FRI-UW-7308
May 1973

PRELIMINARY ASSESSMENT OF THE CEDAR RIVER DISCHARGE AND THE EFFECTS ON SPAWNING SOCKEYE SALMON

by

Q. J. Stober and J. P. Graybill

Annual Progress Report
June 15, 1972 to June 14, 1973
City of Seattle Water Department

UNIVERSITY OF WASHINGTON
COLLEGE OF FISHERIES
FISHERIES RESEARCH INSTITUTE

FRI-UW-7308
May 1973

FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
Seattle, Washington 98195

PRELIMINARY ASSESSMENT OF THE CEDAR RIVER DISCHARGE AND THE EFFECTS ON SPAWNING SOCKEYE SALMON

by

Q. J. Stober and J. P. Graybill

Annual Progress Report
June 15, 1972 to June 14, 1973
City of Seattle Water Department

Approved

Submitted May 7, 1973

Robert L Burgner
Director

CONTENTS

LIST OF TABLES

List of Figures

LIST OF APPENDIX FIGURES

PRELIMINARY ASSESSMENT OF THE CEDAR RIVER DISCHARGE AND THE EFFECTS ON SPAWNING SOCKEYE SALMON

by

Q. J. Stober and J. P. Graybill

INTRODUCTION

The Cedar River watershed is managed by the Seattle City Water Department to serve as the primary source of municipal and industrial water for the Seattle metropolitan area. The river below Landsburg extending to Renton is utilized as a spawning tributary by the predominant Lake Washington sockeye salmon, as well as the less plentiful chinook and coho salmon and steelhead trout. The management of the water resource has a direct impact on these salmonids particularly in the section of river below the City water supply diversion at Landsburg. This effect can be either beneficial to fish or not, depending on discharge, especially in "dry" years, when the conflict between demands placed on the system by the fishery resource and human need becomes most acute.

The Water Department is well aware of the inevitable short and long range problems that must be dealt with in providing an adequate water supply for the metropolitan area and is participating in the Water Resource Management Study sponsored by RIBCO. It has been recognized also that, during years of low runoff, a need exists for information from which a rational resolution of the conflict between human and fishery requirements can be made. The Fisheries Research Institute, University of Washington, was contracted to make an independent evaluation of the minimum discharge levels during dry years and the effects on the spawning of sockeye salmon in the Cedar River.

Accordingly, the present study was designed with the following objectives: (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, general population dynamics, and impact of predicted minimum discharge levels during times of low water supply on future salmon runs. This knowledge is necessary so that the water resource can be managed such that water is not wasted or the fish resource unduly depleted during times of low water supply.

DESCRIPTION OF THE 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 between 200 and 300 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 ten river reaches, in prime spawning areas, below Landsburg (river mile 21.6) for detailed hydraulic and biological investigation. These stations (1 through 10) were located at river miles 19.6, 17.3, 15.6, 13.7, 13.5, 13.0, 12.6, 11.5, 8.5, and 5.2 (Fig. 1) on the basis of spawning activity and the 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

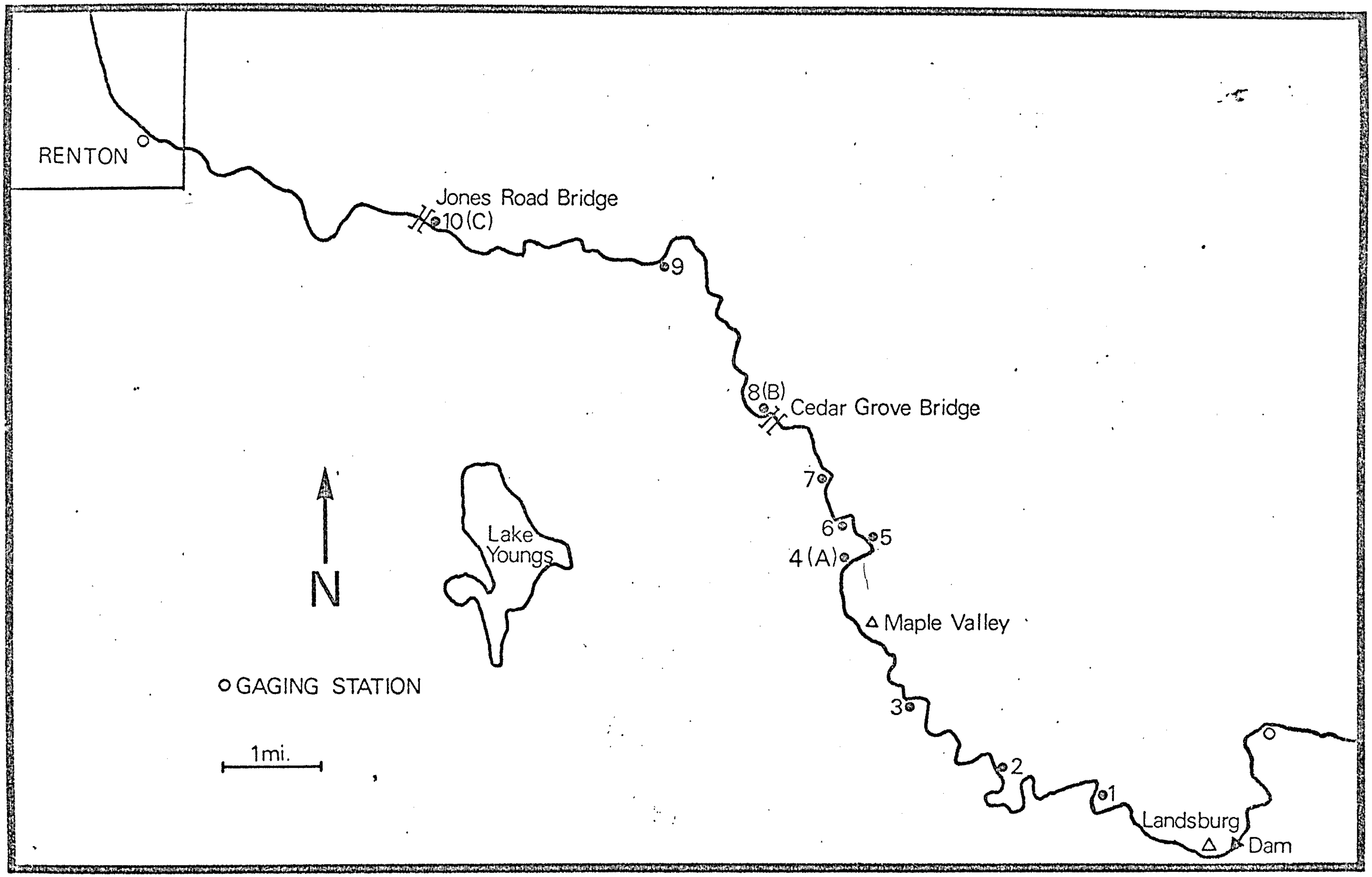

Fig. 1. Study reaches (1-10) between Landsburg and Renton. Reaches 4, 8, and 10 are the same as reaches A, B, and C of Collings et al. (1972).

Valley and the Cedar Grove Bridge, and stations 8, 9, and 10 between the Cedar Grove Bridge and the Jones Road Bridge. A brief description of the river reaches, including figures, is provided in Appendix A.

MATERIALS AND METHODS

Depth and velocity were measured at active sockeye salmon redds according to standard techniques as 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 depths and velocities for spawning Cedar River sockeye salmon were established by elimination of the highest and lowest 10 percent of the measurements.

Along with measurements on active sockeye redds, a systematic study was made on depths and velocities at the ten river stations. Sampling was conducted in accordance with the technique established by Collings et al. (1972). A river stage reference point and four transects were established at each station. River depth and velocity 0.4 ft above the bottom were measured at 20 to 30 points along each transect repeatedly during the spawning season. Each reach was mapped by plane-table methods, including the locations of redds.

A departure from the method of Collings et al. (1972) was the use of a contouring computer program, FRB 726 (SYMAP), to map the area of a river reach within the 80-percent ranges of depths and velocities. The measurements of depth and velocity in the four transects of each reach for a given discharge were used. The computer output consisted of two maps per reach: (1) one map showing the area of the reach with depths within the 80-percent range, and (2) the other showing the area with velocities within the 80-percent range. The separate plots (depth and velocity) were then superimposed, and the area where overlapping occurred was delineated and designated as the estimated area suitable for spawning, i.e., "estimated spawnable area."

Determination of discharge by direct measurement at the time of each river reach survey was not possible because of the large number of replicates required for accurate discharge determination, coupled with the hourly variability in discharge encountered during the field study period. Moreover, discharge was measured hourly at the Landsburg Dam and discharge determinations for each reach were referenced to these measurements. The time it took a crest of water to pass from Landsburg to Renton was determined and then proportioned to each of the study reaches by measurement of the distance to the river reach in question. Thus the hydrograph at the Landsburg Dam was interpreted in terms of the location and the travel time of the water to the sampling stations downstream and was used to determine the discharge during the survey of each reach. The hydrographs at the Landsburg Dam represented the discharge downstream that was available to the spawning sockeye salmon.

RESULTS AND DISCUSSION

Escapement

A history of the estimated sockeye salmon escapement to the Cedar River from 1960 through 1972 is given in Fig. 2. A significant increase is evident beginning in 1967 and continuing through the present. The number of spawners expected to return in the fall of 1973 has been estimated at about 270,000 by Thorne et al. (1973).

Timing of the Run

The sockeye salmon spawning run in 1972 (Fig. 3) began during late August and ended about mid-November. The run is bimodal, as determined by an analysis

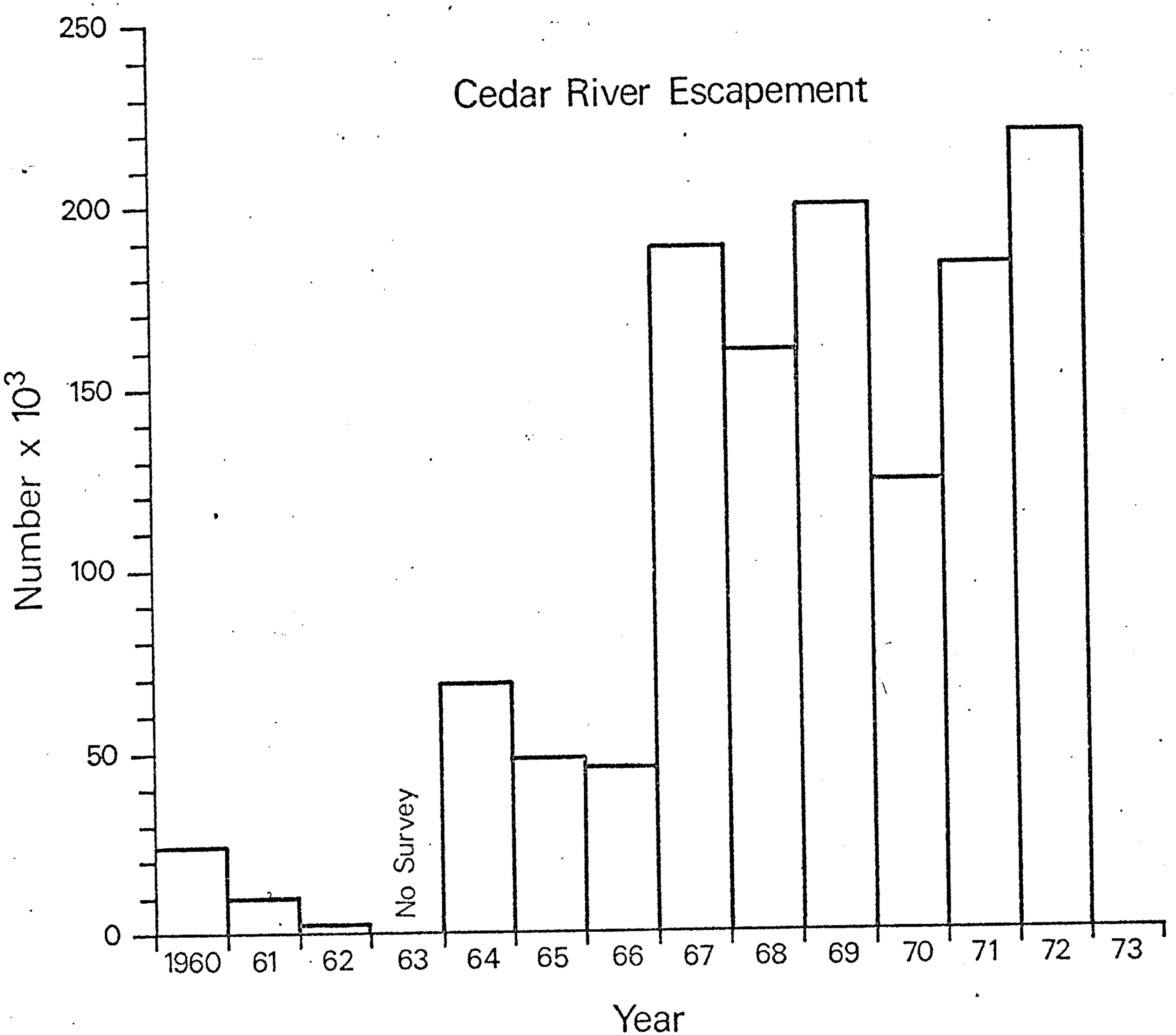

Fig. 2. Sockeye salmon escapements to the Cedar River from 1960 through 1972 as estimated by the Washington State Department of Fisheries.

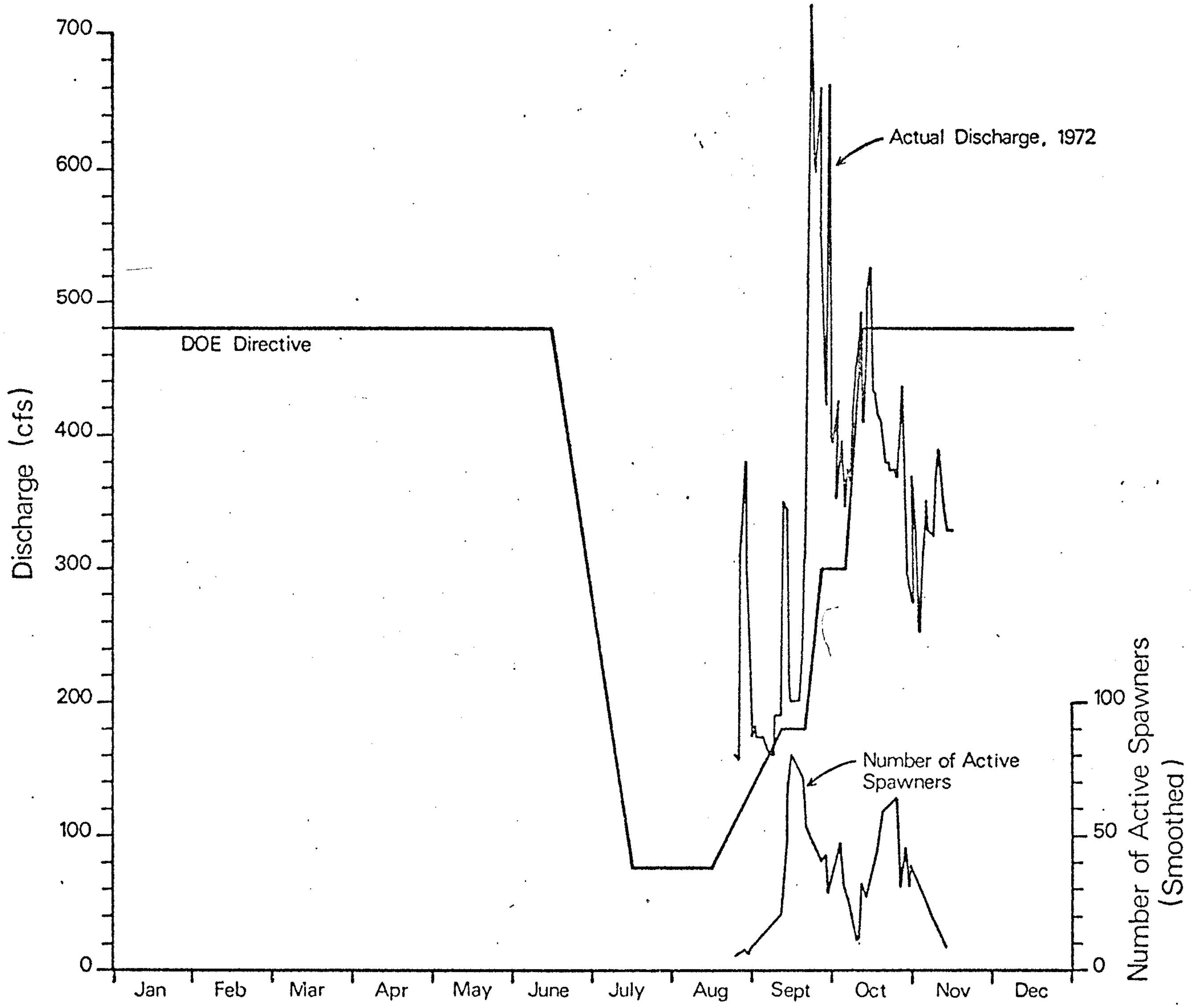

Fig. 3. Relationships between actual discharge and the Department of Ecology's directive during the spawning season, and timing and relative magnitude of the sockeye salmon escapement to the Cedar River.

(moving average of three) of the total number of active redds measured at all reaches during each sampling date. In 1972 the first mode reached a maximum during September, and the second mode by late October. The Department of Ecology has set a minimum flow to accomodate the timing of upstream migration. However, the following analytical approach will endeavor to provide an independent evaluation of the level of discharge required to allow adequate spawning area for sockeye salmon.

Depth and Velocity Suitable for Spawning

Measurements of depth and velocity were taken at 1247 sockeye salmon redds in the Cedar River below Landsburg. 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 Fig. 4. In general the greatest number of spawners occurred in the upper third of the river (reaches 1 to 4), while the middle third (reaches 5 to 8) received moderate use, and in the lower third (reaches 9 and 10) the spawning activity was minimal. Thus, the upper two-thirds of the river was more heavily utilized than the remainder, and served the major portion of the run. The greatest spawning activity occurred in the river reach that is subject to the greatest potential impact of minimum discharge.

Frequency distributions were plotted for depth (Fig. 5) and velocity (Fig. 6) measurements taken at the 1247 redds. Depths ranged from 0.1-3.0 ft, and velocities ranged from 0.06-3.81 ft/sec. As can be seen, the 80-percent intervals range from 0.5-1.8 ft for depths and 0.93-2.59 ft/sec for velocities.

The ranges of depths and velocities "preferred" by spawning sockeye salmon as 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 much larger by comparison, especially in the case of velocities.

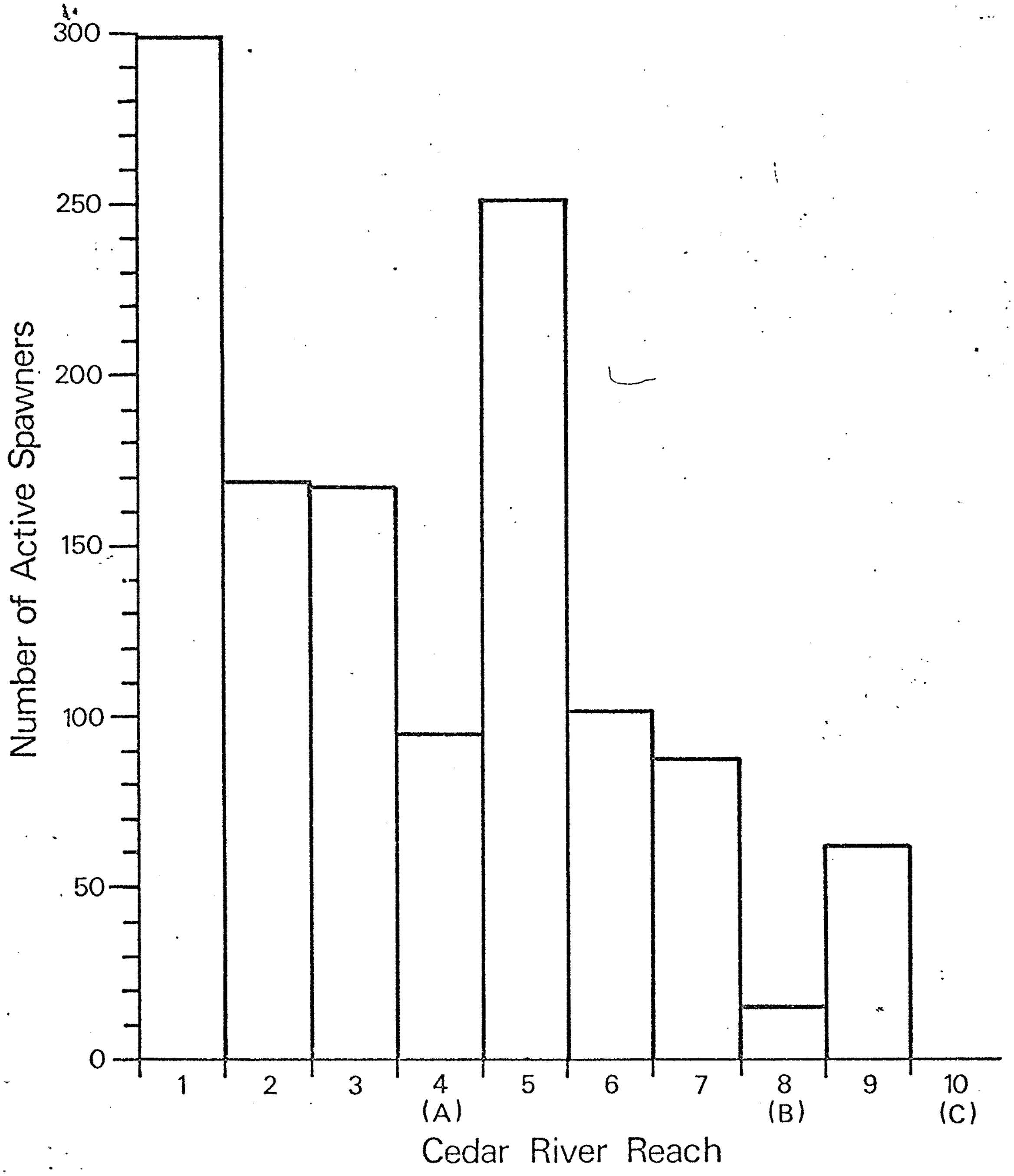

Fig. 4. Distribution of 1247 sockeye salmon redds observed in each reach of the Cedar River during 1972.

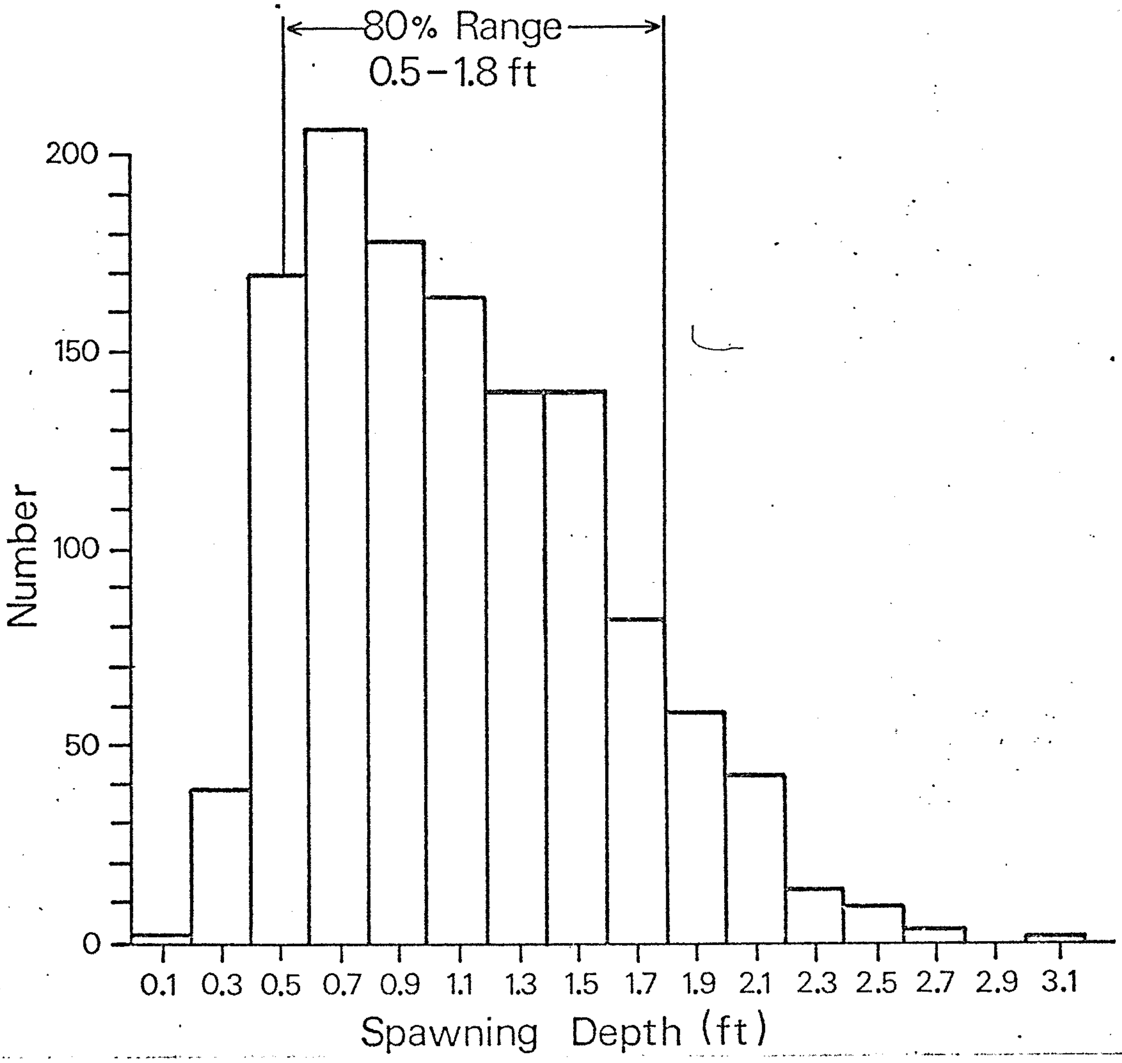

Fig. 5. Sockeye salmon spawning depths measured at 1247 redds in all Cedar River reaches combined.

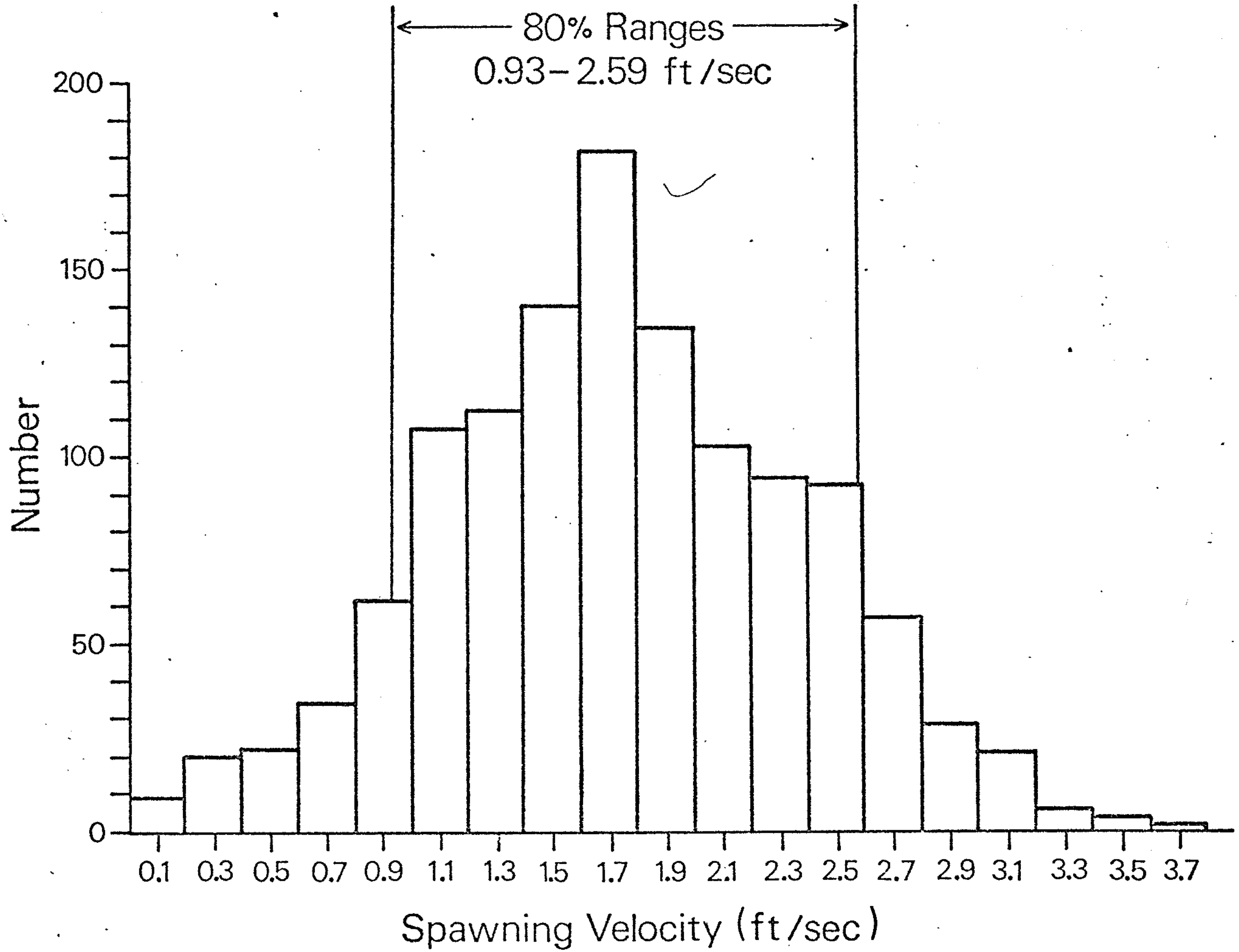

Fig. 6. Frequency distribution of water velocities measured at 1247 sockeye salmon redds in the Cedar River.

The ranges given in the literature appear unrealistic from the results of this study, and, if used in further calculations of suitable area for spawning, would be unnecessarily restrictive.

Relationships between Spawnable Area and Discharge

The various preliminary relationships between area suitable for spawning and discharge established in this study for the Cedar River are summarized in Figs. 7 and 8. For each study reach a family of curves is presented, each of which will be discussed in turn.

The curves which represent the estimated spawnable area were determined from 80-percent ranges of preferred depths and velocities. The points that make up these curves (solid triangles) represent the estimated spawnable areas as determined by the SYMAP analysis. The estimated spawnable area increases with discharge until it reaches some maximum value (where the slope of the tangent is zero), and then begins to decline with further increase in discharge. Thus, over a wide range of discharges, the relationship cannot be linear. The discharge that creates the maximum estimated spawnable area, i.e., the discharge providing the maximum spawning area, is termed the "peak spawning discharge." As can be seen in Figs. 7 and 8, the plots of the estimated spawnable areas do not show a well-defined peak at all sample reaches, and since the relationship cannot be linear, a curve was fitted to these points through 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 peak at or belo a discharge of about 500 cfs. The polynomial curves determined in this manner, however, tended to approach the area axis at low flows. Therefore, to comply with hydraulic theory, we made the additional assumption that the curves should approach the discharge axis at low flows (below 100 cfs). Such an assumption

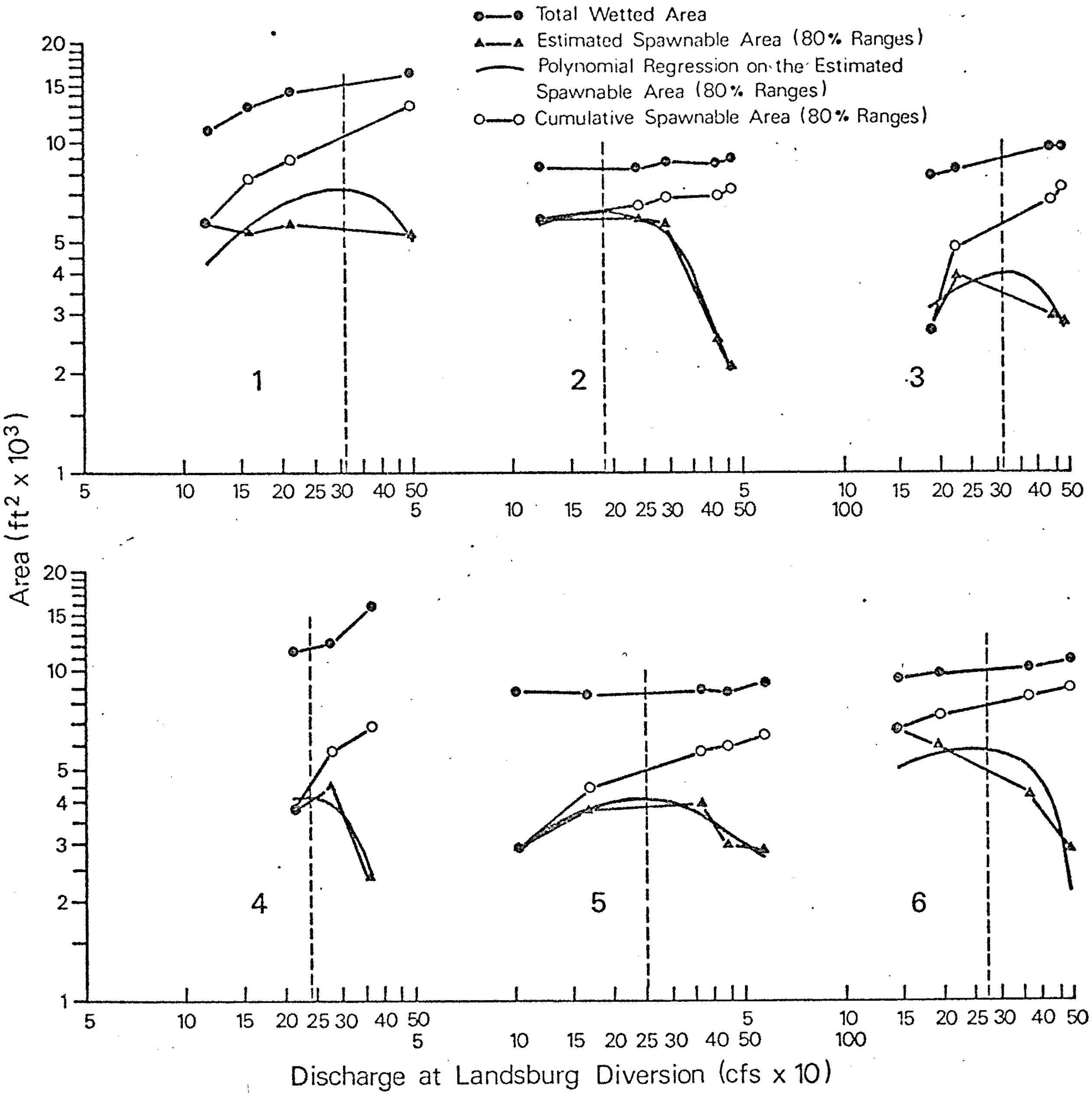

Fig. 7. Relationship between estimated spawnable area (80% ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at reaches 1-6. Vertical dashed line denotes peak spawning discharge.

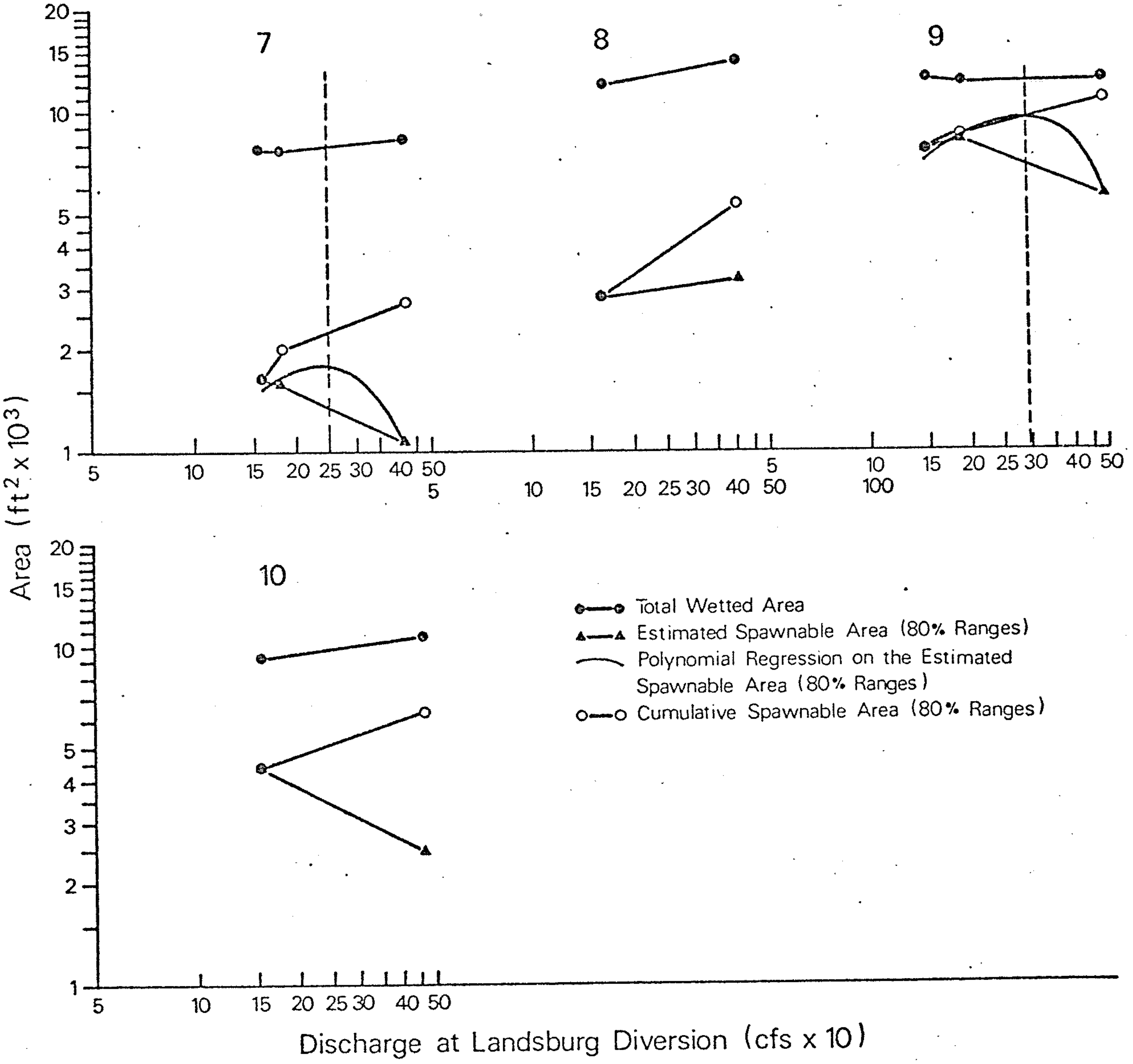

Fig. 8. Relationship between estimated spawnable area (80% ranges), polynomial regression on the estimated spawnable area, cumulative spawning area, and total wetted area for Cedar River sockeye salmon at reaches 7-10. Vertical dashed line denotes peak spawning discharge.

was necessary because of the present lack of data points below 150 cfs as a result of the unusually high flow pattern during the field study period. Therefore, as a first approximation, the curves were calcualted through the origin. The resulting curves are presented in Figs. 7 and 8 for each reach except 8 and 10 and are captioned "polynomial regression on the estimated spawnable area (80-percent ranges)."

The polynomial regression curves for reaches 2 and 5 show a fairly good fit to the estimated spawnable area data points. The fits for the other reaches must be improved by the acquisition of additional data points at intermediate discharges and the fits for all reaches can be improved by the addition of data points at minimum discharges. The preliminary peak flow that will provide the maximum area suitable for spawning during the spawning period was calculated from the polynomial equation for each reach and is designated by the vertical dashed line intersecting that point on the curve for each reach. The peak spawning discharge for reach 4 is 243 cfs; in comparison the value determined by Collings et al. (1972) for the same reach in his previous investigation was 240 cfs. Additional field measurements during the low discharge period will be determined for similar comparisons of reaches 8 and 10. The peak discharges for reaches 8 and 10 as determined by Collings et al. (1972) were approximately 500 cfs and are apparently the basis for the Department of Ecology's current flow requirement of 480 cfs. The mean of the peak spawning discharges for the eight stations on which polynomial regressions were calculated was 268 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 (Figs. 7 and 8, solid circles). 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 450 ft^2 (8370 to 8820 ft^2) with an increase in discharge of 334 cfs (120 to 450 cfs). On the other hand, station 1 increased 5270 ft^2 (10,960 to 16,230 ft^2) with an increase in discharge of 377 cfs (116 to 493 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.

Also calculated for each station was the total cumulative spawning area available to sockeye salmon as discharge increased throughout the spawning period (Figs. 7 and 8, open circles). These were determined by considering the estimated spawnable area at the lowest observed discharge to be the base area suitable for spawning. The area that became available for spawning with each increase in discharge was plotted in a stepwise fashion to the largest possible at the highest measured discharge for 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. This area accumulated at a more rapid rate at stations 1 and 4 than at stations 2 and 5.

A discharge regime of several stepwise increases adds significantly to the spawnable area available to sockeye salmon, especially in unchanneled portions of the river. Table 1 presents the peak spawning discharge (the discharge that will provide the maximum area suitable for spawning) for each reach and the associated estimated spawnable area and the cumulative spawnable area The last was determined for each station by following the vertical dotted line (Figs. 7 and 8) to the intersection with the cumulative spawnable area curve. The sum of the estimated spawnable areas (peak spawning discharges) for the eight stations is 44,332 ft^2. The sum of the cumulative spawnable areas for the eight stations is 52,460 ft^2. Thus, if the discharge regime is increased in a stepwise manner to the peak spawning discharge, the amount of spawnable area can be increased by 18 percent. A stepwise discharge regime during the spawning run is therefore desirable since it spreads the spawners laterally, maximizing use of the spawning beds, and thereby providing for the most efficient use of minimum discharge levels.

Table 1. Comparison of the peak spawning discharge at each reach with the associated estimated spawnable area and the corresponding cumulative spawnable area

Station	Peak spawning discharge (cfs)	Estimated spawnable area (ft^2) at peak spawning discharge	Cumulative spawnable area (ft^2)
1	320	7,426	10,500
2	190	6,434	6,500
3	324	4,072	5,750
4	243	4,161	4,800
5	252	4,126	5,000
6	274	6,560	7,900
7	250	1,787	2,240
9	294	9,766	9,770
		44,332	52,460

The technique used to estimate the spawnable area was examined by consideration of the area actually utilized by spawners in each river reach. The latter area was determined by measuring the area with redds. A spawning territory four times larger than the redd size was utilized (Burner, 1951) which resulted in an isopleth 5 ft around the outside of the outermost redds. The area was divided by the estimated spawnable area and the percentage utilized was found (Table 2). When examining the percentages of utilization given in Table 2, one must bear the following considerations in mind. The majority of the low percentages at stations 1 to 6 are for dates early in the spawning season when

Table 2. Comparison of the estimated spawnable area with the area actually utilized as observed on successive spawning surveys of each of the Cedar River reaches ✓

Station	Date	Flow (cfs)	Estimated spawnable area (ft^2)	Area (ft^2) actually utilized	Percentage of estimated spawnable area utilized	Number of redds measured
1	9/11/72	157	5444	2928	54	16
	9/19/72	210	5632	5924	105	55
	10/11/72	493	5352	5356	100	7
2	8/24/72	120	5800	760	13	6
	9/12/72	240	5876	3516	60	43
	9/20/72	287	5664	4344	77	51
	9/28/72	426	2532	2488	98	16
	10/09/72	454	2064	3044	147	0
3	9/13/72	185	2688	2304	86	13
4	9/20/72	273	4432	2120	48	12
	10/12/72	362	2344	5692	243	50
5	8/30/72	102	2832	996	35	6
	9/14/72	168	3736	3496	94	38
	9/22/72	570	2828	3440	122	51
	9/29/72	367	3964	3804	96	57
	10/10/72	443	2956	2348	79	18
6	8/30/72	145	6648	356	5	3
	9/14/72	193	5928	3356	57	38
	10/03/72	367	4240	1928	45	0
	10/13/72	499	2880	2356	82	14
7	9/15/72	180	1560	4608	295	55
8	10/12/72	399	3216	408	13	7
9	9/01/72	145	7640	80	1	2
	9/15/72	185	8092	6200	77	42
	10/11/72	488	5512	1276	23	7
10	10/09/72	454	2484	0	0	0

few spawners were present. Those at stations 8 to 10 indicate a general underutilization of the lower river. The extremely high percentages for stations 4 and 7 are for dates when moderate flows were occurring that had been preceded by substantially greater flows. The movement of spawners onto the spawning beds had been triggered by the high discharges and the fish had remained in the reach after the flows subsided. Fluctuation in water level resulted both from human activities and rainfall in the lower part of the drainage basin. Daily discharge fluctuations must be reduced whenever possible in order to achieve the most efficient use of both water and spawning area with a gradual stepwise increase in discharge. The majority of the remaining percentages for the upper stations are between 70 and 100 percent. This distribution indicates that the analytical technique used for estimating spawnable area (80-percent ranges of preferred depths and velocities) is a reasonable indicator of the area actually utilized. The fit of redd locations and estimated spawnable area illustrated in the ten example reaches (Figs. A-1 to A-10) indicate that salmon have additional criteria for selection of spawning area. The number of redds measured (Table 2) also reflects the spawning activity observed on each date. The zero values at stations 2 and 6 indicate dates when mass spawning occurred and the spawning areas were delineated but no redds were measured. The correlation between the estimated spawnable area and that actually utilized by spawners will be examined in detail in the final report.

The estimated spawnable area can be used as an index of the actual area utilized for spawning to achieve a basis for predicting losses of area due to discharge reduction from the peak spawning flow. Such an exercise is shown in Table 3. The peak spawning discharge and its associated estimated spawnable area are listed under "peak." The peak discharges are reduced by 10 and 25 percent and the resulting losses in estimated spawnable area are determined from

Table 3. Calculated losses of estimated spawnable area, in ft^2, with 10% and 25% reductions in discharge below the peak spawning discharge for each of the Cedar River reaches. The figures in parentheses are the numbers of females lost

			Percentage reduction from peak spawning discharge	
Station	Parameter	Peak	10%	25%
1	Discharge	320		
	Area	7426 (393)	74 (4)	464 (25)
2	Discharge	190		
	Area	6434 (340)	50 (3)	315 (17)
3	Discharge	324		
	Area	4072 (215)	56 (3)	347 (18)
4	Discharge	243		
	Area	4161 (220)	60 (3)	
5	Discharge	252		
	Area	4126 (218)	26 (1)	188 (10)
6	Discharge	274		
	Area	6560 (347)	65 (3)	407 (22)
7	Discharge	250		
	Area	1787 (95)	18 (1)	111 (6)
9	Discharge	294		
	Area	9766 (517)	93 (5)	599 (32)
	Number of females	2345	23	130
	Percent lost		0.1%	5.5%

the polynomial regression curves. The figures in parentheses are the numbers of female spawners lost if we assume the average redd size of 2.1 yd^2 (18.9 ft^2) (Burner, 1951). Summing the fish counts over the eight stations, we find that the potential capacity of the gravel within all reaches at peak spawning discharge would be 2345 female sockeye salmon. A 10-percent reduction in discharge results in the loss of 23 females or 0.1 percent of the potential capacity, but a 25-percent reduction in discharge results in the loss of 130 females, or 5.5 percent of the potential capacity.

It must be emphasized that this report is preliminary and with collection of additional data, changes may be necessary in the interpretation of these results.

SUMMARY

This study was designed to develop depths and velocities preferred by spawning Cedar River sockeye salmon and to provide an understanding of the minimum discharge regimes necessary during the spawning period to maintain the Lake Washington run. Hydraulic and biological investigations were conducted on ten spawning reaches. A total of 1247 sockeye salmon redds was observed. The 80-percent intervals for "preferred" depths and velocities were 0.5-1.8 ft and 0.93-2.59 ft/sec, respectively. In general the greatest number of spawners occurred in the upper third of the river (reaches 1 to 4), while the middle third (reaches 5 to 8) received moderate use, and in the lower third (reaches 9 and 10) the spawning activity was minimal. The greatest spawning activity occurred in the river reaches that were subject to the greatest impact from minimum flows. Preliminary curves showing the relationships between area suitable for spawning and discharge were plotted for each river reach; further data are required before these relationships can be finalized and the potential spawner capacity at a given discharge determined.

ACKNOWLEDGMENTS

This investigation was conducted under contract with the City of Seattle Water Department. The cooperation received from the Washington State Department of Fisheries and the U.S. Geological Survey during the past year is greatly appreciated. We are grateful to Mr. Charles Howard, with whom discussions have been helpful.

LITERATURE CITED

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish Wildl. Serv., Fish. Bull. 52(61):97-110.

Chambers, J. S., G. H. Allen, And R. T. Pressey. 1955. Research relating to study of spawning grounds in natural areas - annual report 1955. Rep. to Army Corps of Engineers by Washington State Dep. Fish. 175 pp.

Clay, C. H. 1961. Design of fishways and other fish facilities. Canad. Dep. Fish. 301 pp.

Collings, M. R., R. W. Smith, and G. T. Higgins. 1972. The hydrology of four streams in western Washington as related to several Pacific salmon species. Geol. Survey Water-Supply Paper No. 1968. 109 pp.

Heiser, D. W. 1971. Spawning depths and velocities of chum and pink salmon in western Washington. Pp. 42-50 In Pink and chum salmon investigations, 1969. Puget Sound Stream Studies, Suppl. Prog. Rep.

Thorne, R. E., J. J. Dawson, J. J. Traynor, and R. L. Burgner. 1973. Population studies on juvenile sockeye salmon in Lake Washington. Univ. Washington, Fish. Res. Inst. Inform. Rep. to Washington State Dep. Fish., March 30, 1973. 9 pp.

APPENDIX A

DESCRIPTION OF CEDAR RIVER STUDY REACHES

Convention - The right and left river banks are determined with the observer facing downstream.

Reach #1, at river mile 19.6 (Fig. A-1), has a deep channel along the left bank and a shallow gradient bar that was heavily used by spawners along the right half. Just downstream from the spawning bar is a pool. Superimposition was excessive at this reach and thousands of eggs accumulated in the pool. There is no cover along this reach.

Reach #2, at river mile 17.3 (Fig. A-2), is of fairly uniform depth throughout, with a steep shoreline on both banks. There is close cover on both banks. Most of the spawning activity occurred in the left one-third of the reach and in a narrow strip along the right bank. A pool occupies the right half of the river just upstream from the reach.

Reach #3, at river mile 15.6 (Fig. A-3), has a bar with shallow gradient on the right half and a deep channel on the left at the base of a vertical bank. Spawning activity occurred in the right two-thirds of the station. There is close cover on both banks.

Reach #4, at river mile 13.7 (Fig. A-4), corresponds to the USGS reach A. The left bank is nearly vertical with the deep portion of the reach at its base. The right portion of the reach is a bar with shallow gradient, where most of the spawning activity occurred. At higher flows (above about 300 cfs) a side channel is created to the right of the reach. Spawning also occurred in the side channel.

Reach #5, at river mile 13.5 (Fig. A-5), is riprapped on the right bank with the deep portion of the reach at its base. The left shoreline is an 18-inch vertical bank with no cover. The left half of the reach is shallow and was the portion utilized by spawners. Extensive superimposition of redds occurred in this area. The river splits just below the reach into two riffled channels.

Reach #6, at river mile 13.0 (Fig. A-6), has the deeper portion at midchannel. There is no cover on either bank. Most of the spawning activity occurred in the left third of the reach.

Reach #7, at river mile 12.6 (Fig. A-7), is on a curve and is narrow and deep. The right bank has cover but the right third of the reach is too deep and has a sandy substrate and is therefore unsuitable for spawning. The majority of the spawning took place in the left two-thirds of the reach.

Reach #8, at river mile 11.5 (Fig. A-8), corresponds to USGS reach B. It is on a curve with the right bank riprapped. Its deep portion is on the right. Spawning activity was small and occurred along the left bank. There is no cover along this reach.

Reach #9, at river mile 8.5 (Fig. A-9), is the widest of the ten reaches and has a fairly uniform depth throughout. There is some cover on the right bank. Spawning occurred throughout the station, but spawner densities were low.

Reach #10, at river mile 5.2 (Fig. A-10), corresponds to USGS reach C. The left bank is riprapped and at its base the flow is swift and deep. Depths and velocities along the right bank are suitable for spawning, but during the entire 1972 spawning season only 1 pair used this reach.

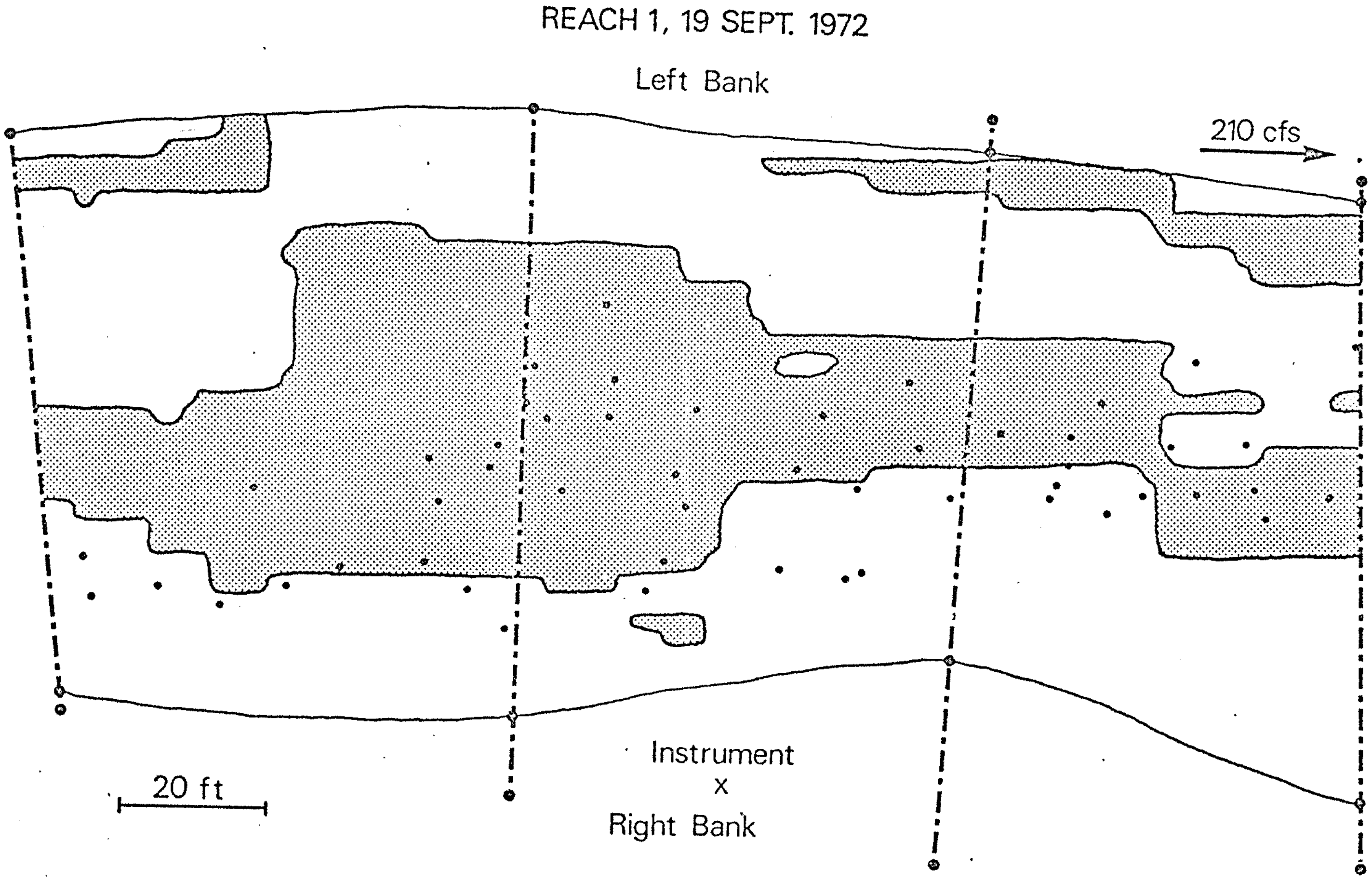

Fig. A-1. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 1. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

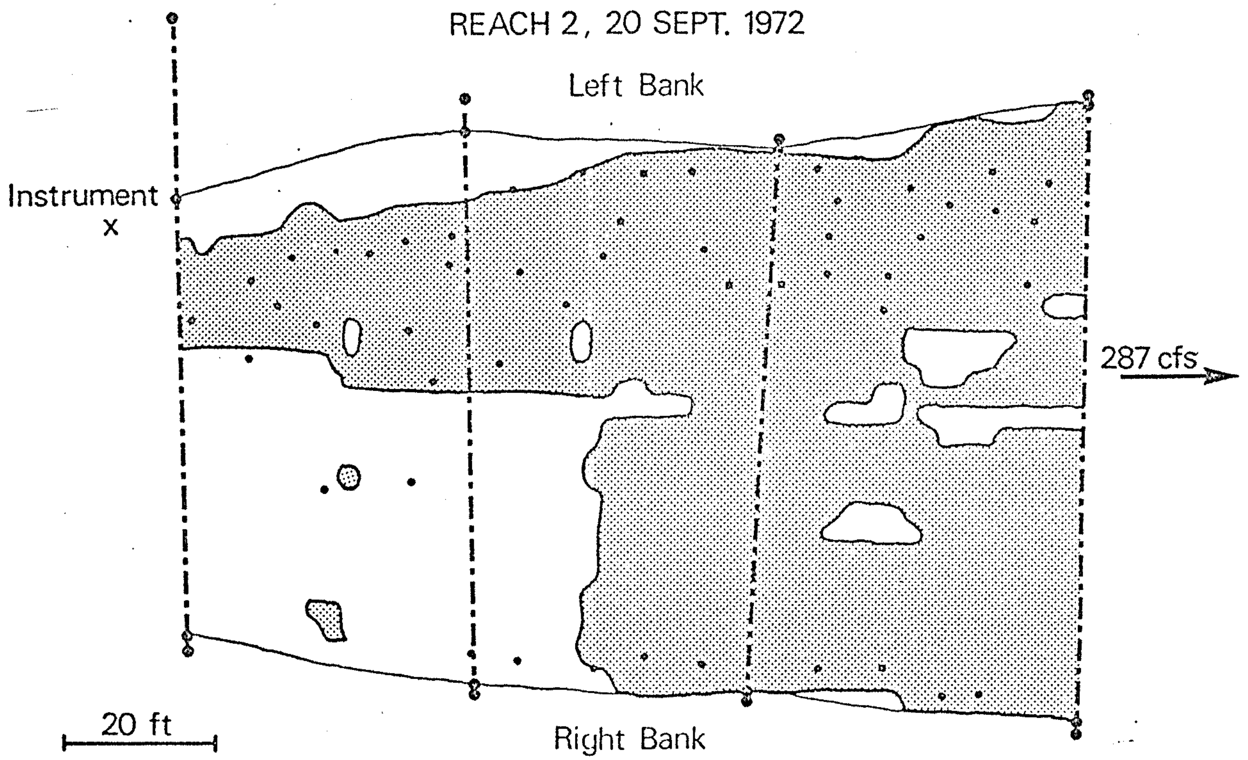

Fig. A-2. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 2. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

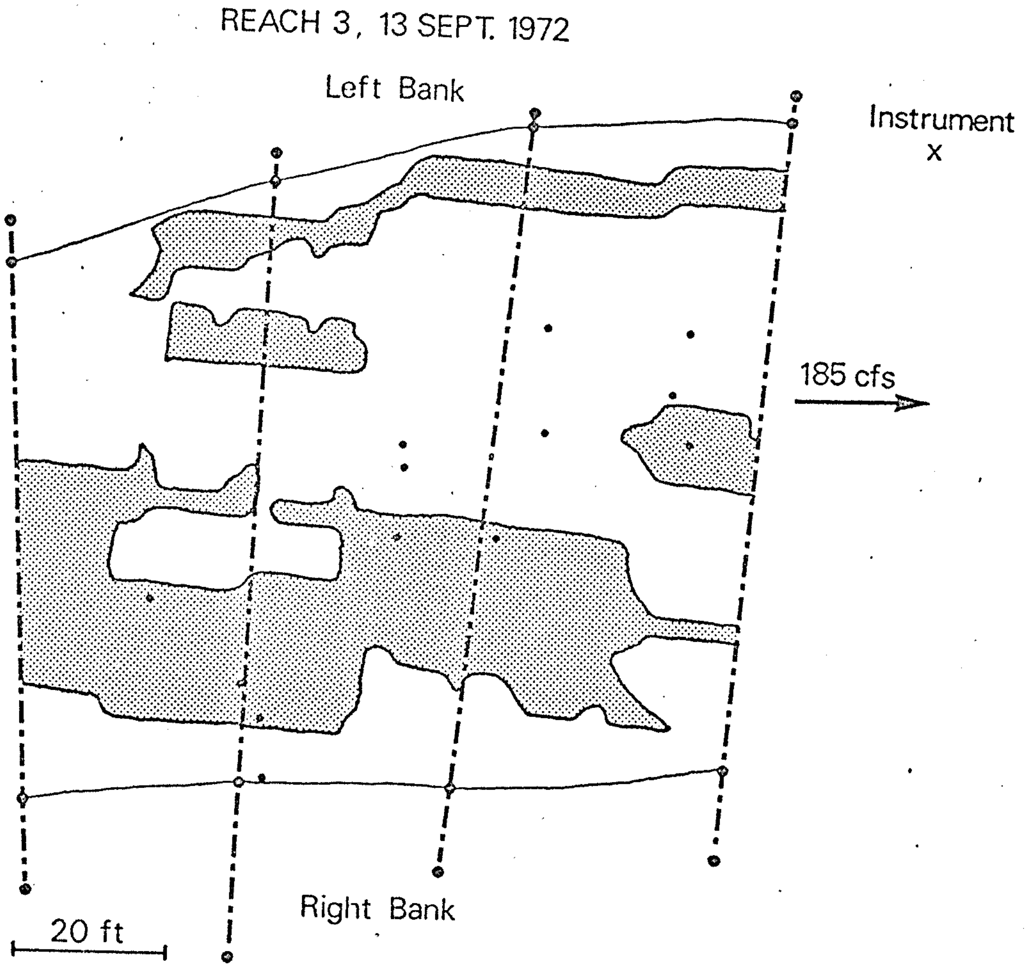

Fig. A-3. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 3. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

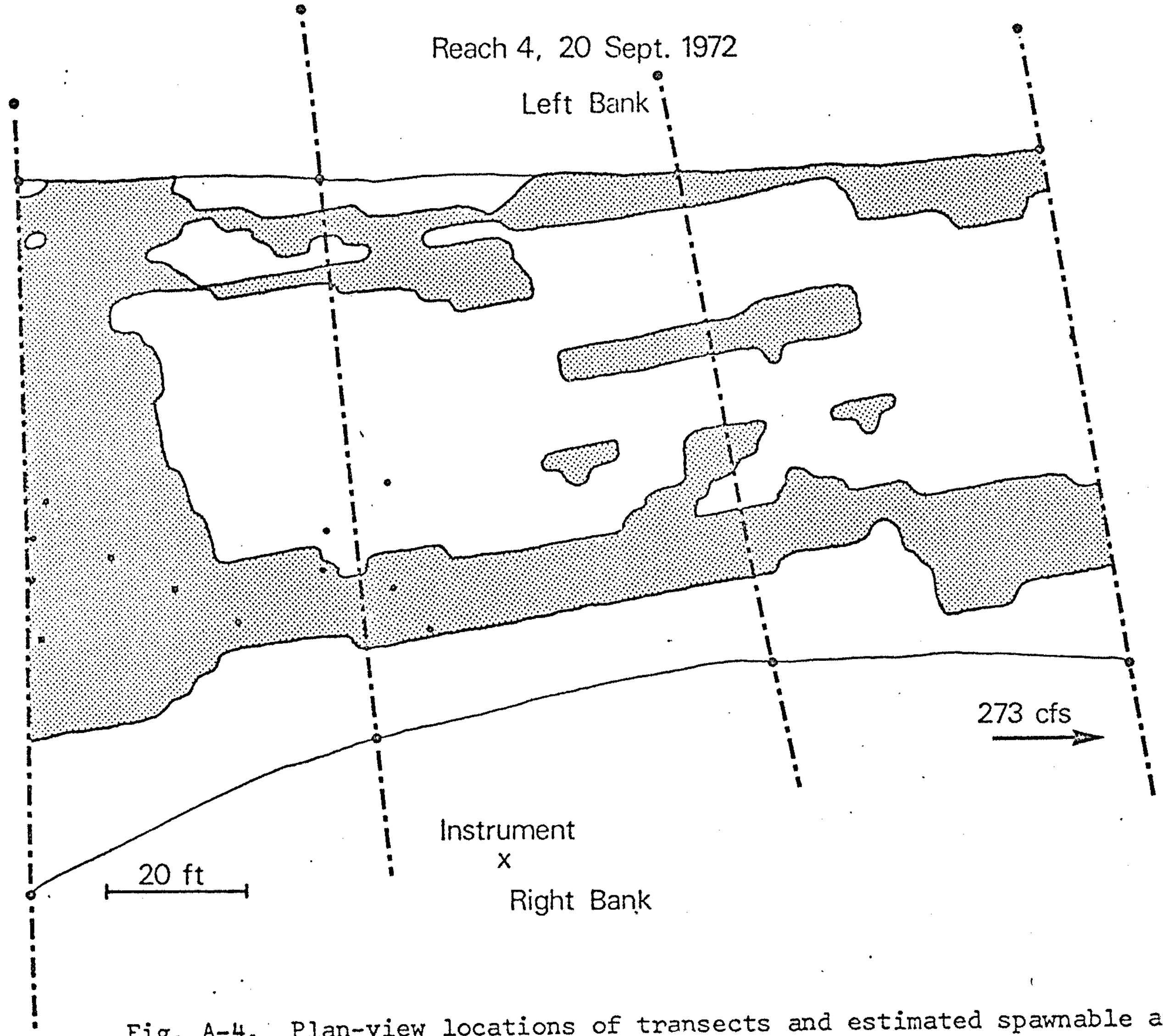

Fig. A-4. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 4. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

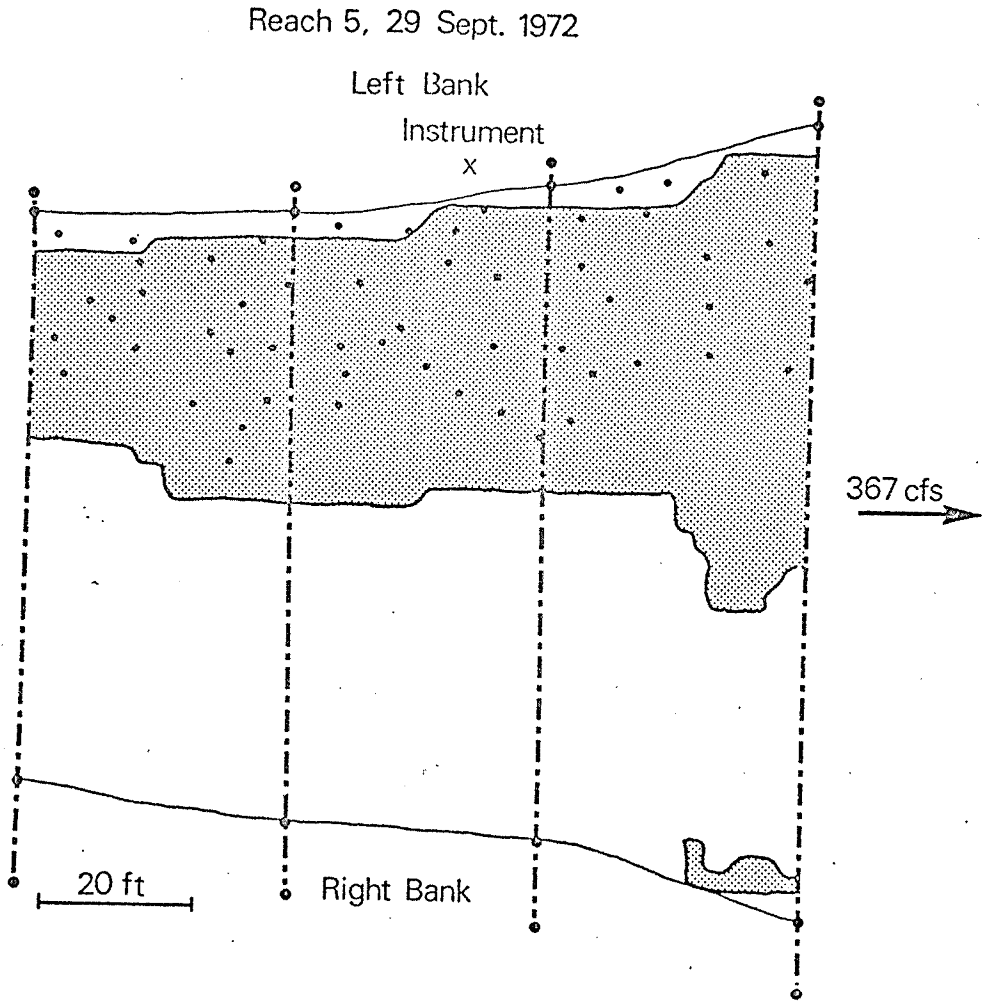

Fig. A-5. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 5. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

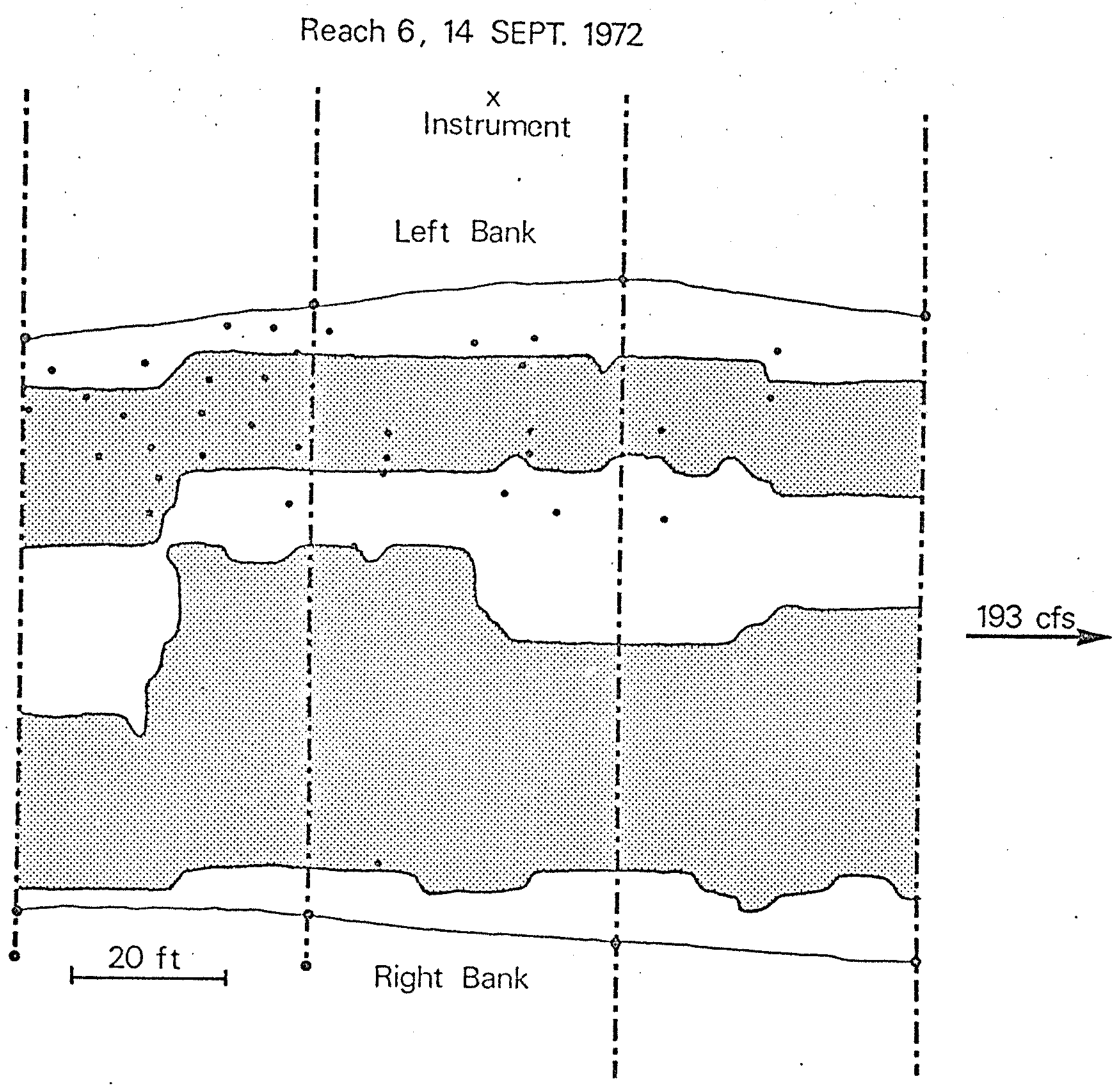

Fig. A-6. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 6. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

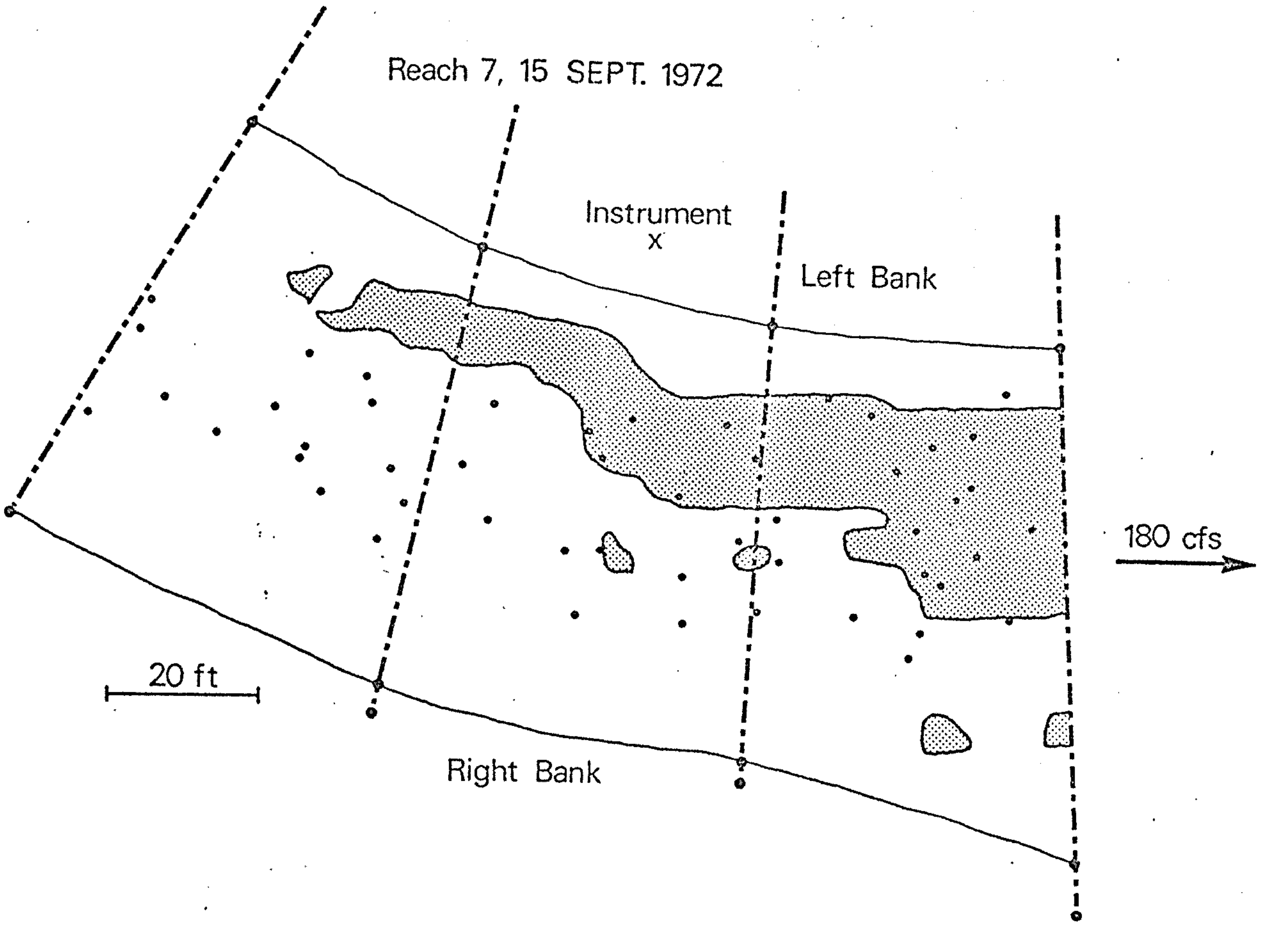

Fig. A-7. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 7. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

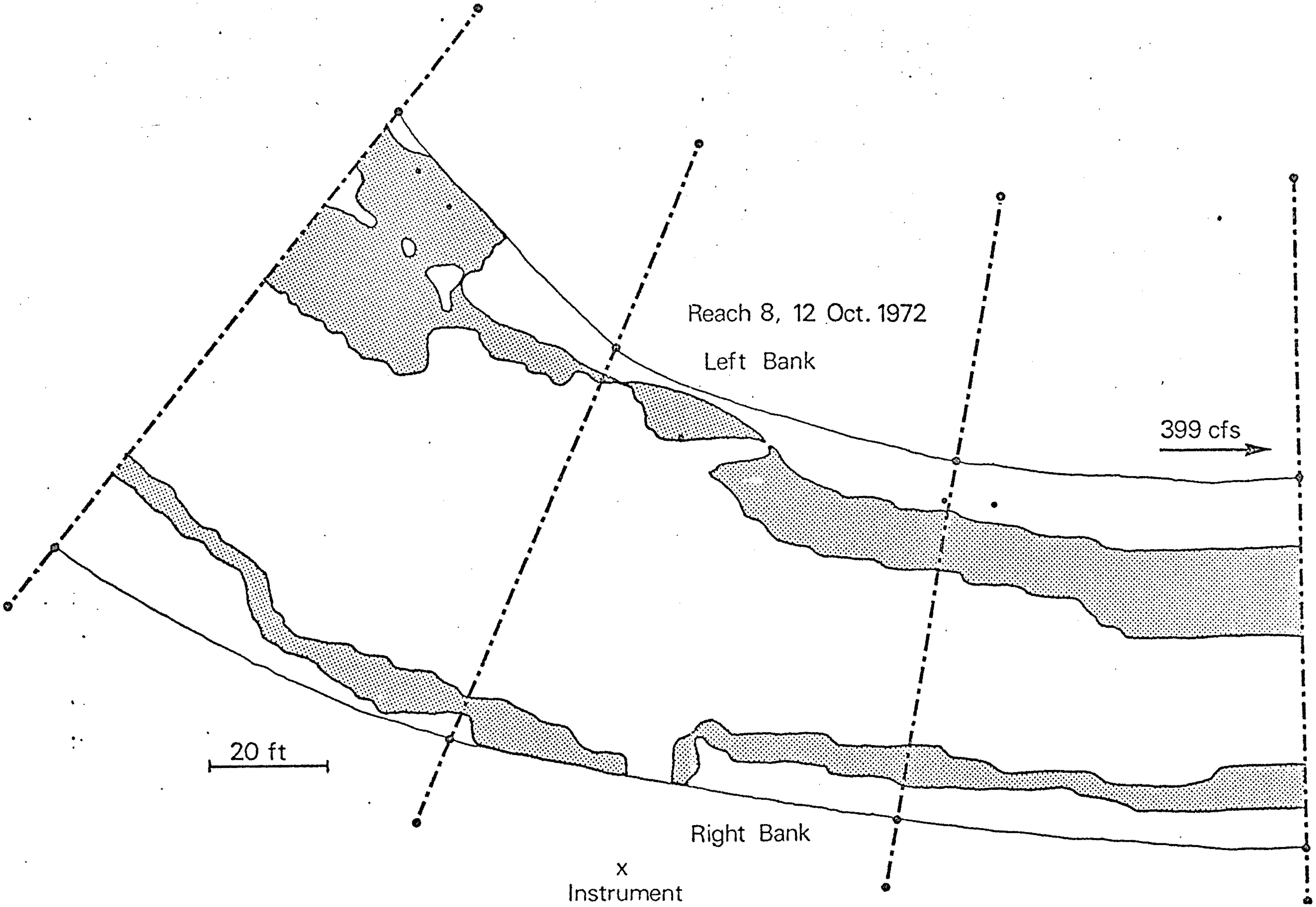

Fig. A-8. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 8. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

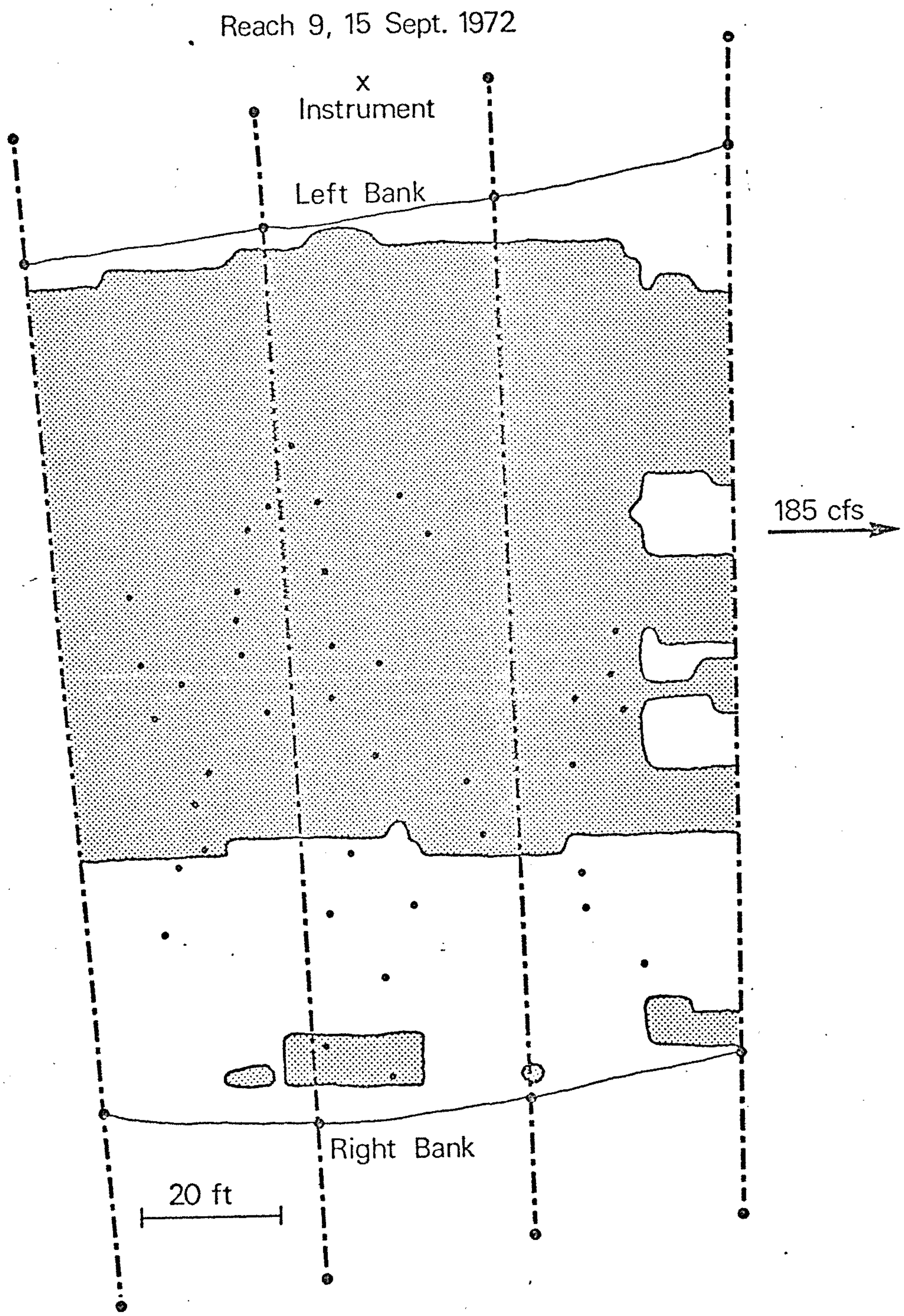

Fig. A-9. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 9. The locations of active sockeye redds measured on the date indicated are designated by the black dots.

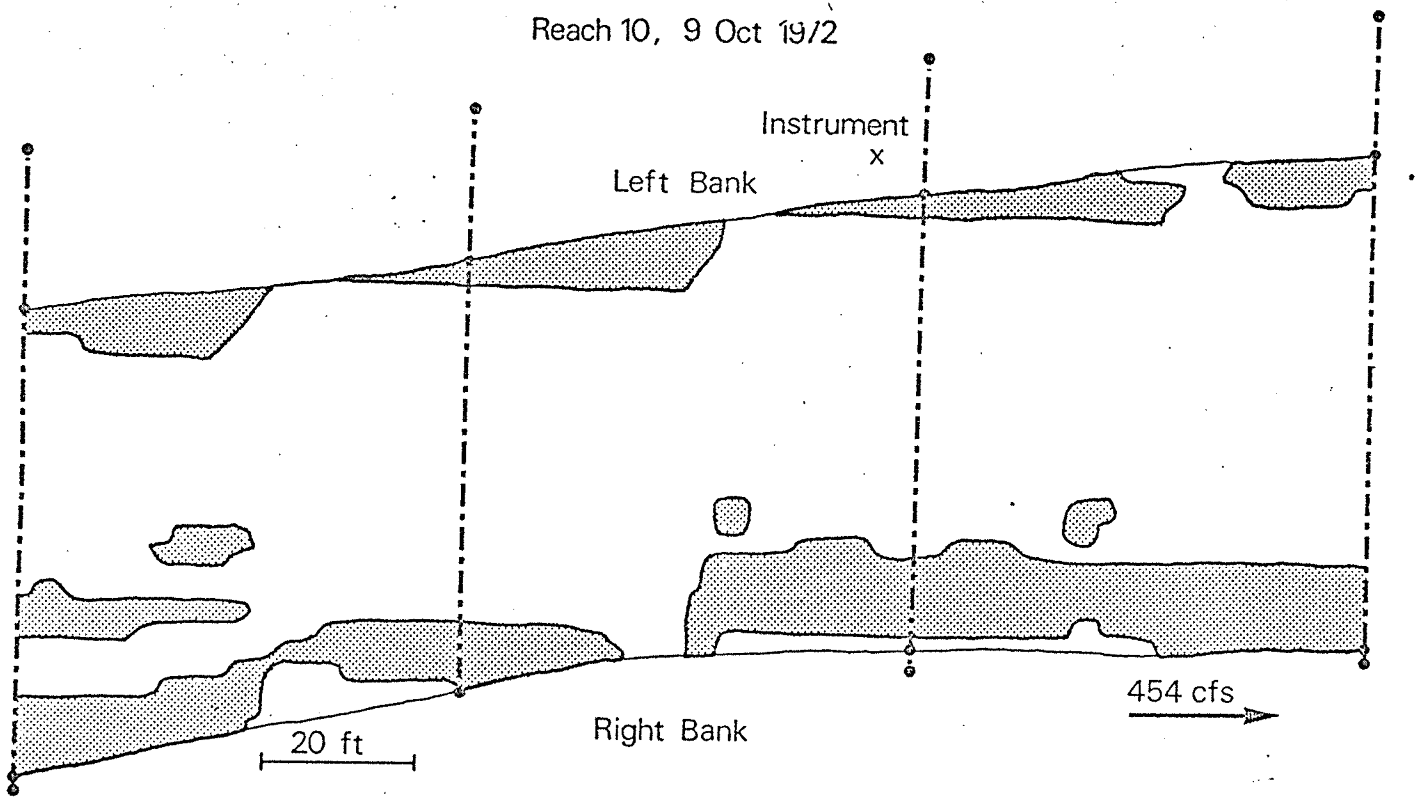

Fig. A-10. Plan-view locations of transects and estimated spawnable area (shaded) at a selected discharge for Cedar River reach 10.