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# PRELIMINARY ANALYSIS OF THE EFFECTS OF INSTREAM FLOW LEVEL ON THE REPRODUCTIVE EFFICIENCY OF CEDAR RIVER SOCKEYE SALMON

by

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# PRELIMINARY ANALYSIS OF THE EFFECTS OF INSTREAM FLOW LEVEL ON THE REPRODUCTIVE EFFICIENCY OF CEDAR RIVER SOCKEYE SALMON

## 1.0 SUMMARY

The escapement of spawning sockeye salmon was monitored on 11 reaches of the Cedar River. These observations included spawner distribution, redd density, and gravel utilization in relation to minimum and maximum discharge regimes. Plane table surveys and depth and velocity transects were made at each reach at a series of discharge levels to obtain hydraulic data needed to define spawnable area in relationship to peak spawning discharge.

Two river reaches were selected to determine the gravel egg densities occurring after successive spawning waves. Egg densities and distribution were determined periodically by hydraulic gravel sampling. Egg densities during the sampling season appeared to approach a maximum of 165 eggs-alevins/ft$^2$ within the spawned area. This was far below the calculated potential density.

Effects of the flood which occurred on December 3 and 4, 1975, (peak discharge 8800 cfs) were determined. Estimated egg loss on reaches 1 and 5, based on post-flood hydraulic sampling, was 94.0 and 34.6%, respectively. The greatest egg loss occurred in the reach with a natural sloping gravel bar, while fewer eggs were lost from the reach with a flattened bar. Loss due to flooding on both reaches was nearly total in mid-channel and declined toward the river bank.

The total number of fry estimated from fyke net samples taken near the river mouth over a 4.5-month period was $2.24 \times 10^6$. This represents a 0.96% egg to fry survival. Calculation of the pre-smolt to spawner ratio versus the flood discharge suggested that above 6,000 cfs no significant additional flood mortality may occur.

Time to emergence was estimated to help explain survival rates, development, and growth of early, middle and late portions of the run. Water quantity and quality (temperature and turbidity) parameters are reported.

New methods developed included: a boat-mounted hydraulic egg sampler for use at high river discharges, and a fyke net fry sampling apparatus that can be efficiently operated by one person.

## 2.0 ACKNOWLEDGEMENTS

This investigation is being conducted with a matching grant from the City of Seattle Water Department in cooperation with the Municipality of Metropolitan Seattle (METRO) and from the State of Washington Water Research Center, with funds from the Office of Water Research and Technology (U.S.D.I.). Cooperation received from the Washington State Department of Fisheries (W.S.D.F.) and the U.S. Geological Survey (U.S.G.S.) is greatly appreciated.

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# 3.0 INTRODUCTION

The Cedar River watershed is managed by the City of Seattle Water Department to serve as a source of municipal and industrial water for the Seattle Metropolitan area. The river below Landsburg serves as the major spawning area for sockeye salmon as well as less abundant coho and chinook salmon and steelhead and cutthroat trout.

Regulation of the river discharge has a direct effect on the anadromous salmonids. Two previous study efforts have dealt with the effects of minimum discharge on the spawnable area for sockeye (Collings, *et al.*, 1970; and Stober and Graybill, 1974) and Miller (1976) investigated the relationships between discharge, fish production, and water supply, in the Cedar River. The present study is directed at the natural production of sockeye fry. Specific objectives include:

1. monitoring of sockeye spawner distribution, abundance, redd density, and timing;
2. determination of egg densities and survival following successive spawning waves at selected areas;
3. observation of the effect of minimum and maximum discharge on pre-emergent fry survival and condition;
4. determination of embryonic development rates and emergence timing of early, middle, and late portions of the run; and
5. determination of natural sockeye fry production resulting from different levels of escapement and discharge regimes.

We anticipate that these data will be useful to the recently formed Cedar River AdHoc Water Resource Management Committee, which includes, in addition to the local sponsors of this contract, the Washington State Departments of Ecology and Game; National Marine Fisheries Service; U.S. Fish and Wildlife Service; U.S. Army Corps of Engineers; and the City of Seattle Department of Lighting.

# 4.0 DESCRIPTION OF STUDY AREA

The Cedar River drainage encompasses a 188-square-mile area. The river heads on the west slope of the Cascade Mountains, flows across the lowlands of the Puget Sound area and empties into the south end of Lake Washington (Fig. 1). Average annual rainfall ranges from 100 inches near the head (primarily as snow), to 32 inches near the mouth (generally as rain). Hydrographic analysis of river discharge indicated high flows during winter and low flows during late summer, a pattern typical of lowland streams. Runoff may occasionally increase during spring snow-melt.

The discharge of the Cedar River presently is regulated both by operation of the Cedar Falls hydroelectric station (30 MWe at 750 cfs) below Chester Morse Lake (Seattle City Light) and by continuous diversion of about 200 cfs at Landsburg by the Seattle Water Department.

Eleven river reaches were selected as sites for intensive hydraulic and biological investigations. Reaches 1 to 11 were 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, respectively (Fig. 1). These stations correspond with those of Stober and Graybill (1974), with the exception of Station 8, which was relocated approximately 200 yards downstream. Stations at RM 13.7 and 5.3 corresponded to Stations A and C, respectively, of Collings, *et al.* (1970). Each reach was originally selected for spawner activity and streambed stability, and was used in this study to maintain continuity with previous work.

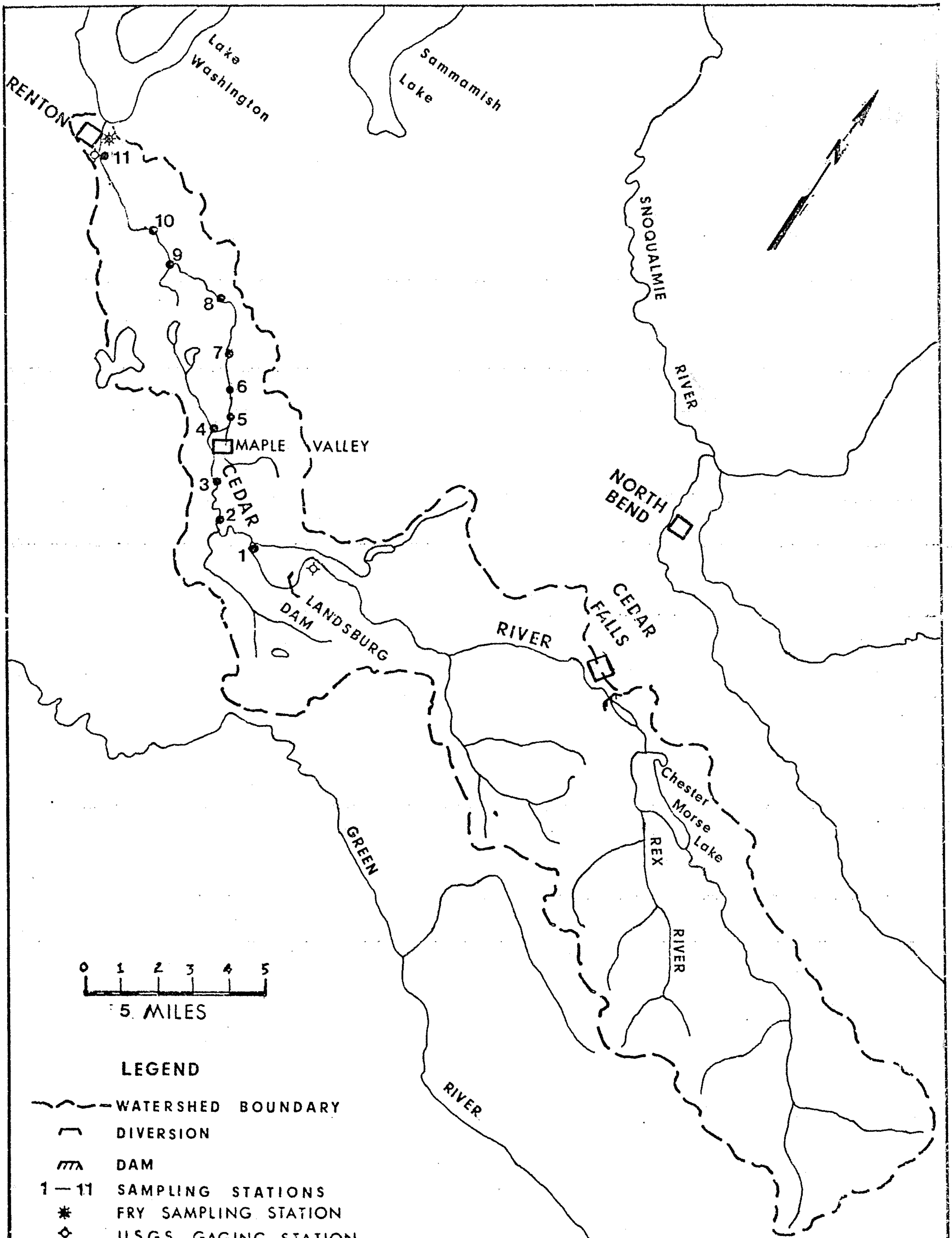



Figure 1. Map of Cedar River watershed, showing location of study reaches stream gages, and fry sampling station.

The effects of multiple waves of spawners on egg density and survival over various discharge regimes were investigated in detail at Stations 1 and 5.

Fry sampling was conducted near the mouth of the Cedar River (Fig. 1) at RM 0.6 (1.0 km). The channel at this site is straight, and the bottom substrate is coarse gravel. A cross-sectional contour (Fig. 2) indicates a bar along the right side of the channel and maximum depth along the left bank. The river width was 134 ft (40.9 m). The average depth varied from 2.0 to 2.8 ft (0.6 to 0.8 m) during the sampling period. Mid-channel current velocities ranged from 1.6 to 2.9 fps (0.5 to 0.9 m/sec). The site was selected because it lies below all major spawning areas in the river.

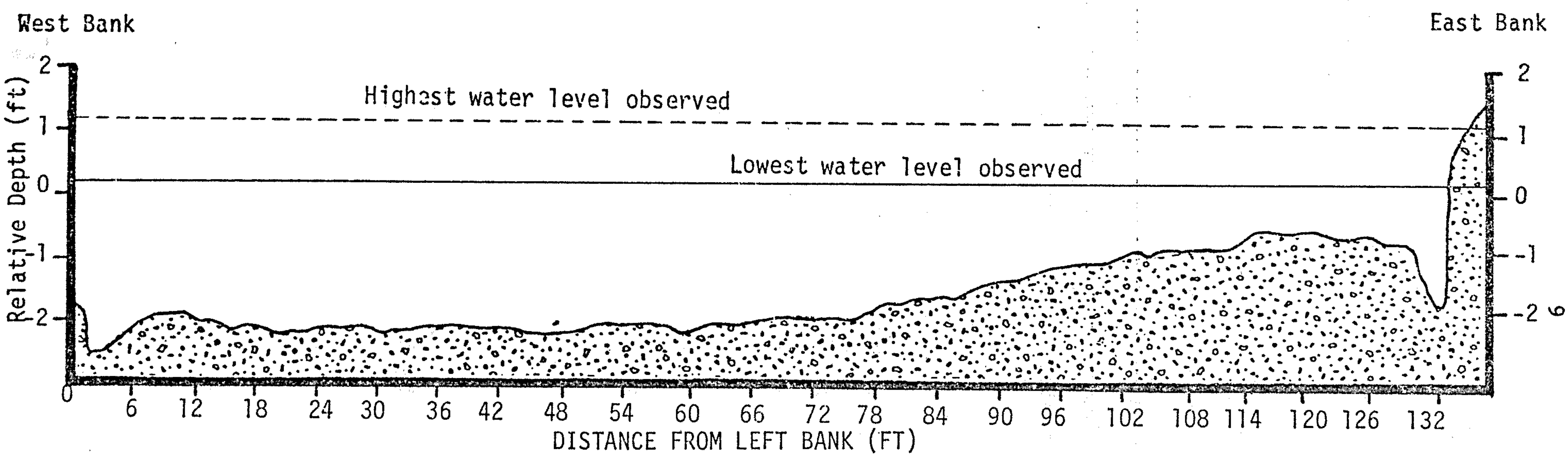



Figure 2. Cross-section of the Cedar River at the fry sampling site.

# 5.0 MATERIALS AND METHODS

## 5.1 Spawner Counts and Hydraulic Measurements

Systematic measurements of depth and velocity along four transects at each sample reach were recorded at several discharges as described by Collings, *et al.* (1972), and Stober and Graybill (1974). A Marsh-McBirney electronic current meter was used. Measurements were used to map the area in each reach suitable for spawning on the basis of a modal analysis of the 80% ranges of preferred depth (0.5 to 1.8 ft) and velocity (0.93 to 2.59 fps) reported by Stober and Graybill (1974). A contouring computer program FRB 726 (SYMAP) was used to plot the preferred spawning area.

The distribution and abundance of spawning sockeye in the Cedar River was monitored in 1975 for comparison with previous years. Active spawners within each of the 11 reaches were counted weekly. On these days, plane table methods were used to map active redds and wetted perimeter. Weekly float trips were made to determine spawner utilization and distribution in the river below Landsburg. Count and distribution data were recorded on photocopies of aerial photographs of the Cedar River taken in 1973. Landmarks (i.e., trees, logs, and boulders) served as reference points in outlining actual spawning areas. The weekly spawned area was determined by the "square" grid (each square = 1/64 $in^2$) method. Extreme discharges and high turbidity forced termination of the float trips in December.

5.2 Egg and Pre-Emergent Fry Sampling

Stations 1 and 5 were selected to monitor egg distribution, abundance, and survival, because of heavy spawner utilization and characteristically different streambed profiles. Station 1 presented a gradually sloping gravel bar. Spawnable area was found to accumulate over the bar from summer low flows to higher late fall discharges which resulted in the maximum wetted area (Fig. 3) (Stober and Graybill, 1974). In contrast, Station 5 was contained by abrupt banks on both sides, was more uniform in depth, and had a reduced gradient (Fig. 4). The cumulative spawnable area did not increase significantly above 200 cfs. Total wetted area was found to remain nearly constant at discharges ranging from less than 100 to about 600 cfs (Stober and Graybill, 1974). A 7,700-$ft^2$ area was added to the downstream portion of Station 5 reported by Stober and Graybill (1974). This area had a steeper gradient than the upstream portion of Station 5, and water velocities were accelerated in twin channels around an island just downstream of Transect -1; however, the addition of this area did not alter the relationships indicated.

Egg sampling was conducted along 4 or 5 randomly selected transect lines perpendicular to the flow of water. Each transect was sampled only once during the study. When low flow conditions permitted wading, samples were collected at 2-ft intervals using a hydraulic sampler as described by McNeil (1964). Each sample took from one to three minutes and penetrated the substrate about 12 inches. Occasionally, large cobble inhibited penetration, however, digging continued until all of the smaller substrate had been expanded. This amount of effort

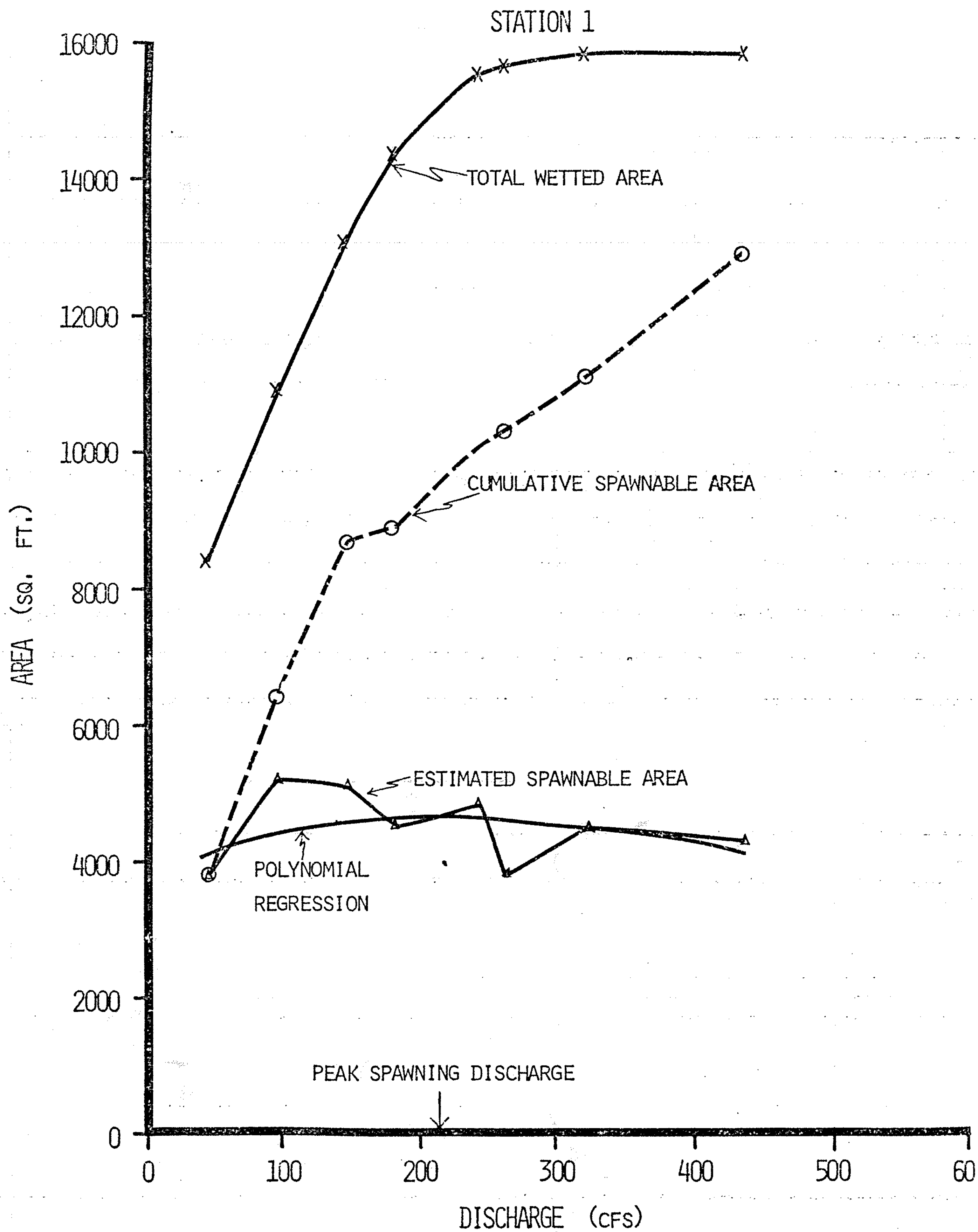



Figure 3. Relationship between estimated spawnable area (80% ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at Station 1 (Stober and Graybill, 1974).

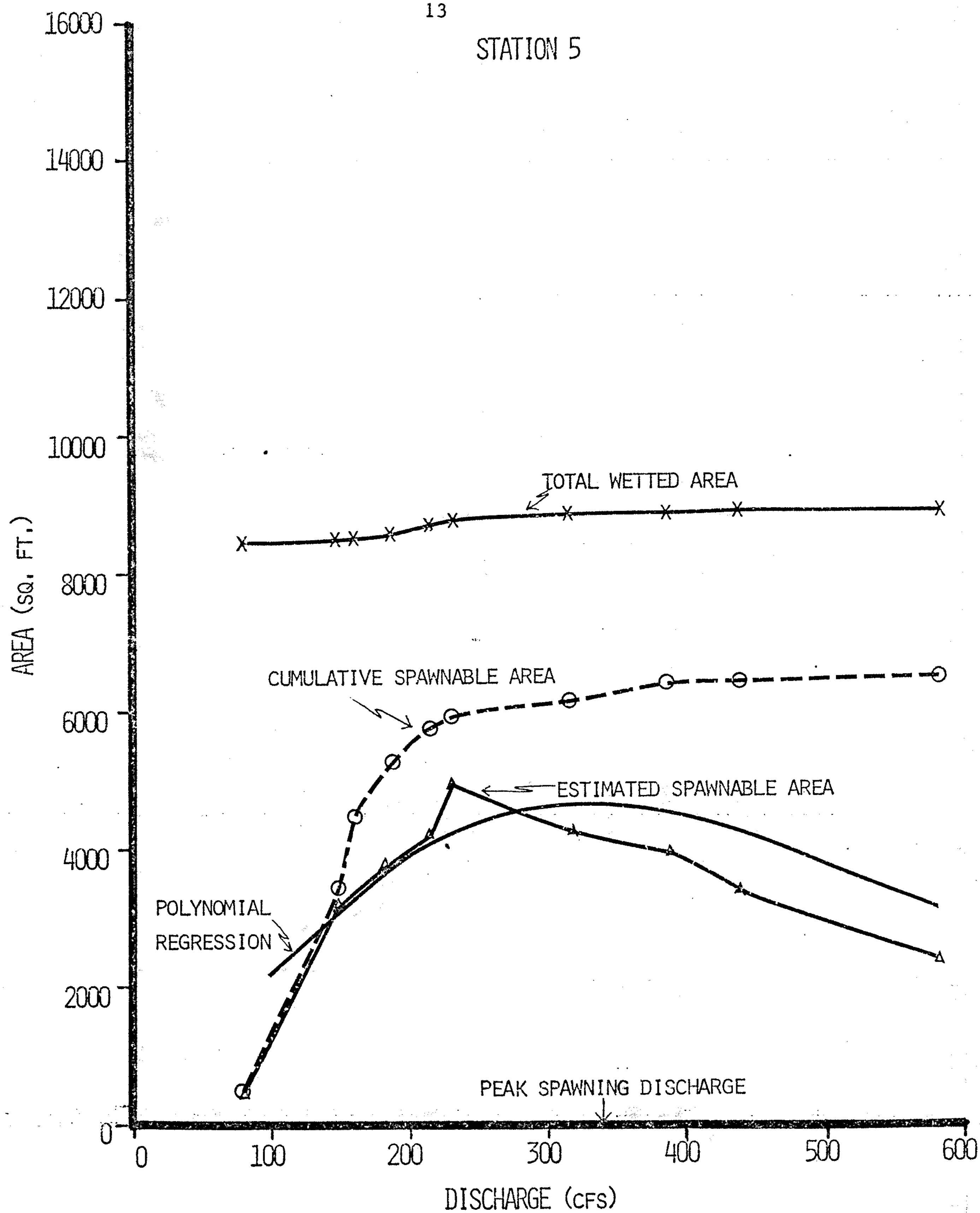



Figure 4. Relationship between estimated spawnable area (80% ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at Station 5 (Stober and Graybill, 1974)

recovered most of the eggs present under the sampled area. Eggs were preserved in Stockard's solution for later study.

When high winter discharges prevented wading, sampling was conducted from a boat (Fig. 5). The collecting basket was modified to reduce the resistance due to the higher flows. The sample area was maintained at 0.5 $ft^2$. Samples were collected at 4-ft intervals along each transect. The reduction in the number of samples was necessary due to an increase in the amount of time required to locate the apparatus over a transect site and to set and retrieve the basket. A rope for positioning the boat was strung over the bow and anchored to both banks. The boat was maneuvered along a transect line by rolling across the rope on pulleys and by tightening or slackening the rope. Once positioned, an iron bar, held on the bow frame, was dropped and planted into the streambed. Four steel rods were also lowered to the bottom along the sides of the boat to add stability. The sampling basket was then lowered to the streambed, guided along the iron bar. The sampling probe was inserted through an apron covering the top of the basket. After each sample, the basket was retrieved and the bucket removed and emptied.

In the laboratory, eggs were classified as either live or dead and enumerated. Eggs were examined under a dissecting scope to determine the stage of embryonic development. The drawings of Ievleva (1951) and Olsen (1968) were used to categorize the developmental stages of eggs and pre-emergent fry, respectively.

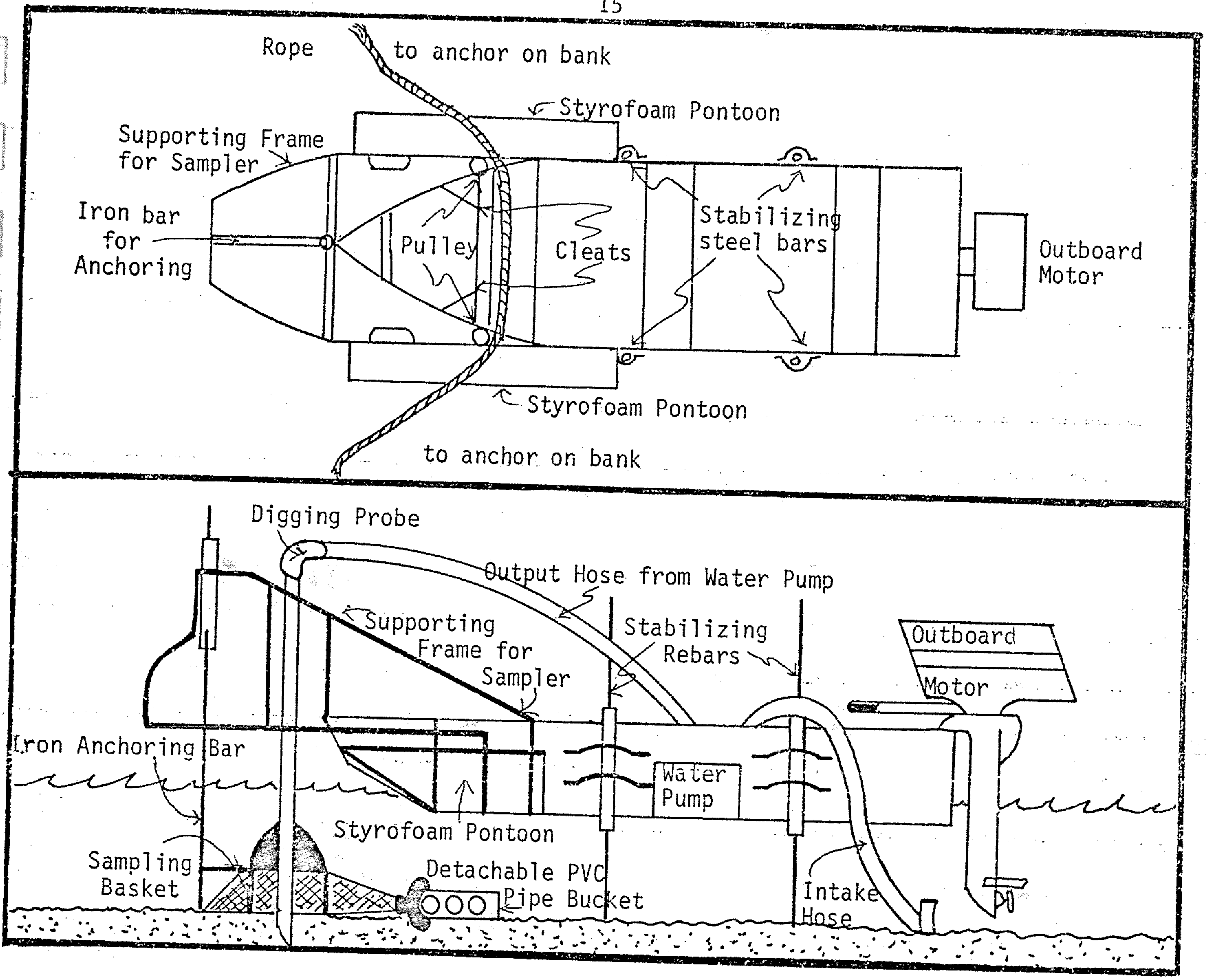



Figure 5 Pre-emergent egg and fry sampling equipment, for use in deep water.

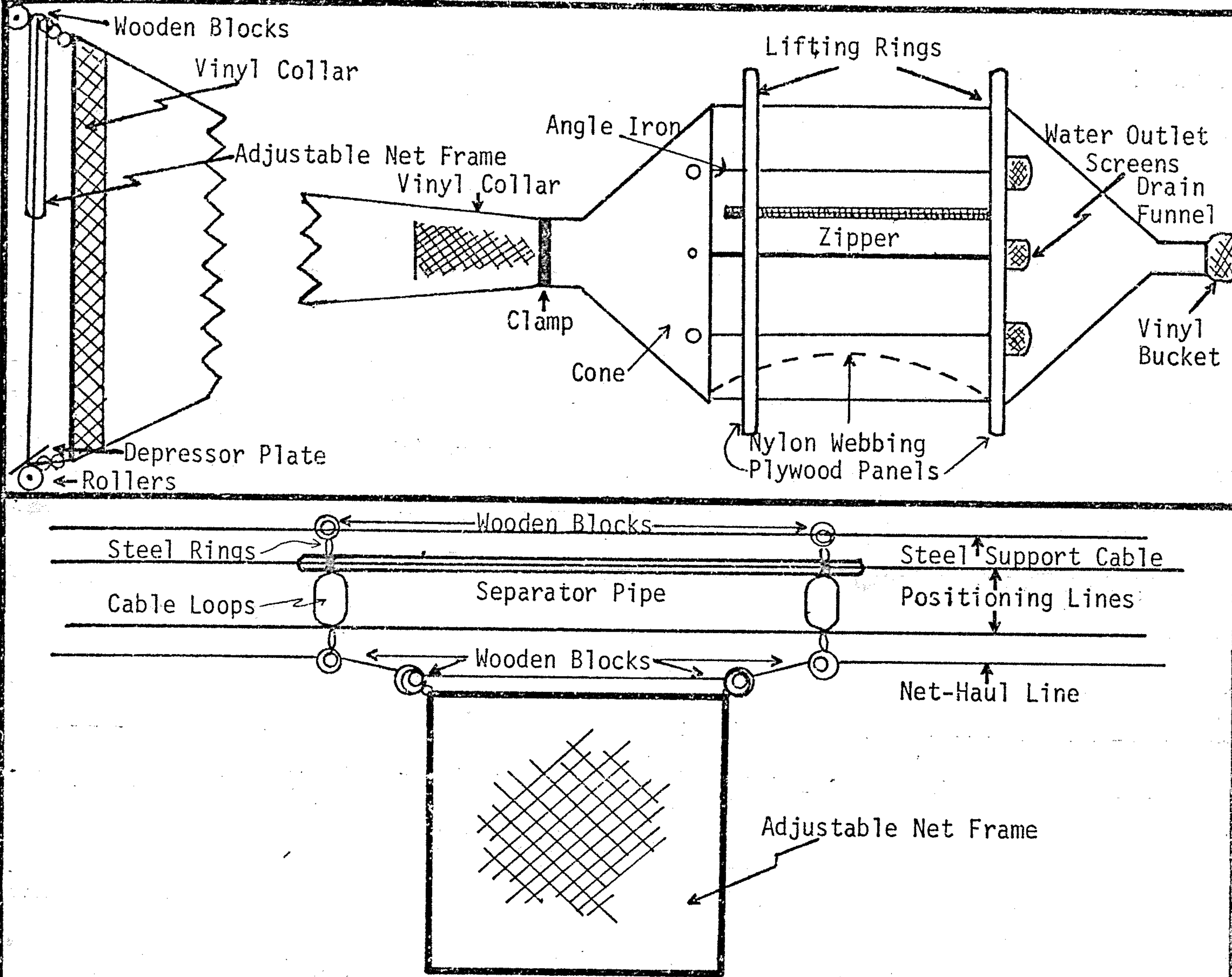
## 5.3 Emigrant Fry Sampling

A fyke net apparatus similar to that of Tyler and Wright (1974) was constructed and used to sample the emigrant sockeye salmon fry. This apparatus, powered by two electric winches, was easily operated by one person.

The net measured 5 ft x 5 ft (1.5 m x 1.5 m) at the mouth, tapering uniformly within 21.4 ft (7.0 m) to an 8-inch (0.5-m) diameter opening, where a 1.6-ft (0.5-m) vinyl collar provided a reinforced surface for clamping to a live tank (Fig. 6). The net was made of 1/8-inch knotless nylon mesh. The seams were sewn with nylon tape and reinforced with 5/8-inch polypropylene lines, which attached the net to the frame. An 8-inch (0.2-m) wide vinyl collar encircled the net mouth to provide a strong, abrasion-resistant surface.

The net frame was constructed of 1/2-inch steel rod and galvanized pipe (Fig. 6). A variable-pitch depressor plate, designed to hold the net on the river bottom, was bolted to the frame. Two rubber rollers held the net slightly off the bottom while it was fishing.

Fish were funnelled into a submersible live tank (Fig. 6) constructed of two end cones made from 8-gauge black iron sheet metal, connected with angle iron. The cylindrical tank measured 73 inches (1.9 m) in length and 28 inches (0.7 m) in diameter. Two steel rings welded to the tank frame served as points of attachment for lifting and for two floats. Seven 1-ft x 2-1/2-ft (0.3-m x 0.8-m) plywood panels were attached to the lifting rings to protect the net from




DIMENSIONS:

**Live Tank**

| | |
|---|---|
| Length | 73 in |
| Diameter (mouth) | 8 in |
| Diameter (body) | 28 in |
| Diameter (outlet) | 4 in |

**Net**

| | |
|---|---|
| Length | 21 ft |
| Width (mouth) | 5 ft |
| Depth (mouth) | 5 ft |
| Diameter (cod end) | 8 in |

**Net Frame**

| | |
|---|---|
| Height | 5 to 6 ft |
| Width | 5 ft |

Figure 6 Schematic diagram of the sockeye fry sampling nets, live tank, and positioning gear.

bottom abrasion. A net, constructed of 1/8-inch knotless nylon webbing, was suspended inside the live tank frame. An 8-inch (0.2-m) long vinyl sleeve was attached to the 4-inch (0.1-m) drain funnel and closed by tying the end. The catch was released through the sleeve into a plastic bucket. A full-length zipper was sewn into one side of the net to facilitate removal of debris.

The fyke net was suspended from a 9/16-inch steel cable placed across the river and supported by two A-frames. The A-frames were constructed of 4 x 4-inch wood beams and anchored to two railroad ties buried three feet (Figs. 7 and 8). Tension on the cable was adjusted by a 2-ft turnbuckle. The A-frames were also guyed upstream with 3/16-inch cables.

Movement of the net across the river was facilitated by a 1/2-inch polypropylene rope (positioning line) running through 5-inch blocks hung from the A-frames to an electric winch with a capstan drum. An 11-ft (3.3-m) x 1/2-inch galvanized separator pipe with rings at each end was attached to the positioning line. Two 6-inch blocks which rolled on the support cable were secured to the pipe rings by 1-ft cable loops. Hung below these rings were two 5-inch wooden blocks to which the net frame was attached by two 30-ft (9.2-m) ropes. The 1/2-inch net haul line (head ropes) ran through these blocks and two similarly-sized blocks on the top of the net frame, and then through a steel snatch block secured to the A-frame. The net-haul line was attached to a 150-ft (45.8-m) cable. The cable was attached to an 8,000-pound (3,632-kg) capacity electric winch used to lift the net out of the water. The foot ropes, each 30 ft

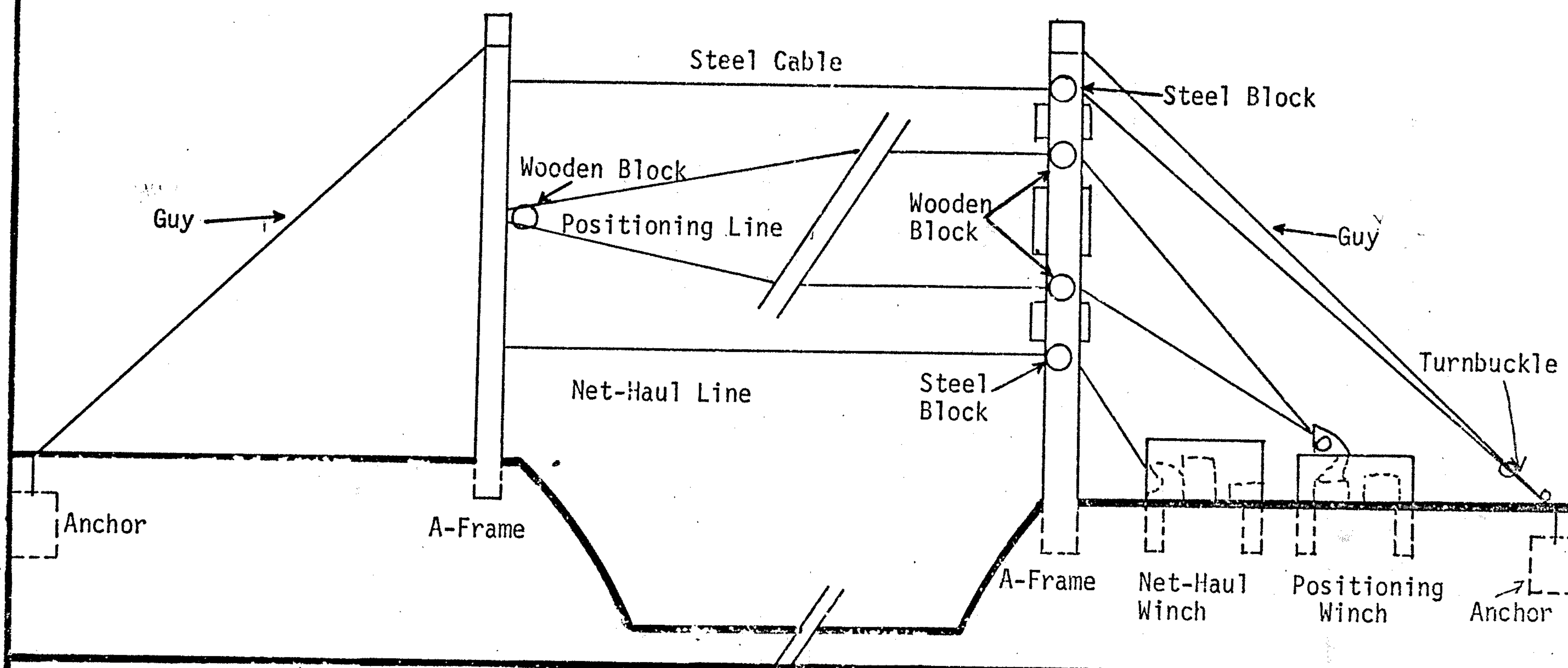



Figure 7 Schematic diagram of the fyke net apparatus (side view).

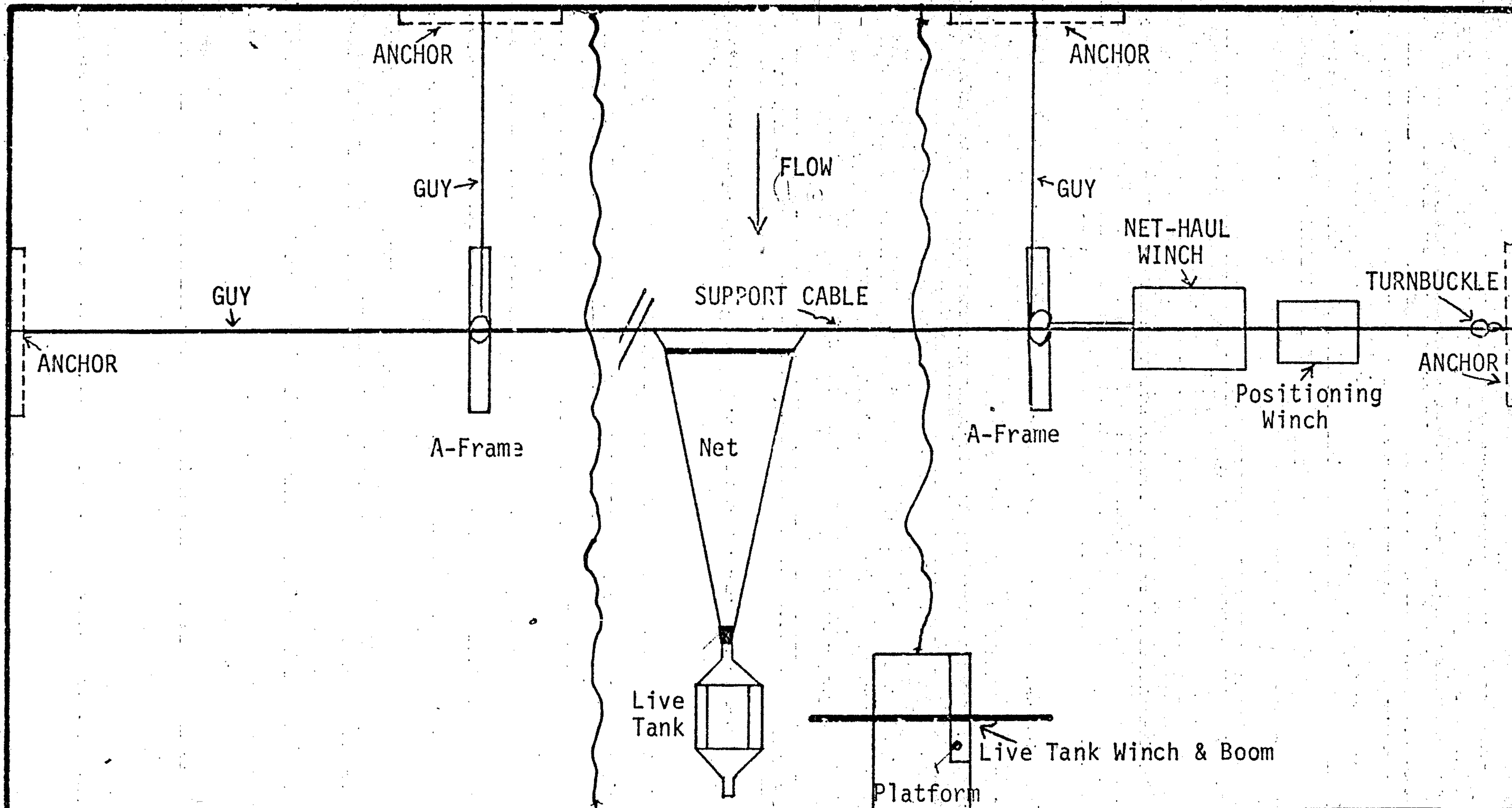



Figure 8. Plan view of the sockeye fry sampling apparatus.

(9.2 m) long, were secured to the lower corners of the frame and to the underside of the 5-inch wooden blocks hung from the separator pipe.

Setting and retrieval of the net was accompanied by wrapping the positioning line twice around the capstan drum and moving the net above the water to the desired location indicated by tape marks along the positioning line. The net haul line was then disengaged and the river current pulled the net downstream into position. This procedure was reversed for retrieval.

The live tank was lifted from the river to remove the catch. The lifting apparatus consisted of a 16-ft x 4-inch boom, supported by a small A-frame. A small hand winch was used for lifting the live tank from the water. The A-frame was mounted on a 4 x 8-ft platform located on the river bank. The catch was identified, counted, and returned to the river unharmed, except that weekly subsamples were taken for length and weight determination.

Diurnal sampling conducted on February 5 and 10, and March 21, showed insignificant emigration during daylight hours, and agreed with previous studies by Hoar (1954), McDonald (1960), and Foerster (1968). Therefore, sampling was conducted at night, beginning prior to sunset and ending after sunrise. Five sampling positions across the river were chosen: one near each bank, and three distributed in the main channel. The site to be fished each period was randomly selected by the roll of a die. The net was fished for one hour each time it was set. This minimized debris accumulation and the holding of fish for excessive lengths of time, and it also allowed sampling of all sites each night. One-half hour was allowed between each set to process the catch, and to clean and reset the net.

Samples were taken every three to five days from February 5 through March 17. On March 19, effort was increased to every other night. This scheme was carried out until May 29, with three exceptions. High river discharge and large accumulations of filamentous algae in the net prevented sampling from May 10 to 15. Due to diminishing catches, the effort was reduced on June 3 from three to five days per week. Sampling terminated on June 28.

Estimates of the daily emigration were derived by using the formula:

$$N_i = (n_j)(\beta_i)(\frac{1}{\alpha_i}) \qquad (1)$$

where,

$N_i$ = estimated number of fish emigrating on day i

$n_j$ = number of fish caught during set j

$\alpha_j$ = proportion of river width sampled on set j

$\beta_i = \dfrac{\text{hours from beginning of set j to beginning of set j + 1}}{\text{hours fished in set j}}$

Estimates for non-sampled days were derived by linear interpolation between sampled days.

A weekly subsample of about 50 fry was preserved in 10% Formalin and returned to the laboratory. Length and weight were determined after at least 10 days to allow length and weight to stabilize (Rogers, 1964).

# 6.0 RESULTS AND DISCUSSION

## 6.1 Water Quantity and Quality

The 1975-76 provisional hydrograph obtained from the U.S.G.S. gaging station at Renton is shown in Fig. 9. September and October flows were near normal with larger discharges occurring in November. A major flood occurred during early December, with a peak discharge of 8,800 cfs. Severe scouring and deposition occurred in the river channel and altered it substantially. Flood flows recurred in January 1976, causing further shifting of the bed load.

The mean daily water temperature (based on hourly readings) for 1974, 1975, and 1976 measured at the Renton gage are given in Fig. 10. The thermal ranges during the 1975 spawning season varied between 5 and 14 C. This was similar to previous years.

The maximum daily turbidity readings for 1975 and 1976 (Fig. 11) were closely related to the discharge pattern. Higher turbidities were associated with high discharges in the late fall and winter.

## 6.2 Escapement

The escapement estimates are those of the Washington State Department of Fisheries (W.S.D.F.) (Fig. 12) as revised by Ames (personal communication) in 1976. The escapements to the Cedar River in 1974 and 1975 were estimated to be 114,500 and 114,100, respectively.

Counts of migrating adult sockeye salmon (Fig. 13) were made by the W.S.D.F. from a tower located at RM 4.9. Immediately prior to the

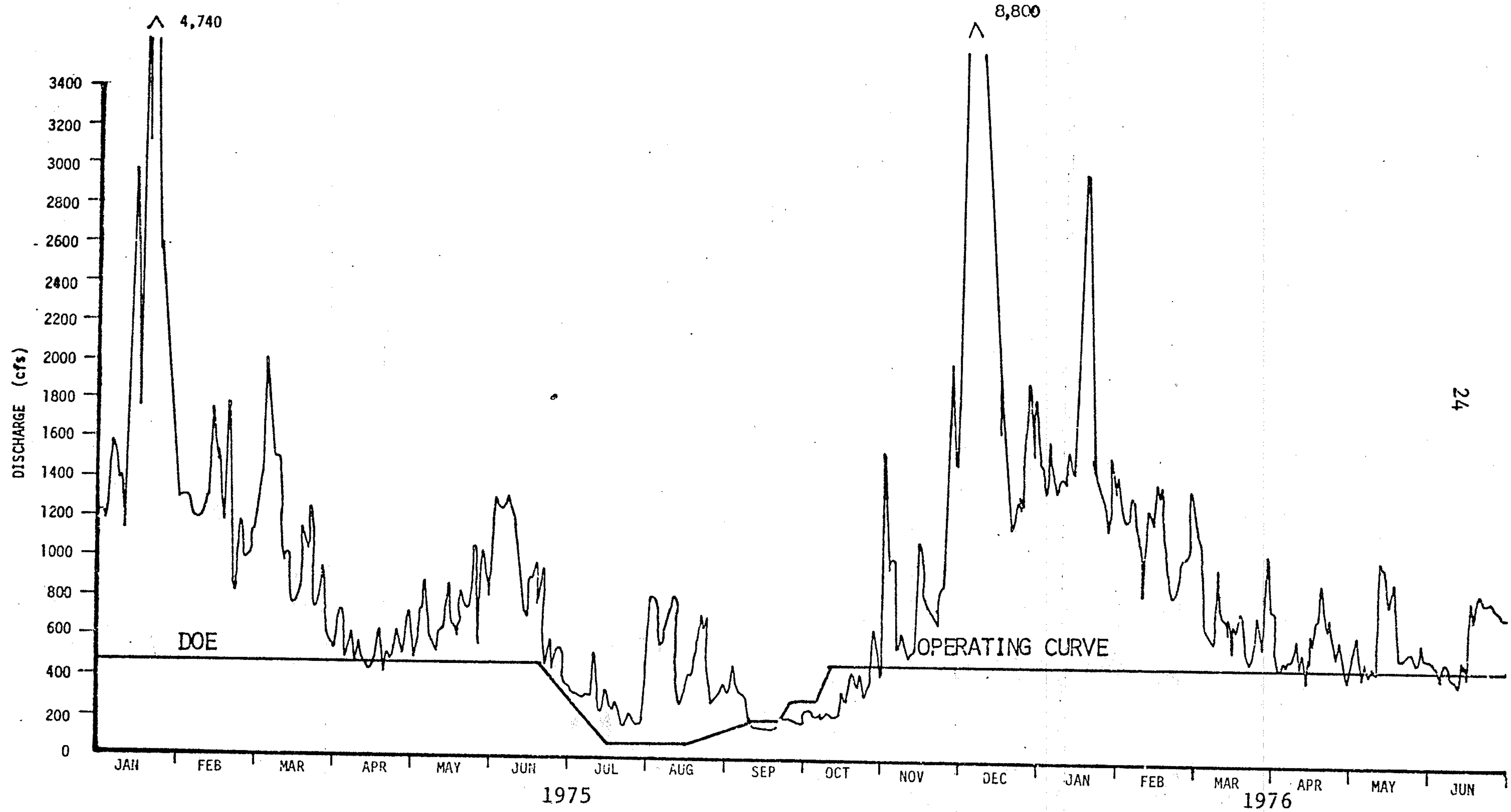



Figure 9. Daily discharge at U.S.G.S. Renton Gage in 1975 and 1976. Source: U.S. Geological Survey (Provisional).

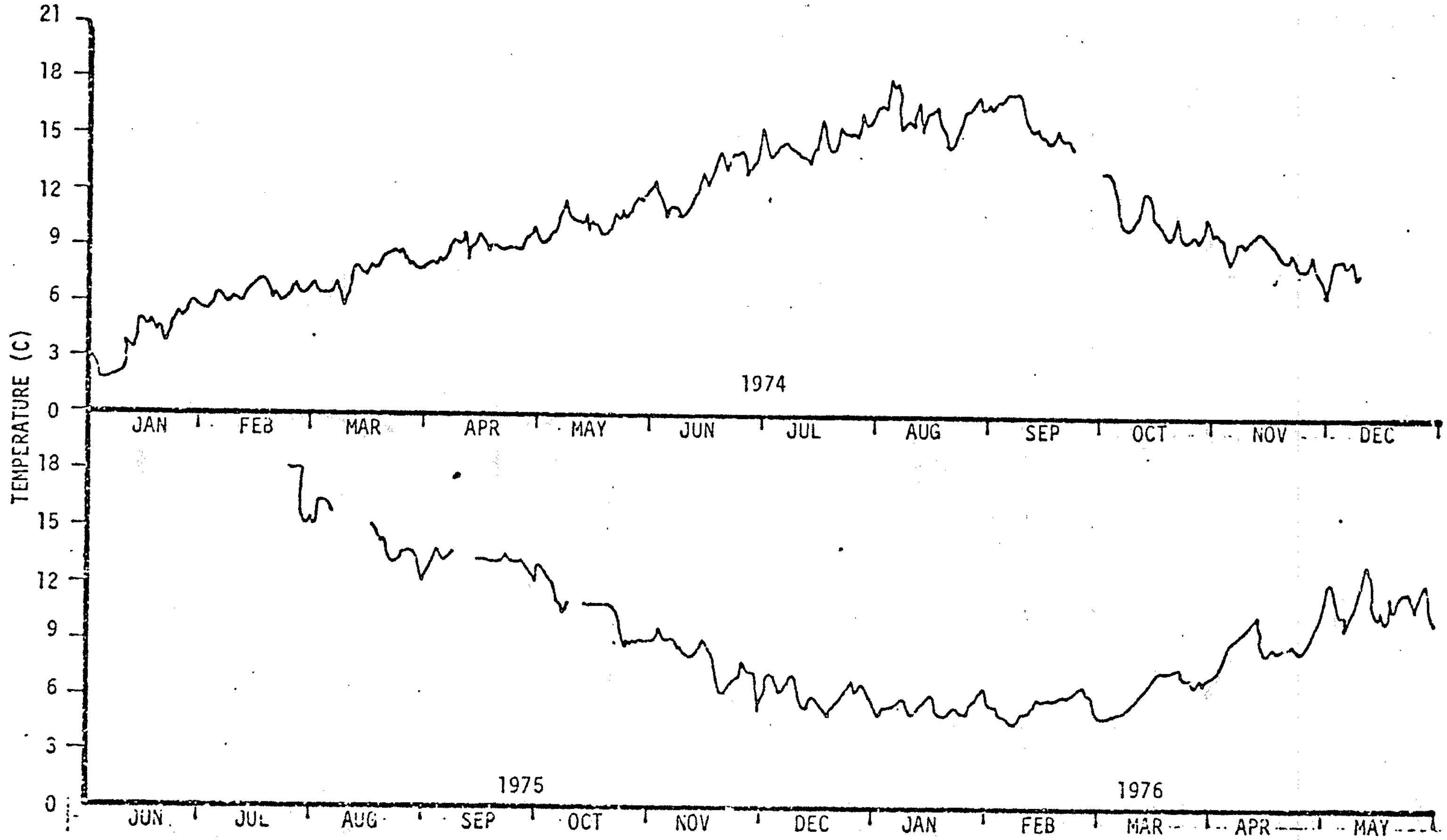



Fig re 10. Mean daily water temperature at Renton, 1974-76.

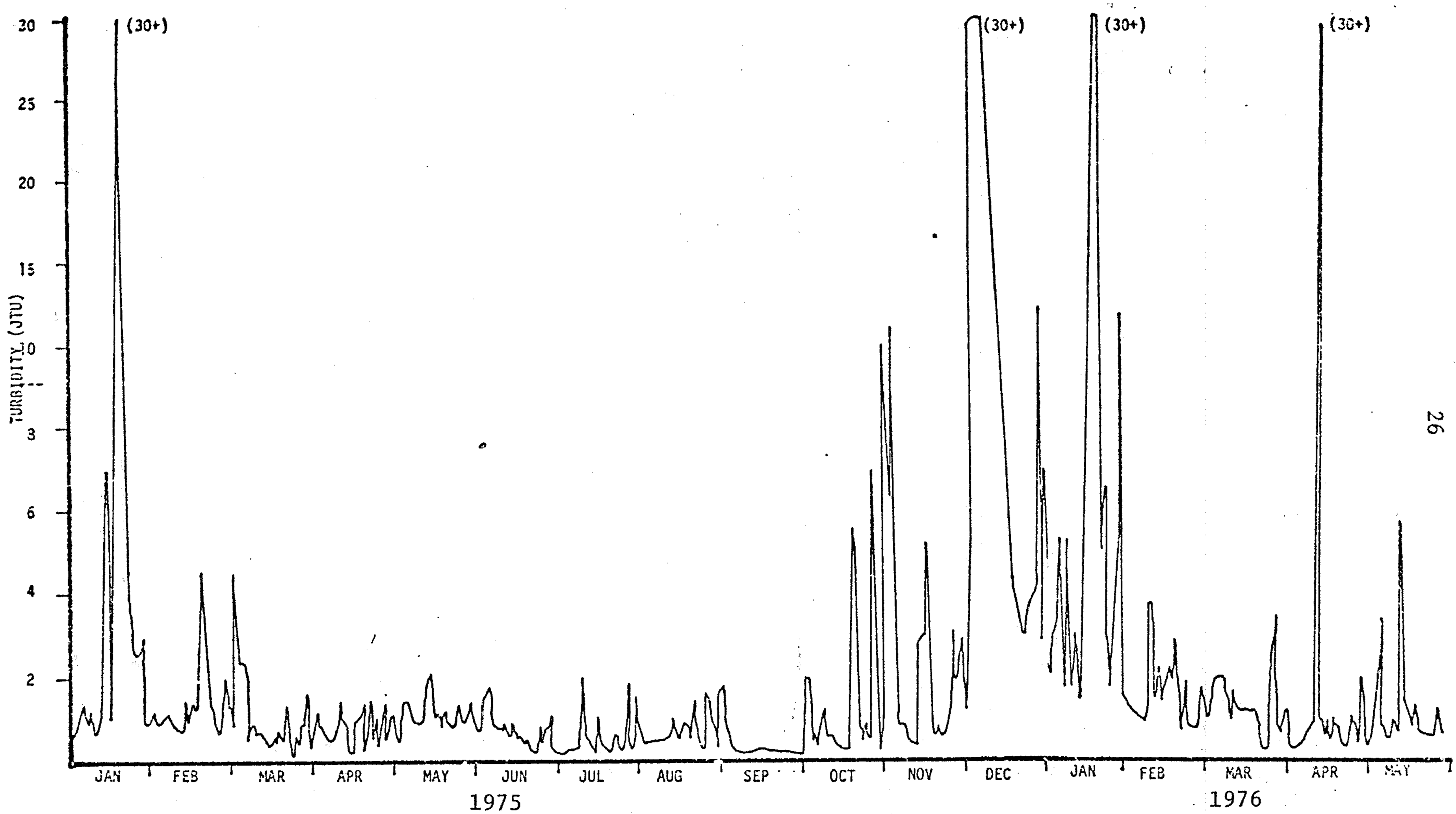



Figure 11. Maximum daily turbidity at Landsburg from January 1975 through May 1976.
Source: Seattle Water Department.

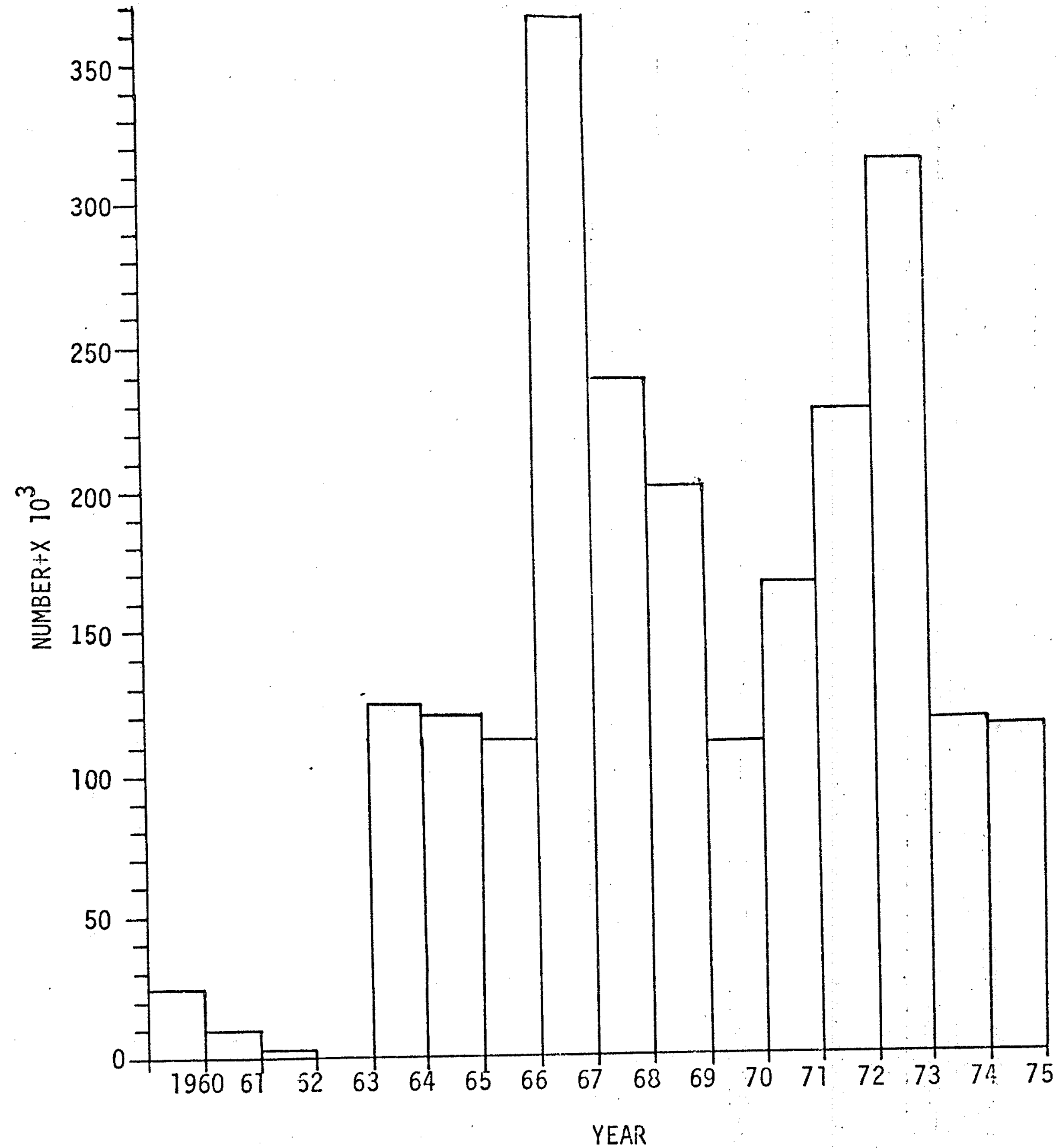



Figure 12. Revised Cedar River sockeye salmon escapements, 1960-1975, estimated by Ames (W.S.D.F., unpublished).

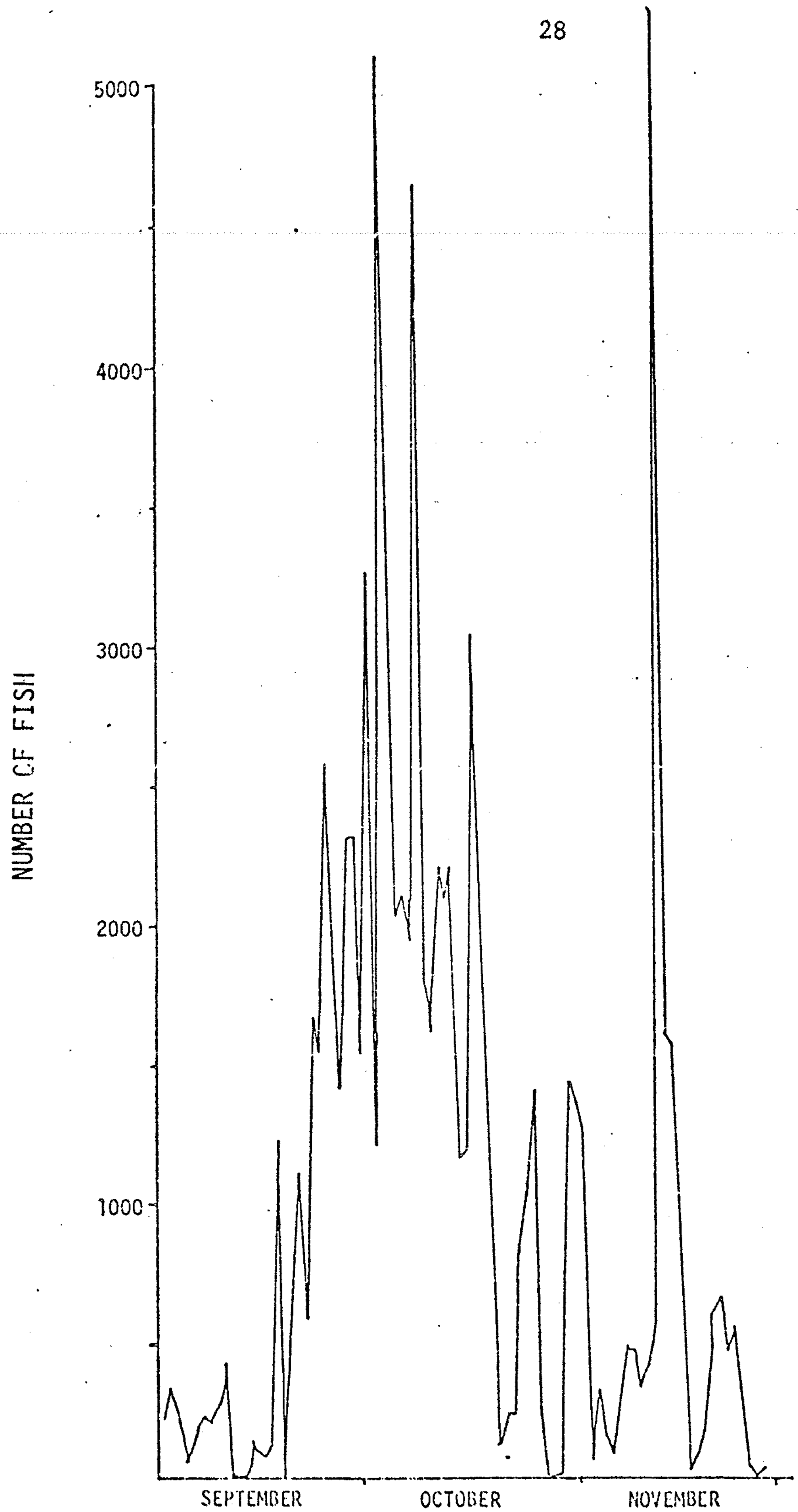



Figure 13. Sockeye salmon tower counts, Cedar River, 1975. Source: W.S.D.F.

tower monitoring period of September 3 to November 30, 1975, the W.S.D.F. conducted a float survey on the river and estimated 11,553 sockeye between Landsburg and the mouth of the river. These fish had entered the river during the higher flows which occurred in August. Counts were hampered by poor visibility after mid-November and were discontinued due to flood conditions on November 30.
The tower counts were bimodal, with peak escapement occurring in early October and mid-November. About 50% of the escapement entered the river by October 8, as compared to September 22, October 12, and October 17, for 1972, 1973, and 1974, respectively (Fig. 14).

6.3 River Utilization

The cumulative number of spawners observed on each reach is presented in Fig. 15. No spawners were observed at Stations 10 and 11. The values for Station 5 and Station 8 are not directly comparable to those of Stober and Graybill (1974) since the area of Station 5 was enlarged and Station 8 was moved downstream in 1975.

The 1975 spawner counts at the 11 reaches followed a pattern similar to that observed during earlier years by Stober and Graybill (1974). Spawning began at the upstream stations in early September. Spawners increased in number until mid-October, when spawner density was greatest. The late season utilization of the lower river noted in previous years (Stober and Graybill, 1974) was observed again (Fig. 16). The early portion of the run moved into the river earlier than usual. This was probably due to the increased flows in August

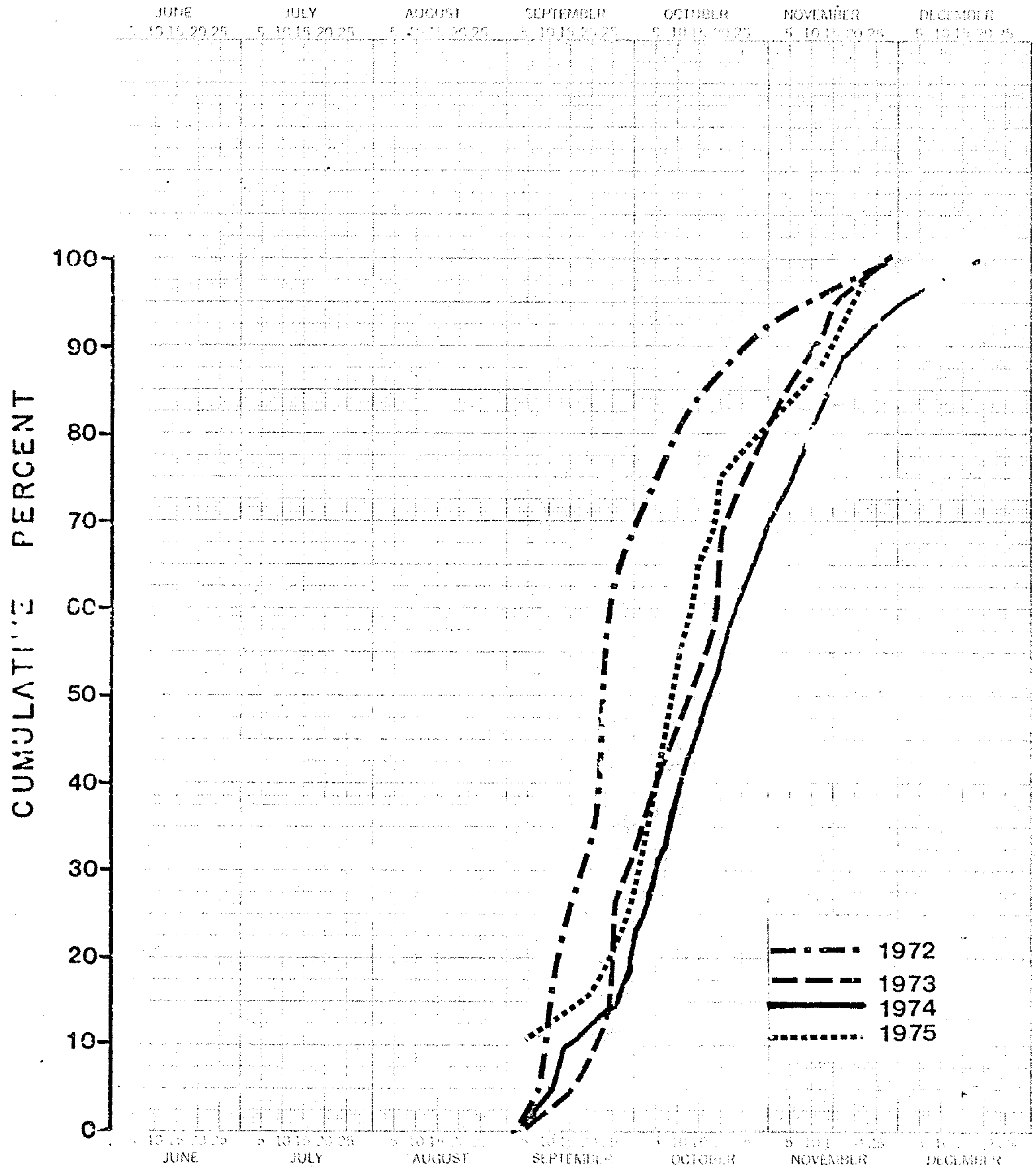



Figure 14. Cumulative percentage by date for the Cedar River sockeye salmon escapement, 1972-1975. (W.S.D.F. Data.)

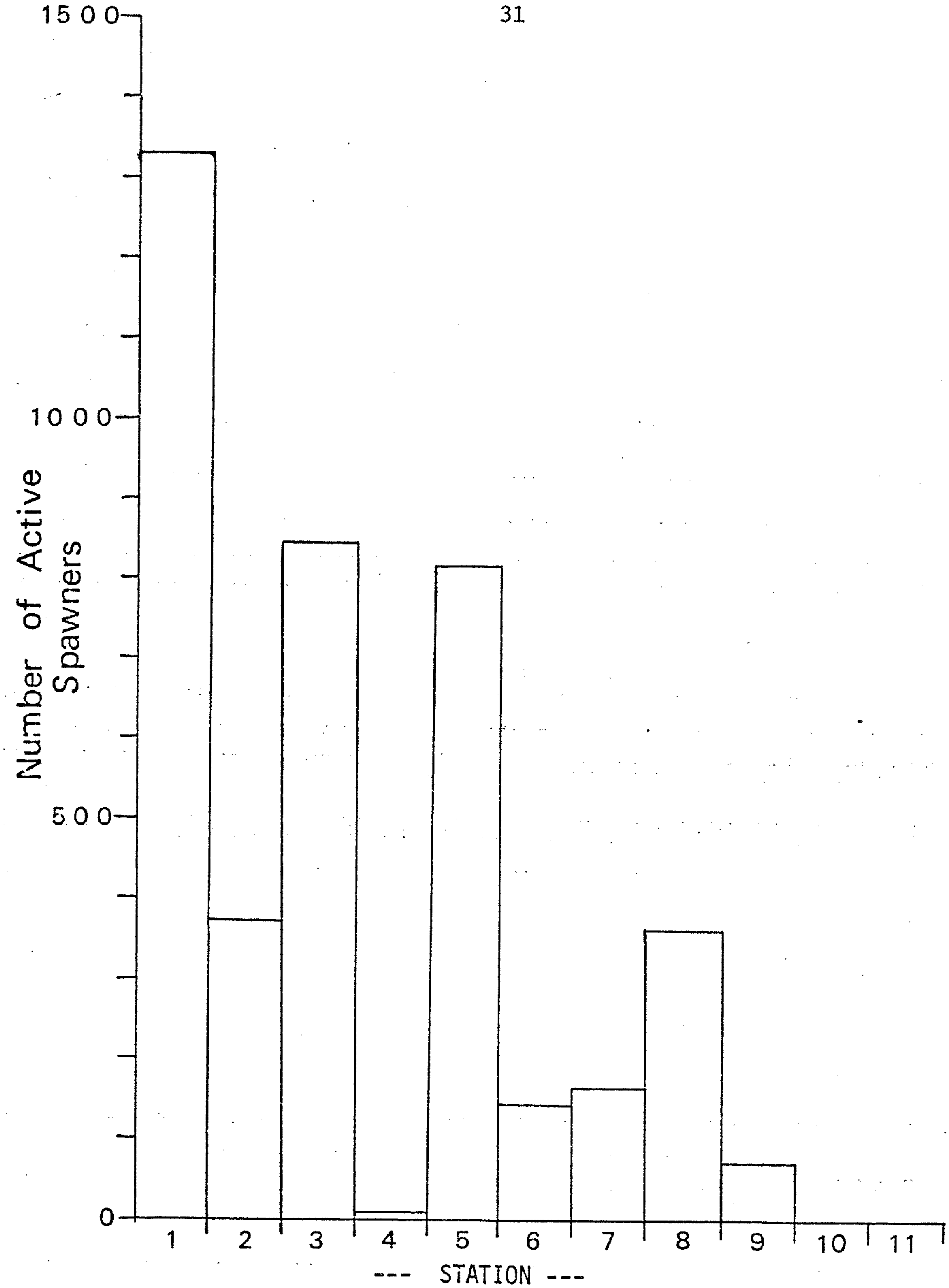



Figure 15. Cumulative number of spawning sockeye in the Cedar River by reach, 1975.

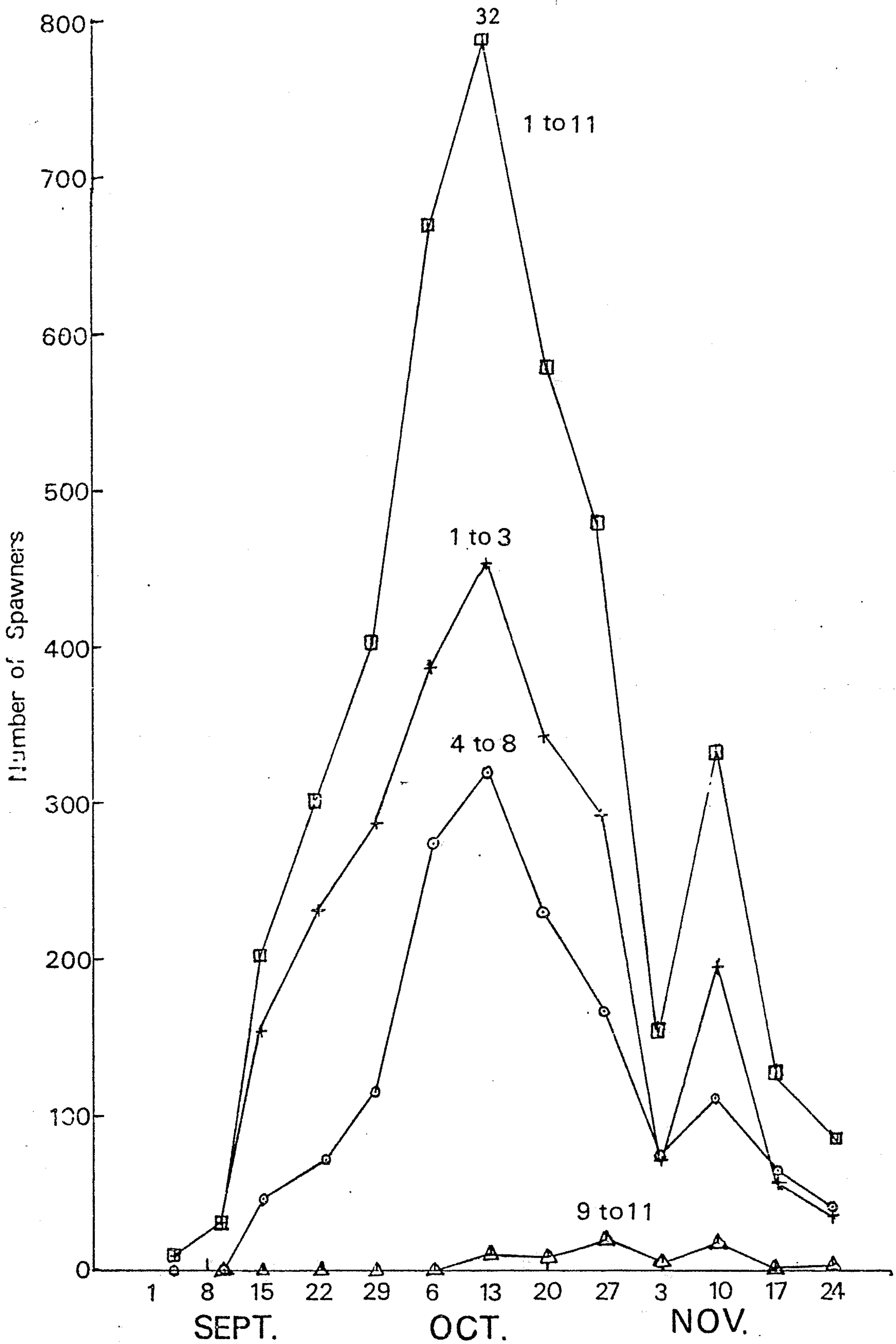



Figure 16. Cedar River spawner counts by week, 1975. Data were grouped by station to illustrate utilization in the lower (9-11), middle (4-8), and upper (1-3) thirds of the river, and for all stations (1-11) surveyed below Landsburg.

resulting from water released from Chester Morse Dam to accomodate construction and maintenance activities (Fig. 9). At Station 1, some redds made during the high flows in August were exposed in September and October when the low flow regime was resumed. Station 9 showed no spawner activity until October.

The decline in the weekly counts on November 3 may have been the result of the increase in discharge which reduced visibility. During this period, daily mean discharge, which had averaged around 430 cfs for the last half of October, increased to 1730 cfs on October 30 and continued at about 1000 cfs until November 4, at which time it decreased to 753 cfs. The flood during the first half of December ended observations of adult sockeye distribution and abundance in the river.

Spawner utilization of the river below the Landsburg diversion was surveyed each week by floating the river. Data from these float surveys are presented in Fig. 17. The upper and lower thirds of this 17.3-mile reach of the river showed the greatest area spawned, while the middle third was the least used. This trend differed from the findings of Stober and Graybill in 1973, when the escapement totaled about 200,000 more fish. The total spawned area at the peak of the season declined in 1975 to about 1 million $ft^2$ from about 1.55 million $ft^2$ spawned in 1973.

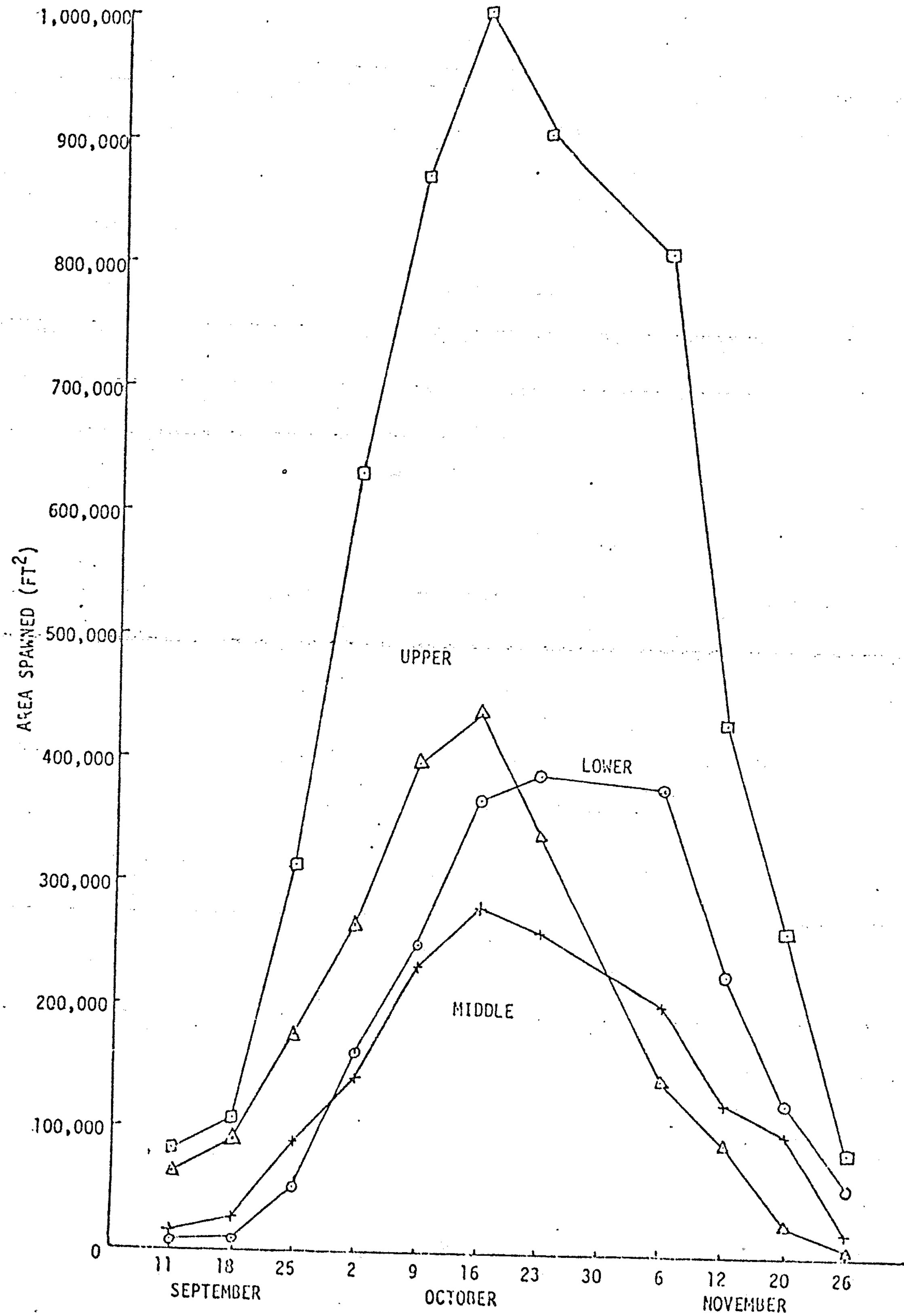



Figure 17. Total area of the Cedar River spawned by sockeye salmon each week in 1975 as determined by float trip surveys. Data expressed for 17.3 miles (total) and for approximately equal thirds of the river.

## 6.4 Egg Densities

Potential egg densities were calculated from the cumulative totals of the observed number of spawners utilizing study reaches 1 and 5, and from the cumulative area spawned in those reaches on successive weeks. These calculations assumed: 1) an average redd life of 7.0 days (Fraser, 1970); 2) a female to male sex ratio of 60:40 (Woodey, 1966); and 3) an average fecundity of 3400 eggs per female (Heiser, 1969). The distribution of redds on each reach is shown in Figs. 18 and 19. The area spawned each week was determined by measuring the area within the distribution of redds with a planimeter.

The calculated potential weekly egg densities for Station 5 are given in Table 1. The data indicate an increase each week after the first week, which was based only on four pairs of spawners. The river channel at Station 5 was relatively uniform in depth, and this resulted in a small amount of new (cumulative) spawnable area above a discharge of about 200 cfs (Stober and Graybill, 1974), even though the peak spawning discharge was calculated at 338 cfs. Since the discharge was at or above 200 cfs throughout most of the spawning season, the weekly spawning activity resulted in a relatively constant increase in potential egg density.

The sampling data (Table 2 and Fig. 20) showed no significant differences in the density of eggs-alevins (live or dead) between October 15 and November 5. Calculated densities were 164.2 and 160.6 eggs-alevins/ft$^2$, respectively. The similarity between sample dates notably differed from the estimated potential increase in density from 300 to 400 eggs/ft$^2$ for the same time period. The observed values

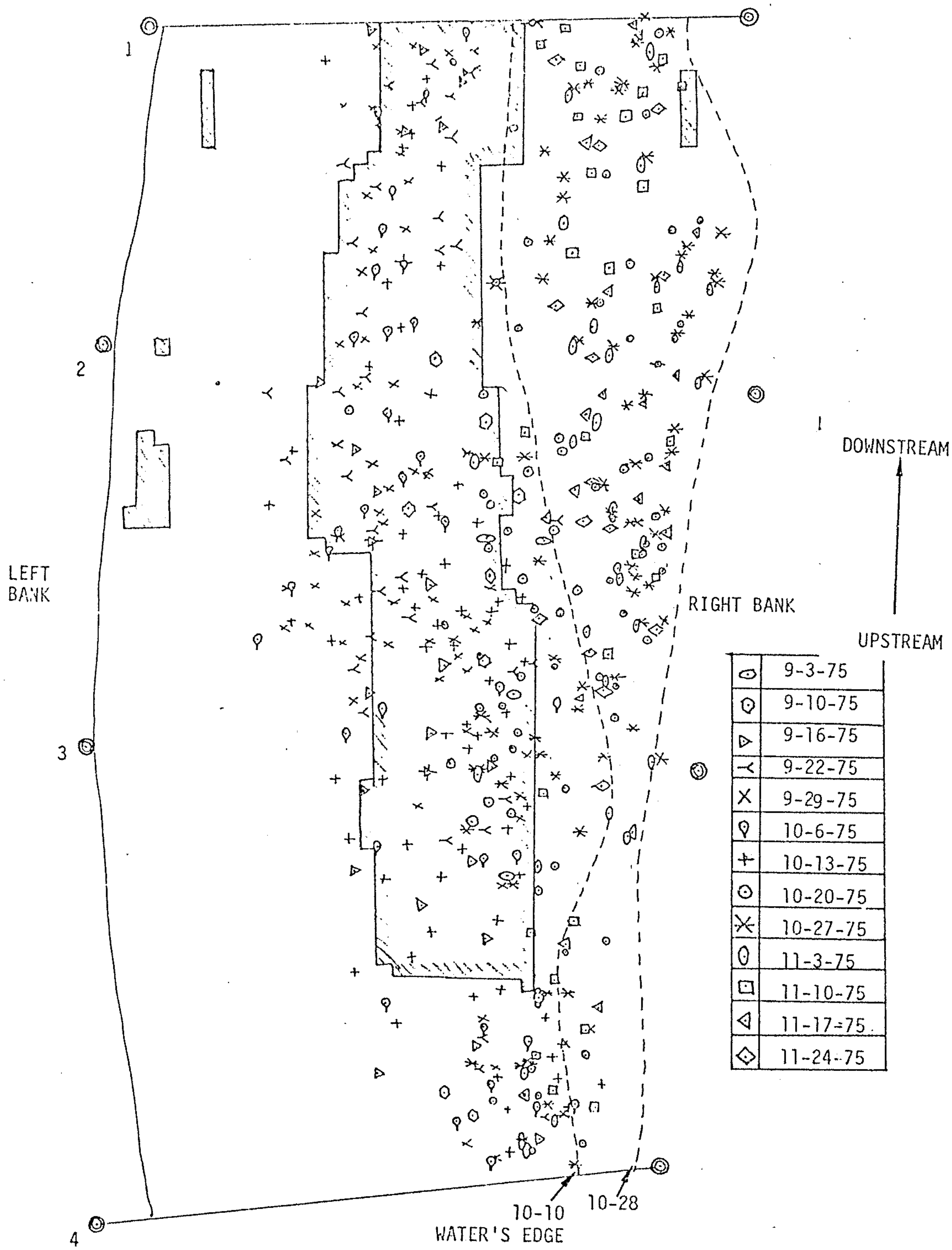



Figure 18. Location of redds recorded each week at Station 1 by plane table survey. Spawnable area calculated by SYMAP based on preferred depths and velocities at a discharge of 342 cfs on September 3, 1975.

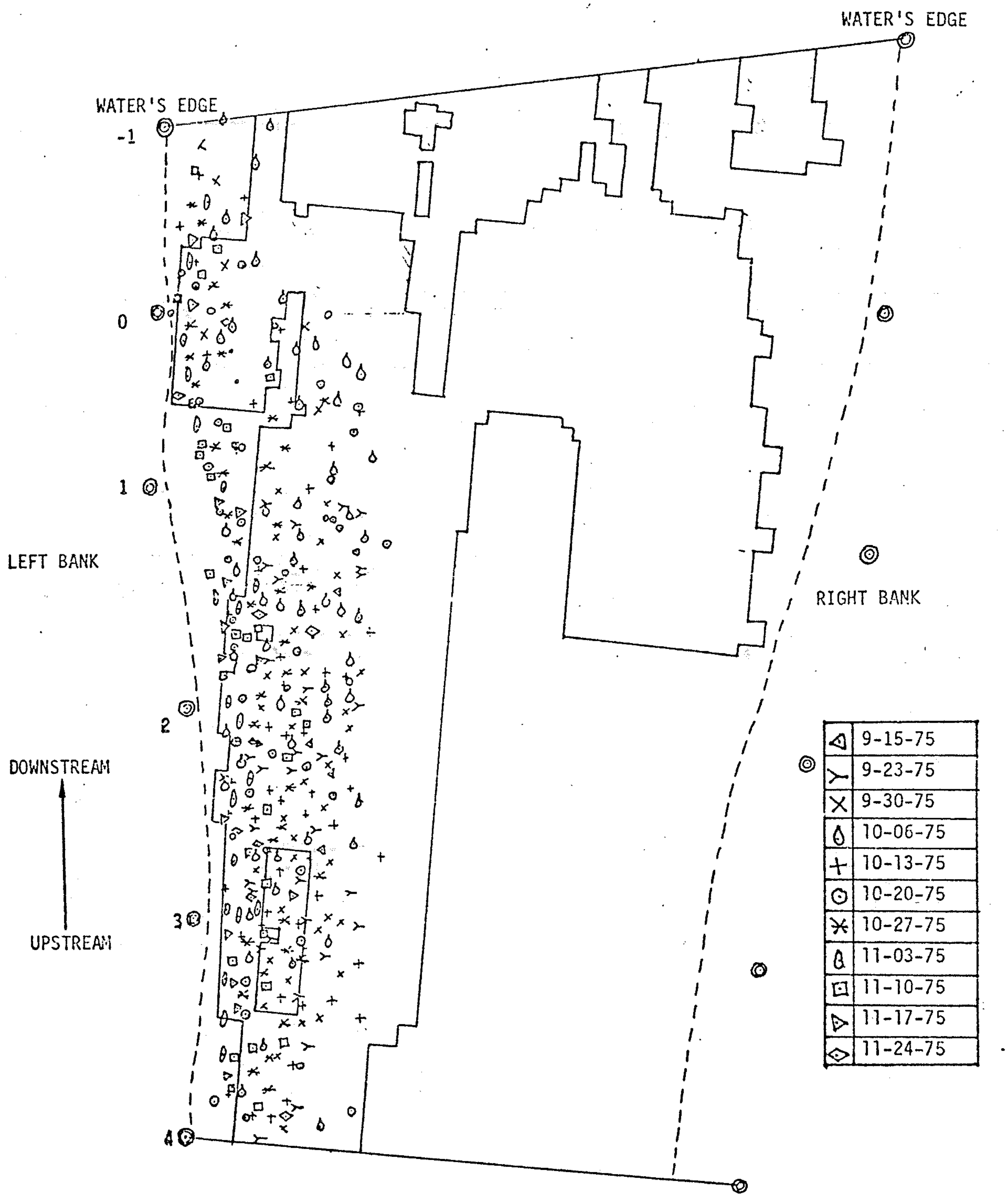



Figure 19. Location of redds recorded each week at Station 5 by plane table survey. Spawnable area calculated by SYMAP based on preferred depths and velocities at a discharge of 392 cfs on September 5, 1975.

Table 1. Estimated potential egg deposition at Station 5, 1975.

| Date | Discharge at Renton | Spawners | | Potential Egg Deposition | | Area ($ft^2$) | | | Weekly Egg Density |
|---|---|---|---|---|---|---|---|---|---|
| | | Week | Total | Week | Total | Week | New | Total | $eggs/ft^2$ |
| 09-15 | 167 | 39 | 39 | 79,560 | 79,560 | 125.1 | 125.1 | 125.1 | 636.0 |
| 09-24 | 199 | 54 | 93 | 110,160 | 189,720 | 1189.2 | 1108.6 | 1233.7 | 153.8 |
| 09-30 | 178 | 81 | 174 | 165,240 | 354,960 | 1748.8 | 879.7 | 2113.4 | 168.0 |
| 10-06 | 254 | 142 | 315 | 289,680 | 664,640 | 2219.4 | 548.5 | 2661.9 | 242.2 |
| 10-13 | 218 | 128 | 444 | 261,120 | 905,760 | 2572.3 | 442.0 | 3103.9 | 291.8 |
| 10-20 | 420 | 118 | 562 | 240,720 | 1,146,480 | 2740.9 | 302.1 | 3405.9 | 336.6 |
| 10-27 | 455 | 87 | 649 | 177,480 | 1,323,960 | 1580.3 | 15.4 | 3421.3 | 387.0 |
| 11-03 | 914 | 39 | 688 | 79,560 | 1,403,520 | 426.1 | 63.6 | 3484.9 | 402.7 |
| 11-10 | 579 | 74 | 762 | 150,960 | 1,554,180 | 1837.8 | 0 | 3484.9 | 446.1 |
| 11-17 | 882 | 34 | 796 | 69,360 | 1,623,840 | 588.2 | 0 | 3484.9 | 466.0 |
| 11-24 | 882 | 18 | 814 | 36,720 | 1,660,560 | 132.9 | 0 | 3484.9 | 476.5 |

Table 2 Estimated densities of eggs and alevins from hydraulic samples at Stations 1 and 5, resulting from spawning activity during 1975.

| | | | | Catch | | | | Density/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Live | | Dead | | | | |
| Station | Date | Number of Digs | Area Sampled (ft$^2$) | Eggs | Alevins | Eggs | Alevins | Live | Dead | Total |
| 1 | 10-14-75 | 77 | 38.5 | 6,372 | 4 | 159 | 0 | 165.6 | 4.1 | 169.7 |
| 1 | 10-28-75 | 91 | 45.5 | 5,822 | 0 | 940 | 0 | 128.0 | 20.7 | 148.6 |
| 1 | 1-13-76 | 36 | 18.0 | 28 | 0 | 63 | 0 | 1.6 | 3.5 | 5.1 |
| 1 | 2-18-76 | 32 | 16.0 | 0 | 206 | 28 | 0 | 12.9 | 1.8 | 14.6 |
| 1 | 3-18-76 | 50 | 25.0 | 0 | 103 | 4 | 0 | 2.1 | 0.2 | 4.3 |
| 5 | 10-15-75 | 40 | 20.0 | 3,211 | 0 | 72 | 0 | 160.6 | 3.6 | 164.2 |
| 5 | 11-05-75 | 53 | 26.5 | 4,058 | 2 | 195 | 0 | 153.2 | 7.4 | 160.6 |
| 5 | 1-08-76 | 17 | 8.5 | 255 | 388 | 30 | 0 | 75.6 | 3.5 | 79.2 |
| 5 | 2-19-76 | 19 | 9.5 | 758 | 122 | 385 | 0 | 92.6 | 40.5 | 133.2 |
| 5 | 3-17-76 | 42 | 21.0 | 82 | 164 | 107 | 0 | 11.7 | 5.1 | 16.8 |

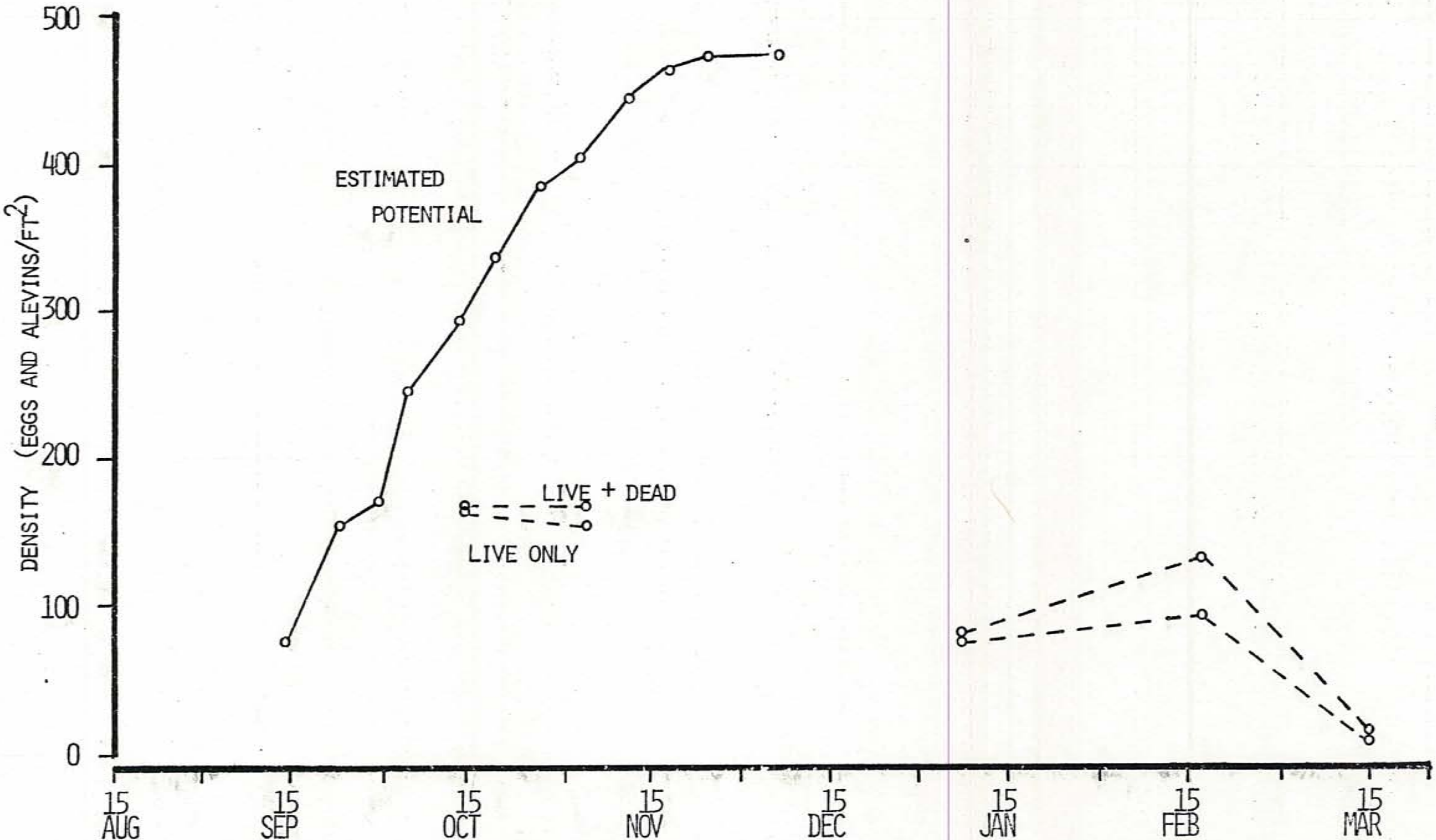



Figure 20. Estimated potential and observed egg-alevin density at Station 5 resulting from spawning activity in 1975.

do, however, agree with Bell's (1973) conclusion that good spawning gravel will hold between 125 and 200 eggs/ft$^2$, suggesting an average gravel egg density on this study site was about 162 eggs-alevins/ft$^2$. These estimates of the potential density indicate that saturation may have been reached by September 30. Since 78.6% of the potential deposition occurred after September 30 (20.3% after October 27), it appears that significant mortality due to superimposition may have occurred on this reach. An analysis of the stages of development of eggs found on these dates is underway to help confirm this assessment.

Three sampling sessions were conducted after the December flood. Significant numbers of fry were found emigrating after mid-February, therefore two estimates of egg-alevin densities were available for the post-flood pre-emergent period. The average density on January 8 and February 19, 1976 was 106.2 eggs-alevins. This represents a 34.6% reduction in average density following the flood. This loss was not uniform within the spawned area, as illustrated by the three zones identified within the spawned area of Station 5 (Fig. 21). An almost total loss of eggs (.06/ft$^2$) occurred within a 1732-ft$^2$ area near the main channel (Zone I). Egg densities were reduced to 14.6 eggs-alevins/ft$^2$ in a 1596-ft$^2$ intermediate area (Zone II). A 630-ft$^2$ area (Zone III) nearest the bank was least affected, with a density of 126.8/ft$^2$. A gradient in flood-imposed egg loss was clearly apparent, ranging from complete loss in mid-channel to minimal losses in a restricted zone near the left bank of the river.

The potential egg density at Station 1 (Table 3 and Fig. 22) increased weekly until October 20, at which time a previously dry

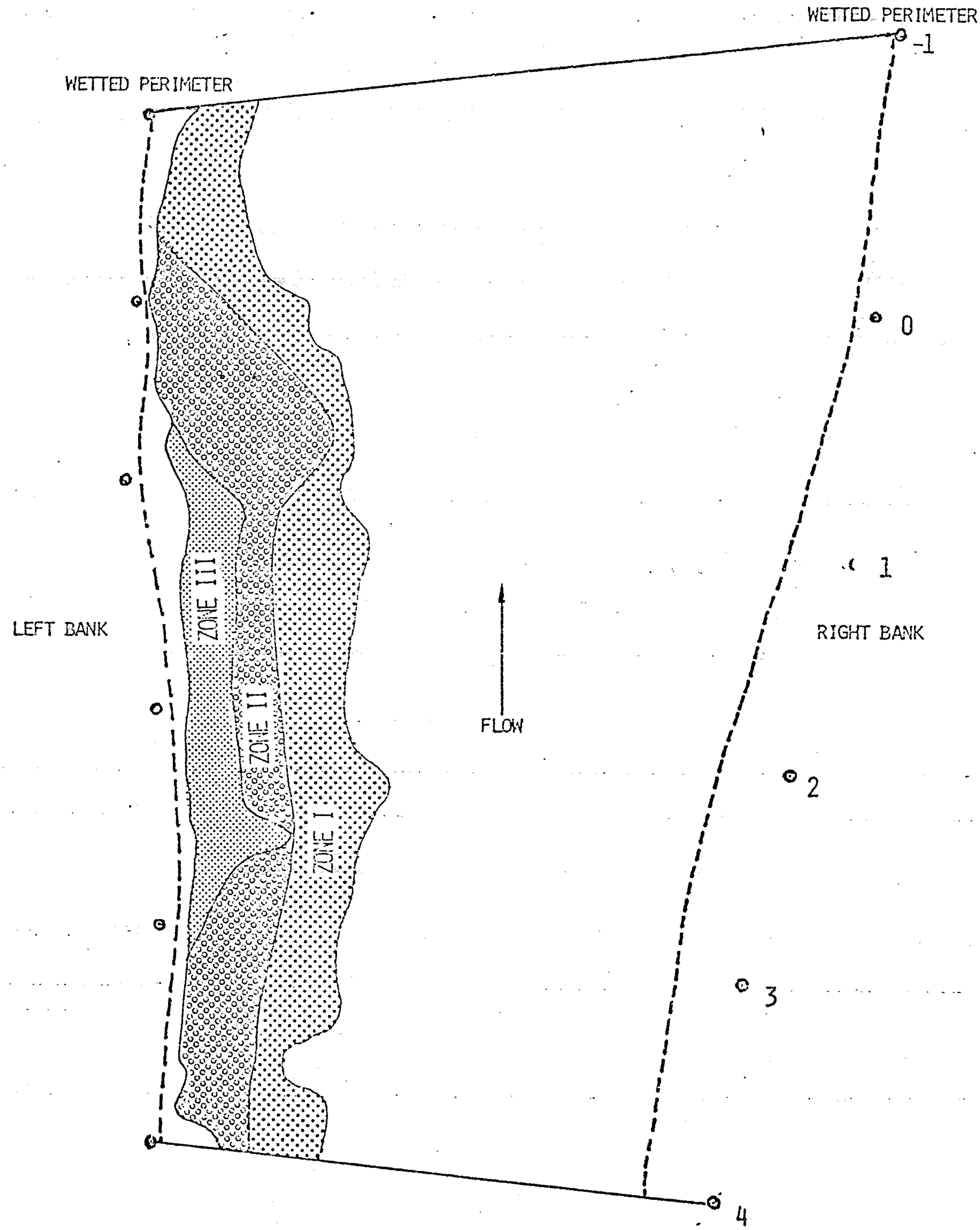



Figure 21. The distribution of sockeye eggs-alevins in the gravel at Station 5, showing zones of survival following the flood of December 1975. Densities of eggs-alevins remaining in Zones I, II, and III, were 0.06, 14.6, and 126.8 per $ft^2$, respectively.

Table 3. Estimated potential egg deposition at Station 1, 1975.

| Date | Discharge at Renton | Spawners | | Potential Egg Deposition | | Area ($ft^2$) | | | Weekly egg Density |
|---|---|---|---|---|---|---|---|---|---|
| | | Week | Total | Week | Total | Week | New | Total | $eggs/ft^2$ |
| 09-03 | 405 | 10 | 10 | 20,400 | 20,400 | 181.2 | 181.2 | 181.2 | 112.6 |
| 09-10 | 234 | 30 | 40 | 61,200 | 81,600 | 589.5 | 544.2 | 725.4 | 112.5 |
| 09-16 | 160 | 120 | 160 | 244,800 | 326,400 | 1689.7 | 1600.6 | 2326.1 | 140.3 |
| 09-22 | 181 | 140 | 300 | 285,600 | 612,000 | 1373.6 | 731.3 | 3057.4 | 200.2 |
| 09-29 | 199 | 177 | 477 | 361,080 | 973,080 | 3008.0 | 1018.5 | 4075.9 | 238.7 |
| 10-06 | 254 | 175 | 672 | 357,000 | 1,330,080 | 2880.8 | 165.4 | 4241.3 | 313.6 |
| 10-13 | 218 | 160 | 832 | 326,400 | 1,656,480 | 3802.9 | 178.1 | 4419.3 | 374.8 |
| 10-20 | 420 | 136 | 968 | 277,440 | 1,933,920 | 4095.4 | 3154.2 | 7573.6 | 255.4 |
| 10-27 | 455 | 123 | 1,091 | 250,920 | 2,184,840 | 3128.8 | 209.9 | 7783.4 | 280.7 |
| 11-03 | 914 | 72 | 1,163 | 146,880 | 2,331,720 | 2209.9 | 63.6 | 7847.0 | 297.2 |
| 11-10 | 579 | 104 | 1,267 | 212,160 | 2,543,880 | 2448.3 | 12.7 | 7859.7 | 323.6 |
| 11-17 | 882 | 49 | 1,316 | 99,960 | 2,643,840 | 2187.6 | 0 | 7859.7 | 336.4 |
| 11-24 | 882 | 33 | 1,349 | 67,320 | 2,711,160 | 1494.4 | 0 | 7859.7 | 344.9 |

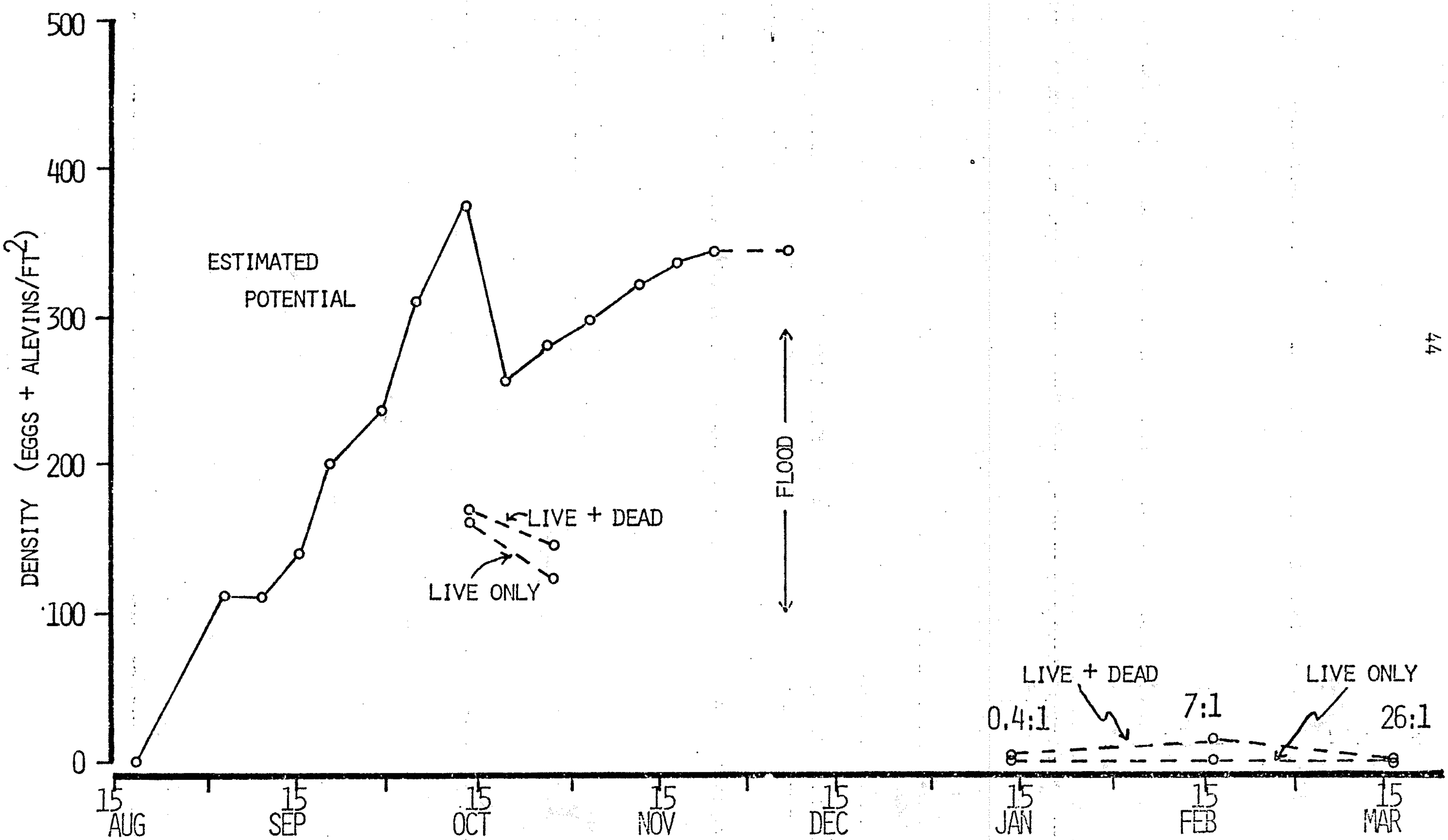



Figure 22. Estimated potential and observed egg-alevin density at Station 1, resulting from spawning activity in 1975.

gravel bar was submerged by increased flows, producing a 71% increase in spawned area over the previous week. Concurrently, a decrease in the number of spawners was observed. These factors produced a sharp decline in the potential egg density. Little new area became available to spawners after October 20, with a discharge of 420 cfs, but spawning continued through November 24. These factors resulted in increasing potential densities in the peripheral spawning area for the next five weeks. The spawnable area-discharge relationship at Station 1 clearly illustrates the lateral movement of spawners with an increasing discharge regime. New spawnable area continues to accumulate to about 420 cfs with a peak spawning discharge calculated at 216 cfs (Stober and Graybill, 1974).

The observed density of 169.7 eggs-alevins/$ft^2$ on October 14 is significantly lower than the estimated potential density of 375 eggs/$ft^2$. It seems probable, therefore, that saturation of the gravel near the center of the channel may have occurred early in the season on this reach. The decline in observed density from 169.7 to 148.6 eggs-alevins/$ft^2$ between October 14 and October 28 was due to the increase in spawned area as the discharge increased.

The maximum observed density of 169.7 eggs-alevins/$ft^2$ is similar to the maximum observed at Station 5. Stober and Graybill (1974) showed that the substrate of reaches 1 and 5 was comparable. In view of the striking similarity of the data showing 1) substantially lower densities than the calculated potential; 2) very similar maximum observed densities, and 3) comparable substrate, it seems reasonable to hypothesize a maximum limit for gravel egg densities of about 165 eggs/ft$^2$ existed for both reaches.

The effect of peak flood discharge on density can be estimated by using either the observed density of 148.6 eggs-alevins/ft$^2$ on October 28, or by assuming that since spawning continued for about 4 weeks, a final density approached the hypothesized maximum of 165 eggs-alevins/ft$^2$. Since fry emigrations started in mid-February, the density found on March 18 was not utilized. Using an average of the densities found on January 13 and February 18 of 9.8 eggs-alevins/ft$^2$ for the post-flood period, a loss of 94% was calculated.

A map showing the areas where eggs-alevins were found prior to and following the flood is presented in Fig. 23. Two zones demonstrating flood effects were identified. Zone I, nearest the center of the channel (7599 ft$^2$), exhibited a nearly total loss of eggs-alevins (0.03/ft$^2$). A restricted area of 1183 ft$^2$ near the bank (Zone II) was the only portion of the spawned area where some eggs-alevins remained. A density of 77.7 eggs-alevins/ft$^2$ indicated that substantial losses had also occurred in this area. On the basis of these data, it appears that egg loss may be more severe in a channel which presents a well-defined gravel bar to spawners (Station 1) than one in which the spawning bar is more uniform (Station 5). Whether this is in fact the case will require further study and interpretation. In addition, it appears that the maximum spawnable area must be presented to each spawning run by step-wise

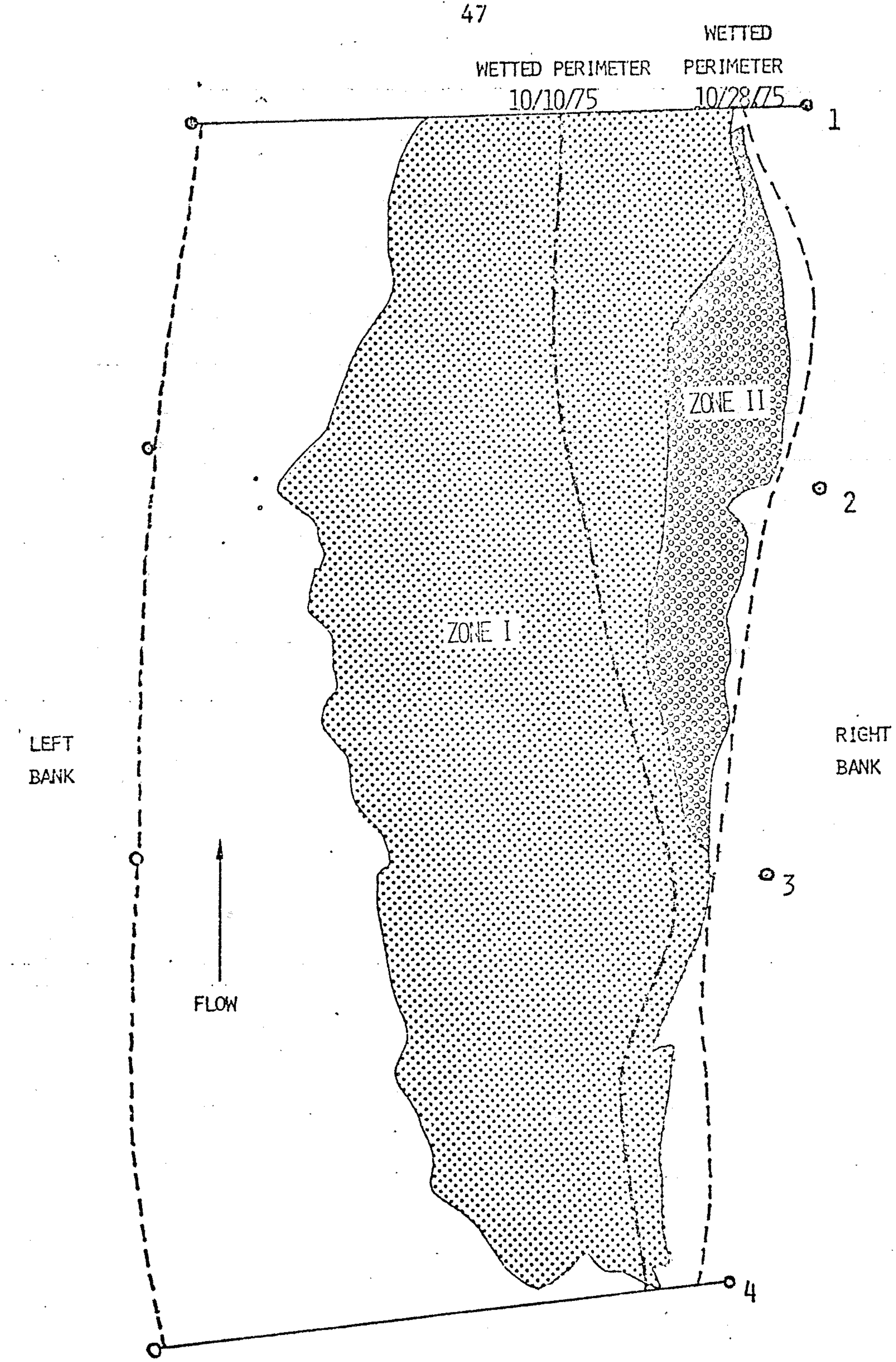



Figure 23. The distribution of sockeye eggs-alevins in the gravel at Station 1, showing zones of survival following the flood of December 1975. Densities of eggs-alevins remaining in Zones I and II were 0.03 and 77.7 per ft$^2$, respectively.

increases in minimum discharge levels in order to utilize as many of the surplus of eggs as possible. This would tend to increase sockeye production in a year when flood flows were not limiting.

## 6.5 Fry Production

The total number of fry estimated to have entered Lake Washington from the 1975 brood year is $2.24 \times 10^6$. Assuming a potential egg deposition of $2.33 \times 10^8$, a 0.96% egg to fry survival was found. Foerster (1968) reported survival rates ranging from 1.8% to 19.3% (mean = 10.6%) for data collected from six river systems in British Columbia and the Soviet Union. It is apparent that when compared to previously published estimates of egg to fry survival, the 1975 year class experienced excessive mortality. We believe that the low survival was due to superimposition and washout.

## 6.5 Flood Effects

Miller (1976) presented a quadratic equation to describe the relationship between the pre-smolt to spawner ratio (P/S) and the instantaneous peak discharge ($Q_f$) at Renton during egg incubation. The equation $P/S = 26.55 - .0037\ Q_f + 1.16 \times 10^{-7}\ Q_f^{\ 2}$ is essentially linear over the range 3000 to 10,000 cfs (Fig. 24). The form of this relationship was dictated to a great extent by two

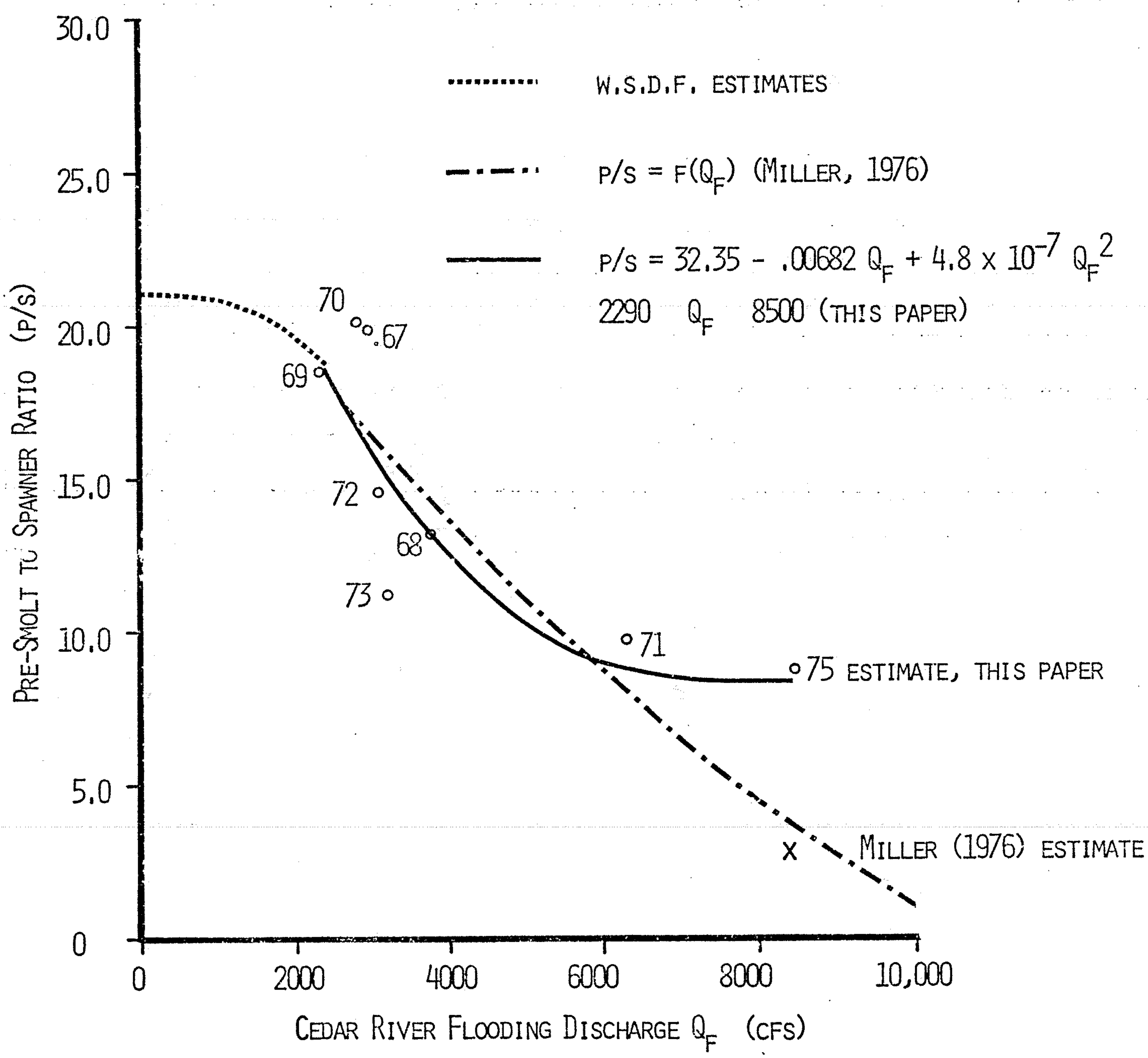



Figure 24. Relationship between the instantaneous discharge at Renton ($Q_f$) during sockeye egg incubation and the pre-smolt to spawner ratio (P/S).

data points, 1971 and 1975. An estimate of $3.0 \times 10^5$ fry entering Lake Washington assumed by Miller (1976) was substantially lower than the present estimate, based on sampling data. The P/S ratio was recalculated with the updated estimate.

In order to make the recalculation, it was necessary to estimate the number of fish surviving to smolt. This was accomplished using the equations of Bryant (1976):

$$S = Je^{-mt} \tag{2}$$

where,

S = number of smolts

J = number of juveniles in Lake Washington on July 1

e = base of the natural logarithms

m = the density-dependent monthly mortality rate calculated from equation (3)

t = number of months of lake residence

$$m = (0.06245) + (0.00674)(J \times 10^{-6}). \tag{3}$$

In order to calculate S, it was first necessary to estimate the number of fish surviving to July 1 (J). This was done using an equation similar to (2) which accounted for changing density resulting from daily influxes of emigrant fry. The number of fish surviving on day i + 1 was calculated by the following equation:

$$N_{(i+1)} = (E_i + n_i)\, e^{-m\frac{1}{t}} \qquad (4)$$

where,

$N_{i+1}$ = number of fish surviving on day i + 1

$E_i$ = number of fish emigrating into Lake Washington on day i

$n_i$ = number of fish surviving on day i which had previously emigrated

m = mortality rate (see equation (3))

t = average number of days per month (30.75).

Through an iterative process using equation (4), we estimated that $1.93 \times 10^6$ fry had survived to July 1. A direct solution of equation (2) indicated that $1.05 \times 10^6$ of these fry will survive to smolt, representing an 8.7 pre-smolt to spawner (P/S) ratio.

The updated P/S ratio is plotted in Fig. 24. Polynomial regression was used to estimate $P/S = f(Q_f)$. New data developed in this study indicate that above about 6,000 cfs no significant additional mortality due to flooding may occur. It is obvious, however, that once again the same two data points (1971 and 1975) played a significant role in determining the shape of the curve. Until the variation in P/S ratio for discharges above 4,000 cfs is more accurately estimated, no definitive form can be ascribed to this relationship. However, it appears that even the most extreme flood may not completely eliminate a year class.

## 6.7 Time of Emergence

The expected emergence curve for the 1975 brood year of Cedar River sockeye salmon and the estimated weekly migration are plotted in Fig. 25 a and b. The expected emergence curve was calculated using the estimated percentage of the total population spawning each week and mean temperatures during the estimated (3-month) incubation period for each wave of spawners. The number of temperature units (TU's) required to yolk sac absorption may be affected by the dissolved oxygen concentration of the water immediately surrounding the eggs. We therefore corrected for the potential oxygen deficits by adding 100 TU's (Brannon, personal communication). The number of TU's used to estimate emergence varied between 1790 and 2008.

Comparisons between the expected emergence curve and observed weekly catches were complicated because the observed average size of emigrating fry was larger on May 29 than on previous dates (Table 4 and Fig. 26). These data indicated that catches after about May 29 included both newly emergent fry and fry which had reared for varying lengths of time prior to capture. In order to facilitate a direct comparison between the expected emergence curve and the weekly catch data, we estimated the date of emergence for those fry exhibiting growth. Since no data were available from which to estimate a growth rate directly, we used three rates representing growth realized by sockeye fry over a broad range of environmental and genetic factors (Woodey, 1972; Parr, 1972; Bilton, 1974).

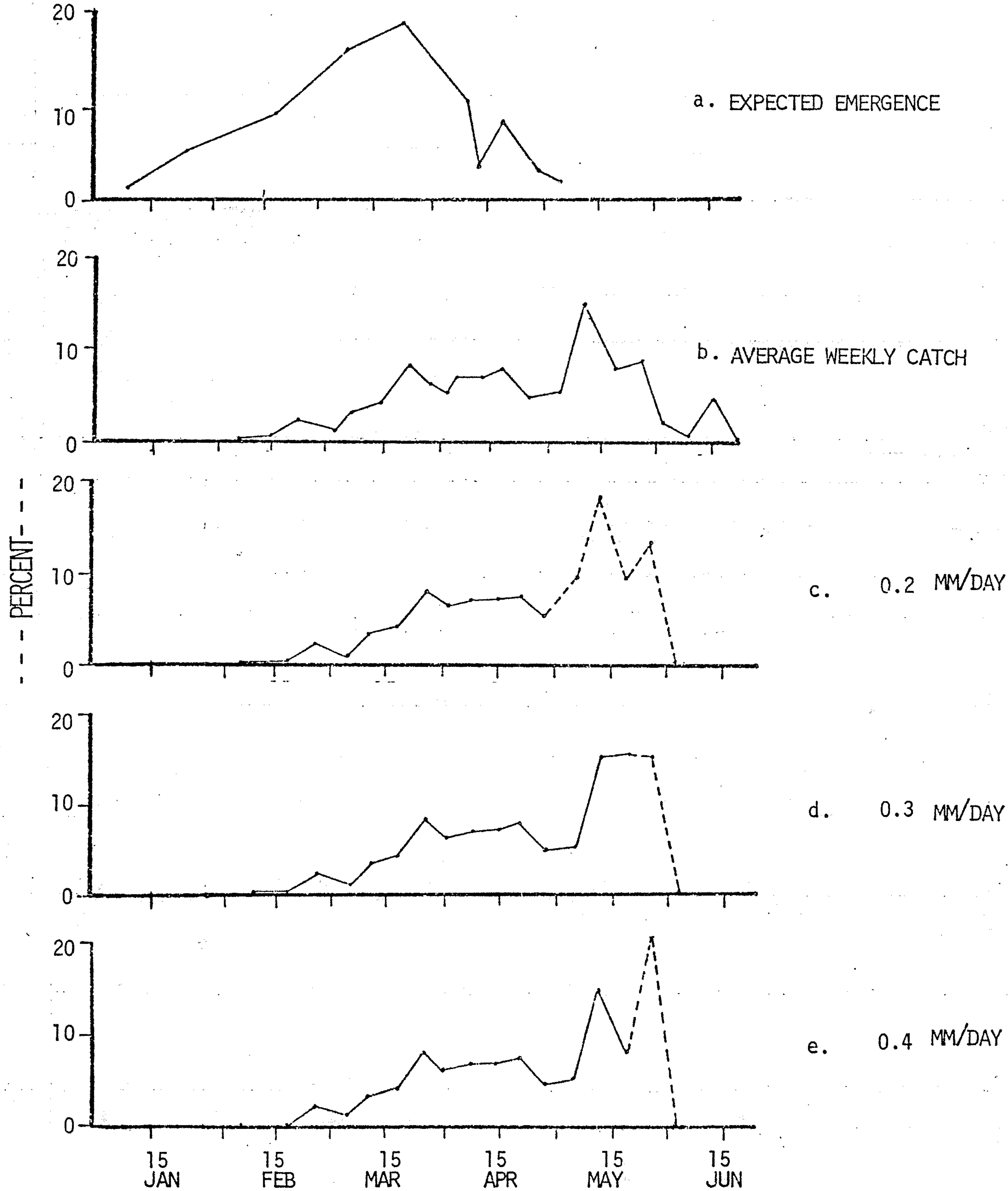



Figure 25. Emergence curves and average weekly catches of Cedar River sockeye fry from the 1975 brood year.

Table 4. Length, weight, condition factor and percentage of complete fusion of the mid-ventral wall for the 1975 brood year sampled by fyke netting in 1976.

| Date | Number Measured | Length (mm) | Weight (g) | Condition Factor | % of Complete Fusion |
|---|---|---|---|---|---|
| 2/5 | 4 | 27.8 | .1500 | .70 | 25.0 |
| 2/10 | 18 | 26.6 | .1278 | .68 | 94.4 |
| 2/15 | 28 | 26.5 | .1339 | .72 | 60.7 |
| 2/20 | 50 | 27.1 | .1338 | .67 | 90.0 |
| 3/14 | 50 | 26.9 | .1360 | .70 | 92.0 |
| 3/21 | 50 | 26.9 | .1498 | .77 | 82.0 |
| 3/29 | 50 | 27.5 | .1388 | .67 | 84.0 |
| 4/2 | 50 | 27.0 | .1568 | .80 | 87.0 |
| 4/12 | 50 | 27.0 | .1546 | .79 | 91.0 |
| 4/18 | 50 | 27.1 | .1446 | .73 | 84.0 |
| 4/25 | 50 | 26.8 | .1422 | .74 | 96.0 |
| 5/1 | 50 | 26.7 | .1402 | .74 | 88.0 |
| 5/9 | 50 | 26.5 | .1360 | .73 | 82.0 |
| 5/29 | 50 | 28.1 | .1782 | .80 | 92.0 |
| 6/10 | 50 | 30.6 | .3200 | 1.12 | 98.0 |
| 6/16 | 50 | 36.0 | .5722 | 1.23 | 100.0 |
| 6/28 | 50 | 39.6 | .7310 | 1.18 | 100.0 |

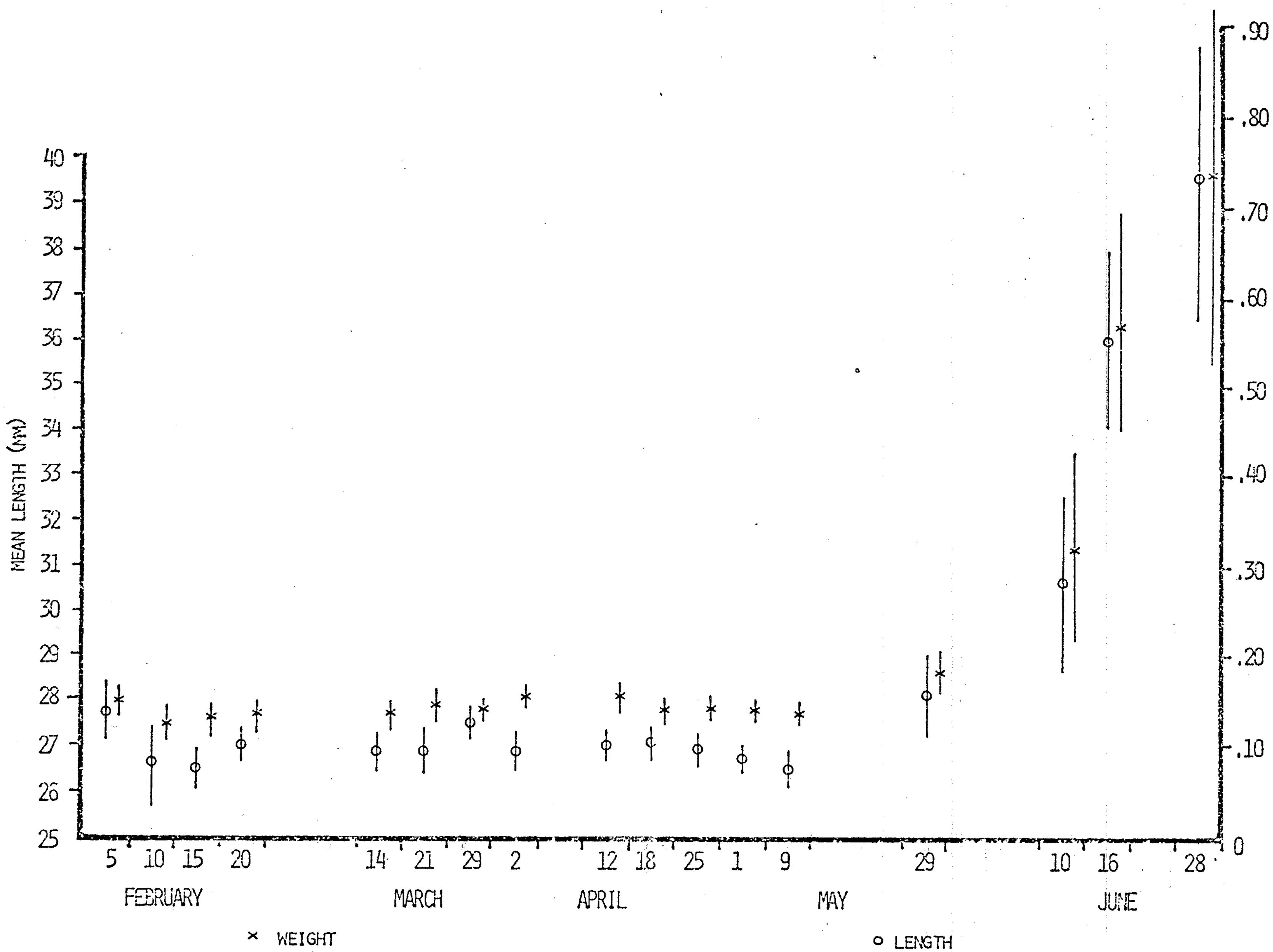



Figure 26. Mean (± 95%) lengths and weights of sockeye salmon fry captured by fyke netting in the Cedar River in 1976.

Estimating the date of emergence for those fish exhibiting growth was made in the following manner. It was assumed that the mean length of all fish captured prior to May 10 represented the mean size at emergence (26.9 mm). The average increase in length for fish sampled on successive dates was then determined. The number of days since emergence, and subsequently the date of emergence, were calculated, by dividing the increase in length by the growth rate, and are summarized in Table 5. Since estimates of the date of emergence were desired for all dates of capture after May 29, least squares linear regression lines were fitted to each data set derived from the use of the three growth rates (Fig. 27). By solving these equations and apportioning the estimated migration to the estimated date of emergence for dates of capture after May 29, a series of emergence curves was calculated (Fig. 25 c, d and e).

In an analysis of these emergence curves, it should be noted that it is unclear where this growth was actually realized. Three non-exclusive hypotheses were formulated:

1. Upon emergence, the fry did not immediately emigrate; rather, they reared in the middle and/or upper reaches of the Cedar River for varying lengths of time.
2. Upon emergence, the fry emigrated to the lower reaches of the Cedar River to rear prior to entering Lake Washington.
3. Upon emergence, the fry emigrated to Lake Washington, but some of them returned to the lower river to feed.

Table 5. Estimated dates of emergence for fry exhibiting growth, based on three growth rate estimates.

| Date of Capture | | Average increase in length above 26.9 mm | DATE OF EMERGENCE | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0.2 mm/day | | 0.3 mm/day | | 0.4 mm/day | |
| Calendar | Julian | | Calendar | Julian | Calendar | Julian | Calendar | Julian |
| 5/29 | 150 | 1.2 | 5/23 | 144 | 5/25 | 146 | 5/26 | 147 |
| 6/10 | 162 | 3.7 | 5/22 | 143 | 5/28 | 149 | 6/01 | 153 |
| 6/16 | 168 | 9.1 | 5/01 | 122 | 5/17 | 138 | 5/24 | 145 |
| 6/29 | 180 | 12.7 | 4/26 | 117 | 5/17 | 138 | 5/27 | 148 |

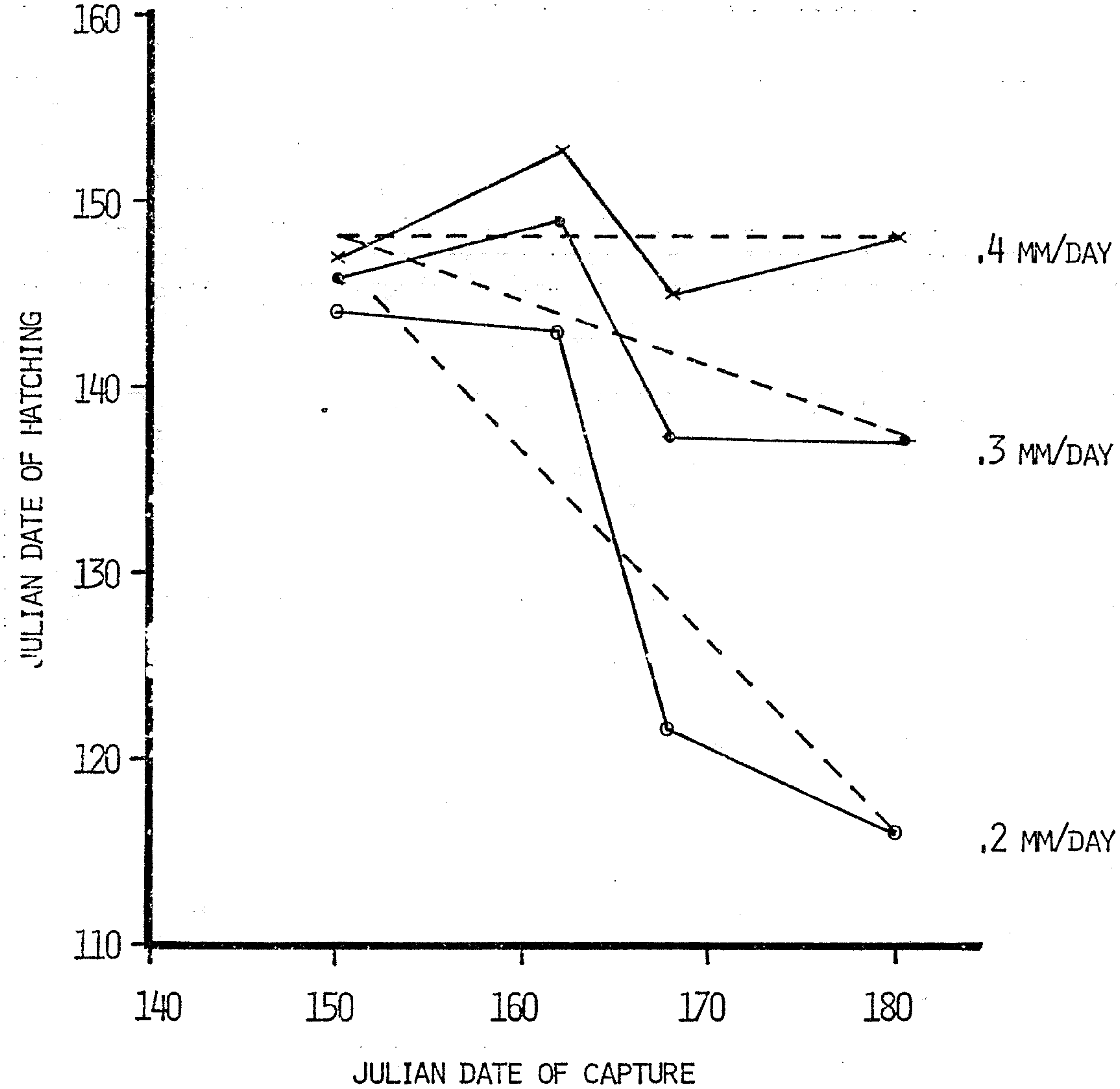



Figure 27. Estimated date of emergence for fry captured from mid-May through June, 1976, assuming three rates of growth.

Egg incubation experiments are being conducted in 1976-77 to provide better definition of development rates and timing. Limited fyke net or beach seine sampling farther upstream than the present fry sampling location may also provide useful data to better understand these phenomena. Discussions in this report assume that the first hypothesis was occurring exclusively, and a sampling effort is being designed for Spring 1977.

The expected curve indicates that the emergence probably began in early January; however, the weekly catch data indicated emergence began in early February. Since sampling did not begin until February 5, it might be hypothesized that the early migration was missed. Two factors suggest that this was not the case. First, catches were considerably lower during the first three weeks of sampling than the expected curve indicated. Second, beach seining conducted on February 9 in Lake Washington near the mouth of the Cedar River caught very few fry. We therefore concluded that no significant portion of the total emigration occurred prior to the commencement of sampling.

The expected curve indicated that emergence ended by the first week of May. Regardless of which of the three growth rates was assumed for late migrating fry, the revised catch data indicate that emergence continued until the first week of June. While the timing of emergence was quite different for these two data sets, both indicated that emergence lasted for approximately 4 months.

The agreement between the expected and observed duration of emergence suggests that the shift to a later emergence than that predicted may be attributable to the following non-exclusive hypotheses:

1. Too few temperature units were used to calculate the expected emergence curve;
2. After completing yolk sac absorption, fry remained in the gravel for perhaps a month prior to emigrating, which would require that no growth was realized during this period.
3. After completing yolk sac absorption, fry emerged but did not emigrate; rather they remained in the river and did not grow for perhaps a month.

A difference in the timing of the peak emergence was also present. The expected curve indicated that peak emergence should have occurred about midway through the emergence cycle. The catch data (regardless of what growth rate was used) showed peak emergence to have occurred toward the end of the cycle. This shift may be attributable to differential survival of eggs deposited during the spawning cycle, with eggs deposited early suffering higher mortality rates, probably due to flooding. This seems a feasible explanation since at Station 1 we found that eggs deposited early in the season near mid-channel were lost as a result of the flood flows, while late spawners which deposited eggs near the river banks were least affected.

## 6.8 Incidental Species

Longfin smelt (*Spirinchus dilatus*) were caught in large numbers during late February and early March (Table 6). This coincides with the peak spawning period of these fish (Moulton, 1970). Frequent catches of cottids (*Cottus, sp.*), threespine stickleback (*Gasterosteus aculeatus*) and lampreys (*Lampetra, sp.*) were also made. Juvenile coho salmon (*Oncorhynchus keta*), chinook salmon (*O. tshawytscha*) and steelhead trout (*Salmo gairdneri gairdneri*) were captured sporadically.

Table 6. Weekly catch of incidental species.

| Date | FRY | | | FINGERLING | | Longfin Smelt (Adults) | Cottids | Threespine Sticklebacks | Lampreys |
|---|---|---|---|---|---|---|---|---|---|
| | Coho | Chinook | Steelhead | Steelhead | Coho | | | | |
| 2/1 | | | | | | | 1 | | 1 |
| 2/8 | | | | | | 448 | 10 | 2 | 1 |
| 2/15 | | | | | | 804 | 14 | | |
| 2/22 | | | | | | 8,974 | 11 | 1 | |
| 2/29 | 1 | | | | 1 | 14,755 | 24 | 2 | 1 |
| 3/7 | | | | | | 4,488 | 20 | 1 | 1 |
| 3/14 | 3 | 8 | | | 2 | 1,151 | ;4 | | 1 |
| 3/21 | | 13 | | 1 | 1 | 425 | 16 | | 1 |
| 3/29 | 6 | 9 | | 2 | | 108 | 28 | 4 | |
| 4/4 | | | | 1 | | 46 | 5 | 2 | |
| 4/11 | | | | | | 12 | 1 | 4 | 2 |
| 4/18 | | 1 | | | | 2 | 3 | 2 | |
| 4/25 | | | | | | | 3 | 1 | |
| 5/2 | | | | | | 1 | | | |
| 5/9 | 1 | | | | 1 | | 6 | | |
| 5/16 | | | | | 12 | | 1 | 9 | 1 |
| 5/23 | 1 | | | | 10 | 1 | 4 | 13 | 1 |
| 5/30 | 6 | | | | 1 | | | 5 | |
| 6/6 | 1 | | | | 6 | | 1 | 6 | 1 |
| 6/13 | 3 | | 16 | | 1 | | 1 | 3 | 3 |
| 6/20 | | | 34 | 1 | | | 3 | 7 | 2 |
| 6/27 | | | 7 | 1 | | | 1 | 1 | 1 |

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