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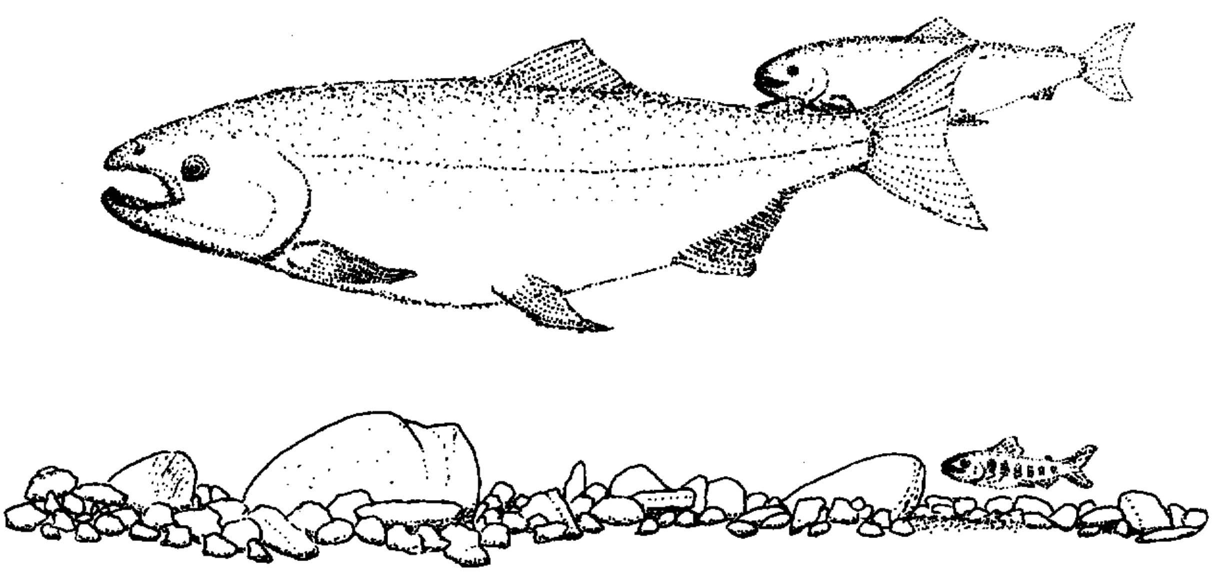
STEELHEAD SMOLT EXIT SELECTION AT GLINES CANYON DAM



FISHERIES ASSISTANCE OFFICE

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AT

GLINES CANYON DAM

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and

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U. S. Fish & Wildlife Service
Fisheries Assistance Office
Olympia, Washington

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ACKNOWLEDGEMENTS

The Lower Elwha Tribe provided test fish used in this study and we appreciate the Tribe's cooperation in this endeavor.

Olympic National Park provided hydroacoustic instruments used in this study.

We appreciate the cooperation of Crown Zellerbach Corporation in providing access for acoustic monitoring equipment at Glines Canyon Dam, as well as dam operational records and test spills during the study period. Mark Lomax, Glines Canyon Dam operator, was especially helpful with physical setup of our monitoring equipment.

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INTRODUCTION

Restoration of anadromous fish to the upper Elwha River is a major goal of Olympic National Park and other parties. Two dams currently in place on the lower Elwha River, the Elwha and Glines Canyon Dams (Figure 1), have eliminated anadromous fish above river mile five since the early 1900's. Determining appropriate operational changes to successfully pass downstream migrants will be key elements in efforts to restore anadromy in the upper Elwha River. In this restoration effort, chinook, coho, and steelhead are of primary interest.

With respect to Glines Canyon Dam, available information suggests that spilling may be a relatively safe and effective means to pass downstream migrants. Specifically, early studies by Schoeneman and Junge (1954) indicated that coho smolts used the spillway exit at Glines Dam rather than sounding 80 ft to the turbine intake in the reservoir forebay. Mortality associated with this spillway exit was minimal, whereas passage through the turbine resulted in over one third loss of migrants tested. Similarly, catch and spill data gathered in 1985 by U.S. Fish & Wildlife Service, Fisheries Assistance Office (FAO), Olympia suggested that naturally outmigrating steelhead smolts also utilized the spillway rather than the turbine exit at Glines Dam and experienced minimal mortality (Wunderlich and Dilley 1986). Spilling therefore appeared to offer a potential means to safely pass steelhead as well as coho smolts with relatively minor operational changes at Glines Canyon Dam.

With respect to Elwha Dam, however, FAO studies (Wunderlich and Dilley 1986; Wampler et al. 1985) suggest that most downstream migrants utilize the surface-mounted turbine intakes and that larger sized downstream migrants (i.e., coho and particularly steelhead smolts) could incur a significant mortality in the Elwha turbines, as length of fish is an important survival factor in Elwha Dam's Francis style turbines. Direct measures of turbine mortality of coho smolts at Elwha Dam previously made by FAO (Wunderlich and Dilley 1985) indicated a substantial mortality at certain generation levels, however no similar evaluations for steelhead have been made.

To address the questions of steelhead smolt choice-of-exit at Glines Canyon Dam and potential mortality through both Elwha dams, FAO Olympia initiated studies of steelhead smolt exit selection and passage mortality in 1986. Specific objectives of this work were: 1) to determine whether and under what conditions steelhead smolts would enter the Glines Canyon Dam turbine, 2) to identify level of spill needed to induce passage of steelhead smolts in the Glines Canyon Dam spillway, and 3) to evaluate, via coded-wire tagging, passage mortality of steelhead smolts through the Elwha dams.

This report describes FAO studies conducted in 1986 and resultant findings regarding steelhead smolt exit selection at Glines Canyon Dam and also the initiation of a coded-wire tag study of steelhead smolt mortality through both Elwha dams.

METHODS

PLAN OF STUDY

The general plan of study consisted of releasing paired groups of coded-wire tagged steelhead smolts above Glines Canyon Dam and below Elwha Dam over the expected natural outmigration period. Movement of test fish (those released above Glines Canyon Dam) through the upper dam's exits was monitored hydroacoustically to assess choice-of-exit. Passage mortality through both Elwha dams will eventually be assessed by comparing coded-wire tag recoveries of adult test and control fish among lower Elwha River fisheries and hatchery racks in 1987-88.

Steelhead from Lower Elwha Tribal Hatchery were used for all releases. These fish were Elwha winter steelhead stock. Table 1 summarizes release information. Test fish were released at the boat ramp in the forebay of Lake Mills, while control releases were made at river mile 3 below Elwha Dam (Figure 1). All groups were approximately 5-6/lb at release and each group was uniquely coded-wire tagged. Tag group sizes were based on projected survival and sampling rates yielding a minimum of 30 adult tag recoveries per group in combined lower river fisheries and rack returns. All groups were held at similar densities until release, and all releases were made by tank truck. Test group release dates were chosen to bracket the expected natural outmigration period for Elwha winter steelhead, while releases of the latter three control groups were each delayed one week to account for observed delay in movement of corresponding test groups in Lake Mills. (The first control group was inadvertently not delayed due to lack of real time acoustic passage data during the initial week of study.) This release strategy was intended to time, as nearly as possible, each test/control pair's arrival at the estuary and thereby minimize any potential effects of differing saltwater entry on long term survival.

Two modifications to customary operations at Glines Canyon Dam were requested during the study period. First, we requested dam operators maintain reservoir levels below the dam crest to avoid potential fish movement over the crest (Figure 2). Crest passage was judged difficult to monitor hydroacoustically and, more importantly, highly injurious to any migrants and therefore undesireable in any long term fish passage plan anyway. Second, we requested low-level night spills on six occasions during otherwise non-spill periods. These low-level night spills were provided during early May and allowed us to evaluate the effects of such spilling on fish movement. These spill levels (approximately 100, 200, and 400 cfs) were typical of lower level spills at Glines Canyon Dam, based on review of historical springtime spill records (Figure 3). These requested spills occurred during night hours (usually 2000 hrs to 0700 hrs) for two reasons: 1) we anticipated a greater degree of nighttime migrant movement based on earlier Elwha work and observations in other systems, and 2) less electrical power demand occurred during night hours so generation loss due to nighttime spilling was less disruptive of hydroelectric production.

HYDROACOUSTIC MONITORING

The hydroacoustic system employed at Glines Canyon Dam consisted of the following components: six 15° 420 kHz transducers, an echo sounder/transceiver, a multiplexer/equalizer, a thermal chart recorder, and an oscilloscope. Table 2 lists model numbers of the equipment used.

The hydroacoustic system operated as follows (Raemhild, undated). When triggered by the echo sounder, the transducer emitted short sound pulses towards the area of interest. As these sound pulses encountered fish or other targets, echoes were reflected back to the transducer which then reconverted the sound energy to electrical signals. These returning signals were amplified by the echo sounder and equalized. A target's range from the transducer was determined by the timing of its echo relative to the transmitted pulse.

The echo sounder relayed the returning signals to the thermal chart recorder and oscilloscope. Return signals were visually displayed on the oscilloscope for measurements of echo strengths and durations. Individual fish traces were displayed on the thermal chart recorder in the form of an echogram which provided a permanent record of all targets detected during the study.

The multiplexer/equalizer (MPX/EQ) permitted the echo sounder to individually interrogate all six transducers at Glines Canyon Dam in an operator-specified sequence. The MPX/EQ channeled transmitted pulses from the echo sounder to the appropriate transducer and also equalized the return signals to compensate for differing receiving channel sensitivities. The hydroacoustic system was operated from May 5th, date of the first hatchery steelhead release, to June 7th, when smolt passage diminished to the point that continued monitoring appeared unnecessary. Over this time period, the hydroacoustic system was operated 24 hours per day.

Transducer Location

The study design of the project called for subsampling all possible fish exits during the entire length of the study. During the study period, Glines Canyon Dam had two potential fish exits: 1) through the single turbine intake located about 80 feet below the surface of the reservoir and about 100 feet upstream of the dam, and 2) under opened spillgates. Figure 2 illustrates these exits. As mentioned above, crest spilling was restricted during the study period and sampling of crest passage was therefore deemed unnecessary.

Turbine Intake and Spillway Transducer Location

To achieve the best possible transducer location at the turbine intake and spillways, three main criteria were considered. They were: 1) maximize sample area, 2) minimize hydroacoustic turbulence, and 3) place in the closest proximity to the passageway. The Glines Canyon Dam turbine intake measures approximately 40 feet in height and 20 feet in width and is located on the bottom of the reservoir in the old river canyon. The canyon at this location is only slightly wider then the intake. Because of the close proximity of the canyon walls to the turbine intake, a surface-mounted transducer could not be used because of the noise produced by echos received from canyon walls. To eliminate this noise, the transducer was mounted on a frame and lowered down the face of the turbine intake tower until a calculated transducer beam width of 20 feet was achieved. This location was approximately 55 feet from the bottom. From this point, the frame was adjusted up and down until maximum range and minimum bottom noise were attained.

Surface-mounted transducers were found to provide the optimum location to monitor under-gate spill. Glines Dam has a total of five spillgates (Figure 2). During a typical spring, only one spillgate is opened. However, to insure that no data would be lost during an unusual flood condition, transducers were mounted on all five spillgates. The latter measure was also intended to detect any substantial milling behavior of migrants in the vicinity of the spillgates.

Transducer Aiming Angle

To maximize information returned by a transducer from the sample area, fish direction, proximity to passageway, and turbulence were considered. The maximum sample area is obtained at maximum range. To determine fish movement the transducer must be aimed off the vertical and parallel to fish movement. In addition, the sample area should be located as close to the exit as possible. This increases the likelihood that fish detected in the sample area, moving toward the intake or spillgate, actually exit the system.

The turbine-mounted transducer was tested every five degrees, looking down and upstream, from twenty-five to forty degrees (zero degrees being straight down). An angle of thirty-five degrees provided maximum range and minimum amount of turbulence and echos from canyon walls. The surface-mounted spillgate transducers were tested in the same manner using a range of fifteen to forty-five degrees. An angle of twenty-five degrees provided the best angle at all five spillgate locations.

Sample Area

The sample area of each transducer (diameter of the beam) was a function of the range from the transducer. The following algorithm was used to determine the diameter (D) of a transducer at any range (X).

$$D = 2((\tan \theta/2) * X)$$

$$R/X = \tan (\theta/2)$$

$$R = \tan (\theta/2) * X$$

$$D = 2 * R$$

System Calibration

To be assured that an echo from a desired fish was received and recorded properly the hydroacoustic system was calibrated prior to data collection. Based on previous calibration information, the adjustable print threshold on the thermal chart recorder was set so that only signals from fish larger than -56dB on axis would be printed. This target strength corresponded to the smallest juvenile salmonid of interest in this study. The calibration information was also used to equalize the system sensitivity for each of the six receiving channels.

Target Strength

Since the hydroacoustic size of the fish determines the effective beam width of the transducer, the target strength of the fish determines the sample volume of the beam. For our purposes, Love's formula (Love, 1971) was used to estimate the target strength. The beam width for each transducer (Table 2) was calculated by applying the target strength derived from Love's formula and the particular characteristics of that transducer.

Echogram Interpretation

For an echogram trace to be a valid detection of fish moving into the turbine intake or under a spillgate, three criteria must be satisfied. These were:

1). The strength of the target echo must exceed the pre-determined threshold (-56dB).

2). The targets must be detected by no less then four consecutive pulses.

3). The targets must show a general movement toward the intake or spillgate.

Since the threshold was predetermined before data collection with the calibration of the hydroacoustic equipment, the first criterion was satisfied. Targets that fell below the threshold (e.g., trout fry) were simply not printed out by the thermal chart recorder. The redundancy requirement in the second criterion (four consecutive pulses) was due to the relatively wide beam width of the transducers, the high pulse repetition rates, and the assumption that the fish were moving at about the same velocity as the water. This redundancy criterion enhanced fish detectability in the presence of background interference and provided sufficient change-in-range information to determine direction of fish movement.

As a fish passes through the ensonified beam a succession of echoes indicates, on the echogram, a fish's change-in-range relative to the transducer. This change-in-range information indicates the fish direction relative to the intake or spillgate because of the known position of the transducer. Fish that were moving toward the intake or spillgate were the only traces considered to be fish passing through the dam.

Trace Types

Traces on the echograms for individual fish were initially classified as one of four different types. Below are the four trace types and characteristics initially used to typify each trace type.

1). LONG TO SHORT - a target exhibiting a rapid change-in-range toward the transducer.
2). SHORT TO LONG - a target exhibiting a rapid change-in-range away from the transducer.
3). WALLOWER - a target which showed little or no change-in-range over an extended period of time.
4). NO CHANGE - a target which showed little or no change in range over a short period of time.

Approximately two weeks into the study the above characteristics for trace types were extensively compared with Glines Canyon Dam echogram traces. This comparison indicated that, for spillgate migrants, fish passing from below the level of the gate produced a short-to-long trace type and were actually moving toward the transducer rather then away. This observation was noted and accounted for during data reduction discussed below.

Environmental parameters such as surface disturbances, floating or submerged debris, or the lake bottom produced gas bubbles which, at times, produced non-fish traces. Occasionally, these non-fish traces obscured fish traces. Therefore, each echogram sample period was assessed for the level of background interference and given a "noise code". Noise codes ranged on a scale of one to four defined as follows:

1). No interference on echogram.
2). Slight interference on echogram.
3). Moderate interference on echogram.
4). Heavy interference on echogram.

Data Reduction

Microcomputers were used for data storage and subsequent data analysis. Data recorded on the echograms for individual fish observations were transformed to data files using a Summagraphics "Bit Pad Two" digitizing pad coupled with a LISP fish data entry program developed by FAO personnel. Raw data files contained the following information for each fish detection:

1). Julian date.
2). Start time of transducer interrogation.
3). Duration of transducer interrogation.
4). Transducer location.
5). Background interference level.
6). Quality code.

7). Midpoint location of trace in decimeters from the surface.
8). Trace type.

Raw data files were then appended to dBase II files and checked for mistakes or inconsistencies in the data base. Additional files were created from these files that contained detections converted to the corresponding number of fish passing into the turbine intake or under the spillgate. These detections were weighted individually using beam width and expansion width. Because the cross-sectional area at the sample location was only partially ensonified, individual fish detections were multiplied by a weighting factor to estimate the total relative number of fish passing the location at that particular range and time. To account for the cone-shaped geometry of the transducer beam, the weighting factor was defined as the ratio of the width at the sample location to the width of the beam at the range of detection. Weighting factors, depending on range, varied from 2.99 to 32.89 for individual detection at the turbine intake and 3.14 to 15.68 at the spillgate. Only long-to-short trace types were considered to be fish exiting the system via the turbine intake. In the case of the spillgate, long-to-short trace types that fell within a range of 10 to 40 decimeters and short-to-long trace types within a range of 30 to 50 decimeters were considered to be fish exiting the system. These subjective ranges were decided by using echograms and plotting trace type locations over a variety of gate openings.

Additional computer files were subsequently created that contained the weighted detections summed for individual location by hour for the entire study. Corresponding hourly gate/flow records for each exit (as recorded by dam operators throughout the study) were also entered in the files. These summary files were then transferred into Lotus 1-2-3 for graphic representation and into Statgraphics for statistical analyses.

RESULTS AND DISCUSSION

The general pattern of streamflow and dam operations during the five-week study period in 1986 was similar to that observed during FAO studies the previous several years in the Elwha. During early May, streamflow was relatively low and clear and, with the exception of a brief freshet on May 8th and 9th, a typical non-spill period prevailed. In mid-May, however, warmer temperatures triggered snowmelt and streamflow substantially increased, causing relatively large and varied spill for the duration of the study. Figure 4 depicts total streamflow (and water clarity as indicated by daily secchi disk readings at Glines Canyon Dam) over this study period. Figure 5 splits total streamflow into spill and turbine flows at Glines Dam for this same period. Of note in Figure 5 are the six requested night spills (two low, two mid, and two high) during early May (Julian dates 127-136) that would not otherwise have occurred without request and which resulted in lower associated turbine flows on each occasion. A brief turbine shut down for maintenance also appears in Figure 5 during late May (Julian date 149).

Over the study period as a whole, agreement between number of test fish released in Lake Mills and the estimated number of fish passing Glines Canyon Dam was good. Of the 13,210 steelhead smolts released in Lake Mills over the study period, an estimated 12,312 or 93.2%, were estimated to have passed Glines Canyon Dam based on hydroacoustic measurements. The remainder may have delayed in the reservoir, as adiposed-clipped steelhead smolts were captured on hook-and-line in the upper reservoir on June 26th, July 15th, and August 20th, after FAO discontinued monitoring of dam exits (John Ward, Olympic Outdoor Sportsmen's Association, personal communication). A comparison of cumulative detections versus cumulative releases over the monitoring period also suggested no anomalies in hydroacoustic-based passage estimates (Figure 6).

Of the smolts estimated to have passed Glines Canyon Dam over the monitoring period, virtually all were detected passing via the spillway exit. Approximately 12,020, or 97.6%, of smolts passing the dam utilized the spillway, and much of this movement occurred during night hours, which were defined as 2100 to 0500 hours. In comparison, the total movement into the turbine penstock was insignificant and comprised only 2.4% of the total migrants detected. This minimal movement into the turbine intake was sporadic and unrelated to spill conditions or time of day (Figure 7). Additionally, during non-spill periods (and spill periods) no appreciable milling behavior was detected near any of the spillgates or the turbine intake.

The passage of smolts through the Glines Canyon Dam spillway bore no strong relation to spillgate openings tested. Figure 8 gives a detailed view of estimated hourly movement and corresponding hourly gate opening from the date of the first test release, May 5th, until the close of the study on June 7th. Although Figure 8 shows several isolated high movement periods in the latter half of the study period during high natural spill events, correlation between all hourly gate openings and passage rates over the entire study period was poor ($r^2 = 0.11$).

The rate of smolt movement through the spillway was greater during the latter portion of the monitoring period (Figure 6); however, this greater movement rate may have simply been due to greater and continued availability of the spillway exit during this period (Figure 8). In contrast, brief but relatively high rates of movement were observed in response to all six night spills requested (Julian dates 127-129, 129-131, 134-136) as well as the natural freshet (Julian dates 132-134) during the early portion of the study (Figure 8).

Further regression analysis incorporating multiple variables did not yield a substantially improved predictive relationship for spillgate passage. For this purpose, we applied stepwise regression incorporating Julian date, time of day, and spillgate opening as independent variables. Results indicated greater gate opening in combination with later evening hours provided the greatest correlation with spillgate passage, yet much of the variation in passage remained unexplained ($r^2 = 0.49$). Additionally, Julian date bore little relationship to observed fish passage and improved model results only slightly.

An examination of hourly movement of smolts through the spillway both before and during the higher flow periods also indicated a strong tendency towards nighttime movement at Glines Dam regardless of spill. For this purpose, low and high spill periods were considered to be 5/15-5/18 and 5/19-6/7, respectively, based on examination of Figure 4. Hourly percentages of fish passing the Glines spillway for these periods are shown in Figure 9. As indicated, peak hourly movement occurred after dusk and before dawn during hours of total darkness during both periods. This preference for nighttime movement was similar to that observed for steelhead and coho smolts passing Elwha Dam in 1985, although a somewhat greater rate of daytime movement during higher flows was evident in that investigation (Wunderlich and Dilley 1986).

SUMMARY

In 1986, FAO Olympia conducted a study of steelhead smolt exit selection at Glines Canyon Dam and simultaneously initiated a study of steelhead smolt mortality through both Elwha dams. Objectives of this work were to determine 1) whether steelhead smolts would enter the Glines Canyon Dam turbine, 2) what level of spill would induce smolts to use the Glines spillway, and 3) what long-term mortality would result from steelhead smolt passage though both Elwha dams. Exit selection was assessed using hydroacoustic techniques and an evaluation of juvenile passage mortality was initiated. The juvenile passage mortality study will be completed by comparing 1987-1988 returns of coded-wire steelhead in lower Elwha River fisheries and hatchery racks.

Findings of the completed exit selection study for steelhead smolts at Glines Canyon Dam were:

1) Steelhead smolts almost exclusively used the spillway to pass Glines Canyon Dam rather than sound 80 ft to the turbine intake in the reservoir forebay. In this study, spillgate No. 5 was the only spillgate tested. Approximately 98% of steelhead migrants detected leaving Lake Mills used this spillway for egress during the study period. This preference for spillway passage was evident during both spill and non-spill periods over the course of the study.

2) Degree of smolt passage through the Glines spillway was not strongly correlated with spillgate openings tested, although higher gate opening in association with later nighttime hours did account for approximately half of the variation in smolt movement observed in the spillway.

3) Three levels of requested night spilling (approximately 100, 200, and 500 cfs) in early May during an otherwise non-spill period produced in each case relatively high steelhead smolt movement through the spillway. Spilling in this range may therefore offer an effective means to pass steelhead smolts by Glines Canyon Dam during otherwise non-spill periods.

4) Steelhead smolts displayed a strong overall tendency towards nighttime movement through the Glines spillway, regardless of total streamflow or associated water clarity. Nighttime movement was defined as movement from approximately 2100 to 0500 hours.

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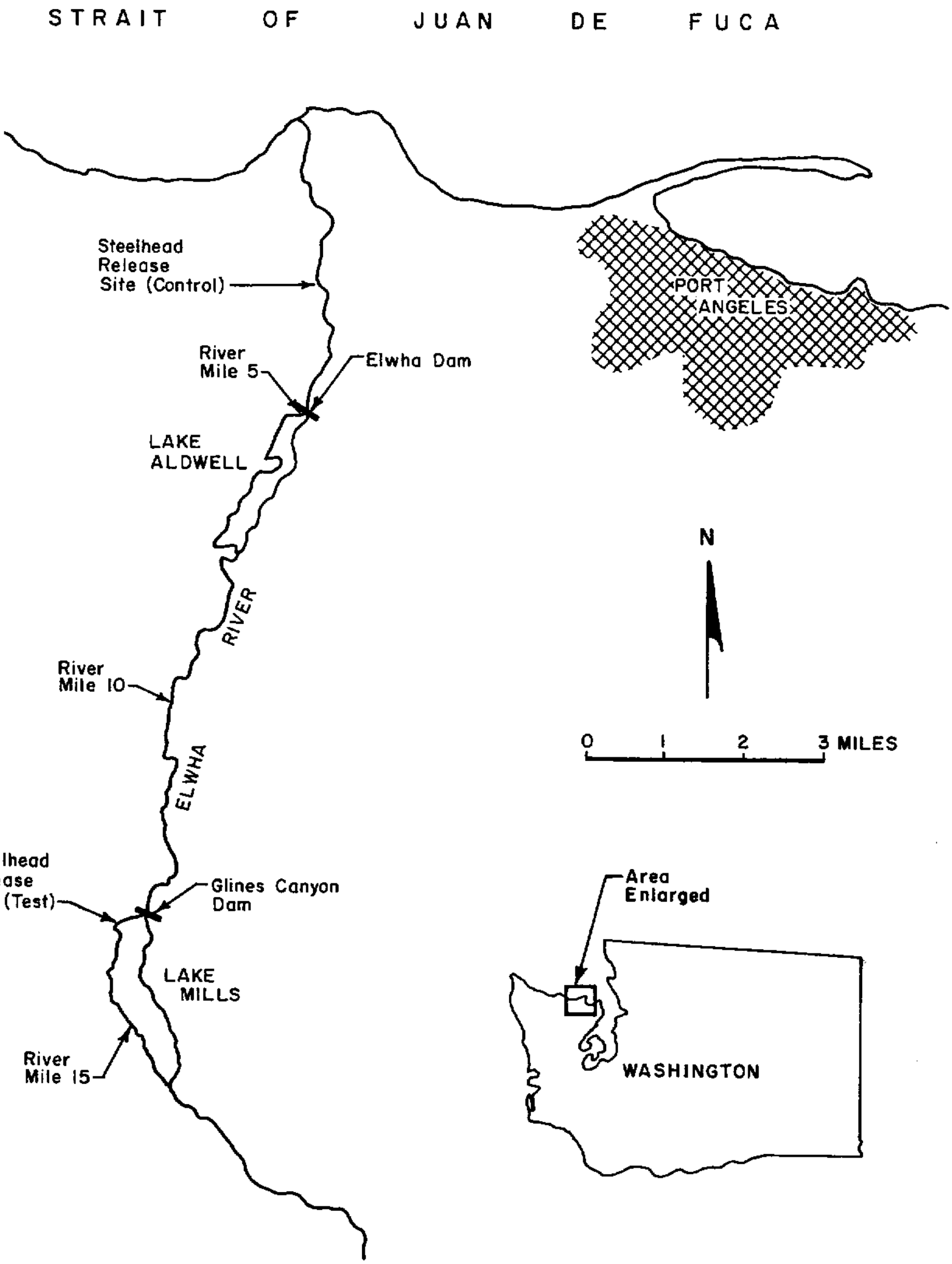

Figure 1. The Elwha River and project features.

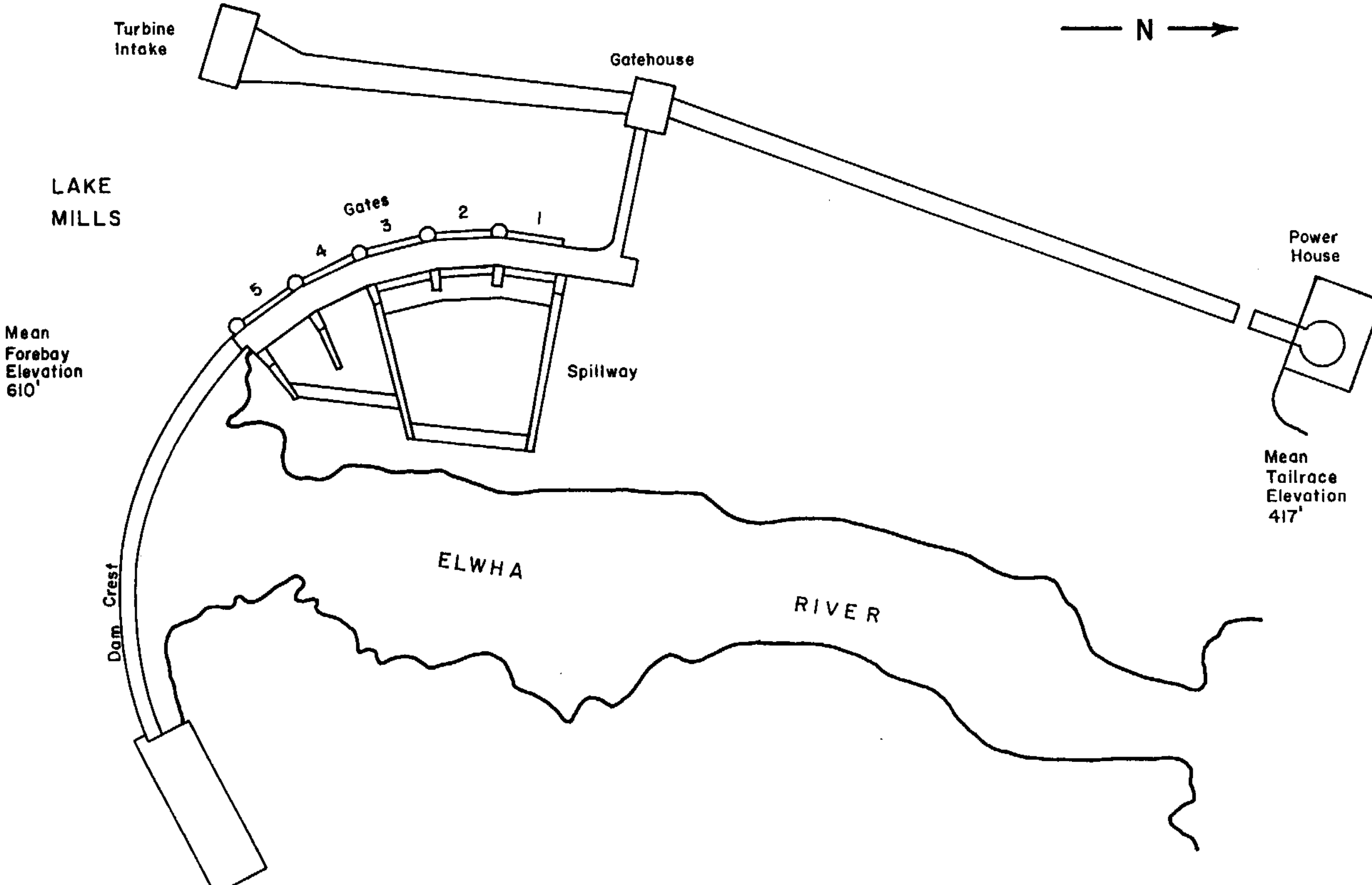

Figure 2. Glines Canyon Dam.

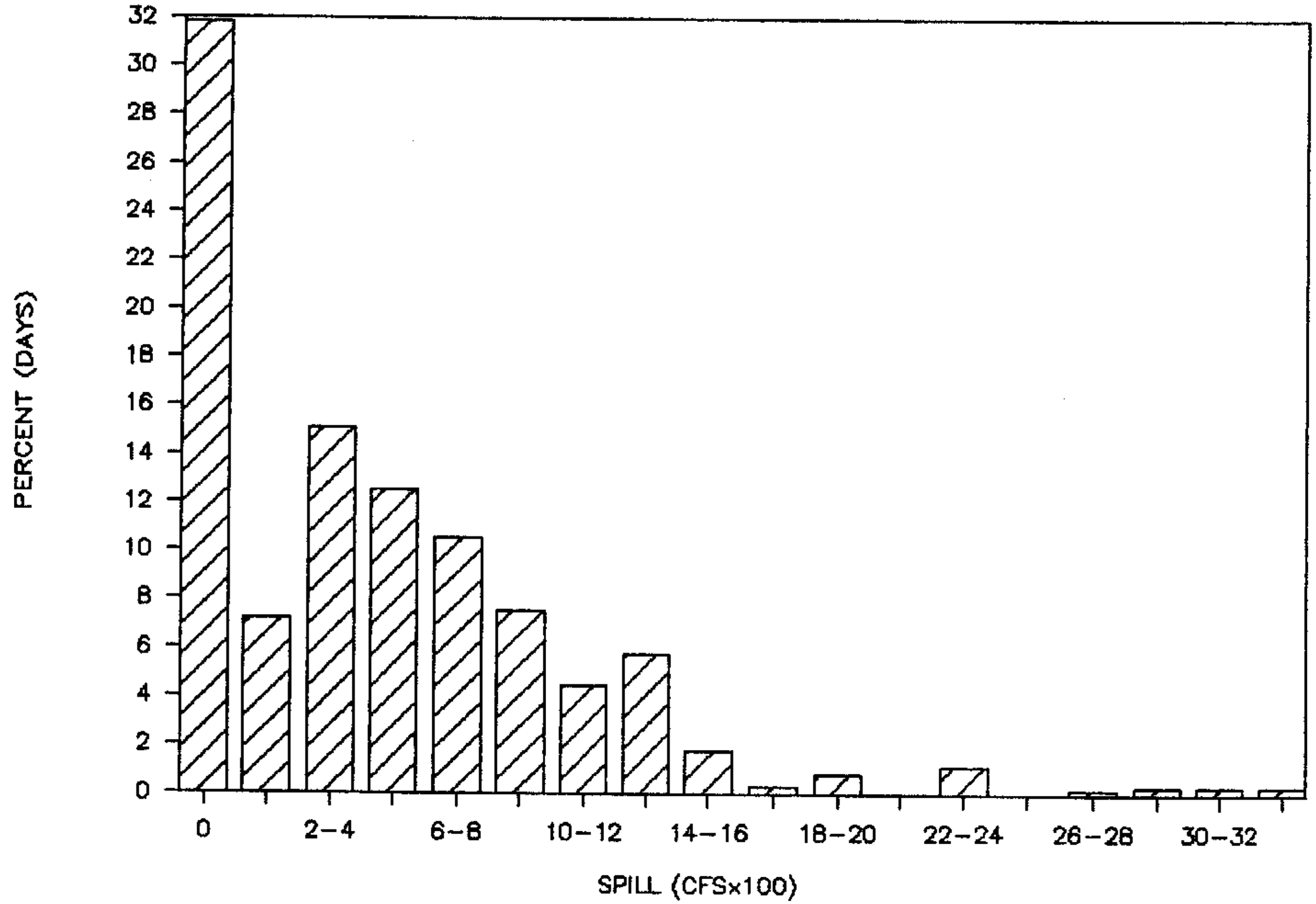

Figure 3. Frequency of spill at Glines Canyon Dam during spring month (4/15 - 6/30) for the years 1978 - 1986.

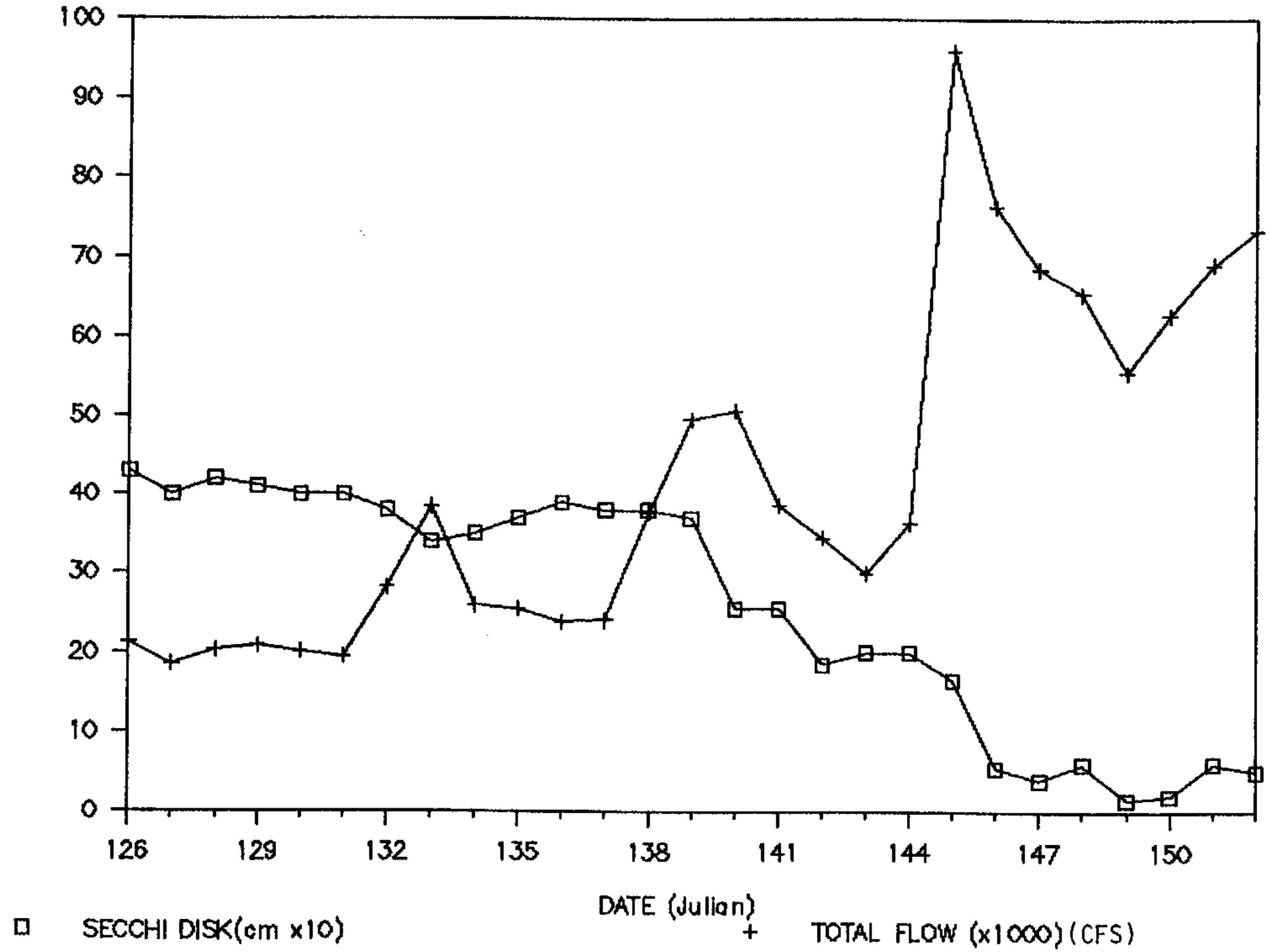

Figure 4. Total daily streamflow and water clarity (as measured by Secchi Disk) at Glines Canyon Dam from May 5th to June 6th, 1986.

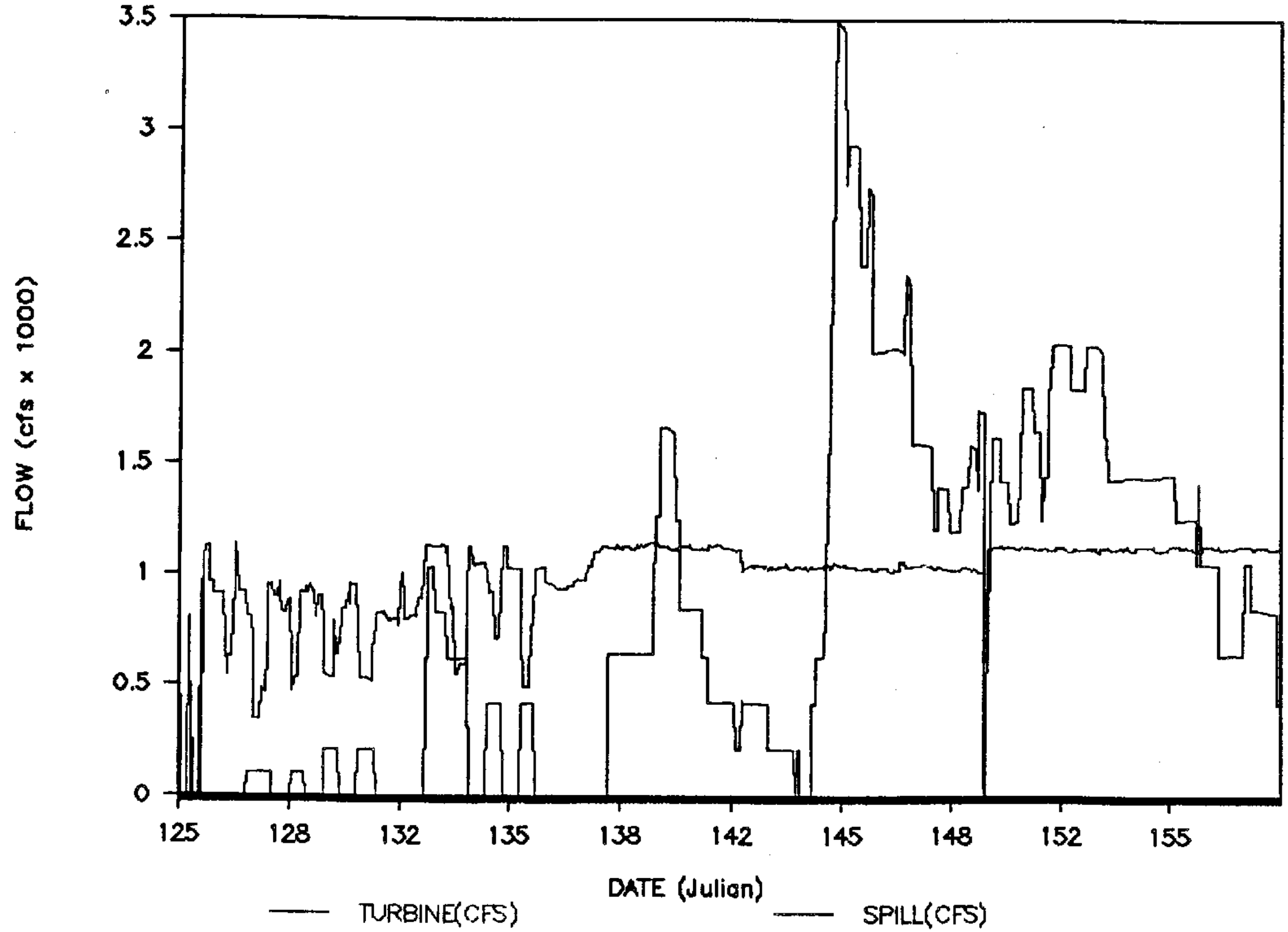

Figure 5. Hourly spillway and turbine flows at Glines Canyon Dam from May 5th to June 6th, 1986.

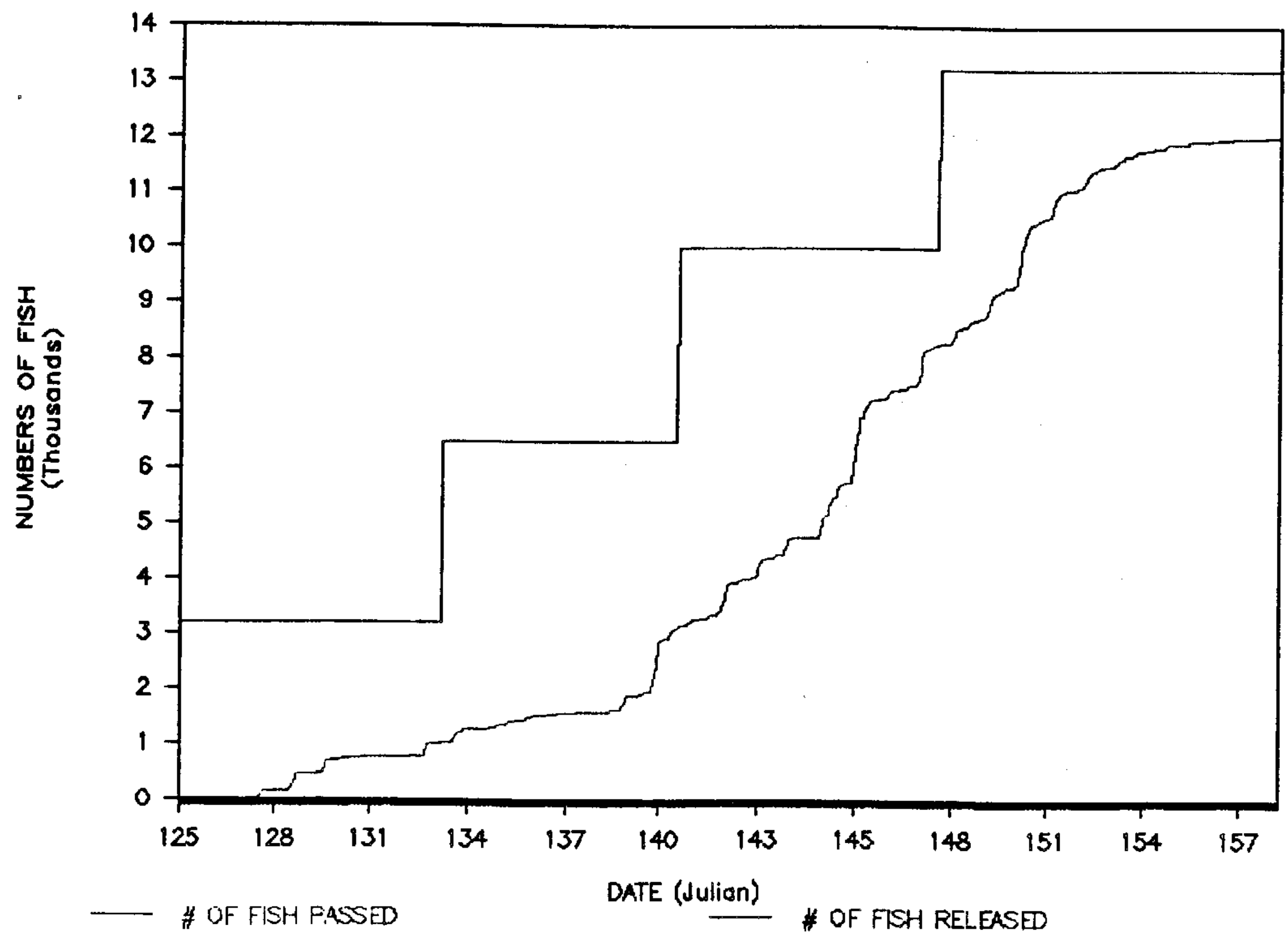

Figure 6. Cumulative numbers of steelhead smolts released in Lake Mills and detected passing Glines Canyon Dam in 1986.

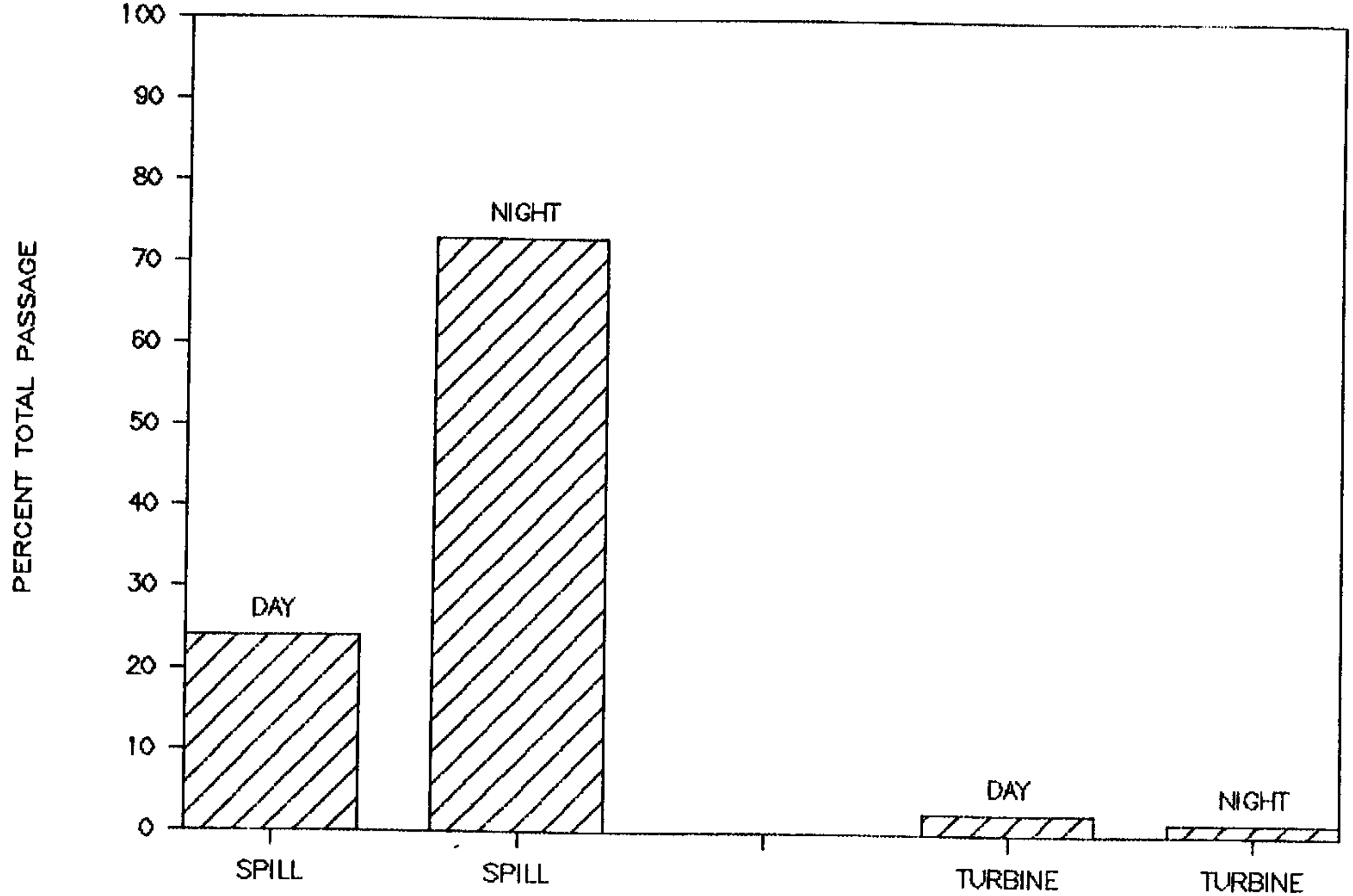

Figure 7. Percent of smolt passage into spillway and turbine intakes during day and night periods. The night period was defined as 2100 to 0500 hours.

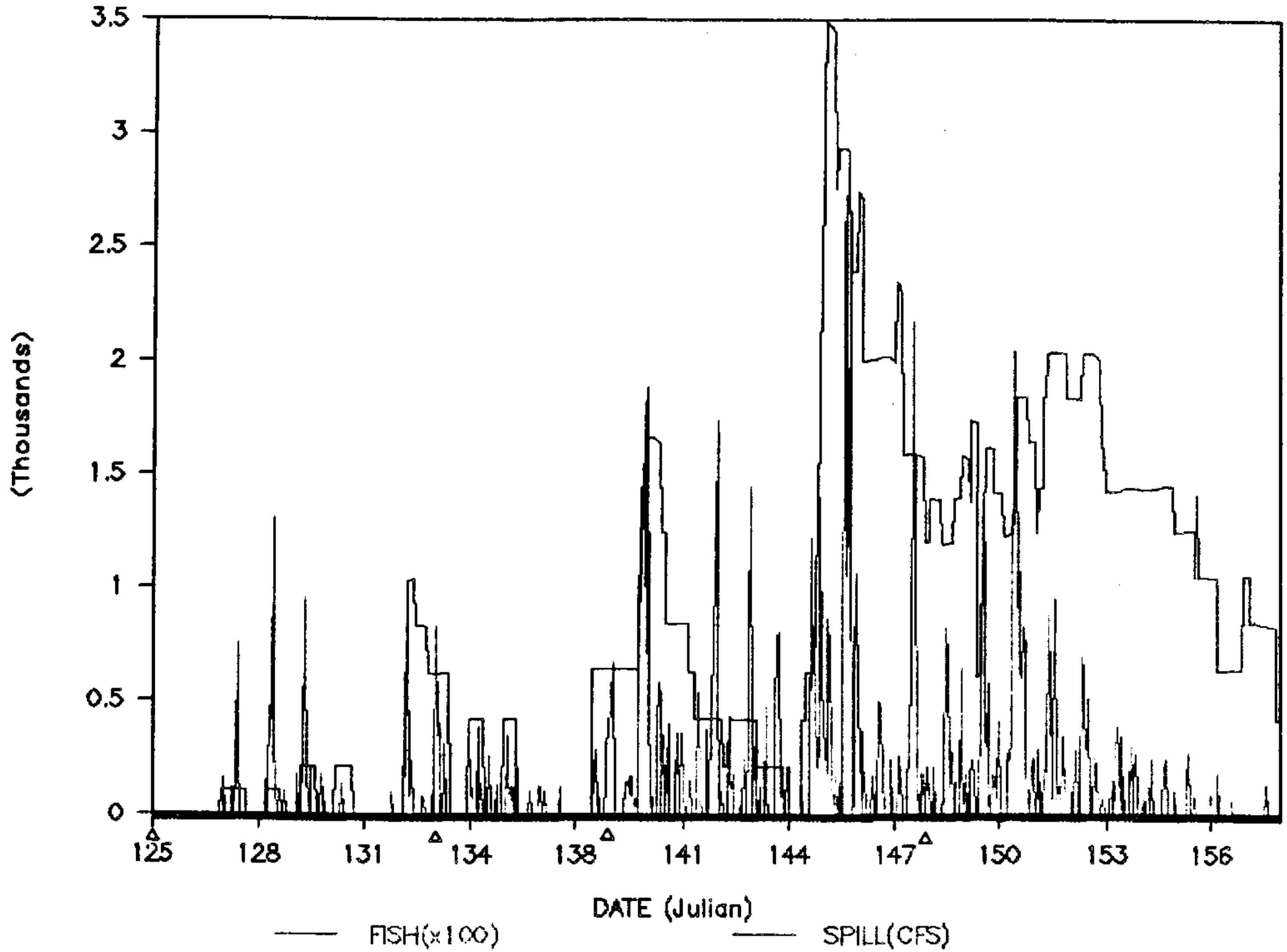

Figure 8. Hourly spillway flow and corresponding smolt movement through the Glines Canyon Dam spillway over the study period. Arrows indicate test fish release dates.

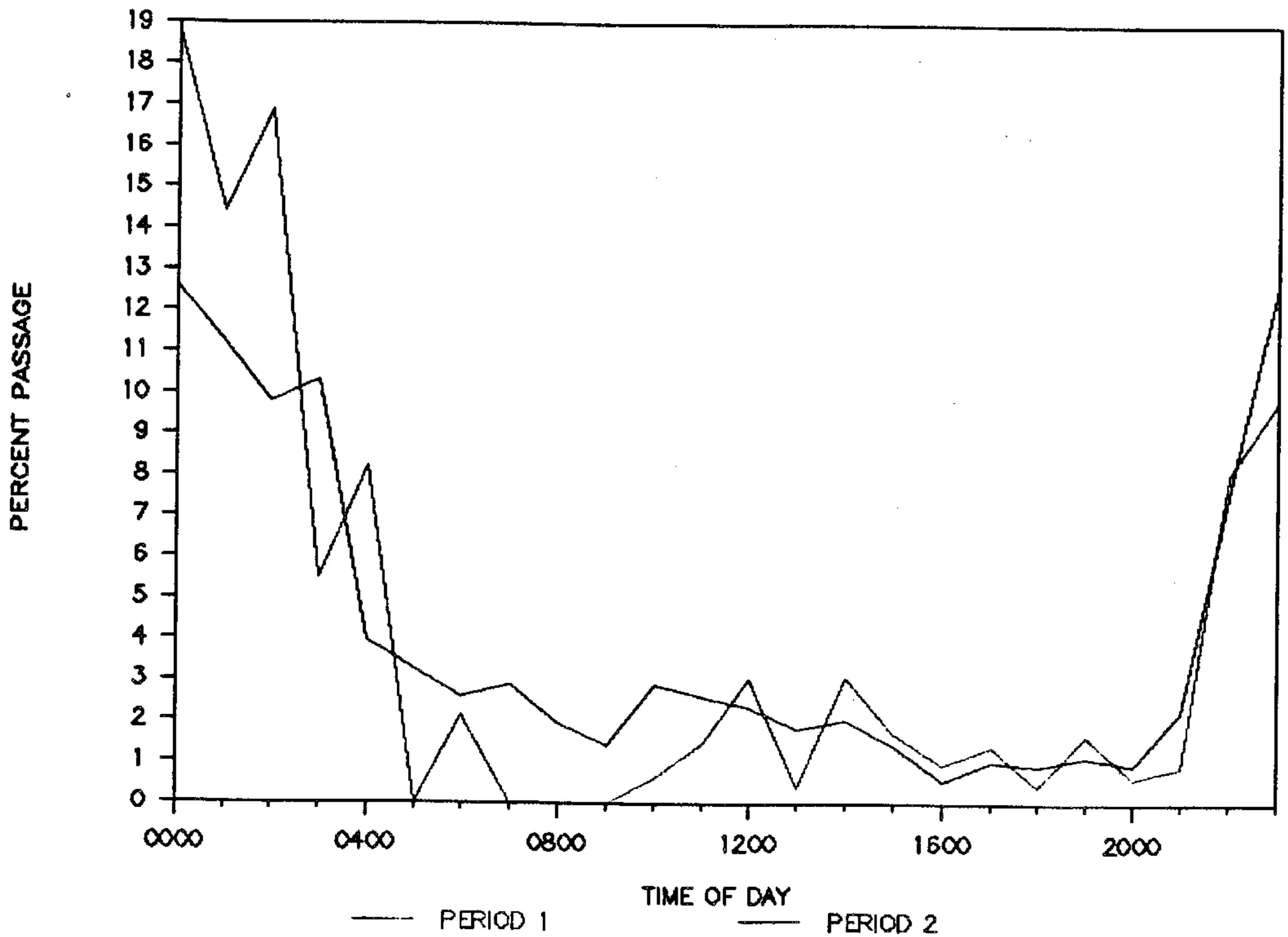

Figure 9. Hourly percentage of fish passage through the Glines spillway during period 1 (5/5 - 5/18) and period 2 (5/19 - 6/7).

Table 1. Test and control releases of winter steelhead smolts in the Elwha R. in 1986.

Purpose	Release Location	Release Date	Group Size	No. Tagged at Release	Tag Code	Mean Fork Length at Release (mm)	(n)
1st Test	Lk. Mills forebay	5/5/86	3,198	2,984	5-17-37	203	100
2nd Test	Lk. Mills forebay	5/13/86	3,295	3,094	5-17-36	195	100
3rd Test	Lk. Mills forebay	5/20/86	3,496	3,069	5-17-35	200	99
4th Test	Lk. Mills forebay	5/28/86	3,221	2,770	5-17-34	202	101
1st Control	River Mile 3	5/7/86	2,415	2,314	5-17-33	199	99
2nd Control	River Mile 3	5/22/86	2,379	2,136	5-17-32	202	100
3rd Control	River Mile 3	5/28/86	2,297	1,923	5-17-30	203	100
4th Control	River Mile 3	6/3/86	2,233	2,057	5-17-31	207	99

Table 2. Hydroacoustic equipment used at Glines Canyon Dam during spring of 1986.

Item	Manufacturer	Model No.
Echo Sounder/Transceiver	BioSonics, Inc.	101
Multiplexer/Equalizer	Biosonics, Inc.	151
Thermal Chart Recorder	BioSonics, Inc.	111
Transducer (15^{0})	BioSonics, Inc.	-
Oscilloscope	Hewlett Packard	1703A