The DO concentration was at or near 100-percent saturation at all stream reaches studied. Variations in DO concentration at a particular reach were mainly the result of water-temperature changes, and variations in DO concentration between reaches or streams were mainly the result of altitude differences. Both temperature and altitude are factors related to the ability of water to hold oxygen in solution.

One of the most severe consequences of high concentrations of suspended sediment in salmon-producing streams is the deposition of fine sediment on and between streambed gravels during the egg-incubation period. Sufficient deposition of fine-textured sediment could partially or totally prevent oxygen-laden water from circulating around the eggs, thereby minimizing the chances of survival.

Specific conductance is a measure of the ability of water to conduct an electric current and therefore is related to the ionic or dissolved mineral concentration in the water. Specific conductance is inversely related to stream discharge, that is, as discharge increases specific conductance decreases, indicating a dilution of the soluble inorganic chemical constituents that are in ionic form. High values of specific conductance--higher than those documented during this study--may indicate stream pollution and may diminish salmon-spawning success in the stream.

Streambed Gravel

Streambed material of the spawning areas must consist of gravel of such size that each individual species can excavate redds for egg deposition, fertilization, and hatching. The size of the gravel also determines the amount removable by the stream at various velocities; the larger the gravel, the faster the current required. However, if the velocity is too fast, the eggs will be washed downstream. Immediately after the eggs are deposited and fertilized, the salmon move some gravel into the redds to cover the eggs. Thereafter, a continuous circulation of water through the gravel and over the eggs is required to ensure successful hatching. Therefore, the gravel must be large enough to provide the interstices needed for this circulation (Rantz, 1964).

No attempt was made to establish or test criteria for specific preferred streambed lithology. As each selected study reach was an observed spawning reach, the assumption was made that if salmon are utilizing the stream's reach for spawning, the streambed material must be acceptable.

The ranges of gravel sizes on each of the 30 study reaches were documented by a size analysis of four or five 50- to 80-pound samples collected from each reach. The streambed samples were obtained with a cylindrical tooth-edge "cookie cutter" 2 feet in length and 14 inches in diameter, patterned after that described by Rantz (1964, p. AA5). The cylinder was forced into the streambed as far as possible (usually 1 to 1.5 ft), the material within was removed by hand and sorted in sieves, and each fraction was weighed.

Streamflow Characteristics

The characteristics defining the variations in streamflow with time are determined from records of river stage and discharge, which are influenced by the stream's drainage basin and its climatic environment. For each of the streams studied monthly frequency distributions of streamflow were computed to show the seasonal magnitudes of flow, and probable ranges in these magnitudes. (For example, see fig. 9.)

The time of occurrence of flows of certain magnitudes governs the period of utilization and degree of success a particular salmon species may have in propagating in the stream. Figure 2 shows the approximate periods of stream utilization by various salmon species for each of the study streams.

Each stream investigated in this study has a streamflow-gaging station with a long-term discharge record and, in most cases, a current stage-discharge relation. The discharge at each study reach was related to the discharge at the stream's gaging station by regression analyses, resulting in a simple regression model of known accuracy for each reach.

The regression models were statistically tested for linearity in each case and the models were compared by analysis of covariance between reaches on the stream to determine if (1) one model would adequately fit the discharges for more than one reach, (2) the flow at one or more reaches was the same as at the long-term gage, and (or) (3) flows at two or more reaches were statistically the same.

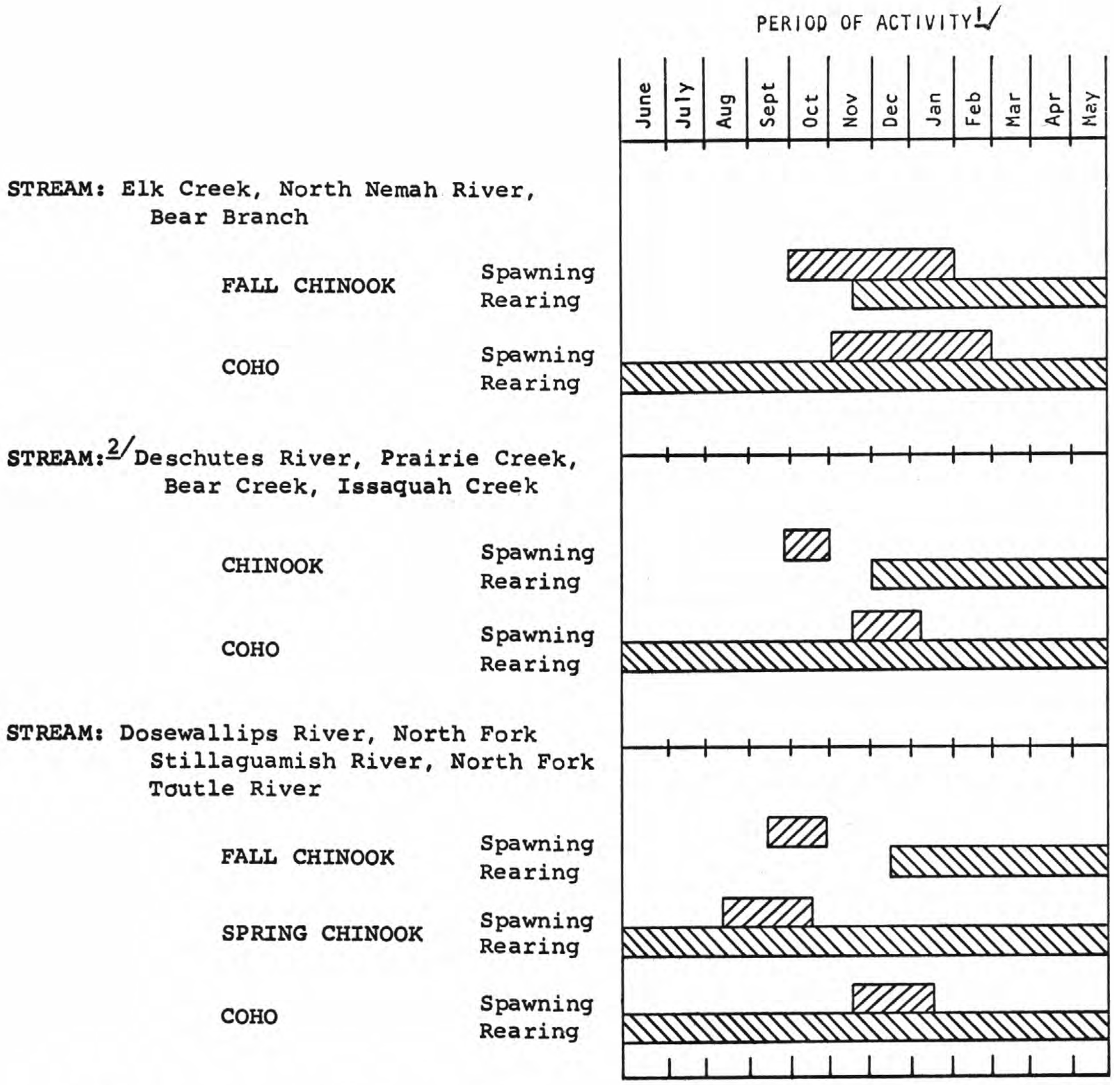
In each case, streamflow records at the gaging stations were of sufficient duration to allow confident definition of the statistical characteristics of the streamflow at these stations. The flow characteristics were defined by determining the mean monthly frequency distributions of flow that show the probability (in percent) of occurrence and magnitude of flows for each month of the year. (For example, see fig. 9). In turn, by using the regression models of the study reaches, the magnitude and probable occurrence of the stream discharge at a study reach can be estimated. For example, the question is posed: What is the magnitude of the stream discharge that will occur 50 percent of the time, on the average, during October at reach A on Bear Branch? From figure 9 the discharge that has a 50-percent probability of occurrence at the gaging station is 62 cfs (cubic feet per second). The regression model between discharges (Q, in cfs) at reach A (Q_A) and discharges at the gage (Q_G) is

$$Q_A = 0.68(Q_G)^{1.03} \quad .$$

With Q_G equal to 62 cfs, the model becomes

$$Q_A = 0.68(62)^{1.03}$$

and Q_A equals 48 cfs (rounded value)--the 50-percent-probability of flow occurrence in October at reach A.



1/ Modified from Bell (1967, p. D-111-1,5).

2/ Sockeye spawning periods are poorly documented; however, from a literature search the general consensus seems to place it from midsummer until late fall. Sockeye rearing usually occurs in fresh-water lakes to which the spawning streams are tributary.

FIGURE 2.--Periods of river utilization by salmon for spawning and rearing.

Of course, the model also can be used to determine the probability of occurrence of a given discharge at reach A. For example, to determine the probability of occurrence of 20 cfs in September at reach A, on Bear Branch, the equation is solved for Q_G, as

$$Q_G = (Q_A/0.68)^{\frac{1}{1.03}}$$

and, substituting 20 for Q_A,

$$Q_G = (20/0.68)^{\frac{1}{1.03}}, \text{ or } 27 \text{ cfs.}$$

Therefore, 27 cfs will occur at the gaging station with the same probability that 20 cfs will occur at reach A--that is, about 34 percent of the time, on the average, 27 cfs at the gaging station and 20 cfs at reach A will be equaled or exceeded (fig. 9).

Determination of Spawning Discharge

Studies by Chambers, Allen, and Pressey (1955) have shown that each salmon species prefers specific ranges in water depth and velocity (table 1). The preferred hydraulic conditions are used to determine the area of a study reach that is preferred for spawning at various discharges.

Stream-discharge, preferred-depth, and preferred-velocity data were collected on each stream study reach after the selection and mapping of the reach had been accomplished. For each discharge measured, the water depth and velocity were measured at 10 to 25 points on each of the four cross sections of the reach. These data, in conjunction with data on the ranges of preferred-depth and preferred-velocity criteria (table 1), were used to determine the area of the reach preferred for spawning (spawnable area in fig. 3).

The discharge at which the greatest area of spawning occurred (preferred spawning discharge) was determined from a number of measurements at various discharges and computations of the areas preferred for spawning at each discharge. These data then were plotted to form a curve representing spawnable area versus discharge for each species. As discharge in the low-water channel increases beyond that preferred for spawning, the area of preferred velocity and (or) depth becomes less and the amount of area preferred for spawning decreases. When water depth increases sufficiently to barely cover a medium river-stage berm, the area of preferred spawning increases sharply. The sequence may be repeated as the river stage (discharge) continues to increase, depending on the number of berms that progressively become submerged. However, if a much longer reach were being considered, not all berms would become submerged at the same time, and consequently, the tendency would be for a smoother curve for spawnable area versus discharge. This smoother, more realistic, curve was obtained by trend fitting with a moving parabolic arc (Whittaker and Robinson, 1932).

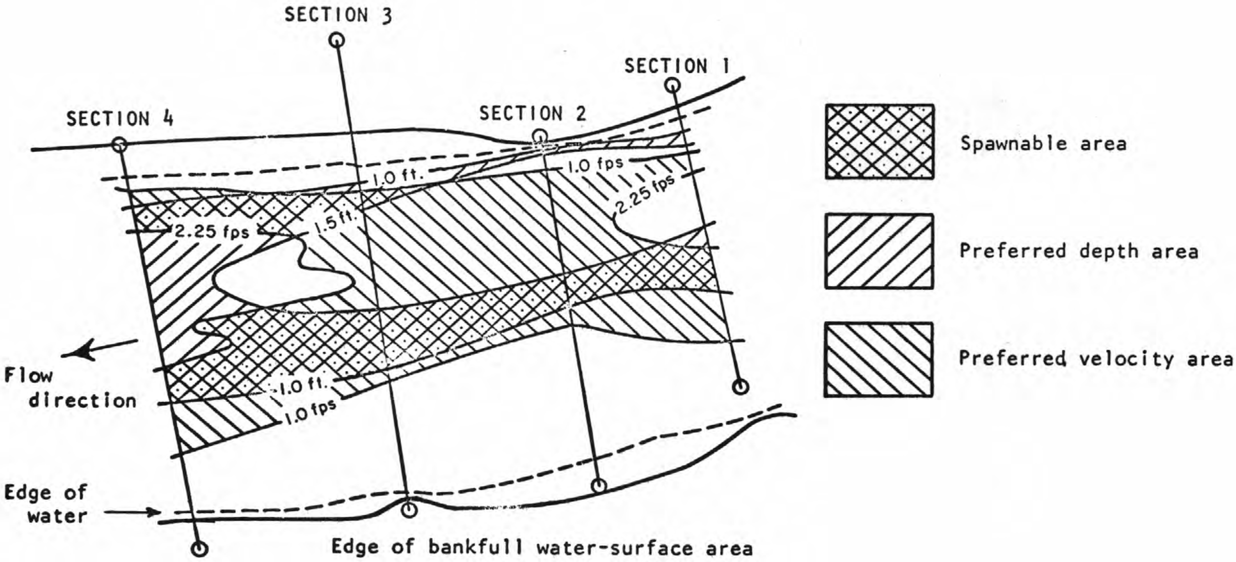
From the trend-fitted curve for spawnable area versus discharge the preferred spawning discharge was chosen, as shown in figure 4, at a location on the curve where the greatest spawnable area occurred.

TABLE 1.--Ranges of depth and velocity preferred by spawning salmon[1]

Salmon species	Depth (ft)	Velocity[2] (fps)
Fall chinook	1.0-1.5	1.0-2.25
Spring chinook	1.5-1.75	1.75-2.25
Sockeye	1.0-1.5	1.75-1.8
Coho	1.0-1.25	1.20-1.80

[1]From Chambers, Allen, and Pressey (1955), except for sockeye velocity which is from Clay (1961, p. 232).

[2]Measured 0.4 foot above streambed.



RESULTS:

Discharge 94.6 cfs.
Preferred depth area 1045 ft^2, between 1.0 -1.5 ft.
Preferred velocity area 1706 ft^2, between 1.0 -2.25 fps.
Area preferred for spawning 726 sq. ft.

FIGURE 3.--Example of method used for determining area of reach preferred for spawning at a given discharge, as shown for fall chinook at study reach B on North Nemah River.

The original measurements of areas of preferred spawning depth and preferred spawning velocities were also trend fitted for each species and each reach, and plotted against discharge. These two additional curves are shown with the appropriate trend-fitted curves for spawnable area versus discharge. (For example, see fig. 10.)

Determination of Rearing Discharge

In the natural-flow streams studied, spawning begins (fig. 2) at approximately the same time the discharge begins to increase--and river stage begins to rise. Thus, the likelihood of the salmon redds being either exposed or out of the water altogether during the incubation period is minimized. About 45 days after spawning--depending on water temperatures--the salmon eggs hatch and the young fish remain in the stream

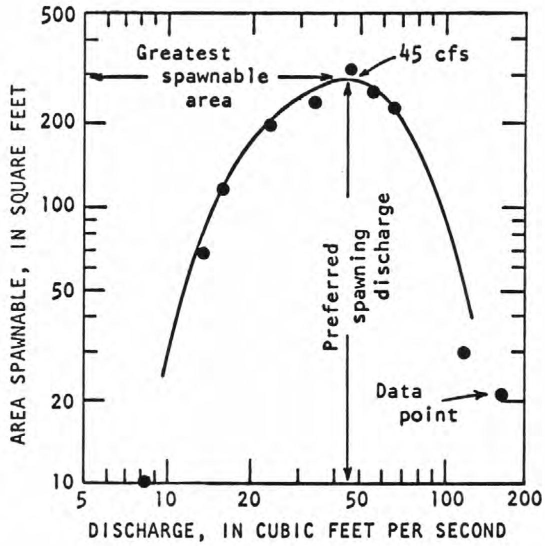


FIGURE 4.--Example of trend-fitted curve, showing method used for selecting preferred spawning discharge, for fall chinook at study reach A on North Nemah River.

for a length of time that differs with various species. For example, young fall chinook stay in the stream from about 4 to 6 months, or into midspring (fig. 2), and migrate to salt water before the low-flow period in late summer or early fall. However, some salmon species spend the entire year rearing in fresh water. Young coho stay in the stream the entire year and are present during the lowest flow period. Under natural conditions, this period may be one of the limiting factors for salmon productivity in some streams.

More studies and more definite criteria, especially for natural streams in Washington, are needed to establish the discharges most preferred for salmon rearing. However, it is logical to assume that an adequate volume of water would be one of the most important--if not the most important--conditions necessary for salmon rearing in a stream.

A relation between wetted perimeter and discharge (fig. 13, p. 45) shows that wetted perimeter--the wetted part of the perimeter of the cross section that is in contact with the stream--increases very rapidly for only a small increase in discharge, starting from a low discharge to a point where the width at the water surface does not increase rapidly. Beyond this point the wetted perimeter increases less rapidly as the discharge increases. Ideally the quantity of water preferred by the salmon for rearing would be available somewhere near the change in direction of the curve of wetted perimeter versus discharge. A curve of water-surface area as a percentage of bankfull area versus discharge for each reach also is given in this report (fig. 13, for example) to aid in selection (in some cases) of the breaking point on the curve for wetted perimeter versus discharge.

To evaluate the chosen rearing discharge and to supply the alternative of using the depth and velocity criteria of either Ruggles (1966) or Kennedy (1967), or both, to evaluate decisions regarding rearing flows,families of curves similar to those in figure 14 are given for each study reach discussed in this report. From these curves the area of the study reach containing specified velocities and depths can be determined for a selected discharge.

From the wetted perimeter-discharge curve a determination was made of the most preferred rearing discharge relative to the stream-channel configuration. However, the actual or natural limiting discharge for salmon that rear the year around in the stream probably would be a minimum discharge that occurs during the month with the lowest flow of the year.

GENERAL EVALUATION OF SPAWNING AND REARING DISCHARGES

The crest shape of the curve for spawnable area versus discharge indicates the resulting effect of a decrease from the preferred spawning discharge. A broad crest indicates that a sizable decrease from the preferred spawning discharge may decrease the spawnable area only slightly, whereas a sharp crest indicates that even a small decrease from the preferred spawning discharge may decrease the spawning area significantly. To show these curve characteristics for each study reach and each species, tables 2 through 11 present spawning discharges, spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions of discharge.

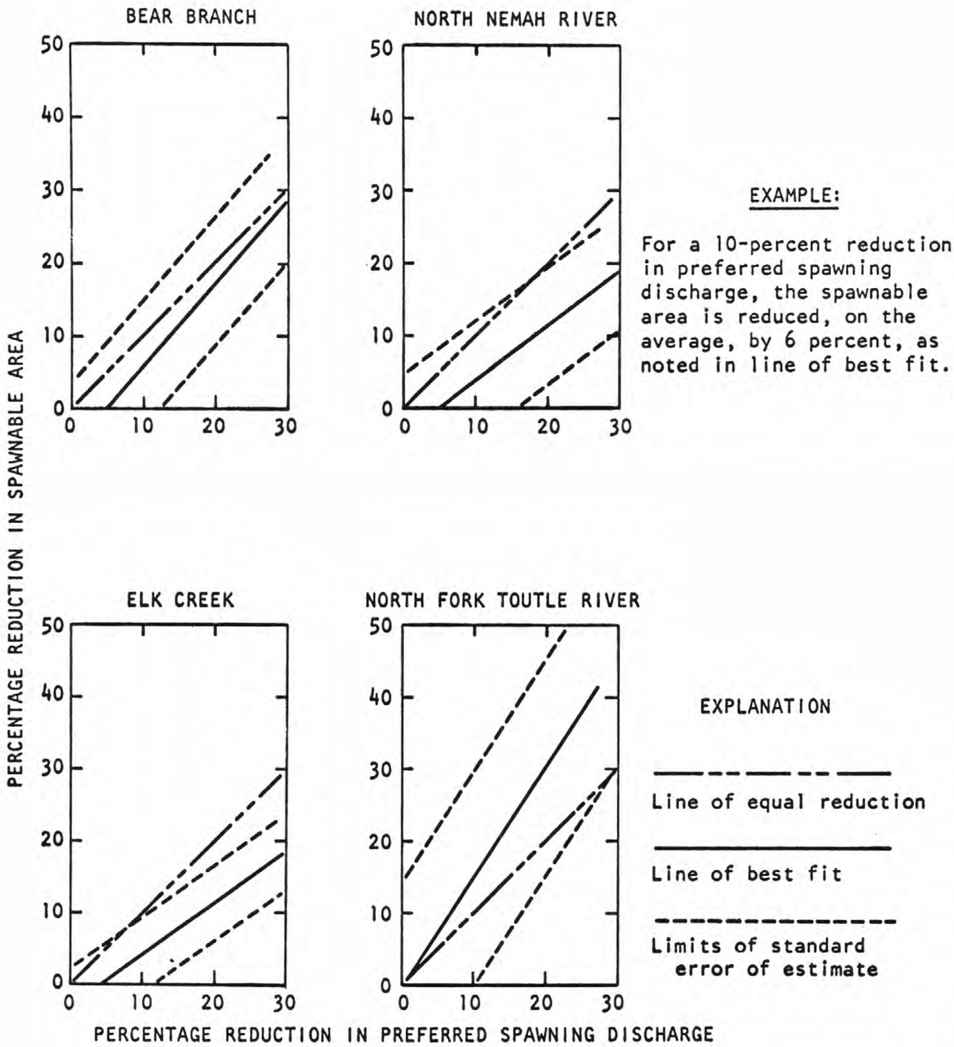


FIGURE 5.--Relations between selected percentage reductions in discharge and comparable percentage reductions in spawnable area, for all reaches and all species on Bear Branch, North Nemah River, Elk Creek, and North Fork Toutle River.

For a general evaluation of the curves of spawnable area versus discharge for all reaches and all species on each river, the percentage reductions of preferred spawnable area were plotted against the percentage reductions in discharge (figs. 5-7). These relations may be useful in determining the effect upon spawnable area of slight differences in regulated discharge. The sets of regression lines show the following three possibilities that can occur, and give a general insight about

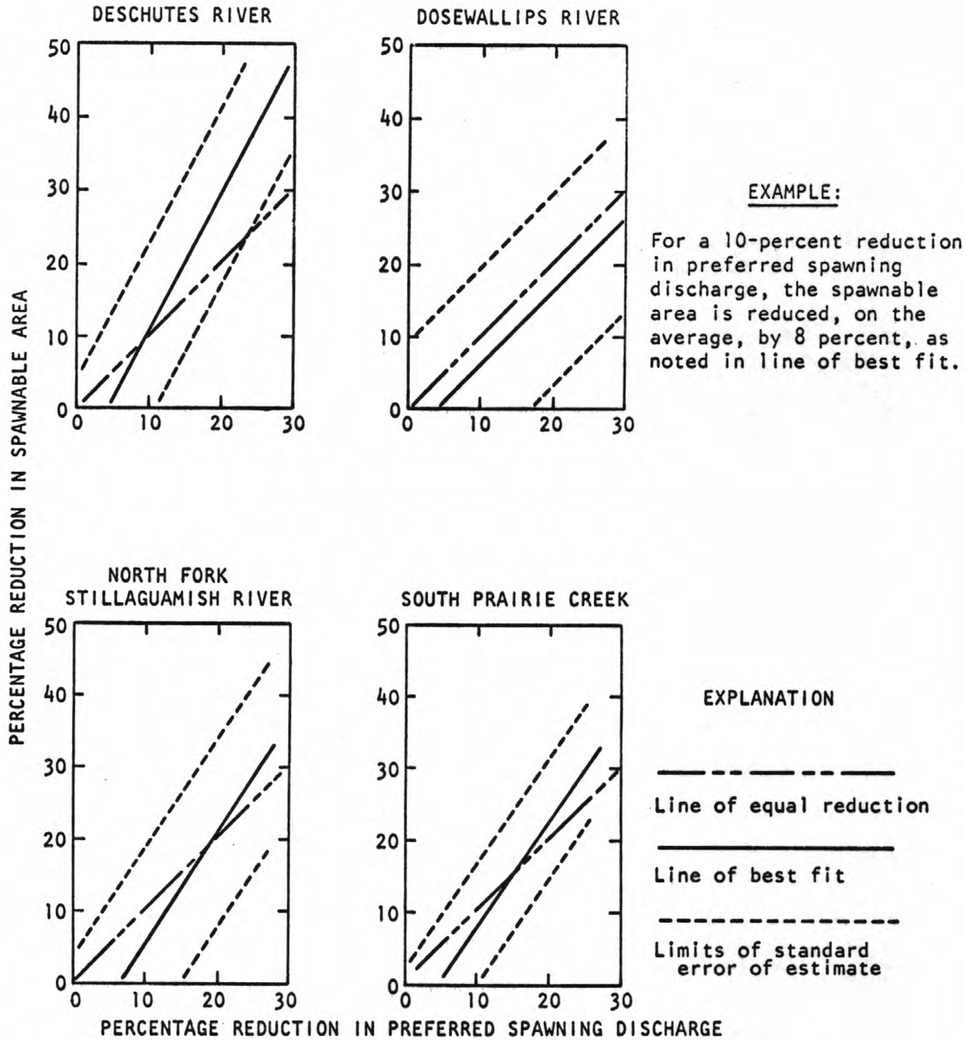


FIGURE 6.--Relations between selected percentage reductions in discharge and comparable percentage reductions in spawnable area, for all reaches and all species on the Deschutes, Dosewallips, and North Fork Stillaguamish Rivers, and South Prairie Creek.

the shape of an average curve of spawnable area versus discharge for the river. (1) The line of best fit crosses the line of equal reduction (for example, fig. 7 for Bear Creek). The part of the line of best fit below and to the right of the line of equal reduction shows a smaller reduction in spawnable area than in spawning discharge. The average curve for spawnable area versus discharge would have a broad section at the crest before steepening. (2) The line of equal reduction and the line of best fit area parallel (for example, fig. 6 for Dosewallips River). It is apparent that, over the

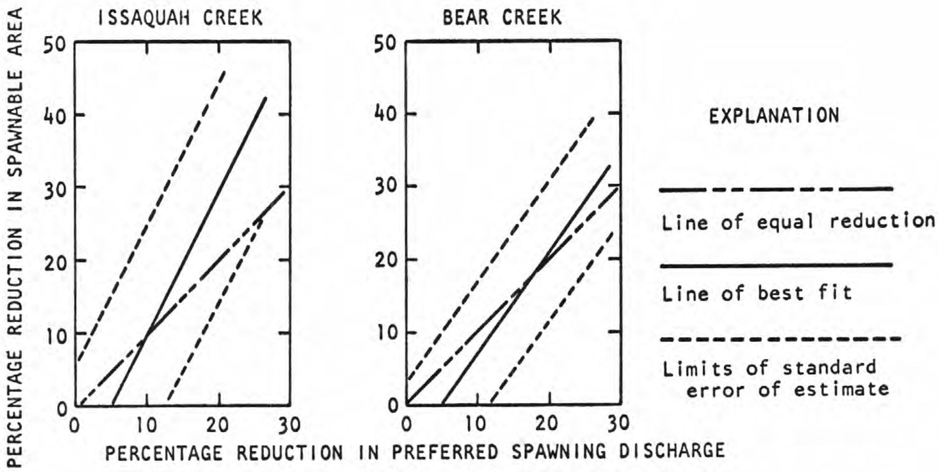


FIGURE 7.--Relations between selected percentage reductions in discharge from the preferred spawning discharge and comparable percentage reductions in spawnable area, for all reaches and all species on Issaquah and Bear Creeks.

reduction range shown, the reduction in discharge will always be greater than the spawnable-area reduction because the line of best fit is to the right of the line of equal reduction. The average curve of spawnable area versus discharge would have a broad crest. (3) The line of best fit and the line of equal reduction have the same origin (both starting at zero) and the line of best fit is always to the left of the line of equal reduction (for example, fig. 5 for North Fork Toutle River). The discharge reduction is always less than the spawnable-area reduction and an average curve of spawnable area versus discharge for the river would have a sharp crest. Such information is especially useful in reaches where discharge during the spawning period is entirely, or almost entirely, subject to regulation.

For naturally occurring streamflow conditions the preferred discharges selected for spawning seem reasonable. As natural flow begins to increase, during the beginning of winter precipitation, salmon spawning also begins. About the time of maximum river utilization by spawning salmon the preferred spawning discharges usually occur. In addition, the chance of the redds of early spawners being out of the water is minimized because the increasing river discharge covers an increasingly larger part of the channel.

Rearing conditions in some streams may be a limiting factor on production of some salmon species. The rearing discharges selected as preferred--the basis of channel configuration only--lack several aspects that make confidence in them somewhat less than complete. First, the study reaches were selected because of their desirability as spawning reaches and not as areas for rearing, and second, the existing hydrologic information and criteria on what constitutes a good natural rearing area is neither satisfactory nor usable in this type of study. The minimum flow available year around may be a natural limit on the number of salmon that can rear in a stream. However, the preferred rearing discharges selected tend to be greater than the naturally occurring 50-percent-probability discharges during the month of the year with the lowest flow.

TABLE 2.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, Bear Branch

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	54	51	49	46	40	66	63	59	56	50	85	81	76	72	64
	Area[2]	1,170	1,160	1,130	1,090	960	1,390	1,370	1,250	1,180	950	1,400	1,390	1,360	1,310	1,180
	Percentage reduction in area	--	1	3	7	9	--	1	10	15	32	--	1	3	6	16
Sockeye	Discharge	58	55	52	49	44	69	66	62	59	52	115	109	104	98	86
	Area	77	75	68	51	40	89	88	87	85	74	81	81	80	80	79
	Percentage reduction in area	--	3	12	34	48	--	1	2	4	17	--	0	1	1	2
Spring chinook	Discharge	[3](125)	(119)	(112)	106	94	(135)	(128)	(122)	(115)	101	(135)	128	122	115	101
	Area	(340)	(335)	(320)	295	240	(208)	(205)	(201)	(195)	155	(320)	300	280	235	170
	Percentage reduction in area	--	1	6	13	29	--	1	3	6	25	--	6	12	27	47
Coho	Discharge	41	39	37	35	31	47	45	42	40	35	70	66	63	60	52
	Area	420	418	410	395	340	505	500	495	480	400	365	360	355	350	310
	Percentage reduction in area	--	0	2	6	19	--	1	2	5	21	--	1	3	4	15

[1]Discharge in cubic feet per second.

[2]Area in square feet.

[3]Values in parentheses are extrapolated.

TABLE 3.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, North Nemah River

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	45	43	40	38	34	95	90	86	81	71	60	57	54	51	45
	Area[2]	292	290	285	280	260	757	750	740	720	670	290	289	287	282	265
	Percentage reduction in area	--	1	2	4	11	--	1	2	5	11	--	0	1	3	9
Sockeye	Discharge	48	46	43	41	36	94	89	85	80	70	70	66	63	60	52
	Area	16	16	16	15	14	68	67	65	63	57	34	34	34	34	34
	Percentage reduction in area	--	0	0	6	12	--	1	4	7	16	--	0	0	0	0
Spring chinook	Discharge	54	51	49	46	40	150	142	135	128	112	180	171	162	153	135
	Area	74	72	66	54	30	263	258	253	245	225	127	127	126	117	100
	Percentage reduction in area	--	3	11	27	59	--	2	4	7	14	--	0	1	8	21
Coho	Discharge	31	29	28	26	23	94	89	85	80	70	46	44	41	39	34
	Area	79	79	78	77	75	247	245	240	230	213	97	96	95	94	88
	Percentage reduction in area	--	0	1	3	5	--	1	3	7	14	--	1	2	3	9

[1]Discharge in cubic feet per second.

[2]Area in square feet.

TABLE 4.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, Elk Creek basin

Salmon species	Preferred parameter	Reach A[3]					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	7.5	7.1	6.8	6.4	5.6	72	68	65	61	54	60	57	54	51	45
	Area[2]	230	230	230	230	225	1,500	1,500	1,500	1,450	1,300	410	410	405	400	380
	Percentage reduction in area	--	0	0	0	2	--	0	0	3	13	--	0	1	2	7
Sockeye	Discharge	9.0	8.6	8.1	7.6	6.8	77	73	69	65	58	220	209	198	187	165
	Area	19	19	18.5	17	15	860	860	850	840	780	35	35	34	33	31
	Percentage reduction in area	--	0	3	10	21	--	0	1	2	9	--	0	3	6	11
Spring chinook	Discharge	9.0	8.6	8.1	7.6	6.8	170	162	153	144	128	220	209	198	187	165
	Area	86	83	75	65	56	200	200	200	195	180	70	69	67	64	55
	Percentage reduction in area	--	3	13	24	35	--	0	0	2	10	--	1	4	8	21
Coho	Discharge	6.5	6.2	5.8	5.5	4.9	54	51	49	46	40	250	238	225	212	188
	Area	150	145	140	135	125	620	620	610	600	500	135	133	130	128	115
	Percentage reduction in area	--	3	7	10	17	--	0	2	3	19	--	1	4	5	15

[1]Discharge in cubic feet per second.

[2]Area in square feet.

[3]On tributary Smith Creek; preferred discharge and area are based on preferred velocity determinations only.

TABLE 5.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, North Fork Toutle River

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	400	380	360	340	300	290	276	261	246	218	570	542	513	484	428
	Area[2]	5,550	5,400	5,000	4,900	--	2,650	2,550	[3](2,200)	--	--	10,000	9,900	9,800	9,700	9,200
	Percentage reduction in area	--	3	10	12	--	--	4	(17)	--	--	--	1	2	3	8
Sockeye	Discharge	390	370	351	332	292	300	285	270	255	225	600	570	540	510	450
	Area	680	540	540	540	480	250	245	(190)	(40)	--	1,060	1,035	960	860	520
	Percentage reduction in area	--	21	21	21	29	--	2	(24)	(84)	--	--	2	9	19	51
Spring chinook	Discharge	480	456	432	408	360	345	328	310	293	259	680	646	612	578	510
	Area	1,430	1,420	1,400	1,200	680	875	855	810	670	(530)	2,620	2,590	2,490	2,250	1,600
	Percentage reduction in area	--	1	2	16	52	--	2	7	23	(39)	--	1	5	14	39
Coho	Discharge	380	361	342	323	285	300	285	270	255	225	390	370	351	332	292
	Area	1,190	900	740	705	--	1,020	970	640	(450)	--	3,520	3,480	3,270	2,500	--
	Percentage reduction in area	--	24	38	41	--	--	5	37	(56)	--	--	1	7	29	--

[1]Discharge in cubic feet per second.

[2]Area in square feet.

[3]Values in parentheses are extrapolated.

TABLE 6.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, Deschutes River

		Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
Salmon species	Preferred parameter	0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	145	138	130	123	109	100	95	90	85	75	145	138	130	123	109
	Area[2]	4,000	3,800	3,500	3,200	2,650	1,590	1,585	1,550	1,510	1,370	10,000	9,700	9,400	8,800	7,400
	Percentage reduction in area	--	5	12	20	34	--	0	3	5	14	--	3	6	12	26
Sockeye	Discharge	165	157	148	140	124	140	133	126	119	105	170	162	153	145	128
	Area	500	495	470	350	220	247	240	180	140	108	900	880	850	810	610
	Percentage reduction in area	--	1	6	30	56	--	3	27	44	56	--	2	6	10	32
Spring chinook	Discharge	160	152	144	136	120	210	200	189	178	158	230	218	207	196	172
	Area	500	495	490	470	185	360	335	290	220	120	2,190	2,150	1,950	1,650	1,100
	Percentage reduction in area	--	1	2	6	63	--	7	19	39	67	--	2	11	25	50
Coho	Discharge	130	124	117	110	98	105	100	94	89	79	125	119	112	106	94
	Area	1,500	1,400	950	910	840	600	595	570	560	500	4,800	4,700	4,450	4,000	3,300
	Percentage reduction in area	--	4	37	39	44	--	1	5	7	17	--	2	7	17	31

[1]Discharge in cubic feet per second.

[2]Area in square feet.

TABLE 7.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, Dosewallips River

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	175	166	158	149	131	330	314	297	280	248	190	180	171	162	142
	Area[2]	3,650	3,630	3,600	3,430	3,200	3,100	3,100	3,090	3,050	2,920	4,250	4,200	4,150	4,000	3,450
	Percentage reduction in area	--	0	1	6	12	--	0	0	2	6	--	1	2	6	19
Sockeye	Discharge	200	190	180	170	150	195	185	176	166	146	210	200	189	178	158
	Area	250	250	245	235	180	440	435	330	68	--	350	345	330	320	295
	Percentage reduction in area	--	0	2	6	25	--	1	2	85	--	--	1	6	9	16
Spring chinook	Discharge	280	266	252	238	210	210	200	189	178	158	350	332	315	298	262
	Area	600	590	575	545	420	660	640	510	475	455	600	595	590	580	530
	Percentage reduction in area	--	2	4	9	30	--	3	23	28	31	--	1	2	3	12
Coho	Discharge	125	119	112	106	94	180	171	162	153	135	200	190	180	170	150
	Area	1,330	1,320	[3](1,250)	(1,130)	(900)	1,110	1,100	1,050	950	810	1,010	1,010	1,000	990	920
	Percentage reduction in area	--	1	(6)	(15)	(32)	--	1	5	14	27	--	0	1	2	9

[1]Discharge in cubic feet per second.

[2]Area in square feet.

[3]Values in parentheses are extrapolated.

TABLE 8.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, North Fork Stillaguamish River

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	145	138	130	123	109	150	142	135	128	112	410	390	369	348	308
	Area[2]	1,570	1,570	1,560	1,520	1,500	2,730	2,720	2,690	2,640	2,300	7,630	7,580	6,800	6,100	5,100
	Percentage reduction in area	--	0	1	3	4	--	0	1	3	16	--	1	11	20	33
Sockeye	Discharge	113	107	102	96	85	145	138	130	123	109	370	352	333	314	278
	Area	159	158	153	136	52	334	332	329	320	300	405	400	375	355	335
	Percentage reduction in area	--	1	4	14	67	--	1	1	4	10	--	1	7	12	17
Spring chinook	Discharge	180	171	162	153	135	290	276	261	246	218	450	428	405	382	338
	Area	510	508	480	300	70	495	485	465	435	395	1,510	1,500	1,480	1,420	700
	Percentage reduction in area	--	0	6	41	86	--	2	6	12	20	--	1	2	6	54
Coho	Discharge	135	128	122	115	101	125	119	112	106	94	250	238	225	212	188
	Area	425	425	420	415	405	850	840	800	750	640	2,000	1,950	1,900	1,750	1,450
	Percentage reduction in area	--	0	1	2	5	--	1	6	12	25	--	2	5	12	28

[1]Discharge in cubic feet per second.

[2]Area in square feet.

TABLE 9.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, South Prairie Creek

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	70	66	63	60	52	128	122	115	109	96	120	114	108	102	90
	Area[2]	860	855	840	820	710	405	400	385	355	270	900	895	890	875	780
	Percentage reduction in area	--	1	2	5	17	--	1	5	12	33	--	1	1	3	13
Sockeye	Discharge	70	66	63	60	52	146	139	131	124	110	156	148	140	133	117
	Area	96	95	88	70	51	20	20	19	18	14	42	41	40	39	37
	Percentage reduction in area	--	1	8	27	47	--	0	5	10	30	--	2	5	7	12
Spring chinook	Discharge	195	185	176	166	146	116	110	104	99	87	210	200	189	178	158
	Area	141	140	136	124	85	26	25	23	20	19	128	127	119	102	74
	Percentage reduction in area	--	1	4	12	47	--	4	8	23	27	--	1	7	20	42
Coho	Discharge	67	64	60	57	50	154	146	139	131	116	88	84	79	75	66
	Area	280	275	250	200	180	77	76	75	71	65	270	265	230	195	140
	Percentage reduction in area	--	2	11	29	36	--	1	3	8	16	--	6	15	28	48

[1]Discharge in cubic feet per second.

[2]Area in square feet.

TABLE 10.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15-, and 25-percent reductions in discharge, Issaquah Creek

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	[3](90)	(86)	(81)	(76)	(68)	140	133	126	119	105	83	79	75	71	62
	Area[2]	(108)	(107)	(104)	(98)	(86)	145	145	145	145	140	540	535	525	505	405
	Percentage reduction in area	--	1	4	9	20	--	0	0	0	3	--	1	3	6	25
Sockeye	Discharge	(140)	(133)	(126)	(119)	(105)	105	100	94	89	79	60	(57)	(54)	(51)	(45)
	Area	(15)	(15)	(14)	(14)	10	260	250	160	95	40	50	(50)	(49)	(45)	(30)
	Percentage reduction in area	--	0	7	7	33	--	4	38	63	85	--	0	2	10	40
Spring chinook	Discharge	(170)	(162)	(153)	(144)	(128)	(200)	(190)	(180)	(170)	(150)	200	190	180	170	150
	Area	(28)	(27)	(25)	21	13	(370)	(360)	(340)	(300)	200	137	137	125	100	32
	Percentage reduction in area	--	4	11	25	54	--	3	8	19	46	--	0	9	27	77
Coho	Discharge	82	78	74	70	62	130	124	117	110	98	82	78	74	70	62
	Area	35	34	30	25	16	600	600	570	440	420	192	190	185	180	152
	Percentage reduction in area	--	3	14	28	54	--	0	5	27	30	--	1	4	6	21

[1]Discharge in cubic feet per second.

[2]Area in square feet.

[3]Values in parentheses are extrapolated.

TABLE 11.--Summary of preferred spawning discharges and spawnable areas, and corresponding reductions of spawnable areas at 5-, 10-, 15, and 25-percent reductions in discharge, Bear Creek

Salmon species	Preferred parameter	Reach A					Reach B					Reach C				
		Percentage reduction from preferred spawning discharge														
		0	5	10	15	25	0	5	10	15	25	0	5	10	15	25
Fall chinook	Discharge[1]	19	18	17	16	14	[3](26)	(25)	23	22	20	35	33	32	30	26
	Area[2]	145	140	135	130	120	(29)	(28)	25	24	20	40	39	39	38	35
	Percentage reduction in area	--	3	7	10	17	--	3	14	17	31	--	2	2	5	12
Sockeye	Discharge	19	18	17	16	14	16	15	14	14	12	30	28	27	26	22
	Area	14	13	12	11	10	3	3	2.8	2.8	1.6	4.3	4.2	4.2	4.0	1.0
	Percentage reduction in area	--	7	14	21	28	--	0	7	7	47	--	2	2	7	75
Spring chinook	Discharge	(26)	(25)	(23)	(22)	(20)										
	Area	(7)	(7)	(6)	(6)	(5)			Too shallow					Too shallow		
	Percentage reduction in area	--	0	14	14	28										
Coho	Discharge	13	12	12	11	10	20	19	18	17	15	33	31	30	28	25
	Area	50	50	50	48	40	11	10	9.5	8.5	6	11	11	11	10	9.5
	Percentage reduction in area	--	0	0	4	20	--	9	14	23	45	--	0	0	4	14

[1]Discharge in cubic feet per second.

[2]Area in square feet.

[3]Values in parentheses are extrapolated.

STREAM DATA AND ANALYSIS

Bear Branch

Location.--Figure 1 shows the location of the river and the study reaches. The study reaches are described as follows:

Reach A. Lat 46°18'47", long 123°52'43", in NW¼NE¼ sec.35, T.10 N., R.10 W., at river mile 7.9.

Reach B. Lat 46°19'13", long 123°53'51", in NW¼SE¼ sec.27, T.10 N., R.10 W., at river mile 6.6.

Reach C. Lat 46°19'48", long 123°54'36", in SE¼SE¼ sec.21, T.10 N., R.10 W., at river mile 5.3.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	138	40	15
Wetted perimeter (ft)[1]	46	50	55
Channel width (ft)[1]	43	48	53
Channel depth (ft)[1]	2.3	2.2	2.4
Bankfull water-surface area (sq ft)	3,500	3,480	5,060
River and basin parameters:			
Drainage area (sq mi)	8.80	9.64	11.7
Main-stem length (mi)	5.9	7.2	8.5
Main-stem channel slope (ft/mi)	74	67	58
Mean basin altitude (ft msl)	557	544	546
The altitude at the source of the river is 800 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

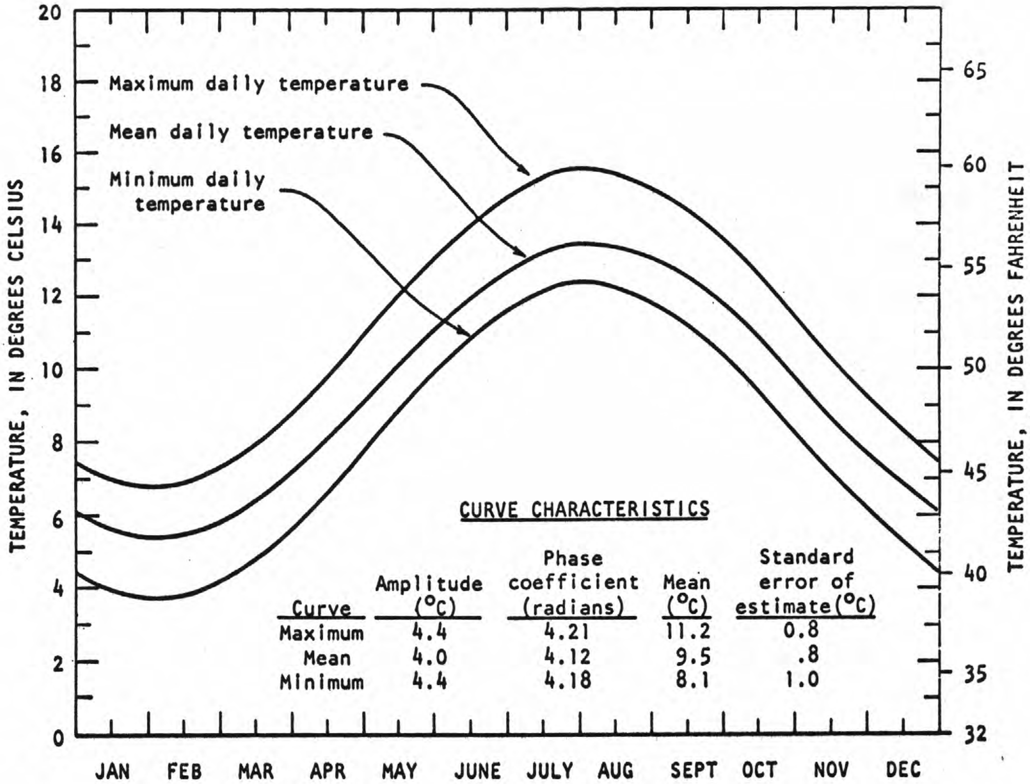


FIGURE 8.--Annual stream-temperature distribution in 1971, Bear Branch near Naselle (12009500). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

Chemical characteristics.--For documentation purposes, table 12 presents some physiochemical characteristics of the water at each of the three study reaches, along with stream discharge.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on Bear Branch (12009500) and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1971 are shown in figure 8.

All water sampled at each study reach had nearly 100-percent DO saturation.

TABLE 12.--Selected chemical and physical characteristics of water in study reaches on Bear Branch

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
3-19-71	55	5.6	42	12.2	5	--
4- 1	121	6.7	44	11.8	3	48
4- 5	48	8.9	48	11.2	1	51
4-13	79	8.9	48	11.2	3	48
4-21	41	7.8	46	11.5	3	51
4-27	29	10.0	50	11.0	1	53
5- 6	17.4	11.1	52	10.7	4	54
6-10	20	11.1	52	10.7	--	58
7- 6	13.4	11.7	53	10.5	8	61
7-28	9.4	13.9	57	10.0	4	62
			Reach B			
3-19-71	63	6.7	44	11.8	1	--
4- 1	118	7.2	45	11.7	8	49
4-13	83	9.4	49	11.1	7	48
4-20	46	8.9	48	11.2	4	52
4-27	33	10.0	50	11.0	5	54
6-10	21	10.4	54	12.2	--	60
7-28	9.4	15.0	59	--	3	63
			Reach C			
3-19-71	70	7.8	46	11.5	1	--
4- 1	143	6.7	44	11.8	6	51
4-13	104	8.9	48	11.2	2	51
4-20	53	8.9	48	11.2	4	54
4-27	38	10.0	50	11.0	5	57
5- 6	24	12.2	54	10.4	158	58

The suspended-sediment concentrations were low, ranging from 1 to 8 mg/l (milligrams per liter) except for a high of 158 mg/l for the sample taken on May 6, 1971--probably due to runoff from an area being logged adjacent to the stream above reach C.

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

Study reach	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	7.0	16.9	37.3	32.9	5.9
B	--	4.2	31.4	41.0	23.4
C	--	1.5	39.1	47.3	12.1

Most of the gravel in the river was in the 0.15- to 3-inch range. The greater percentage of fine material in the streambed at reach B probably was the result of logging activities in the basin upstream from this reach.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station on Bear Branch (12009500) to obtain a simple linear regression model for each reach--discharges (Q, in cubic feet per second) at reach C, located at the gaging-station site (Q_G), are the same as those at the gage. The regression models for reaches A (Q_A) and B (Q_B) were found to be significantly different, as follows:

$$Q_A = 0.68(Q_G)^{1.03} \quad , \text{ and } Q_B = 0.75(Q_G)^{1.03} \quad .$$

The standard errors of estimate are 4 and 5 percent, respectively.

Discharge records at the gaging station are of sufficient length to allow computation of the monthly mean probability distributions (fig. 9) for that site. By using the above regression models and figure 9 the probabilities of various discharges can be estimated for each study reach.

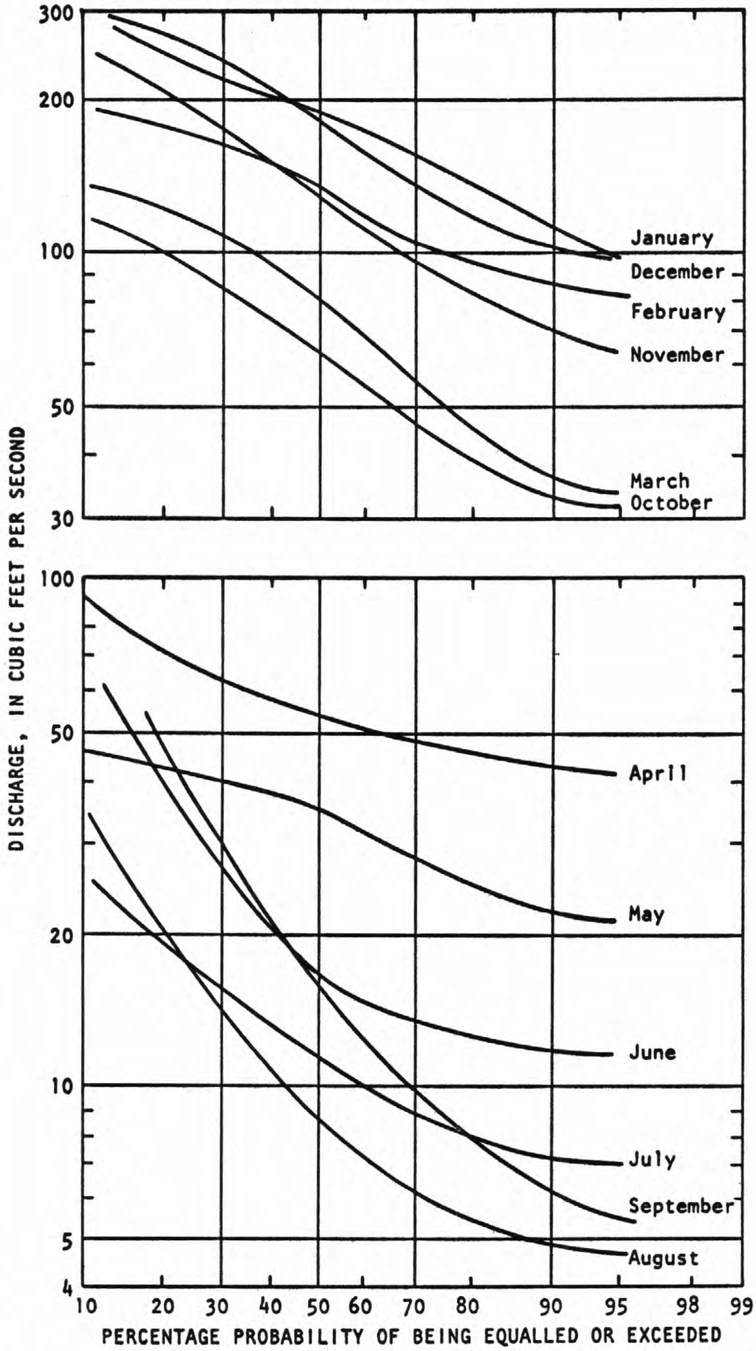


FIGURE 9.--Probability distributions of monthly mean discharges, Bear Branch near Naselle (12009500).

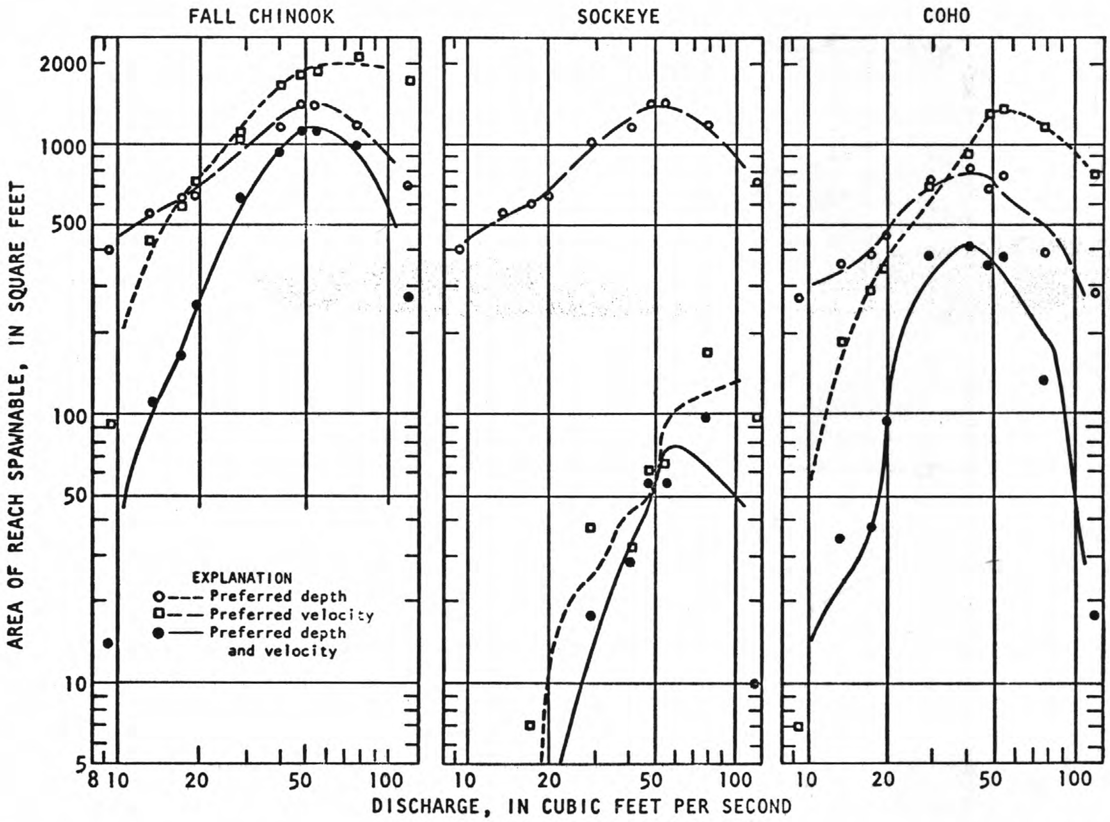


FIGURE 10.--Curves of spawnable area versus discharge, Bear Branch reach A.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 10-12. Following is a list of the preferred spawning discharges, by species and study reach, for Bear Branch:

Salmon species	Preferred spawning discharge (cfs) Study reach A	B	C
Fall chinook	54	66	85
Sockeye	58	69	115
Coho	41	47	70

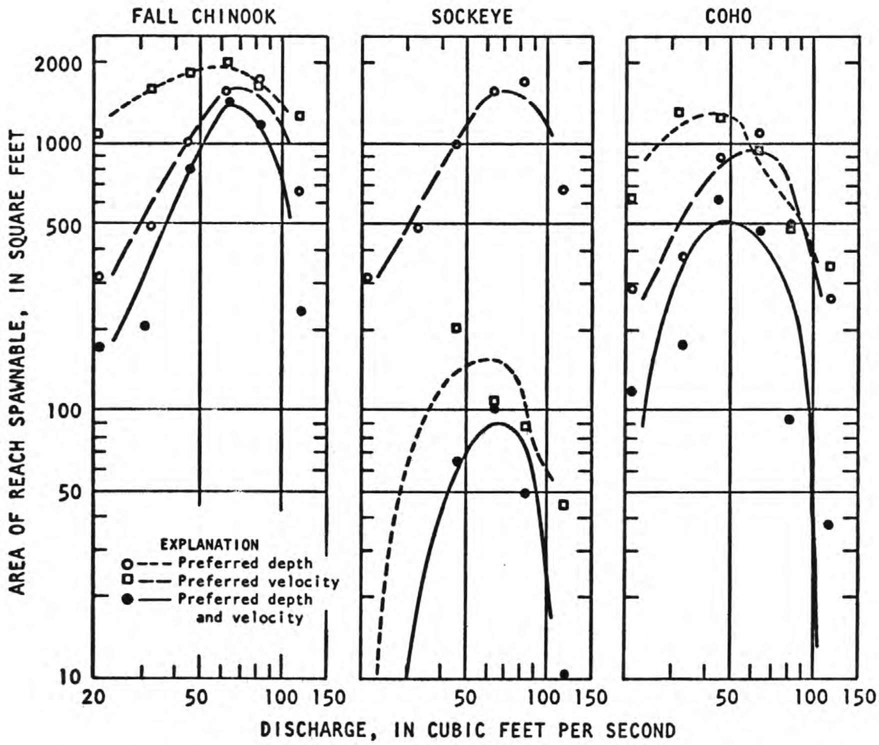


FIGURE 11.--Curves of spawnable area versus discharge, Bear Branch reach B.

The crests of all curves for three species of salmon are well defined. The curves for spring chinook were not defined because spring chinook do not utilize Bear Branch for propagation.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 13 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these discharges, are shown in figure 14.

The following table shows the results of the rearing-discharge investigation:

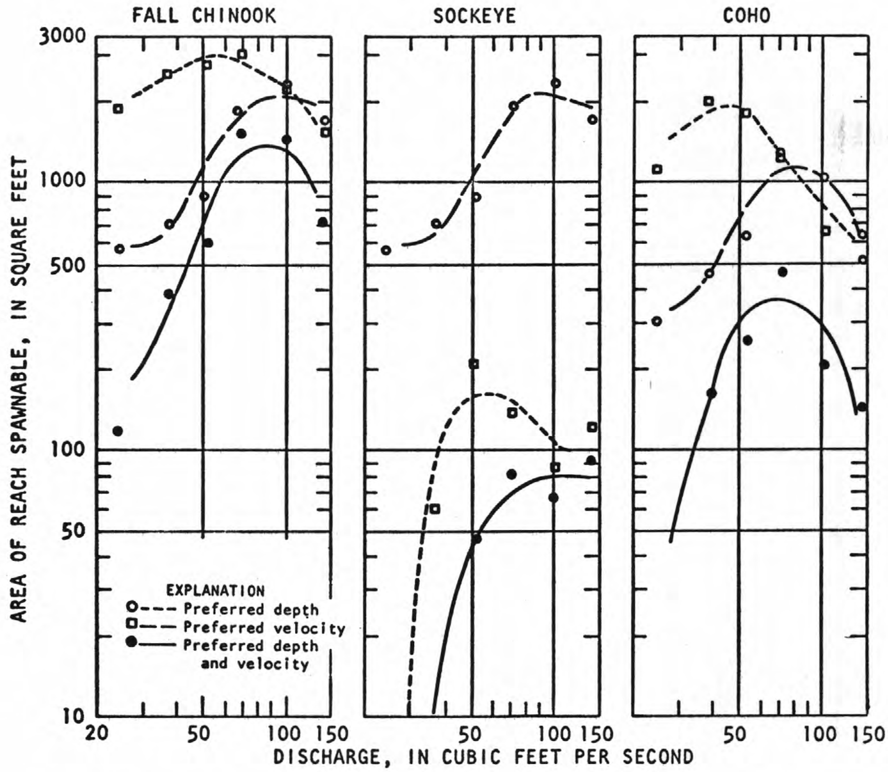


FIGURE 12.--Curves of spawnable area versus discharge, Bear Branch reach C.

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	25	25	40
Equivalent discharge at the gage (cfs)	33	30	40
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig.9)	less than 10	less than 10	less than 10
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	6.6	7.2	9

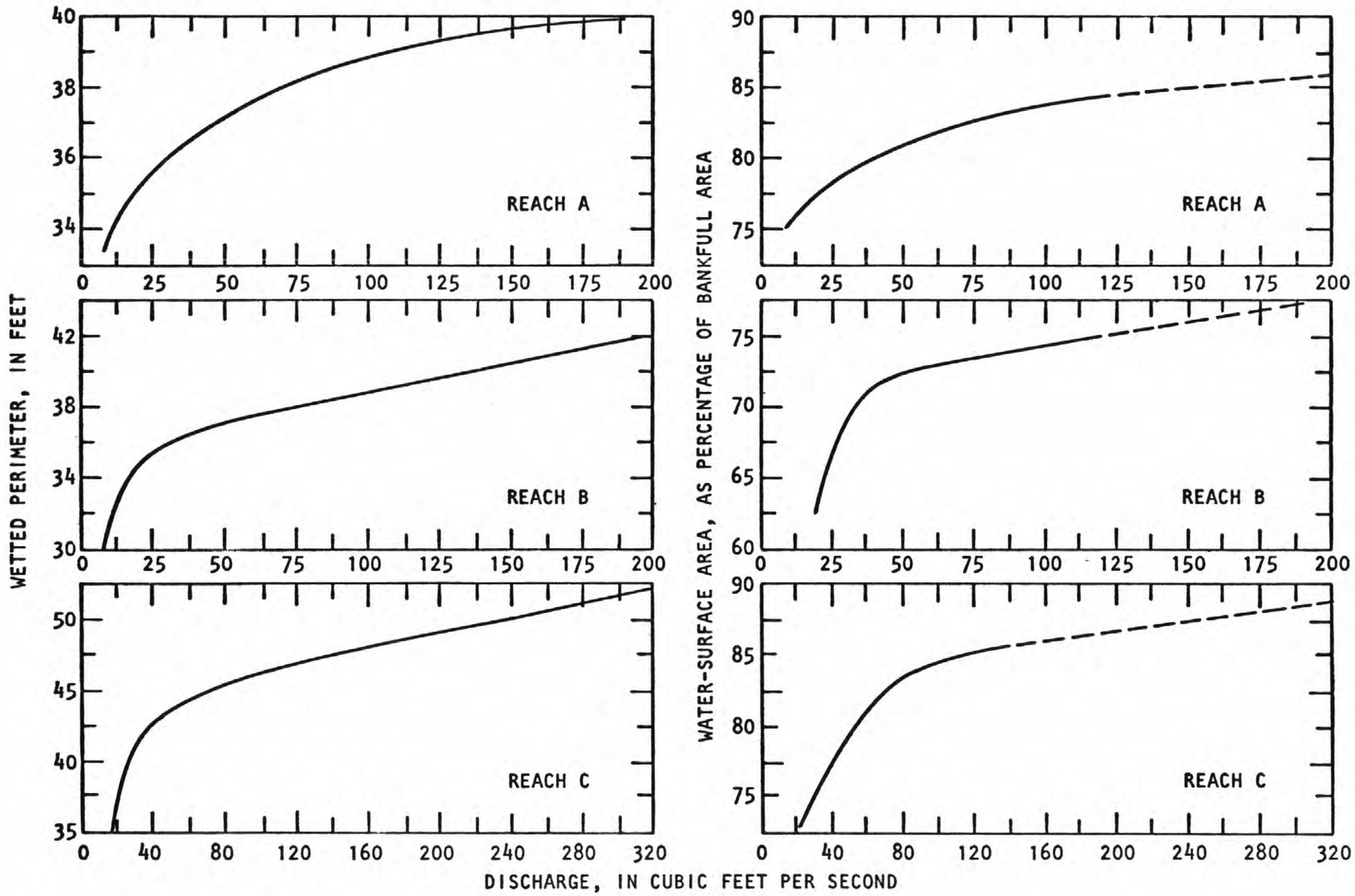


FIGURE 13.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, Bear Branch study reaches.

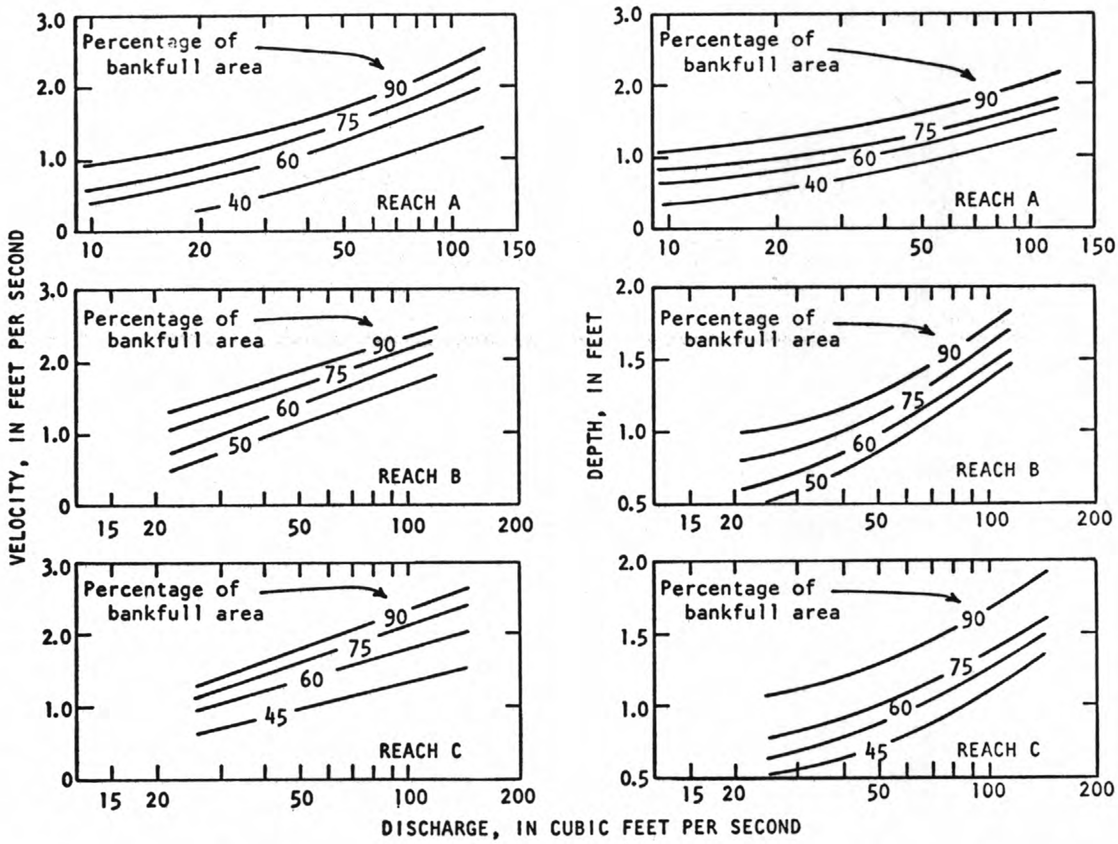


FIGURE 14.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, Bear Branch study reaches.

The equivalent discharge at the gage was determined by solving the reach regression models for Q_G and substituting the preferred rearing discharges into the equations. The discharge at the 50-percent-probability level for the lowest flow month (August in fig. 9) was assumed to be the naturally occurring limiting discharge for salmon that utilize the stream for rearing the year around (fig. 2).

North Nemah River

Location.--Figure 1 shows the location of the river and the study reaches. The study reaches are described as follows:

Reach A. Lat 46°28', long 123°45'51", in SW¼NW¼ sec.2, T.11 N., R.9 W., at river mile 10.8.

Reach B. Lat 46°30'12", long 123°50'30", in SW¼SW¼ sec.19, T.12 N., R.10 W., at river mile 4.8.

Reach C. Lat 46°30'27", long 123°50'37", in NE¼SE¼ sec.24, T.12 N., R.10 W., at river mile 4.4.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	245	35	30
Wetted perimeter (ft)[1]	47	53	51
Channel width (ft)[1]	46	50	47
Channel depth (ft)[1]	1.6	2.4	2.7
Bankfull water-surface area (sq ft)	2,540	3,930	3,820
River and basin parameters:			
Drainage area (sq mi)	6.70	18.8	19.1
Main-stem length (mi)	3.4	9.4	9.8
Main-stem channel slope (ft/mi)	75	46	45
Mean basin altitude (ft msl)	822	674	666

The altitude at the source of the river is 700 ft (msl).

[1]Average value for four cross sections at bankfull river stage.

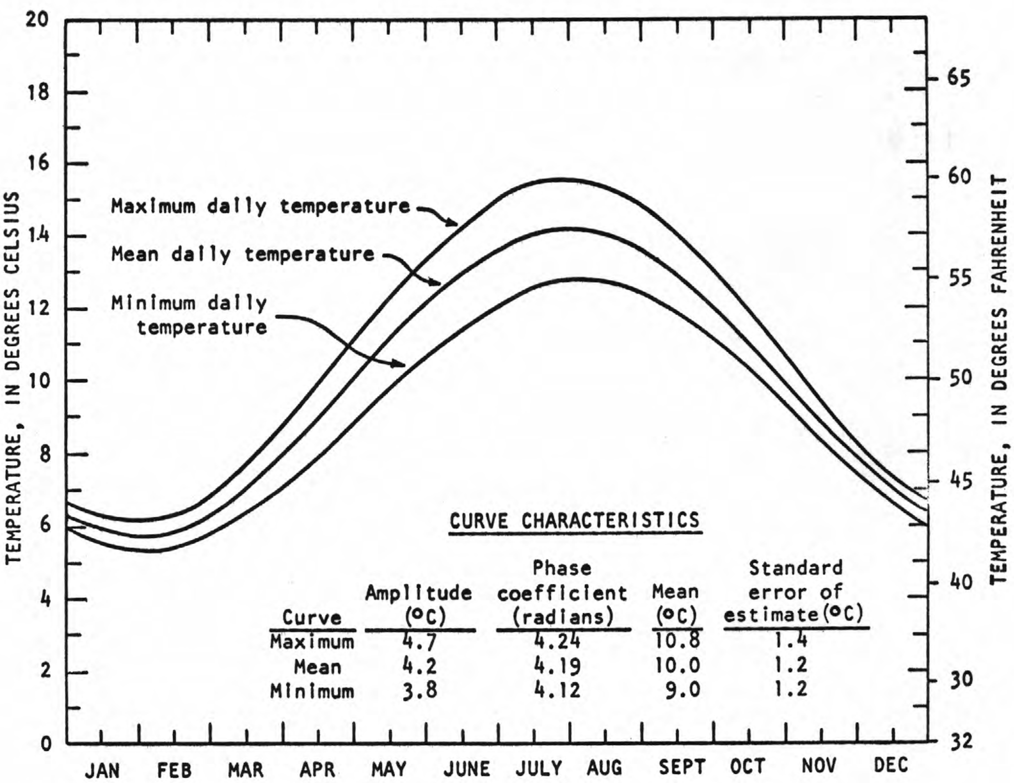


FIGURE 15.--Annual stream-temperature distribution in 1971, North Nemah River near South Bend (12011000). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

<u>Chemical characteristics</u>.--For documentation purposes, table 13 presents some physiochemical characteristics of the water at each of the three study reaches, along with stream discharge.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on North Nemah River (12011000) and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1971 are shown in figure 15.

All water sampled at each study reach had nearly 100-percent DO saturation.

TABLE 13.--Selected chemical and physical characteristics of water in study reaches on North Nemah River

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
3-18-71	55	7.8	46	11.5	3	--
3-31	118	7.8	46	11.5	8	46
4- 5	46	7.8	46	11.5	6	51
4-13	63	7.8	46	11.5	4	48
4-20	33	7.8	46	11.5	5	52
4-27	23	8.9	48	11.2	1	54
5- 6	15.4	7.8	46	11.5	2	57
6-10	13.3	10.0	50	11.0	--	58
7-27	8.1	12.2	54	10.4	7	62
			Reach B			
3-18-71	162	7.2	45	11.7	10	--
3-31	296	8.9	48	11.2	11	44
4- 5	124	8.9	48	11.2	14	57
4-13	179	8.9	48	11.2	6	54
4-20	95	8.9	48	11.2	4	58
4-27	67	10.0	50	11.0	4	59
5- 6	42	9.4	49	11.1	2	61
6-10	36	11.1	52	10.7	--	63
7- 6	32	13.3	56	10.2	9	66
7-27	21	17.0	63	9.3	7	80
			Reach C			
3-18-71	175	6.1	43	12.0	5	--
3-31	316	8.9	48	11.2	8	53
4- 5	135	10.0	50	11.0	6	57
4-13	190	10.0	50	11.0	5	54
4-20	96	8.9	48	11.2	5	56
4-27	71	10.0	50	11.0	1	59
5- 6	48	10.0	50	11.0	4	51
6-10	42	11.7	53	10.5	--	60
7- 6	39	13.9	57	10.0	7	65
7-27	21	16.5	--	--	3	80

The suspended-sediment concentrations were low, ranging from 1 to 14 mg/l for the 26 samples collected at all reaches (table 13).

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

Study reach	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	0	29.2	36.2	26.6	8.0
B	0	0	44.0	47.2	8.8
C	0	2.8	59.8	31.9	5.5

More than 90 percent of the gravel sampled at reaches B and C was in the 0.15- to 3-inch size range. At reach A, 92 percent of the gravel sampled was fairly evenly distributed in the three size ranges between 0.15 and 6 inches. There was no gravel in the 3- to 6-inch range at reach B and very little in that range at reach C; none larger than 6 inches was collected at any of the reaches. The gravel size of all reaches is similar to that of the other streams.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station to obtain simple linear regression models for each reach. The regression analyses indicate that the discharges at reaches B and C are not significantly different from that at the gage (Q_G). The regression model for reach A (Q_A) is

$$Q_A = 0.38(Q_G)^{0.99} \quad .$$

The standard error of estimate is 7 percent.

Discharge records at the gaging station are of sufficient length to allow computation of the probability distributions of the mean monthly discharges (fig. 16). By using the above regression model for reach A, the discharge at the gage for reaches B and C, and figure 16, the probabilities of various discharges can be estimated for each of the reaches.

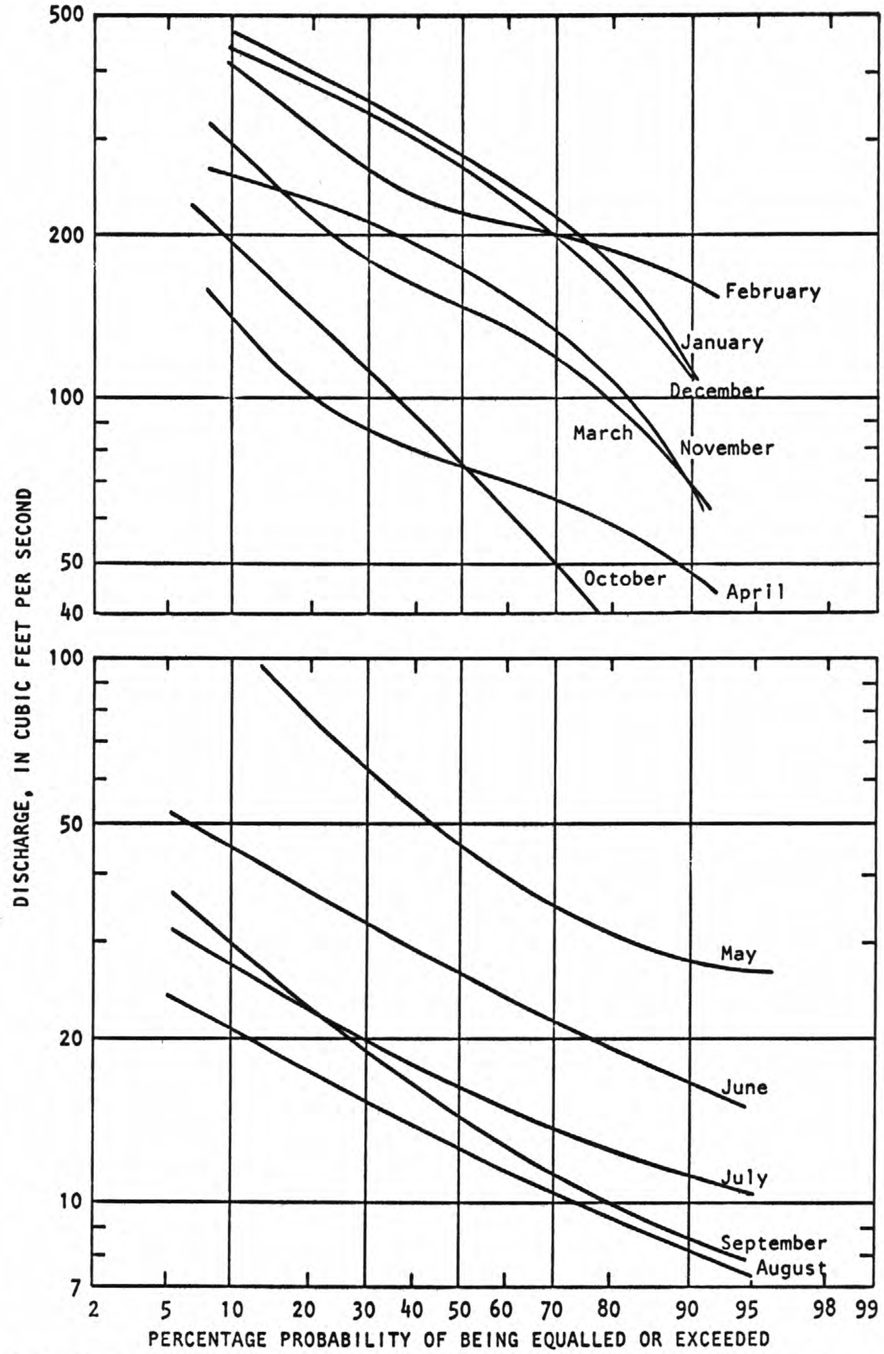


FIGURE 16.--Probability distributions of monthly mean discharges, North Nemah River near South Bend (12011000).

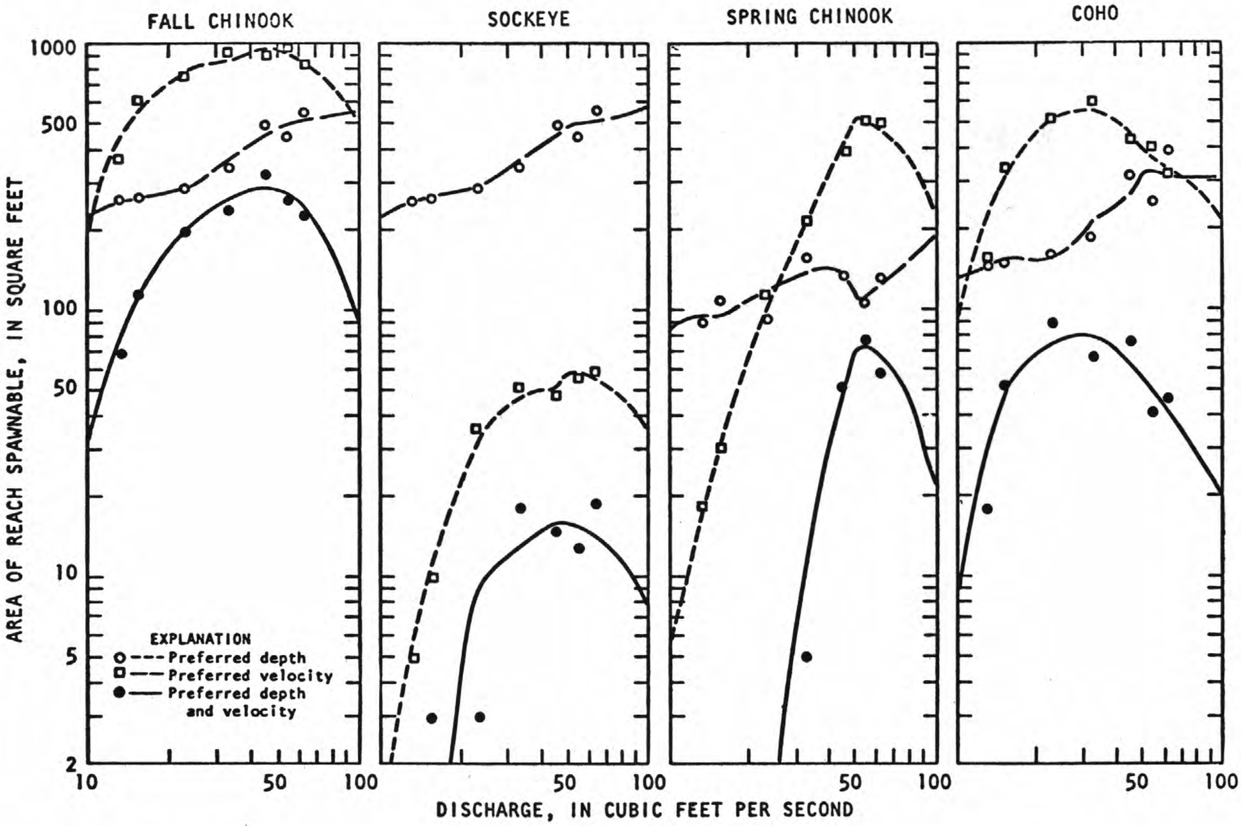


FIGURE 17.--Curves of spawnable area versus discharge, North Nemah River reach A.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 17-19. Following is a list of the preferred spawning discharges, by species and study reach, for North Nemah River:

	Preferred spawning discharge (cfs)		
	Study reach		
Salmon species	A	B	C
Fall chinook	45	95	60
Sockeye	48	94	70
Spring chinook	54	150	180
Coho	31	94	46

The crest of all curves (figs. 17-19) were well defined.

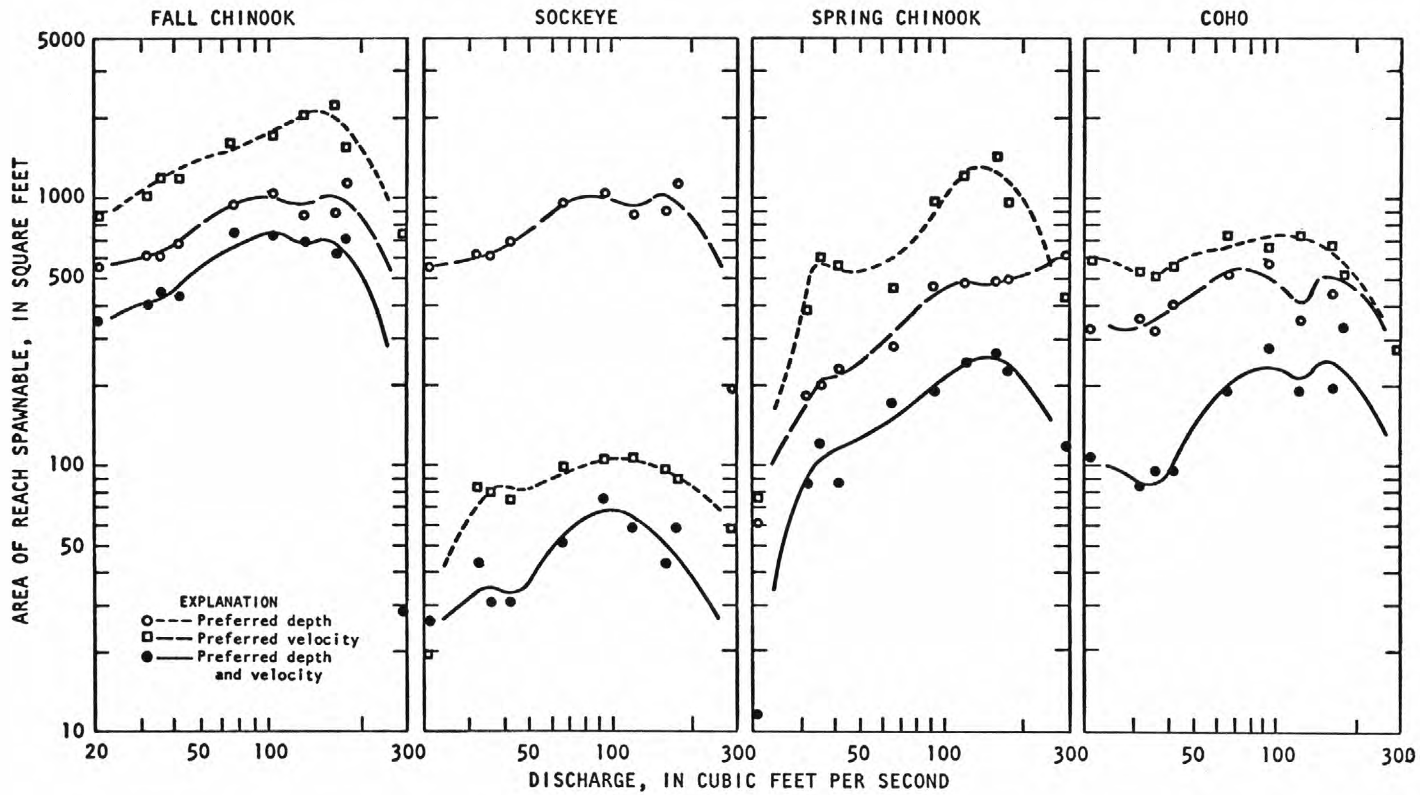


FIGURE 18.--Curves of spawnable area versus discharge, North Nemah River reach B.

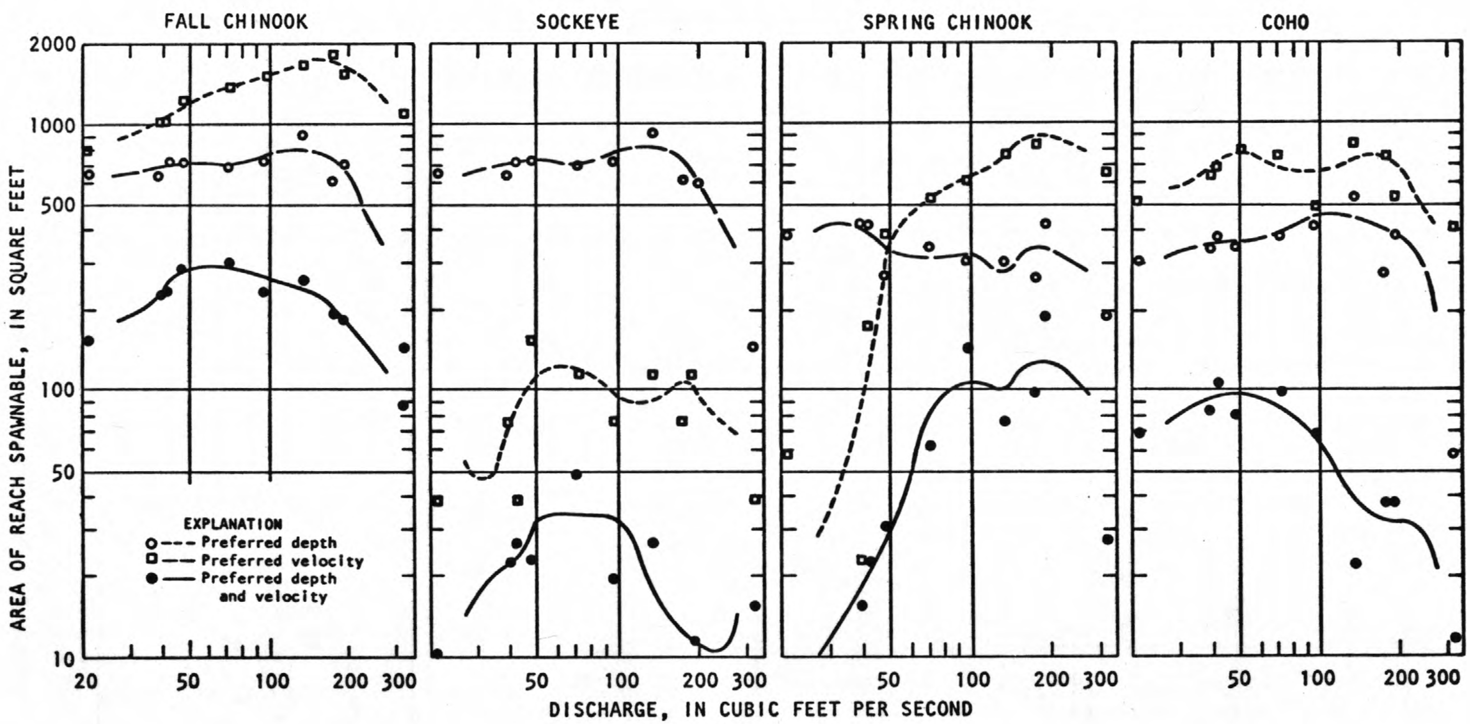


FIGURE 19.--Curves of spawnable area versus discharge, North Nemah River reach C.

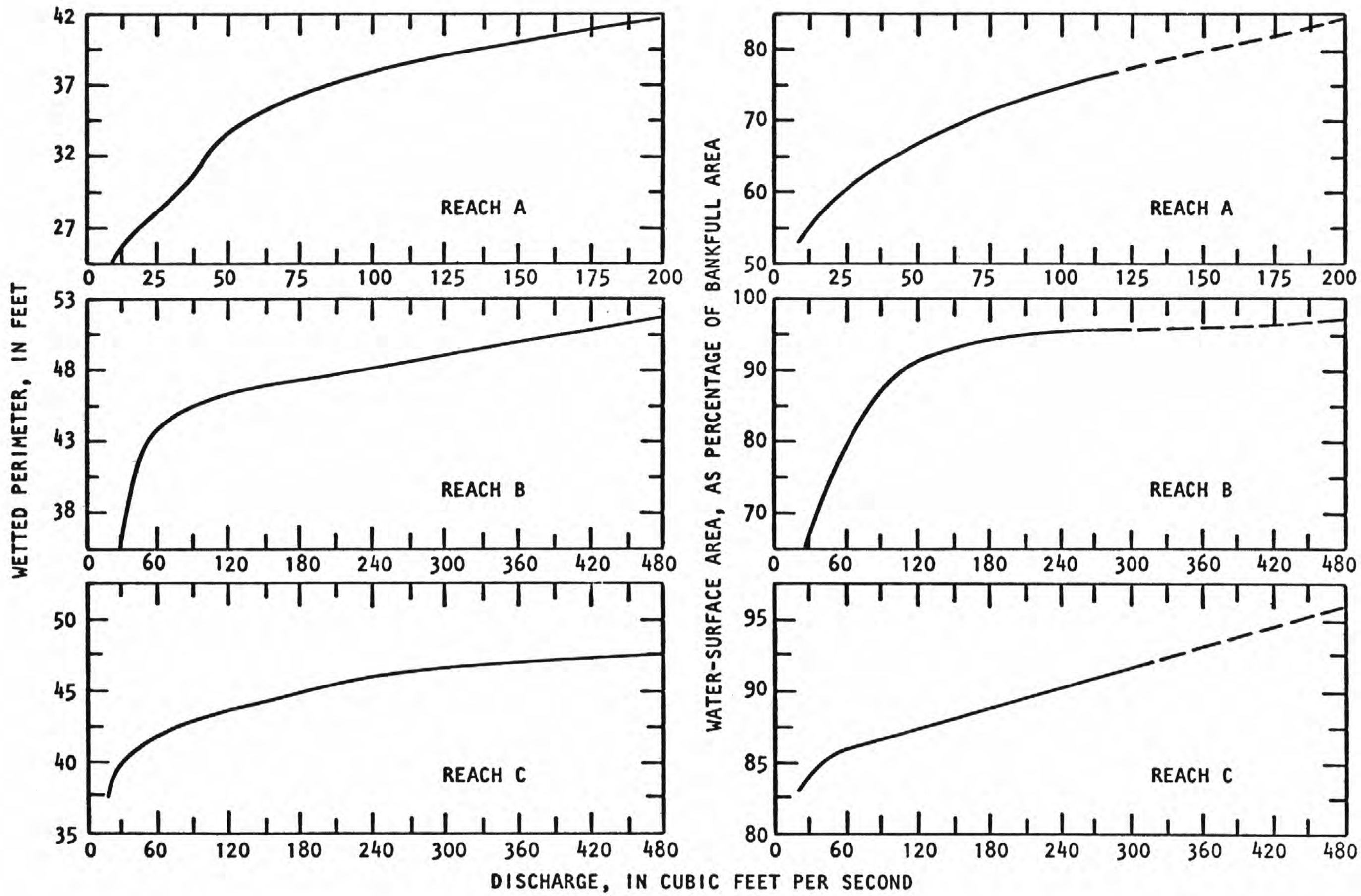


FIGURE 20.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, North Nemah River study reaches.

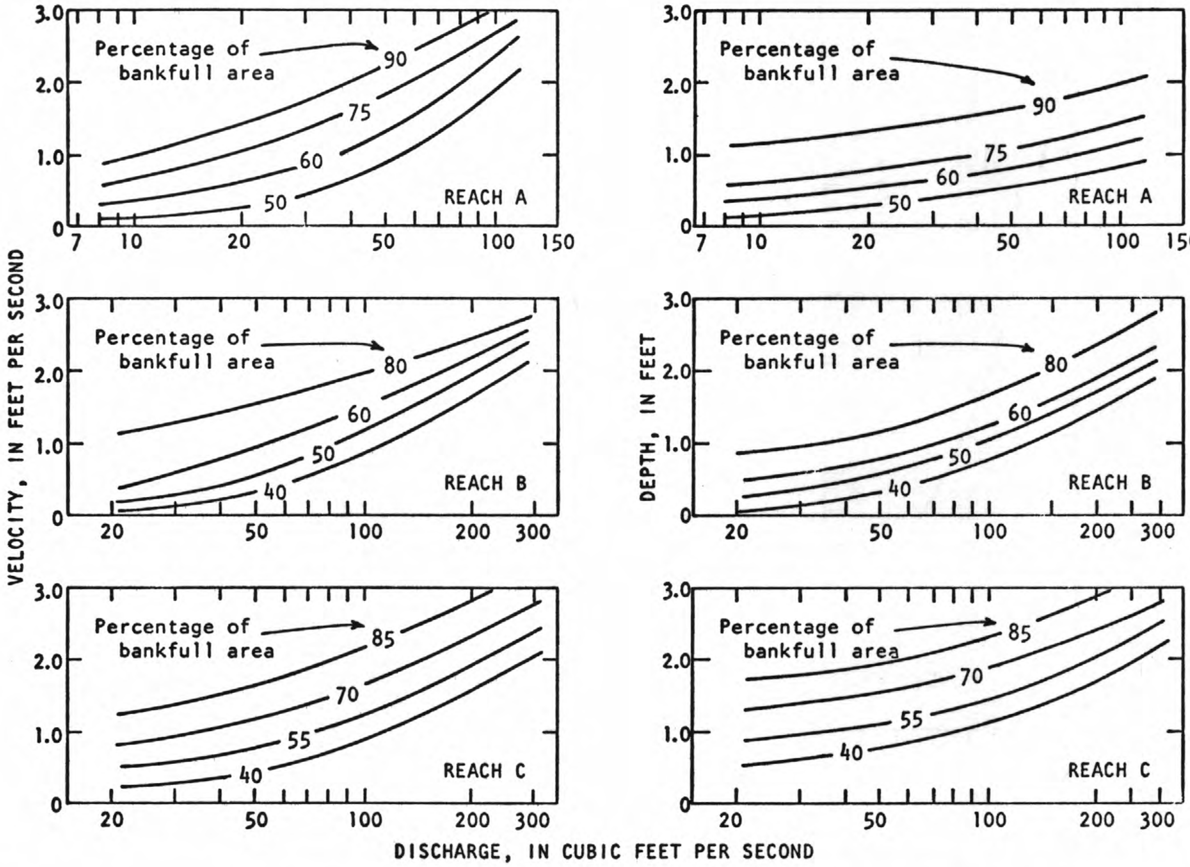


FIGURE 21.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, North Nemah River study reaches.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 20 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these discharges, are shown in figure 21.

The following table shows the results of the rearing-discharge investigation:

	Study reach A	Study reach B	Study reach C
Preferred rearing discharge (cfs)	25	50	45
Equivalent discharge at the gage (cfs)	69	50	45
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig. 16)	less than 5	less than 5	less than 5
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	5.0	14	14

The equivalent discharge at the gage for reach A was determined by solving the reach regression model for Q_G and substituting the preferred rearing discharge of the reach into the equation. The equivalent discharge at the gage for reaches B and C was found to be the same as Q_G. (See streamflow characteristics and evaluation.) The month with the lowest flow for rearing discharges at all three reaches was August (fig. 16). The discharge at the 50-percent-probability level for August was assumed to be the naturally occurring limiting flow for salmon that utilize the stream for rearing the year around (fig. 2).

Elk Creek

Location.--Figure 1 shows the location of Elk and Smith Creeks and the study reaches. The study reaches are described as follows:

Reach A. Lat 46°39'04", long 123°23'38", in SW¼SE¼ sec.35, T.13 N., R.5 W., on Smith Creek, a tributary to Elk Creek, 0.3 mile upstream from mouth and 7.1 miles upstream from reach B.

Reach B. Lat 46°37'42", long 123°19'50", in SW¼NE¼ sec.8, T.13 N., R.5 W., at river mile 2.5.

Reach C. Lat 46°38'02", long 123°17'41", in NE¼NW¼ sec.10, T.13 N., R.5 W., at river mile 0.7.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	500	360	310
Wetted perimeter (ft)[1]	28	61	104
Channel width (ft)[1]	27	58	94
Channel depth (ft)[1]	1.6	3.3	3.7
Bankfull water-surface area (sq ft)	1,200	7,600	9,820
River and basin parameters:			
Drainage area (sq mi)	3.48	46.7	57.6
Main-stem length (mi)	4.4	13.4	15.2
Main-stem channel slope (ft/mi)	209	16.8	15.5
Mean basin altitude (ft msl)	1,037	810	817
The altitude at the source of the river is 2,160 ft (msl)			

[1]Average value for four cross sections at bankfull river stage.

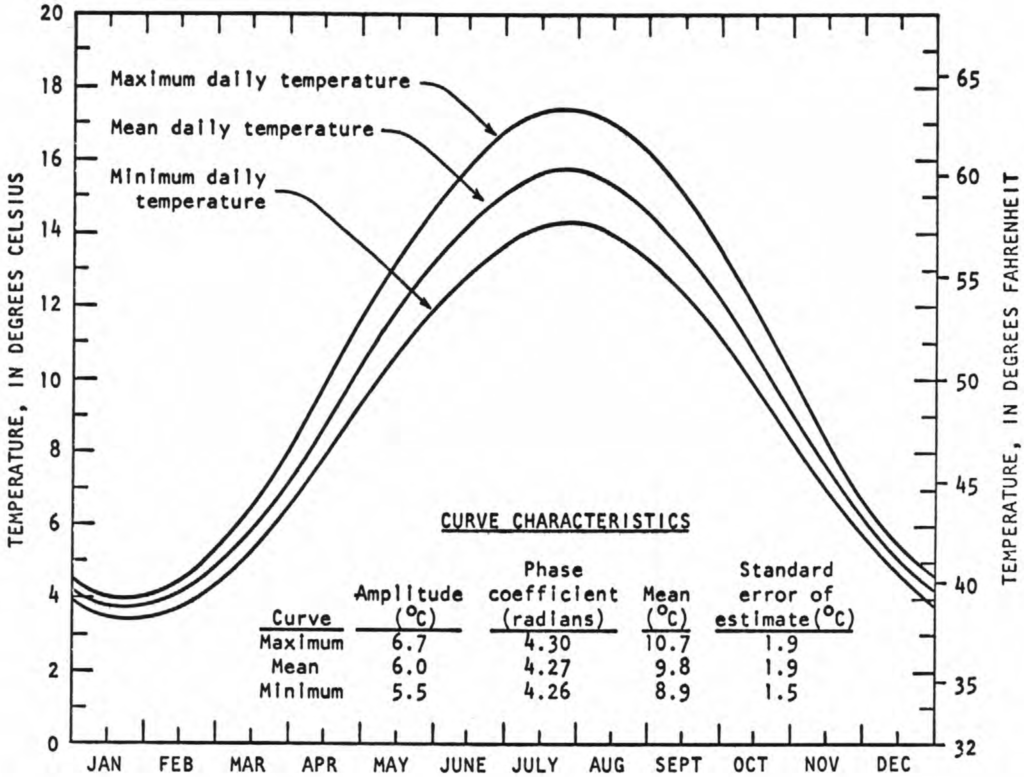


FIGURE 22.--Annual stream-temperature distribution in 1971, Elk Creek near Doty (12020500). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

Chemical characteristics.--For documentation purposes, table 14 presents some physiochemical characteristics of the water at each of the three study reaches, along with discharges.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on Elk Creek (12020500) and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1971 are shown in figure 22.

All water sampled at each study reach had nearly 100-percent DO saturation.

The suspended-sediment concentrations were low, ranging from 2 to 26 mg/l for the 26 samples collected at all reaches (table 14).

TABLE 14.--Selected chemical and physical characteristics of water in study reaches on Elk and Smith Creeks

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A (Smith Creek)			
3-17-71	25	6.1	43	12.0	4	--
3-31	52	6.1	43	12.0	13	52
4- 6	13.2	6.7	48	11.8	8	56
4-14	11.2	6.7	44	11.8	8	58
4-21	8.2	6.7	44	11.8	5	58
4-28	6.8	8.9	48	11.2	2	62
5- 7	4.8	11.1	52	10.7	2	65
6-11	3.6	11.7	53	10.5	--	70
7- 7	2.4	12.2	53	10.4	17	74
			Reach B (Elk Creek)			
3-17-71	344	6.1	43	12.0	12	--
3-31	680	6.1	43	12.0	26	42
4- 6	224	6.7	48	11.8	3	46
4-14	203	8.3	47	11.4	2	47
4-21	144	7.8	46	11.5	9	49
4-28	107	10.0	50	11.0	5	39
5- 7	77	12.2	54	10.4	2	53
6-11	54	12.2	54	10.4	--	59
7- 7	46	12.2	46	10.4	3	63
7-26	24	18.9	24	9.0	7	70
			Reach C (Elk Creek)			
3-17-71	445	6.1	43	12.0	10	--
3-31	950	6.1	43	12.0	20	44
4- 6	276	6.7	48	11.8	2	48
4-14	246	6.7	48	11.8	23	49
4-21	163	8.3	47	11.4	8	50
4-28	126	10.0	50	11.0	4	45
5- 7	86	12.2	54	10.4	2	55
6-11	60	12.2	54	10.4	--	60
7- 7	44	12.8	55	10.3	7	64
7-26	24	17.8	64	9.2	7	71

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

Study reach	Average weight fraction of total sample (percent) — Gravel size (inches): Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	0	2.2	65.0	28.0	4.8
B	0	43.6	28.3	21.1	7.0
C	4.5	9.1	36.0	38.8	11.6

The percentage of gravel in the 0.15- to 6-inch size range was similar between reaches A and C, with more than 75 percent being in the 0.15- to 3-inch size range. At reach C, the gravels were finer than those of reach B, as shown by the higher percentages in each of the three size ranges less than 3 inches. However, reach C was the only reach with gravels larger than 6 inches.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station (Q_G) to obtain a simple linear regression model for each reach. As reach B was located at the gaging station, therefore, the discharges are equal. The regression models for reaches A (Q_A) and C (Q_C) are:

$$Q_A = 0.04(Q_G)^{1.09}$$

$$Q_C = 0.73(Q_G)^{1.10} \quad .$$

The standard errors of estimate for reaches A and C are 11 and 4 percent, respectively.

Discharge records for the gaging station cover a period of sufficient length to allow computation of the probability distributions of the mean monthly discharges (fig. 23). By using the above regression models and figure 23 the probabilities of various discharges can be estimated for each of the reaches.

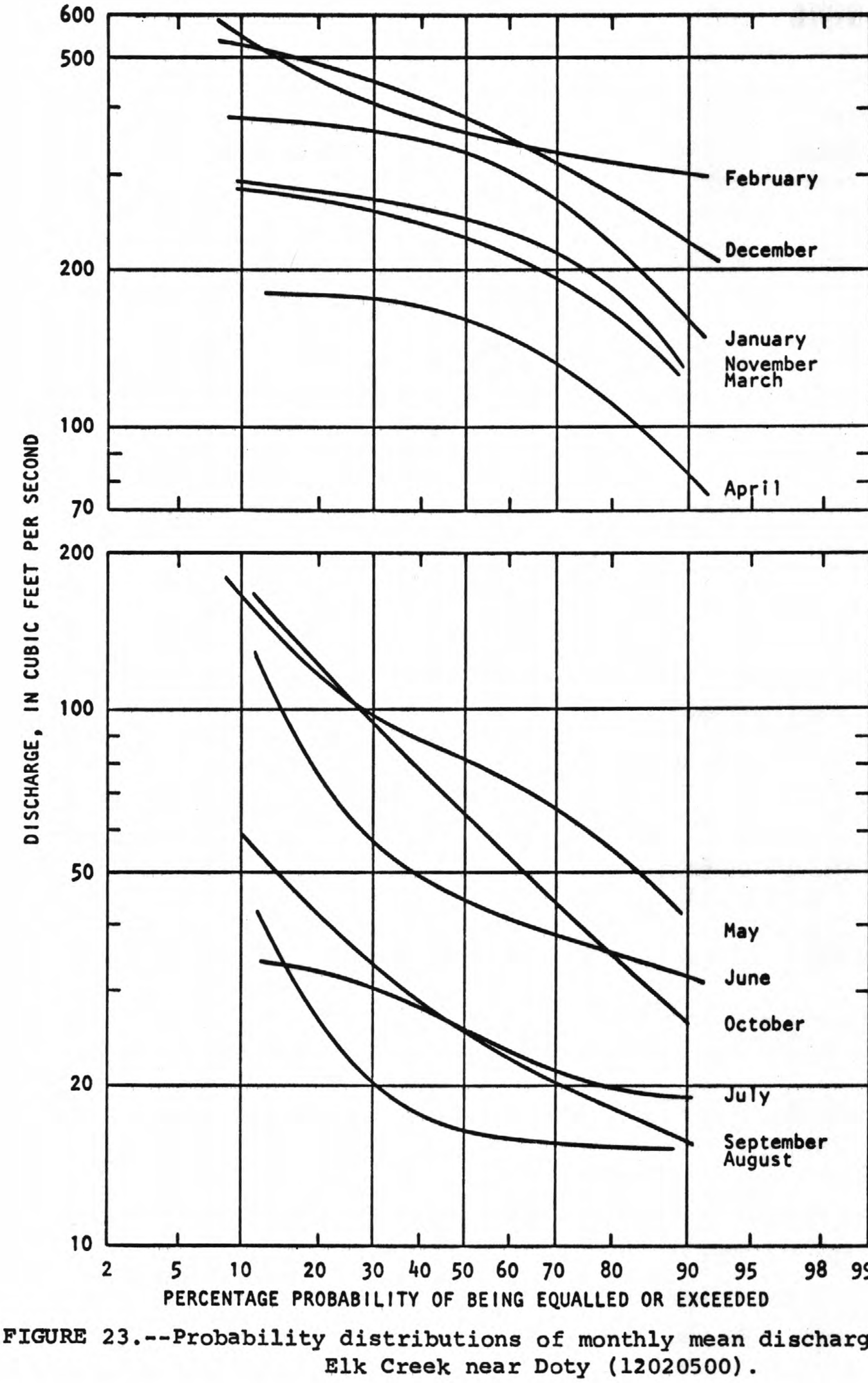


FIGURE 23.--Probability distributions of monthly mean discharges, Elk Creek near Doty (12020500).

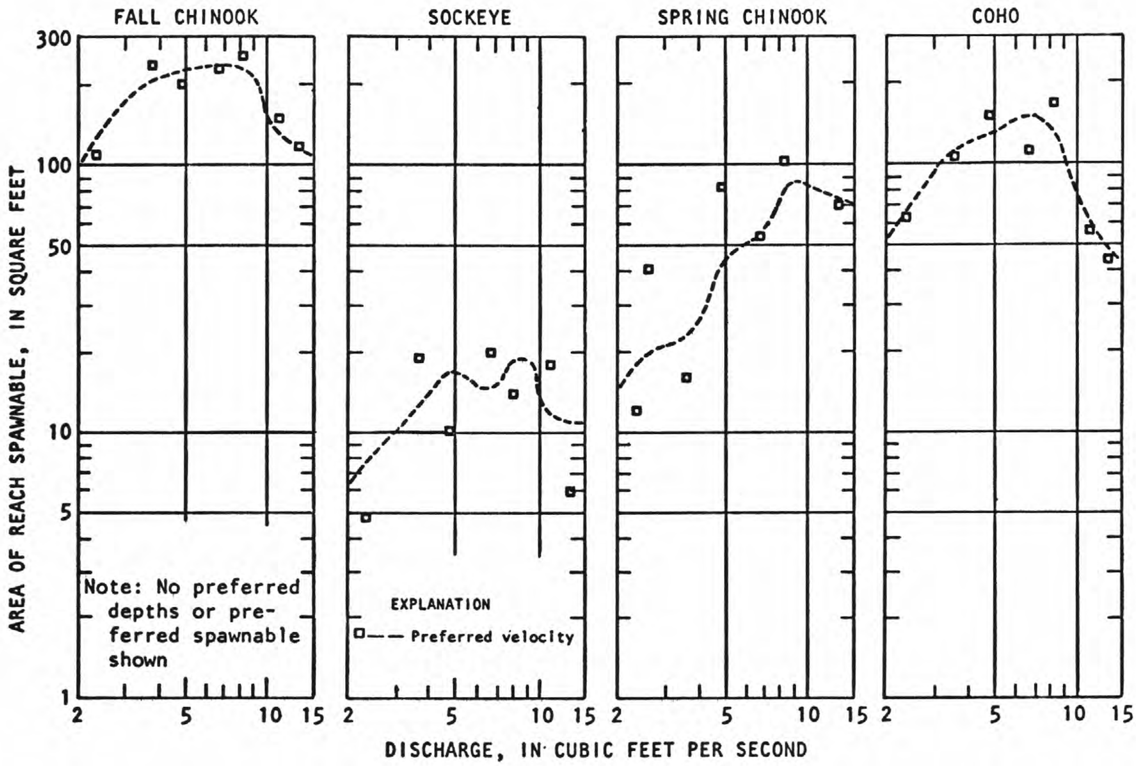


FIGURE 24.--Curves of spawnable area versus discharge, Elk Creek basin reach A (on Smith Creek).

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 24-26. Following is a list of the preferred spawning discharges, by species and study reach, for Smith Creek (reach A) and Elk Creek (reaches B and C):

Salmon species	Preferred spawning discharge (cfs) Study reach A	B	C
Fall chinook	7.5	72	60
Sockeye	9.0	77	220
Spring chinook	9.0	170	220
Coho	6.5	54	250

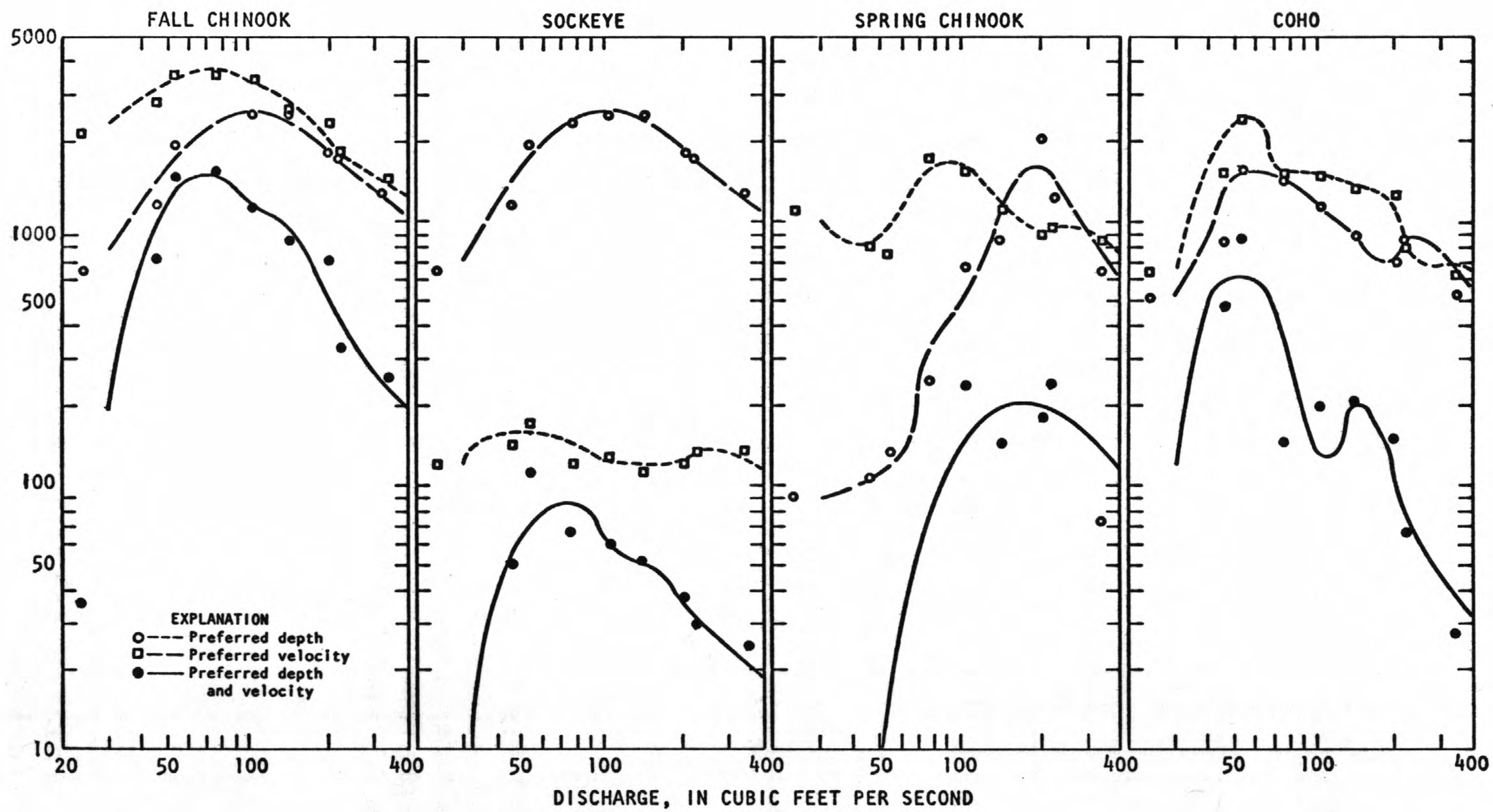


FIGURE 25.--Curves of spawnable area versus discharge, Elk Creek reach B.

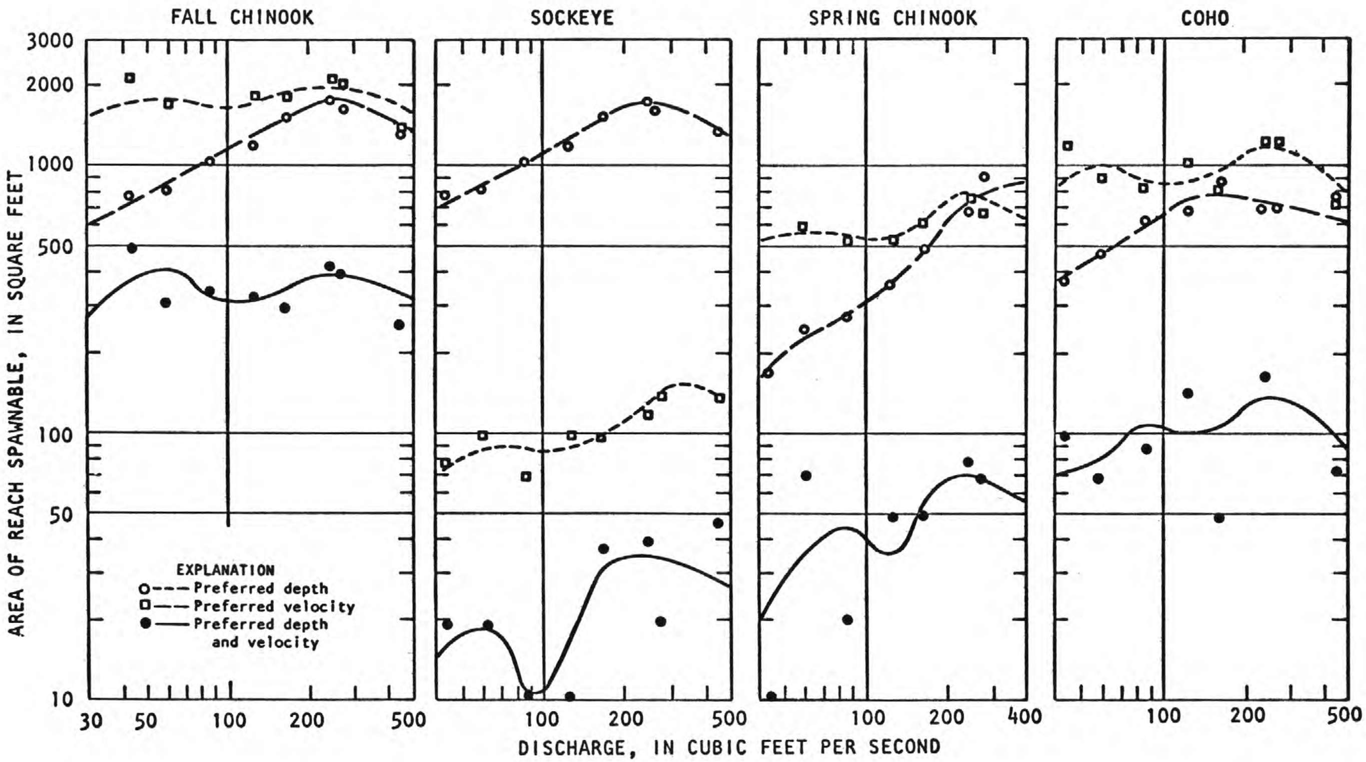


FIGURE 26.--Curves of spawnable area versus discharge, Elk Creek reach C.

The crest of all curves (figs. 25-26) for reaches B and C were well defined. Only the preferred-velocity curve crested and could be defined for reach A (fig. 24). Therefore, the preferred-velocity curve for reach A was used to determine the preferred spawning discharges for each of the salmon species.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 27 on the basis of the part of the reach covered by water. Additional curves used for evaluating the water depths and velocities at these rearing discharges are shown in figure 28.

The following table shows the results of the rearing-discharge investigation:

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	2.5	60	40
Equivalent discharge at the gage (cfs)	44	60	38
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig. 23)	less than 10	less than 10	less than 10
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	1.0	16	16

The equivalent discharge at the gage was determined by solving the reach regression models for Q_G and substituting the preferred rearing discharge of the reach into the equation. The month with the lowest flow for rearing discharges at all three reaches was August (fig. 23). The discharge at the 50-percent-probability level for August was assumed to be the naturally occurring limiting flow for salmon that utilize the stream for rearing the year around (fig. 2).

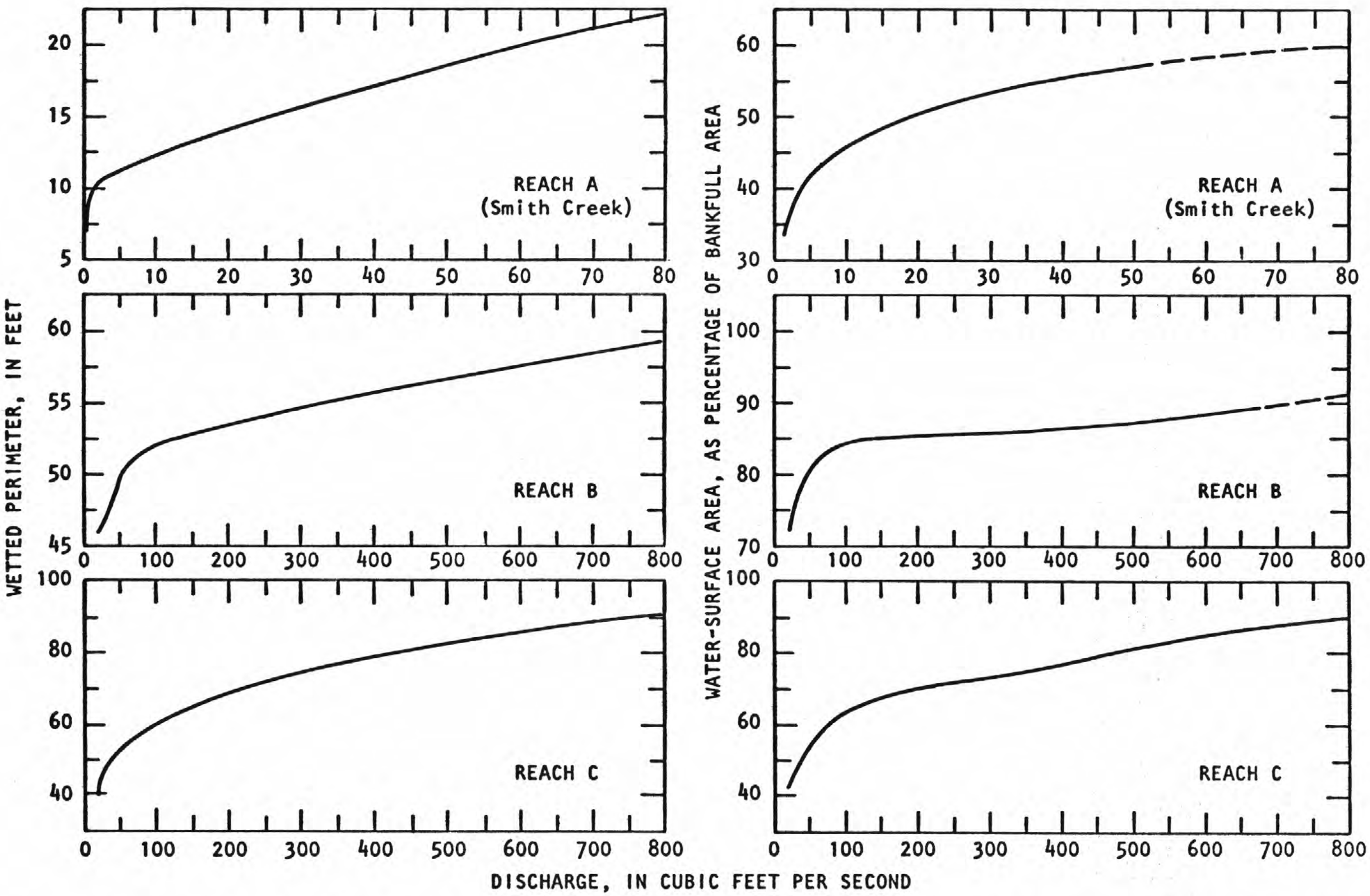


FIGURE 27.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, Elk Creek study reaches.

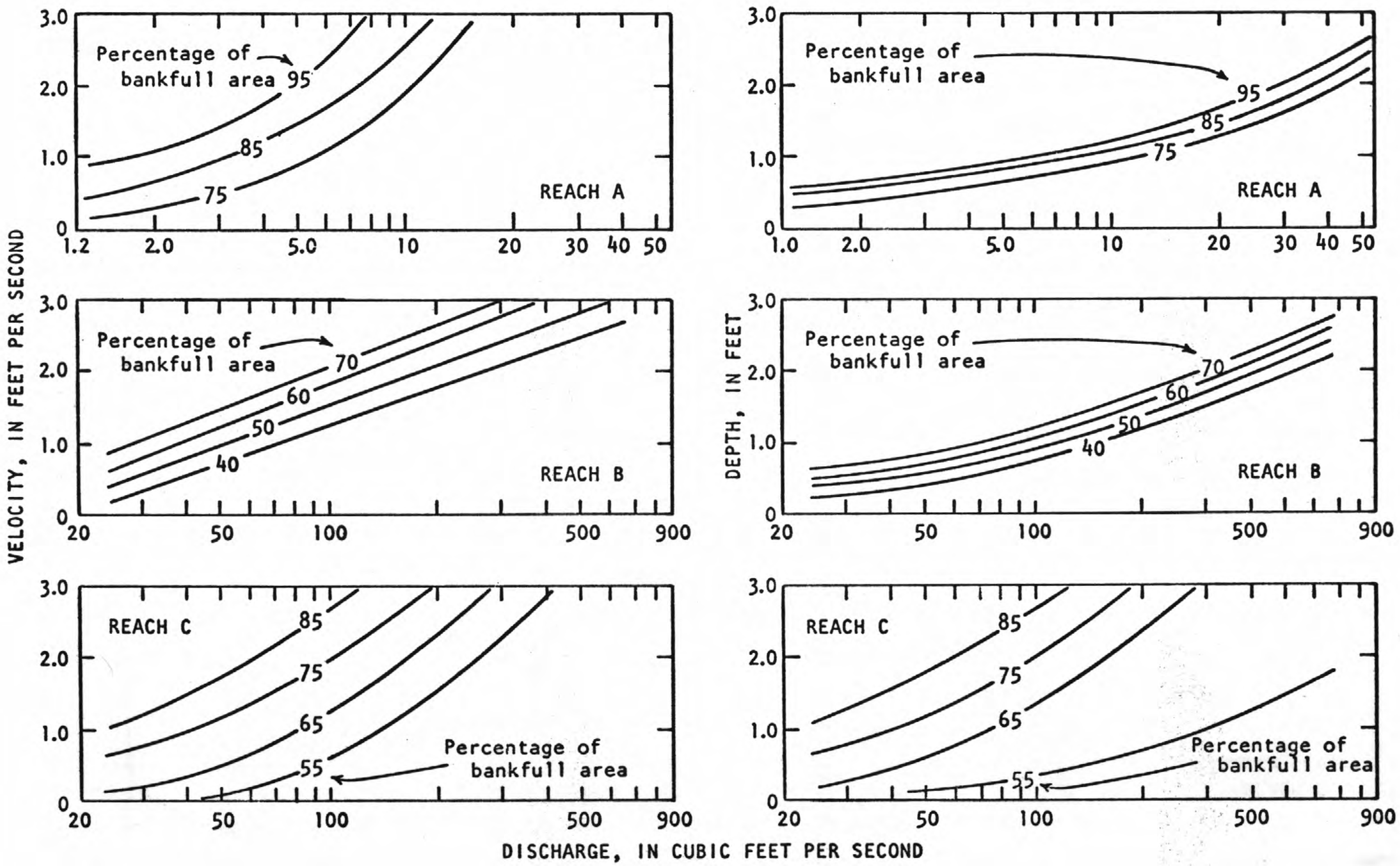


FIGURE 28.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, Elk Creek study reaches.

North Fork Toutle River

Location.--Figure 1 shows the location of the river and the study reaches. The study reaches are described as follows:

Reach A. Lat 46°22'23", long 122°34'57", in NW¼NE¼ sec.8, T.10 N., R.2 E., at river mile 11.2.

Reach B. Lat 46°21'19", long 122°39'06", in NW¼NW¼ sec.14, T.10 N., R.1 E., at abandoned bridge site, at river mile 5.4.

Reach C. Lat 46°20'22", long 122°42'28", in SW¼NE¼ sec.20, T.10 N., R.1 E., at river mile 1.2.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	720	550	440
Wetted perimeter (ft)[1]	177	210	217
Channel width (ft)[1]	172	205	213
Channel depth (ft)[1]	2.5	2.9	2.3
Bankfull water-surface area (sq ft)	24,100	27,400	34,400
River and basin parameters:			
Drainage area (sq mi)	277	286	291
Main-stem length (mi)	32.2	38.0	42.2
Main-stem channel slope (ft/mi)	97.5	88.4	80.7
Mean basin altitude (ft msl)	2,790	2,730	2,690
The altitude at the source of the river is 5,200 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

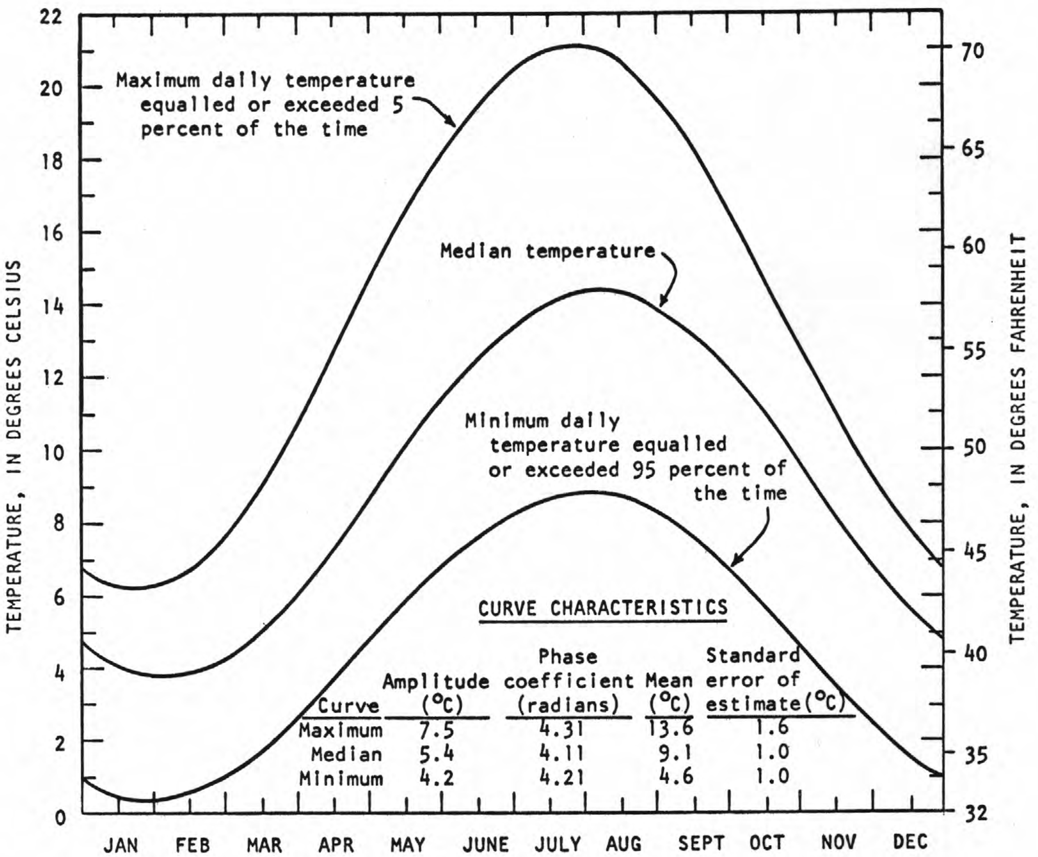


FIGURE 29.--Annual stream-temperature distribution. Curves represent the 90-percent confidence interval between the maximum and minimum water temperatures for the period 1950-67, Toutle River near Silver Lake (14242500).

Chemical characteristics.--For documentation purposes, table 15 presents some physiochemical characteristics of the water at each of the three study reaches, along with stream discharge.

Stream temperatures were documented by an analysis of the long-term thermograph record from the gaging station on Toutle River (14242500), and also by measurements made during each visit to the reaches. The results are in the form of a graph containing three curves which define the 90-percent-probability range of water temperatures and the mean water temperatures for 1950-67 (fig. 29).

All water sampled at each of the study reaches had nearly 100-percent DO saturation.

TABLE 15.--Selected chemical and physical characteristics of water in study reaches on North Fork Toutle River

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (μmhos/cm at 25°C)
Reach A						
6-10-70	900	9.4	49	11.1	4	78
6-19	790	12.8	55	10.3	5	84
6-29	662	10.6	51	10.8	6	62
7- 7	525	13.3	56	10.2	5	66
7-22	386	12.2	54	10.4	4	78
8- 6	350	14.4	58	9.9	12	86
8-20	293	12.8	55	10.3	36	--
9-22	390	11.1	52	10.7	25	89
10- 2	311	8.9	48	11.2	28	90
11- 4	638	7.2	45	11.7	--	--
Reach B						
6-19-70	820	15.0	59	9.8	4	78
6-29	618	11.7	53	10.5	7	60
7- 7	518	15.6	60	9.7	6	64
7-22	395	14.4	58	9.9	3	77
8- 6	308	16.7	62	9.4	8	83
8-13	311	16.1	61	9.5	--	90
8-20	276	13.9	57	10.0	13	90
9-22	336	11.1	52	10.7	19	94
10- 2	271	11.1	52	10.7	8	92
11- 4	604	7.8	46	11.5	--	--
Reach C						
6-10-70	1,050	11.7	53	10.5	5	72
6-19	858	17.2	63	9.3	3	77
6-29	648	13.3	56	10.2	6	59
7- 7	501	18.9	66	9.0	8	63
7-22	384	17.2	63	9.3	14	75
8-13	307	16.7	62	9.4	7	87
8-20	282	16.1	61	9.5	6	90
9-22	361	12.2	54	10.4	15	88
10- 2	331	13.3	56	10.2	8	91
11- 4	646	7.8	46	11.5	--	--

The suspended-sediment concentrations in 26 water samples ranged from 3 to 36 mg/l. Concentrations were slightly higher at reach A than at reaches B and C.

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
Study reach	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	18.8	31.9	23.5	14.6	11.2
B	2.7	35.9	39.4	8.2	13.8
C	6.8	34.0	26.2	22.2	10.8

Reach A had a greater fraction of rocks larger than 6 inches than did reaches B or C.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station on the Toutle River to obtain a simple linear regression model for each reach. To further evaluate the relations between the discharges at the reaches and the discharge at the gaging station (Q_G), the regression models were statistically tested and a single regression model was found to be sufficient to define the relationship for all three reaches, as follows:

$$Q_{A,B,C} = 0.94(Q_G)^{0.98} \quad .$$

The model has a standard error of estimate of 8 percent.

Discharge records at the gaging station covered a period of sufficient length to allow computation of monthly mean probability distributions (fig. 30) for that site. By using the above regression model and figure 30, the probabilities of various discharges can be estimated for each study reach.

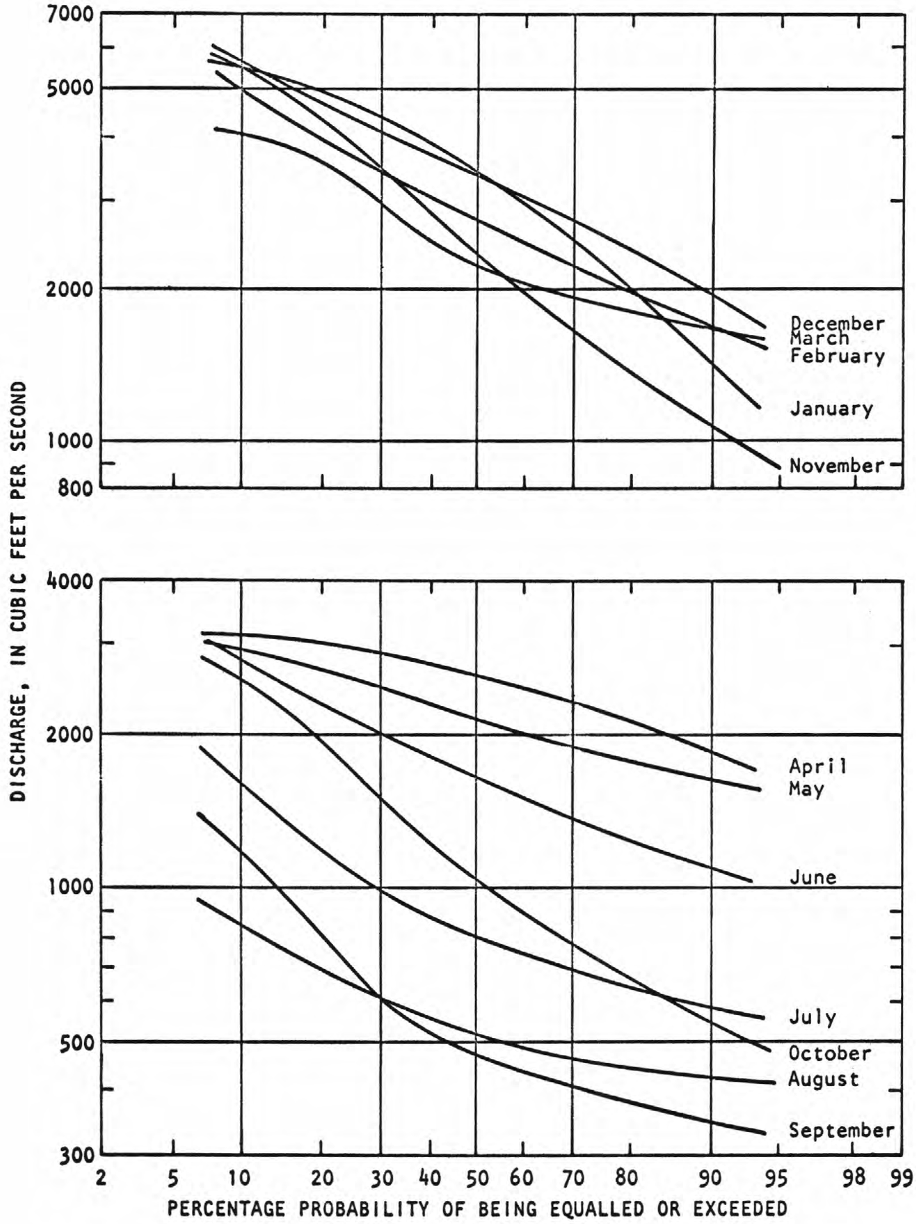


FIGURE 30.--Probability distributions of monthly mean discharges, Toutle River near Silver Lake (14242500).

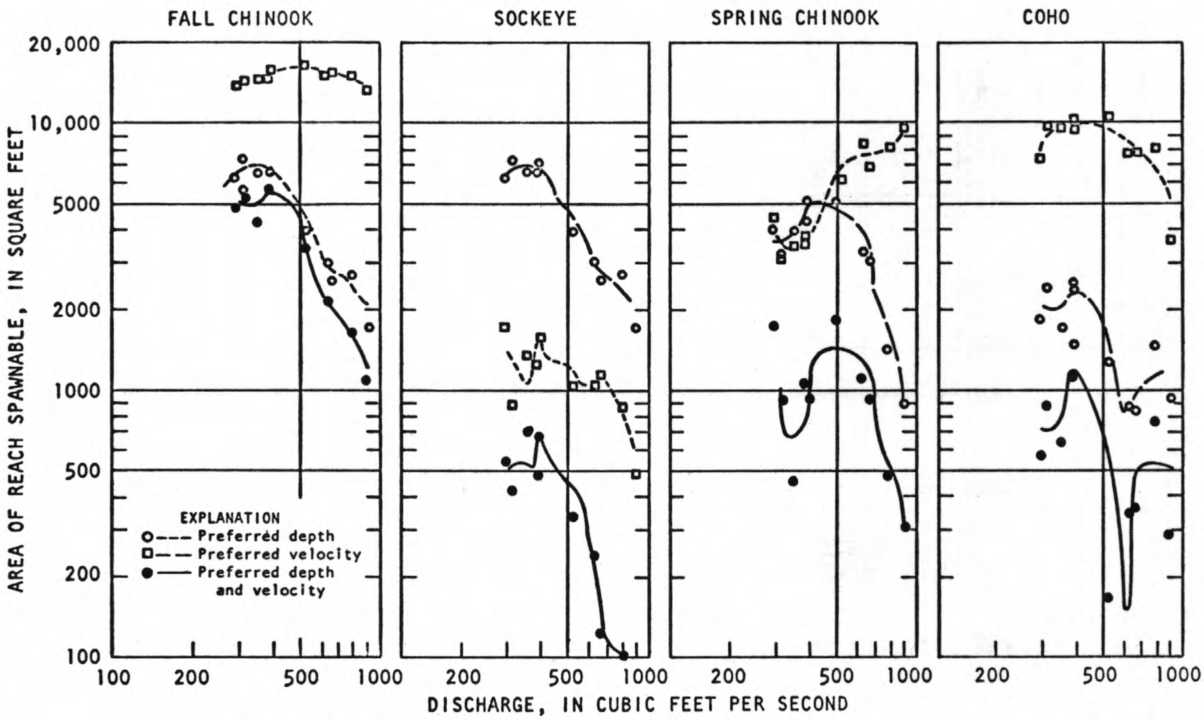


FIGURE 31.--Curves of spawnable area versus discharge, North Fork Toutle River reach A.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 31-33. Following is a list of the preferred spawning discharges, by species and study reach, for the North Fork Toutle River:

Salmon species	Preferred spawning discharge (cfs) Study reach A	B	C
Fall chinook	400	290	570
Sockeye	390	300	600
Spring chinook	480	345	680
Coho	380	300	390

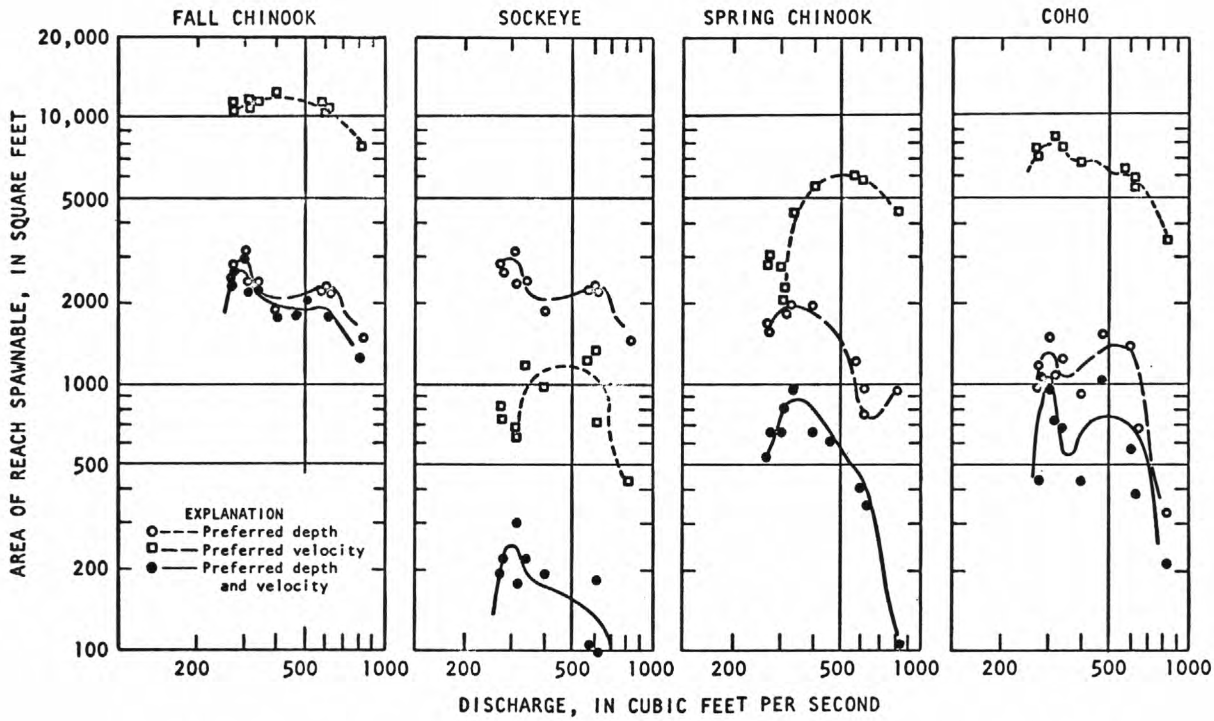


FIGURE 32.--Curves of spawnable area versus discharge, North Fork Toutle River reach B.

The crests of all curves (figs. 31-33) are fairly well defined.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 34 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities for these rearing discharges, are shown in figure 35.

The following table shows the results of the rearing-discharge investigation:

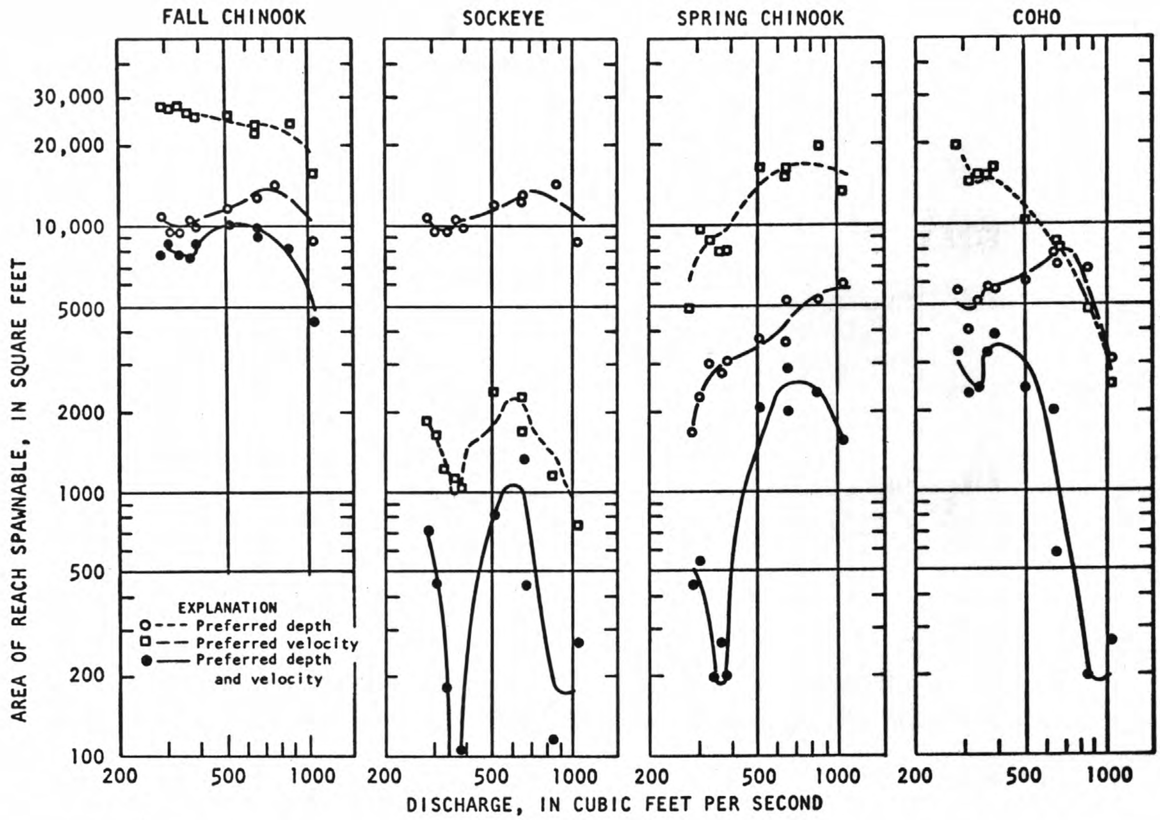


FIGURE 33.--Curves of spawnable area versus discharge, North Fork Toutle River reach C.

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	410	350	500
Equivalent discharge at the gage (cfs)	494	420	605
Percentage probability of rearing discharge being equaled or exceeded during September, the month with the lowest flow (fig.30)	45	65	29
Discharge at the 50-percent-probability level for September (cfs)	391	391	391

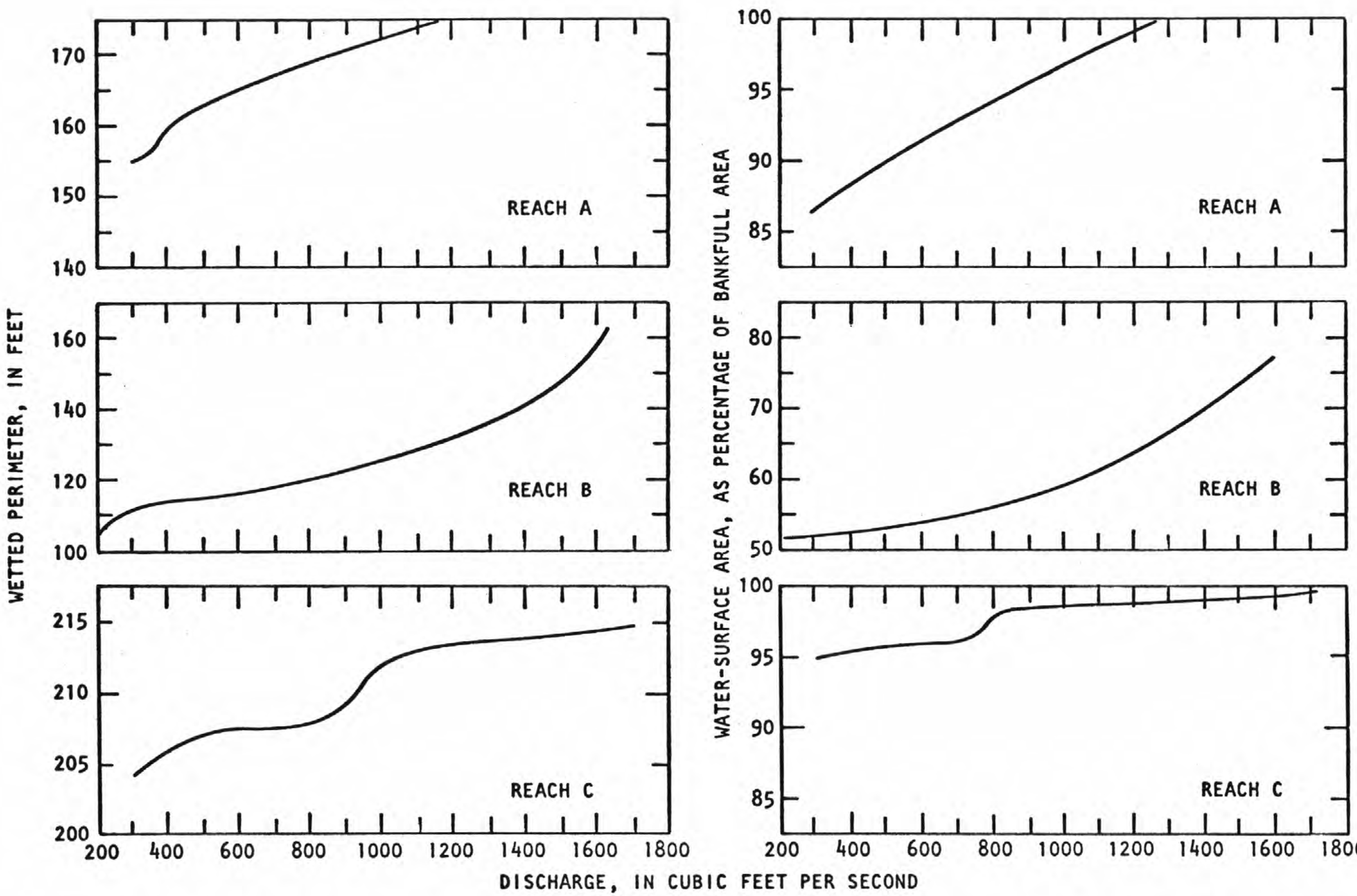


FIGURE 34.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, North Fork Toutle River study reaches.

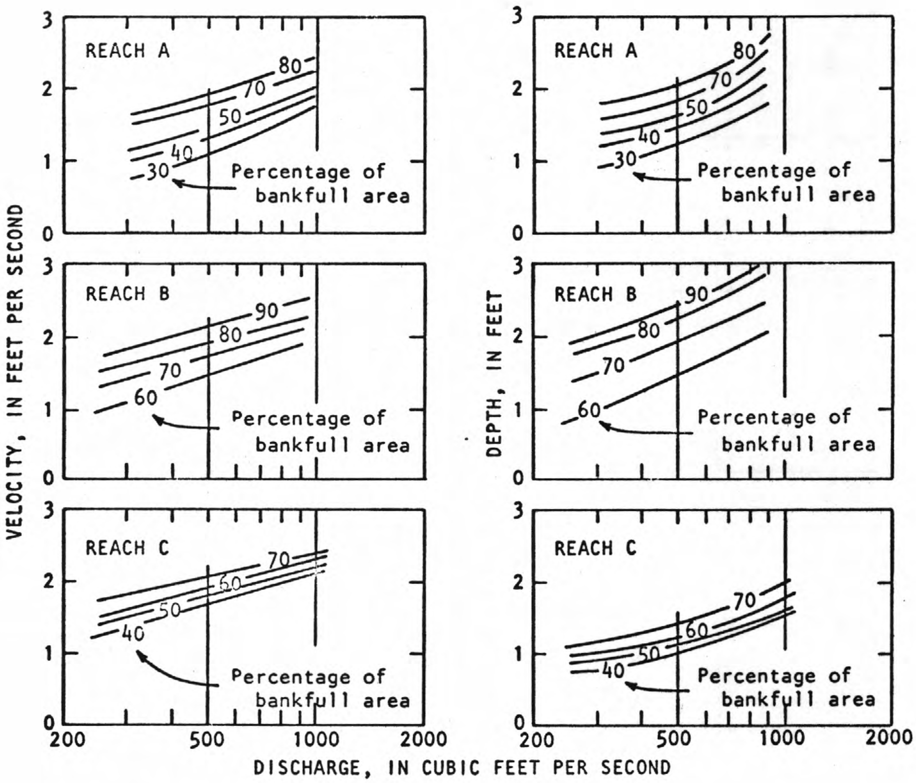


FIGURE 35.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, North Fork Toutle River study reaches.

The equivalent discharge at the gage was determined by solving the reach regression model for Q_G and substituting the preferred rearing discharge of the reach into the equation. The discharge at the 50-percent-probability level for September was assumed to be the naturally occurring limiting discharge for salmon that utilize the stream for rearing year around (fig. 2).

The desirability of a river as a rearing area is partly dependent on the amounts of pools and riffles in the stream (Ruggles, 1966). From aerial photographs of an 8.1-mile length of river, measurements showed that 72.4 percent of this length was riffle area and 27.6 percent was pool area. Investigations of reaches B and C starting from a point 3.1 miles below reach A, showed a decreasing amount of riffle area in the downstream direction. The results of the measurements above and (or) below reaches B and C are as follows:

Study reach	Miles of river near or including study reach	Percentage riffle area
B	3.6	72.7
C	3.3	68.9

Deschutes River

Location.--Figure 1 shows the location of the river and the study reaches. The study reaches are described as follows:

Reach A. Lat 46°47'53", long 122°29'02", in NW¼SW¼ sec.7, T.15 N., R.3 E., at river mile 37.4.

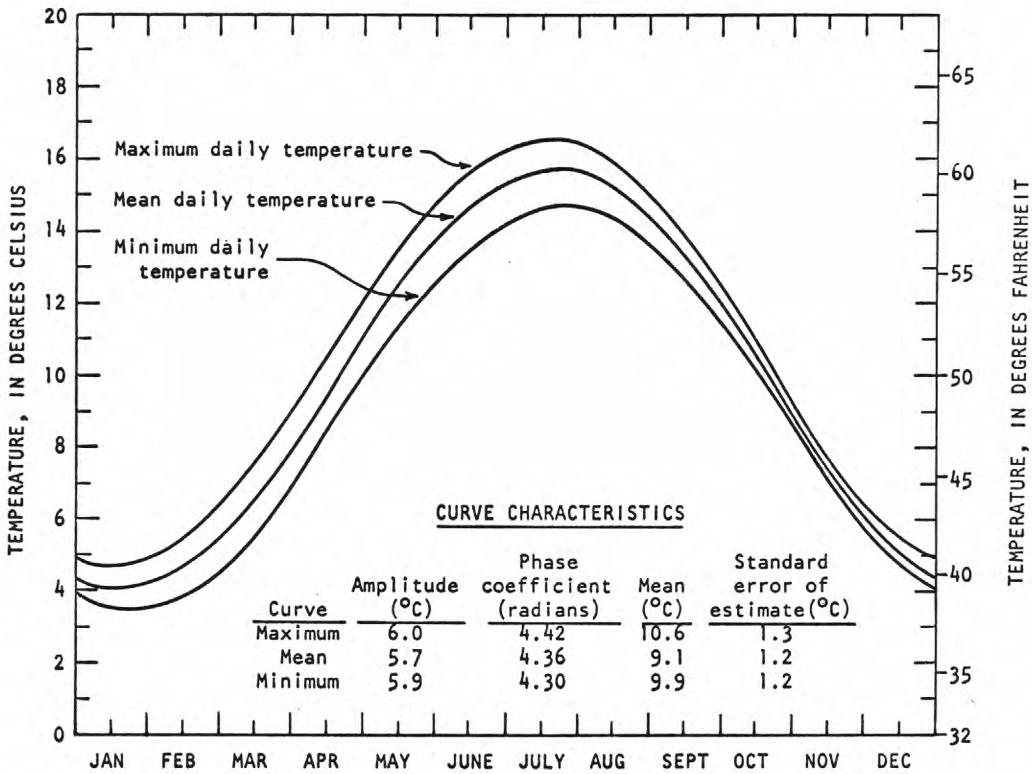
Reach B. Lat 46°50'42", long 122°36', in SW¼NE¼ sec.30, T.16 N., R.2 E., at river mile 28.9.

Reach C. Lat 46°57'27", long 122°52', in NE¼SE¼ sec.13, T.17 N., R.2 W., at river mile 9.4.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	550	415	165
Wetted perimeter (ft)[1]	78	100	93
Channel width (ft)[1]	72	96	88
Channel depth (ft)[1]	2.5	2.4	3.3
Bankfull water-surface area (sq ft)	12,600	13,300	19,600
River and basin parameters:			
Drainage area (sq mi)	56.2	76.0	139
Main-stem length (mi)	15.7	24.8	44.3
Main-stem channel slope (ft/mi)	88	59	28
Mean basin altitude	1,670	1,460	1,060
The altitude at the source of the river is 3,280 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.



Curve	Amplitude (°C)	Phase coefficient (radians)	Mean (°C)	Standard error of estimate (°C)
Maximum	6.0	4.42	10.6	1.3
Mean	5.7	4.36	9.1	1.2
Minimum	5.9	4.30	9.9	1.2

FIGURE 36.--Annual stream-temperature distribution in 1970, Deschutes River near Rainier (12079000). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

Chemical characteristics.--For documentation purposes, table 16 presents some physiochemical parameters of the water at each of the three study reaches, along with stream discharges.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on the Deschutes River (12079000), and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1970 are shown in figure 36.

All water sampled at each of the study reaches had nearly 100-percent DO saturation.

The suspended-sediment concentrations were low, only ranging from 0 to 7 mg/l for the 30 samples collected at all reaches (table 16).

TABLE 16.--Selected chemical and physical characteristics of water in study reaches on Deschutes River

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
3-19-70	186	4.4	40	12.5	3	58
4- 8	108	6.7	44	11.8	1	65
4-14	154	6.1	43	12.0	1	58
4-17	104	10.0	50	11.0	1	63
4-23	91	7.8	46	11.5	1	67
5-20	68	10.0	50	11.0	0	71
5-27	55	10.6	51	10.8	1	74
6- 3	47	20.6	69	8.8	1	79
6-22	31	22.2	72	8.5	2	85
7-20	22	16.7	62	9.4	3	90
			Reach B			
3-19-70	250	5.6	42	12.2	3	65
4- 8	149	8.9	48	11.2	1	77
4-14	206	7.2	45	11.7	2	69
4-17	144	10.0	50	11.0	3	76
4-23	124	9.4	49	11.1	3	80
5-20	88	11.7	53	10.5	2	84
5-27	68	11.7	53	10.5	1	90
6- 3	58	17.8	64	9.2	1	94
6-22	40	18.3	65	9.1	3	102
7-20	26	17.8	64	9.2	6	113
			Reach C			
3-19-70	397	7.8	46	11.5	3	83
4- 8	246	9.4	49	11.1	--	93
4-14	313	10.0	50	11.0	4	86
4-17	240	10.0	50	11.0	3	93
4-23	225	10.6	51	10.8	6	98
5-20	170	12.2	54	10.4	2	104
5-27	139	13.3	56	10.2	3	104
6- 3	127	16.7	62	9.4	5	113
6-22	93	16.7	62	9.4	7	120
7-20	68	17.2	63	9.3	6	127

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
Study reach	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	0	34.0	31.3	24.6	10.2
B	0	8.8	39.2	32.9	19.1
C	0	11.5	43.2	28.5	16.8

The percentage of gravel in the 0.15- to 6-inch size range was fairly uniform between reaches B and C but the gravel was coarser at reach A.

Streamflow characteristics and evaluation.--The measured discharges at each reach (Q_A, Q_B, Q_C) were related to contemporaneous discharges at the gaging station (Q_G) to obtain a simple linear regression model for each reach. In addition, all discharge data were grouped and an analysis of covariance was performed. This analysis indicated that all reach models were significantly different, as follows:

$$Q_A = 0.41(Q_G)^{1.09}$$

$$Q_B = 0.39(Q_G)^{1.16}$$

$$Q_C = 2.75(Q_G)^{0.88} \quad .$$

The standard errors of estimate of the models are 2, 3, and 4 percent for reaches A, B, and C, respectively.

Discharge records at the gaging stations cover a period of sufficient length to allow computation of the probability distributions of the mean monthly discharges (fig. 37). By using the above regression models and figure 37, the probabilities of various discharges can be estimated for each of the reaches.

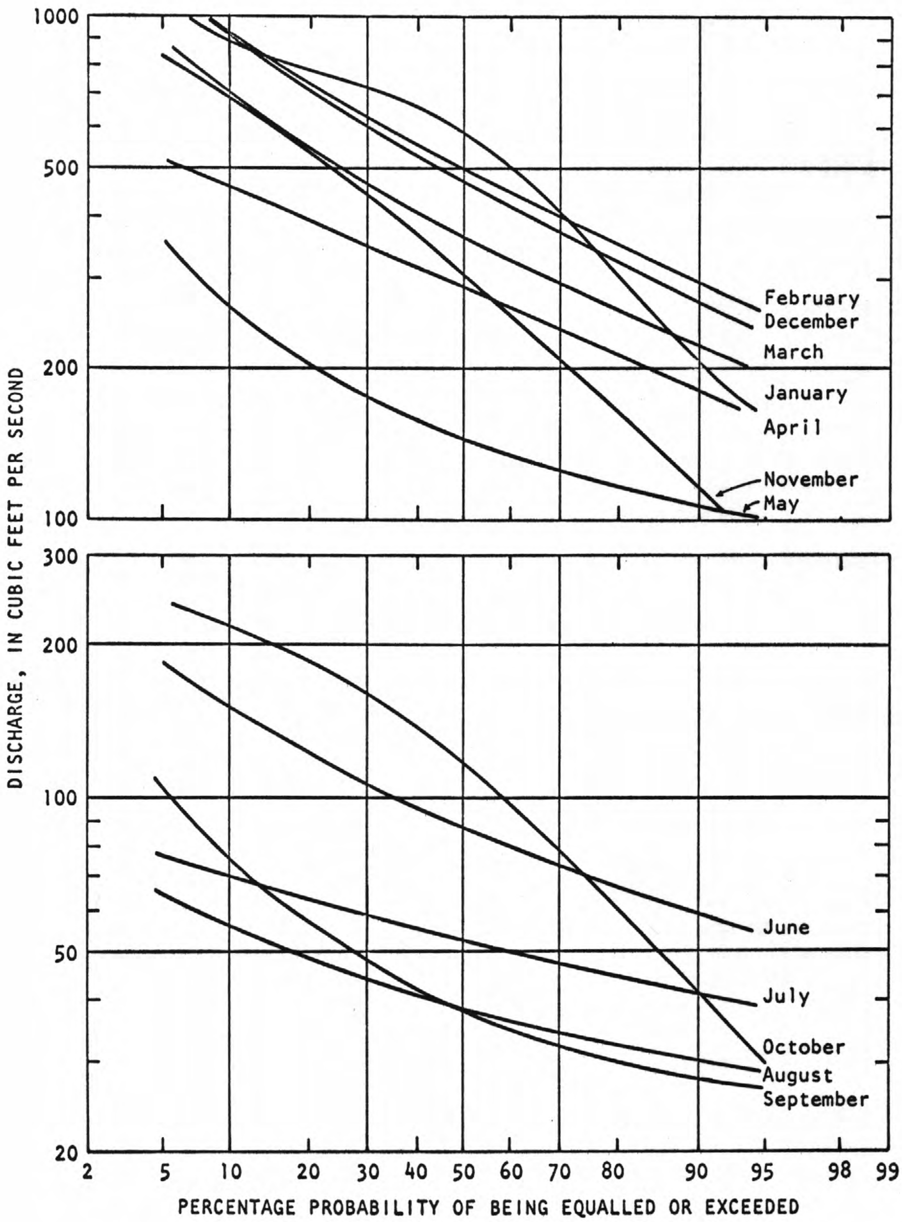


FIGURE 37.--Probability distributions of monthly mean discharges, Deschutes River near Rainier (12079000).

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 38-40. Following is a list of the preferred spawning discharges, by species and study reach, for the Deschutes River:

Salmon species	Preferred spawning discharge (cfs)		
	Study reach		
	A	B	C
Fall chinook	145	100	145
Sockeye	165	140	170
Spring chinook	160	210	230
Coho	130	105	125

The crests of all curves (figs. 38-40)are well defined.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 41 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these rearing discharges, are shown in figure 42.

The following table shows the results of the rearing-discharge investigation:

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	40	40	50
Equivalent discharge at the gage (cfs)	67	54	27
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig. 37)	5	12	94
Discharge at the 50-percent-probability level for September, the month with the lowest flow (cfs)	22	26	68

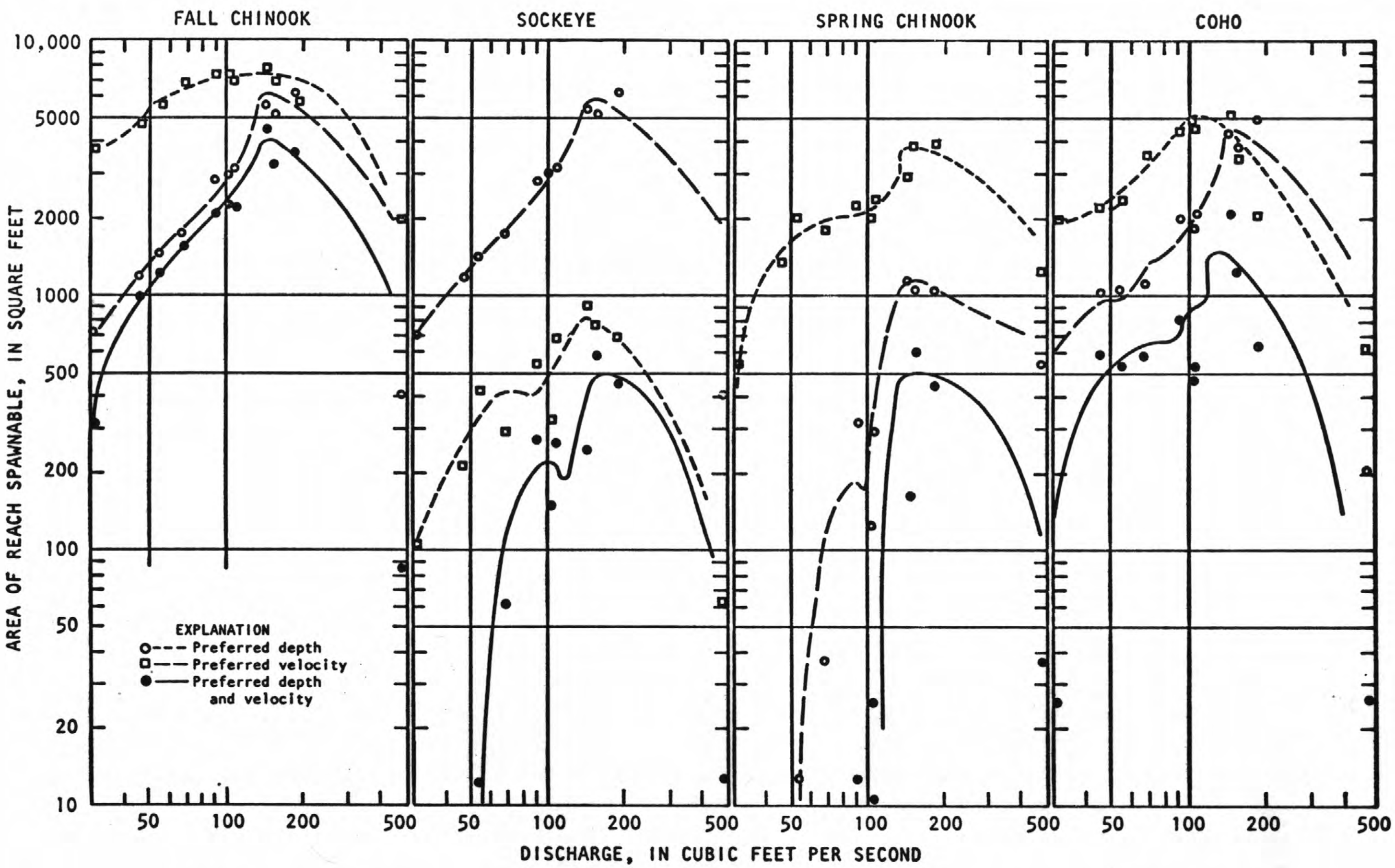


FIGURE 38.--Curves of spawnable area versus discharge, Deschutes River reach A.

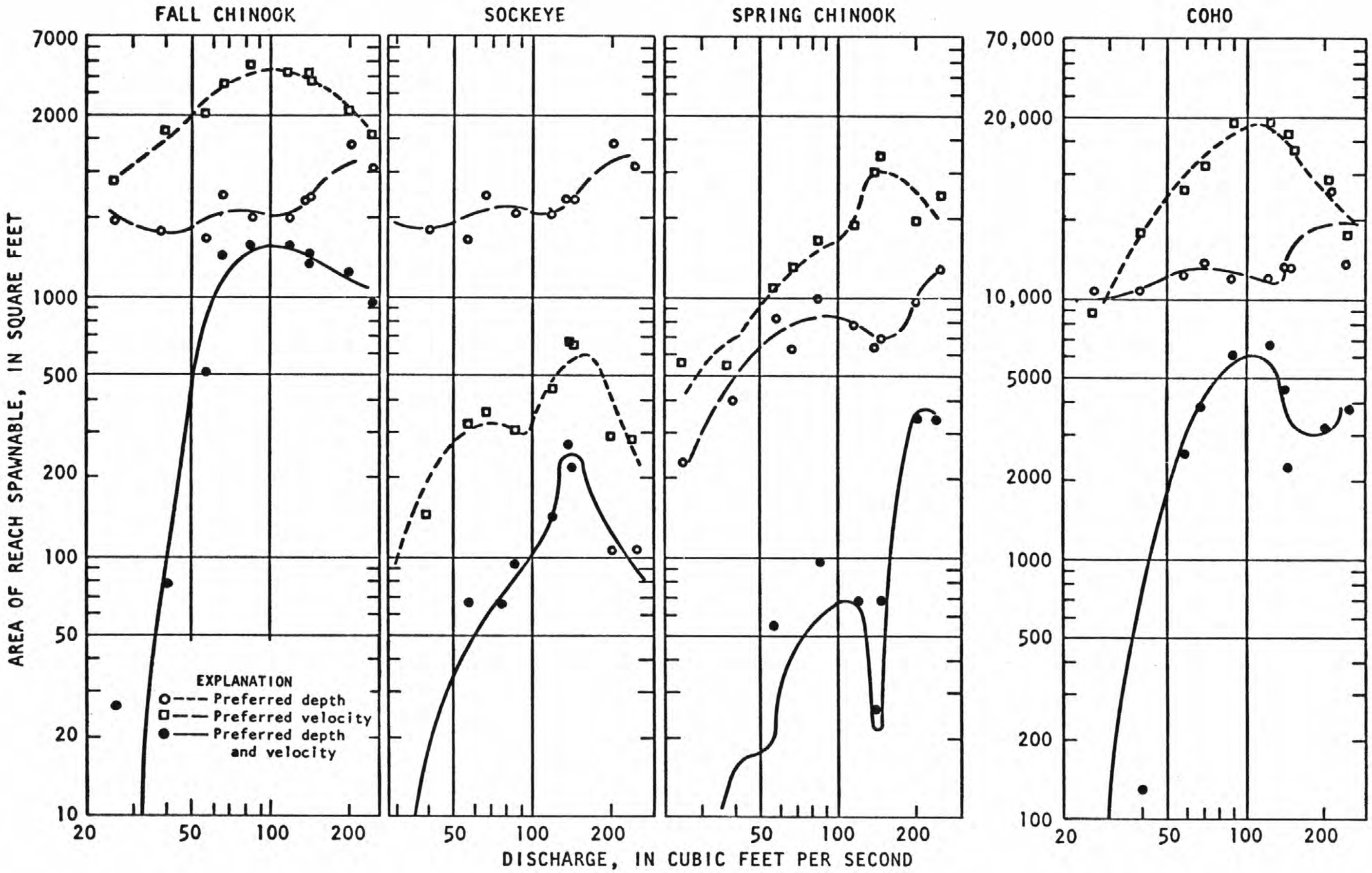


FIGURE 39.--Curves of spawnable area versus discharge, Deschutes River reach B.

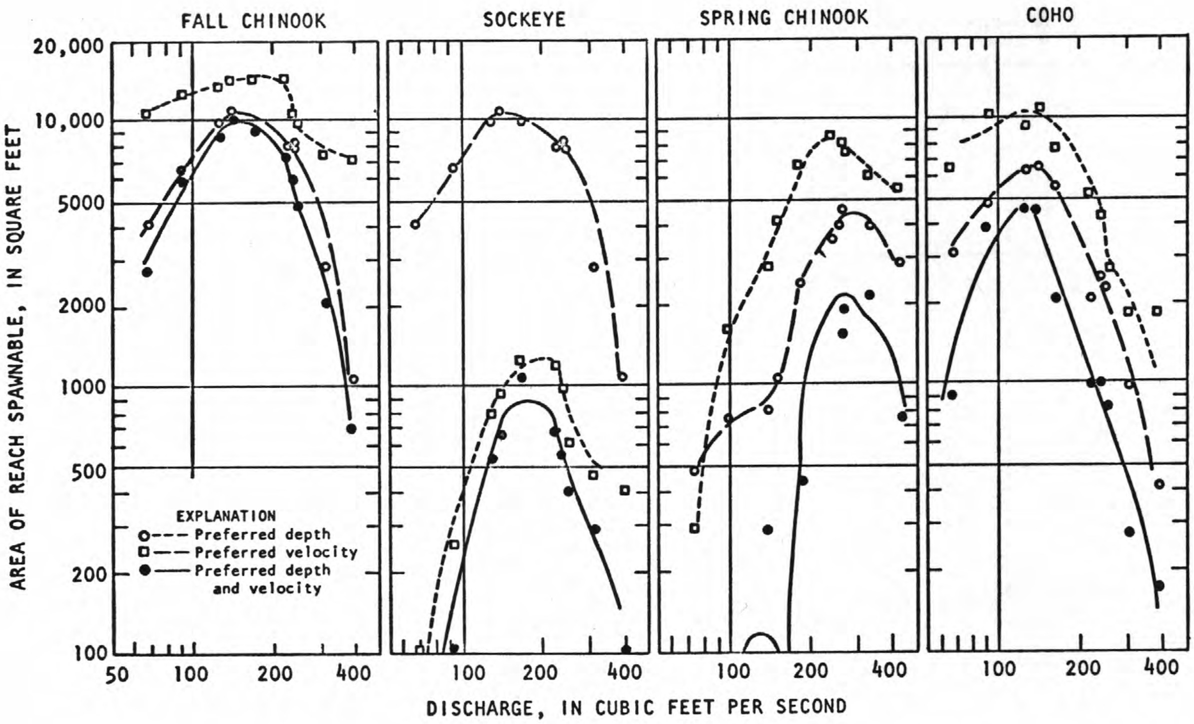


FIGURE 40.--Curves of spawnable area versus discharge, Deschutes River reach C.

The equivalent discharge at the gage was determined by solving the reach regression models for Q_G and substituting the preferred rearing discharge of the reach into the equation. The month of the lowest flow for rearing discharges was August for reaches A and B (fig. 37) and September for reach C. The discharge at the 50-percent-probability level for these months at these reaches is assumed to be the naturally occurring limiting flow for salmon that utilize the stream for rearing year around (fig. 2).

The desirability of a river as a rearing area is partly dependent upon the amounts of pools and riffles in the stream (Ruggles, 1966). Aerial photographs taken at a scale of about 1:2,000 and over a 37.4-mile length of the river about the study reaches show that 38 percent of the river area was riffle.

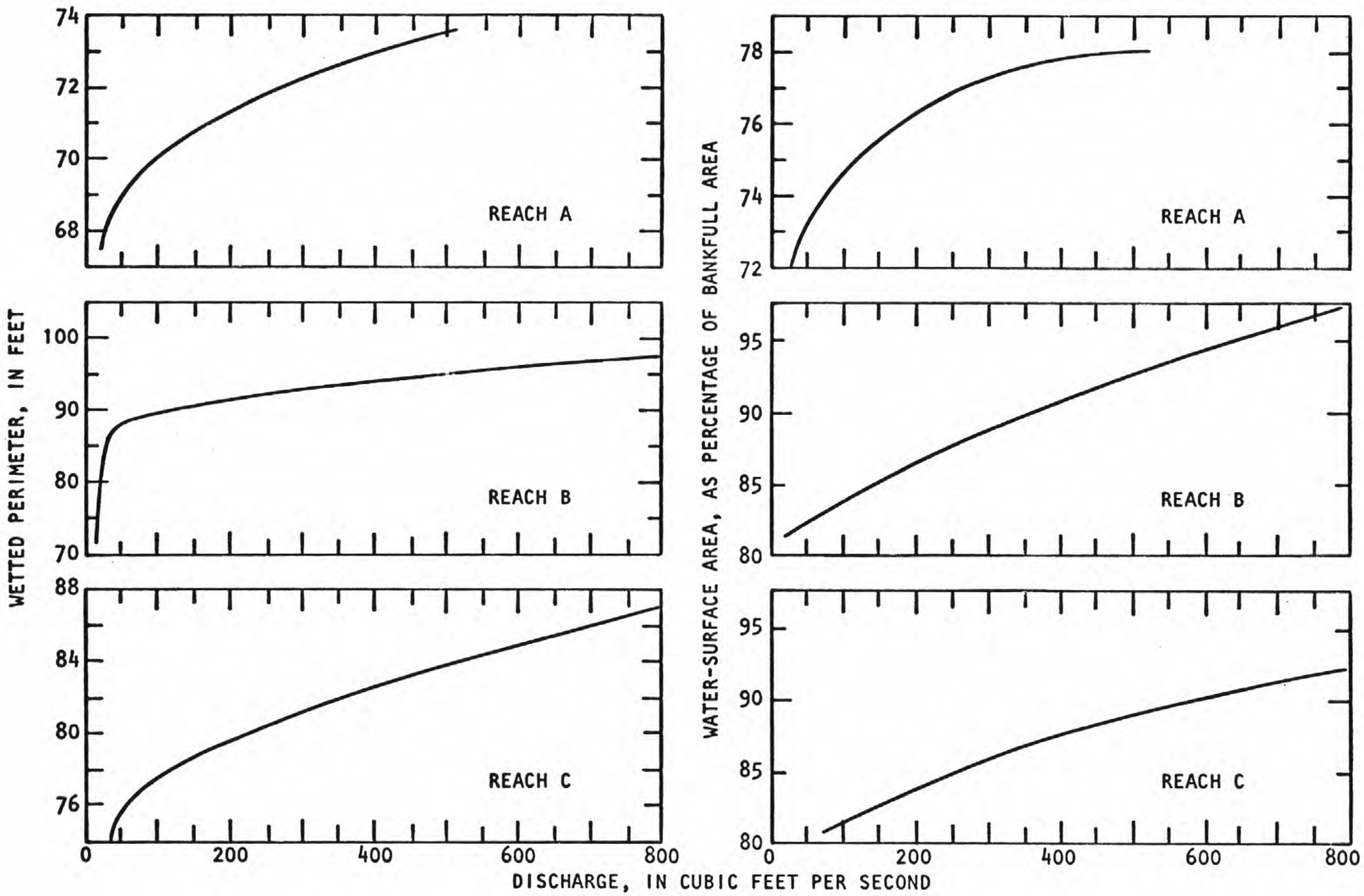


FIGURE 41.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, Deschutes River study reaches.

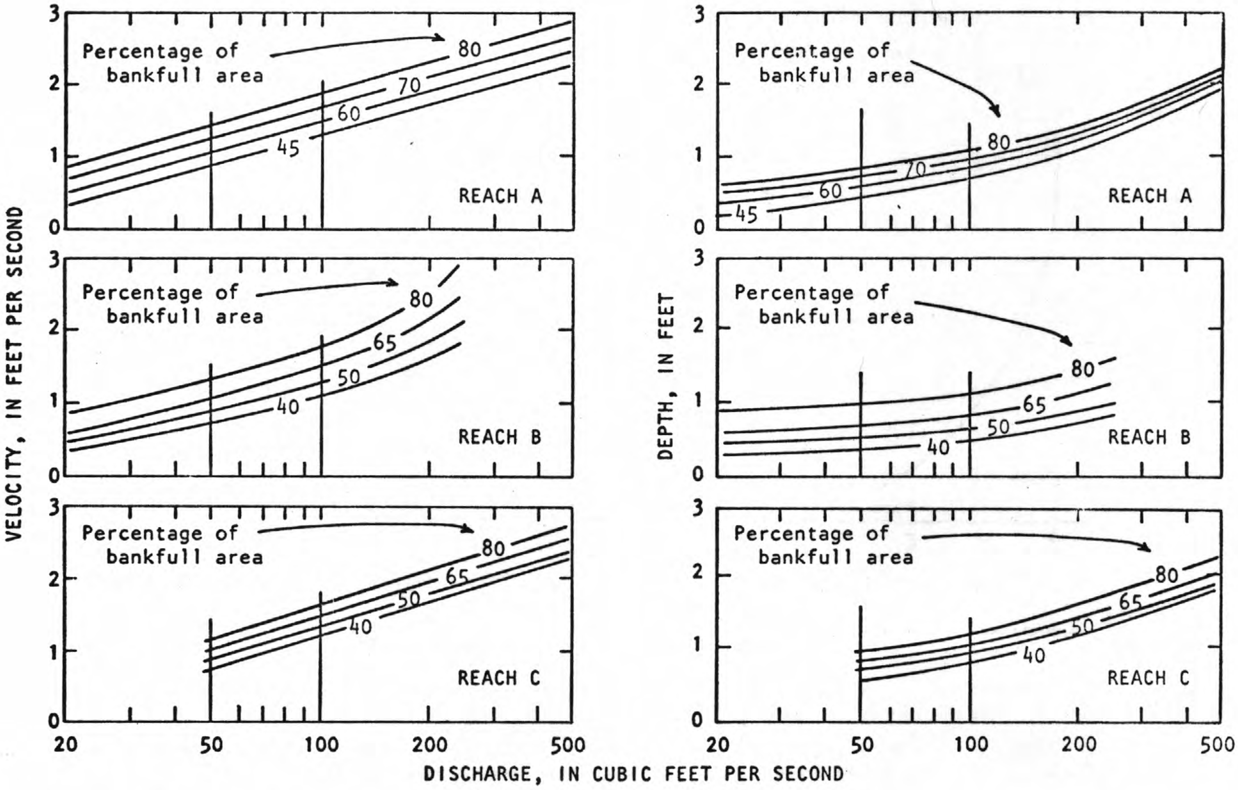


FIGURE 42.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, Deschutes River study reaches.

The reach investigation included a length of river from 4.0 miles above reach A to 5.5 miles below reach C. Determinations about each study reach showed that the pool-and-riffle relationship is about the same within the vicinity of reaches A and B but is considerably different in the vicinity of reach C. The results of the determinations of percentage of pools and riffles about each study reach are given below:

Study reach	Miles of river near or including study reach	Percentage riffle area
A	7.9	31.5
B	14.0	31.2
C	15.5	58.7

Dosewallips River

Location.--Figure 1 shows the location of the river and study reaches. The study reaches are described as follows:

Reach A. Lat 47°43'42", long 123°00'52", in NE¼SE¼ sec. 23, T. 26 N., R. 3 W., at river mile 7.2.

Reach B. Lat 47°43'05", long 122°56'50", in NE¼NE¼ sec. 29, T.26 N., R. 3 W., at river mile 3.9.

Reach C. Lat 47°41'44", long 122°54'33", in SE¼SE¼ sec. 34, T.26 N., R.2 W., at river mile 0.8.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	320	130	30
Wetted perimeter (ft)[1]	117	110	128
Channel width (ft)[1]	116	106	124
Channel depth (ft)[1]	3.0	3.2	2.4
Bankfull water-surface area (sq ft)	12,500	15,600	19,300
River and basin parameters:			
Drainage area (sq mi)	91.9	99.9	114.8
Main-stem length (mi)	20.4	23.7	26.8
Main-stem channel slope (ft/mi)	199	178	156
Mean basin altitude (ft msl)	4,750	4,480	4,130
The altitude at the source of the river is 6,000 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

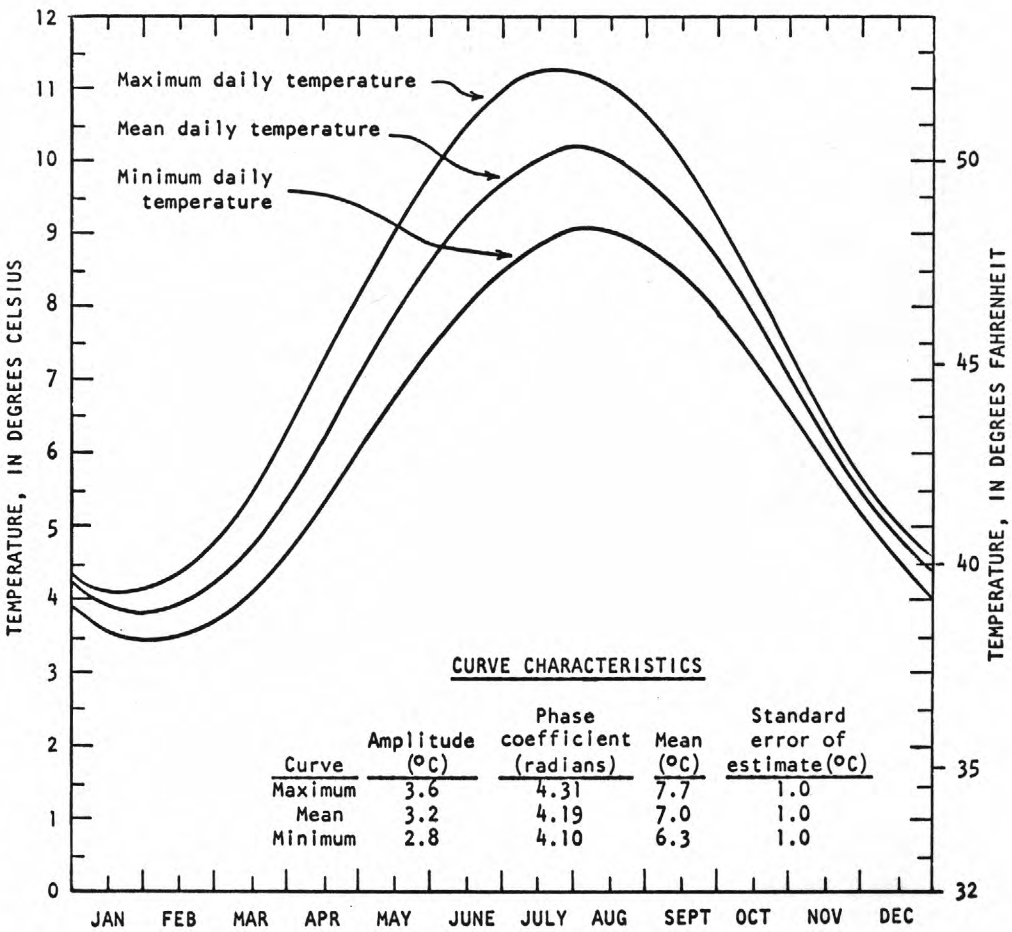


FIGURE 43.--Annual stream-temperature distribution in 1970, Dosewallips River near Brinnon (12053000). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

Chemical characteristics.--For documentation purposes, table 17 presents some physiochemical characteristics of the water at each of the three study reaches, along with stream discharges.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on the Dosewallips River (12053000), and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1970 are shown in figure 43.

All water sampled at each of the study reaches had nearly 100-percent DO saturation.

TABLE 17.--Selected chemical and physical characteristics of water in study reaches on Dosewallips River

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
5-27-70	830	6.1	43	12.0	10	75
6-17	750	7.8	46	11.5	6	73
7- 9	640	9.4	49	11.2	7	72
7-21	396	10.0	50	11.0	6	84
8- 4	273	10.6	51	10.8	5	92
8-10	233	11.7	53	10.5	4	96
8-20	179	11.7	53	10.5	3	100
9- 4	189	10.0	50	11.0	7	100
9-14	131	7.2	45	11.7	4	115
9-29	136	8.9	48	11.2	2	110
			Reach B			
5-27-70	778	6.1	43	12.0	13	80
6-17	731	9.4	49	11.1	5	75
7- 9	627	11.1	52	10.7	8	74
7-21	419	10.6	51	10.8	5	82
8- 4	267	12.2	54	10.4	5	92
8-10	226	13.9	57	10.0	1	96
8-20	196	13.6	56	10.1	3	100
9- 4	186	11.1	52	10.7	7	99
9-14	128	8.3	47	11.4	3	106
9-29	131	10.6	51	10.8	3	110
			Reach C			
5-27-70	775	7.2	45	11.7	12	76
6-17	712	11.1	52	10.7	12	88
7- 9	571	12.8	55	10.3	5	75
7-21	401	11.1	52	10.7	7	86
8- 4	264	13.3	56	10.2	4	92
8-10	235	15.0	59	9.8	0	96
8-20	185	14.4	58	9.9	2	100
9- 4	198	12.2	54	10.4	10	98
9-14	129	10.6	51	10.8	3	105
9-29	131	11.1	52	10.7	4	105

The suspended-sediment concentration was generally low, less than 13 mg/l in all samples collected.

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

Study reach	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	10.8	29.6	20.2	26.4	13.0
B	9.0	21.8	27.0	29.2	13.0
C	7.1	30.7	35.2	19.4	7.6

The percentage of gravel in the 0.15- to 6-inch size range increased in a downstream direction--that is, reach A had 76.2 percent, reach B had 78.0 percent, and reach C had 85.3 percent of its total sample within this size range.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station to obtain a simple linear regression model for each reach. In addition, an analysis of covariance was performed on the three discharge relations. The analysis indicated that (1) the discharge at reach A (Q_A) was equivalent to the discharge at the gaging station (Q_G), and (2) the discharges at reaches B (Q_B) and C (Q_C) were virtually equal, being defined by the relation:

$$Q_{B,C} = 1.17(Q_G)^{1.00} \quad .$$

The relation has a standard error of estimate of 4 percent.

Discharge records for the gaging station cover a period of sufficient length to allow computation of probability distributions of the mean monthly discharges (fig. 44). By using the above regression models and figure 44, the probabilities of various discharges can be estimated for each study reach.

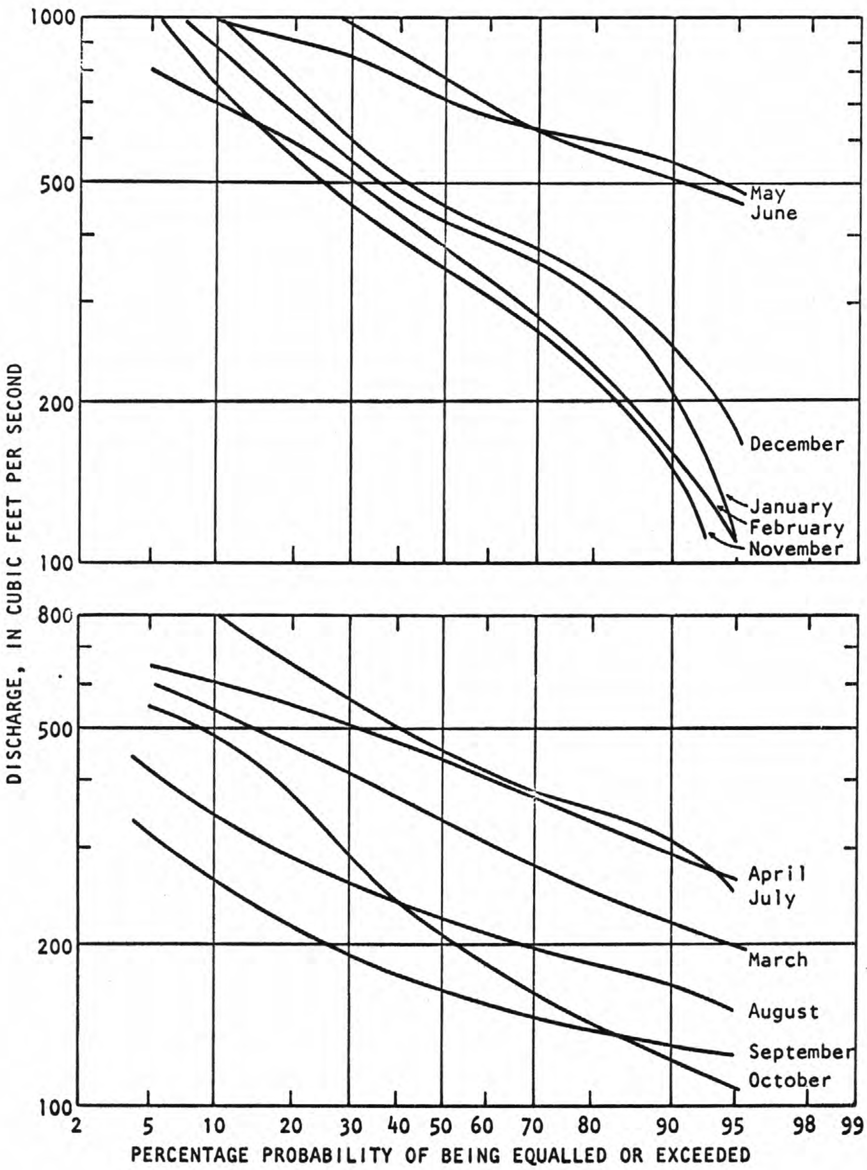


FIGURE 44.--Probability distributions of monthly mean discharges, Dosewallips River near Brinnon (12053000).

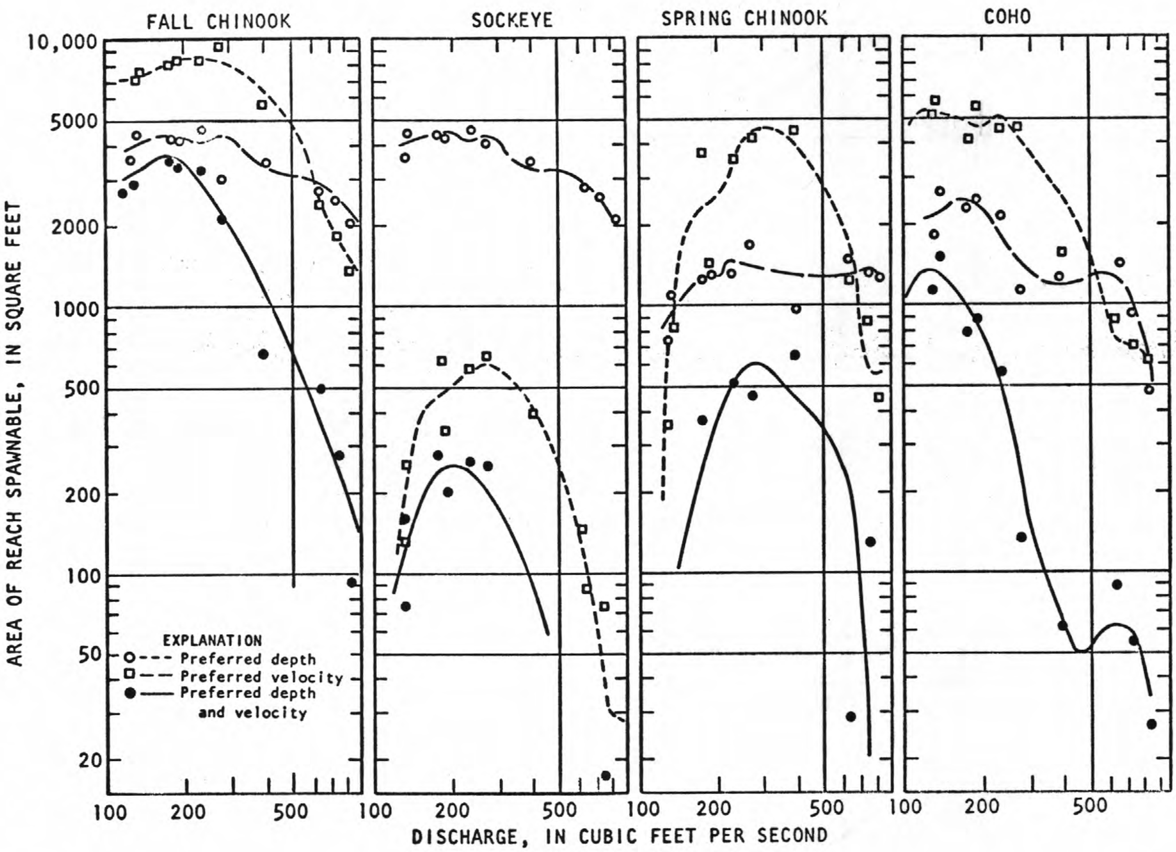


FIGURE 45.--Curves of spawnable area versus discharge, Dosewallips River reach A.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 45-47. Following is a list of the preferred spawning discharges, by species and study reach, for the Dosewallips River:

	Preferred spawning discharge (cfs)		
	Study reach		
Salmon species	A	B	C
Fall chinook	170	330	190
Sockeye	200	195	210
Spring chinook	280	210	350
Coho	125	180	200

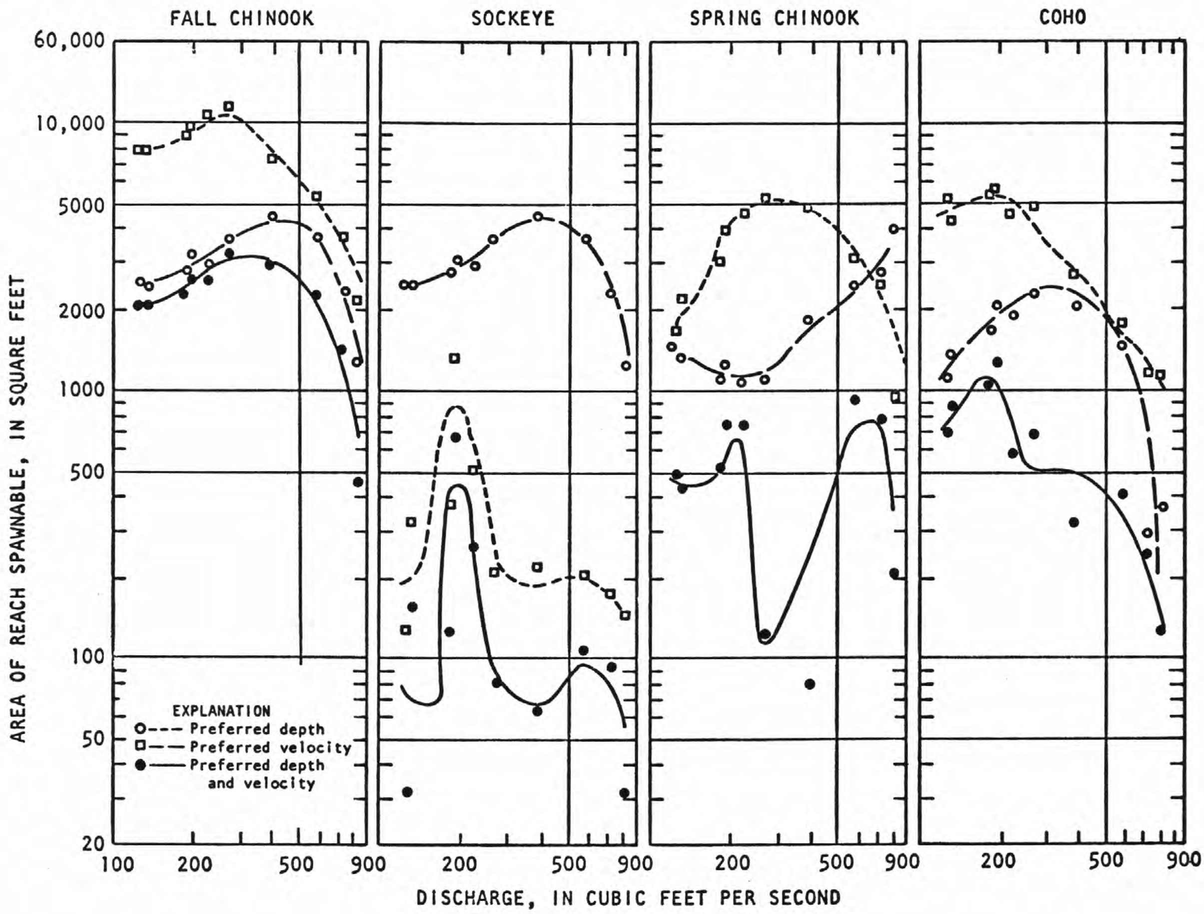


FIGURE 46.--Curves of spawnable area versus discharge, Dosewallips River reach B.

The crests of all curves are well defined (figs. 45-47) except those for spring chinook at reach B (fig. 46) where the curve shows two crests; the discharges represented by these crests were 210 and 650 cfs. The lower discharge (210 cfs) was selected as the preferred spawning discharge because velocity curve crests near that point and the increase in spawnable area is small.

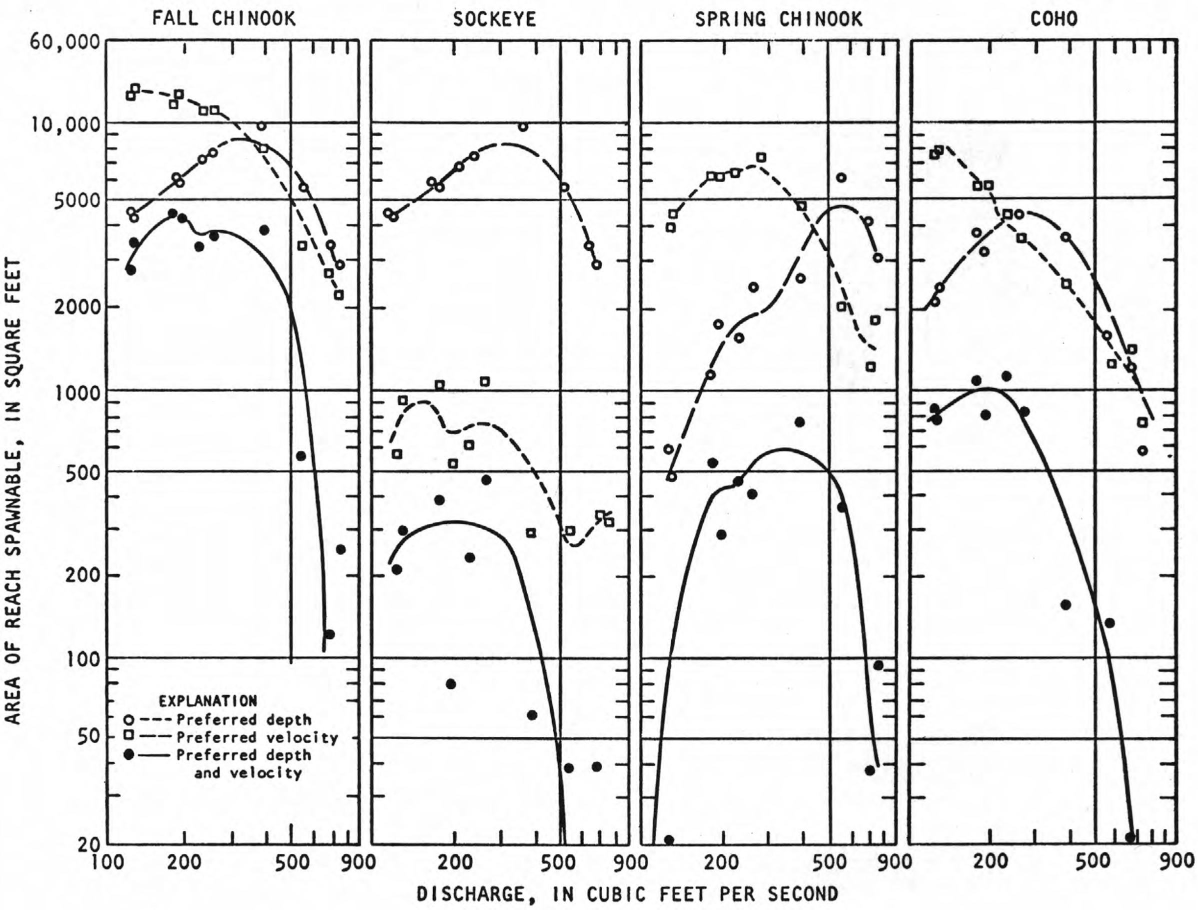


FIGURE 47.--Curves of spawnable area versus discharge, Dosewallips River reach C.

<u>Discharges for rearing</u>.--Discharges for salmon rearing were determined from the curve in figure 48, which allowed selection of a rearing discharge on the basis of the area of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these discharges, are shown in figure 49.

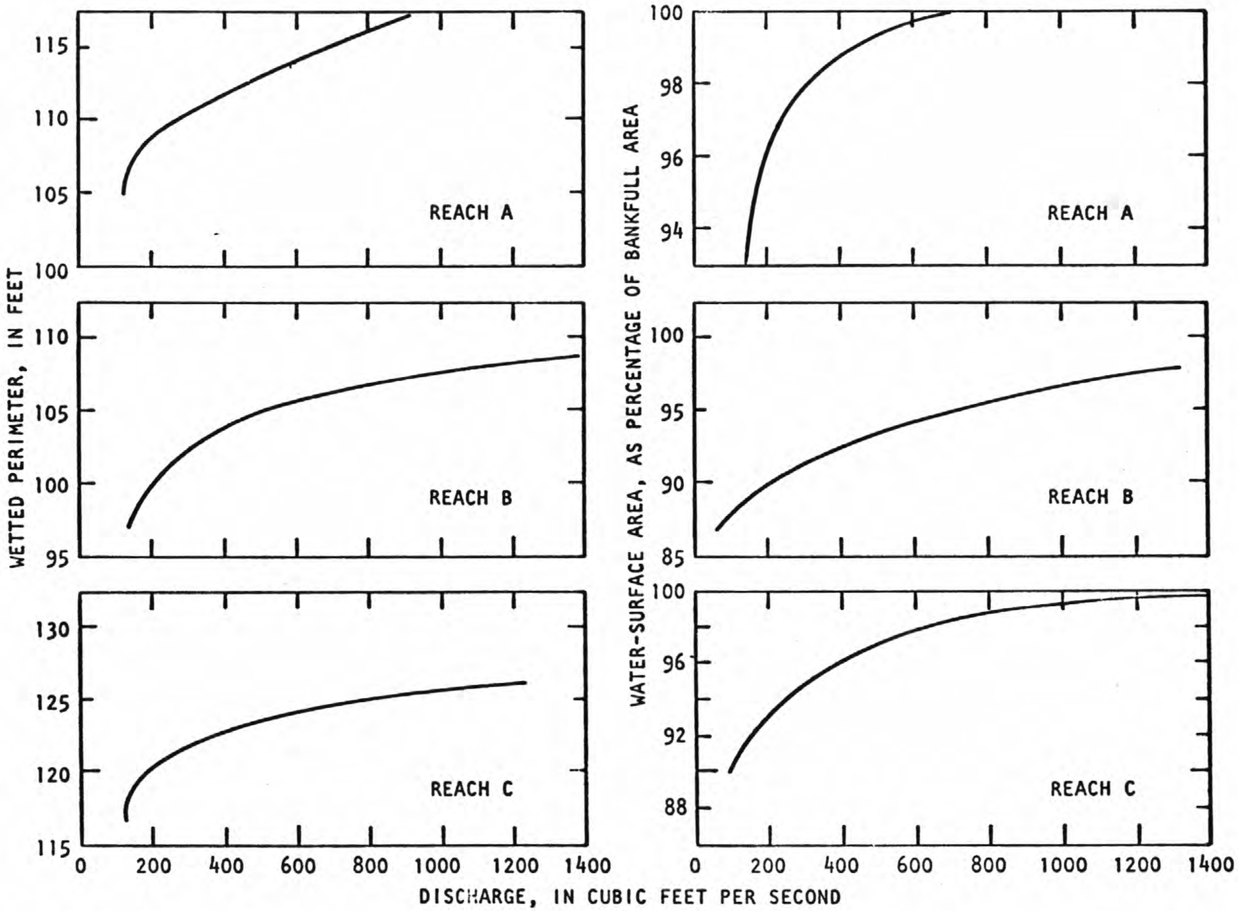


FIGURE 48.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, Dosewallips River study reaches.

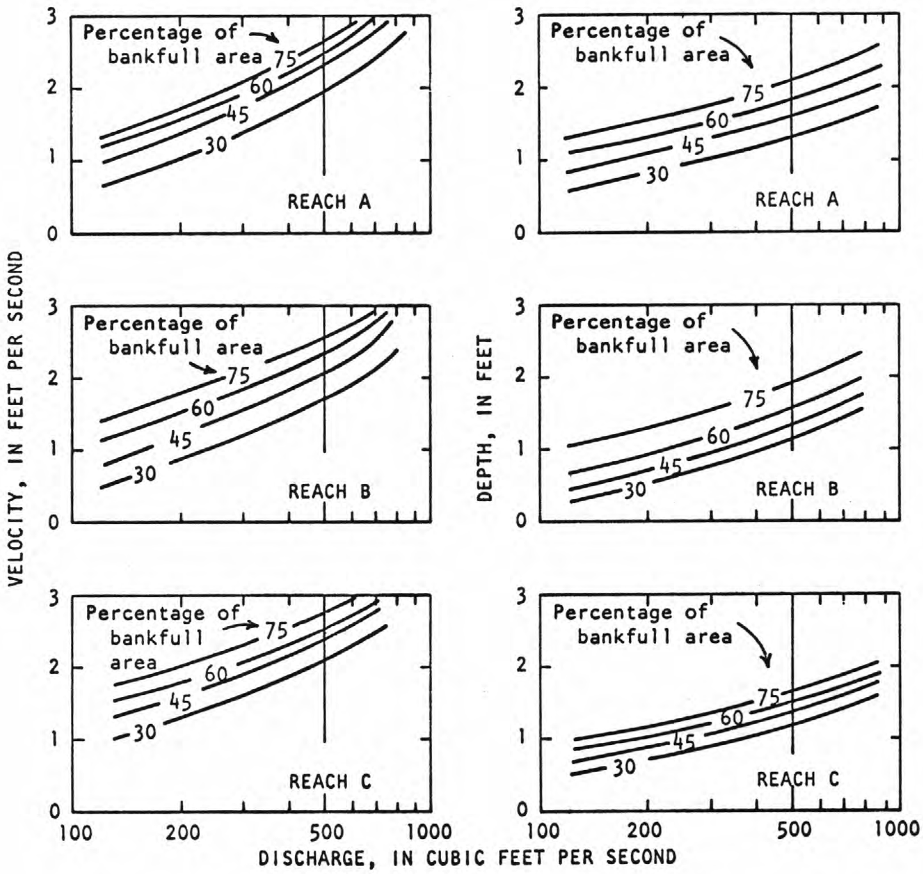


FIGURE 49.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, Dosewallips River study reaches.

The following table shows the results of the rearing-discharge investigation:

	Study reach A	Study reach B	Study reach C
Preferred rearing discharge (cfs)	180	300	220
Equivalent discharge at the gage (cfs)	180	256	188
Percentage probability of rearing discharge being equaled or exceeded in September (fig. 44)	40	10	35
Discharge at the 50-percent-probability level for September, the month with the lowest flow (cfs)	165	193	193

The equivalent discharge at the gage was determined by solving the reach regression model for Q_G and substituting the preferred rearing discharge of the reach into the equation.

The Dosewallips River is used mainly by pink salmon, which start migration to salt water after rising from the gravel. However, coho and spring chinook utilize water for rearing during every month of the year. The naturally occurring limiting flow for the year was selected as the discharge which has a 50-percent probability of occurrence in September--the month with the lowest flow of the year.

North Fork Stillaguamish River

Location.--Figure 1 shows the location of the river and study reaches. The study reaches are described as follows:

Reach A. Lat 48°16'33", long 121°38'38", in NE¼SE¼ sec. 9, T.32 N., R.9 E., at river mile 34.0.

Reach B. Lat 48°16'52", long 121°42'52", in NE¼NE¼ sec.12, T.32 N., R.8 E., at river mile 29.0.

Reach C. Lat 48°16'37", long 121°54'31", in SW¼NE¼ sec.9, T.32 N., R.7 E., at river mile 16.1.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	460	385	190
Wetted perimeter (ft)[1]	123	202	204
Channel width (ft)[1]	120	198	200
Channel depth (ft)[1]	2.6	6.3	3.5
Bankfull water-surface area (sq ft)	14,100	24,800	37,400
River and basin parameters:			
Drainage area (sq mi)	51.5	89.7	162
Main-stem length (mi)	14.5	19.5	32.4
Main-stem channel slope (ft/mi)	125	90	50
Mean basin altitude (ft msl)	2,500	2,340	2,480
The altitude at the source of the river is 3,210 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

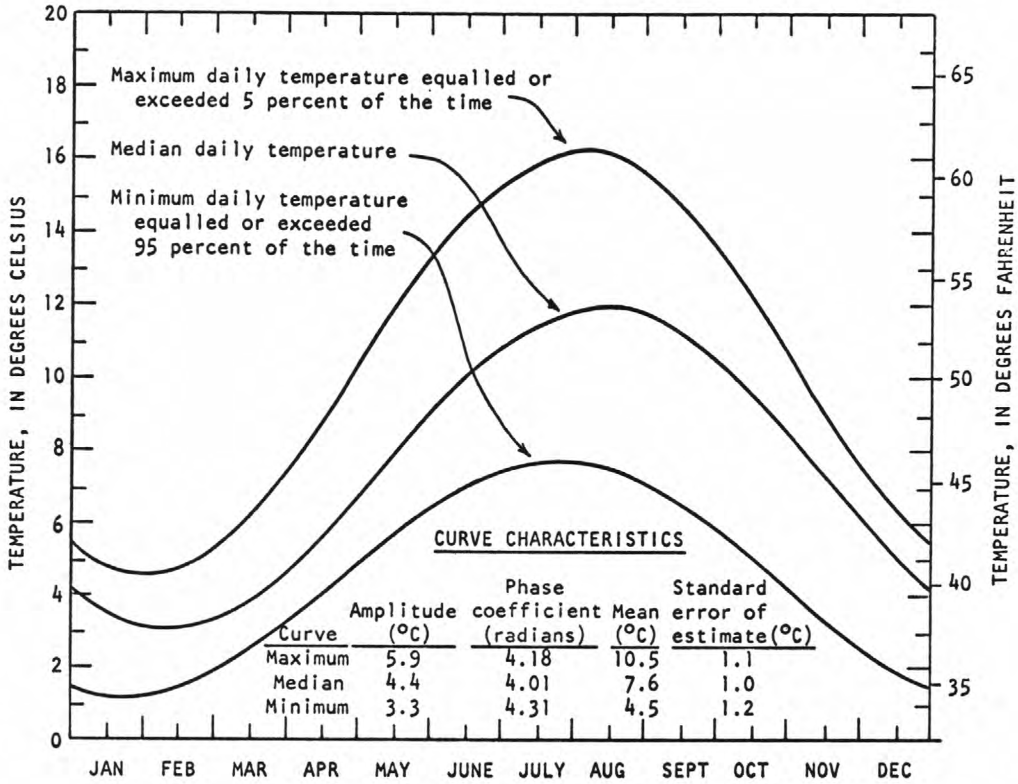


FIGURE 50.--Annual stream-temperature distribution for North Fork Stillaguamish River near Darrington (12167000). Curves represent the 90-percent confidence interval between the maximum and minimum water temperatures during 1959-69.

Chemical characteristics.-- For documentation purposes, table 18 presents some physiochemical characteristics of the water at each of the three study reaches, along with stream discharge.

Stream temperatures were documented by an analysis of the long-term thermograph record from the gaging station on the North Fork Stillaguamish River (12167000), and by measurements made during each visit to the reaches. The results, which define the 90-percent-probability range of water temperatures and the mean water temperatures for 1959-69, are shown in figure 50.

All water sampled at each of the study reaches had nearly 100-percent DO saturation.

TABLE 18.--Selected chemical and physical characteristics of water in study reaches on North Fork Stillaguamish River

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
4-24-70	208	5.0	41	12.3	10	--
5- 4	347	8.3	47	11.4	3	38
5-12	182	6.1	43	12.0	1	46
6-15	100	10.6	51	10.8	1	54
6-23	59	13.9	57	10.0	1	58
6-30	42	10.6	51	10.8	5	65
7- 8	28	15.6	60	9.7	3	79
7-15	22	15.6	60	9.7	2	85
8-12	20	15.6	60	9.7	0	78
8-26	15	13.9	57	10.0	0	85
			Reach B			
4-24-70	407	6.1	43	12.0	7	47
5- 4	642	8.3	47	11.4	--	36
5-12	367	6.7	44	11.8	1	43
6-15	325	9.4	49	11.1	2	42
6-23	260	13.9	57	10.0	2	39
6-30	168	10.6	51	10.8	1	47
7- 8	133	13.9	57	10.0	4	41
7-15	92	14.4	58	9.9	2	49
8-12	73	16.7	62	9.4	0	59
8-26	47	14.4	58	9.9	0	68
			Reach C			
5- 4-70	1,200	8.3	47	11.4	9	47
5-12	796	6.7	44	11.8	1	55
5-15	700	9.4	49	11.1	1	--
6-23	600	16.7	62	9.4	3	45
6-30	414	12.8	55	10.3	4	60
7- 8	367	17.8	64	9.2	5	58
7-15	301	18.9	66	9.0	2	65
8-12	245	18.9	66	9.0	1	74
8-26	203	17.8	64	9.2	--	79
9-30	357	12.8	55	10.3	1	70

The suspended-sediment concentrations were very low, ranging from 0 to 10 mg/l for the 28 samples collected at all reaches (table 18) over a discharge range of 15 to 1,200 cfs.

<u>Streambed gravel</u>.--Samples of streambed gravel from each reach were evaluated, with the following results:

Study reach	Average weight fraction of total sample (percent) — Gravel size (inches): Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	0	8.1	32.9	42.3	16.7
B	3.7	39.0	26.1	23.1	8.1
C	14.4	22.8	25.0	24.8	13.0

Reach A showed a larger fraction of fine gravels (0.15-1 inch) than did reaches B and C.

<u>Streamflow characteristics and evaluation</u>.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station (Q_G) to obtain a simple linear regression model for the three reaches (Q_A, Q_B, and Q_C). To further evaluate the relations between the discharge at each reach and the discharge at the gaging station, the regression models were statistically tested and found to be significantly different from each other, as follows:

$$Q_A = 0.004(Q_G)^{1.49}$$

$$Q_B = 0.13(Q_G)^{1.12}$$

$$Q_C = 3.44(Q_G)^{0.75} \quad .$$

The standard errors of estimate are 17, 19, and 13 percent for the models of reaches A, B, and C, respectively.

Discharge records at the gaging station cover a period of sufficient length to allow computation of the probability distributions of the mean monthly discharges (fig. 51). By using the above regression models with figure 51, the probabilities of various discharges can be estimated for each study reach.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 52-54. Following is a list of the preferred spawning discharges, by species and study reach, for the North Fork Stillaguamish River:

	Preferred spawning discharge (cfs)		
	Study reach		
Salmon species	A	B	C
Fall chinook	145	150	410
Sockeye	113	145	370
Spring chinook	180	290	450
Coho	135	125	250

The crests of all curves (figs. 52-54) are well defined.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 55 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these discharges, are shown in figure 56.

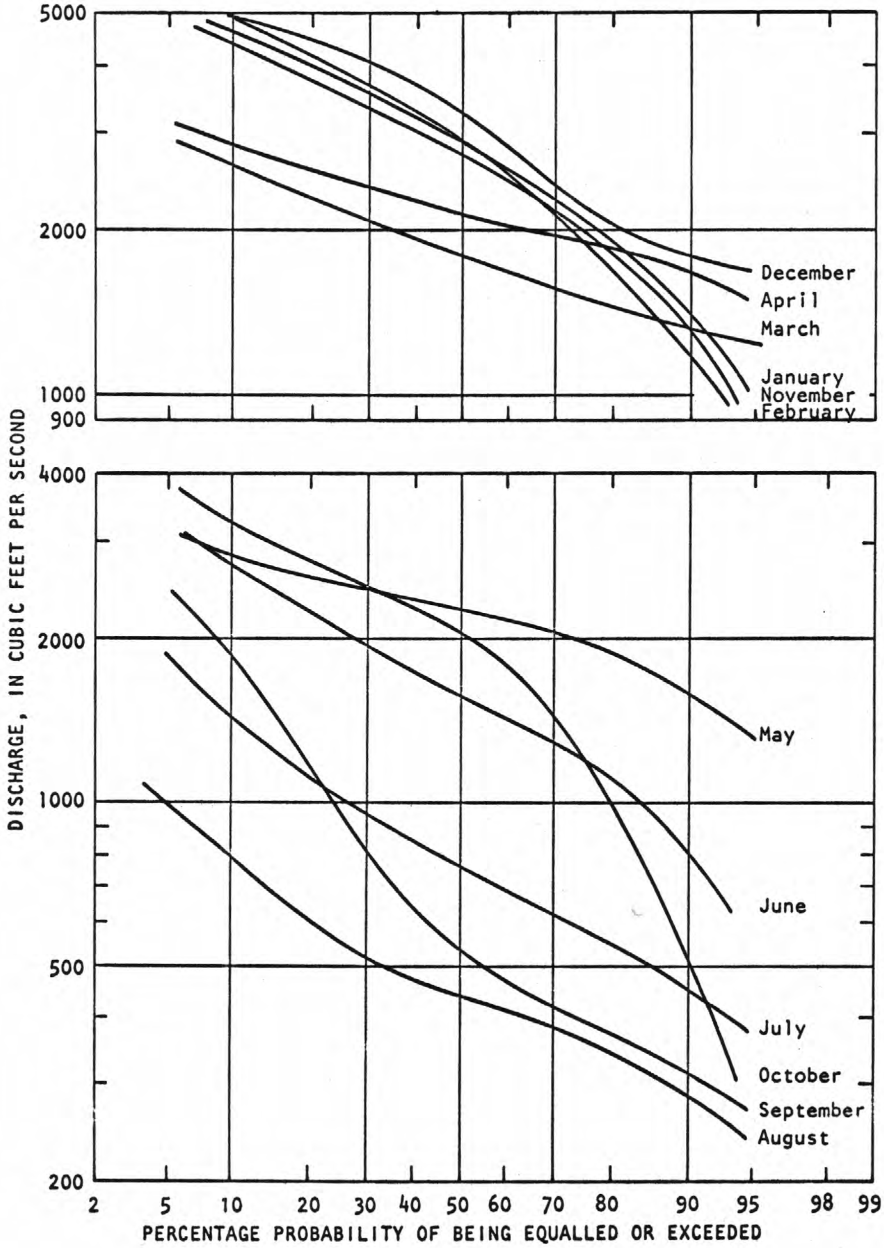


FIGURE 51.--Probability distributions of monthly mean discharges, North Fork Stillaguamish River near Arlington (12167000).

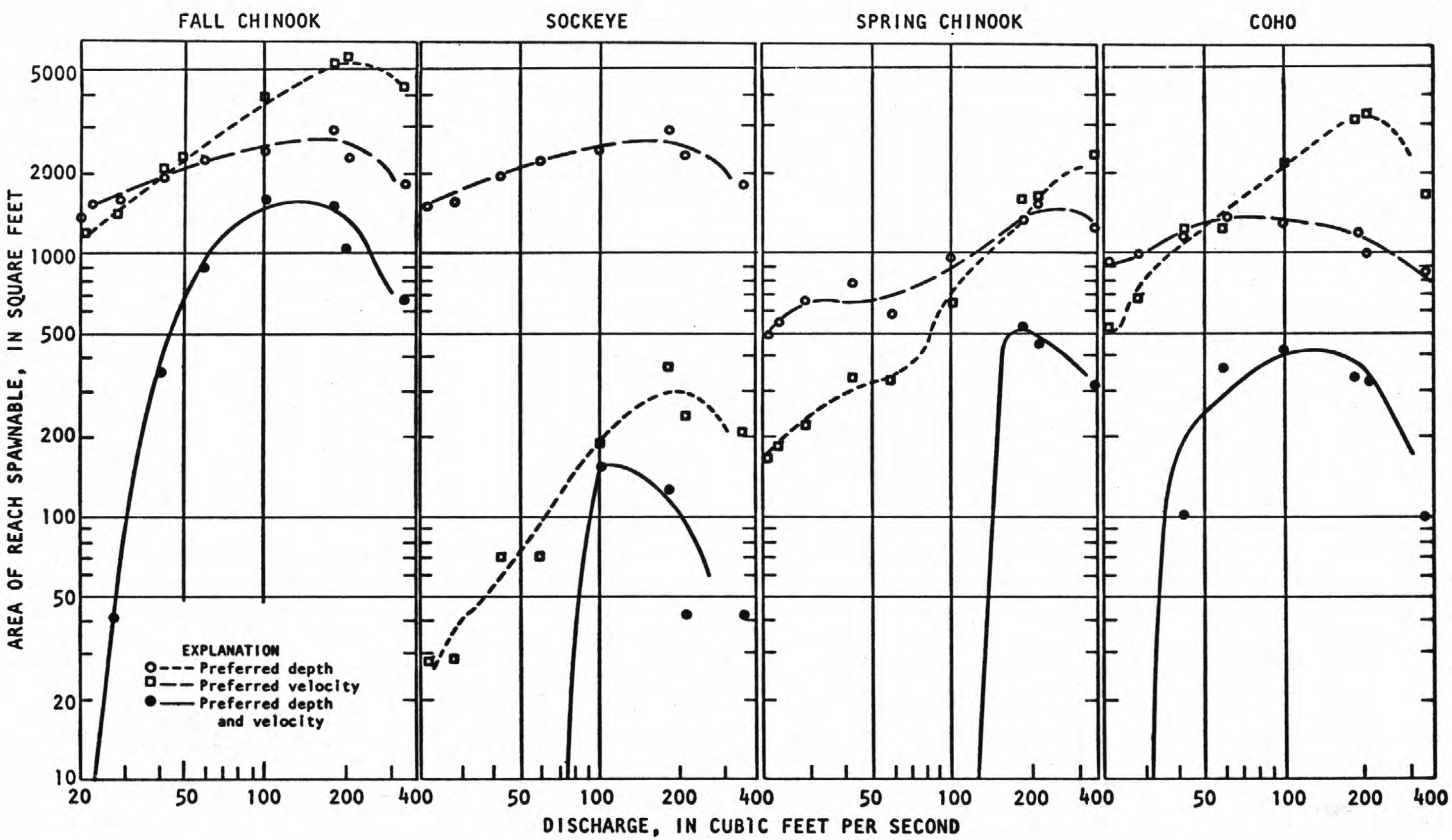


FIGURE 52.--Curves of spawnable area versus discharge, North Fork Stillaguamish River reach A.

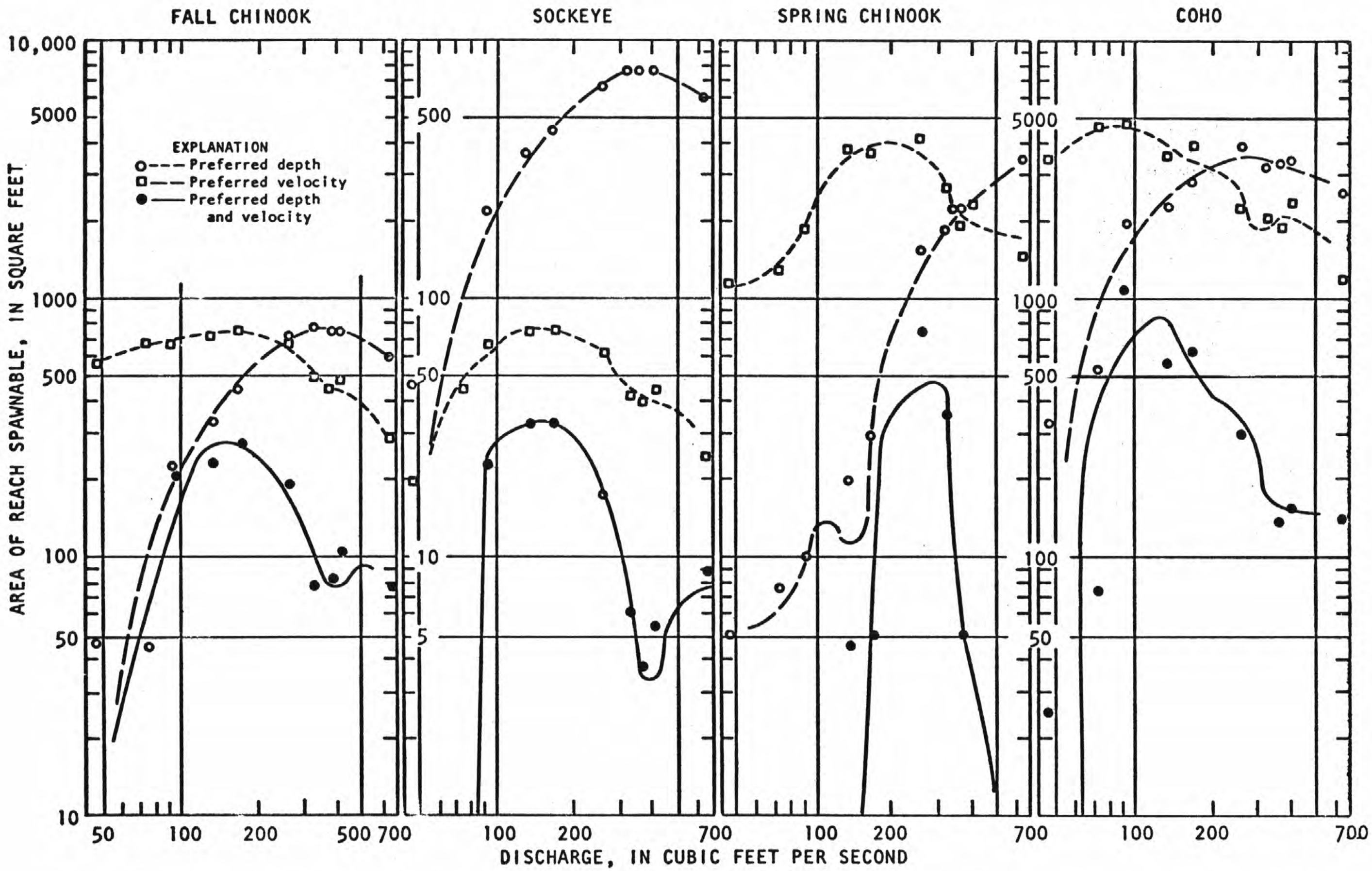


FIGURE 53.--Curves of spawnable area versus discharge, North Fork Stillaguamish River reach B.

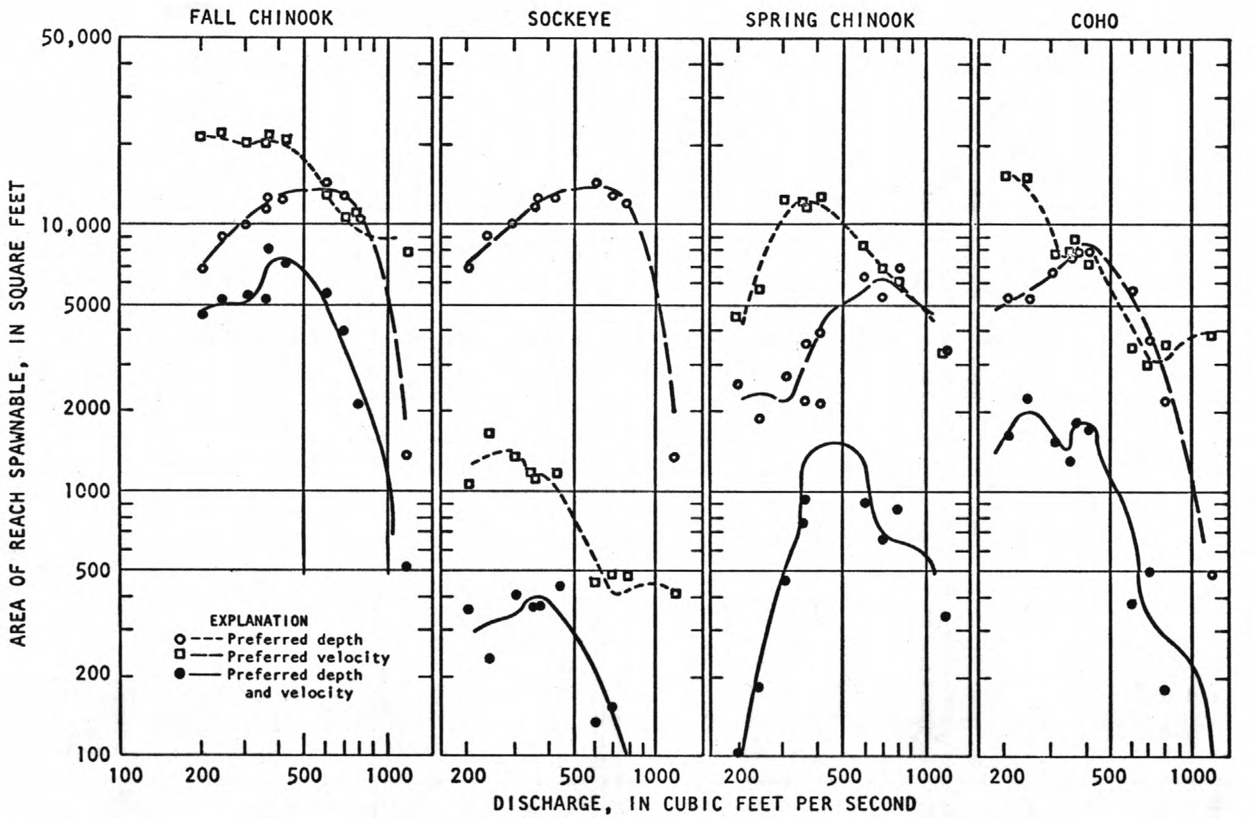


FIGURE 54.--Curves of spawnable area versus discharge, North Fork Stillaguamish River reach C.

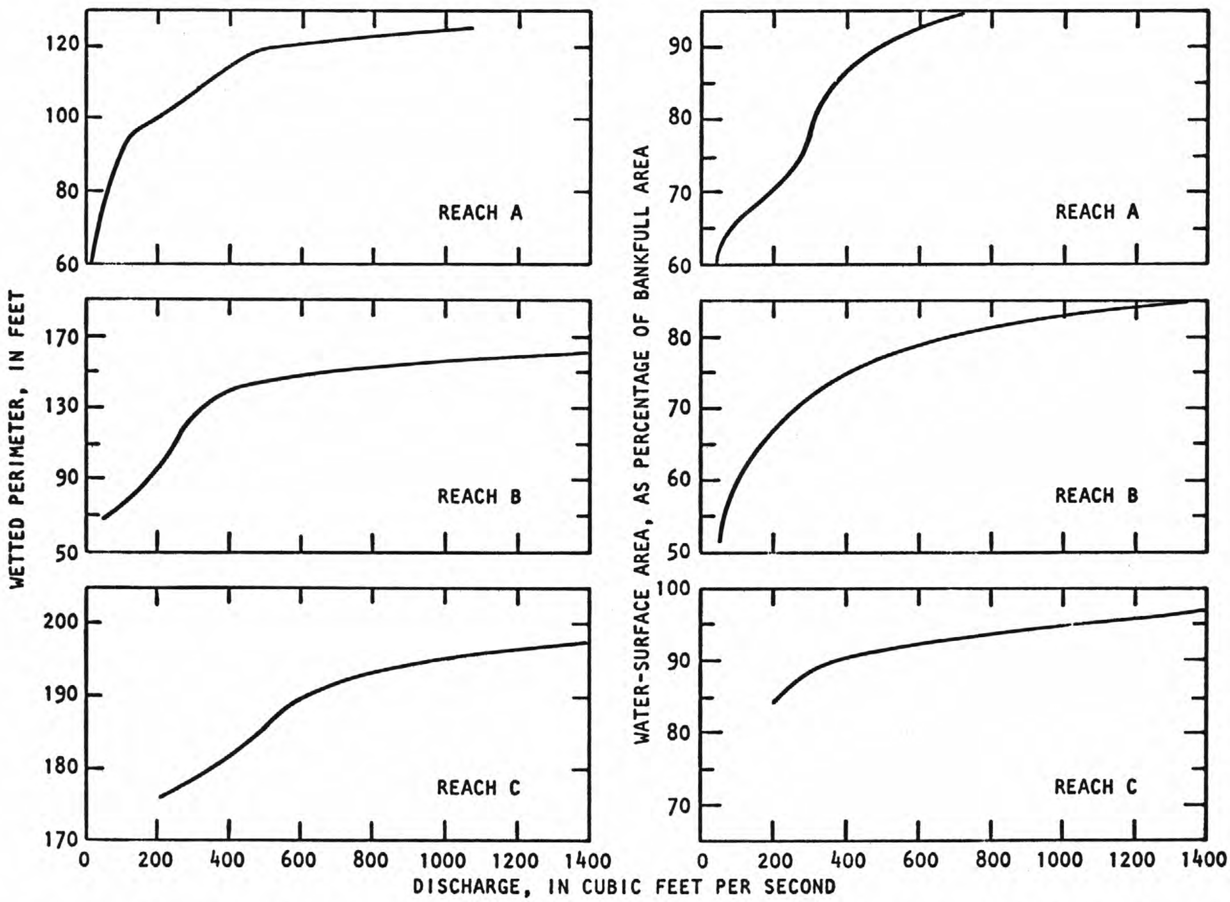


FIGURE 55.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, North Fork Stillaguamish River study reaches.

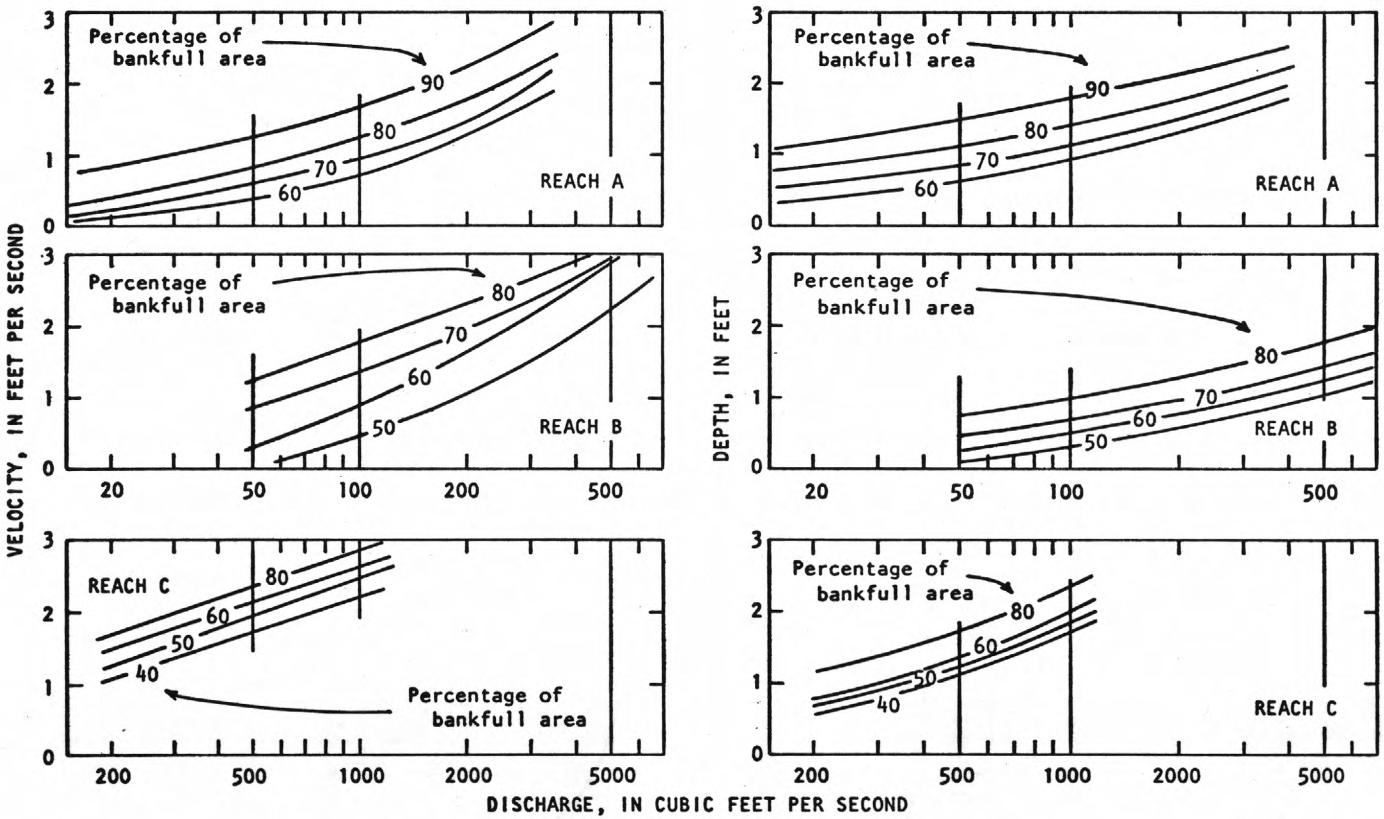


FIGURE 56.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, North Fork Stillaguamish study reaches.

The following table shows the results of the rearing-discharge investigation:

	Study reach A	B	C
Preferred rearing discharge (cfs)	110	230	400
Equivalent discharge at the gage (cfs)	954	794	568
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig. 51)	6	10	23
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	34	117	328

The equivalent discharge at the gage was determined by solving the reach regression model for Q_G and substituting the preferred rearing discharge of the reach into the equation. The discharge at the 50-percent-probability level for August is assumed to be the naturally occurring limiting flow for salmon that utilize the stream for rearing year around (fig. 2).

The desirability of a river as a rearing area is partly dependent on the amounts of pools and riffles in the stream (Ruggles, 1966). Aerial photographs taken at a scale of about 1:2,000 and over a 28.8-mile length of the river about the study reaches show that 60 percent of this river area was riffle. The reach investigation included a length of river from 12.6 miles above reach A to reach C. Determinations about each study reach showed that the pool-and-riffle relationship is similar throughout the river. The results of the determinations about each study reach are given below:

Study reach	Miles of river near or including study reach	Percentage riffle area
A	14.4	60
B	10.6	60
C	3.8	61

South Prairie Creek

Location.--Figure 1 shows the location of the river and study reaches. The study reaches are described as follows:

Reach A. Lat 47°07', long 122°01'11", N½SE¼ sec. 15, T.19 N., R.6 E., at river mile 10.3.

Reach B. Lat 47'07'25", long 122°03'16", in NW¼SW¼ sec.16, T.19 N., R.6 E., at river mile 8.0.

Reach C. Lat 47°07'13", long 122°07'56", in NE¼NE¼ sec.23, T.19 N., R.5 E., at river mile 2.6.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	620	510	330
Wetted perimeter (ft)[1]	79	86	86
Channel width (ft)[1]	74	84	85
Channel depth (ft)[1]	2.2	2.2	3.0
Bankfull water-surface area (sq ft)	4,480	6,950	8,590
River and basin parameters:			
Drainage area (sq mi)	16.5	69.7	87.2
Main-stem length (mi)	11.8	14.1	19.5
Main-stem channel slope (ft/mi)	230	187	137
Mean basin altitude (ft msl)	2,559	2,504	2,149
The altitude at the source of the river is 5,440 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

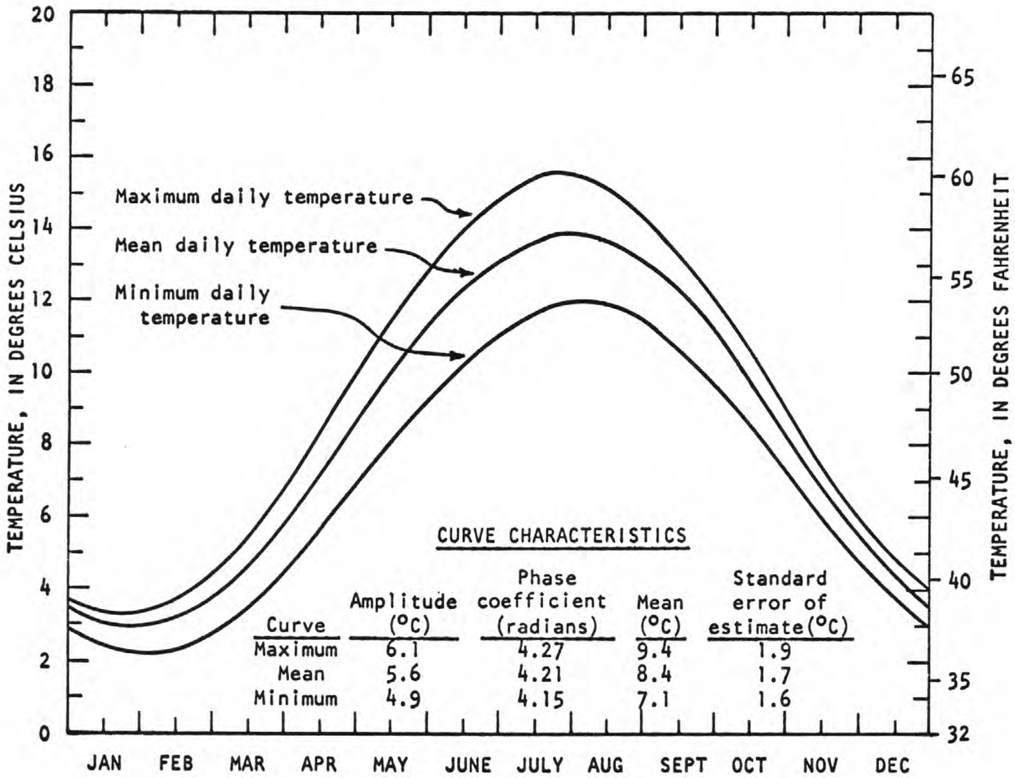


FIGURE 57.--Annual stream-temperature distribution in 1970, South Prairie Creek at South Prairie (12095000). Curves represent the best fit of maximum, mean, and minimum daily temperatures.

Chemical characteristics.--For documentation purposes, table 19 presents some physiochemical characteristics of the water at each of the three study reaches, along with discharges.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on South Prairie Creek (12095000) and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1970 are shown in figure 57.

All water sampled at each study reach had nearly 100-percent DO saturation.

The suspended-sediment concentrations were low, ranging from 1 to 7 mg/l for the 24 samples collected at all reaches (table 19).

TABLE 19.--Selected chemical and physical characteristics of water in study reaches on South Prairie Creek

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (μmhos/cm at 25 °C)
			Reach A			
3-19-71	123	6.1	43	12.0	3	--
3-29	199	7.2	45	11.7	7	41
4-29	166	--	--	--	1	--
6-11	265	7.8	46	11.5	5	32
7-21	136	12.8	55	10.3	5	--
7-30	84	14.4	58	9.9	5	49
8- 3	60	13.3	56	10.2	2	56
8- 6	56	16.0	61	9.5	--	59
8-12	43	19.5	67	8.9	--	66
8-31	35	13.0	55	10.3	--	75
			Reach B			
3-19-71	126	5.0	41	12.3	1	72
3-29	203	7.2	45	11.7	3	53
4-29	165	--	--	--	4	--
6-11	268	8.3	47	11.4	3	39
7-21	139	14.4	58	9.9	2	--
7-30	86	14.4	58	9.9	2	62
8- 3	61	14.4	58	9.9	2	72
8- 6	57	15.5	60	9.7	--	76
8-12	48	18.0	64	9.2	3	88
8-31	39	13.9	57	10.0	--	95
			Reach C			
3-19-71	224	3.9	39	12.7	3	80
3-29	348	7.2	45	11.7	4	58
4-29	252	9.4	49	11.1	1	--
6-11	370	8.9	48	11.2	5	47
7-21	167	17.8	64	9.2	3	--
7-30	108	15.6	60	9.7	2	77
8- 3	80	17.8	64	9.2	6	84
8- 6	79	16.8	62	9.4	3	92
8-12	62	18.5	65	9.1	3	104
8-31	55	15.6	60	9.7	--	112

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

Study reach	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
	Greater than	3-6	1-3	0.15-1	Less than 0.15
A	5.4	40.2	29.9	15.5	9.0
B	7.3	28.3	30.5	23.1	10.8
C	6.4	31.8	32.7	19.7	9.4

The greatest percentage of gravel at all reaches was in the 1- to 6-inch range--70.1 percent at reach A, 58.8 percent at reach B, and 64.5 percent at reach C.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station on South Prairie Creek to obtain a simple linear regression model for each reach. To further evaluate discharges at the three reaches, all reach discharges (Q_A, Q_B, and Q_C) were related to the gaging-station discharges (Q_G) and an analysis of covariance was performed. Findings show that the regression models for reaches A and B are not significantly different and may be defined as follows:

$$Q_{A,B} = 1.57(Q_G)^{0.86} \quad .$$

The standard error of estimate of the relation is 11 percent. However, the regression model for reach C was significantly different from the other models and should be treated independently as

$$Q_C = 1.62(Q_G)^{0.93} \quad ,$$

which has a standard error of 4 percent.

Discharge records at the gaging station cover a period of sufficient length to allow computation of the monthly mean probability distributions (fig. 58) for that site. By using the above regression models and figure 58, the probabilities of various discharges can be estimated for each study reach.

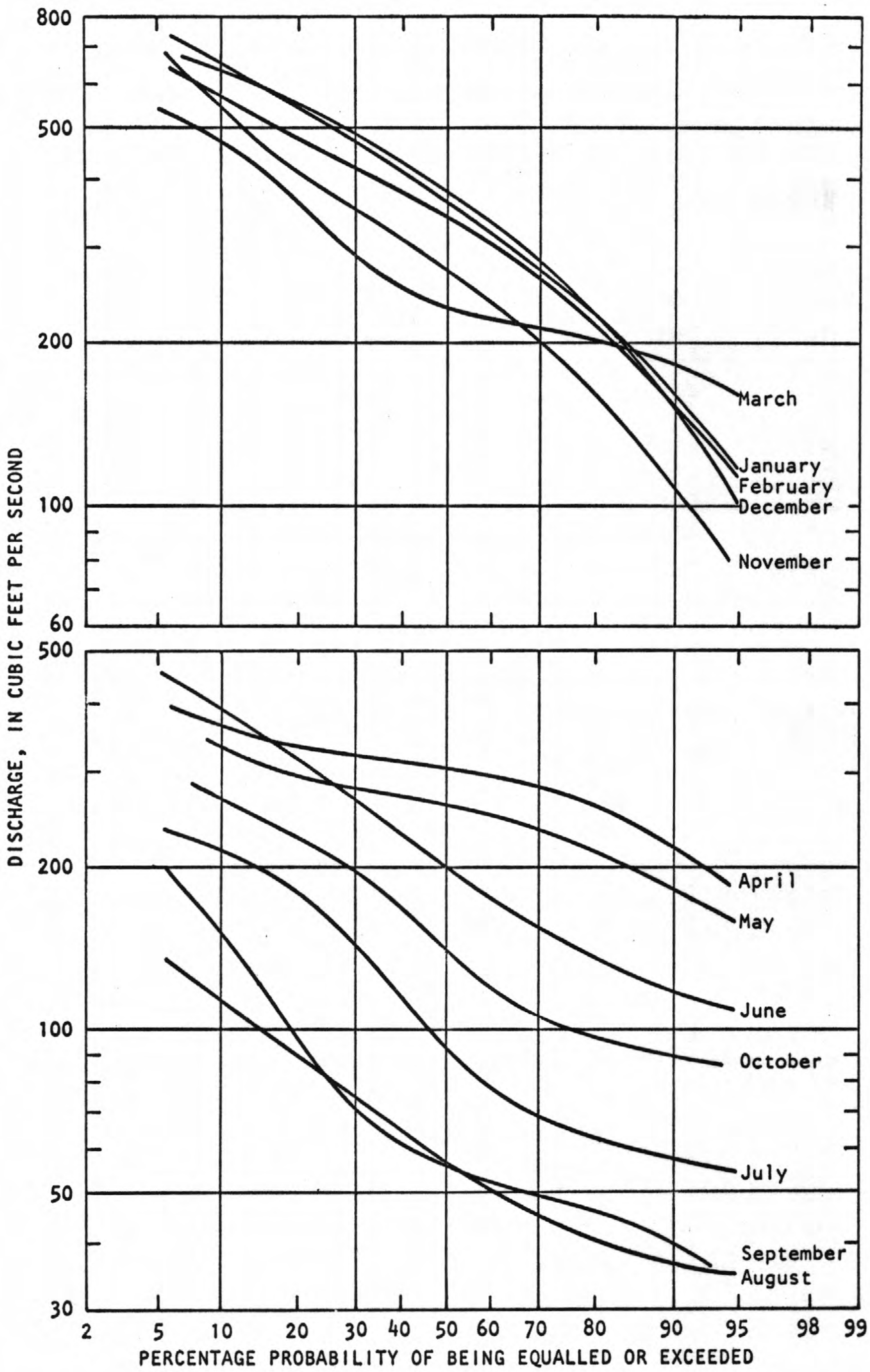


FIGURE 58.--Probability distributions of monthly mean discharges, South Prairie Creek at South Prairie (12095000).

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 59-61. Following is a list of the preferred spawning discharges, by species and study reach, for South Prairie Creek:

	Preferred spawning discharge (cfs)		
	Study reach		
Salmon species	A	B	C
Fall chinook	70	128	120
Sockeye	70	146	156
Spring chinook	195	116	210
Coho	67	154	88

The crests of all curves (figs. 59-61) are fairly well defined.

Discharges for rearing.--Discharges for salmon rearing were selected from figure 62 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these rearing discharges, are shown in figure 63.

The following table shows the results of the rearing-discharge investigation:

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	80	100	100
Equivalent discharge at the gage (cfs)	97	125	73
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig. 58)	16	7	29
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	46	46	74

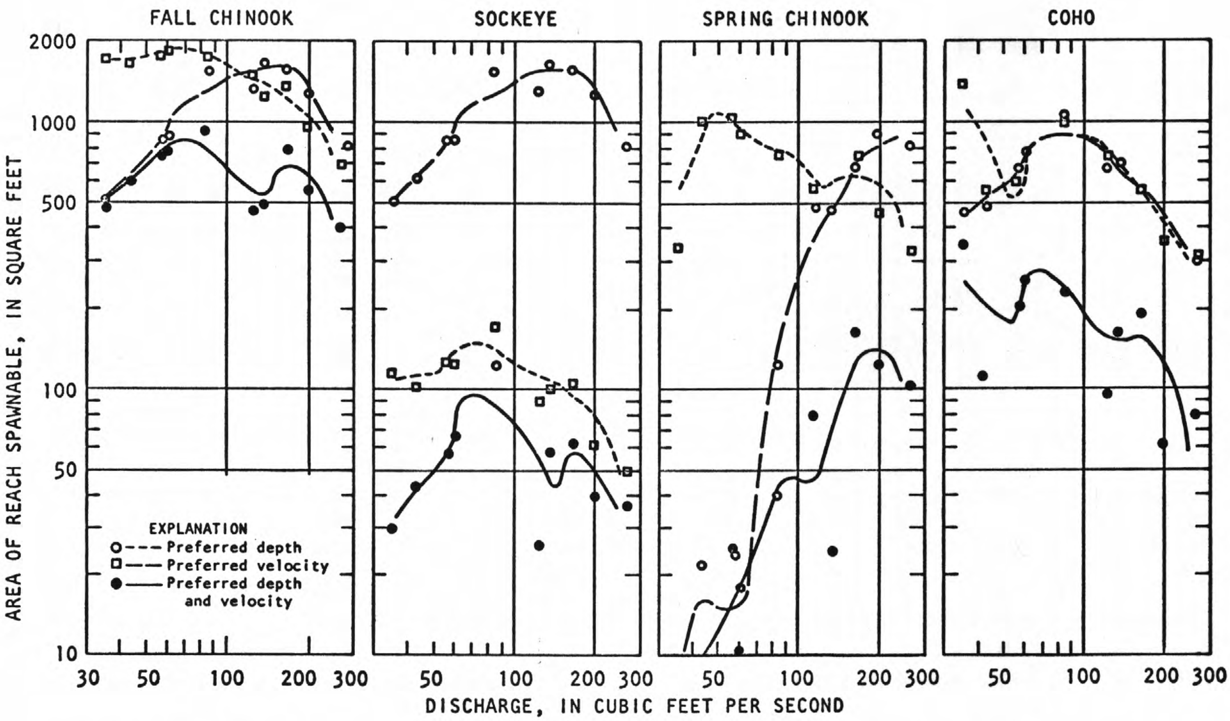


FIGURE 59.--Curves of spawnable area versus discharge, South Prairie Creek reach A.

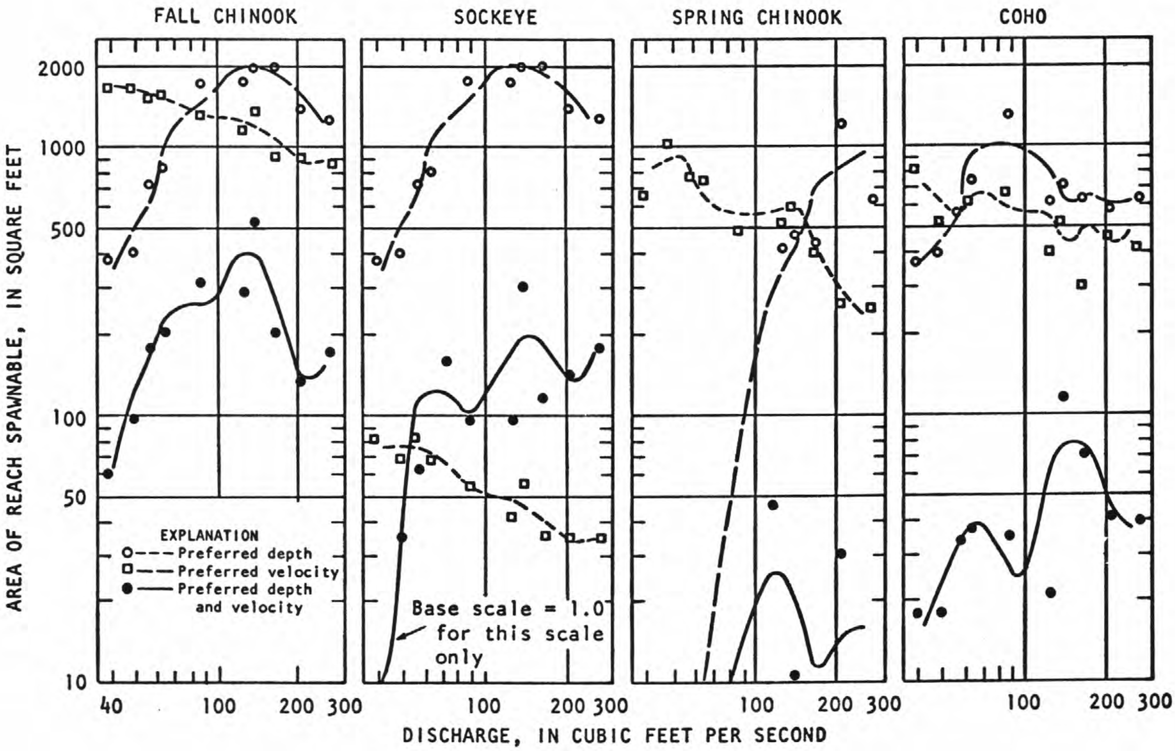


FIGURE 60.--Curves of spawnable area versus discharge, South Prairie Creek reach B.

The equivalent discharge at the gage was determined by solving the reach regression models for Q_G and substituting the preferred rearing discharges into the equations. The discharge at the 50-percent-probability level for the lowest flow month (August in fig. 58) was assumed to be the naturally occurring limiting discharge for salmon that utilize the stream for rearing year around (fig. 2).

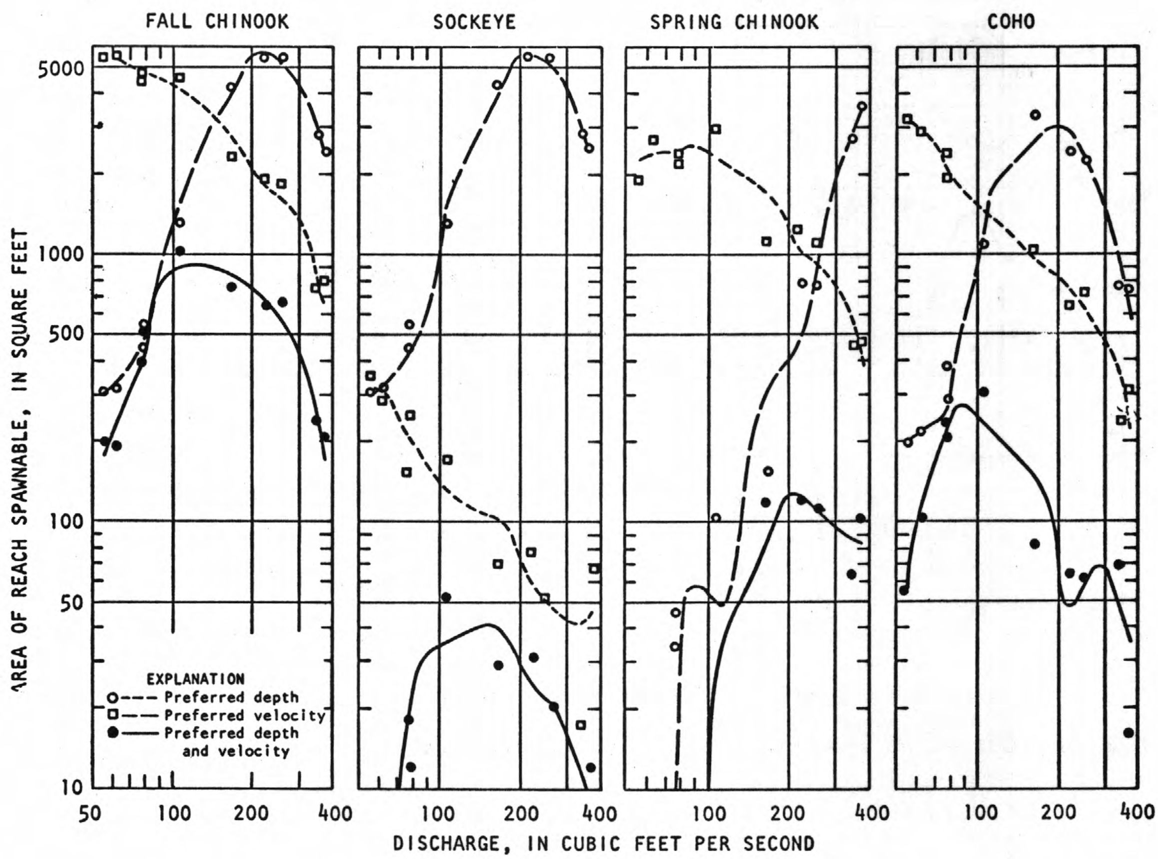


FIGURE 61.--Curves of spawnable area versus discharge, South Prairie Creek reach C.

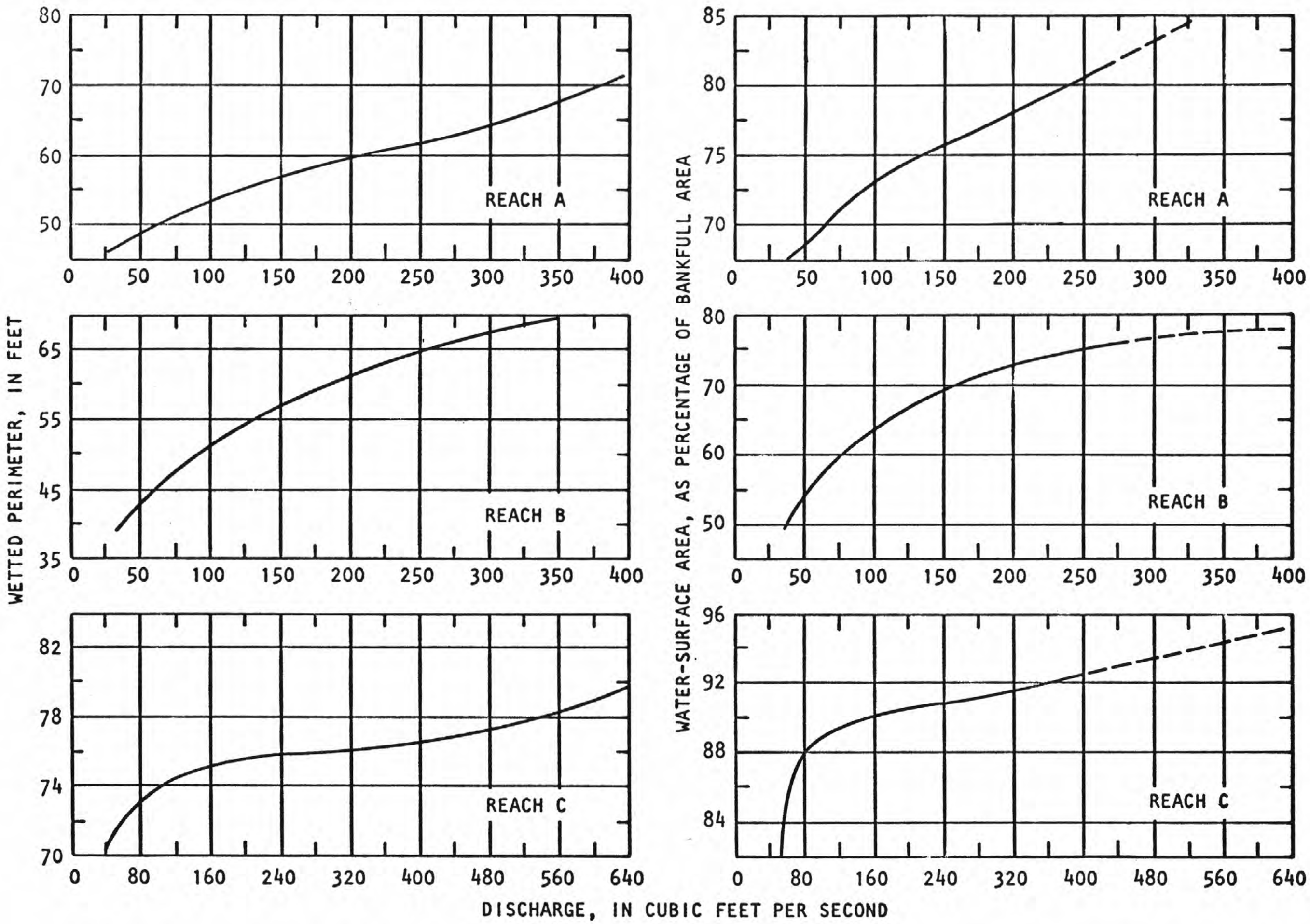


FIGURE 62.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, South Prairie Creek study reaches.

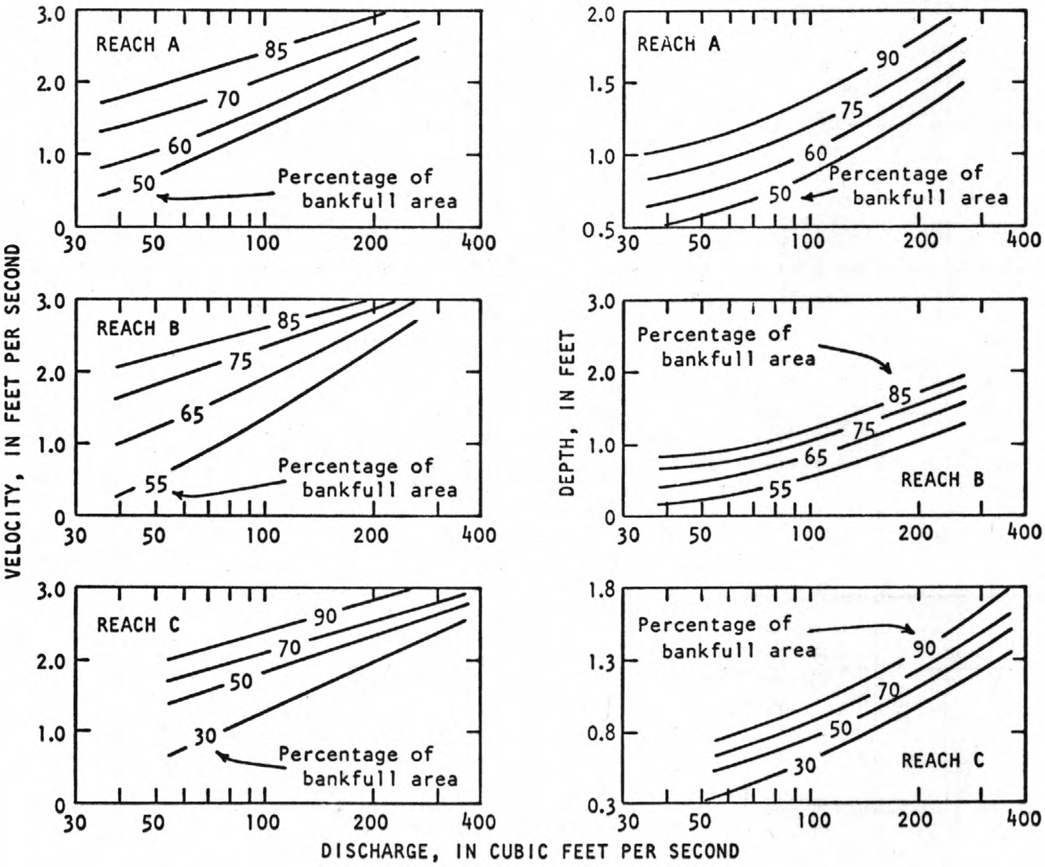


FIGURE 63.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, South Prairie Creek study reaches.

Issaquah Creek

Location.--Figure 1 shows the location of the stream and study reaches. The study reaches are described as follows:

Reach A. Lat 47°27'28", long 122°00'13", in NE¼NW¼ sec.26, T.23 N., R.6 E., at river mile 10.6.

Reach B. Lat 47°28'55", long 122°02'10", in SW¼NW¼ sec.15, T.24 N., R.6 E., at river mile 7.4.

Reach C. Lat 47°31', long 122°01'58", in SW¼SW¼ sec.34, T.24 N., R.6 E., at river mile 4.2.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	300	200	95
Wetted perimeter (ft)[1]	43	50	58
Channel width (ft)[1]	42	48	56
Channel depth (ft)[1]	1.9	2.2	2.9
Bankfull water-surface area (sq ft)	3,840	4,300	7,480
River and basin parameters:			
Drainage area (sq mi)	17.6	27.0	31.8
Main-stem length (mi)	7.4	10.6	13.8
Main-stem channel slope (ft/mi)	238	144	108
Mean basin altitude (ft msl)	1,130	940	996
The altitude at the source of the river is 2,700 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

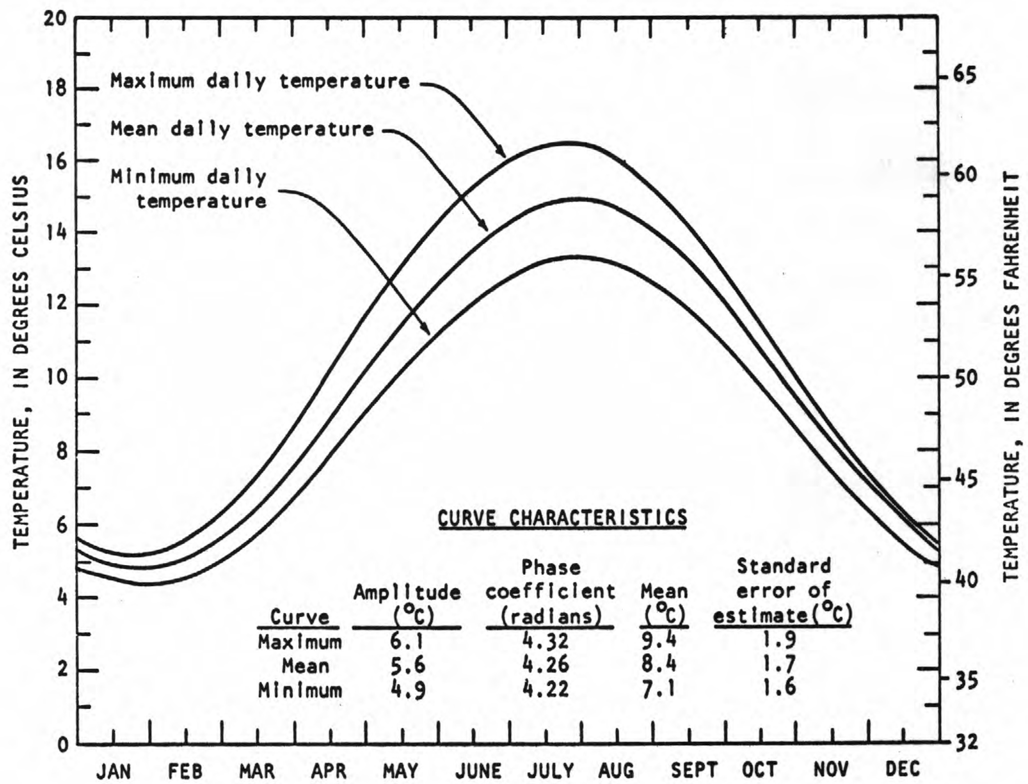


FIGURE 64.--Annual stream-temperature distribution in 1970, Issaquah Creek near the mouth, near Issaquah (12121600). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

Chemical characteristics.--For documentation purposes, table 20 presents some physiochemical characteristics of the water at each of the three study reaches, along with discharges.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on Issaquah Creek (12121600) and also by measurements made during each visit to the reaches. The results of an analysis of the maximum, minimum, and mean daily water temperatures for 1970 are shown in figure 64.

All water sampled at each of the study reaches had nearly 100-percent DO saturation.

The suspended-sediment concentrations were low, ranging from 1 to 25 mg/l for the 27 samples collected at all reaches (table 20).

TABLE 20.--Selected chemical and physical characteristics of water in study reaches on Issaquah Creek

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
3-18-71	86	4.4	40	12.5	16	69
3-25	104	4.4	40	12.5	23	62
4- 5	58	11.7	53	10.5	4	56
4-12	90	8.9	48	11.2	11	63
4-15	67	8.3	47	11.4	9	71
4-19	46	11.7	53	10.5	3	75
4-28	35	7.8	46	11.5	4	--
5- 4	27	10.0	50	11.0	4	90
6-30	36	9.4	49	11.1	8	79
11- 5	169	5.6	42	12.2	--	65
			Reach B			
3-18-71	114	5.6	42	12.2	15	70
3-25	135	6.1	43	12.0	25	65
4- 5	80	11.7	53	10.5	9	66
4-12	125	9.4	49	11.1	11	66
4-15	92	8.3	47	11.4	10	71
4-19	69	11.1	52	10.7	2	78
4-28	50	8.3	47	11.4	5	--
5- 4	37	10.0	50	11.0	2	92
6-30	50	10.5	--	--	5	86
11- 5	194	6.0	--	--	--	68
			Reach C			
3-18-71	164	7.2	45	11.7	15	71
3-25	200	6.7	44	11.8	23	65
4- 5	124	11.7	53	10.5	9	54
4-12	190	10.0	50	11.0	9	45
4-15	139	7.2	45	11.7	6	73
4-19	100	10.0	50	11.0	3	79
4-28	82	8.9	48	11.2	7	--
5- 4	57	10.6	51	10.8	1	92
6-30	70	12.2	54	10.4	4	86
11- 5	283	6.1	43	12.0	--	80

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
Study reach	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	0	14.6	41.0	29.1	15.3
B	0	26.6	31.6	28.1	13.7
C	0	4.5	49.9	30.8	14.8

The total percentages for each reach in the 1- to 6-inch range was about the same--reach A, 55.6 percent; reach B, 58.2 percent; and reach C, 54.4 percent.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station on Issaquah Creek to obtain a simple linear regression model for each reach. To further evaluate the relations between the discharge at the three reaches (Q_A, Q_B, and Q_C) and the discharge at the gaging station (Q_G), the simple linear regression models were statistically tested and were found to be significantly different from each other, as follows:

$$Q_A = 0.32(Q_G)^{1.02}$$

$$Q_B = 0.56(Q_G)^{0.97}$$

$$Q_C = 0.92(Q_G)^{0.95} \quad .$$

The standard errors of estimate are 10, 6, and 5 percent for the models of reaches A, B, and C, respectively.

Discharge records at the gage cover a period of sufficient length to allow computation of monthly mean probability distributions (fig. 65) for that site. By using the above regression models with figure 65, the probabilities of various discharges can be estimated for each study reach.

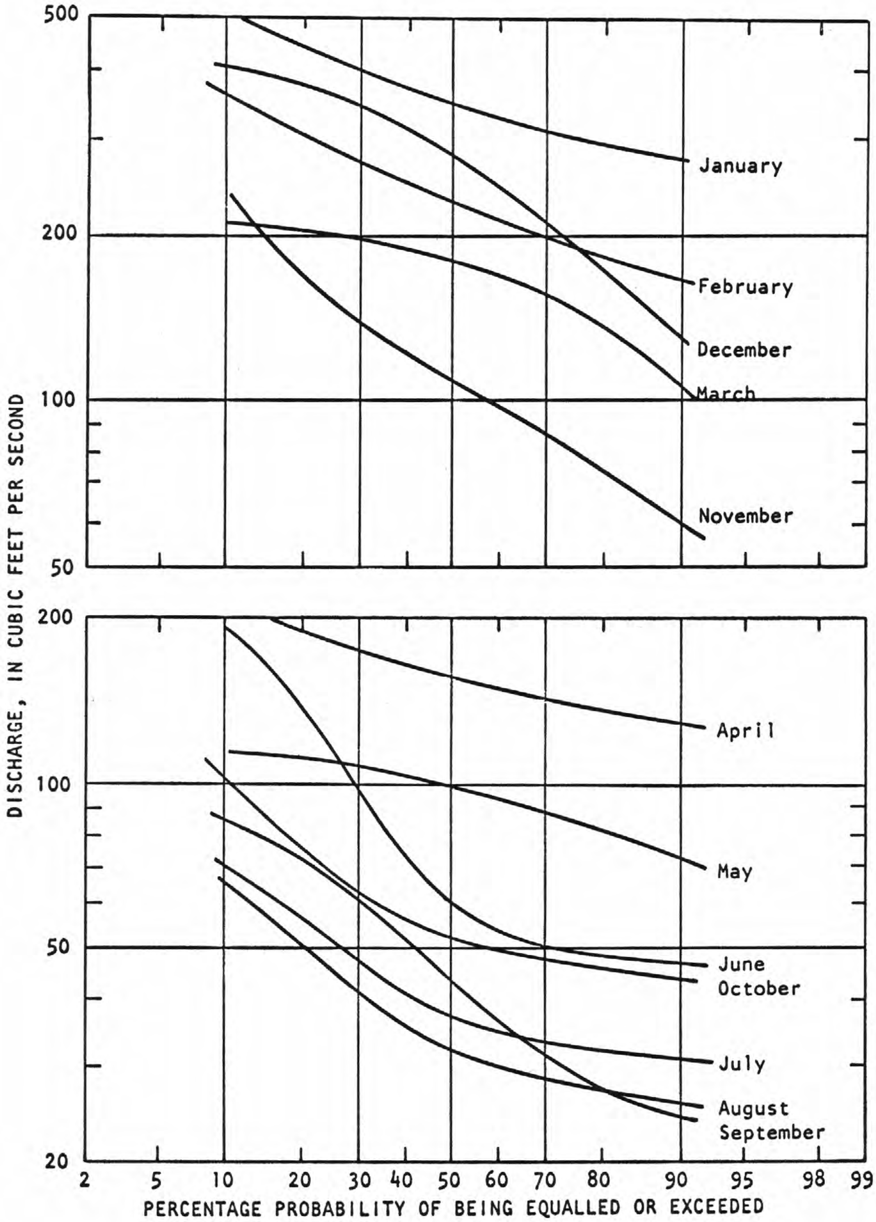


FIGURE 65.--Probability distributions of monthly mean discharges, Issaquah Creek near mouth, near Issaquah (12121600).

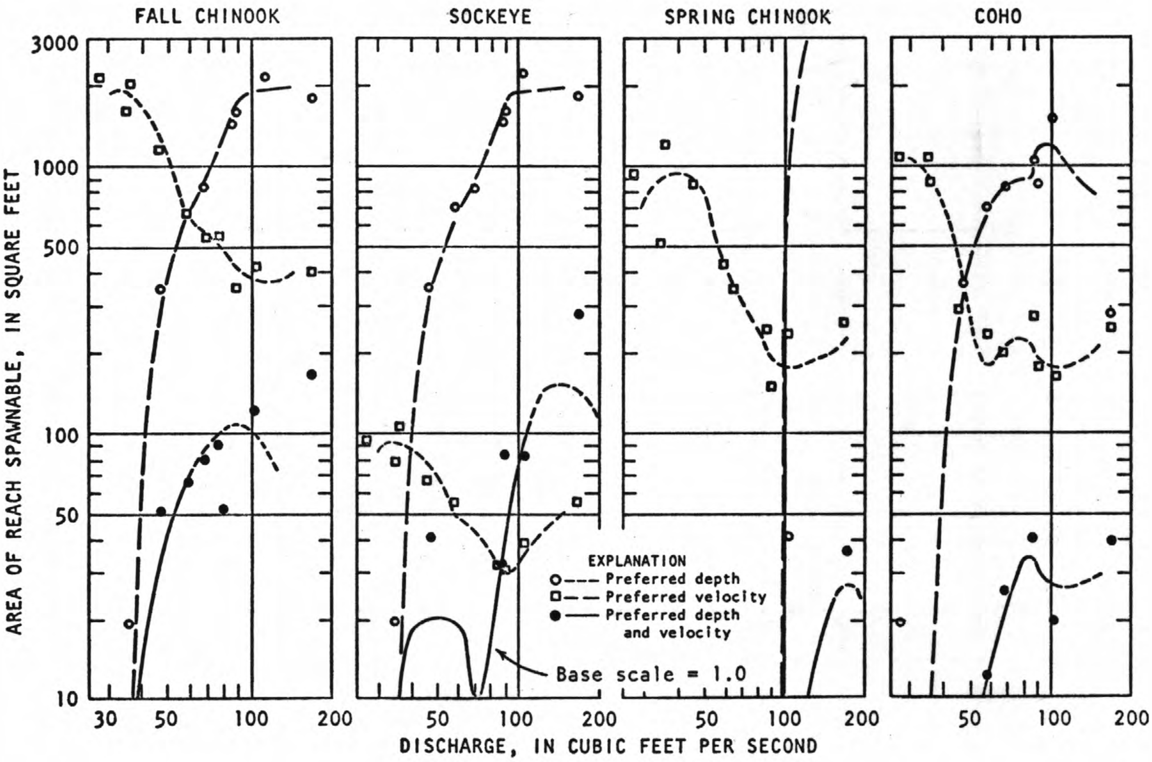


FIGURE 66.--Curves of spawnable area versus discharge, Issaquah Creek reach A.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 66-68. Following is a list of the preferred spawning discharges, by species and study reach, for Issaquah Creek:

Salmon species	Preferred spawning discharge (cfs) Study reach A	B	C
Fall chinook	*90	140	83
Sockeye	*140	105	60
Spring chinook	*170	*200	200
Coho	82	130	82

*Values determined by estimated curve extension.

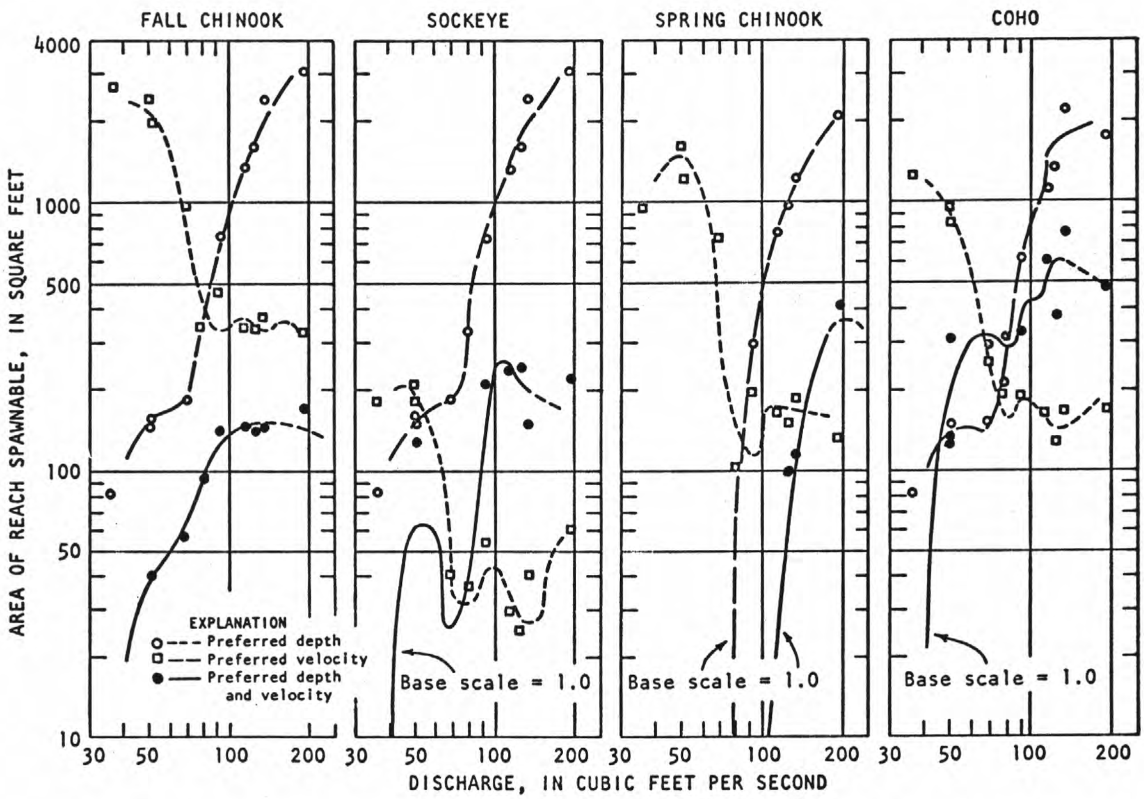


FIGURE 67.--Curves of spawnable area versus discharge, Issaquah Creek reach B.

In cases where the curves (figs. 66-68) were not defined, values for preferred spawning discharge were derived by estimated curve extension. The majority of the curve crests are fairly well defined.

<u>Discharges for rearing</u>.--Discharges for salmon rearing were selected from figure 69 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these discharges, are shown in figure 70.

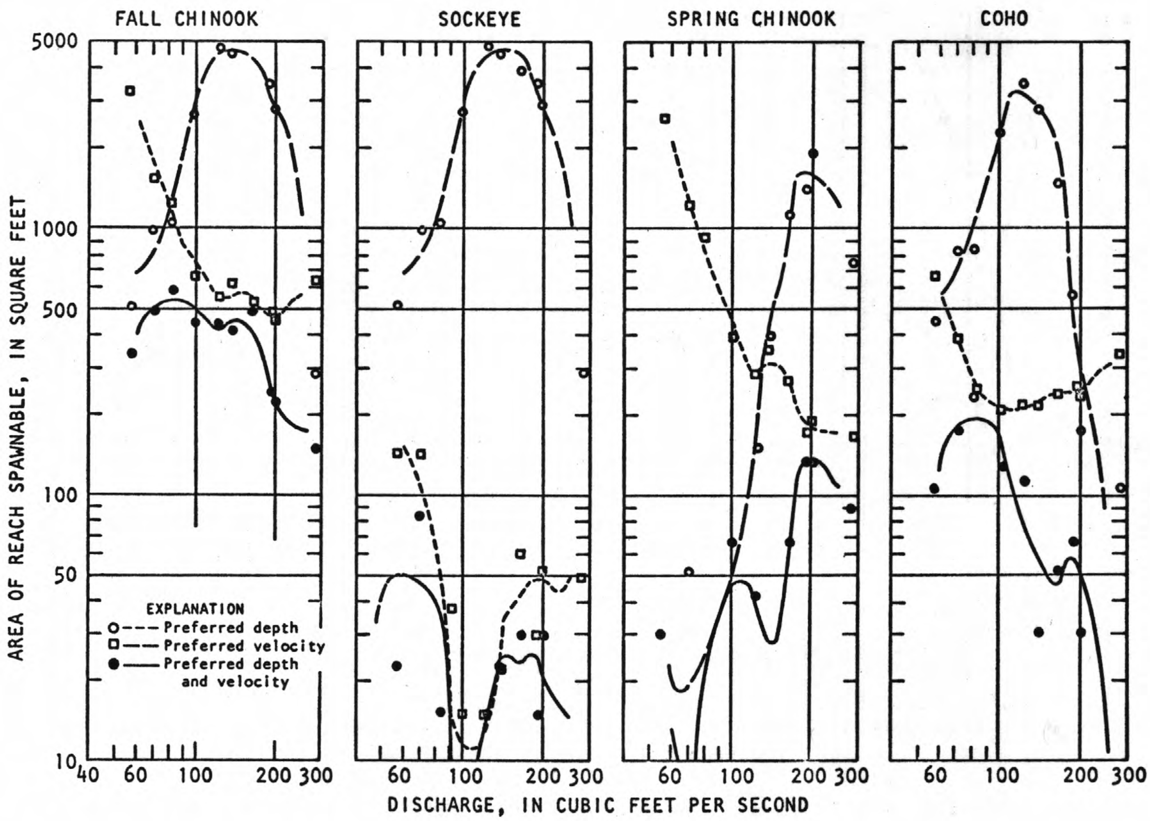


FIGURE 68.--Curves of spawnable area versus discharge, Issaquah Creek reach C.

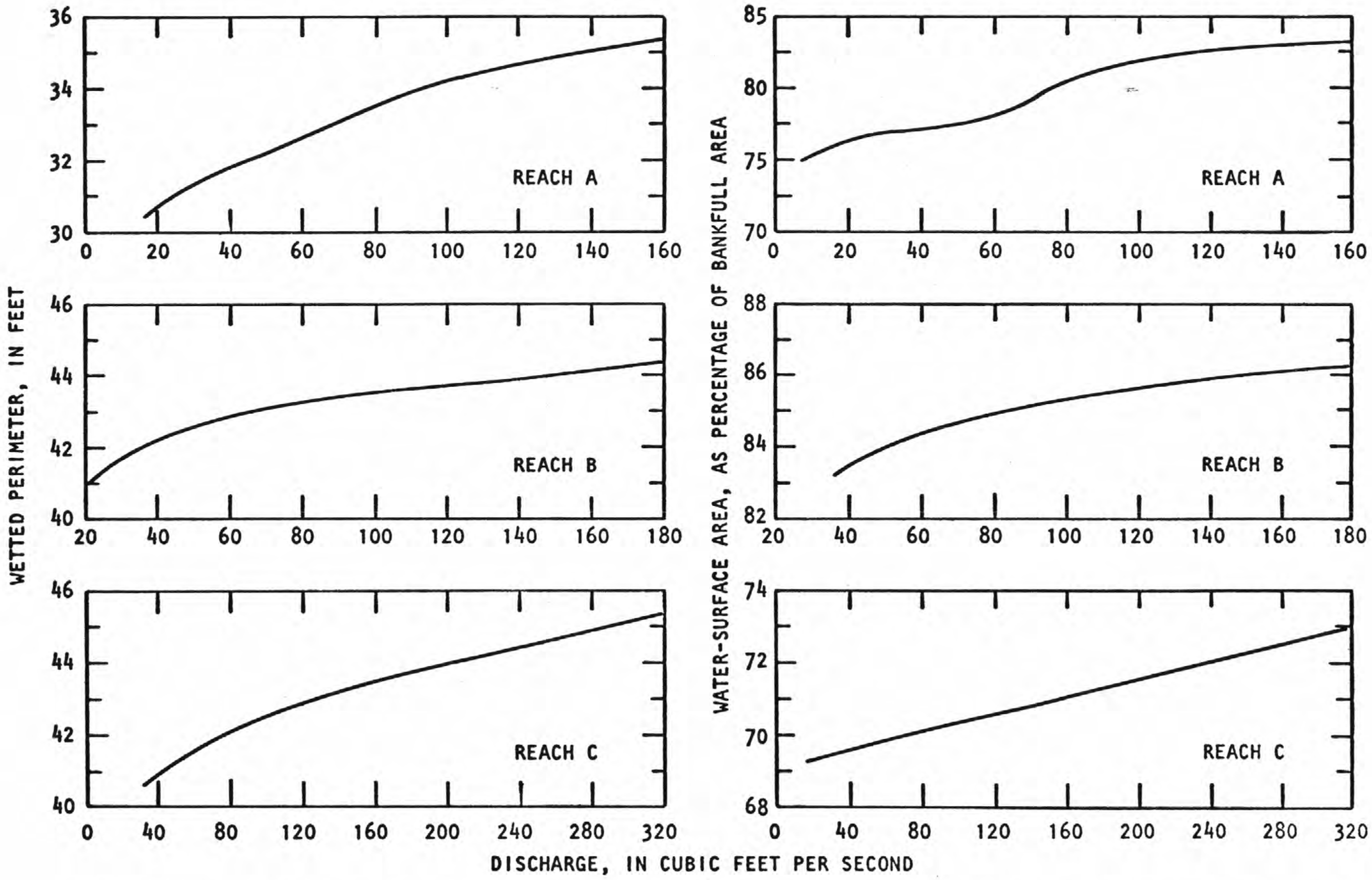


FIGURE 69.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, Issaquah Creek study reaches.

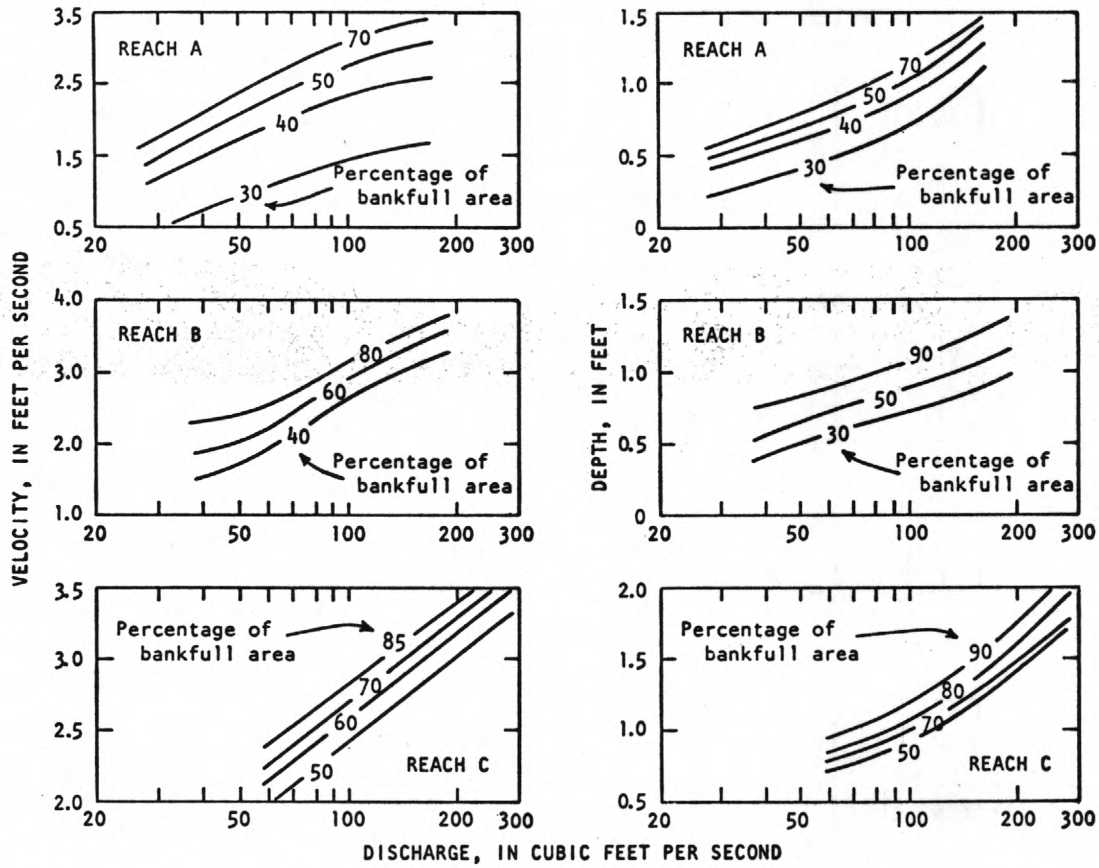


FIGURE 70.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, Issaquah Creek study reaches.

The following table shows the results of the rearing-discharge investigation:

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	25	35	50
Equivalent discharge at the gage (cfs)	72	71	67
Percentage probability of discharge being equaled or exceeded during August (fig. 65)	less than 10	less than 10	less than 10
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	11	16	25

The equivalent discharge at the gage was determined by solving the reach regression model for Q_G and substituting the preferred rearing discharge into the equation. The discharge at the 50-percent-probability level for August was assumed to be the naturally occurring limiting flow for salmon that utilize the stream for rearing year around (fig. 2).

Bear Creek

Location.--Figure 1 shows the location of the river and study reaches. The study reaches are described as follows:

Reach A. Lat 47°49'10", long 122°09'32", in SW¼SW¼ sec.15, T.27 N., R.5 E., at river mile 5.6.

Reach B. Lat 47°48'39", long 122°09'28", in SW¼ sec.22, T.27 N., R.5 E., at river mile 4.9.

Reach C. Lat 47°47'36", long 122°08'33", in SE¼SE¼ sec.27, T.27 N., R.5 E., at river mile 3.4.

Physical characteristics.--The following table lists some of the channel-geometry indices of the study reaches and some river and basin parameters upstream from the study reaches:

	Study reach		
	A	B	C
Channel geometry at reach:			
Altitude (ft msl)	260	210	150
Wetted perimeter (ft)[1]	38	20	25
Channel width (ft)[1]	37	18	24
Channel depth (ft)[1]	.9	1.3	1.7
Bankfull water-surface area (sq ft)	2,120	842	1,460
River and basin parameters:			
Drainage area (sq mi)	4.39	5.85	10.8
Main-stem length (mi)	2.9	3.6	5.1
Main-stem channel slope (ft/mi)	84	82	70
Mean basin altitude (ft msl)	441	420	405
The altitude at the source of the river is 490 ft (msl).			

[1]Average value for four cross sections at bankfull river stage.

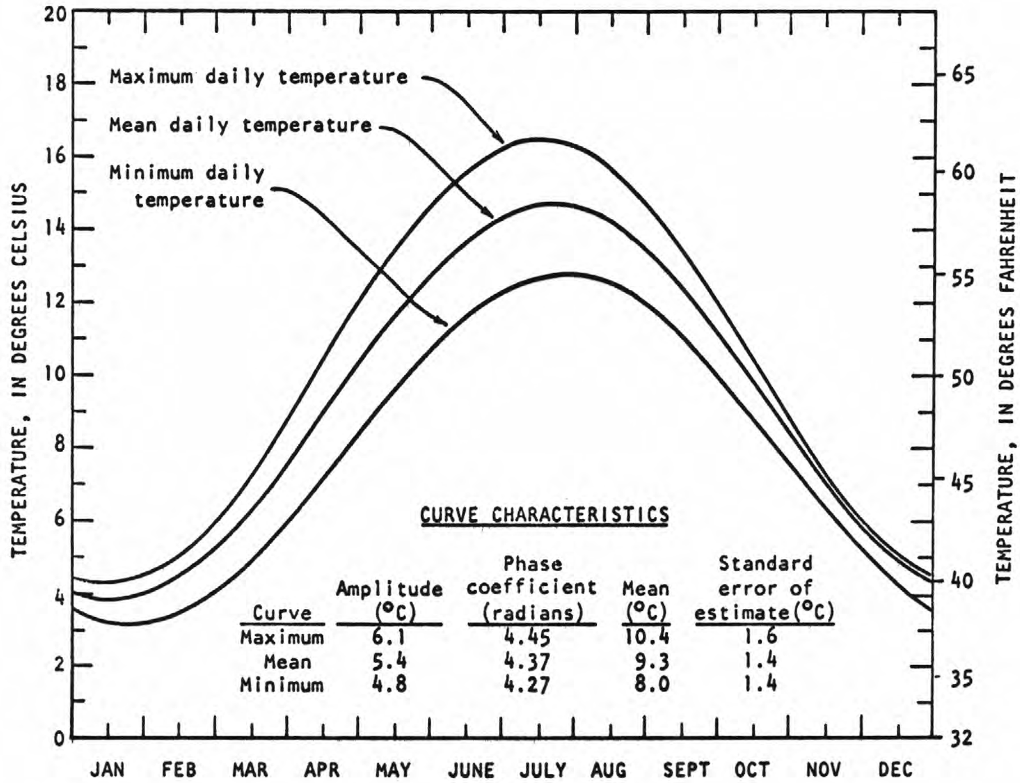


FIGURE 71.--Annual stream-temperature distribution in 1971, Bear Creek at Woodinville (12125500). Curves represent the best fit of maximum, mean, and minimum daily water temperatures.

Chemical characteristics.--For documentation purposes, table 21 presents some physiochemical characteristics of the water at each of the three study reaches, along with discharges.

Stream temperatures were recorded by a thermograph installed at the gaging-station site on Bear Creek (12125500) and also by measurements made during each visit to the reaches. The results of an analysis of maximum, minimum, and mean daily water temperatures for 1971 are shown in figure 71.

All water sampled at each study reach had nearly 100-percent DO saturation.

TABLE 21.--Selected chemical and physical characteristics of water in study reaches on Bear Creek

Date of sample	Discharge (cfs)	Temperature °C	Temperature °F	Dissolved oxygen (mg/l)	Suspended sediment (mg/l)	Specific conductance (µmhos/cm at 25 °C)
			Reach A			
3-17-71	12	4.4	40	12.5	9	71
3-26	21	6.7	44	11.8	24	65
4- 1	12	7.8	46	11.5	15	--
4- 4	8.9	6.7	44	11.8	7	77
4-20	7.1	6.7	44	11.8	4	86
4-27	6.8	8.3	47	11.4	12	84
7-14	4.8	13.3	56	10.2	3	100
			Reach B			
3-17-71	14	5.6	42	12.2	12	70
3-26	30	6.7	44	11.8	32	63
4- 1	14	7.8	46	11.5	--	--
4- 4	11	7.2	45	11.7	15	51
4-20	8.3	6.7	44	11.8	5	84
4-27	7.6	8.3	47	11.4	6	83
7-14	5.4	12.2	54	10.4	4	--
11- 4	16	1.2	45	11.7	--	99
			Reach C			
3-17-71	27	6.7	44	11.8	9	69
3-26	56	6.7	44	11.8	27	60
4- 1	27	7.2	45	11.7	9	--
4- 4	17	8.9	48	11.2	17	53
4-20	13	7.8	46	11.5	7	81
4-27	11	9.4	49	11.1	4	84
7-14	7.4	9.9	58	14.4	18	--

The suspended-sediment concentrations were fairly low, ranging from 3 to 32 mg/l for the 20 samples collected at all reaches (table 21).

Streambed gravel.--Samples of streambed gravel from each reach were evaluated, with the following results:

	Average weight fraction of total sample (percent)				
	Gravel size (inches)				
Study reach	Greater than 6	3-6	1-3	0.15-1	Less than 0.15
A	0	0	4.8	54.8	40.4
B	12.0	25.6	26.5	11.8	24.1
C	0	15.2	35.2	32.1	17.5

The gravel sizes were considerably smaller on reach A than on reaches B or C, with the very fine material (less than 0.15 inch) accounting for a large part of the total.

Streamflow characteristics and evaluation.--The measured discharges at each reach were related to contemporaneous discharges at the gaging station on Bear Creek to obtain a simple linear regression model for each reach. To further evaluate the relations between the discharge at the three reaches (Q_A, Q_B, and Q_C) and the discharge at the gaging station (Q_G) the regression models were statistically tested and were found to be significantly different from each other, as follows:

$$Q_A = 0.55(Q_G)^{0.86}$$

$$Q_B = 0.45(Q_G)^{0.97}$$

$$Q_C = 0.39(Q_G)^{1.17} \quad .$$

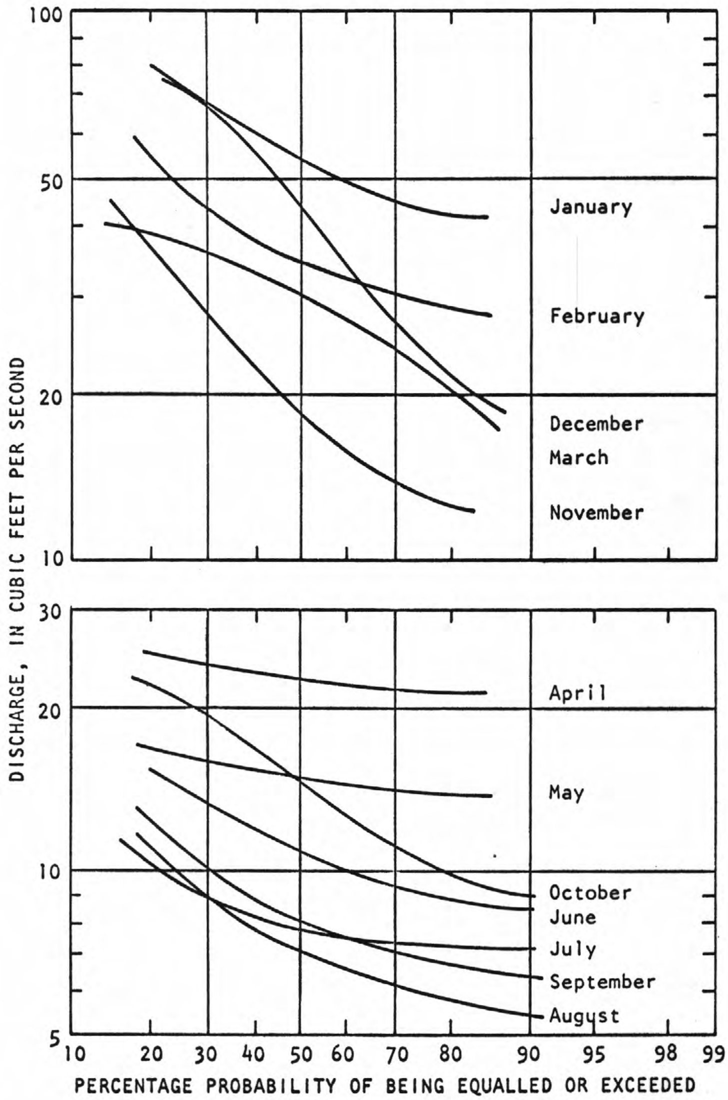


FIGURE 72.--Probability distributions of monthly mean discharges, Bear Creek at Woodinville (12125500).

The standard errors of estimate were 7, 8, and 5 percent for the models of reaches A, B, and C, respectively. Discharge records at the gaging station cover a period of sufficient length to allow computation of monthly mean probability distributions (fig. 72) for that site. By using the above regression models and figure 72, the probabilities of various discharges can be estimated for each study reach.

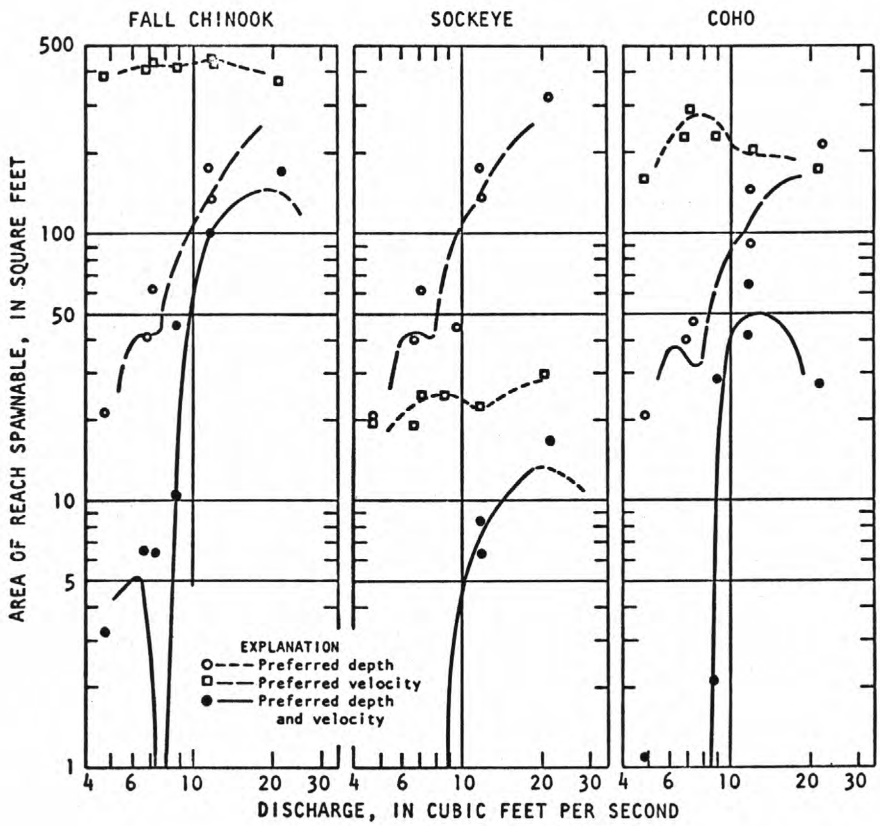


FIGURE 73.--Curves of spawnable area versus discharge, Bear Creek reach A.

Preferred spawning discharges.--The preferred spawning discharge for each salmon species was determined from the curves in figures 73-75. Following is a list of the preferred spawning discharges, by species and study reach, for Bear Creek:

Salmon species	Preferred spawning discharge (cfs) Study reach A	B	C
Fall chinook	19	26	35
Sockeye	19	16	30
Coho	13	20	33

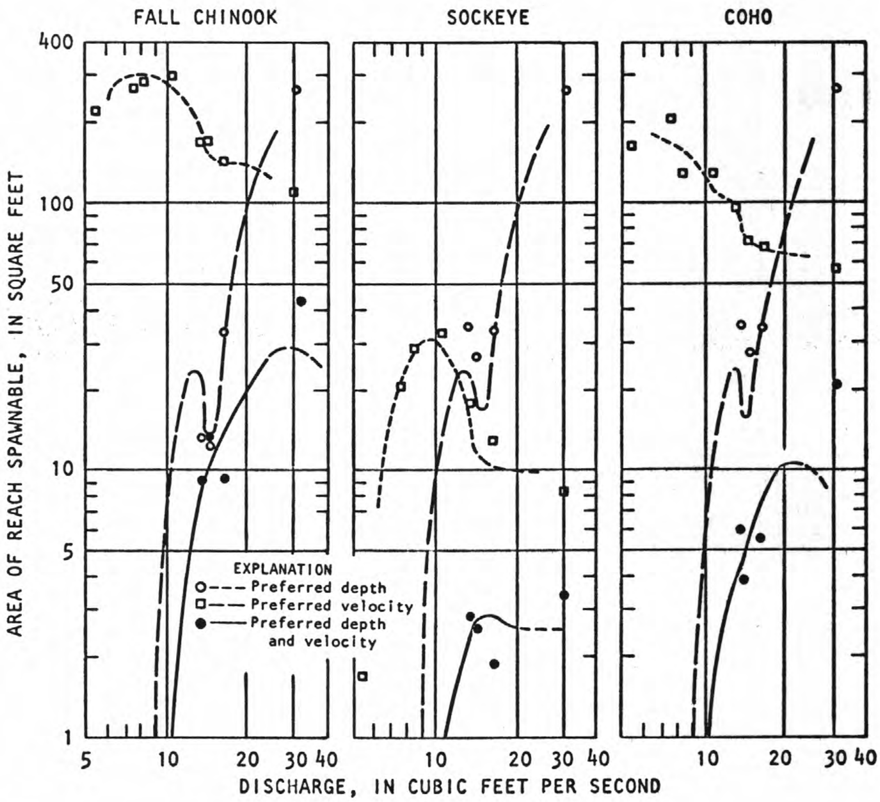


FIGURE 74.--Curves of spawnable area versus discharge, Bear Creek reach B.

The crests of the curves are not well defined for sockeye on reach A (fig. 73) and for fall chinook on reach B (fig. 74).

Bear Creek is utilized mainly by coho, to a lesser extent (and then mainly in the lower reaches of the river) by fall chinook and sockeye, and not at all by spring chinook. A possible reason for spring chinook not utilizing the river may be that the probability of adequate discharges occurring during the critical propagation periods is extremely low--adequate discharges are available less than 15 percent of the time in December, as determined from the reach regression models and figure 72. Spawning discharges are available 46 and 53 percent of the time for fall chinook and sockeye, respectively, on reach C, but only 34 percent of the time on reach A.

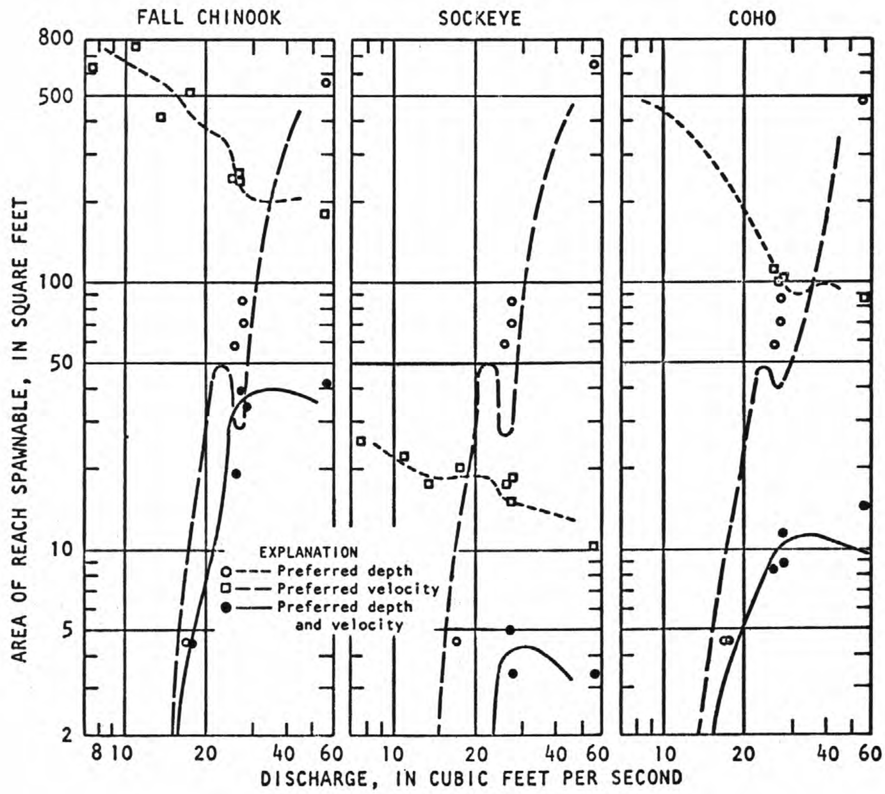


FIGURE 75.--Curves of spawnable area versus discharge, Bear Creek reach C.

Discharges for rearing.--Discharges for salmon rearing were determined from figure 76 on the basis of the part of the reach covered by water. Additional curves, used for evaluating the water depths and velocities at these rearing discharges, are shown in figure 77.

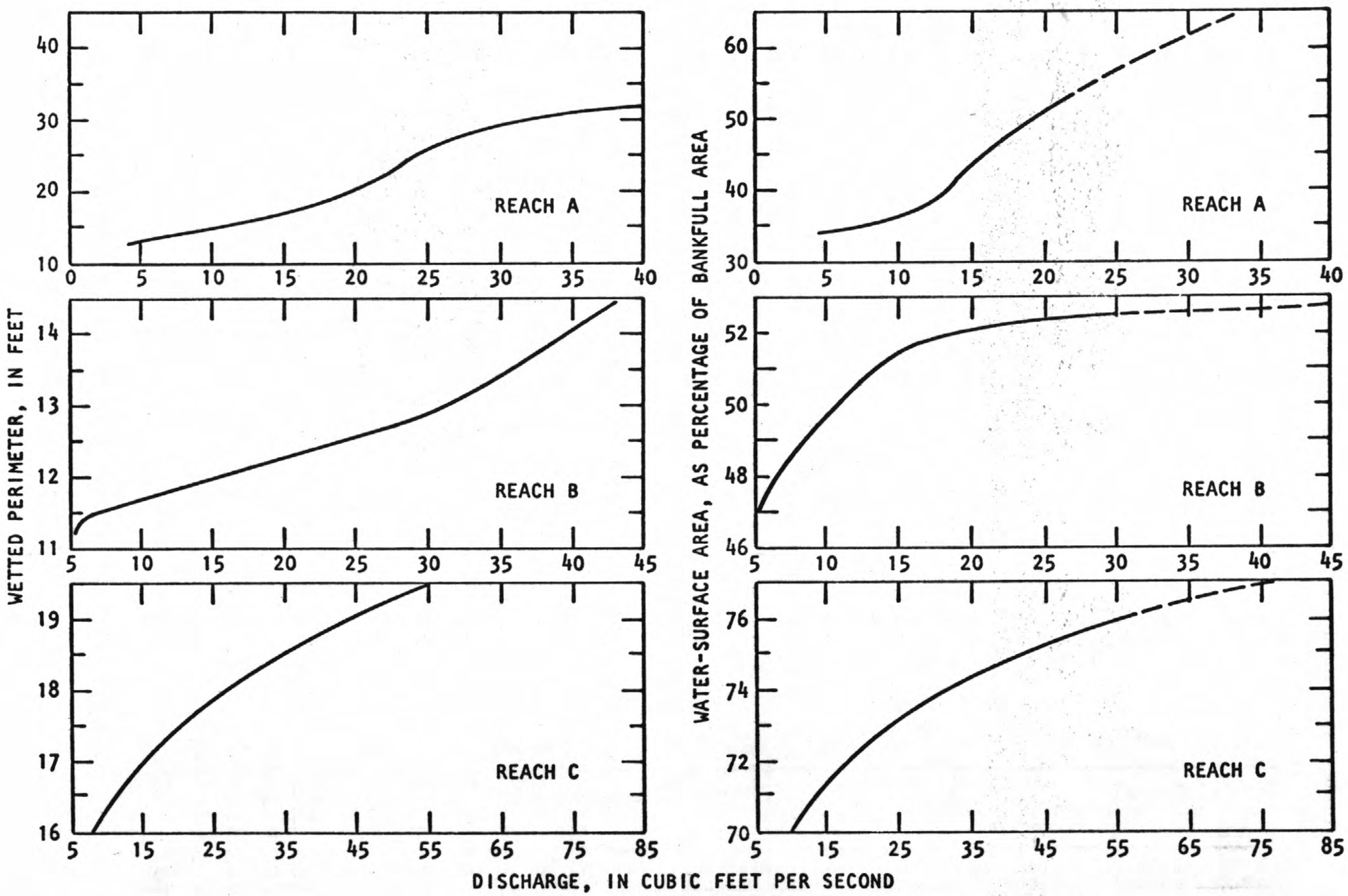


FIGURE 76.--Relations of discharge to wetted perimeter and to percentage of bankfull area covered by water, Bear Creek study reaches.

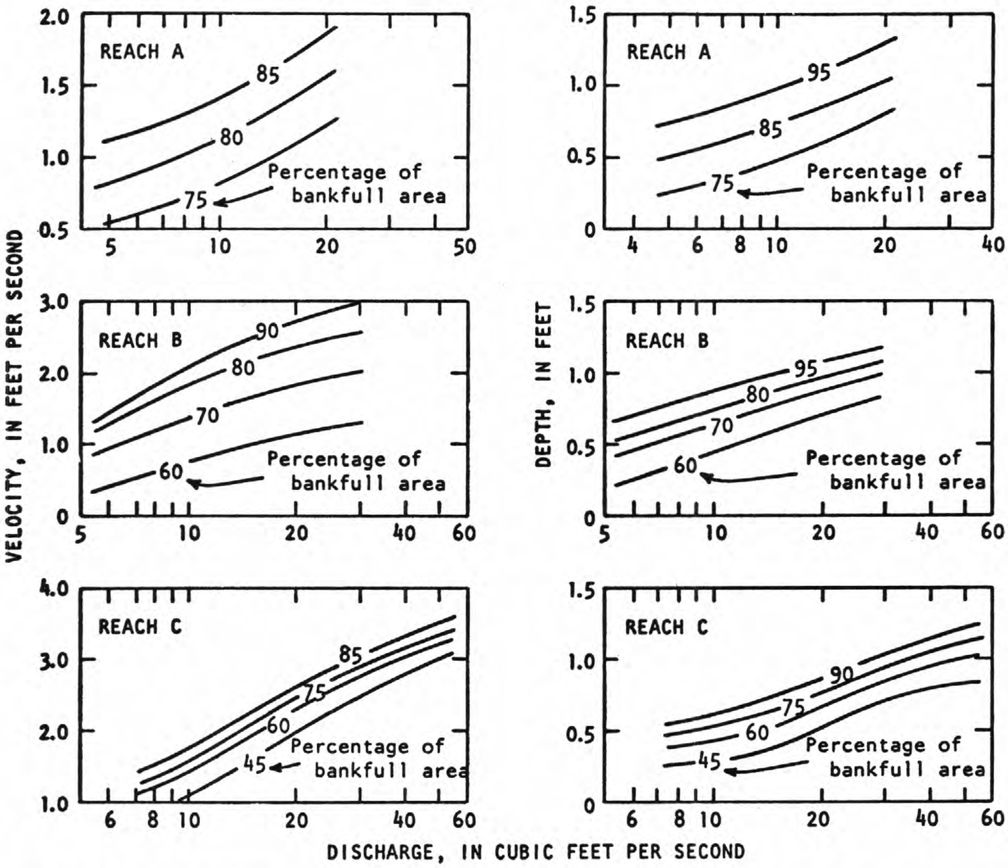


FIGURE 77.--Relations of discharge to velocity and to depth for selected percentages of bankfull area, Bear Creek study reaches.

The following table shows the results of the rearing-discharge investigation:

	Study reach		
	A	B	C
Preferred rearing discharge (cfs)	5	7	8
Equivalent discharge at the gage (cfs)	13	17	13
Percentage probability of rearing discharge being equaled or exceeded during the month with the lowest flow (fig. 72)	less than 15	less than 15	less than 15
Discharge at the 50-percent-probability level for August, the month with the lowest flow (cfs)	3	3	4

The equivalent discharge at the gage was determined by solving the reach regression models for Q_G and substituting the preferred rearing discharges into the equations. The discharge at the 50-percent-probability level for the lowest flow month (August, fig. 72) was assumed to be the naturally occurring limiting discharge for salmon that utilize the stream for rearing year around (fig. 2).

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