

FRI-UW-7407  
June 1974

FISHERIES RESEARCH INSTITUTE  
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Seattle, Washington 98195

EFFECTS OF DISCHARGE IN THE CEDAR RIVER  
ON SOCKEYE SALMON SPAWNING AREA

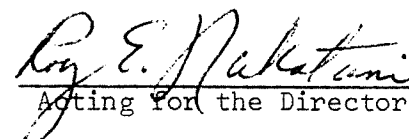
by

Q. J. Stober and J. P. Graybill

FINAL REPORT  
June 15, 1972 to June 14, 1974  
City of Seattle Water Department

Approved

Submitted June 28, 1974

  
Acting for the Director

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Hydraulic and biological investigations conducted at eleven study reaches on the Cedar River were designed to determine depths and velocities preferred by spawning Cedar River sockeye salmon and to provide an understanding of the effects of discharge on spawning sockeye during low flow periods. River utilization by spawning sockeye was investigated during 1972 and 1973 and in general, the greatest spawning activity occurred in the middle third of the river with lower numbers utilizing the upper and lower thirds. During the first half of the season spawning activity was greater in the upper and middle river and during the last half it was greater in the lower river. Measurements of depth and velocity were taken on a total of 1,239 sockeye salmon redds. The 80-percent intervals for "preferred" depths and velocities were 0.5-1.8 ft and 0.93-2.59 ft/sec, respectively. The relationships between area suitable for spawning and discharge were plotted for each river reach and the mean "peak" spawning discharge for the eleven study reaches was 240 cfs (250 cfs referenced to the Renton gage).

The capacity of the Cedar River to accommodate spawning sockeye was estimated to range from 167,000 to 376,000 spawners. A method based on the spawnable area gained or lost is presented for predicting the effect of discharges which deviate from the mean peak spawning discharge. This can be used to arrive at a rational resolution of the conflict among municipal-industrial, public use and fishery requirements during low flow periods.

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past two years is greatly appreciated. We are grateful to Mr. Milo Bell, Mr. Charles Howard, and Dr. Stephen Mathews with whom discussions have been helpful and to Mr. Cliff Olds and Mr. Terry Wright who provided able assistance in the field and with data analysis. In addition, we would like to thank Mason Bryant, Sam Casne, Jim Malick and Mike Stansbury for their voluntary assistance in the field.

#### INTRODUCTION

The Cedar River watershed is managed by the City of Seattle Water Department to serve as one of two sources of municipal and industrial water supply for the Seattle metropolitan area. The river below Landsburg extending to Renton is utilized as the primary spawning tributary by the Lake Washington sockeye salmon, as well as by less plentiful chinook and coho salmon and steelhead and cutthroat trout. Regulation of the river discharge has a direct effect on the anadromous salmonids in the section of river below the City water supply diversion at Landsburg. This effect can either be beneficial to fish or not, especially during periods of low runoff, when the conflict among demands placed on the system by the fishery resource, public use and the municipal and industrial needs become most acute.

The short and long range problems that must be dealt with in providing an adequate water supply for the metropolitan area will become more critical. During years of low runoff, a need exists for information from which a rational resolution of the conflict between human and fishery requirements may be reached. Therefore, an evaluation of the minimum discharge levels during dry years and the effects of such levels on the spawning of sockeye salmon in the Cedar River was conducted. This effort was designed to complement the Water Resource Management study sponsored by RIBCO. The present study objectives included: (1) determination of the depths and velocities "preferred" by spawning sockeye salmon in the Cedar River; (2) development of the relationships between spawnable area and discharge; (3) formulation of the relationship between actual spawner use and empirical calculations of spawnable area within river reaches; and (4) assessment of the timing of the



run, population dynamics, and effects of predicted discharge levels during times of low water supply on future salmon runs. This knowledge will allow management of the resources to insure that water is not wasted or the fishery unduly depleted during times of low runoff.

#### DESCRIPTION OF STUDY AREA

The discharge of the Cedar River is regulated both by operation of the Cedar Falls hydroelectric station below Chester Morse Lake (Seattle City Light) and by continuous diversion of approximately 200 cfs at Landsburg by the Seattle Water Department. Hydrographic analysis of stream discharge indicated high flows during winter and low flows in late summer, a pattern typical of a lowland stream.

Stations were established in eleven river reaches below Landsburg (river mile 21.6) for detailed hydraulic and biological investigation. These stations (1 through 11) located at river miles 19.8, 17.4, 15.7, 13.7, 13.4, 13.0, 12.5, 11.5, 8.4, 5.3 and 1.5 (Figure 1) were selected on the basis of spawning activity and relative stability of the stream bed. Stations 4, 8 and 10 were established at stations A, B and C used in a previous investigation by Collings et al. (1972) so that a basis could be provided for comparison of results. Stations 1, 2 and 3 were located between Landsburg and Maple Valley, stations 4 through 7 between Maple Valley and the Cedar Grove Bridge, stations 8, 9 and 10 between the Cedar Grove Bridge and the Jones Road Bridge, and station 11 at the U.S.G.S. gaging station in Renton.

#### MATERIALS AND METHODS

Depth and velocity were measured at active sockeye salmon redds during the 1972 spawning season according to standard techniques established by Heiser (1971). A Gurley current meter was placed at the upstream lip of each redd at 0.4 ft above the bottom, or at 0.1 ft below the surface if the depth was less than 0.4 ft. From these measurements, the 80-percent ranges of depth and velocity used by spawning Cedar River sockeye salmon were established by elimination of the highest and lowest 10 percent of the measurements.

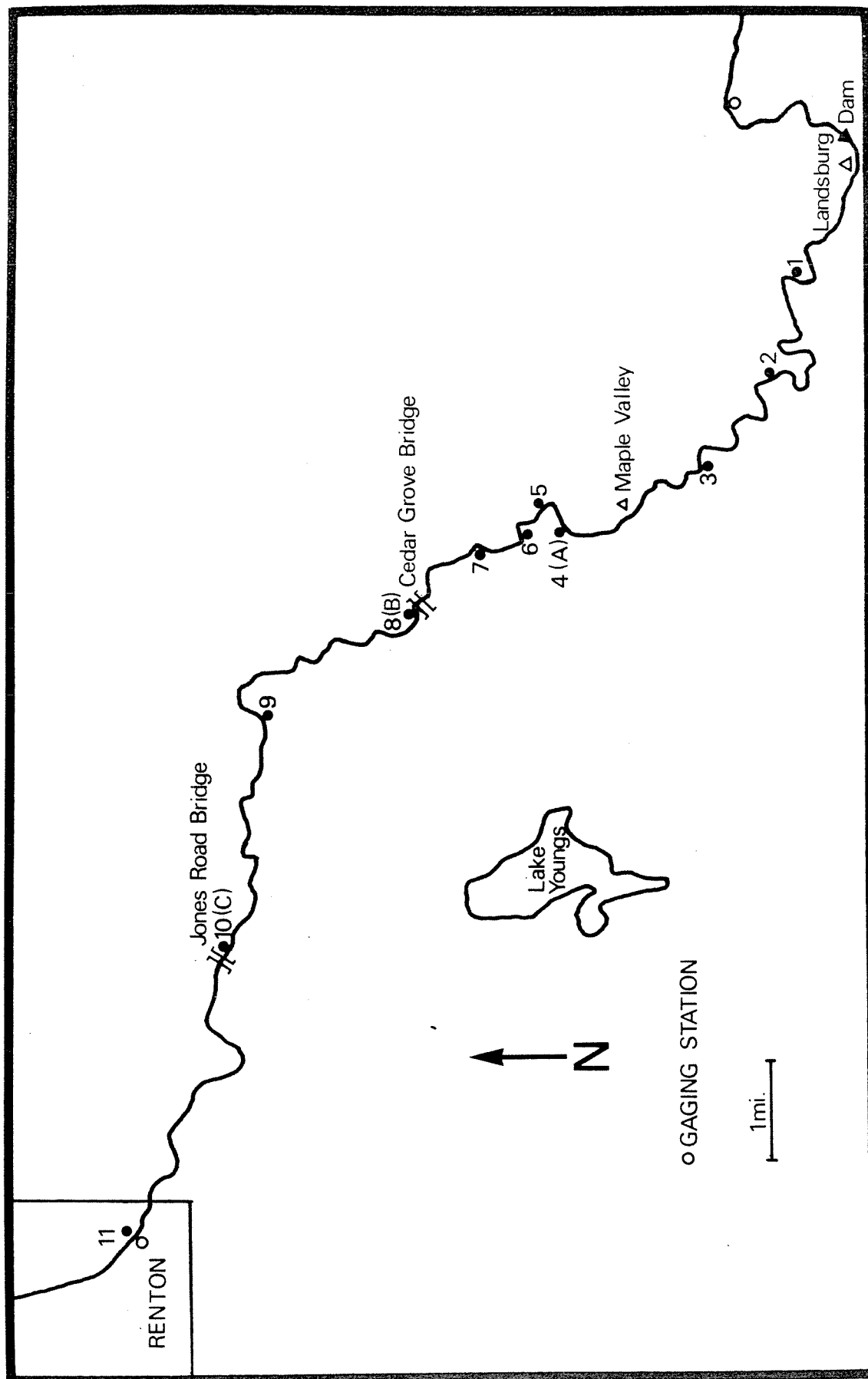


Fig. 1. Cedar River study reaches (1-11) between Landsburg and Renton. Reaches 4, 8 and 10 coincide with reaches A, B and C of Collings et al. (1972). U.S.G.S. gaging stations are shown.

Along with measurements on active sockeye redds, a systematic study was made on depth and velocity at the eleven river stations. Sampling was conducted in accordance with the technique established by Collings et al. (1972). Four transects were surveyed at each station. River depth and velocity 0.4 ft above the bottom were measured repeatedly at 20 to 30 points along each transect during the 1972 and 1973 spawning seasons. Each reach was surveyed over a range of discharges and mapped by plane-table methods.

A departure from the time consuming data analysis method of Collings et al. (1972) was made by using a contouring computer program, FRB 726 (SYMAP), to map the area of each river reach at several discharge levels. The measurements of depth and velocity for each point along a transect were classified as being within the respective 80-percent ranges. This area was designated as the estimated area suitable for spawning.

Bihourly records from permanent U.S. Geological Survey (U.S.G.S.) gaging stations located at Renton and near Landsburg were used to determine discharge. Direct measurement of discharge at the time of each river reach survey was not possible because of the large number of replicates required for accuracy. Therefore, discharge at each station was determined in the following way: the discharge at the Landsburg Dam was determined by subtracting the amount of the Landsburg diversion from the discharge at the Landsburg gaging station (*see Figure 1*). The inflow between Landsburg and Renton was determined by subtracting the discharge at the Landsburg Dam from the Renton discharge. This inflow was prorated to the tributaries of the Cedar River on the basis of drainage area between the Landsburg and Renton gages. The analysis based on U.S.G.S. topographic maps indicated that 54% of the surface inflow occurred immediately below station 1, 8% between stations 2 and 3, 4% between 3 and 4, 25% between 5 and 6 and 9% between 10 and 11. The Walsh Lake diversion to the river below station 1 contributed the largest percentage of the inflow between Landsburg and Renton. Thus the discharge at the river reaches at the time of each survey was determined by adding the prorated inflow upstream of each reach to the discharge at the Landsburg Dam.

Spawner distribution, density and river utilization were investigated during the 1972 and 1973 spawning seasons. Each of the eleven reaches was observed at least once each week. Counts of the active spawners within the reaches were made and the areas in which spawning activity occurred were mapped using plane table techniques. Float trips of the upper 17.3 miles of the Cedar River below Landsburg were also made each week during the 1973 spawning season. The distribution of the spawning sockeye was outlined on xeroxed copies of aerial photographs (scale = 1:2400) to ascertain the extent of the river utilization between the eleven river stations. Aerial photographs allowed the reference of spawning areas to actual landmarks (boulders, logs, and bank vegetation). The airphoto mission was carried out on August 20, 1973 and provided full black and white stereo coverage at 60% overlap of the entire river channel below Landsburg. A "square grid" (each square =  $1/64$  inch<sup>2</sup>) was then used to measure the area occupied each week by the spawning sockeye salmon.

Four to eight substrate samples were taken at each study reach during August 1973 to determine gravel composition according to the method outlined by Koo (1964). The sampler took a 6 inch by 6 inch cylindrical core. Sample analysis included separation by nine sieves ranging from 0.105 to 26.9 mm. The fraction retained by each sieve was determined volumetrically.

## RESULTS AND DISCUSSION

### Escapement

The present run of sockeye salmon into the Lake Washington watershed is comprised entirely of introduced stocks (Woodey, 1966). A history of the estimated sockeye salmon escapement to the Cedar River from 1960 through 1973 is presented in Figure 2. A significant increase is evident, beginning in 1967 and continuing through the present. Escapement during 1972 and 1973 was estimated by the Washington State Department of Fisheries at 225,862 and 314,284, respectively.

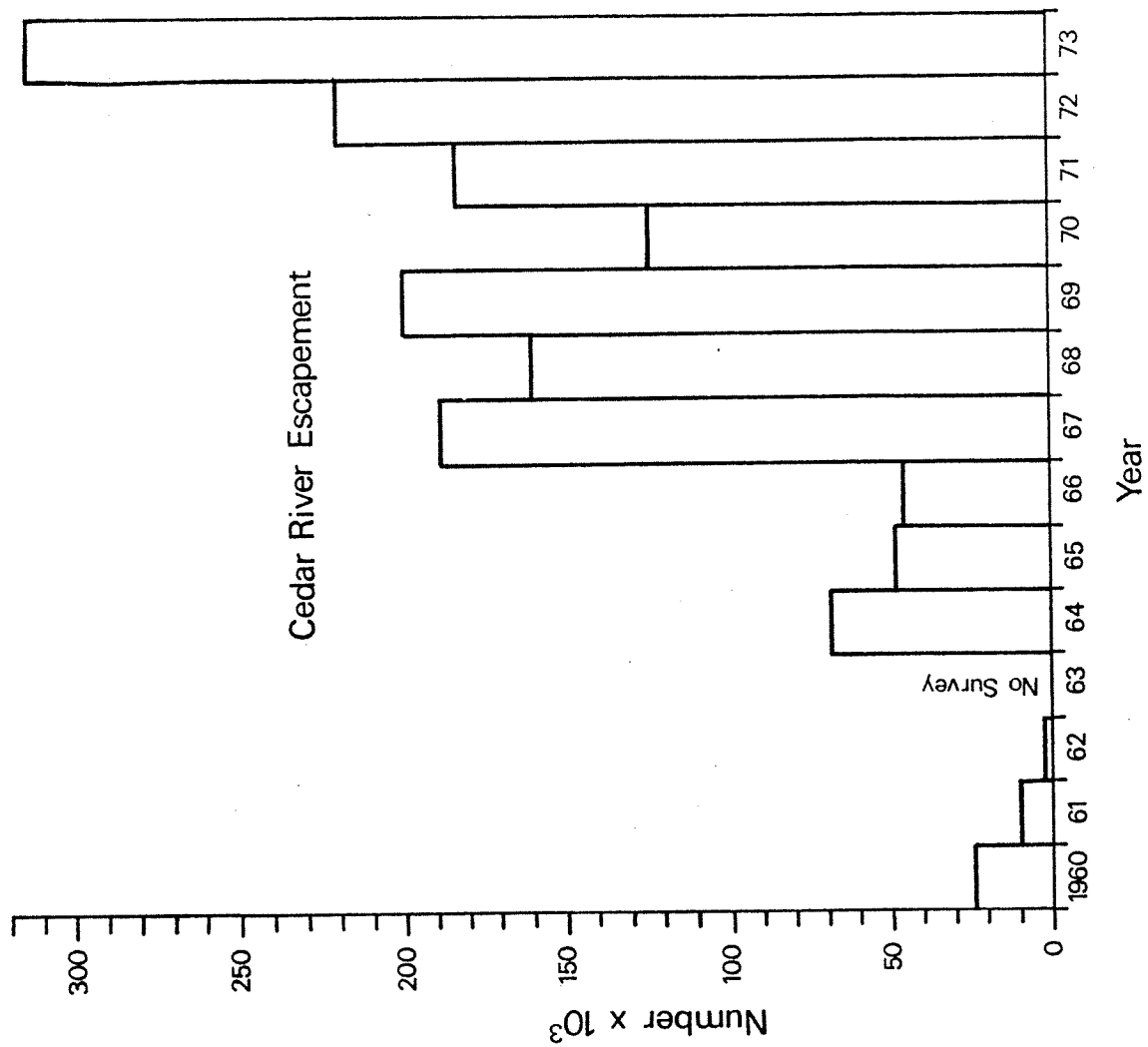


Fig. 2. Sockeye salmon escapements to the Cedar River from 1960 through 1973 as estimated by the Washington State Department of Fisheries.

### Timing of Run

The Washington Department of Fisheries maintains a counting tower at river mile 4.9. The daily counts of sockeye passing this tower during the 1972 and 1973 spawning seasons are shown in Figures 3 and 4, respectively. A comparison of the data indicates that the timing of the runs was very different for the two years. The earliest sockeye salmon were observed in the Cedar River during late August of both years with significant numbers beginning to arrive in early September. However, the plot for the 1972 run (Figure 3) indicated that nearly 70% (158,000 fish) of the run was in the river by 30 September. From 1 October until the end of the run in December the counts declined gradually. The tower counts for 1973 (Figure 4) indicated the run was bimodal with the first mode reaching a maximum in late September and the second in mid-October. In contrast to 1972, only 35% (109,000 fish) of the run was in the river by 30 September.

The 1972 and 1973 hydrographs obtained from the U.S.G.S. gaging station at Renton are also shown in Figures 3 and 4. The difference in the timing of the two runs is partially explained by comparison with each respective hydrograph. The massive movement of sockeye observed on 21 and 22 September 1972 was directly associated with a large increase in discharge over the same period. Nearly 23% (51,489) of the total 1972 run entered the river on those two days alone. The relatively large counts on 7, 10 and 11 September 1972 occurred during a period of relatively constant discharge. The discharge pattern for 1973 indicated a general increase through the spawning season and the bimodal tower counts were not associated with any large fluctuations in discharge. This was in part a result of careful management of the stream discharge made necessary by the 1973 drought.

The mean daily water temperatures (based on hourly readings) measured at Renton during the 1972 and 1973 spawning seasons are given in Figures 3 and 4, respectively. The relatively large numbers of sockeye counted on 7, 10 and 11 September 1972 were associated with a decrease in temperature of two

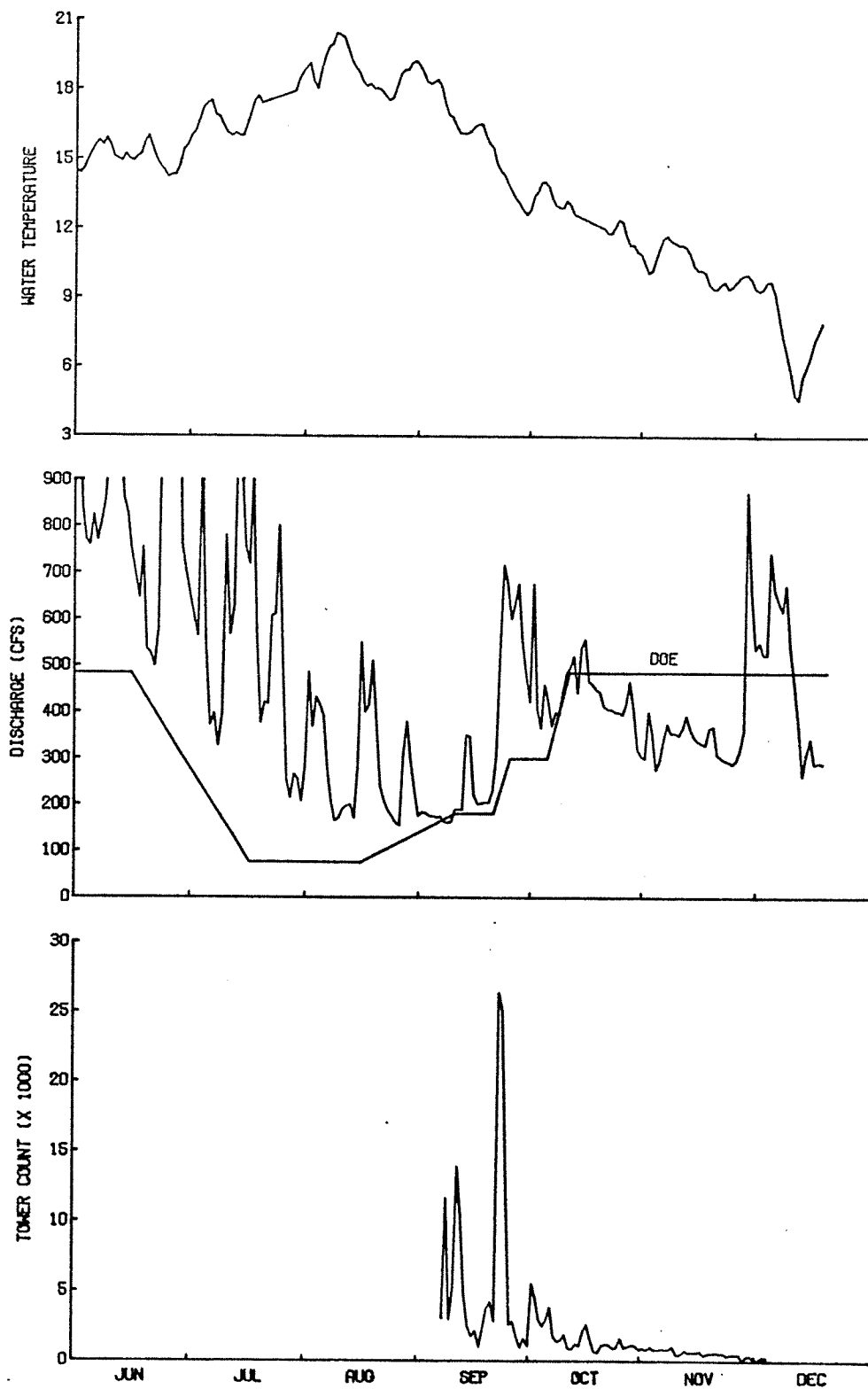


Fig. 3. Mean daily water temperature, Renton hydrograph and D.O.E. directive from June 1 to December 15, 1972. The number of sockeye salmon passing the W.S.D.F. counting tower each day during the 1972 spawning season are shown.

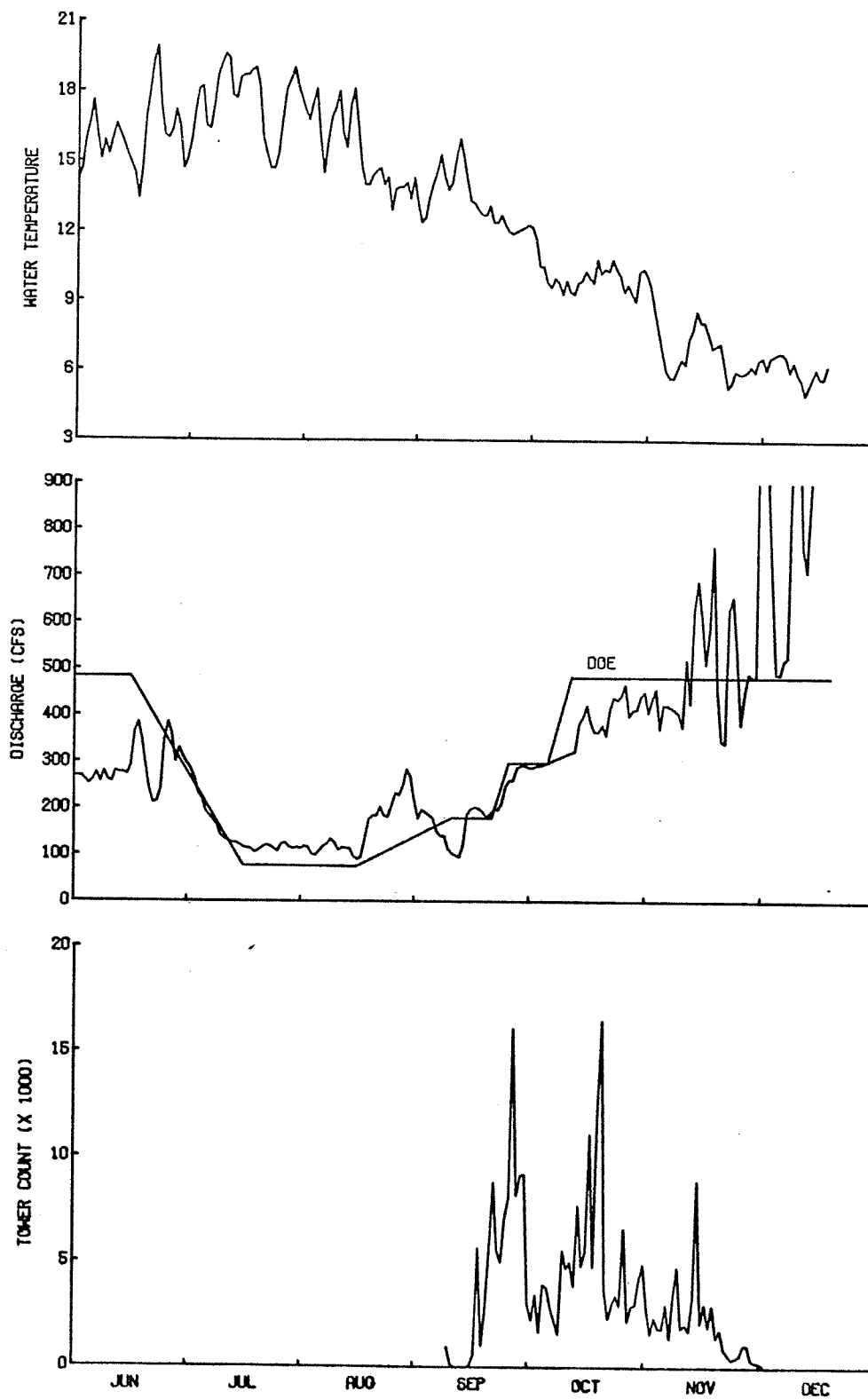


Fig. 4. Mean daily water temperature, Renton hydrograph and D.O.E. directive from June 1 to December 15, 1973. The number of sockeye salmon passing the W.S.D.F. counting tower each day during the 1973 spawning season are shown.



degrees ( $18^{\circ}$  to  $16^{\circ}$  C). Another sharp decline in temperature, which occurred between 17 and 26 September ( $16^{\circ}$  to  $13^{\circ}$  C) was related to a rapid increase in discharge and the combined effects resulted in massive sockeye migration. A general decline in temperature was noted from late September to the end of November.

In 1973, a decline in temperature from  $16^{\circ}$  to  $12^{\circ}$  C occurred in late September with an associated general increase in discharge and fish migration. The October fish migration mode occurred during a period of relatively steady temperatures (approximately  $10^{\circ}$  C). A sharp decline in mean daily temperature during late October and early November was due to climatological factors. Comparison of both years showed that temperature was lower during the 1973 spawning season than during 1972. General agreement was found with the thermal ranges given by Bell (1973) for sockeye migration ( $7.2$ - $15.6^{\circ}$  C) and spawning ( $10.6$ - $12.2^{\circ}$  C). It was apparent that the movement of sockeye could be influenced by the single or combined influence of discharge or temperature and that variability may be encountered when comparing a single sockeye population to general environment criteria.

The Department of Ecology has set a minimum flow to accommodate the timing of upstream migration which has also been indicated in Figures 3 and 4. The following analytical approach will endeavor to provide an independent evaluation of the discharge levels required to allow adequate spawning area for sockeye salmon.

A general substrate analysis of each of the eleven Cedar River stations was conducted to determine if gross differences existed (Figure 5). All stations were similar except for station 4 which showed a lower percentage of all fractions. Higher water velocities at this station may have resulted in removal of the smaller gravel and sand fractions. However, due to the difficulty of analyzing a significant number of substrate samples for each station the data indicate no apparent qualitative deficiencies.

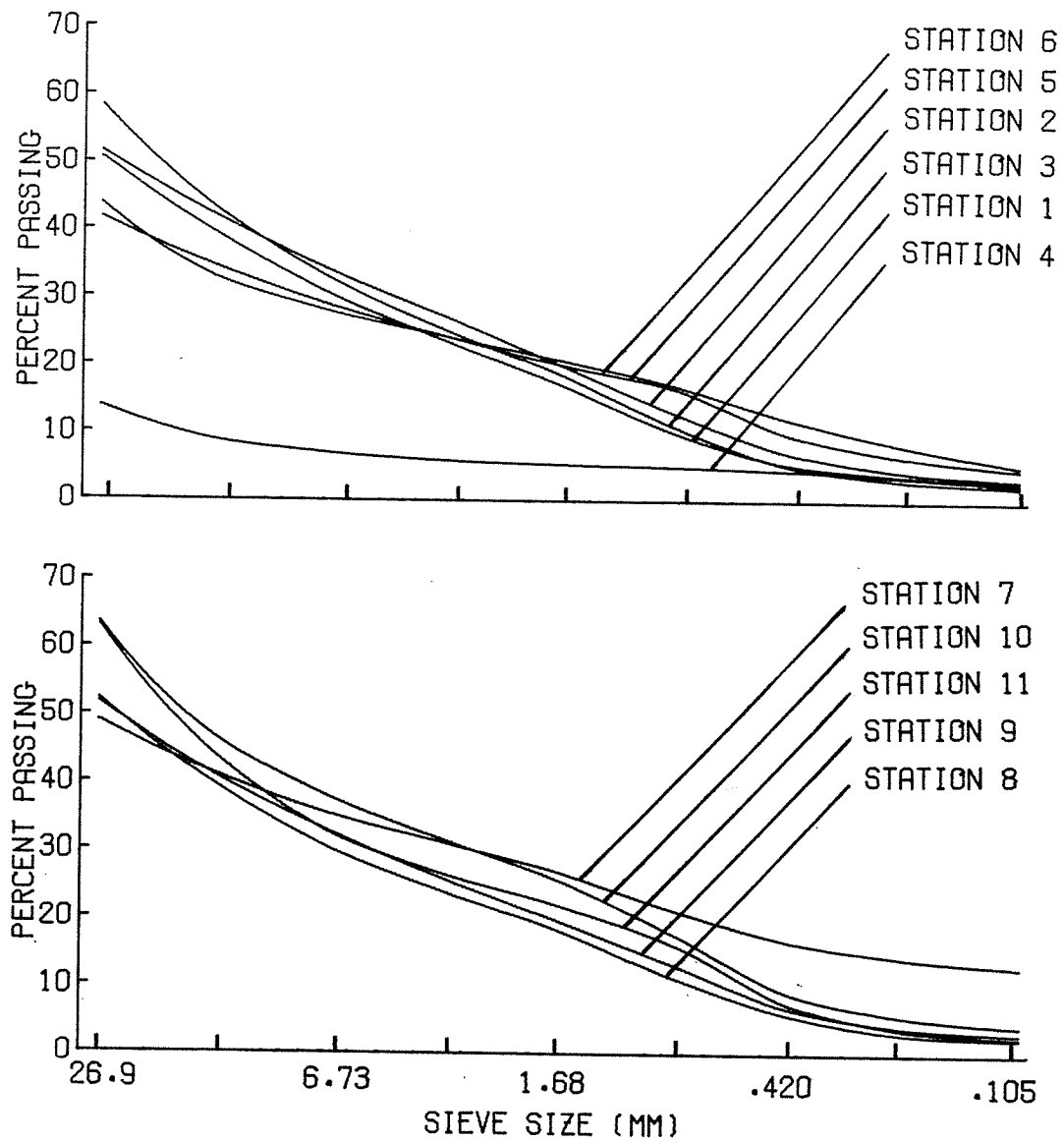


Fig. 5. Curves showing average grading of several substrate samples from each of the eleven Cedar River study reaches.

Spawner Distribution and Timing by Reach

Fraser (1969) in a study of Cedar River sockeye determined the mean redd life for a combined sample of 15 males and 15 females to be 6.7 days with a standard deviation of 2.4 days. On the basis of this value the eleven stations were observed at 7 day intervals through the 1973 spawning season. Therefore, on the average, different fish were counted each week and represent individual "waves" of spawners.

Weekly spawner counts were combined by station (1-3, 4-8, and 9-11) to represent the upper, middle, and lower river, respectively (Figure 6). The spawner counts for the upper river stations were significantly larger than those for the middle and lower river areas which showed successive declines. A similar distribution was observed during the 1972 spawning season.

The utilization of the stations did not reflect the bimodal arrival of the 1973 run indicated by the tower counts (Figure 4). Thus many of the fish that entered the river in the first mode (late September), apparently delayed their movement onto the spawning grounds. The peak of the second mode (mid-October), however, did correspond with the peak use of the upper and middle river stations. Thus the sockeye entering the river in mid-October (second mode) moved onto the spawning grounds with less delay than those which entered the river in late September.

The peak spawning activity as indicated by the counts for all stations (Figure 6) occurred during October for the 1973 run. Sixty-two percent of the active spawners were observed in the stations during that month. This agrees with the observations of Woodey (1966) for the 1965 Cedar River sockeye run.

As noted earlier, the peak use of the upper and middle river stations (1-8) occurred in mid-October, but utilization of the lower river stations (9-11) occurred from late October to mid-November. The trend of later utilization of the lower river was also indicated by the gradual decline of

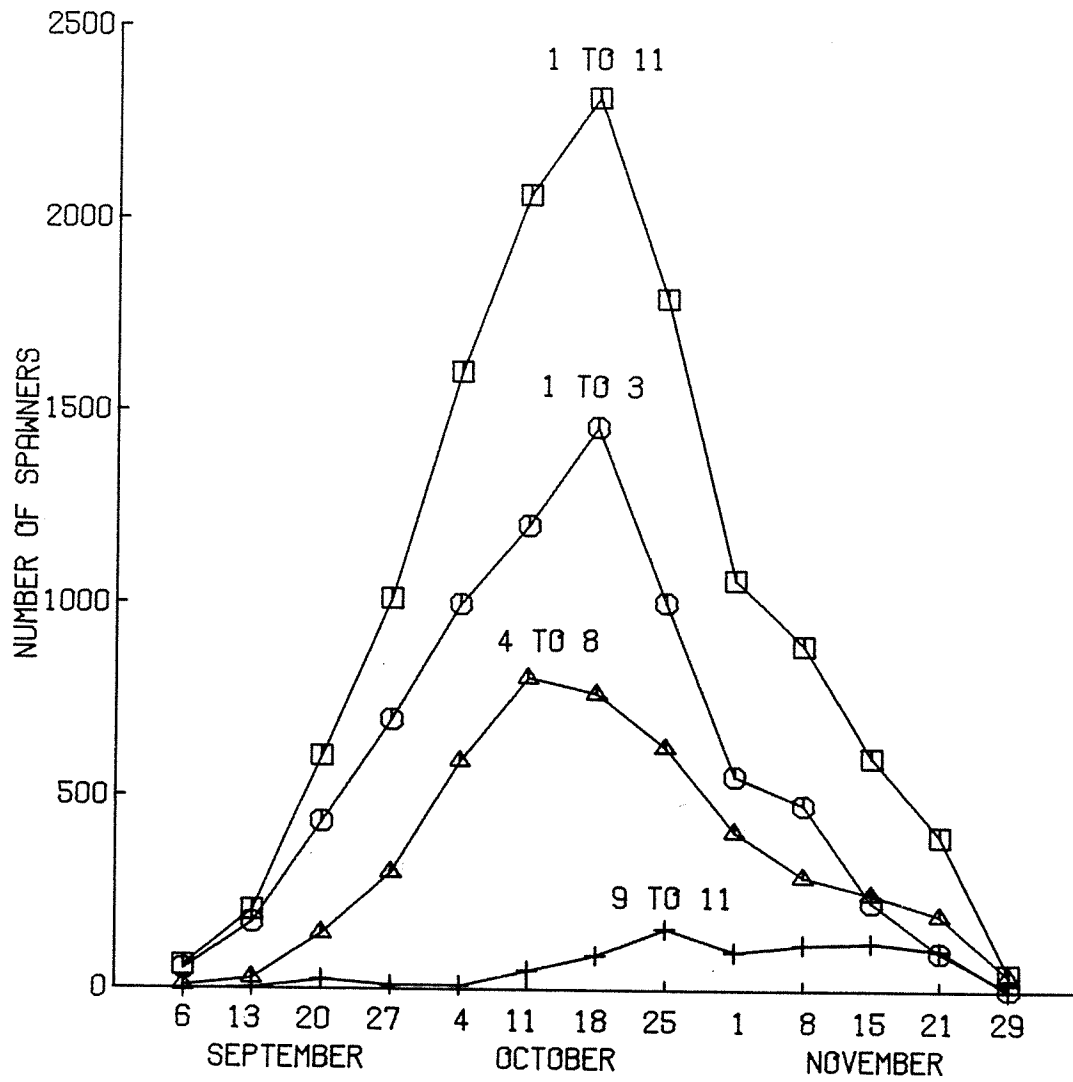


Fig. 6. Cedar River spawner counts by week during 1973 combined by station (1-11, 1-3, 4-8 and 9-11).

the spawner counts for the middle stations (4-8) during early and mid-November as opposed to the sharp decline for the upper stations (1-3) during the same period.

Figure 7 illustrates the total spawner counts by station. Heavy utilization was observed at station 1 (nearly 4,000 spawners) and light utilization at stations 10 and 11 (less than 100 spawners at each). This pattern accounts in part for the relative difference in magnitude of the upper, middle and lower stations as seen in Figure 6.

#### Spawner Density by Reach

The spawning densities within the study stations were determined for the 1973 Cedar River sockeye run, by dividing the area utilized by the number of spawners present. However, converting this to area per female is dependent on the sex ratio.

The male to female ratio was reported for the 1964 (Woodey, 1966) and 1969 runs (Fraser, 1969) to be 1:1.44 (59.1% females) and 1:1.52 (60.3% females), respectively. Thus, on the basis of a male to female ratio of 40:60 the spawning density ranged from 23.7 to 93.0 ft<sup>2</sup>/female with a mean of 47.6 ft<sup>2</sup>/female (0.19 females/ft<sup>2</sup>).

Heiser (1969) indicated the fecundity of Cedar River sockeye was 3,545 and 3,638 eggs per female for 1968 and 1969 runs, respectively and for both years combined (92 fish total) was 3,588 eggs/female. This agrees with the preliminary results of a current study based on the 1973 sockeye run (M. D. Bryant, personal communication). The average egg retention (300 samples) for 1968 sockeye was between 150 and 200 eggs per female (WSDF, 1969). Thus, the potential egg deposition for Cedar River sockeye is approximately 3,400 eggs per female.

With a mean spawning density of 47.6 ft<sup>2</sup>/female and a fecundity of 3,400 eggs/female, the potential egg deposition was 71 eggs/ft<sup>2</sup>. Bell (1973) states

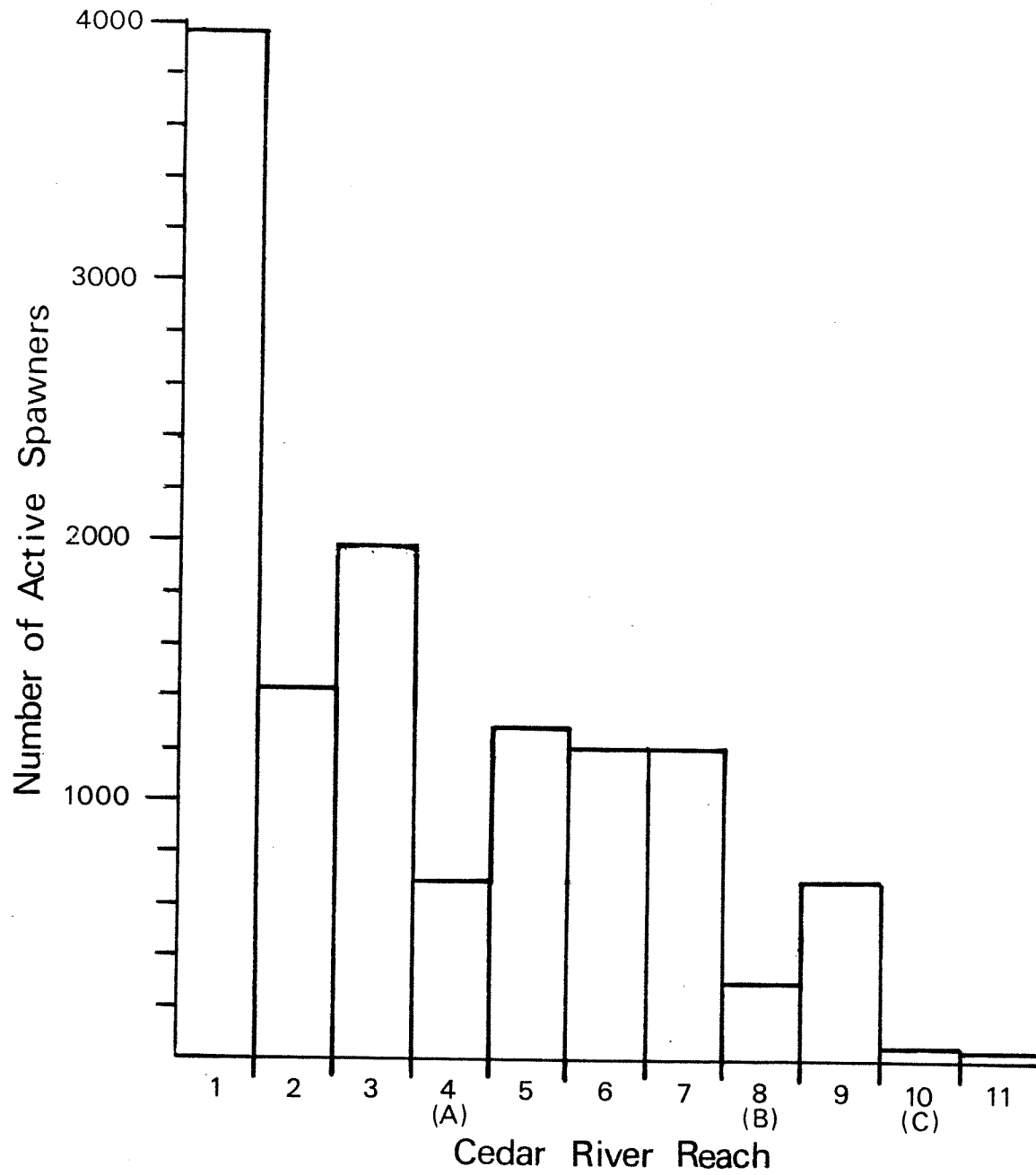


Fig. 7. Distribution of spawning sockeye salmon at each Cedar River study reach during 1973.

that a square foot of good spawning bed contains from 125 to 200 eggs. This capacity can be achieved, therefore, with 2-3 waves of Cedar River spawners.

The International Pacific Salmon Fisheries Commission (IPSFC, 1966) indicates that the maximum spawning density permissible for spawning efficiency and high egg-to-fry survival is 0.67 females/yd<sup>2</sup> (13.5 ft<sup>2</sup>/female). The resulting egg density is 250 eggs/ft<sup>2</sup> and the number of waves of Cedar River fish to reach this density would be 3.5 (47.5/13.5). During the 1973 season as many as 10 waves were observed using the same area at some stations resulting in a potential egg density of 710 eggs/ft<sup>2</sup>. For example, at station 1, 5,040 ft<sup>2</sup> or 32% of the total station (at 436 cfs) was utilized by 8-10 waves of spawners. This condition occurred even though the discharge pattern, indicated in Figure 4, increased gradually from approximately 100 cfs in early September to 600 cfs in late November. From this it appears that spawning sockeye overutilized station 1 with the probable result of dislodged eggs from superimposition of redds or the resultant increase in egg-to-fry mortality due to density dependent factors. Spawning bed egg densities, stream survival and fry production studies are needed to assess this problem.

#### River Utilization

The area spawned each week in the upper 17.3 miles of the Cedar River as determined from analysis of the 1973 float trip data is presented in Figure 8. The lower 4.3 miles of river was not included since spawning activity was observed to be very low. Stations 1-3 were included in the upper section, 4-8 in the middle section and 9-10 in the lower section. Each section represented approximately one-third of the total 17.3 miles.

The general form of these plots is similar to the plots for station utilization (Figure 6). The peak activity for the total spawners over the season and those spawning in the upper and middle thirds of the river occurred in mid-October. The lower third received maximum utilization from late October to mid-November. A comparison of the curves confirms that the upper and middle sections of the river were more heavily utilized early in the season while the

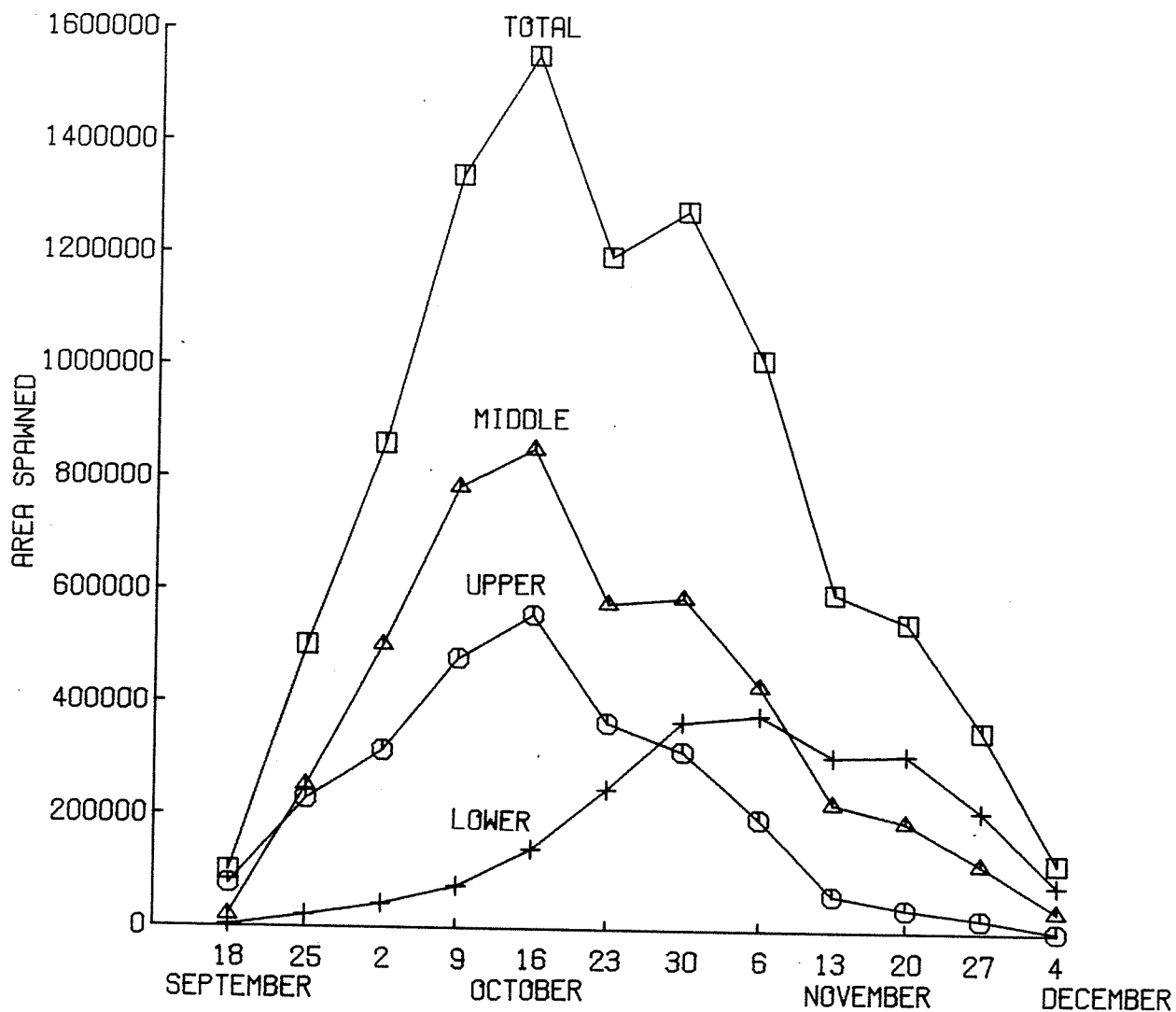


Fig. 8. Total area of the Cedar River spawned by sockeye salmon each week during 1973 determined from float trip data. Data expressed for 17.3 miles (total) and approximately equal divisions (upper, middle and lower thirds) of the river.



lower river was utilized later in the season. However, the relative magnitude of the area utilized in the upper river was less than that indicated in the analysis of the combined stations (Figure 6) whereas the converse was true for the lower section. This resulted from the fact that station 1 was heavily utilized and stations 10 and 11 were underutilized.

The bimodality of sockeye arrival into the river as shown by tower counts (Figure 4) was not reflected in the utilization pattern for the total river.

#### Depth and Velocity Criteria for Spawning

Measurements of depth and velocity were taken at 1,239 sockeye salmon redds in the Cedar River below Landsburg during 1972. Each station was visited at least once each week, and depth and velocity were measured when sockeye salmon were found in the act of spawning. A distribution of the redds according to station is given in Figure 9.

Frequency distributions were plotted for depth (Figure 10) and velocity (Figure 11) measurements taken at the 1,239 redds. Depths ranged from 0.3-3.0 ft with a mean of 1.06 ft (SD = 0.50) and velocities ranged from 0.06-3.81 ft/sec with a mean of 1.74 ft/sec (SD = 0.65). The 80-percent intervals ranged from 0.5-1.8 ft for depth and 0.93-2.59 ft/sec for velocity.

The ranges of depth and velocity "preferred" by spawning sockeye salmon determined by Chambers et al. (1955) and Clay (1961) are 1.0-1.5 ft and 1.75-1.80 ft/sec, respectively. The 80-percent ranges determined in this study are larger by comparison, especially in the case of velocity. Depth and velocity given in the literature are probably adequate for a determination of the discharge which provides the maximum area (peak spawning discharge suitable for spawning) since only the relative amount of area is needed to define a "peak." However, if the absolute amount of suitable spawning area available to accommodate spawners is desired, the ranges given in the literature appear to be unnecessarily restrictive for Cedar River sockeye salmon.

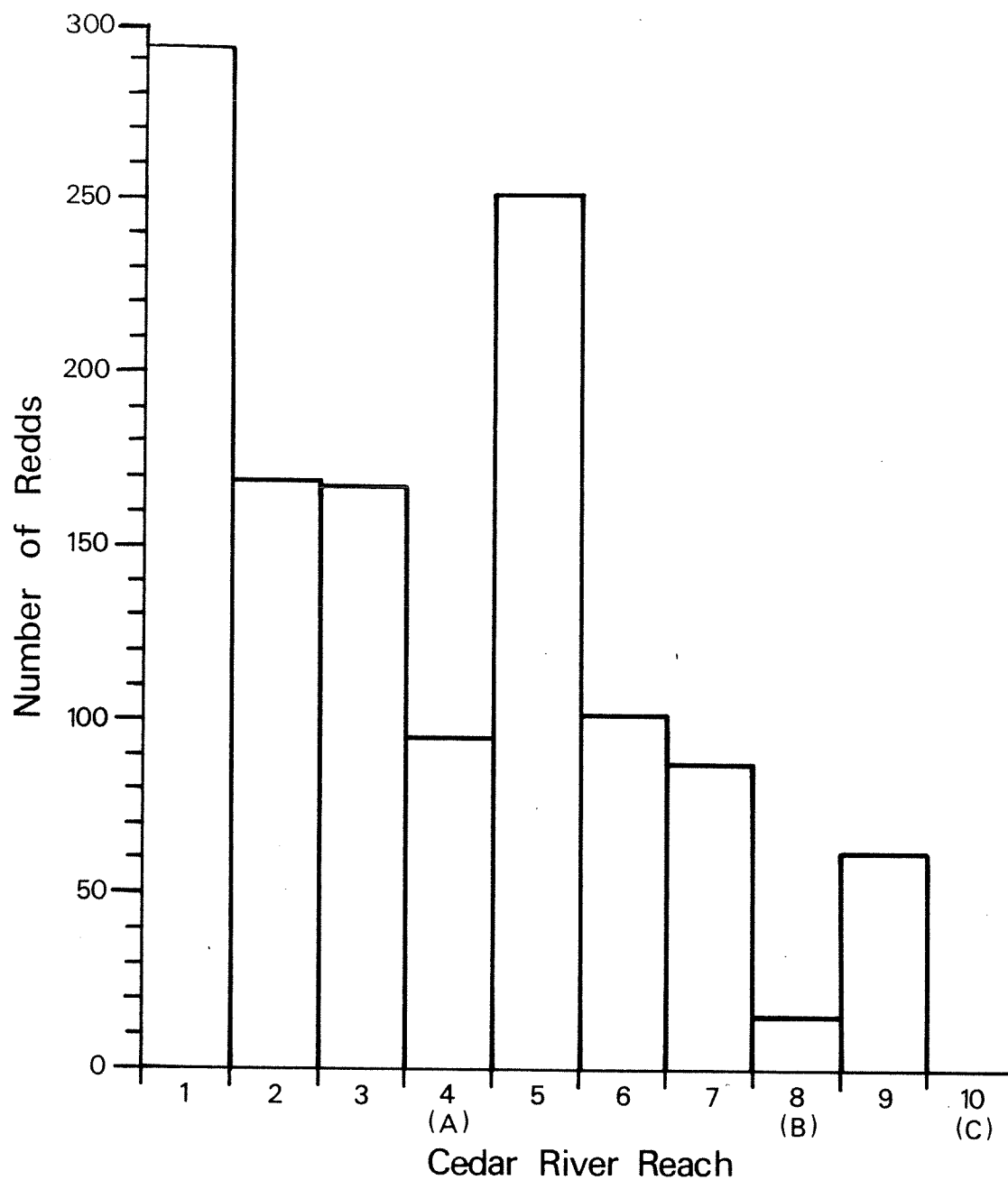


Fig. 9. Distribution of 1,239 sockeye salmon redds at which depth and velocity measurements were taken in the Cedar River study reaches during 1972.

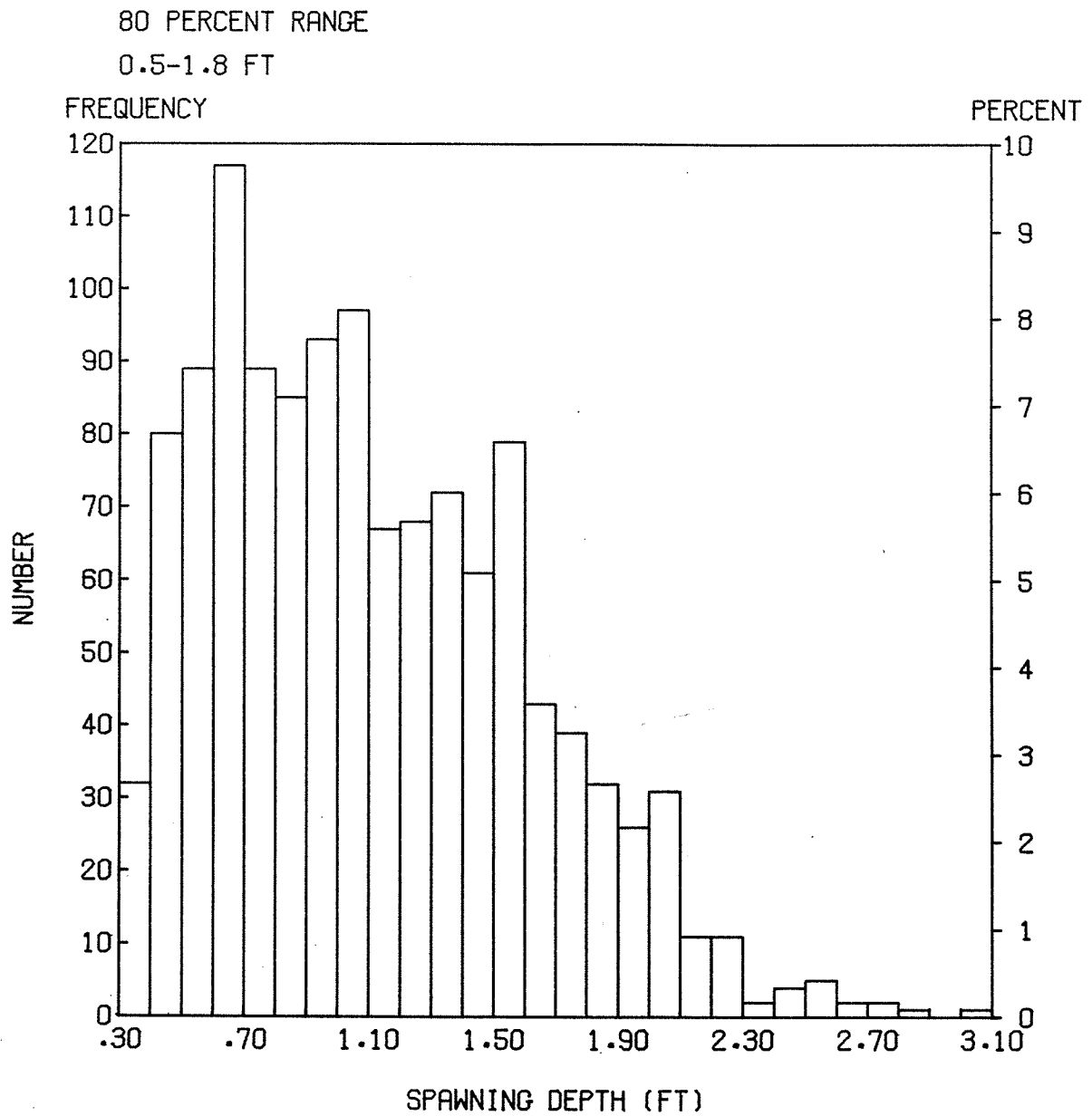


Fig. 10. Frequency distribution of sockeye salmon spawning depths measured at 1,239 redds in all Cedar River reaches combined.

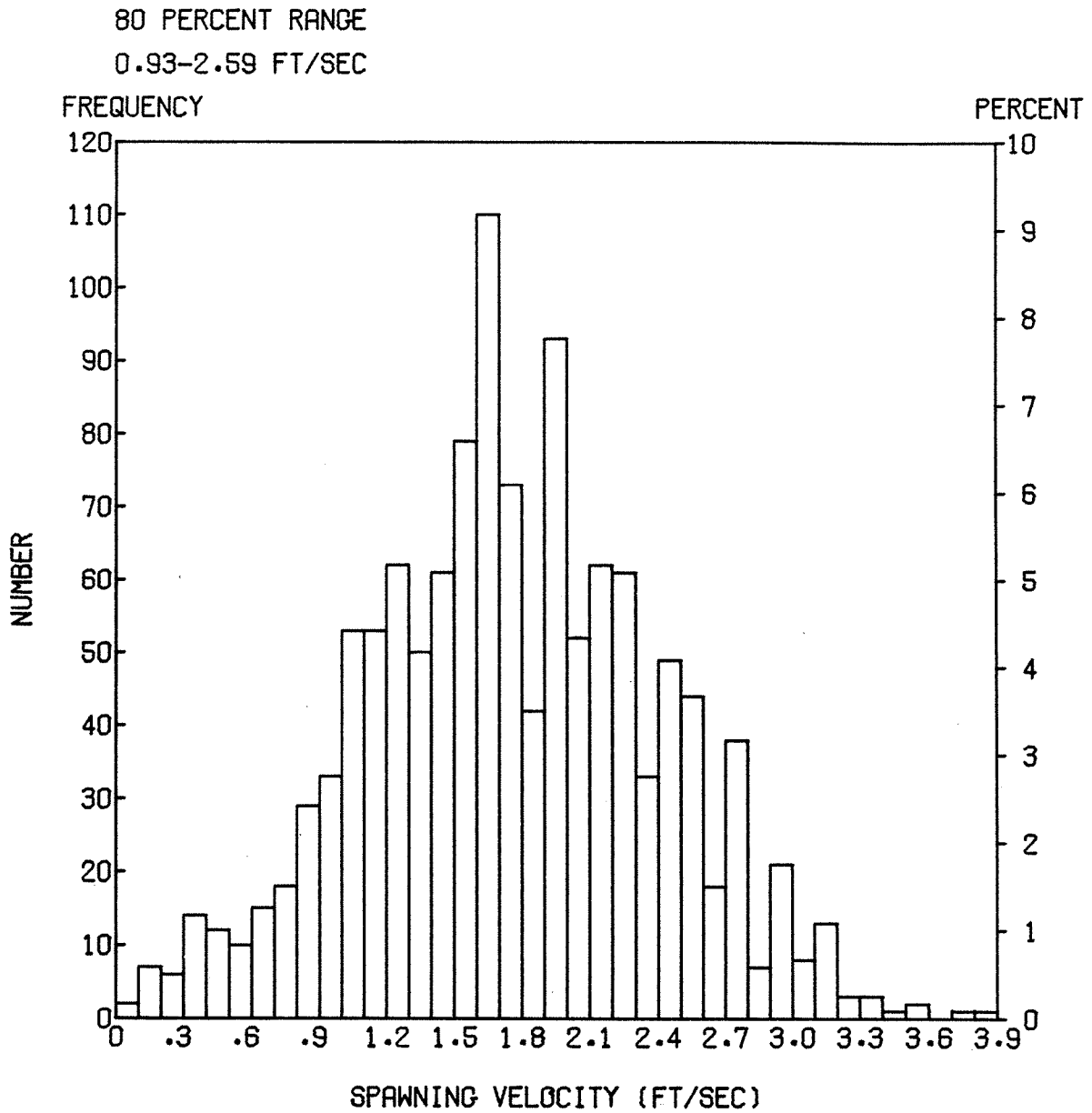


Fig. 11. Frequency distribution of water velocities measured at 1,239 sockeye salmon redds in all Cedar River reaches combined.

### Relationships of Spawning Area to Discharge

The relationships between area and discharge developed in this study for the Cedar River are presented for each reach (Figures 12-15). The curves that represent the estimated spawning area were determined from the 80-percent ranges of preferred depths and velocities. The points that make up these curves (open squares) represent the estimated spawning areas as determined by the SYMAP analysis. The estimated spawning area increases with discharge until it reaches some maximum value (where the slope of the tangent equals zero), and then begins to decline with further increase in discharge. The discharge that creates the maximum estimated spawning area, i.e., the discharge providing the maximum spawning area, is termed the "peak spawning discharge." The "peak spawning discharge" represents the optimum for spawning sockeye salmon since it is the discharge that results in the most efficient use of the water by providing the greatest area suitable for spawning.

Since the relationships between spawning area and discharge cannot be linear, a curve was fitted to these points by polynomial regression. The assumption was made that, because of the configuration of the stream bed, namely, the existence of a lower gradational terrace (Collings et al., 1972), the polynomial curve should reach a peak below a discharge of 500 cfs.

The peak spawning discharge that provides the maximum area suitable for spawning during the spawning period was calculated (tangent equals zero) from the polynomial equation for each reach and designated by the vertical dashed line intersecting that point on the curve. The polynomial equation, peak spawning discharge and associated maximum area suitable for spawning for each of the eleven Cedar River stations is given in Table 1. The peak spawning discharges for reaches 4, 8 and 10 were 201, 225 and 306 cfs, respectively. In comparison, the values determined by Collings et al. (1972) for the same reaches in his previous investigation were 240, 440 and 510 cfs, respectively. The peak discharges for reaches 8 and 10 as determined by Collings et al. (1972) were apparently the basis for the Department of Ecology's discharge requirement of 480 cfs. The mean of the peak spawning discharges for the

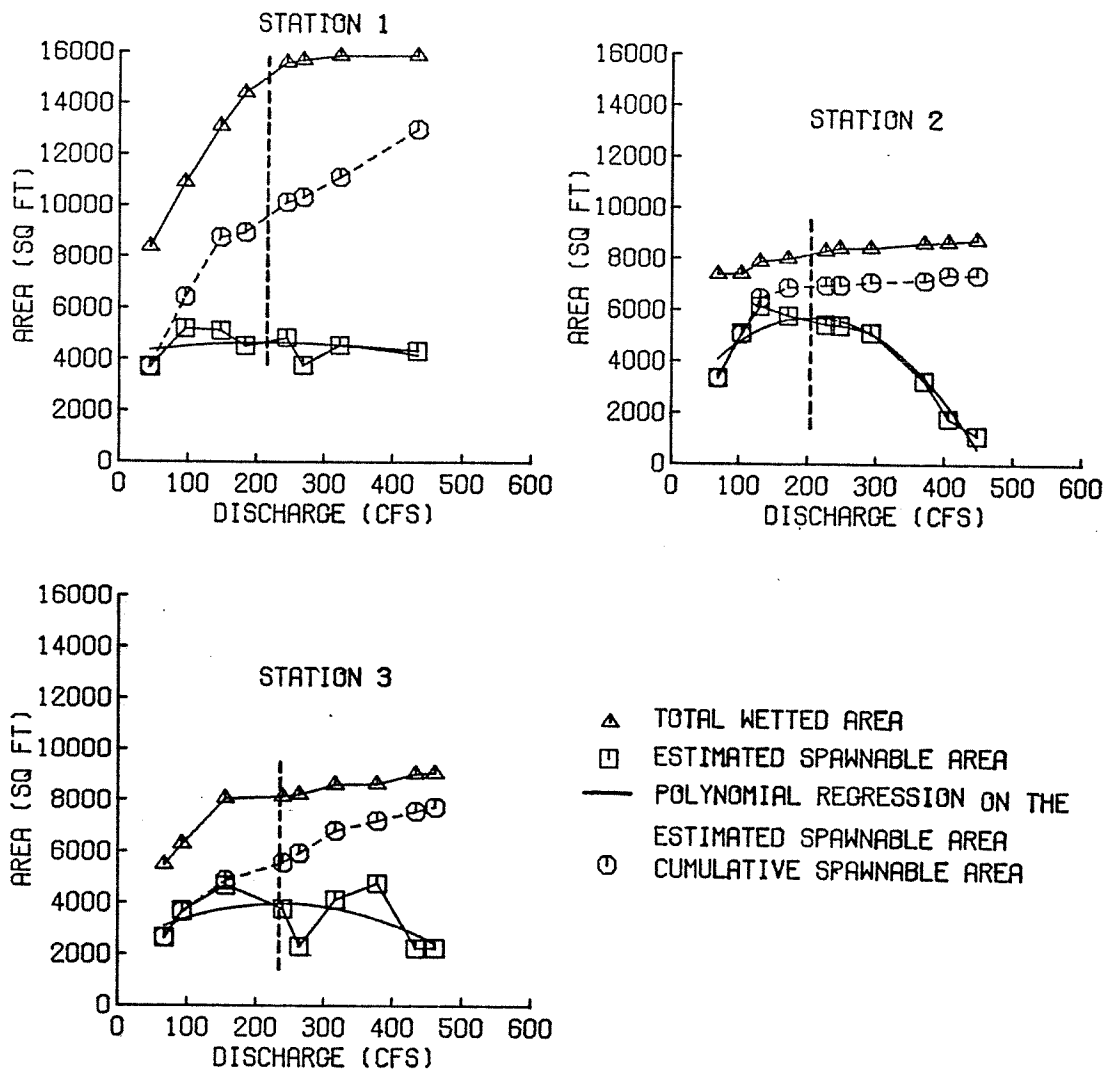


Fig. 12. Relationship between estimated spawning area (80% ranges), polynomial regression on the estimated spawning area, cumulative spawning area, and total wetted area for Cedar River sockeye salmon at reaches 1-3. Vertical dashed line denotes peak spawning discharge.

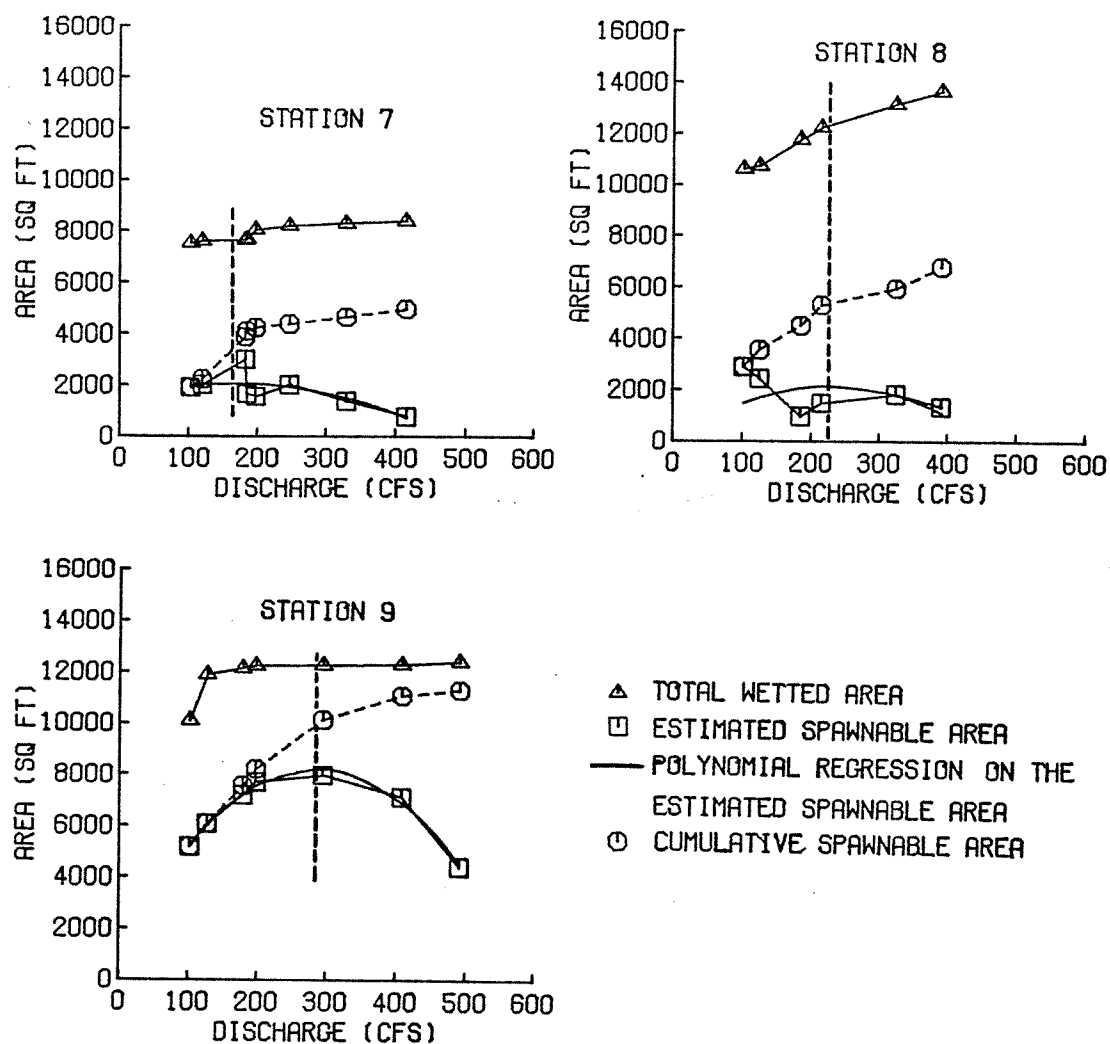


Fig. 14. Relationship between estimated spawnable area (80% ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at reaches 7-9. Vertical dashed line denotes peak spawning discharge.

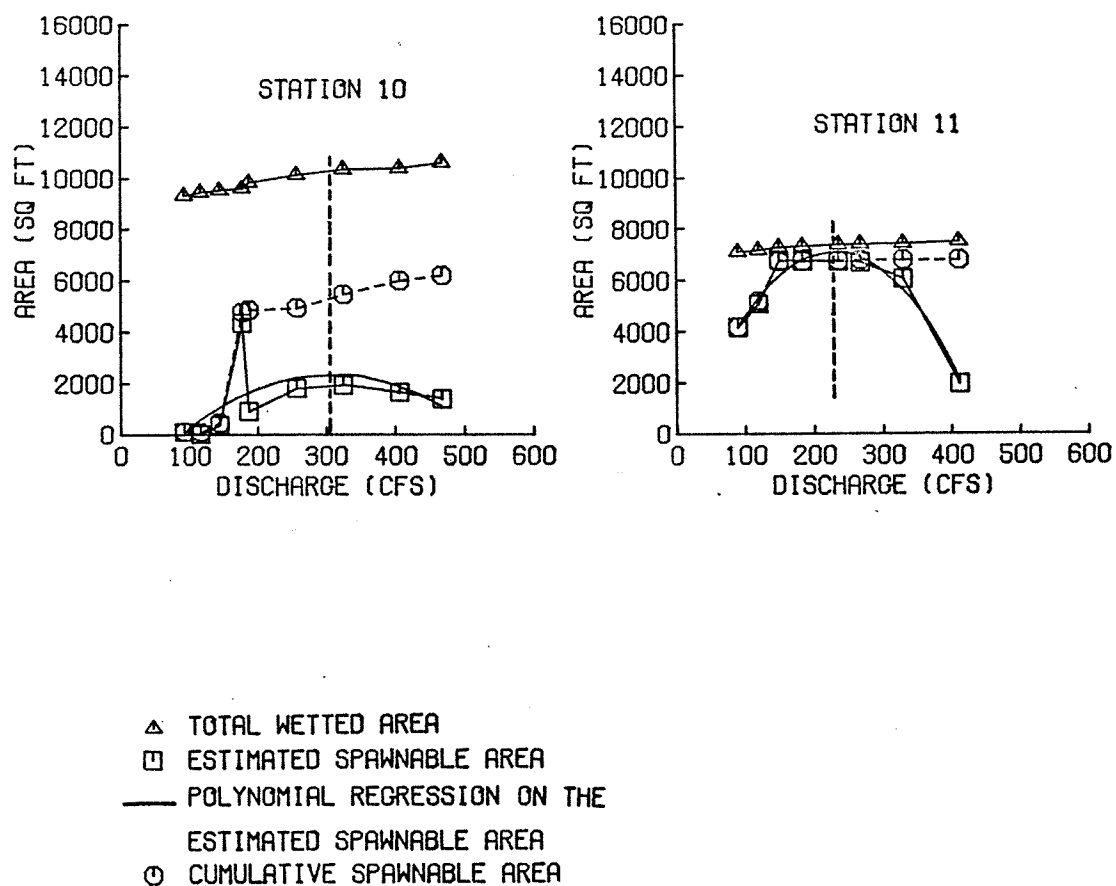


Fig. 15. Relationship between estimated spawnable area (80% ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at reaches 10-11. Vertical dashed line denotes peak spawning discharge.



Table 1. The polynomial equations for each of the eleven Cedar River reaches. The calculated peak spawning discharge and the associated area suitable for spawning are listed. The mean peak discharge = 240 cfs

Station	Polynomial equation					Peak			
						Discharge	Area		
1	y	=	$-.01046166x^2$	+	$4.526843x$	+	4177.278	216	4667
2	y	=	$-.08751594x^2$	+	$36.05097x$	+	2039.403	206	5752
3	y	=	$-.03043451x^2$	+	$14.33733x$	+	2284.991	236	3974
4	y	=	$-.1039616x^2$	+	$41.86841x$	+	84.91335	201	4300
5	y	=	$-.04457925x^2$	+	$30.14023x$	-	470.3042	338	4624
6	y	=	$-.05041813x^2$	+	$22.54291x$	+	3408.315	224	5928
7	y	=	$-.02165839x^2$	+	$7.153553x$	+	1479.975	165	2071
8	y	=	$-.04059x^2$	+	$18.69927x$	+	0	225	2152
9	y	=	$-.08828290x^2$	+	$50.40126x$	+	1041.991	285	8236
10	y	=	$-.04906425x^2$	+	$29.98443x$	-	2221.385	306	2360
11	y	=	$-.1500921x^2$	+	$68.79747x$	-	770.7250	229	7113

eleven stations determined by polynomial regression analysis in this investigation was 240 cfs. This is substantially lower than the Department of Ecology's minimum discharge requirement during the period October to June.

The total wetted area versus discharge was plotted for each station (Figures 12-15, open triangles). Curves for stations 2 and 5 showed only a slight increase with discharge; these are reaches where the river is channelized with a nearly flat bottom configuration, allowing for little increase in total wetted area. For example, the area of station 2 increased only 1,160 ft<sup>2</sup> (7,508 to 8,668 ft<sup>2</sup>) with an increase in discharge of 379 cfs (69 to 448 cfs). In contrast, station 1 increased 7,452 ft<sup>2</sup> (8,400 to 15,802 ft<sup>2</sup>) with an increase in discharge of 391 cfs (45 to 436 cfs). This station has a deep channel to one side and a gravel bar with a shallow gradient where the wetted area progressively increased laterally as the water level rose with increasing discharge.

The total cumulative spawning area available to sockeye salmon as discharge increased throughout the spawning period was calculated for each station (Figures 12-15, open octagons). Cumulative spawning area was determined by considering the estimated spawnable area at the lowest observed discharge to be the base area suitable for spawning. The area in addition to the base area that became available for spawning with each incremental increase in discharge was accumulated in a stepwise fashion until it reached a maximum area at the highest discharge measured at each reach. As with the total-wetted-area curve, the steepness of the cumulative spawnable area curve indicates the rate at which new spawnable area was added with each increase in discharge. For example, this area accumulated at a more rapid rate at stations 1 and 4 than at stations 2 and 5.

A regime of gradually increasing discharges adds significantly to the spawnable area available to sockeye salmon during the spawning season, especially in unchanneled portions of the river. The estimated spawnable area and the cumulative spawnable area values were determined for each station at

240 cfs by reading each respective curve (Figures 12-15). The sum of the estimated spawnable areas at the mean peak spawning discharge for the eleven stations was 49,800 ft<sup>2</sup>. The sum of the cumulative spawnable areas for the eleven stations was 73,000 ft<sup>2</sup>. Thus, if the discharge were increased gradually through the spawning season to the mean peak spawning discharge, the amount of spawnable area could be increased by 49 percent. A gradually increasing discharge regime during the spawning run therefore is desirable since it spreads the spawners laterally across the river bottom, maximizing use of the spawning beds, and thereby providing for the most efficient use of minimum discharge levels.

#### Correlation of Hydrological and Biological Data

Giger (1974) aptly stated in his review of streamflow requirements for salmonids that the understanding of the hydraulic characteristics of stream discharge and its influence on the aquatic biota would be greatly benefitted by improvement in the coincident collection of hydrological and biological data. In the current study, the depth and velocity criteria for spawning sockeye were determined and used to predict the area within the stations that was suitable for spawning. In order to compare the two, an index (I) was developed (S. B. Mathews, personal communication);

$$I = \frac{\text{percent of the predicted area used for spawning}}{\text{percent of the nonpredicted area used for spawning}}$$

The index makes use of the relationship between the predicted area and the nonpredicted area, i.e., the area outside the predicted area, and is independent of the relative size of the two areas. If sockeye distribution was random within a station then the percent of the predicted area actually utilized would equal the percent of the nonpredicted area actually utilized and the expected value would be  $I = 1$ . If a greater proportion of the predicted area is utilized then the expected value would be  $I$  greater than 1 and the hydraulic parameters, depth and velocity, can be used to predict areas suitable for spawning. Conversely, if  $I$  is less than 1 then the area suitable for spawning cannot be predicted from the depth and velocity criteria.

The weekly spawner distribution maps for each station throughout the 1973 spawning season were compared with maps of the estimated area suitable for spawning from the SYMAP analysis having similar discharges. The index for 79 such comparisons ranged from 1.2 to 37.0 with a mean of 6.7. There are an additional 15 comparisons where the index equals infinity (i.e., the denominator equals zero); these occurred either early or late in the season when few spawners were present in the station and all fish spawned within the predicted areas.

On the basis of this index, it was concluded that the hydraulic parameters, depth and velocity can be used to predict the areas suitable for spawning. This does not preclude the importance of other factors, such as gravel composition, dissolved oxygen, intragravel flow, and temperature. For example, Figure 15 indicates that nearly 7,000 ft<sup>2</sup> would be suitable for spawning at station 11. However, during the 1973 spawning season less than 50 sockeye utilized that station.

#### Spawner Capacity of the Cedar River

When developing a multiple-use water resource management scheme in a system where a fishery resource is affected, it is essential to establish a reasonable spawner capacity for the river. Ideally, this should be based on stream survival rates and the actual numbers of fry produced from the river. In the absence of this kind of data and consistent with the scope of this study, an estimate of the capacity of the Cedar River has been developed on the basis of the area available to accommodate spawners.

The relationship between total wetted area and discharge for the upper 17.3 miles of the river has been used for this determination. The top width (which approximates the wetted perimeter for a river the size of the Cedar) was measured at each transect (four per station) from the plane-table maps made at various discharges. The total wetted area for a particular discharge was then calculated by multiplying the mean top width for

stations 1-10 by the effective length of the river (17.3 miles). Thus, at 100 cfs (top width = 67.9 ft) the wetted area for the upper 17.3 miles was estimated to be just over 6 million  $\text{ft}^2$  and increased to nearly 8 million  $\text{ft}^2$  at a discharge of 450 cfs (top width = 86.6 ft).

Even though this amount of wetted area was potentially available for spawning, only a fraction was utilized by the Cedar River sockeye. The estimated area suitable for spawning from the depth and velocity surveys averaged 40 percent of the total wetted area over all study stations. During the 1973 spawning season, 40 percent of the total area of the study stations was spawned by sockeye. However, the locations for the study stations were chosen on the basis of previous spawning activity and did not include other reach types such as pools or chutes. Therefore, the 40 percent estimate based entirely on the study stations was probably an over estimate of the utilization for the entire 17.3 miles.

This bias was confirmed by the 1973 float trip data. The area utilized at the peak of the spawning activity on October 16, 1973 was 1.55 million  $\text{ft}^2$ , or approximately 20 percent of the total area in the upper 17.3 miles. The total area utilized over the entire spawning season was 2.37 million  $\text{ft}^2$  which amounted to an overall 30 percent utilization. On this basis the 20 to 40 percent utilization of the upper 17.3 miles of the Cedar River was considered a reasonable range over which to estimate the capacity to accommodate spawning sockeye. In order to convert the 20, 30 and 40 percent estimates of the total wetted area to numbers of females, the areas were divided by 13.5  $\text{ft}^2/\text{female}$ . The three estimates are presented in Figure 16. The density figure, 13.5  $\text{ft}^2/\text{female}$  (0.67 females/ $\text{yd}^2$ ), is considered the maximum spawning density permissible for spawning efficiency and high egg-to-fry survival by the IPSFC (1966). Figure 16 indicates that, given the maximum area and density possible, the approximate number of females that could be efficiently accommodated would range from 100,000 to 225,000. Assuming a male:female ratio of 40:60 (Woodey, 1966 and Fraser, 1969), a reasonable estimate for the total escapement (males and females) ranges from 167,000 to 376,000 spawners.

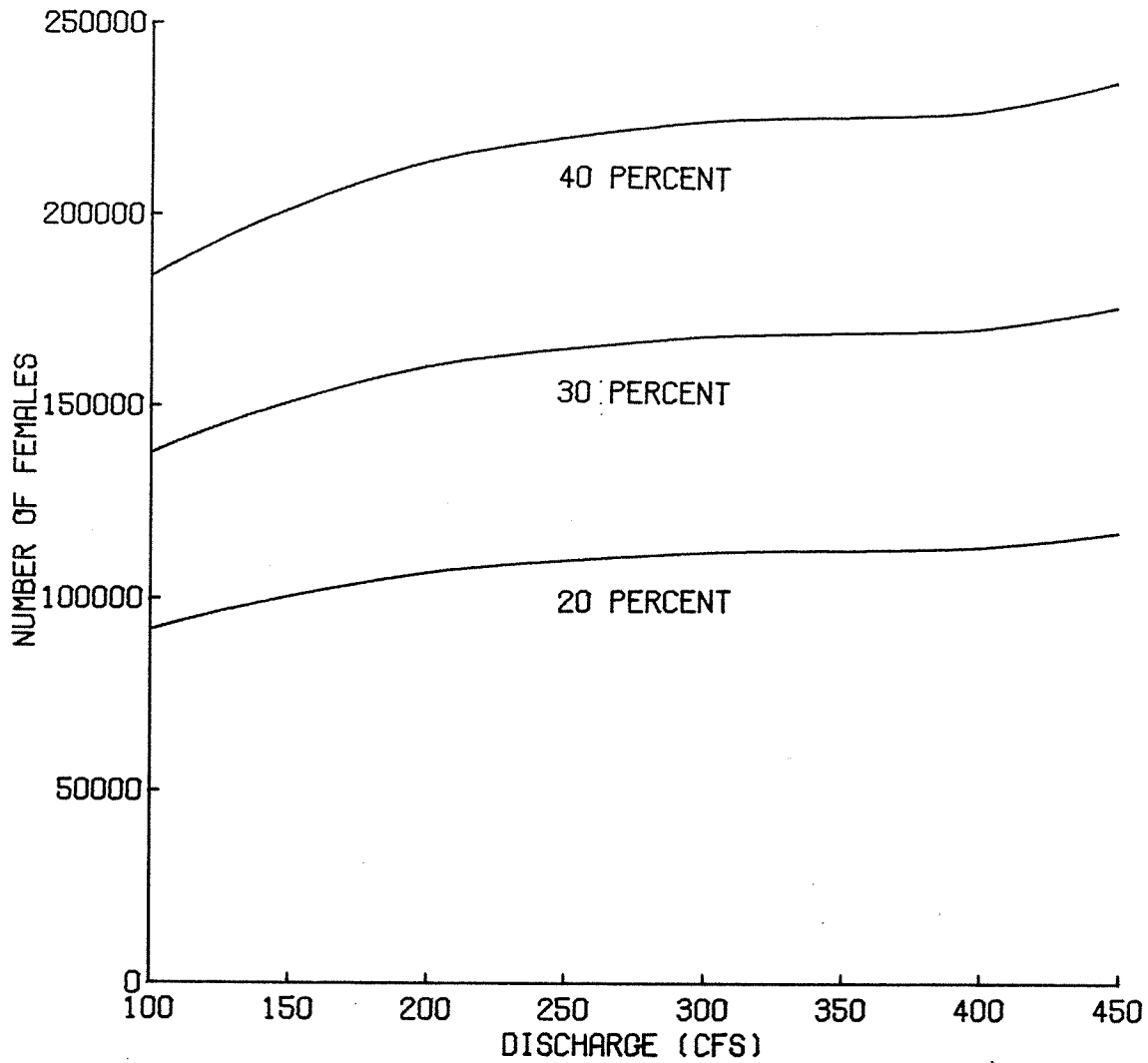


Fig. 16. Estimated spawner capacity (number of females) of 17.3 miles of the Cedar River based on utilization of 20, 30 and 40 percent of the total wetted area.

It should be noted that this estimate does not include the lower river reach from mile point 4.3 to the mouth. This section was observed to be grossly underutilized during the 1972 and 1973 spawning seasons. Possible reasons include the increased input of sediment from surrounding developments, the reduced stream bed gradient or reduced groundwater percolation. These factors result in intragravel flows which are inadequate for incubation even though Figure 15 indicates that for station 11, substantial area (approximately 7,000 ft<sup>2</sup>) was estimated to be suitable for spawning on the basis of depth and velocity alone. If the factors responsible for this underutilization could be determined and corrected the capacity could be increased by an estimated 25 percent.

#### Effects of Discharge on Sockeye Spawning Area

It was found that the "peak" spawning discharges for the eleven Cedar River stations ranged from 165 cfs to 338 cfs. Since it is difficult to optimize conditions at each reach simultaneously over the entire Cedar River below Landsburg, the mean peak spawning discharge was utilized. Management of a river on the basis of either the upper or lower extremes may result in adverse impacts on those reaches near the opposite extreme and may preclude other beneficial uses.

The mean peak spawning discharge for all stations was determined to be 240 cfs. This was equivalent to zero inflow between Landsburg and Renton. In order to aid in management application, the peak spawning discharge was calculated with reference to the U.S.G.S. gaging station at Renton where the discharge is presently being monitored. Since the discharge relationship at different points along the river is dependent on the amount of inflow between Landsburg and Renton, minimum inflow levels of 40 and 80 cfs were investigated based on observations during August, September and October of 1972 and 1973. The inflow of 40 and 80 cfs was prorated to each individual station on the basis of drainage area as described previously and the polynomial area-discharge curves were adjusted along the discharge axis in order to reference the peak spawning discharge to the Renton gage.

The area suitable for spawning from the polynomial curves for each station was summed at selected discharge levels and plotted. The peak spawning discharges (referenced to the Renton gage) determined in this manner were approximately 245 and 255 cfs with inflows of 40 and 80 cfs, respectively. A discharge of 250 cfs based on all stations was determined to be the mean peak spawning discharge referenced to the Renton gage.

It was shown in a previous section that the area suitable for spawning can be significantly increased by gradually increasing the discharge throughout the spawning season. In order to predict the effects of different discharge levels, the cumulative area curves for each station (open octagons, Figures 12-15) were combined into a single curve (Figure 17). Summing the areas at selected discharges over all stations, resulted in a curve which represents the cumulative area suitable for spawning at all stations combined. The peak spawning discharge at Renton (250 cfs) and its associated cumulative area (approximately 74,000 ft<sup>2</sup>) were considered the base conditions. Deviations above and below these levels were shown on a percentage basis. For example, if the discharge increased 100 percent (from 250 to 500 cfs) there would be an 20 percent increase in area suitable for spawning, or, if the discharge were reduced by 50 percent (from 250 to 125 cfs) there would be a corresponding 38 percent reduction in area. Use of the cumulative area-discharge relationship has the advantage that the effects of discharges greater than the mean peak spawning discharge can be assessed as well as the effects of those that are lower than the mean peak spawning discharge. The effects of any given discharge can then be expressed in terms of change in spawnable area.

Discharge regimes can be determined on the basis of spawnable area, however, the precise number of spawning sockeye which should be allowed to escape for any given discharge is more difficult to determine. The "peak" spawning flow of 250 cfs at Renton has been determined to be the optimum discharge. The discharge pattern to maximize the area suitable for spawning is shown in Figure 18. The discharge begins to increase from the



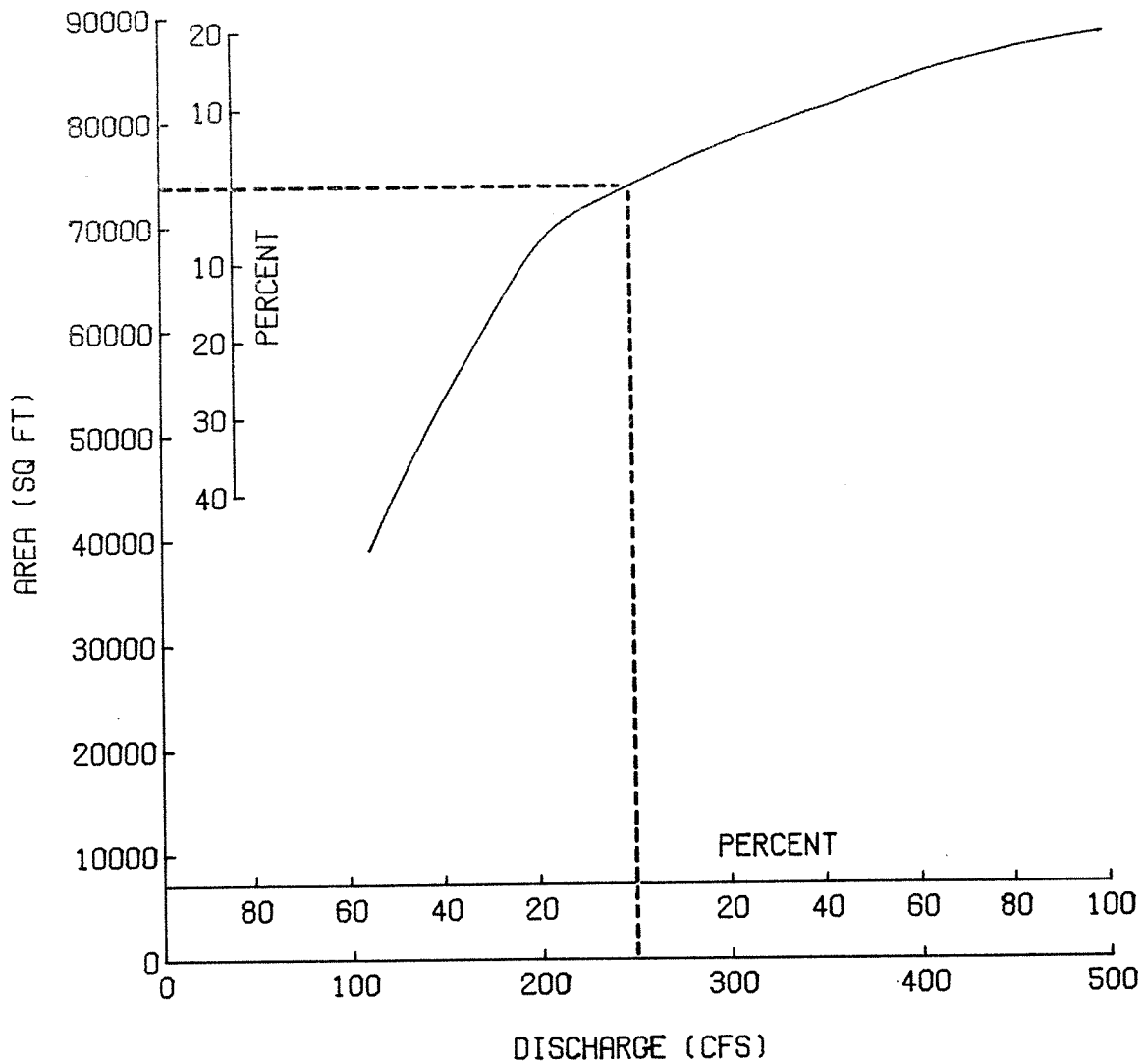


Fig. 17. Effects of discharge on sockeye salmon spawning area above and below the mean peak spawning discharge of 250 cfs referenced to the Renton gage with 60 cfs inflow.

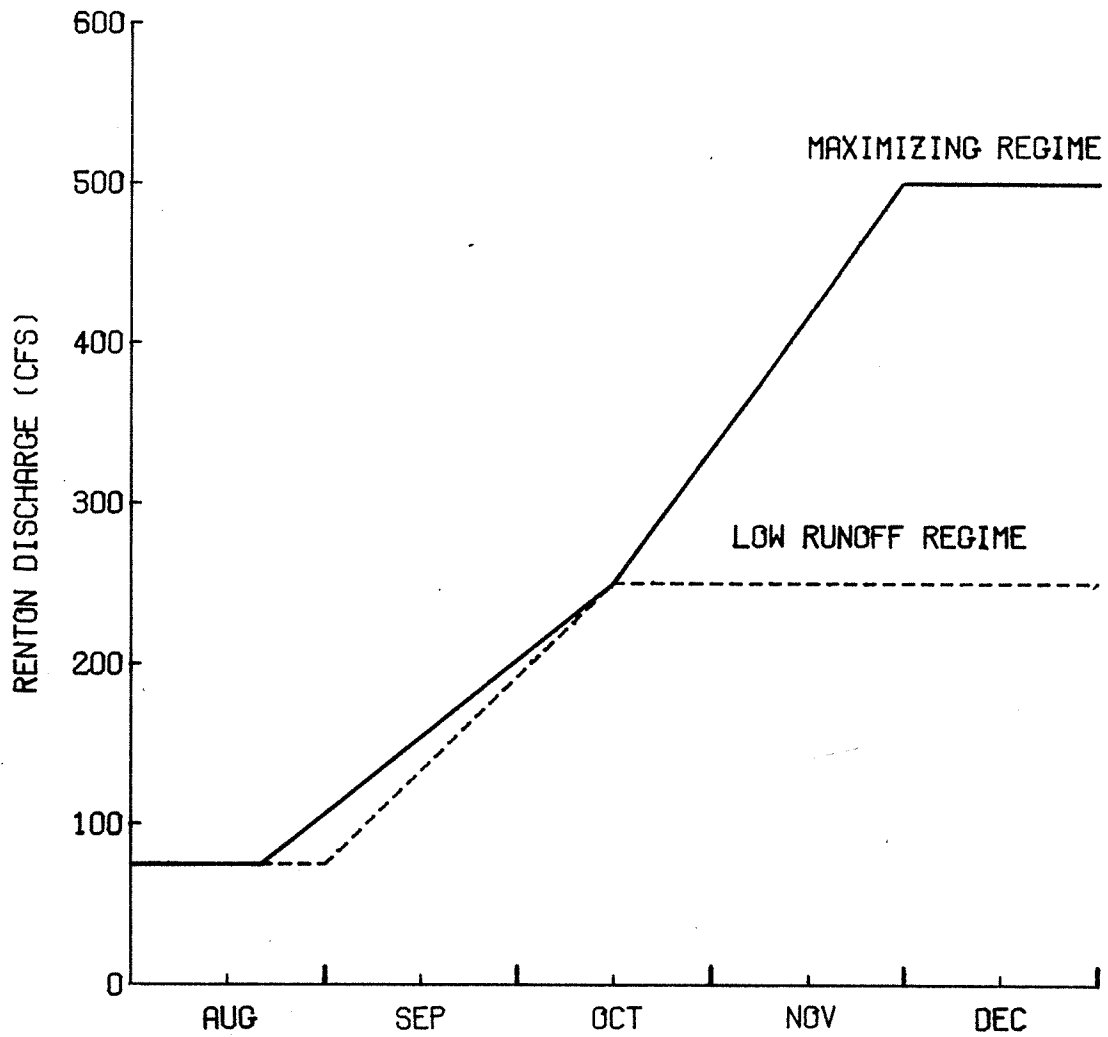


Fig. 18. Suggested maximizing and low runoff regimes for the Cedar River during the sockeye salmon spawning season.

summer minimum level of 75 cfs beginning on 20 August, the time when sockeye were observed to begin entering the river. Discharge would then increase gradually and continuously, reaching 250 cfs on 15 October. At this point, the availability of the maximum area suitable for spawning coincides with the peak spawning activity. After 15 October assuming additional water is available for fish, the discharge may continue to increase until it reaches 500 cfs on 30 November near the completion of the spawning run. Figure 17 indicates that very little additional spawning area is obtained after the discharge has passed 450 cfs.

During low runoff years the maximizing regime could be delayed to begin increasing from 75 cfs on 1 September and increasing linearly until 15 October, after which the discharge could be maintained at the peak spawning discharge of 250 cfs at Renton (low runoff regime). This is justified since fish passage occurs at 75 cfs and little spawning was observed to occur prior to 1 September. If water should become available after 15 October due to seasonal precipitation, then the maximum discharge regime could be resumed through 30 November. In any case, the highest discharge level attained by 30 November must be maintained until the completion of incubation and emergence of sockeye fry from the gravel the following spring.

The peak spawning discharge is based on the concept of obtaining the maximum spawning area for the minimum discharge. A method based on the spawnable area gained or lost has been presented for use in predicting the effects of discharges on spawning sockeye which deviate from the mean peak spawning discharge. On this basis two water management regimes have been suggested. However, the actual production of sockeye fry from the river remains a key question, since it not only is dependent on river discharge but on the population biology of the sockeye. A combined and objective management scheme for both water and fisheries resources can be developed from these data. It would be useful to evaluate the fry production in the natural river channel during the first few years of a multiple use management scheme, especially before any mitigative procedures are initiated.

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