Stream Hydrology Related to the Optimum Discharge for King Salmon Spawning in the Northern California Coast Ranges

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779–AA

Prepared in cooperation with the California Department of Fish and Game

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By S. E. RANTZ

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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STREAM HYDROLOGY RELATED TO THE OPTIMUM DISCHARGE FOR KING SALMON SPAWNING IN THE NORTHERN CALIFORNIA COAST RANGES

By S. E. Rantz

ABSTRACT

This report presents the results of a reconnaissance study to test the hypothesis that in a geologically homogeneous region, such as the northern California Coast Ranges, the optimum discharges for king salmon spawning are related to some characteristic discharge of the streams and to an index of their channel geometry. For the purpose of this study, optimum discharge is defined as the minimum discharge that will give the maximum spawning area. Verification of the existence of a significant correlation between optimum discharge and hydrologic characteristics that are readily determined would provide a means of estimating optimum discharge at a fraction of the cost in time and money now spent for that purpose.

A short spawning reach was selected for study on each of nine streams in the Eel and Mad River basins of northern California. Optimum discharge was determined at each reach by field observations made in accordance with criteria and methods developed by the California Department of Fish and Game and by other conservation agencies. These optimum discharges (Q_o) were then correlated with mean discharge (Q_m) and ratio of stream width to drainage area $\left(R_{\frac{w}{d.a}}\right)$. The computed regression equation is $Q_o=0.89(Q_m)^{1.09}\left(R_{\frac{w}{d.a}}\right)^{1.44}$. The multiple correlation coefficient, 0.912, is highly significant from a statistical standpoint.

This study was of an exploratory nature; the general applicability of its methodology should be tested further.

INTRODUCTION

PURPOSE AND SCOPE

California's increasing population and burgeoning economy place a heavy demand on the available water supply. To meet the expanding and conflicting water requirements of the various segments of the economy, the development of surface-water supplies is being planned along multiple-purpose lines. In most of these multiple-purpose projects the conservation of fishlife is an important element, and although the water requirements for fishlife do not constitute a consumptive use of water, they frequently conflict with the demand for water for hydroelectric generation and for other beneficial uses, such as irrigation and domestic or municipal supply. If fishlife is to be protected, or possibly enhanced, in a stream whose natural regimen is to be changed by a manmade development, it is necessary that streamflow requirements for fish reproduction, transportation, and rearing of the young be determined while the proposed development is still in the planning stage.

Present methods of determining the flows needed for fishlife require extensive field study of the hydrography and fish-spawning patterns in each stream. The purpose of this study was to explore the possibility that the discharge required for fishlife in streams in a geologically homogeneous region is related to hydrologic characteristics of the region. Establishment of such a relation would provide a means of estimating the flows needed for fishlife at a fraction of the cost in time and money now spent for that purpose.

This investigation was limited to a study of the optimum discharge for king salmon spawning in streams in a single physiographic region, the northern California Coast Ranges (fig. 1). Determination of the flow regimen needed for the transportation of king salmon adults to, and the young salmon from, spawning areas will require a study of broader scope.

DEFINITION OF TERMS

Several terms used in the preceding paragraphs require explanation. "Geologically homogeneous region," as used in this report, refers to the physiographic subdivisions of the country described by Fenneman (1931). By Fenneman's classification there are two distinct physiographic sections, or geologically homogeneous regions, in north coastal California, namely the Klamath Mountains and the California Coast Ranges. This study was limited to streams in the Coast Ranges.

The term "optimum discharge" refers to the minimum discharge that will give the maximum spawning area for king salmon. If, for example, a spawning area is at a maximum when the river discharge ranges from 300 to 400 cfs (cubic feet per second), the optimum discharge is 300 cfs. A spawning area is defined as a reach of stream which king salmon are likely to select for spawning, that is, a reach having the proper combination of depth, bottom velocity, water temperature, and streambed composition. Usable criteria have been established by various conservation agencies for these spawning-area elements for king salmon. Similar criteria remain to be established for silver salmon and steelhead trout in coastal streams before a study similar to this one can be made for these other two species of anadromous fish.

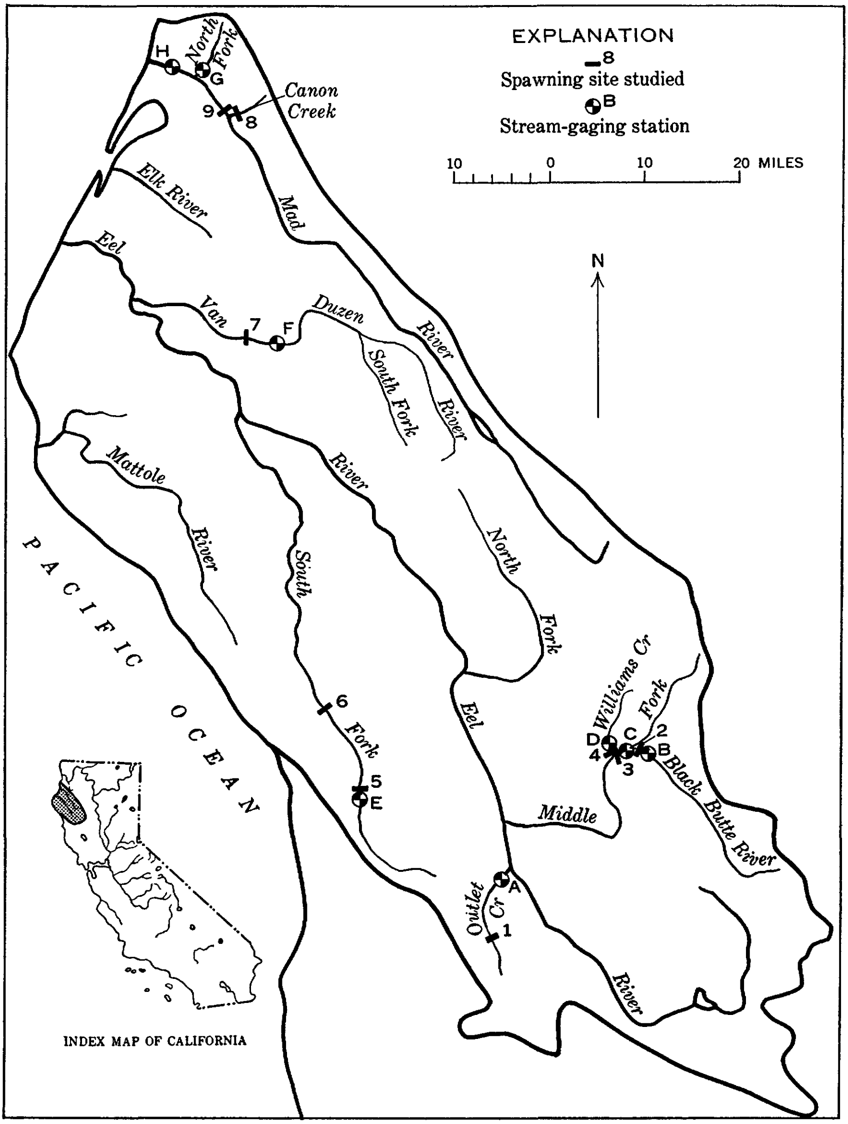

FIGURE 1.—Sketch map showing location of salmon spawning sites studied in northern California Coast Ranges.

ACKNOWLEDGMENTS

This study was authorized by a cooperative agreement between the U.S. Geological Survey and the California Department of Fish and Game. The report was prepared under the general direction of Walter Hofmann, district engineer of the Geological Survey. The assistance of C. K. Fisher, Jr., and John M. Hayes, fishery biologists of the Department of Fish and Game, is gratefully acknowledged. Mr. Hayes assisted in selecting the spawning sites used in the study, and Mr. Fisher instructed Geological Survey personnel in the methods used by the Department to sample streambed material and determine optimum discharge from field observations.

CHARACTERISTICS OF A SPAWNING AREA

Bed material of spawning areas must consist of gravel of such size that king salmon can excavate redds (nests) in which their eggs can be deposited, fertilized, and hatched. The preferred areas are either in riffles or at the downstream end of pools, where velocities are fairly rapid. The force of the current assists the salmon in moving the gravel; the larger the gravel, the faster the current required. If, however, the current 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 insure successful hatching. The gravel must therefore be large enough to provide the interstices needed for this circulation. Water temperatures should be between 42°F and 53°F for proper incubation of the eggs. In the north Coast Ranges region, the spawning season, mid-October to the end of February, coincides with the high-water season, and during this period water temperatures are usually in the desired range.

The criteria for favorable spawning conditions used in this study are:

1. Depth of water: 10 inches or more.
2. Bottom velocity (measured 0.3 foot above streambed): 1 to 3 feet per second.
3. Streambed composition:

Size (inches)	*Weight fraction of total sample (Percent)*
Silt and sand	20 or less
$\frac{5}{32}$ to $\frac{1}{2}$	20 or less
$\frac{1}{2}$ to 1	20 or less
1 to 3	50 or less
3 to 6	10 or more
6 to 12	30 or less

These criteria were not developed specifically for conditions in the streams studied, but are rather a composite of criteria derived from studies of various streams by the California Department of Fish and Game (Westgate, 1958) and by other Pacific Coast conservation agencies. The gravel classification shown in the table refers to bed material sampled to a depth of 1 foot, which is the approximate depth of king salmon redds. The bed material is considered unsatisfactory if the percentage present in any size classification fails to meet the criterion shown.

DETERMINATION OF OPTIMUM DISCHARGE

The first step in this study was to determine the optimum discharge at nine selected salmon-spawning sites on streams in the north Coast Ranges region. Optimum discharge, it will be recalled, is the minimum discharge that will give the maximum spawning area. Furthermore, an area is considered to be favorable for spawning if it meets the criteria of depth, bottom velocity, and streambed composition listed above. In general, spawning sites were selected in the vicinity of stream-gaging stations where the streamflow characteristics were known. An exception was the spawning site on Canon Creek (site 8 on fig. 1), an ungaged stream that the California Department of Fish and Game wished to study. All sites selected were in the Eel or Mad River basins. A prime consideration in the selection of sites was that they sample a wide range of drainage-area sizes. Table 1 lists the selected spawning sites and the size of drainage area upstream from each site. Spawning had been observed in previous years at some of the sites, and all sites selected had reaches of streambed that were at least partly composed of gravel of favorable size. The length of reach used as a representative spawning area was dependent, at each site, on the areal extent of the gravel of favorable size. The lengths chosen ranged from as little as 40 feet on one small stream to 200 feet on the medium and large streams.

On each reach of channel selected for study, three to five cross sections, or transects, were established at right angles to the direction of flow. Within each reach, 6 to 12 samples of bed material were taken, where needed, to delineate the potentially usable spawning area, that is, the actual area that had gravel of favorable size. A potentially usable spawning area needs only to have proper combination of depth of water and bottom velocity to be a favorable area for salmon spawning. The bed sampling equipment consisted of a tooth-edged cylindrical "cookie-cutter," a set of graduated sieves, and a spring weighing scale. The "cookie-cutter" was 14 inches in diameter, 2 feet long, and made of light steel plate. In the sampling process, it was forced into the streambed to a depth of 1 foot, and the bed material within it was removed by hand, sorted in the sieves, and weighed on the scale. Figure 2, a map of the site selected on the Van Duzen River near Carlotta, illustrates a typical study area. On this figure are shown the streambed sampling points, the potentially usable spawning area, and the transect lines. It is along these transects that depth and bottom velocity were measured at various discharges to determine the area favorable for spawning. Table 1 indicates the potentially usable spawning area at each site, as planimetered from large-scale maps similar to figure 2; the dates when measurements of

TABLE 1.—*Summary of field data collected at spawning sites*

Spawning site		Drainage area (sq mi)	Potentially usable spawning area (sq ft)	Date of measurement	Discharge (cfs)	Ratio of favorable spawning area to potentially usable area (percent)
No. (fig. 1)	Name and location					
1	Outlet Creek near Arnold (3 miles south of Longvale).	95.4	10,280	11-19-62	15.7	0
				12-6-62	275	47.7
				1-3-63	71.1	20.9
				2-13-63	536	73.5
				2-20-63	149	55.5
2	Black Butte River near Covelo (0.3 mile upstream from mouth).	162	7,150	12-20-62	305	82.7
				1-9-63	86	8.4
				2-14-63	688	0
				2-19-63	418	33.9
				3-6-63	155	37.8
				3-18-63	142	33.6
3	Middle Fork Eel River near Covelo (0.6 mile upstream from Williams Creek).	374	19,450	12-20-62	1,090	50.4
				1-8-63	255	52.3
				1-21-63	162	41.4
				2-14-63	1,890	16.2
				2-18-63	1,160	39.3
				3-6-63	396	70.7
4	Williams Creek near Covelo (0.6 mile upstream from mouth).	30.5	760	12-21-62	72.8	59.2
				1-9-63	15.8	1.3
				2-13-63	139	0
				2-18-63	71.2	57.8
				3-6-63	26.3	9.9
				3-18-63	29.8	11.6
5	South Fork Eel River near Branscomb (0.2 mile upstream from Jack of Hearts Creek).	43.9	1,880	12-21-62	186	52.5
				1-3-63	68.6	19.6
				2-7-63	301	42.5
				2-14-63	298	39.8
6	South Fork Eel River near Leggett (0.3 mile north of Lane's Redwood Flat resort and 4.7 miles north of Leggett).	258	3,720	11-20-62	202	60.4
				12-20-62	1,270	26.8
				1-28-63	173	45.3
				2-14-63	1,700	20.1
				2-19-63	906	32.2
				2-25-63	585	100.0
				3-8-63	327	93.3
7	Van Duzen River near Carlotta (0.8 mile upstream from Grizzly Creek).	222	15,290	11-6-62	136	0
				2-4-63	2,740	28.4
				2-7-63	2,010	47.7
				2-9-63	1,560	58.7
				2-11-63	1,080	84.0
				2-20-63	1,080	75.9
				2-22-63	784	56.9
8	Canon Creek near Korbel (0.2 mile upstream from mouth).	16.2	2,620	2-1-63	190	70.2
				2-2-63	114	63.5
				2-3-63	123	67.4
				2-13-63	81.8	57.6
				3-28-63	266	53.3
				3-29-63	378	41.0
9	Mad River near Korbel (3.0 miles downstream from Canon Creek).	393	27,400	11-7-62	333	13.0
				2-2-63	8,460	8.0
				2-3-63	7,150	19.8
				2-3-63	6,860	22.1
				2-4-63	4,730	28.0
				2-6-63	3,220	25.8
				2-11-63	1,410	58.4
				2-13-63	2,840	49.1

discharge, depth, and bottom velocity were made; the measured discharges on those dates; and the percentages of potentially usable spawning area that had favorable depths and bottom velocities on those dates.

The data in the last two columns of table 1 were plotted, and curves were fitted to the plotted points to obtain values of optimum discharge for each site. For illustrative purposes the plotted data for three sites are shown on figure 3. The curves on figure 3 are ex-

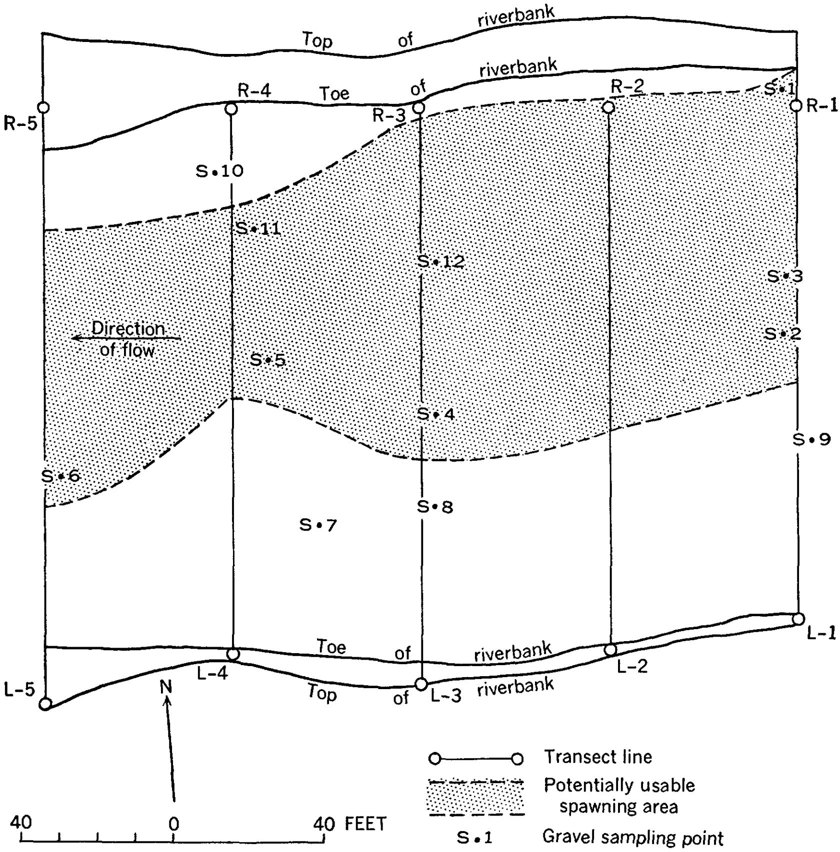

FIGURE 2.—Sketch map of spawning site on Van Duzen River near Carlotta (site 7).

plained as follows: At the lower flows, favorable spawning area increases with discharge as the increasing flows submerge additional areas of gravel. A maximum value of favorable spawning area is reached when the discharge attains such a value that any further increase in flow creates bottom velocities in excess of 3 feet per second and thereby decreases the favorable spawning area. While the plotted points usually provided enough information to define the shape of the curves of discharge versus favorable spawning area, additional information concerning the shape of the curves was often obtained by inspection of the depth and bottom velocity observations made at the various flow rates. The optimum discharges ontained from the curves are listed in column 3 of table 2.

During the investigation, streambed conditions at several of the sites varied with time. This occurrence is normal in streams in this region. High flows will often move the gravels, and during the recession phase of these rises fine materials such as sand and silt may

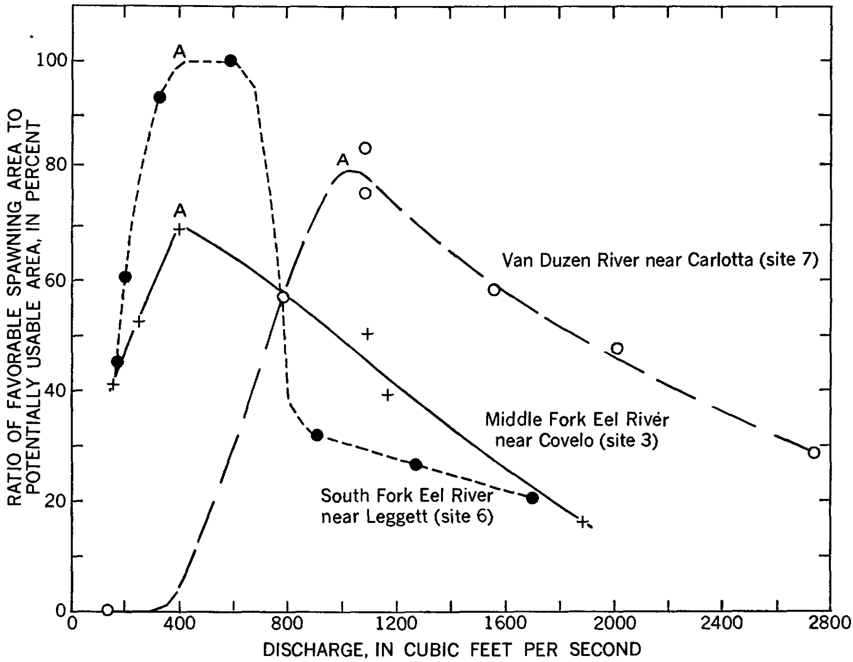

FIGURE 3.—Graph for determination of optimum discharge at selected spawning sites. Letter "A" indicates optimum discharge for each of the spawning sites.

TABLE 2.—*Pertinent streamflow and physical characteristics of spawning sites studied*

Spawning site		Streamflow characteristics				Physical characteristics			
No.	Name and location	Optimum discharge (cfs)	Percent of time optimum discharge is exceeded	Mean discharge (cfs)	Median discharge (cfs)	Drainage area (square miles)	Stream width at mean discharge (ft)	Ratio of stream width to drainage area	Channel slope (feet per foot)
1	2	3	4	5	6	7	8	9	10
1	Outlet Creek near Arnold	480	13	261	23	95.4	94	0.99	0.0028
2	Black Butte River near Covelo.	280	31	285	78	162	93	.57	.0042
3	Middle Fork Eel River near Covelo.	400	44	951	260	374	164	.44	.0034
4	Williams Creek near Covelo.	73	22	76	13	30.5	31	1.02	.0100
5	South Fork Eel River near Branscomb.	185	20	168	29	43.9	57	1.30	.0044
6	South Fork Eel River near Leggett.	400	34	958	165	258	122	.47	.0033
7	Van Duzen River near Carlotta.	1,000	19	810	165	222	141	.64	.0080
8	Canon Creek near Korbel	165	4	37	8	16.2	31	1.91	.0096
9	Mad River near Korbel	1,400	23	1,280	273	393	271	.69	.0025

be deposited on the coarse gravels. Later, this fine material may be removed by ensuing medium-stage flows. These changes are generally ephemeral. Stream-gaging sites in the region do not show a steady pattern of either aggradation or degradation, but indicate a state of what might be called "unstable equilibrium"; scour at a local site is generally followed by fill, and vice versa. Consequently streambed conditions at the selected study sites are assumed to be generally representative of those at most spawning sites in the streams, although in some years the gravel composition at the selected sites may be unfavorable at times when the salmon are spawning. For these reasons, the boundaries of potentially usable gravel that were delineated at each site at the start of the study were considered to be constant throughout the investigation.

The reader may wonder what justification can be made for basing the optimum discharge of a stream on observations made at a single spawning site. Normally when the Department of Fish and Game makes a similar study of a stream, long reaches of the channel are studied. It is obviously not feasible to study the entire channel, and consequently even the extensive investigations of the Department represent only a statistical sampling of all possible spawning reaches of the stream being investigated. In this study a sampling procedure was also used but, instead of taking a sample of nine spawning reaches on a single stream, our sample consists of one spawning reach on each of nine streams of various drainage area size. In the next section of this report the nine optimum discharges listed in column 3 of table 2 are considered in relation to the hydrologic characteristics of the streams. A good correlation would indicate that the value of optimum discharge of a stream, shown by the derived relationship, is probably more reliable than that obtained by observing the single short spawning reach. That is, because the observed optimum discharges are subject to random error, the curve of relation may be more reliable than the individual values on which the curve is based.

RELATION OF OPTIMUM DISCHARGE TO HYDROLOGIC CHARACTERISTICS

After values of optimum discharge for each of the nine sites were obtained, an attempt was made to relate these discharges to hydrologic characteristics of the region. It was hypothesized that in a geologically homogeneous region, such as the northern Coast Ranges province, the optimum discharges are related to some characteristic discharge of the streams and to an index of their channel geometry. With a sample of only nine sites available, it was almost mandatory that any relationship investigated be limited to a linear or simple exponential function involving two, or at most, three variables in order to conserve "degrees of freedom." A discussion of the statistical concept of degrees of freedom is beyond the scope of this paper. Suffice it to say that the number of degrees of freedom is equal to the number of items in the sample (nine) minus the number of constants in the regression equation and that, when small samples are used, the reliability of the regression equation decreases markedly as the number of degrees of freedom decreases. Therefore, few variables were used in the correlations testing our hypothesis, although many were considered; variables considered are in table 2.

The figures shown in columns 4, 5, and 6 of table 2 were derived from Geological Survey records. The stream-gaging stations whose records are pertinent to this study are given in table 3 and are shown on figure 1.

TABLE 3.—*Stream-gaging stations whose records are pertinent to this study*

Identifying letter (fig. 1)	Name of station	Drainage area (square miles)	Period of record
A	Outlet Creek near Longvale	161	1956–63
B	Black Butte River near Covelo	162	1958–63
C	Middle Fork Eel River below Black Butte River, near Covelo	367	1951–63
D	Williams Creek near Covelo	30.4	1961–63
E	South Fork Eel River near Branscomb	43.9	1946–63
F	Van Duzen River near Bridgeville	216	1911–13, 1939–63
G	North Fork Mad River near Korbel	40.5	1957–63
H	Mad River near Arcata	485	1910–13, 1950–63

In table 2, all values shown in columns 4, 5, and 6 are for the 60-year base period 1900–59. Column 4 is the percent of time on the long-term flow-duration curve that the optimum discharge is exceeded. Column 5 is the long-term mean discharge and column 6 is the long-term median discharge at each of the nine spawning sites. In general, the mean discharge of streams in the northern California Coast Ranges is exceeded about 24 percent of the time. A previous study (Rantz, 1964) was the source of the values in columns 4, 5, and 6 for Black Butte River near Covelo (site 2), Middle Fork Eel River near Covelo (site 3), South Fork Eel River near Branscomb (site 5), and Van Duzen River near Carlotta (site 7). The remaining figures in the three columns were obtained by applying standard Geological Survey correlation procedures to the records for the gaging stations listed in table 3 and the discharge measurements listed in table 1.

Physical characteristics of the spawning sites are shown in the last four columns of table 2. The latest topographic maps were used to obtain drainage areas (column 7) and channel slopes (column 10). The stream widths (column 8) corresponding to the mean discharges (column 5) were obtained from discharge-measurement data. Column 9 is the ratio of column 8 to column 7.

After all pertinent data was compiled, the analysis was begun. It was originally theorized that the stream-channel geometry in a geologically homogeneous region might be related to some characteristic discharge and to size of drainage area. In other words, all streams of a given drainage-area size might tend to have common geometric characteristics at discharges that have equal probability of being exceeded. For example, the optimum discharge for a 50 square-mile drainage basin might be one that is exceeded 20 percent of the time; for a 100 square-mile basin it might be the discharge that is exceeded 25 percent of the time. To test this hypothesis a linear correlation was computed; percent of time that optimum discharge is exceeded (column 4 of table 2) and drainage area (column 7) were used in the computation. The correlation coefficient, 0.673 for 7 degrees of freedom, was significant at the 5 percent level. However, the differences between measured and computed optimum discharges were excessive. The explanation for these excessive differences is: The percentages in column 4 of table 2 were obtained from flow-duration curves. Because of the great variability of flow in streams in the northern California Coast Ranges, the flow-duration curves are very steep and a small increment of percentage represents a large increment of discharge. Thus the computed standard error, 9.3 percent in this correlation, represented a large error when converted to cubic feet per second. Additional parameters such as channel slope, ratio of stream width to drainage area, and mean annual runoff per square mile were next considered, but they offered no improvement in the correlation.

A second approach to the problem was more successful. Inspection of columns 3 and 5 of table 2 showed that optimum discharge and mean discharge are roughly of the same magnitude. A linear correlation computed with these two variables had a correlation coefficient of 0.783 (7 degrees of freedom), which is significant at the 2 percent level. The agreement between measured and computed optimum discharges was increased but was still unsatisfactory. However, when the differences between the measured and computed values were compared with the ratios of stream width to drainage area (column 9 table 2), the computed values of optimum discharge were low when the ratios were low and high when the ratios were high. This variation can be explained thus: For streams having equal mean discharge, optimum discharge tends to increase directly with increase in stream width, because increased stream width usually means a greater width of potentially usable gravel and higher flows are generally required to submerge the wider expanse of gravel. Stream width in turn varies with drainage area, and those streams that are disproportionately wide, that is, that have a large ratio of stream width to drainage area, will therefore tend to have disproportionately high optimum discharges. A multiple linear correlation was therefore computed with optimum discharge (Q_o) as the dependent variable and mean discharge (Q_m) and ratio of stream width to drainage area $\left(\frac{R_w}{da}\right)$ as the independent variables. A logarithmic transformation of the data was used to eliminate the "joint relation" that existed when natural values of the variables were used. (A joint relation exists when neither of the independent variables can be considered individually to determine its effect on the dependent variable; the associated or joint effect of both independent variables must be considered.)

The computed regression equation is

$$Q_o=0.89(Q_m)^{1.09}\left(\frac{Rw}{da}\right)^{1.44}$$

This equation is shown as a family of curves on figure 4. Also shown on the figure are the plotted points; the number above the point identifies the spawning site and the number below is the ratio of stream width to drainage area. The multiple correlation coefficient 0.912, is highly significant. (For 6 degrees of freedom, a multiple correlation coefficient of 0.886 would be significant at the 1 percent level.) Figure 5 provides a visual comparison of measured and computed optimum discharge, values of which are listed in table 4.

TABLE 4.—*Comparison of measured and computed optimum discharge*

Spawning site		Optimum discharge		
No. (fig. 1)	Name and location	Measured (cfs)	Computed (cfs)	Percent difference referred to measured discharge
1	Outlet Creed near Arnold	480	379	−21
2	Black Butte River near Covelo	280	189	−32
3	Middle Fork Eel River near Covelo	400	481	+20
4	Williams Creek near Covelo	73	103	+41
5	South Fork Eel River near Branscomb	185	346	+87
6	South Fork Eel River near Leggett	400	533	+33
7	Van Duzen River near Carlotta	1,000	694	−31
8	Canon Creek near Korbel	165	116	−30
9	Mad River near Korbel	1,400	1,270	−9

The regression equation will probably give more reliable estimates of optimum discharge for a stream than will current-meter and depth observations made over a range of discharges at a single short spawning reach. However, it is not to be inferred that the optimum discharges computed in this study are necessarily more reliable than those observed. What is meant is that the regression equation may give more reliable estimates if the stream width used in the equation is the average width of the stream, observed at many long potential spawning reaches when the discharge is at or near its mean value. Nor is

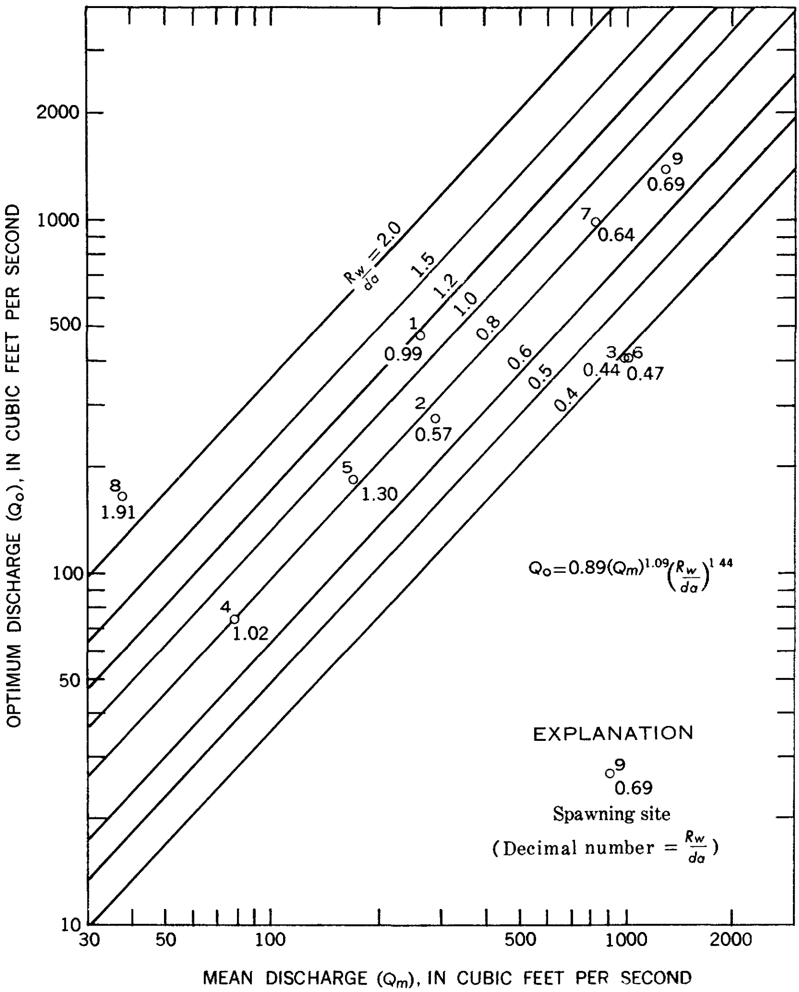

FIGURE 4.—Graph showing the relation of optimum discharge to mean discharge and to ratio of stream width to drainage area.

it to be inferred that optimum discharges so computed will be as reliable as those determined in the extensive investigations made on individual streams by the Department of Fish and Game. The regression equation does, however, offer a quick, cheap method of making preliminary estimates of optimum discharges that appear to be of acceptable accuracy. Unfortunately, there is no way, at the moment, of making a quantitative check on the reliability of the optimum discharges, either observed or computed, that were obtained in this study. The only stream in this study that had been investigated by the Department of Fish and Game was Middle Fork Eel River near Covelo (site 3), and there the Department had observed

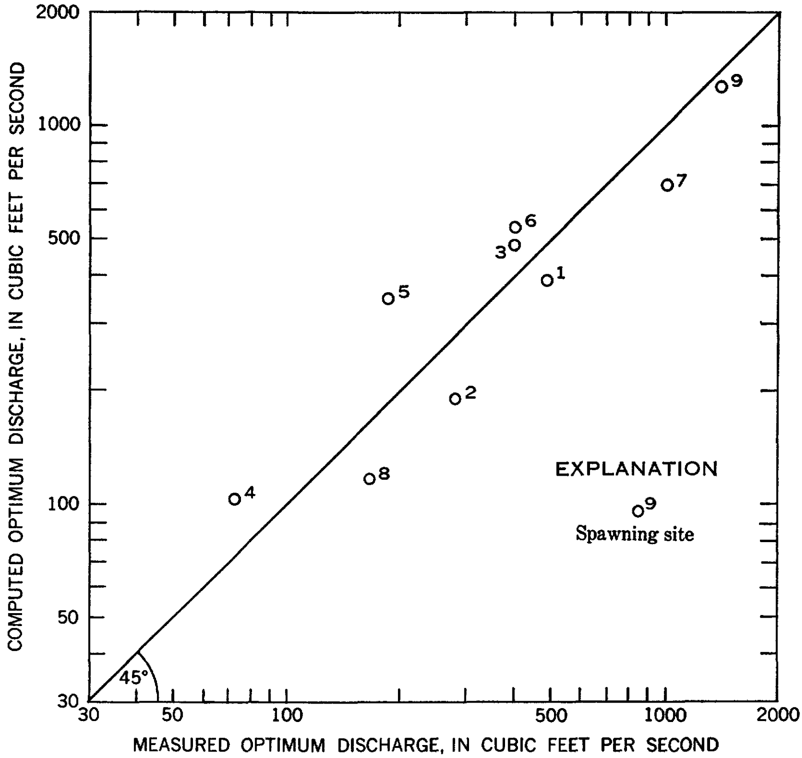

FIGURE 5.—Graph showing the comparison of measured and computed optimum discharge.

discharges only as high as 270 cfs. The Department study established the fact that of the discharges observed, 270 cfs gave the greatest amount of favorable spawning area. In this study the observed optimum discharge was 400 cfs and the computed optimum discharge was 481 cfs.

APPLICATION OF THE DERIVED RELATION

The procedure for applying the regression-equation method to the determination of optimum discharge at a spawning reach in the northern California Coast Ranges is as follows:

1. Determine the long-term mean discharge at the spawning reach: If the spawning reach has been gaged for 10 years or more, the desired figure is available in Rantz (1964). If the gaging station at the spawning reach is a recent installation, the long-term mean discharge may be obtained by correlating concurrent monthly mean discharges at the spawning-site gage and at the nearest comparable gaging station for which the long-term mean discharge is known. If the spawning reach is ungaged,

the first step is to make five or six discharge measurements over a wide range of discharge at the spawning reach. To obtain the desired mean, the measured flows are then correlated with concurrent discharges at the nearest comparable gaging station for which the long-term mean discharge is known.

2. Determine the drainage area at the spawning reach: If the spawning reach is gaged, the drainage area may be obtained from Geological Survey streamflow publications. If ungaged, the drainage basin above the reach is first outlined on topographic maps. The desired drainage area is then measured by planimeter.
3. Determine the average stream width at the spawning reach when the discharge is at or near its mean value: If the spawning reach is gaged, the stage of the mean discharge will be known. If the spawning reach is ungaged, the stage corresponding to mean discharge can be deduced from the discharge measurements that had been made at the reach. Observations of stream width corresponding to the desired stage should be made in sufficient numbers to establish the average width for the full extent of the spawning reach or reaches. Commonly in the northern California Coast Ranges, the lowest line of vegetation on the stream banks is approximately at the stage of mean discharge.
4. Determine optimum discharge at the spawning reach by use of the regression equation or curves. The optimum discharge may be calculated from the data obtained in the three steps described above, by use of the regression curves on figure 4, or by substitution in the regression equation

$$Q_o=0.89(Q_m)^{1.09}\left(R\frac{w}{da}\right)^{1.44},$$

where Q_o is optimum discharge in cubic feet per second, Q_m is mean discharge in cubic feet per second, $R\frac{w}{da}$ is the ratio of stream width, in feet, to drainage area, in square miles.

SUMMARY AND RECOMMENDATIONS

For the purpose of this study, optimum discharge is defined as the minimum discharge that will provide the maximum spawning area for king salmon and an area is considered favorable for king salmon spawning if it meets the criteria for depth, bottom velocity, water temperature, and streambed composition currently being used by fishery biologists of the California Department of Fish and Game. These criteria were used in field observations made to determine the optimum discharge at a short spawning reach on each of nine streams in the Eel and Mad River basins in the northern California Coast Ranges. These optimum discharges correlated well with a characteristic discharge of the streams (mean discharge) and an index of their channel geometry (ratio of stream width to drainage area). The relation obtained should prove useful for making preliminary estimates of optimum discharge that are reasonably reliable and which yet require only a small expenditure of time and money.

This investigation has been of an exploratory nature; it is recommended that it be pursued further along the lines indicated in this report. Extensive studies, such as those customarily made by the California Department of Fish and Game, should be carried out on streams in the northern California Coast Ranges to test the validity of the derived relation more completely. The methodology used in that region should also be applied in other physiographic provinces to test its general applicability. To broaden the scope of the investigation, criteria for favorable spawning conditions for silver salmon and steelhead trout should be established and a similar study should be made for these two species of anadromous fish.

REFERENCES CITED

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill Book Co., 534 p.

Rantz, S. E., 1964, Surface-water hydrology of coastal basins of northern California: U.S. Geol. Survey Water-Supply Paper 1758. (In press.)

Westgate, John, 1958, The relationship between flow and usable salmon spawning gravel, Cosumnes River, 1956: Calif. Dept. Fish and Game Administrative Rept. 58-2, 8 p.