To Alaska Power Authority
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December 1982

EFFECTS OF HYDROELECTRIC DISCHARGE FLUCTUATION ON SALMON AND STEELHEAD IN THE SKAGIT RIVER, WASHINGTON

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FINAL REPORT
December 1979 to December 1982

for

City of Seattle
Department of Lighting
Office of Environmental Affairs
Seattle, Washington

UNIVERSITY OF WASHINGTON
SCHOOL OF FISHERIES
FISHERIES RESEARCH INSTITUTE

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Approved:

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Director

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1.0 ABSTRACT

The escapement levels of (summer-fall) chinook, pink and coho salmon for 1978-1981 were comparable to previous years. A strong year class of chum salmon occurred in 1978 with a less than average return in 1980. The most heavily spawned section of the mainstem Skagit River for summer-fall chinook was between Diobsud Creek and the Cascade River. The number and distribution of spawning steelhead trout was most concentrated in the mainstem Skagit between the Cascade and Sauk Rivers.

The behavioral study of spawning chinook, chum and pink salmon exposed to fluctuating flows showed a general pattern of activity indicating females would complete redds if fluctuating discharge provided adequate flows over a redd site at least several hours daily.

The incubation of steelhead trout eggs at several Skagit River sites indicated that 1050 temperature units are required to reach the button-up stage of development.

The effects of dewatered or static water conditions on the survival of incubating chinook, coho, and chum salmon and steelhead trout eggs and alevins in selected gravel environments were examined. A 9 x 4 factorial design was employed in the first year studies with 5 dewatered or static conditions (0, 4, 8, 16 and 24 hrs (continuous) per day) and 4 gravel sizes (0.33-1.35, 0.67-2.67, 1.35-5.08, and 0.08-5.08 cm) as the environmental variables. In the second year a single gravel composition representative of Skagit River substrate was used with dewatering times of 0, 2, 4, 8, 16 and 24 hrs/day. Eggs were tested from the time of fertilization through hatching.

Prehatching survival generally was high for all species, gravel sizes and dewatering or static regimes tested. Posthatching survival for all species

and gravel sizes generally decreased in direct relation to the amount of time dewatered or in static condition. For all species, gravel size and dewatering regimes at least 50 percent of the alevins had died within a week after hatching.

The alevin behavior studies have shown that salmonid alevins are capable of making downward migrations through some gravel substrates to avoid dewatering. The size of the gravel substrate is directly related to the number of successful migrations.

The relationship between ramping rates from 357 to 2757 cfs/hr and salmon fry stranding was investigated. The inclusion of daylight as a variable suggested an interaction with downramping and salmon fry stranding; however, steelhead fry indicated an opposite effect with more stranded at night. Additional behavioral studies are needed to define the responses of juvenile salmonids to flow fluctuation.

2.0 ACKNOWLEDGMENTS

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Fisheries Research Institute, University of Washington

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Mr. Greg Tutmark

Skagit System Cooperative

Mr. Steve Fransen

U.S. National Marine Fisheries Service, Seattle

Mr. Jon Linvog

U.S. Fish and Wildlife Service, Olympia

Mr. Tom Payne

In addition to the above organizations, the U.S. Forest Service and North Cascades National Park Service are represented on the Skagit Interim Agreement

Standing Committee.

The valuable cooperation and assistance received from Mr. John Clayton and Mr. Steve Stout at the Washington Department of Fisheries Skagit Salmon Hatchery is greatly appreciated. Mr. R. Orrell from WDF's Skagit laboratory provided information on Skagit River salmon and additional assistance in the field. Messrs. Engman and Tutmark (WDG) conducted aerial and field surveys and provided additional information on Skagit River game fish. Mr. Sterling Cross (WDG) assisted in the supply of steelhead eggs. The U.S. Geological Survey provided timely discharge and temperature data for the Skagit River. Thanks are due to Dr. E. Brannon, University of Washington, School of Fisheries, for technical advice on salmon egg development, handling, and salmon alevin behavior; Mr. G. Yokoyama, University of Washington Hatchery for supplying eggs and technical assistance. Additional part-time FRI personnel who assisted in construction of the laboratory facility were Lynn McComas, Gloria McDowel and Asko Hamalainen. Mike Goebel and Paul Dinnel provided temporary assistance in the field studies.

3.0 INTRODUCTION

3.1 History of the Skagit Project

The City of Seattle began development of the hydroelectric potential of the Skagit River in the early 1900's. The Lighting Department of the City undertook a staged development of three dams: Gorge, Diablo and Ross, which were begun in 1919, 1927, and 1937, respectively. Plans for development included the multistage construction of Ross Dam which was completed to an elevation of 1,365 ft in 1940, to 1,550 ft in 1946, and to the present elevation of 1,615 ft in 1949. The presence and operation of these dams has altered the general flow and thermal regimes of the Skagit River downstream of the Skagit Project.

Operational constraints in addition to those specified by Federal license were implemented in 1972 by informal agreement between the Washington Department of Fisheries (WDF) and Seattle City Light (SCL). Minimum flows were established during the period of peak juvenile salmon abundance in an effort to reduce the impact of dam operation on downstream fish survival.

In 1979, relicensing of these existing projects stimulated negotiations to obtain greater resolution of the relationships between regulated discharge and salmon and steelhead production. The City of Seattle, Washington Departments of Fisheries and Game, Skagit System Indian Tribes, U.S. Fish and Wildlife Service, and U.S. National Marine Fisheries Service entered into a two-year interim agreement (FERC Docket No. EL-78-36) regulating the rate and magnitude of flow fluctuation in the Skagit River. The present fisheries studies were required by this agreement to obtain additional data on salmon and steelhead reproduction.

3.2 Objectives

Field study objectives were designed to determine the effects of Skagit River flow fluctuations on the spawning behavior, egg deposition efficiency, incubation, fry survival to emergence and fry stranding of steelhead trout and chinook and chum salmon. Laboratory studies encompassed two areas: (1) the effects of fluctuating flows on survival of eggs and alevins and 2) the behavior of pre-emergent alevins. Specific objectives in the first area were to 1) determine the tolerance to continuous dewatering on pre- and post-hatching egg-alevin development stages of chinook, coho, chum and pink salmon and steelhead trout; 2) determine the tolerance to multiple dewatering regimes of 2, 4, 8, and 16 hours per day on pre- and post-hatching stages of each species; 3) determine the tolerance to multiple dewatering regimes (2, 4, 8, and 16 hours daily) throughout all developmental stages; 4) determine survival rates for each of the above dewatering or static water regimes in specific gravel substrates and 5) determine the quality of fry surviving each dewatering regime. Specific objectives in the second area were to determine 1) the ability of alevins to make downward intragravel migrations to avoid dewatering; 2) if intragravel movement of alevins occurs under conditions of adequate velocity, dissolved oxygen, and darkness; 3) the level of water velocity that will stimulate movement of alevins and record if that movement is random or indicative of a positive or negative rheotactic response; 4) the survival and movement of alevins in response to various levels of dissolved oxygen; 5) the direction and magnitude of alevin photo response; and 6) if the developmental stage of an alevin alters its response to the preceding environmental stimuli.

4.0 STUDY AREA

The Skagit River, with headwaters in Canada, flows south across the international boundary through a reservoir complex made up of Ross, Diablo and Gorge reservoirs, then continues generally west where it enters Puget Sound near Mount Vernon, Washington. The Skagit is the largest river flowing into the Sound. There are three major tributaries to the Skagit River: the Cascade River, which flows in at the town of Marblemount at river mile (RM) 78.1; the Sauk River, which enters near Rockport at RM 67.0; and the Baker River, which flows in at Concrete at RM 56.5. Numerous additional small tributaries enter the Skagit River.

These studies were conducted primarily in the Skagit River between Newhalem and the confluence of the Sauk River. This area of the Skagit River immediately downstream of Newhalem is most affected by operation of SCL dams. A map showing the Skagit River study area is presented in Fig. 1. The locations of U.S. Geological Survey gaging stations, salmon hatchery and laboratory and rearing facilities operated by WDF and WDG are also indicated.

The 1980-81 daily maximum, minimum and mean gage heights at Newhalem and Marblemount are presented in Figs. 2, 3, 4, and 5. The gage heights have been converted into discharge in cubic feet per second which indicate a consistent change in daily discharge throughout the year. A complete set of these data plotted by hour and day can be found in Appendix I.

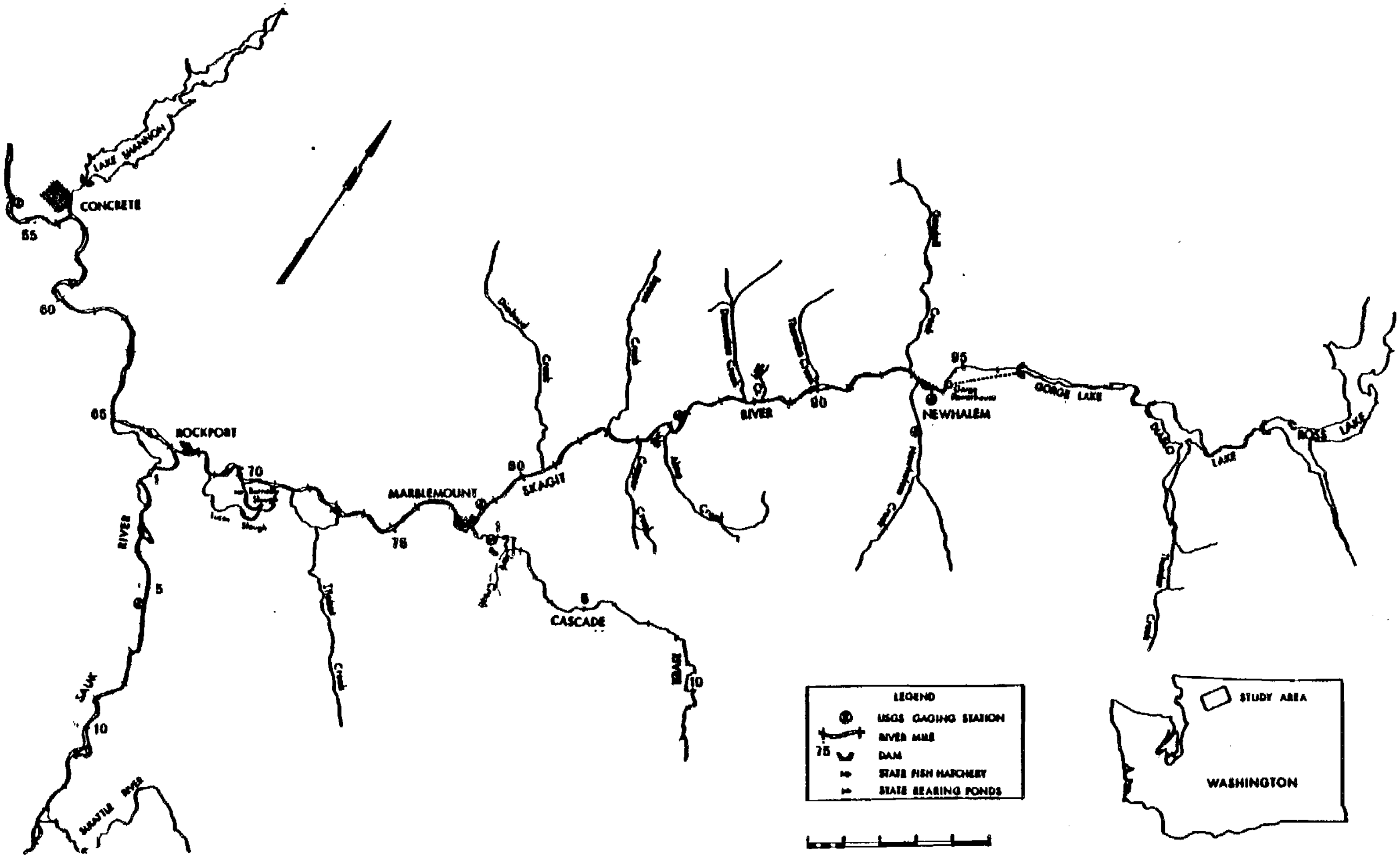

Fig. 1. Skagit Basin study area.

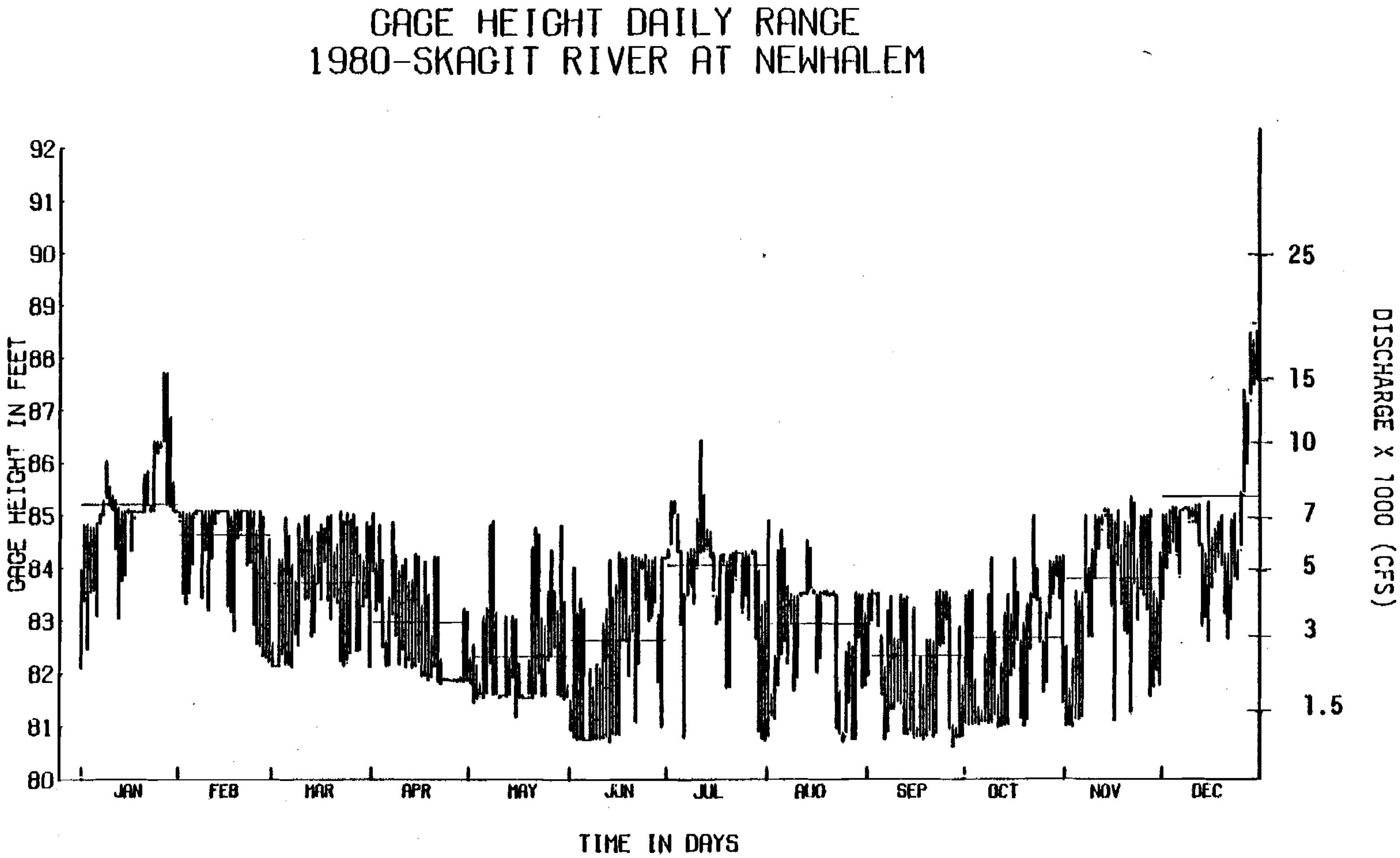

Fig. 2. Daily range of flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for 1980. The mean daily and monthly discharges are also shown.

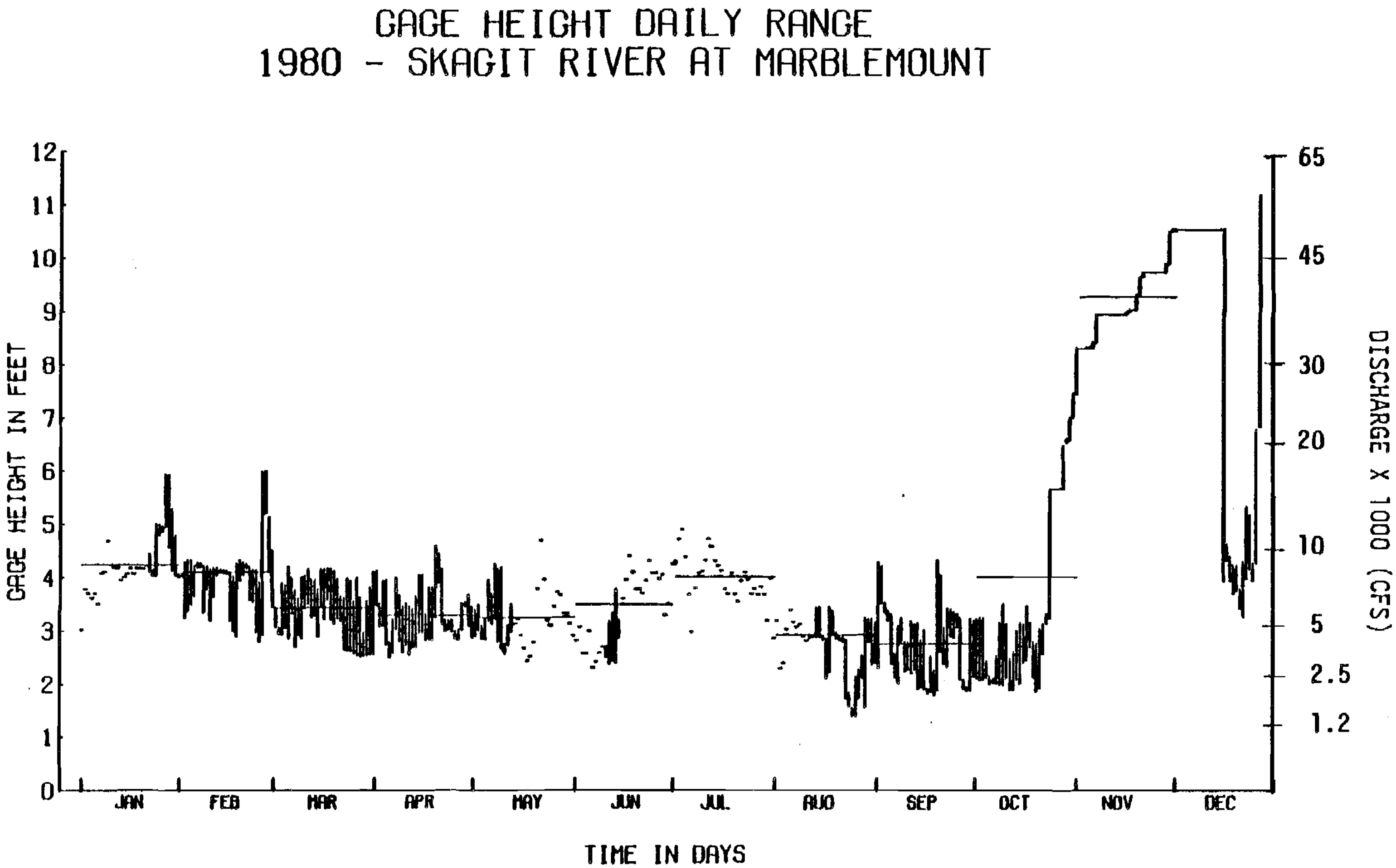

Fig. 3. Daily range of flow fluctuations in ft and cfs for Skagit River at Marblemount (USGS) for 1980. The mean daily and monthly discharges are also shown.

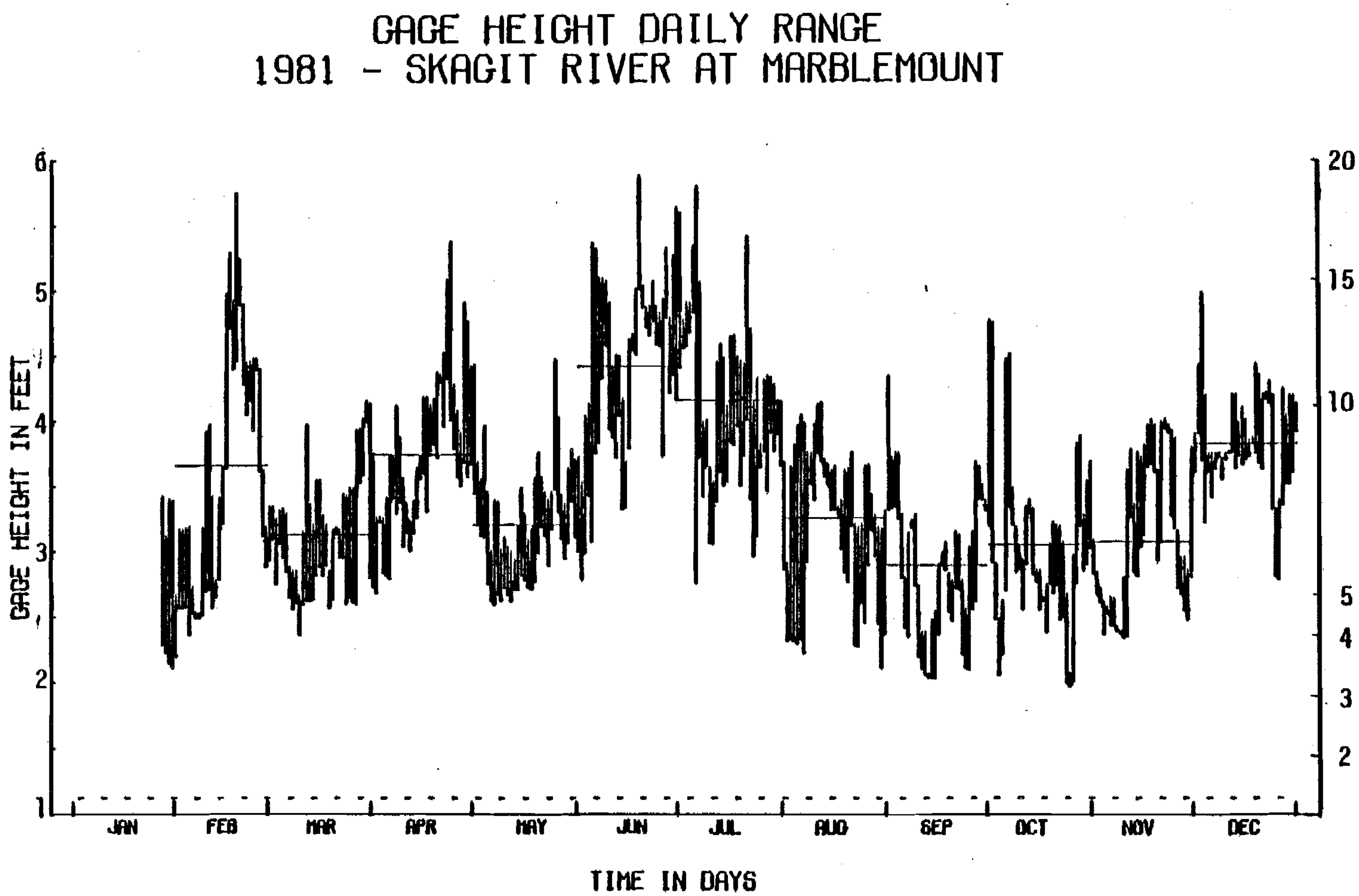

Fig. 4. Daily range in flow fluctuations in ft and cfs for Skagit River at Marblemount (USGS) for 1981. The mean daily discharges and the mean monthly discharges are also shown.

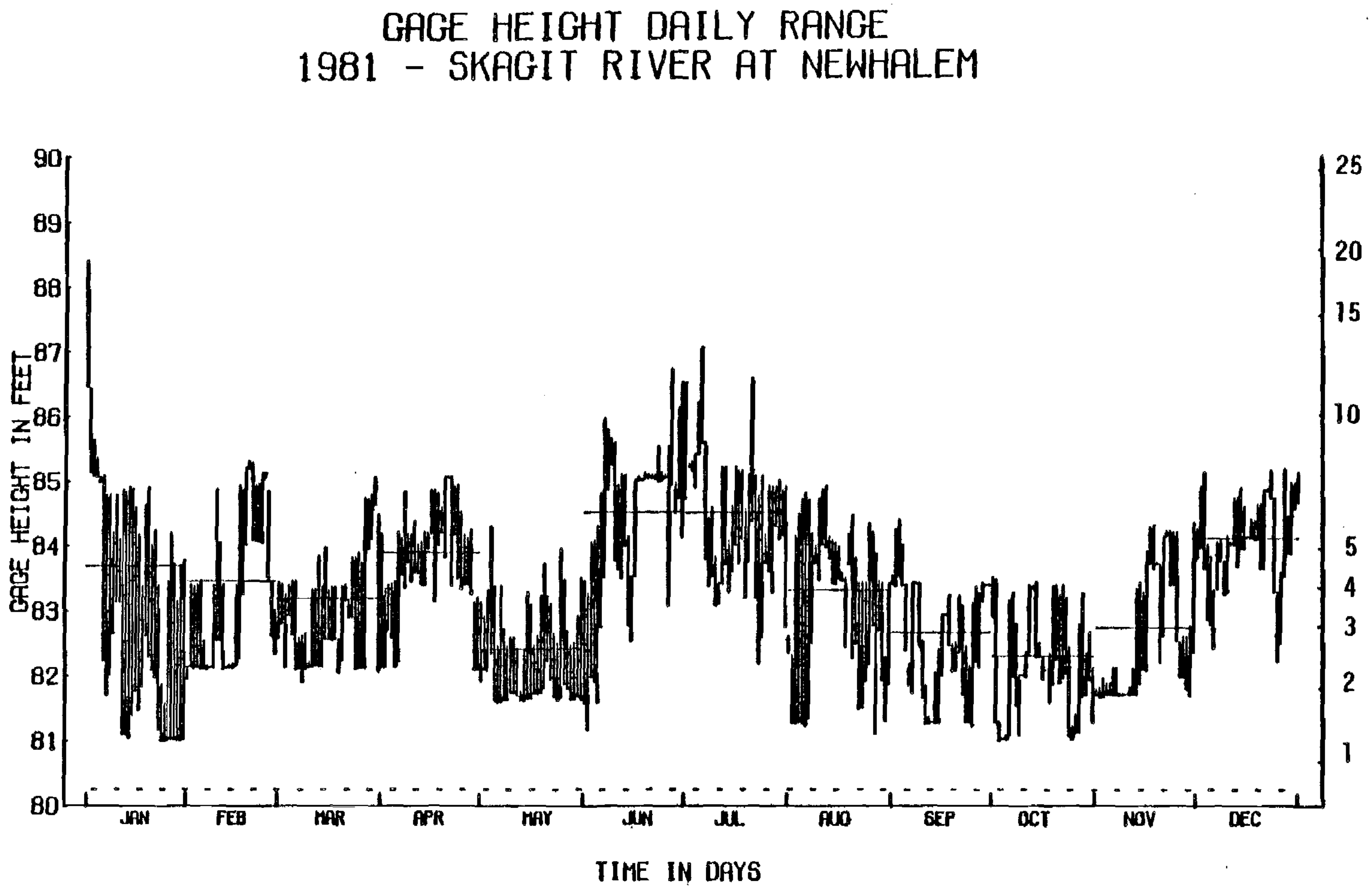

Fig. 5. Daily range in flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for 1981. The mean daily discharges and the mean monthly discharges are also shown.

5.0 METHODS AND MATERIALS

5.1 Escapements, Spawner Distribution and Area Spawned

5.1.1 Salmon

Boat and aerial surveys (helicopter or fixed wing) were conducted by WDF to estimate the Skagit system natural spawning escapements and distributions for chinook (summer-fall and spring), pink, chum and coho salmon. Aerial photographs of the Skagit River between Newhalem and the Sauk River were taken on October 6, 1980, two weeks after the peak of the chinook salmon run and on October 11, 1981 to document the latter part of the chinook run and the peak of the pink salmon spawning

5.1.2 Steelhead

The distribution and timing of steelhead spawning activity by river section was determined by plotting the location of redds on recent aerial photos of the river during periodic aerial spawning surveys. The length of time individual redds were visible from the air was established by marking artificial or natural redds and noting the elapsed time to obscurity. Estimates of redd life were devèloped by WDG steelhead management biologists.

The information obtained from spawning surveys was used in three ways. First, it enabled the location and subsequent relocation of a number of redds for study of relationships between Gorge Powerhouse discharge and water depth in spawning areas. Secondly, these surveys allowed the prediction of locations and approximate timing of emergence of large concentrations of steelhead fry. These fry were subjects of stranding experiments during the summer. Third, the information from spawning surveys provided an estimate of total steelhead run size in the Skagit River. Total run size was used to evaluate the relative strength of the naturally spawning steelhead population and to provide a baseline for comparison to future conditions.

5.2 Adult Spawning-Flow Fluctuation Studies

5.2.1 Salmon Spawning Behavior

Chinook salmon females selecting redd sites in less than two feet of water were chosen for study. Two methods were employed: the first involved marking individual female chinook which had initiated their spawning activity, and the second involved marking redds in the initial stages of construction. In the first few days of the study, chinook females were spotted digging redds in shallow water and marked by snagging them on the back with a treble hook with a piece of surveyor flag attached. This method of tagging was abandoned because it was very difficult to be certain that the desired female was tagged. Actively spawning females were always accompanied by several males, and a positive determination of which fish in the group was marked was difficult. Subsequent marking was accomplished by entangling female chinook from selected redds with a drifted 6 1/2 inch mesh gill net. This capture method allowed for positive identification of females as well as determination of their condition, i.e., unspawned, partially spawned or spawned out. Peterson disk tags with tabs and flagging were utilized to mark the chinook females captured in the gill net. Color combinations were utilized to uniquely identify each female. The area sampled was from RM 78 to RM 83.

Observations by boat and on foot were made daily to record spawning behavior patterns in the river in general and of marked females specifically. Concurrent with the marking of female chinook, redds located in depths of two feet or less were marked by placing painted rocks near the redd. Only those redds which were newly initiated were marked. These redds were monitored daily to determine when subsequent digging activity and eventual completion of the redds occurred.

The fluctuating flows during the chinook study period were monitored via the U.S.G.S. stream gage at Marblemount (No. 12181000). The general flow conditions were monitored with spot checks of the gage, and details on daily flow fluctuations were determined from the U.S.G.S. flow records after the field observation period. The daily range of flow fluctuations during this study period were influenced by maintenance activity at Gorge Power House, which restricted generating capacity. This activity restricted the maximum powerhouse discharge to about one-half its normal maximum but did not influence minimum flows in 1981.

Two sampling locations were selected for the marking of chum salmon females and observation of their spawning activity. These sites were the Thornton Creek side channel at RM 90 and Marblemount Slough at RM 78. These discrete spawning areas were selected because it was believed the best opportunity to mark unspawned females entering a spawning area occurred where subsequent observations could be made.

To capture females for marking a 6 1/2 inch mesh gill net was set to block the study slough or side channel below an area of known spawning activity. The net was set at nightfall and fish were picked from the net for tagging immediately after becoming entangled.

Unspawned and partially spawned females were marked for individual identification with color-coded Peterson disk tags with backup plastic tabs. The disks were 1 inch in diameter and the tabs were 3/4 inch wide by 3 inches long. Daily observations on foot were made in Marblemount Slough to record the general spawning activity of chum salmon and the specific activity of the marked females.

The spawning behavior of adult chinook and pink salmon was monitored in the fall of 1981 by observing the activity around redds marked with painted rocks rather than marking individual females.

5.2.2 Steelhead Redd Depth - Flow Relationship

In 1982, the method for developing relationships between flow and steelhead spawning was improved from that used in 1981. In 1981, redd depth was measured after each spawning survey flight, however; in addition to measuring redd depths after spawning surveys, redds were marked with color-coded construction bricks in 1982. This additional feature allowed identification of individual redds long after each redd was no longer visible. This method provided the ability to determine the effects of unusually low flows (lower than observed in 1982) on steelhead spawning areas.

5.3 Instream Incubation Tests

5.3.1 Steelhead Temperature Unit Requirements

One ripe female steelhead and two males were obtained from the WDG Barnaby Slough rearing station on March 31, 1980. Eggs were stripped from the female and milt from the two males added to the eggs, mixed, and allowed to stand for 1 min. The eggs were rinsed several times, permitted to water-harden for 30 min and transported to three sites on the Skagit River at Newhalem (RM 92), Sutter Creek (RM 70), and Rockport below the Sauk (RM 65). Fifty eggs and 3/4 inch gravel were loaded in 17 oz perforated freezer containers. A set of ten containers was placed in each of three expanded metal cages which in turn were positioned on the river bottom at each of the three locations. Approximately six weeks after the fertilization and planting date of March 31, one container was removed from each location and subsequent containers removed at two-week intervals. A Ryan thermograph was used to monitor water temperature in the river near the incubation containers.

5.3.2 Flow Fluctuation Tests

Field incubation studies were initiated with chum salmon in two side channels of the Skagit River in which this species was historically known to spawn. The upper site opposite the mouth of Thornton Creek at RM 90 is 4.2 mi downstream from Gorge Powerhouse and experiences the full magnitude of flow fluctuations. The lower site, designated Marblemount Slough, at RM 77.5 is 16.7 mi downstream of Gorge Powerhouse and experiences somewhat dampened flow fluctuations due to unregulated tributary inflow.

Skagit chum salmon eggs, fertilized on approximately December 10, 1979, were obtained from the Skagit Tribes Cooperative at the eyed stage on January 19, 1980. Groups of fifty eggs were mixed with 3/4 inch gravel and placed in either perforated plastic freezer containers or Whitlock-Vibert (W-V) boxes. Ten freezer containers were positioned double-file, in 8-inch deep trenches and covered with substrate at each of four water depths. These water depths at the time of planting were 0.5', 1.0', 1.5' and 2.5' and corresponded to Newhalem and Marblemount gage heights of 85.07 ft and 4.17 ft, respectively. The eggs buried to 2.5' water depth ($\sim$3.0' egg depth) were considered unlikely to be dewatered and served as controls. In addition, a Ryan thermograph was buried at each of the four artificial redd depths to determine the rate of temperature unit (TU) accumulation and to detect any significant temperature fluctuation that could be attributed to a dewatering event.

Following planting, a freezer container and/or W-V box was removed every two weeks from each redd depth and the development stage and live-to-dead ratios of the eggs or alevins were recorded. The eggs were preserved in Stockard's solution and the alevins in 10 percent formalin for subsequent analysis.

analysis.

5.4 Laboratory Incubation Tests

5.4.1 Experimental Facilities

An experimental hatchery facility was constructed at the Skagit Salmon Hatchery to test the effects of controlled flow fluctuations on salmonid eggs and alevins. The 116-m^2 laboratory was supplied with fresh spring-fed Clark Creek water at the rate of 19 L/sec. This water was pumped through a 7 1/2 hp Peabody Barnes (Model 15 CCE) self-priming centrifugal pump (with a second pump plumbed in tandem for back-up) into two head tanks located adjacent to the building. These tanks provided a 3-m head of water which was gravity-fed into a series of 16 1.22 by 2.44 m water tables (modified from Hickey et al. 1979). Each table (Fig. 6) was divided into four separately controlled compartments and contained a total of 128 10 cm diameter by 38 cm long PVC incubation cylinders. The cylinders had flat stock PVC bottoms and 8 screened 4 cm diameter holes located in the lower 10 cm (Fig. 7). Water entered a false bottom in each compartment and upwelled through each of 32 cylinders per section. Removal of a vertically adjustable plug near the bottom of each section dewatered that section to desired levels.

5.4.2 Artificial Redds

In the first year of studies, eggs and milt were obtained from chinook salmon spawned at the University of Washington Fish Hatchery and transported separately in cooled containers to the Skagit Salmon Hatchery. Groups of eggs were then fertilized with water activated sperm as needed. Similar procedures were repeated with coho salmon obtained from the Skagit Salmon Hatchery and steelhead trout from Barnaby Slough steelhead rearing pond. A limited number

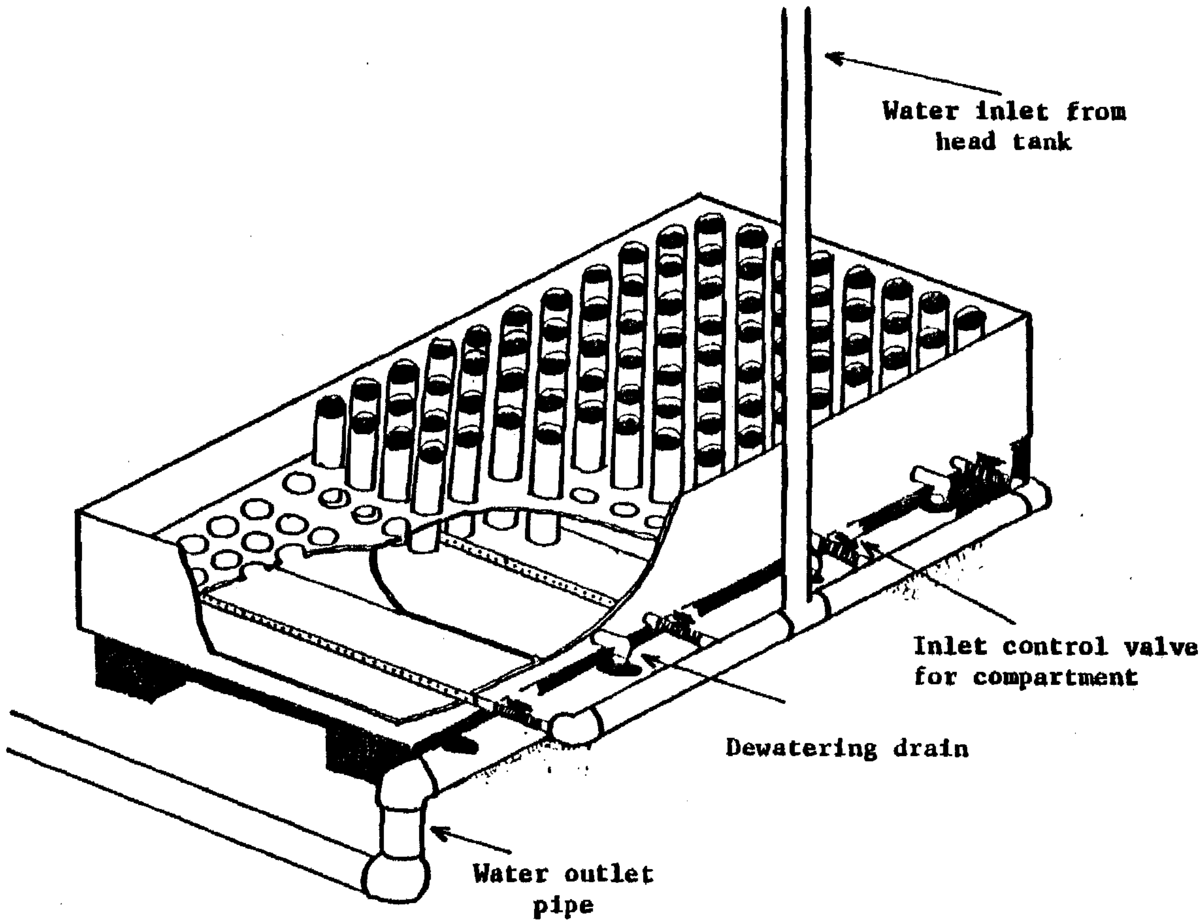

Fig. 6. Diagram of experimental water table with section of false bottom and sides removed to show water flow to several separately controlled compartments.

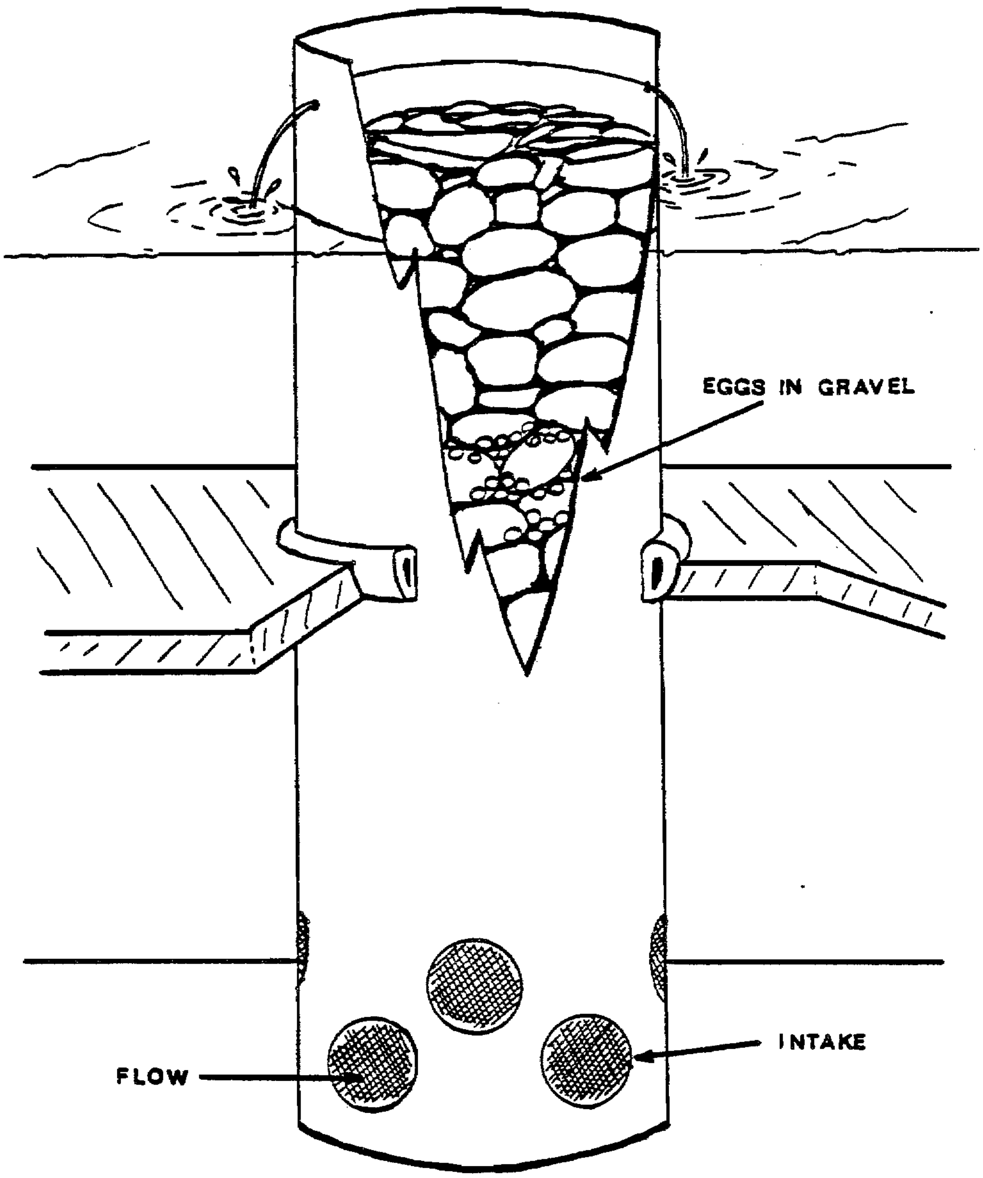

Fig. 7. Artificial redd with section cut away to show egg placement in gravel.

of chum salmon were acquired at the eyed egg stage from the Skagit Hatchery. Sources of eggs for the second year of studies were the Skagit Salmon Hatchery for chinook and pink salmon, Nooksack Salmon Hatchery for chum salmon and the Barnaby Slough trap for steelhead trout.

Following fertilization 50 eggs were added to each cylinder which had been half filled with gravel. The remainder of the cylinder was then filled with gravel. Water entered through the screened holes, upwelled through the gravel and flowed out two 3.2 mm diameter holes drilled 2.5 cm from the top of each cylinder. The water velocity through each cylinder was set at 300 cm/hr. A water bath continuously flowed around the upper half of each cylinder to maintain a controlled temperature for dewatered eggs. Each dewatered cylinder retained about 5 cm of water in the bottom to simulate a source of humidity likely to occur in the natural environment.

The four gravel sizes tested in 1980-81 were designated as large (range from 1.35 to 5.08 cm), medium (0.67 to 2.67 cm), small (0.33 to 1.35 cm) and mixed (0.08 to 5.08 cm). The mixed gravel approximated the gravel composition found in chinook redds sampled with a McNeil gravel sampler in the Skagit River. More extensive gravel sampling of chinook and pink salmon redds was undertaken with a freeze core apparatus in 1981 and an artificial gravel composition which closely represented these results for both species was used for all species and dewatering regimes tested in 1981-82. The large, medium and small gravel sizes were not tested in 1981-82.

5.4.3 Physical Parameters

Physical parameters that were monitored during the study were temperature, humidity and dissolved oxygen. The water temperature in the head tank was recorded on a Ryan J-90 (three-month) thermograph. Temperatures in selected experimental redds were monitored in 1980-81 by probes connected to an Applied Research Austin (ARA) electronic thermometer and Scanner (SO-20) and recorded on an ARA recorder (Model 400). During the first year relative humidity inside and outside the laboratory was measured daily with a Taylor sling psychrometer. The temperature monitoring system used in 1981-82 consisted of a multichannel Yellow Springs Instrument (YSI) Tele-Thermometer (Model 47TD) connected to a YSI strip chart recorder (Model 80A).

5.4.4 Experimental Design

First year (1980-81) experiments designed to test the effects of static or dewatered conditions caused by flow reduction or cessation utilized a 9 x 4 factorial design. Static or dewatering times of 0 (control), 4, 8, 16 or 24 hrs (continuous) per day and the four gravel sizes previously described were tested. These experimental conditions were tested over two developmental stages of the embryo: 1) fertilization to eyed, and 2) eyed through hatching. Long-term effects were tested through the entire fertilization to hatching period. Not all experimental conditions were tested for each species due to shortages of eggs or design modifications. Experiments not performed are specifically mentioned in the results. Based on the first year's results, second year (1981-82) testing was reduced to one gravel size and dewatering times of 0, 2, 4, 8, 16, and 24 hrs per day. These dewatering times were tested over the developmental period extending from fertilization through hatching. In addition, single event dewatering experiments of alevins in artificial redds during the period from hatching to emergence were also undertaken. These dewatering times ranged from 1 to 24 hrs in duration.

A large number of replicates was designed into each treatment to allow repetitive sampling without replacement. Sampling was conducted in duplicate the first year and in triplicate the second and consisted of removing randomly selected cylinders from each test compartment at various time intervals. The contents of individual cylinders were emptied onto a sampling table and the conditions of all biological material was examined and recorded. Sampling frequency was increased as hatching began. All live embryos were placed in a compartmentalized Heath incubator the first year and allowed to develop at normal water flow. The second year live alevins from each test regime were placed in 10 percent formalin immediately after hatching.

5.4.5 Alevin and Fry Quality

A sample of 30 alevins, or as many as were available if less, was removed from the Heath incubator at the button up stage from selected test conditions and preserved in 10 percent formalin. Each alevin was patted dry and weighed on a top-loading Mettler balance (PN 1210) to the nearest hundredth of a gram (0.01 g) and measured from the tip of the snout to the fork of the tail to the nearest half millimeter. The formula used in computing condition factors was:

$$\frac{(\text{weight in g}) \times 10^5}{(\text{length in mm})^3}$$

A correction factor for the effect of preservation on length and weight changes over time was established by determining the condition factors of four groups of 30 untested and Heath incubated alevins weighed and measured in the fresh state and on subsequent dates in the preserved state.

In the 1981-82 the quality of newly hatched alevins was determined by obtaining the yolk dry weights at the time of spawning and the body and yolk sac weights of alevins separately immediately after hatching in the following manner.

A sample of 50 eggs was obtained from chinook, pink and chum salmon and steelhead at the time of spawning and placed in 10% formalin. The membrane surrounding the yolk was removed on a subsequent date just prior to weighing. Alevins of each species and dewatering regime were removed immediately after hatching and placed in 10% formalin. The bodies and yolk sacs were separated and subsequently weighed. Dry weights were determined for initial egg yolk, alevin bodies, and alevin yolk by drying for 24 hours at 103 C and weighing on a Mettler H20T analytical balance. The body and yolk weights were expressed as a proportion of the initial yolk. The weight loss due to metabolism was then estimated with the following formula:

$$\Delta E = 1 - \left[\frac{b_1}{y_0} + \frac{y_1}{y_0}\right]$$

where, ΔE = change in weight due to metabolism

y_0 = initial yolk weight

y_1 = yolk weight of alevin

b_1 = body weight of alevin

5.5 Intragravel Alevin Survival, Movement and Behavior

5.5.1 Intragravel Behavior Studies in 1981

Intragravel behavior studies were conducted in two different experimental chambers in 1981. Early studies on chinook were conducted in clear plexiglass cylinders similar to the standard PVC incubation cylinders. Later studies on steelhead were in specially constructed plexiglas aquaria. These aquaria were 12.7 cm wide, 62 cm high and 77 cm long with two water inlets for separately controlled laminar or upwelling flow (Fig. 8).

In post-hatching sampling of all dewatered and static artificial chinook redds the number of alevins recovered from the bottom of the cylinder was recorded to determine if intragravel movement had occurred. If the alevin had successfully moved to the bottom of the cylinder in dewatered tests it could survive in the five cm of water retained.

Studies of later stage alevins were conducted in clear plexiglas cylinders to facilitate observations of movement. Samples of 10 pre-emergent alevins near button-up were placed in the flowing water above the gravel in plexiglas cylinders. The water was turned off and drained at the rate of 30 cm per minute. The four gravel sizes tested were large, medium and small and mixed. After 30 minutes the cylinders were sampled and the relative location of the alevins in each cylinder was recorded to determine if intragravel movement had occurred. Alevins that moved to the bottom of a cylinder could survive in the water retained.

Posthatching movement of coho alevins was determined by recording the number of alevins collected from the bottom of each cylinder at sampling time. Intragravel movement of later stages of pre-emergent coho alevins was observed in the clear plexiglas cylinders utilizing the same methods used for chinook

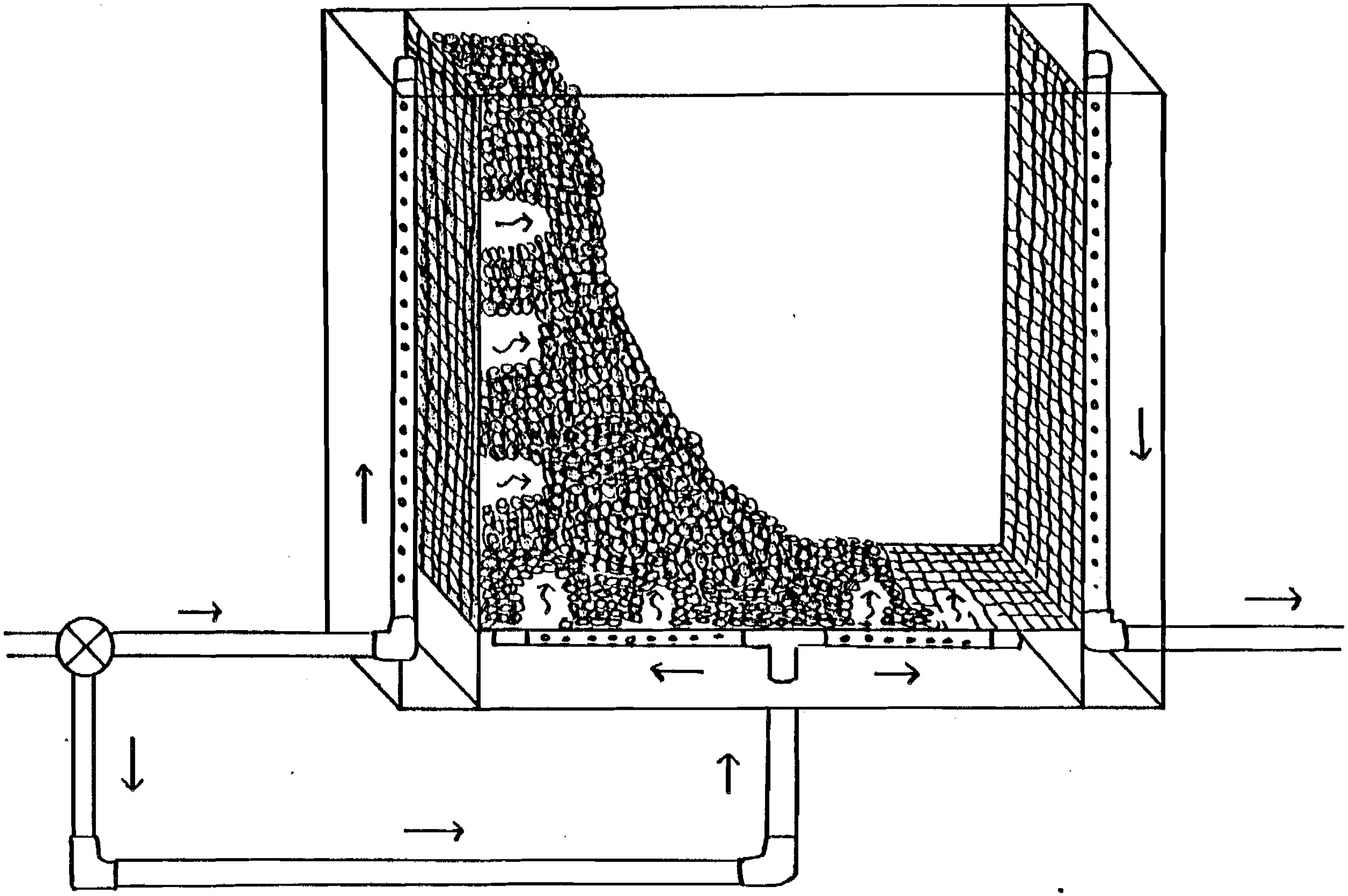

Fig. 8. Alevin behavior chamber.

alevins.

Immediate post-hatching movement of steelhead alevins was recorded as the number of alevins successfully moving to the bottom of the cylinder as in the chinook and coho studies. More intensive observations were made on the later stages of pre-emergent steelhead alevins by utilizing the plexiglas aquarium. Steelhead alevins at various stages of development were placed in the plexiglas aquaria and movement was recorded as water was drained at rates ranging from 2.5 cm/hr to 30 cm/hr. Laminar flow was used in all tests.

5.5.2 Intragravel Behavior Studies in 1982

The 1982 studies were conducted at the Fisheries Research Institute, University of Washington. The experimental stocks for these studies were obtained as eyed eggs from the Skagit Research Laboratory in Marblemount, Washington and transported to the campus. The eggs were kept in a Heath Incubator inside a 10 x 12 x 8 foot room constructed of black polyethylene to maintain total darkness. Infrared lights illuminated the room while experiments were set up and data was recorded. Lake Washington water pumped to the laboratory was used in the Heath Incubator and all of the experimental tanks.

Several different substrates were used during the behavior experiments. In early studies gravel was transported from the Skagit River and graded or mixed for different studies. Gravel sizes were the same used in egg incubation studies during the first year; large (1.35 to 5.08 cm), medium (0.67 to 2.67 cm), small (0.33 to 1.35 cm) and mixed (0.08 to 5.08 cm). In later experiments two sizes (large - 2.16 cm; small - 1.44 cm) of clear glass marbles were used to facilitate observations of intrasubstrate movement or dispersal of alevins. The standardized size of the marbles and their interstitial spaces also eliminated the problem of nonuniform substrate interferring with alevin movement by blocking passage in certain directions.

5.5.3 Aquaria Behavior Studies

The procedures designed to study the ability of alevins to migrate to avoid dewatering utilized four specially designed plexiglass aquaria constructed to facilitate observations of alevins in the intragravel environment. These observation tanks were 7.5 cm wide, 77 cm long, and 62 cm high (Fig. 9). The tanks were filled with selected substrates and supplied with lateral water flow. Groups of 50 embryos or alevins were placed near the front viewing plate in these tanks and movement or behavior was recorded during the incubation experiments. Alevin traps were placed below the substrate to determine if there was a positive or negative rheotactic component involved in the alevin movement. Water velocity was adjusted and dissolved oxygen levels were monitored to determine if movement occurred under apparently favorable conditions.

These aquaria tests were conducted on chinook and pink salmon alevins. The results obtained from these studies indicated that additional experiments would be necessary to test the alevin responses to specific environmental variables.

5.5.4 Velocity Studies

The procedures designed to study the alevins responses to velocity utilized a flow box (Fig. 10). The flow box was a simple wooden trough 30 cm x 30 cm x 90 cm long with water entering one end of the trough and flowing through an enclosed gravel bed in the center and out a downstream stand pipe. A false bottom 5 cm deep under the gravel bed was placed in the center of the trough to facilitate entrapment of the alevins which moved from the gravel. The appropriate gravel composition for each species was determined from the literature. A lid was placed over the entire box to eliminate all light. A

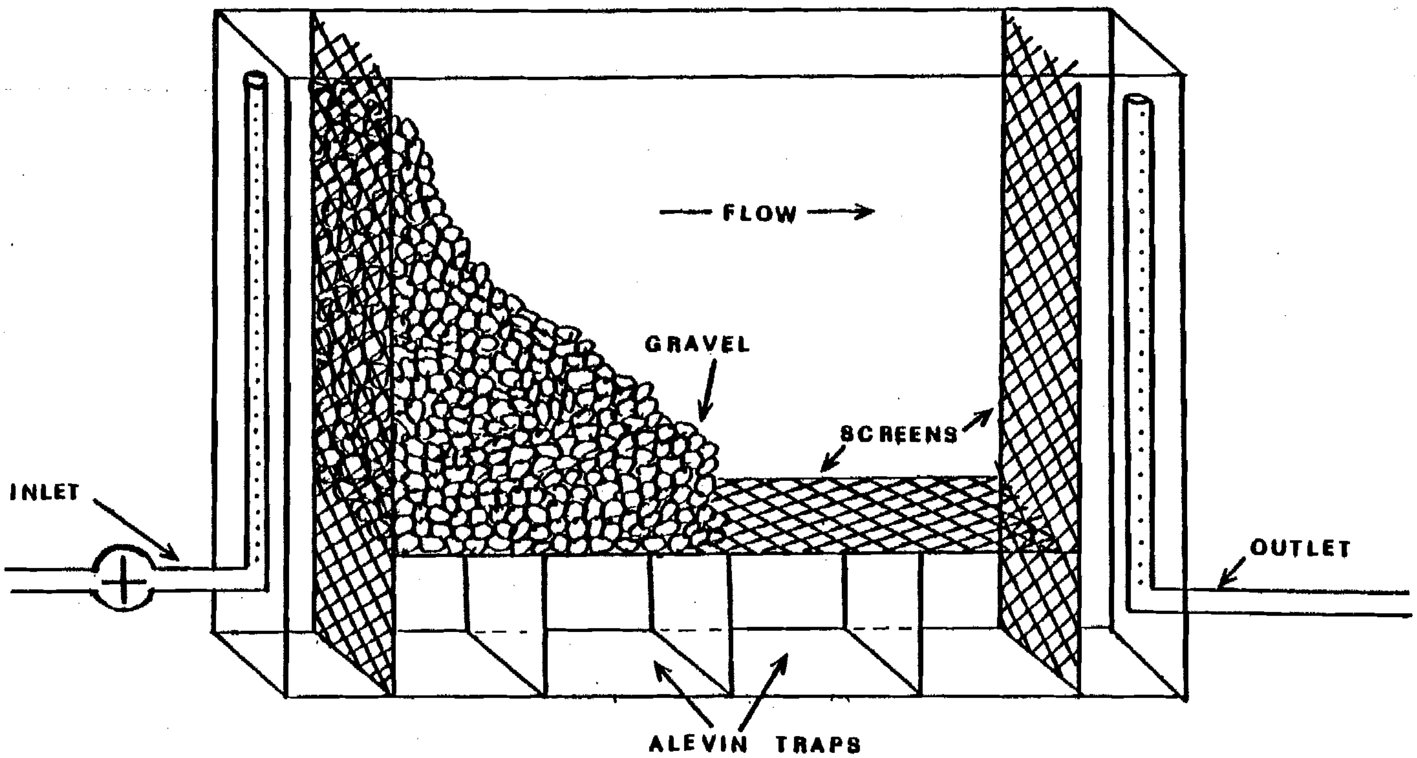

Fig. 9. Alevin behavior aquarium with alevin traps underneath to determine rheotactic movement.

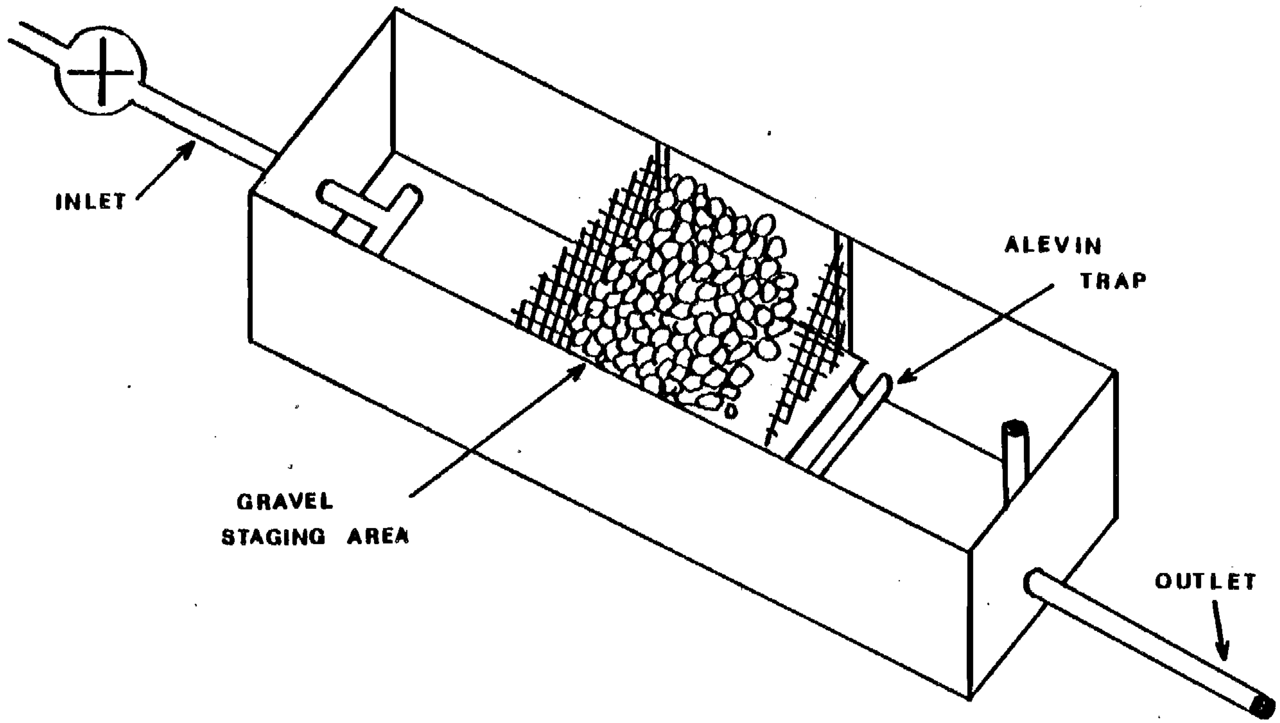

Fig. 10. Alevin flow box for studies on effect of velocity on movement and behavior.

group of 30 alevins was placed in the enclosed gravel bed in the center of the trough and flows ranging from 0 cm/sec; 0.5 to 1.0 cm/sec, (medium); and 1.5 to 2.5 cm/sec, (high) were tested. These velocities were achieved by manipulating the water inlet valve. Alevin traps made from 1-1/2 inch PVC pipe were placed up and downstream from the gravel bed to determine the number and direction of alevin movement at each velocity.

5.5.5 Dissolved Oxygen Studies

Experiments designed to study alevin behavior related to oxygen levels utilized a Y-maze designed to test the ability of alevins to select between two water sources varying only in the concentration of dissolved oxygen (Fig. 11). These tests were designed to determine the lethal levels of dissolved oxygen and the ability of alevins to differentiate between different levels of this environmental parameter and migrate toward the source of the least stress. A range of levels from lethal to highly desirable was tested. Dissolved oxygen was regulated using a stripping tower with a counter flow of nitrogen gas to deoxygenate the incoming water. Any desired level of dissolved oxygen could be achieved by mixing this deoxygenated water with various quantities of oxygen saturated water. Dissolved oxygen levels were determined by using a YSI Model 54 oxygen meter and the azide modification of the iodometric winkler method (Standard methods).

5.5.6 Photobehavior Studies

The procedures for testing photobehavior utilized a light-dark choice tank (Fig. 12). This rectangular aquarium (50 x 25 x 25 cm) has a 21 cm center partition dividing it into two equal compartments. The 4 cm space beneath the partition allowed the alevins to migrate freely between the two sections. A lid was placed over one side or the other creating a dark and light compartment. After 15 minutes of adjustment time the alevins on the

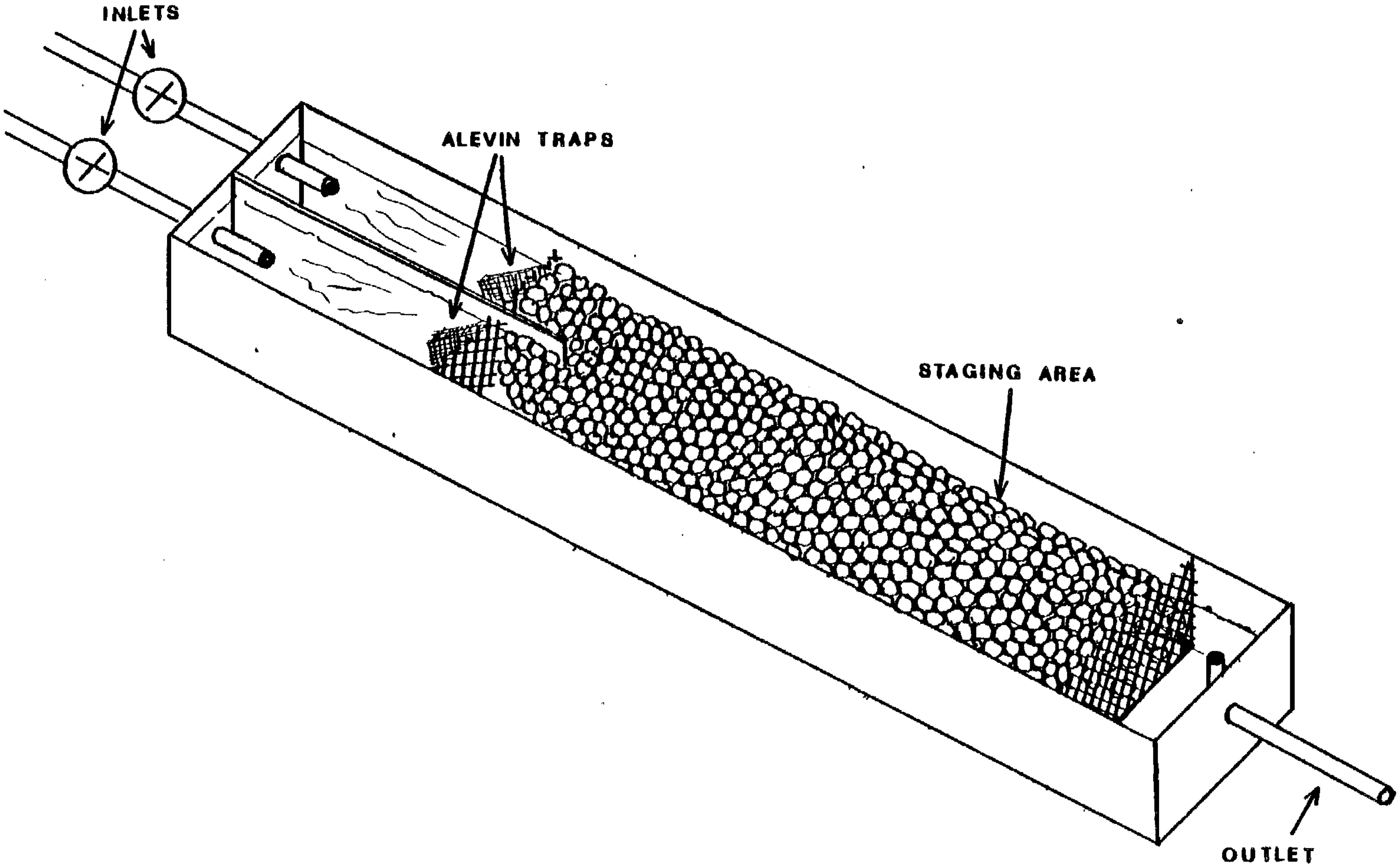

Fig. 11. Y-maze used in studies of alevin movement and behavior related to dissolved oxygen levels.

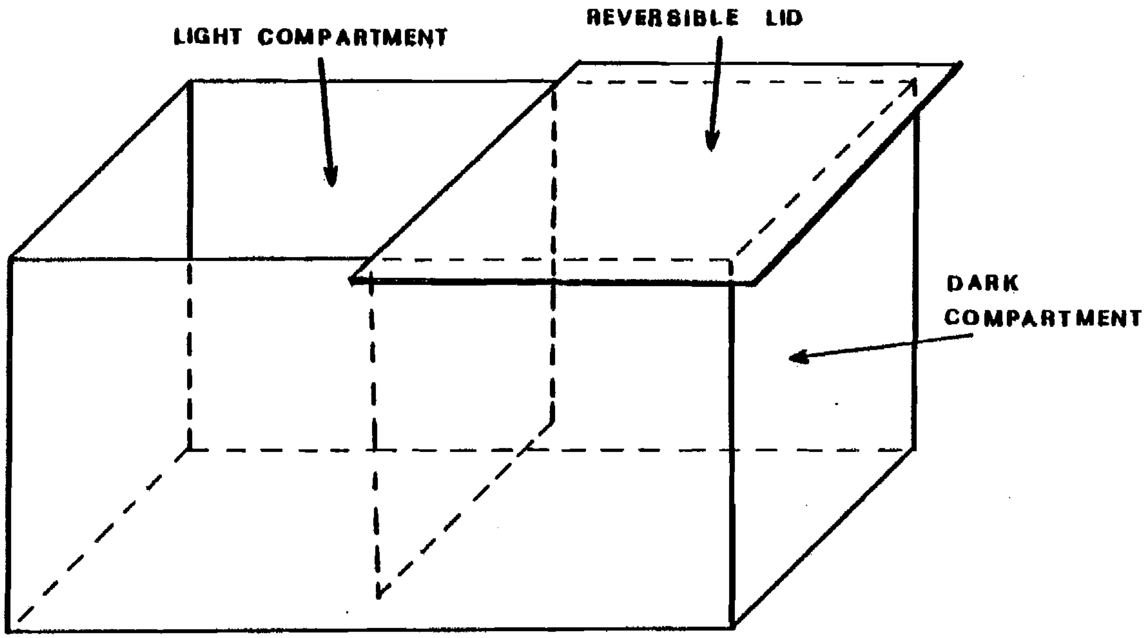

Fig. 12. Light-dark choice box used in studies of photo-behavior.

light side were counted at one minute intervals for 10 minutes. The lid was then placed on the previous light side and similar counts were made. This test was to determine the photo behavioral response of the alevins. Light sources tested were fluorescent room lights, infrared spot lights, and direct sunlight. Light levels were determined by using a Li-Cor Model LI-185 Quantum/Radiometer/Photometer.

Objective seven tested the effect of developmental stage on alevin response to environmental stimuli. To accomplish this objective all of the preceeding experiments and observations were made at three stages of the development of the alevins whenever possible. The first test period was the early yolk sac fry shortly after hatching. The second period was at the mid-point of alevin development, and the final testing period was just prior to emergence. Testing at these stages of the incubation period was used to determine if changes in alevin response to environmental stimuli or ability to respond to those stimuli occurred.

5.6 Fry Standing

5.6.1 Salmon

5.6.1.1 Survey Sites and Techniques

The gravel bars studied in this program are representative of the Skagit River between Newhalem and the mouth of the Sauk River. The spacing of the study bars reflects a gradation in substrate composition, bar slope and tributary inflow. The average size of gravel bar substrate and bar slope decrease downstream. Conversely, the tributary inflow increases downstream.

Three gravel bars on the Skagit River between the Gorge powerhouse and the confluence of the Sauk River were selected for examination. These were the Thornton Creek site No. 1 (RM 90.2), Marblemount Bar site No. 2 (RM 78.2) and Rockport Bar site No. 3 (RM 67.7) (Fig. 1). For the 1982 study the upstream study site No. 1 was moved to the County Line Bar (RM 89.0). Parallel transects twenty feet wide were spaced along these bars at one hundred foot intervals, perpendicular to the flow line. During a stranding survey the areas within the transects were examined followed by the areas between the transects. This practice was discontinued after the second survey because the number of fry within transects was low, and it was more efficient to survey back and forth between the high and low water lines from one end of a gravel bar to the other and back again.

The observation crew initially consisted of two persons per gravel bar but with experience only one person per bar was required. All observations began at daybreak to prevent loss of fry on the study sites due to scavenging birds. The observers collected only fry which were visible without moving substrate material. The goal was to obtain a relative index of stranding at various ramp rates, not estimates of total number of fry killed.

5.6.1.2 Monitoring of Fry Abundance

An electroshocker, Smith Root Type VII, was used to monitor the abundance of fry along the study gravel bars. Electrofishing was conducted the afternoon prior to each downramp test. Two hundred feet of shoreline out to a depth of about 1.5 feet were sampled. During the 1980 sample period the area electrofished was two one-hundred foot sections separated by about 300 feet of shoreline. During the 1981 and 1982 sample periods the area electrofished was a continuous two hundred foot section of each gravel bar.

5.6.1.3 Stream Flow

Seattle City Light regulated the discharge at Gorge powerhouse according to a request to provide prespecified downramp rates between a high flow of greater than 5,000 cfs and a minimum flow of 2,300 cfs. Comparisons were made between the U.S.G.S. records for the Newhalem (No. 12-1780) and Marblemount (No. 12-1810) gages to determine the level of tributary inflow during the downramp tests. The flow comparison was made during the stable minimum flow period following each downramp cycle.

5.6.1.4 Index of Stranding

The counts of all fry found stranded within the survey area of each study gravel bar were recorded by species. The raw count of stranded salmon fry was converted to an index number by the following steps:

1) Adding one to the count. This data transformation created numbers which could be adjusted by the abundance data and resulted in an integer value which facilitated presentation and comparison of stranding indices.

2) Dividing by the salmon fry abundance factor. This was done to adjust for fluctuating fry abundance. Assuming all other variables equal, a change in fry abundance adjacent to the study sites would change the stranding rate and the change would be directly proportional to the change in fry abundance.

The abundance factor was computed by dividing the number of fish sampled on each occasion by the lowest number of fish obtained for a given site. Thus the day with the lowest fry abundance for a given site in a given year has a factor of 1.0. The abundance factor was computed independently for each year because the locations for electrofishing within each study site were changed between years.

5.6.1.5 Time Factor

During the course of the field studies it became evident that portions of study gravel bars dewatered after dawn had a substantially greater occurrence of stranded fry than the portions dewatered prior to dawn. This was most evident at the Rockport Bar site during 1982 when tributary inflow was more stable than during 1980 and 1981.

Several of the downramping tests in 1982 were modified to alter the timing of the downramp occurrence at similar downramp rates. This manipulation in study procedure produced dramatic shifts in stranding rates. As a result of these observations and data collection the entire data base 1980-1982 was evaluated to determine the time of downramping at each site relative to dawn. Dawn was standardized as one-half hour prior to sunrise as measured at Seattle, Washington.

A time factor was computed for each test and study site by subtraction of the time of dawn from the time of maximum gravel bar dewatering following downramp. Those occasions where the computation resulted in a negative number (i.e., prior and equal to dawn) the time factor was assigned a value of 1.0. This was done based on the assumption that all dewatering in darkness was equivalent in terms of light effect on the incidence of stranding. The value of 1.0 was added to the remaining positive values.

The delay time for dewatering at each study site was determined by placement and monitoring of site specific staff gages. Detailed observation of the site specific gages was conducted on 19 and 30 March 1982 to establish the relationship between completion of a downramping event at Newhalem and completion of dewatering at the study sites (Appendix II, Tables 1A and 1B).

5.6.2 <u>Steelhead</u>

Investigations in 1982 were directed toward determination of the effects of fluctuating water levels resulting from power generation on stranding of steelhead fry. Conditions in 1981 did not permit controlled fry stranding experiments, however, the 1982 season proved excellent once the snowmelt runoff had subsided. Due to limitations on available staff, two study sites were selected. One was the river bar at the Skagit County Park at Rockport; the other was at Marblemount on the right bank just above the mouth of the Cascade River. Both of the these sites were previously used in studies of chinook fry stranding. These sites were easily accessible and it was possible to sample both on the same day during one low water event. Both of these sites were near areas of high steelhead spawning activity and were expected to have a large number of fry.

In an effort to minimize variability, each stranding experiment was repeated on two consecutive days. Also only one variable was changed at a time. For example, if ramp rate were changed for an experiment, timing and magnitude of the change were held constant. The experimental condition was a downramp of 2000 cfs per hour, timed so that the minimum flow at Newhalem of 1400 cfs was reached by midnight. High flow at Gorge during the stranding test series was approximately 5700 cfs each day. The tests were scheduled on consecutive days, Tuesdays, Wednesdays, and Thursdays, since these days had the best potential to provide identical conditions from day to day. At both sites a known length of bar (425 feet at Rockport and 300 feet at Marblemount) was systematically inspected and all stranded fry collected. The river level had dropped to the minimum at either of the sites by daylight. Sampling began at dawn and continued until no additional fry could be found. Usually, this occurred by mid-morning when the bars had dried. Electrofishing to determine fry abundance was done on rising flows on the day prior to the fry stranding test.

6.0 RESULTS

6.1 Escapements, Spawner Distribution and Area Spawned

6.1.1 Salmon

The data presented in this section update those previously compiled by Graybill et al. (1979). The Skagit system natural spawning escapements estimated for 1978-1981 by WDF for summer-fall chinook, pink, chum and coho salmon are presented in Table 1. The escapement levels for summer-fall chinook, pink, and coho were generally comparable to previous years. A particularly strong high cycle (even-year) escapement was estimated for chum salmon in 1978 (115,200) and a less than average escapement in 1980 (21,350).

Escapement levels to the Skagit Hatchery racks for 1978 to 1981 are shown in Table 2. Coho were most abundant and ranged from 11,078 to 40, 084, chinook 88 to 1,010 followed by pink and chum salmon.

Tables 3, 4, and 5 list chinook salmon redd counts made by WDF from helicopter and fixed wing surveys from 1977-1981. As in past years, two river sections, Bacon Creek to Diobsud Creek, and Diobsud Creek to Cascade comprising 17.7 percent of the river miles above the Sauk accounted for approximately 40 percent of the total spawning.

Aerial photographs were taken of the Skagit River between Newhalem and the Sauk River on October 6, 1980. The percentage distribution of redds observed in most river sections were similar to the percentages of redds counted in those sections from helicopter and fixed-wing surveys (Table 6). The total area spawned as determined from the photographs was 58,810 m^2 or 2,162 m^2/mi. The river section with the greatest area spawned per river mile (5,365 m^2), was Diobsud Creek to Cascade River (Table 7). The date on which

Table 1. Estimated Skagit River system spawning escapements (Washington Department of Fisheries).[1]

Year	Summer-fall chinook	Pink	Chum	Coho
1978	13,209	—	115,200[2]	9,800
1979	13,605	336,000	16,575	28,000
1980	20,345	—	21,350	21,000
1981	8,670	100,000	12,500	15,900

[1]WDF - R. Orrell, personal communication.

[2]Revised from 1976 and 1977 tagging studies.

Table 2. Salmon escapement to the Skagit Hatchery racks 1978-1981.[1]

Year	Coho	Chinook	Pink	Chum
1978	11,078	88		284
1979	11,792	267	384	8
1980	21,893	1,010		17
1981	40,084	450	153	-

[1]WDF, J. Clayton, personal communication.

Table 3. Chinook salmon redd counts made by the Washington Department of Fisheries from helicopter and fixed-wing surveys of the Skagit River from Newhalem to the Sauk River. [Surveys made on September 26, 1977 and September 14 and 20 and October 4 and 30, 1978]

River section	Number of redds		Percent of total redds		River miles	Percent of total river miles
	1977	1978	1977	1978		
Newhalem to County Line	142	444	11.4	11.4	4.8	17.6
County Line to Copper Creek	79	132	6.3	3.4	5.1	18.8
SUBTOTAL (NEWHALEM TO COPPER CREEK)	221	576	17.7	14.7	9.9	36.4
Copper Creek to Bacon Creek	107	210	8.6	5.4	1.4	5.1
Bacon Creek to Diobsud Creek	173	404	13.8	10.3	2.2	8.1
Diobsud Creek to Cascade River	321	940	25.7	24.0	2.6	9.6
Cascade River to Corkindale Creek	205	799	16.4	20.4	4.0	14.7
Corkindale Creek to Illabot Creek	30		2.4		2.5	9.2
Illabot Creek to Sauk River	194	984	15.5	25.1	4.6	16.9
SUBTOTAL (COPPER CREEK TO SAUK RIVER)	1030	3337	23.3	85.3	17.3	63.6
TOTAL (NEWHALEM TO SAUK RIVER)	1251	3913	100	100	27.2	100

Table 4. Chinook salmon redd counts made by the Washington Department of Fisheries from helicopter and fixed-wing surveys of the Skagit River from Newhalem to the Sauk River. [Surveys made on September 15 and October 5, 1979 and September 9 and 26 and October 23, 1980]

River section	Number of redds		Percent of total redds		River miles	Percent of total river miles
	1979	1980	1979	1980		
Newhalem to County Line	274	383	10.9	10.9	4.8	17.6
County Line to Copper Creek	128	151	5.1	4.3	5.1	18.8
SUBTOTAL (NEWHALEM TO COPPER CREEK)	402	534	15.9	15.2	9.9	36.4
Copper Creek to Bacon Creek	263	147	10.4	4.2	1.4	5.1
Bacon Creek to Diobsud Creek	343	547	13.6	15.6	2.2	8.1
Diobsud Creek to Cascade River	664	847	26.3	24.1	2.6	9.6
Cascade River to Corkindale Creek	217	403	8.6	11.5	4.0	14.7
Corkindale Creek to Illabot Creek	215	182	8.5	5.2	2.5	9.2
Illabot Creek to Sauk River	418	848	16.6	24.2	4.6	16.9
SUBTOTAL (COPPER CREEK TO SAUK RIVER)	2120	2974	84.1	84.8	17.3	63.6
TOTAL (NEWHALEM TO SAUK RIVER)	2522	3508	100	100	27.2	100

Table 5. Chinook salmon redd counts made by the Washington Department of Fisheries from helicopter and fixed-wing surveys of the Skagit River from Newhalem to the Sauk River. (Surveys made on September 8 and October 14, 1981)

River section	Number of redds 1981	Percent of total redds 1981	River miles	Percent of total river miles
Newhalem to County Line	93	9.4	4.8	17.6
County Line to Copper Creek	76	7.7	5.1	18.8
SUBTOTAL (NEWHALEM TO COPPER CREEK)	169	17.1	9.9	36.4
Copper Creek to Bacon Creek	51	5.2	1.4	5.1
Bacon Creek to Diobsud Creek	168	17.0	2.2	8.1
Diobsud Creek to Cascade River	229	23.2	2.6	9.6
Cascade River to Corkindale Creek	81	8.2	4.0	14.7
Corkindale Creek to Illabot Creek	33	3.3	2.5	9.2
Illabot Creek to Sauk River	258	26.1	4.6	16.9
SUBTOTAL (COPPER CREEK TO SAUK RIVER)	820	82.19	17.3	63.6
TOTAL (NEWHALEM TO SAUK RIVER)	989	100	27.2	100

Table 6. Chinook salmon redd counts from aerial photographs of the Skagit River from Newhalem to the Sauk River in 1980. [Photographs taken on October 6, 1980].

River section	Number of redds	Percent of total redds	River miles	Percent of total river miles
Newhalem to County Line	100	6.3	4.8	17.6
County Line to Copper Creek	57	3.6	5.1	18.8
SUBTOTAL (NEWHALEM TO COPPER CREEK)	157	9.9	9.9	36.4
Copper Creek to Bacon Creek	87	5.2	1.4	5.1
Bacon Creek to Diobsud Creek	221	14.0	2.2	8.1
Diobsud Creek to Cascade River	375	23.7	2.6	9.6
Cascade River to Corkindale Creek	164	10.4	4.0	14.7
Corkindale Creek to Illabot Creek	123	7.8	2.5	9.2
Illabot Creek to Sauk River	459	29.0	4.6	16.9
SUBTOTAL (COPPER CREEK TO SAUK RIVER)	1424	90.1	17.3	63.6
TOTAL (NEWHALEM TO SAUK RIVER)	1581	100	27.2	100

Table 7. Area spawned by chinook salmon as determined from aerial photographs of the Skagit River from Newhalem to the Sauk River.
[Photographs taken on October 6, 1980]

River section	Area spawned ($m^2 \times 10^3$)	Percent of total area spawned	Area spawned per river mile (m^2/mi)	River miles	Percent of total river miles
Newhalem to County Line	3.72	6.3	775	4.8	17.6
County Line to Copper Creek	2.12	3.6	416	5.1	18.8
SUBTOTAL (NEWHALEM TO COPPER CREEK)	5.84	9.9	590	9.9	36.4
Copper Creek to Bacon Creek	3.05	5.2	2,179	1.4	5.1
Bacon Creek to Diobsud Creek	8.22	14.0	3,736	2.2	8.1
Diobsud Creek to Cascade River	13.95	23.7	5,365	2.6	9.6
Cascade River to Corkindale Creek	6.10	10.4	1,525	4.0	14.7
Corkindale Creek to Illabot Creek	4.58	7.8	1,832	2.5	9.2
Illabot Creek to Sauk River	17.10	29.1	3,717	4.6	16.9
SUBTOTAL (COPPER CREEK TO SAUK RIVER)	52.97	90.1	3,062	17.3	63.6
TOTAL (NEWHALEM TO SAUK RIVER)	58.81	100	2,162	27.2	100

the aerial photographs were taken coincided with a time of relatively low flow, Marblemount mean gage height of 2.06 ft. Examination of the aerial photographs did not reveal any redds dewatered at this stage. Other low-flow days and Marblemount gage heights during the chinook spawning season were as follows: September 16 - 1.89; September 17 - 2.08; September 18 - 2.03; September 27 - 1.96; and September 28 - 1.89. The minimum flow on any of these dates was 1.80 on September 18. The difference between this gage height reading of 1.80 ft and 2.06 ft on October 6 is 0.25 ft and consequently it is unlikely that any chinook redds were dewatered during the spawning season.

Salmon production in the Skagit River is supplemented by the Skagit Salmon Hatchery located near Marblemount which is maintained and operated by the Washington Department of Fisheries. Fish production from the Skagit Hatchery and fish plants in the Skagit system between Boyd Creek (river mile [RM] 44.7) and Newhalem are summarized in Table 8 for the period 1978 to 1982. The principal species produced in recent years have been spring-summer-fall chinook and coho salmon.

6.1.2 Steelhead Trout

The Skagit system naturally spawning steelhead escapements for 1977-1978 to 1981-1982 estimated by WDG are summarized in Table 9. These are the first years for which escapement estimates were available, so comparisons with previous years are not possible.

Aerial surveys were conducted during the 1979 to 1982 steelhead spawning seasons for the Skagit and Sauk rivers by WDG. Steelhead redd counts from these surveys are presented in Tables 10-13. Spawning generally commenced in mid-March and extended through June. Peak counts of 67, 427, and 299 in the mainstem Skagit and 73, 23, and 209 in the Sauk occurred on June 9, 1980, May 22, 1981, and May 13, 1982, respectively. In 1979 surveys were not conducted

Table 8. Fish production of the Skagit Hatchery and fish plants by WDF in the Skagit system from Boyd Creek (river mile 44.7) to Newhalem, 1978-1982.

Year planted	Brood year	Species		Number of Fish: Skagit Hatchery production	Number of Fish: Fish plants by WDF in the Skagit system from Boyd Creek to Newhalem
1982	1980	Summer chinook	(yr)*	808,768	808,768
	1981	Fall chinook	(fg)	5,995,600	2,100,322
	1981	Coho	(fr)	1,250,680	449,580
	1981	Coho	(fg)	1,931,100	404,500
	1980	Coho	(yr)	1,548,933	340,700
1981	1979	Spring chinook	(yr)	53,881	53,881
	1980	Summer chinook	(fg)	570,840	570,840
	1979	Summer chinook	(yr)	242,358	242,358
	1980	Fall chinook	(fg)	720,987	720,987
	1979	Fall chinook	(yr)	559,507	559,507
	1980	Coho	(fg)	485,000	480,000
	1980	Coho	(fr)	1,464,940	0
	1979	Coho	(yr)	1,126,594	657,276
	1978	Spring chinook	(yr)	18,950	18,950
1980	1978	Summer chinook	(yr)	463,539	463,539
	1979	Fall chinook	(fg)	1,111,250	1,111,250
	1978	Fall chinook	(yr)	581,047	581,047
	1979	Coho	(fg)	820,165	459,514
	1978	Coho	(yr)	2,154,250	991,150
	1979	Chum	(fr)	7,656	7,656
1979	1978	Spring chinook	(fg)	1,872	1,872
	1977	Spring chinook	(yr)	72,501	51,080
	1977	Summer chinook	(yr)	397,000	397,000
	1978	Fall chinook	(fg)	961,289	961,289
	1977	Fall chinook	(yr)	779,000	779,000
	1978	Coho	(fr)	1,079,448	955,032
	1977	Coho	(yr)	919,398	743,510
1978	1977	Spring chinook	(yr)	10,080	10,080
	1976	Spring chinook	(yr)	22,051	22,051
	1977	Summer chinook	(yr)	147,900	147,900
	1976	Summer chinook	(yr)	147,066	147,066
	1977	Fall chinook	(fg)	119,848	119,848
	1976	Fall chinook	(fg)	149,862	149,862
	1977	Coho	(fg)	1,358,456	1,050,647
	1976	Coho	(yr)	1,169,830	753,598
	1977	Chum	(fg)	5,820,000	5,820,000
	1977	Pink	(fg)	4,300,000	4,300,000

* yr = yearling (270 + days reared)
fg = fingerling (14-269 days reared)
fr = fry (0-14 days reared)

Table 9. Estimated Skagit River system steelhead spawning escapements (WDG).

	Mainstem Skagit	Tributaries
1977-1978	1425	5869
1978-1979	913	3030
1979-1980	1248	4761
1980-1981	1897	3538
1981-1982	3362	6422

Table 10. Summary of steelhead trout redd counts from aerial surveys of mainstem Skagit and Sauk Rivers, 1979 (WDG).

		Steelhead Redd Counts — 1979 (WDG)	
		3/22	4/19
SKAGIT RIVER			
River Section			
Newhalem to Bacon Creek	(11.3 mi)	12 (e)	11 (e)
Bacon Creek to Cascade River	(4.8 mi)	2 (f)	9 (f)
Cascade River to Sauk River	(11.1 mi)	28	38
Sauk River to Baker River	(10.5 mi)	25	34
Baker River to Sedro Woolley	(33.7 mi)	21	66
Sedro Woolley to Mt. Vernon	(11.4 mi)	0	2
Total	(82.8 mi)	86	160
SAUK RIVER			
River Section			
Mouth to Suiattle River	(13.2 mi)	6	16
Suiattle River to Darrington Bridge	(8.2 mi)	4	36
Darrington Bridge to White Chuck River	(10.5 mi)	0 (d)	3 (d)
White Chuck River to Sauk River forks	(7.8 mi)	(a)	(a)
Sauk River forks to North Fork falls	(1.4 mi)	(a)	(a)
Total	(41.1 mi)	10	55

Table 11. Summary of steelhead trout redd counts from aerial surveys of mainstem Skagit and Sauk Rivers, 1980 (WDG).

		Steelhead Redd Counts — 1980 (WDG)					
		3/06	3/21	4/05	4/21	5/07	6/09
SKAGIT RIVER							
River Section							
Newhalem to Bacon Creek	(11.3 mi)	0	0	0	1	2	7
Bacon Creek to Cascade River	(4.8 mi)	0	0	0	2	7	16
Cascade River to Sauk River	(11.1 mi)	1	3	5	3	26	17
Sauk River to Baker River	(10.5 mi)	0	17	15	(b)	6	9
Baker River to Sedro Woolley	(33.7 mi)	1 (b)	10	9	(b)	10	18
Sedro Woolley to Mt. Vernon	(11.4 mi)	(b)	0	0	(b)	0	0
Total	(82.8 mi)	1	30	29	5	51	67
SAUK RIVER							
River Section							
Mouth to Suiattle River	(13.2 mi)	0	3	15	(b)	(b)	4
Suiattle River to Darrington Bridge	(8.2 mi)	0	3	5	(b)	(b)	19
Darrington Bridge to White Chuck River	(10.5 mi)	(a)	(a)	(a)	(b)	(b)	(d)
White Chuck River to Sauk River forks	(7.8 mi)	(a)	(a)	(a)	(b)	(b)	(a)
Sauk River forks to North Fork falls	(1.4 mi)	(a)	(a)	(a)	(b)	(b)	(a)
Total	(41.1 mi)	0	6	20			23

Table 12. Summary of steelhead trout redd counts from aerial surveys of mainstem Skagit and Sauk Rivers, 1981 (WDG).

		Steelhead Redd Counts — 1981 (WDG)							
		3/03	3/17	4/02	4/13	5/12	5/22	6/04	6/25
SKAGIT RIVER									
River Section									
Newhalem to Bacon Creek	(11.3 mi)	0	1	1	1	17	62	37	2
Bacon Creek to Cascade River	(4.8 mi)	0	3	2	1	22	66	50	23
Cascade River to Sauk River	(11.1 mi)	2	6	22	23	158	176	92	69
Sauk River to Baker River	(10.5 mi)	2	11	15	20	43	37	(b)	(b)
Baker River to Sedro Woolley	(33.7 mi)	0	4	7	15	68	84	(b)	(b)
Sedro Woolley to Mt. Vernon	(11.4 mi)	0	0	0	0	(a)	2	(b)	(b)
Total	(82.8 mi)	4	25	47	60	308	427	179	94
SAUK RIVER									
River Section									
Mouth to Suiattle River	(13.2 mi)	0	1	5	5	(a)	7	(b)	(b)
Suiattle River to Darrington Bridge	(8.2 mi)	0	3	3	1	(a)	61	(b)	(b)
Darrington Bridge to White Chuck River	(10.5 mi)	(a)	1	1 (d)	0 (d)	(a)	5 (d)	(b)	(b)
White Chuck River to Sauk River forks	(7.8 mi)	(a)	(a)	(a)	(a)	(a)	(a)	5	(b)
Sauk River forks to North Fork falls	(1.4 mi)	(a)	(a)	(a)	(a)	(a)	(a)	(b)	(b)
Total	(41.1 mi)	0	5	9	6		73		

Table 13. Summary of steelhead trout redd counts from aerial surveys of mainstem Skagit and Sauk Rivers, 1982 (WDG).

		Steelhead Redd Counts - 1982 (WDG)					
		2/26	3/16	4/6	4/26	5/13	6/2
SKAGIT RIVER							
River Section							
Newhalem to Bacon Creek	(11.3 mi)	(a) (e)	0 (e)	0 (e)	0 (e)	1 (e)	4 (e)
Bacon Creek to Cascade River	(4.8 mi)	0 (f)	0 (f)	1 (f)	3 (f)	16 (f)	13 (f)
Cascade River to Sauk River	(11.1 mi)	9	8	18	64	132	92
Sauk River to Baker River	(10.5 mi)	0	2	16	42	64	(b)
Baker River to Sedro Woolley	(33.7 mi)	0	(b)	47	75	75	(b)
Sedro Woolley to Mt. Vernon	(11.4 mi)	0	0	0	5	0	(b)
Total	(82.8 mi)	9	10	82	189	299	109
SAUK RIVER							
River Section							
Mouth to Suiattle River	(13.2 mi)	0	0	8	20	71	(b)
Suiattle River to Darrington Bridge	(8.2 mi)	0	0	12	61	88	(b)
Darrington Bridge to White Chuck River	(10.5 mi)	(a)	0 (d)	2	19	37	(b)
White Chuck River to Sauk River forks	(7.8 mi)	(a)	(a)	(a)	15	13	(b)
Sauk River forks to North Fork falls	(1.4 mi)	(a)	(a)	(a)	(a)	(a)	(a)
Total	(41.1 mi)	0	0	22	115	209	0

(a) No Count
(b) Too turbid to count
(c) Peak count
(d) Incomplete count
(e) Newhalem to Ala Creek (9.0 mi)
(f) Alma Creek to Cascade River (7.1 mi)

beyond April, so a peak count was not obtained.

Based on the 1980 and 1981 peak counts approximately 80 percent of the redds were located in the mainstem Skagit (Sedro Woolley to Newhalem) with 20 percent in the mainstem Sauk (primarily from the mouth to Darrington). However, the higher visibility in the Sauk in 1982 indicated a peak count distribution of 60% mainstem Skagit and 40% mainstem Sauk. The section of the Skagit mainstem most heavily spawned extended from the Cascade River to the Sauk River.

Both timing of peak spawning activity and distribution of spawning in 1982 were different from the previous year. In 1981, spawning activity peaked in mid-May, however, in 1982 the peak came nearly two weeks earlier. Between April 2 and May 12, 1981 just under 30 percent of the spawning upstream from the Sauk River had occurred. In 1982, between April 6 and May 13 for that same reach 65 percent of the total had spawned. While these percentages may not be absolute proportions, they do provide a strong indication that spawning in 1982 peaked earlier than in 1981. High counts in mid-May shown on Table 13 reflect spawning taking place prior to the time of each survey. Redd life in 1982 was 16 to 22 days and in mid-May was almost 20 days, therefore redds observed on May 13 could have been dug as early as late April.

The distribution of spawning activity changed from 1981 to 1982 with fewer fish spawning above the mouth of the Cascade River. In 1982, of the spawning above the Sauk River, 37.1 percent was observed between the mouth of the Sauk and Illabot Creek; 52.9 percent between Illabot and the mouth of the Cascade River; and 10 percent above the Cascade. Since 1974 the spawning above the Sauk has been distributed as follows: to Illabot - 33.5 percent; Illabot to Cascade - 41.2 percent; above Cascade - 25.3 percent. These values are mean percent distributions for 1974 to 1982. The annual percent distributions are presented in Table 14. Even though spawning distribution varied considerably from year to year, no significant trends or patterns are present. A two-way analysis of variance at the 0.05 level on these distributions failed to reject the hypothesis of no difference between reaches through the years.

Steelhead catch statistics for the Skagit River system, calculated and compiled by the WDG, are presented for the period 1977 to 1982 for winter-run sport harvest (Table 15), summer-run sport harvest (Table 16), and Skagit system treaty Indian harvest (Table 17).

6.2 Adult Spawning - Flow Fluctuation Studies

6.2.1 Salmon Spawning Behavior

6.2.1.1 Chinook

The flows during the chinook observation period in September-October 1980 were relatively stable as indicated in the hourly gage height records at the Marblemount gage (Figs. 13 and 14). The mean change in river stage for the observation period was 0.80 feet with a maximum of 2.43 feet on September 19 and a minimum of .11 feet on September 16. The overall range in river height for the entire observation period was 2.52 feet. This represents a range of flows at Marblemount from 1,770 cfs to 9,030 cfs. The mean discharge for the study period was 3,570 cfs measured at Marblemount.

The tagging locations and identifying colors for the 29 female chinook tagged from 9/3/80 to 9/16/80 are presented in Appendix III, Table 1. Only 9 (31 percent) of the marked females were completely unspawned at the time of marking. This is an indication of the high degree of difficulty associated with capturing these "target" fish. It should be noted that the use of

Table 14. Percent Distribution Steelhead Spawning Above Sauk River 1974 to 1982.

Year	Percent Sauk River to Illabot Creek	Percent Illabot Creek to Cascade River	Percent Above Cascade River
1974	32.3	49.0	18.7
1975	46.2	36.1	17.1
1976	25.0	28.6	46.4
1977	34.1	34.6	31.3
1978	34.6	39.1	26.3
1979	38.0	28.0	34.0
1980	43.0	17.4	39.6
1981	28.2	43.2	28.6
1982	37.1	52.9	10.0
1974 to 1982 mean	33.5	41.2	25.3

Table 15. Sport harvest of Skagit system winter-run (November-April) steelhead trout, 1977-1978 through 1981-1982 from creel census data (WDG).

Year	Skagit	Sauk	Suiattle	Cascade	Total
1977-1978	2383	178	—	82	2643
1978-1979	4027	211	—	5	4243
1979-1980	3058	248	—	8	3314
1980-1981	2270	172	—	27	2469
1981-1982	2040	135	—	31	2206

Table 16. Sport harvest of Skagit system summer run (May-October) steelhead trout, 1977-1981 (WDG). Figures are corrected for nonresponse bias.

Year	Skagit	Suiattle	Cascade	Sauk	Total
1977	281	21	42	60	383
1978	210	—	44	139	393
1979	197	—	20	71	288
1980	341	—	61	160	562
1981	353	—	86	90	529

Table 17. Skagit system Treaty Indian harvest of winter-run steelhead, 1977-1978 through 1981-1982 (WDG).

Year	Steelhead taken
1977-1978	4250
1978-1979	4886
1979-1980	4199
1980-1981	2949
1981-1982	2697

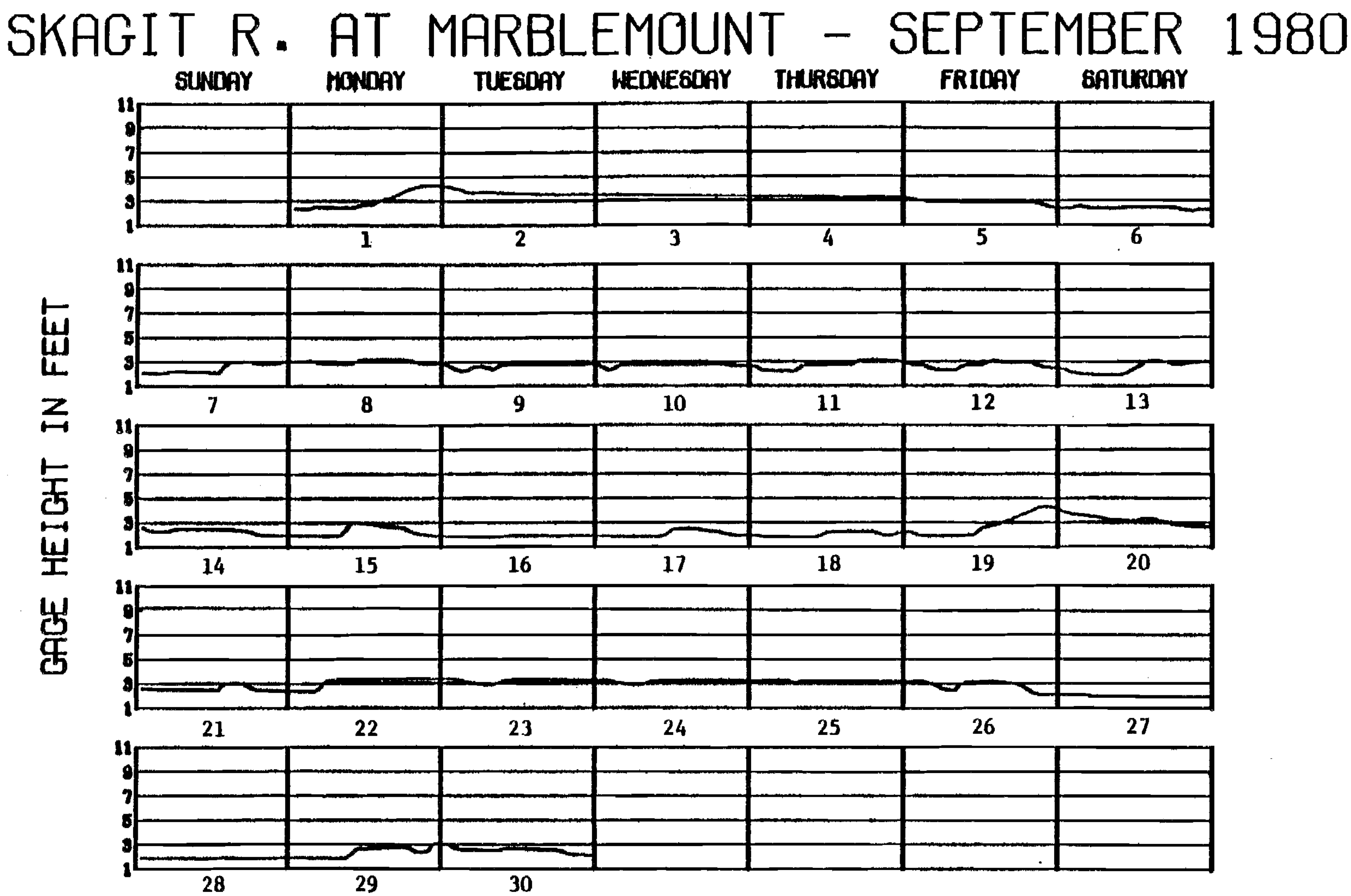

Fig. 13. Hourly gage height data for Skagit River at Marblemount (USGS), September 1980.

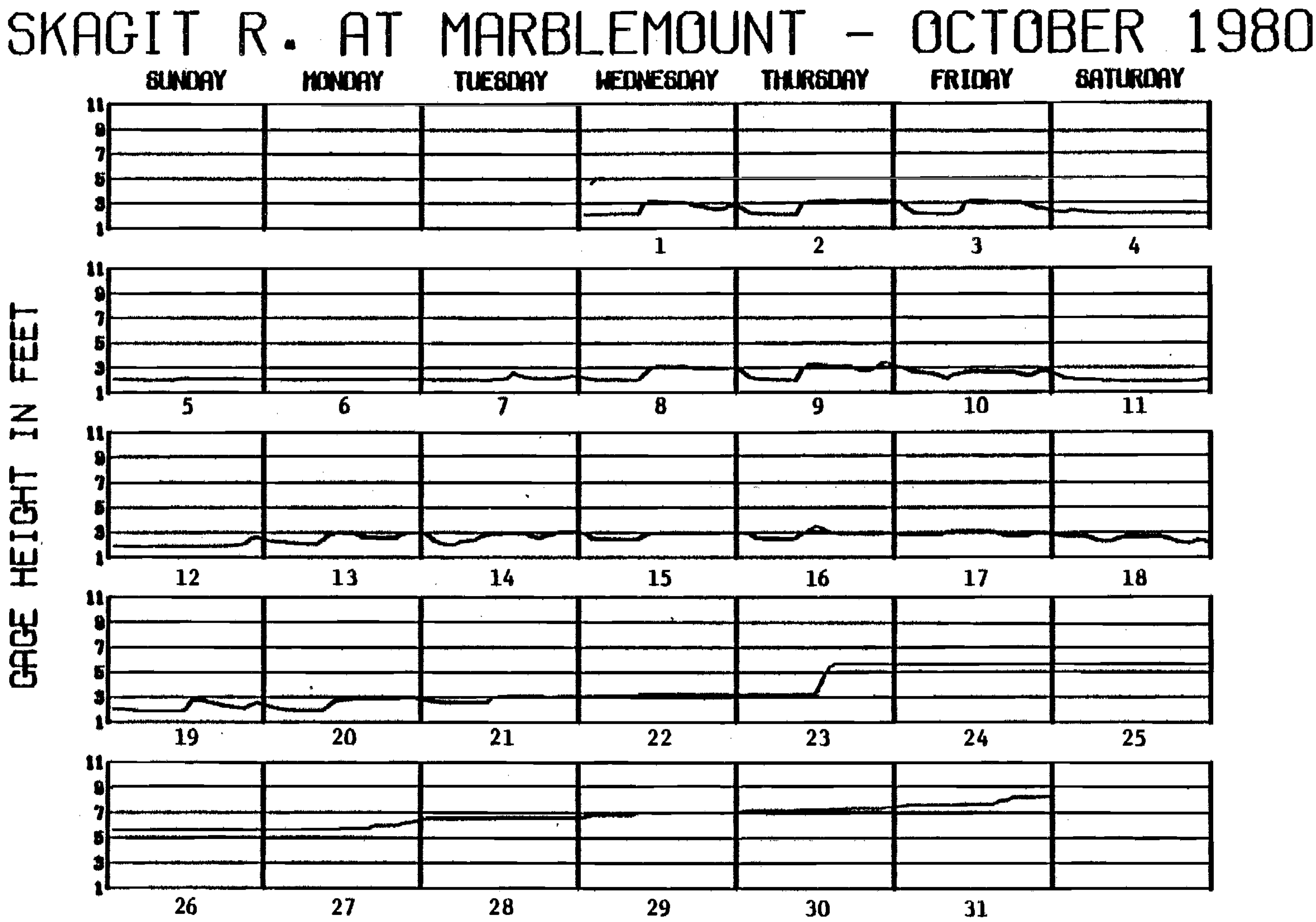

Fig. 14. Hourly gage height data for Skagit River at Marblemount (USGS), October 1980.

flagging glued to the plastic strip was discontinued after the 20th fish was tagged. The flagging lacked durability and tore from the plastic strips in one to three days after liberation of the marked fish.

The locations and activity of the observed marked females are presented in Appendix III, Table 2. The general conditions for observation of the chinook spawning activity and marked females were generally good (Appendix III, Table 3). A chronological summary of tagging and observation dates is presented in Appendix III, Table 4). Five of the chinook females tagged with the Peterson disk tags were not seen after liberation. Four of these were partially spawned at the time of tagging and the stress of the tagging operation may have caused a delayed mortality in these fish. The majority (13 of 21) of the females observed after marking were seen the next day in the vicinity of their redds. The determination that marked females were spawned out was the result of recapturing marked females while attempting to capture additional females for marking.

There was some variance in behavior but individual females generally returned to the same redd once it had been started. Only one female (No. 5) was observed spawning in two different locations. It was also noted that females stayed at their redds through moderate changes in flow. It was not uncommon to see females occupying redds with six inches to a foot of water over their backs remain on these redds when reduced flows partially exposed their backs. When further flow reductions nearly completely dewatered some active redds the females left the redds but returned later after flows increased.

While observing redds marked with painted rocks only two redds out of twenty-five were judged not to have been completed. Both of these were started during a high flow period associated with a rain storm. After the rain storm these redds were frequently dewatered.

The general pattern of activity indicated that the female chinook would complete their redds if the flow levels provided adequate flows over the redd site for at least several hours each day.

6.2.1.2 Chum

The flows during the chum salmon spawning period (November-December 1980) were moderately high and very stable (Figs. 15 and 16). Spot checks of the Marblemount gage indicated flows ranging between 5,950 cfs and 8,950 cfs over the entire observation period, which resulted in a river height fluctuation of 0.80 feet. The U.S.G.S. records were not examined for this period because there were no observed flow fluctuations which restricted the spawning distribution or activity of the chum salmon.

The tagging locations and identifying colors for the 7 female chum tagged from December 1, 1980 to December 7, 1980 are presented in Appendix III, Table 5. The small number of "target" females tagged is partially a reflection of the small chum escapement in 1980 and the degree of difficulty involved in capturing unspawned females on the spawning grounds.

The locations and activity of the observed marked females are presented in Appendix III, Table 6. The general conditions for observation of chum spawning activity and marked females (Appendix III, Table 7) were fair to excellent. A chronological summary of tagging and observation dates is presented in Appendix III, Table 8. The marked females were seldom observed on redds. Only 4 of the 16 observations of marked females were of females on redds. There were no occasions when chum females were forced form their redds by reduced flows. It is possible that the tagging of the females or the presence of observers discouraged them from remaining on or near their redds. Another possibility is that the low density of spawners gave the females

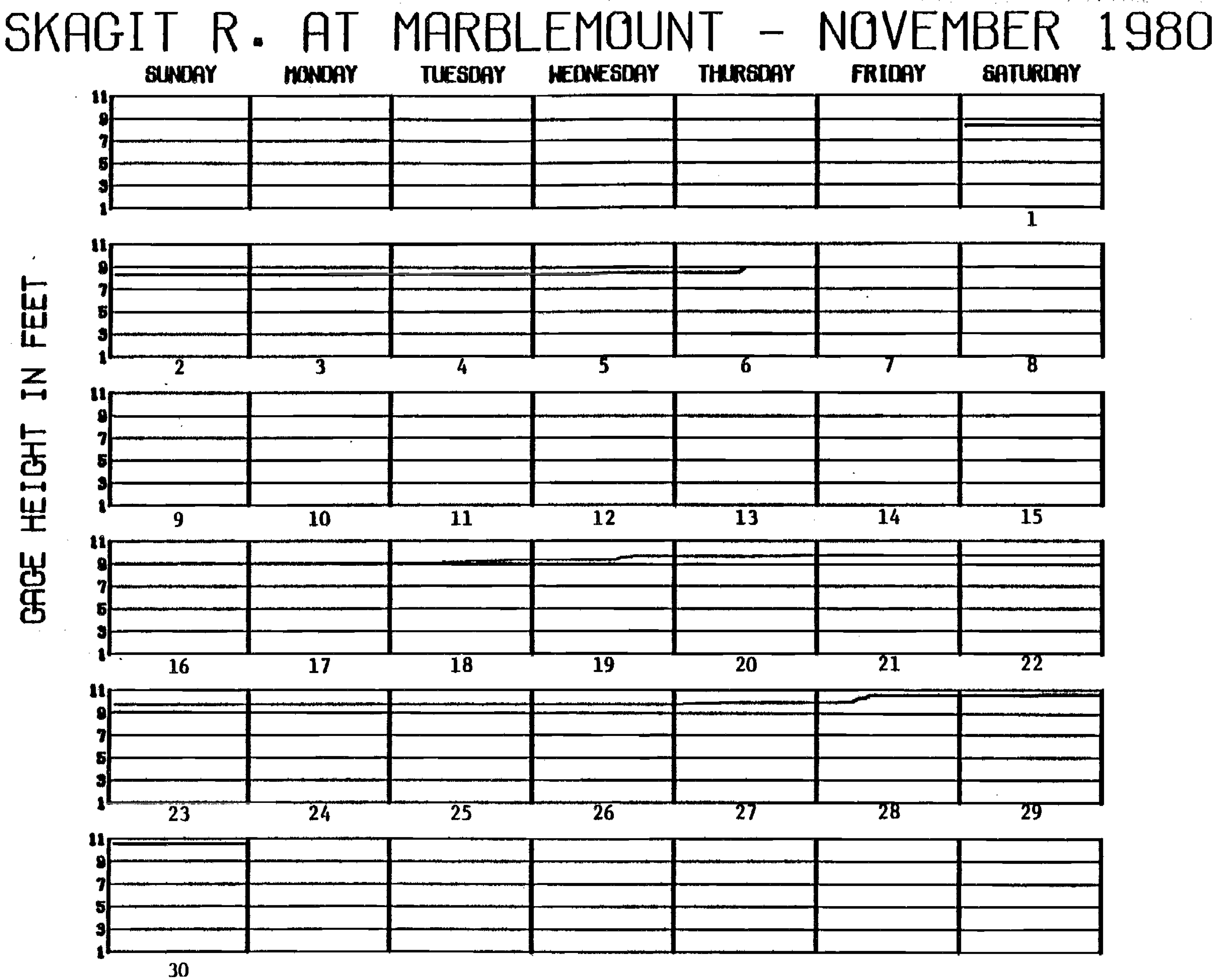

Fig. 15. Hourly gage height data for Skagit River at Marblemount (USGS), November 1980.

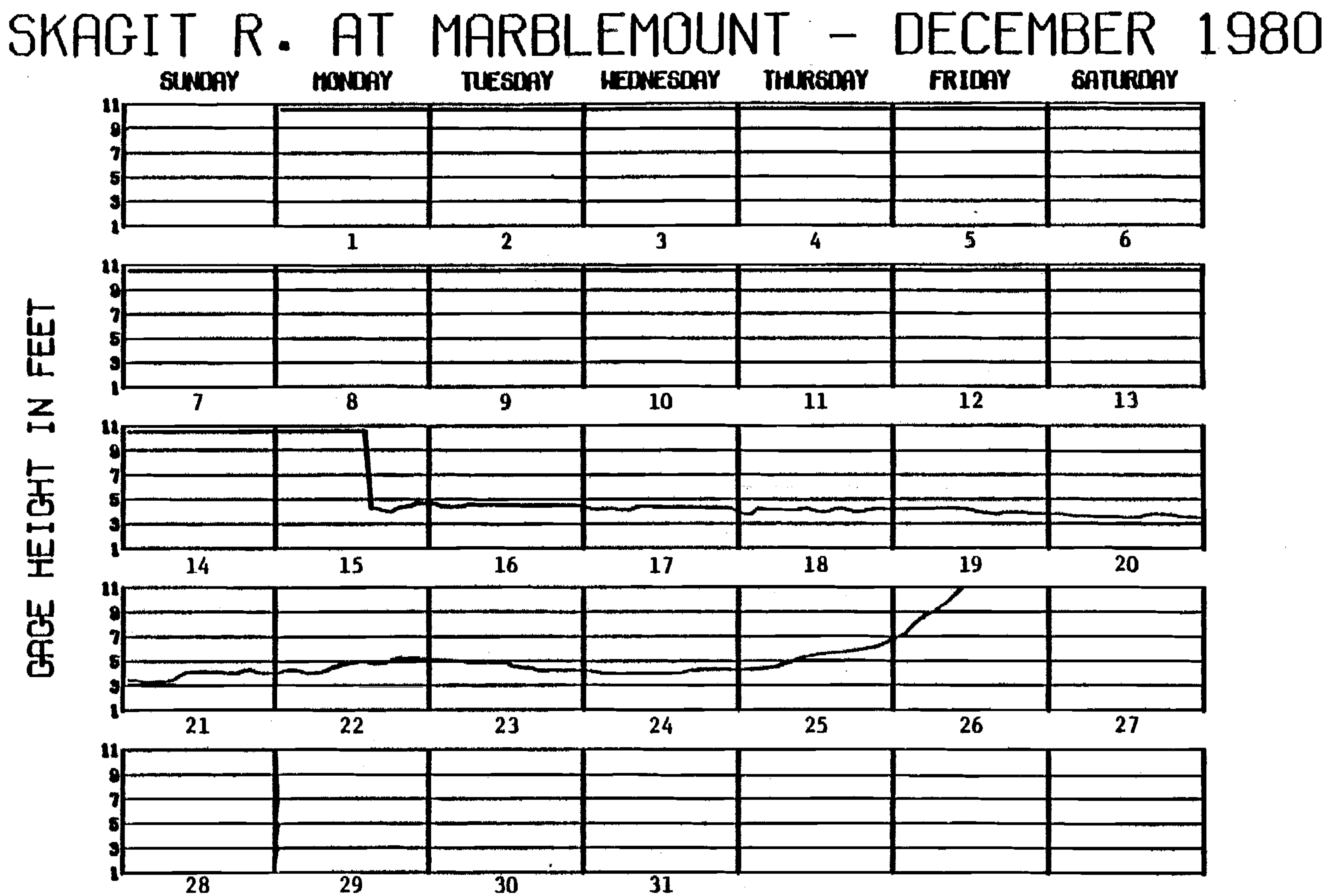

Fig. 16. Hourly gage height data for Skagit River at Marblemount (USGS), December 1980.

little incentive to guard their redds. For whatever reason, the small amount of time that marked females were spending on or near redds appeared unusual.

The 1981 observations of marked redds for both chinook and pink salmon confirmed the 1980 observation that females are forced off redds by flow reductions and return to complete their redds if a reasonable opportunity occurs.

6.2.2 Steelhead Redd Depth - Flow Relationships

A total of 64 redds were marked in 1982 between April 28 and May 18. Most of the marks were put in areas of high spawning activity. Subsequent field observations in the spring indicated that most of the bricks had remained in place on the redds. Flows at Marblemount during this time ranged from approximately 4700 to 9500 cfs with flows at Newhalem about 3000 cfs less. Tributary inflow accounteds for the difference. It is apparent that with flows of this order, even relatively low Gorge Powerhouse discharges would not seriously endanger steelhead redds as long as there was substantial tributary inflow below Newhalem. Adult spawning behavior could be affected, but established redds probably would not be dewatered. However, in late July and early August depending on timing of the end of runoff or when tributary inflow is small, redds may be subject to dewatering prior to fry emergence. Due to the large snowpack and length of the runoff in 1982, steelhead redds were not dewatered before fry emerged. This may not be the case with different runoff patterns and lower tributary inflow.

Due to the above average 1982 snowpack, runoff continued until the middle of August resulting in a delay in field observations. By the time marked redds could be observed following the decline in discharge spawning chinook salmon had managed to obliterate most of the marks. River discharge at the Marblemount gage the day redds were measured was about 2320 cfs. The redd sites hidden by spawning salmon were below the water surface at this discharge and would almost never be subject to dewatering under normal operating conditions. Steelhead redd depth measurements at the time of spawning and on subsequent dates for the Marblemount, Illabot-Corkindale, and upper Rockport areas, respectively, are presented in Appendix IV Tables 1, 2, and 3. Thirteen marked redds were located of the original 64 marked last spring. Ten marks were in the Marblemount area above the mouth of the Cascade River. Most of these ten redds were within a few hundred feet of each other. River discharge at the Marblemount gage was approximately 8550 cfs (4.2 feet) on May 18 when these redds were marked. On September 30 when these redds were remeasured, discharge was 2320 cfs, and the staff gage was 2.1 feet. Due to the close proximity of the redds to the Marblemount gage, the ten redds near Marblemount were the only ones measured. Water depths over these redds ranged from 2.0 to 4.5 feet when marked on May 18. These redds were most likely made during the period of May 5-18. Mean daily discharge and daily low release at Gorge Powerhouse for May 5-18 are summarized in the Table 18.

On May 18, hourly discharges at Newhalem from 5 am to 10 am were 5200, 5048, 4953, 5466, 6001, and 6379 cfs. There is at least two hours or more time difference depending on discharge between a change at Newhalem and its arrival at Marblemount (SCL Power Control, pers. comm.). On May 18, Marblemount flow was 8550 cfs at 7 am and 9350 cfs at noon. The lowest flow for the preceding days was 1700 cfs measured at Newhalem. With addition of tributary inflow, it is likely that the redds marked on May 18 were created at flows of at least 4500 cfs. This flow corresponds to a staff reading of 3.0 feet at Marblemount.

On September 30, discharge at Gorge Powerhouse was held virtually constant from before dawn until noon. This was reflected by a gage reading at

Table 18. Mean daily discharge and minimum release at Gorge Powerhouse.

Date	Daily Mean Discharges (cfs)	Minimum Releases (cfs)
5-5	4700	2000
5-6	4500	1700
5-7	4900	1700
5-8	3900	1700
5-9	5200	1700
5-10	4800	1700
5-11	5300	2500
5-12	4900	1900
5-13	5100	1900
5-14	4600	1700
5-16	4000	1700
5-17	4600	1700
5-18	6300	5000

Marblemount of 2320 cfs throughout the morning. The marked redds were found from 0.5 feet above the water surface elevation to 1.3 feet beneath it. The change in depth due to reduced flow ranged from 2.2 to 3.2 feet. The change at the gage was 2.1 feet down from 8550cfs. These differences between the gage and spawning sites are explained by varying cross-sectional areas of the stream channel (i.e., a larger cross sectional area will show a smaller vertical change than the alternative). Gorge discharges that result in flows approaching 2000cfs at Marblemount will jeopardize redds spawned at flows of 4500cfs at Marblemount. Furthermore, it appears that any Gorge discharge which results in a sustained stage of more than one foot less than low flows during spawning, at the Marblemount gage, will probably result in steelhead redd dewatering. Downstream, near Rockport these changes would be less than at the gage due to the moderating influence of tributary inflow from the Cascade River, Illabot Creek and smaller streams.

6.3 Instream Incubation Tests

6.3.1 Steelhead Temperature Unit Requirement

Hatching of steelhead eggs occurred at all three sites between sampling dates of May 15, 1980 and June 1, 1980. The length of time between sampling dates did not permit an accurate estimate of the temperature units (TU) to hatching. All groups appeared to reach emergence condition (button-up) by June 30 and required approximately 1,050 TUs.

The unavailability of additional fish at later dates precluded incubation studies at the warmer temperature regimes in the Skagit River experienced by the peak of the natural spawning run in mid- to late-May. However, the timing of the emergence was determined through electrofishing efforts by WDG.

6.3.2 Instream Flow Fluctuation Tests

Egg boxes used to test instream flow fluctuation effects on chum salmon were planted in the gravel on January 19, 1980 and removed at biweekly intervals at each of the four redd depths at each site from February 2 to March 28, 1980. The live-to-dead ratios of eggs and alevins in freezer containers for the Thornton Creek and Marblemount Slough sites are presented in Tables 19 and 20, respectively. Similar data for the Whitlock-Vibert boxes at the Thornton Creek site are presented in Table 21. Some mortality was detected as early as two weeks following planting. However, most of the embryos had died in all groups at about the time of hatching, which occurred between February 15 and 29. During the course of the incubation study at the Thornton Creek site the freezer container incubation boxes appeared to provide

Table 19. Live-to-dead ratios of chum salmon eggs and alevins incubated in freezer containers in the Skagit River at the Thornton Creek study site. Eyed eggs were planted on 1/19/80 and sampled without replacement on indicated dates.

	Redd Depths*							
	.5'		1.0'		1.5'		2.5'	
Recovery dates	Eggs	Alevins	Eggs	Alevins	Eggs	Alevins	Eggs	Alevins
2/02/80	50/0	—	50/0	—	49/1	—	50/0	—
2/15/80	50/0	—		—		—		—
2/29/80	1/+	41/4	11/1+	0/3+	10/2	13/+	6/7+	2/2+
3/14/80	2/3	5/3	0/6	0/+	0/17	0/+	0/6+	19/0+
3/28/80	0/+	0/+	0/+	0/+	0/+	0/+	0/+	0/+

* Staff gage heights corresponding to Newhalem gage height of 85.07.

+ Indistinguishable remains.

Table 20. Live-to-dead ratios of chum salmon eggs and alevins incubated in freezer containers in the Skagit River at Marblemount Slough study site. Eyed eggs were planted on 1/19/80 and sampled without replacement on the indicated dates.

	Redd Depths*							
	.5'		1.0'		1.5'		2.5'	
Recovery dates	Eggs	Alevins	Eggs	Alevins	Eggs	Alevins	Eggs	Alevins
2/02/80	50/0	—	50/0	—	50/0	—	49/1	—
2/15/80	49/1	—	8/0+	35/0+	50/0	—	0/0	6/0+
2/29/80	0/+	0/+	0/+	3/+	4/0+	3/0+	0/0	0/0+
3/14/80	0/+	0/+	0/13+	0/+	0/6+	0/0+	0/0+	0/0+
3/28/80	0/+	0/+	0/+	0/+	0/+	0/+	0/+	0/+

* Staff gage heights corresponding to Newhalem gage height of 85.07.

+ Indistinguishable remains.

Table 21. Live-to-dead ratios of chum salmon eggs and alevins incubated in Witlock-Vibert boxes in the Skagit River at the Thornton Creek study site. Eyed eggs were planted on 1/19/80 and sampled without replacement on the indicated dates.

	Redd Depths*							
	.5'		1.0'		1.5'		2.5'	
Recovery dates	Eggs	Alevins	Eggs	Alevins	Eggs	Alevins	Eggs	Alevins
2/02/80	50/0	—	49/1	—	49/1	—	50/0	—
2/15/80	49/1	—	50/0	—	49/1	—	46/0	4/0
2/29/80	1/0+	19/2	2/+	1/+	5/3+	6/2+	9/0+	3/2+
3/14/80	0/+	0/+	0/+	0/+	0/17+	0/+	0/+	0/+
3/28/80	0/+	0/+	0/+	0/+	0/+	0/+	0/+	0/+

* Staff gage heights corresponding to Newhalem gage height of 85.07.

+ Indistinguishable remains.

slightly higher percentages of survival at each of the redd depths than the W-V boxes; however, the very low survival rates in each of these tests rendered the experiments unsatisfactory.

Thermograph recordings from the shallower redd depths, 0.5, 1.0 and 1.5 ft which may have been indicative of a dewatering event, did not reveal any marked deviations from the temperature pattern at the control depth of 2.5 ft.

The high mortality observed in the artificial redds irrespective of redd depth and the lack of substantial flow reductions during the incubation precluded establishing any correlations between egg and alevin survival and dewatering events.

6.4 Laboratory Incubation Tests

6.4.1 Environmental Parameters

The temperature of the Clark Creek water used in the laboratory experiments is plotted with the temperature of the Skagit River at Alma Creek for 1980-81 and 1981-82, in Figs. 17 and 18, respectively. The spring-fed Clark Creek water temperature regime was more stable than the Skagit River and thus was cooler in the fall and warmer through the winter than the Skagit River.

The relative humidity measured inside and outside the laboratory for 1980-81 and 1981-82 is shown in Figs. 19 and 20, respectively. There appears to be no trend where the humidity inside the laboratory was either consistently higher or lower than outside. Thus the high survival of the dewatered eggs was not confounded by artificially altered humidity inside the laboratory building.

The dissolved oxygen levels monitored in the static water experiments of

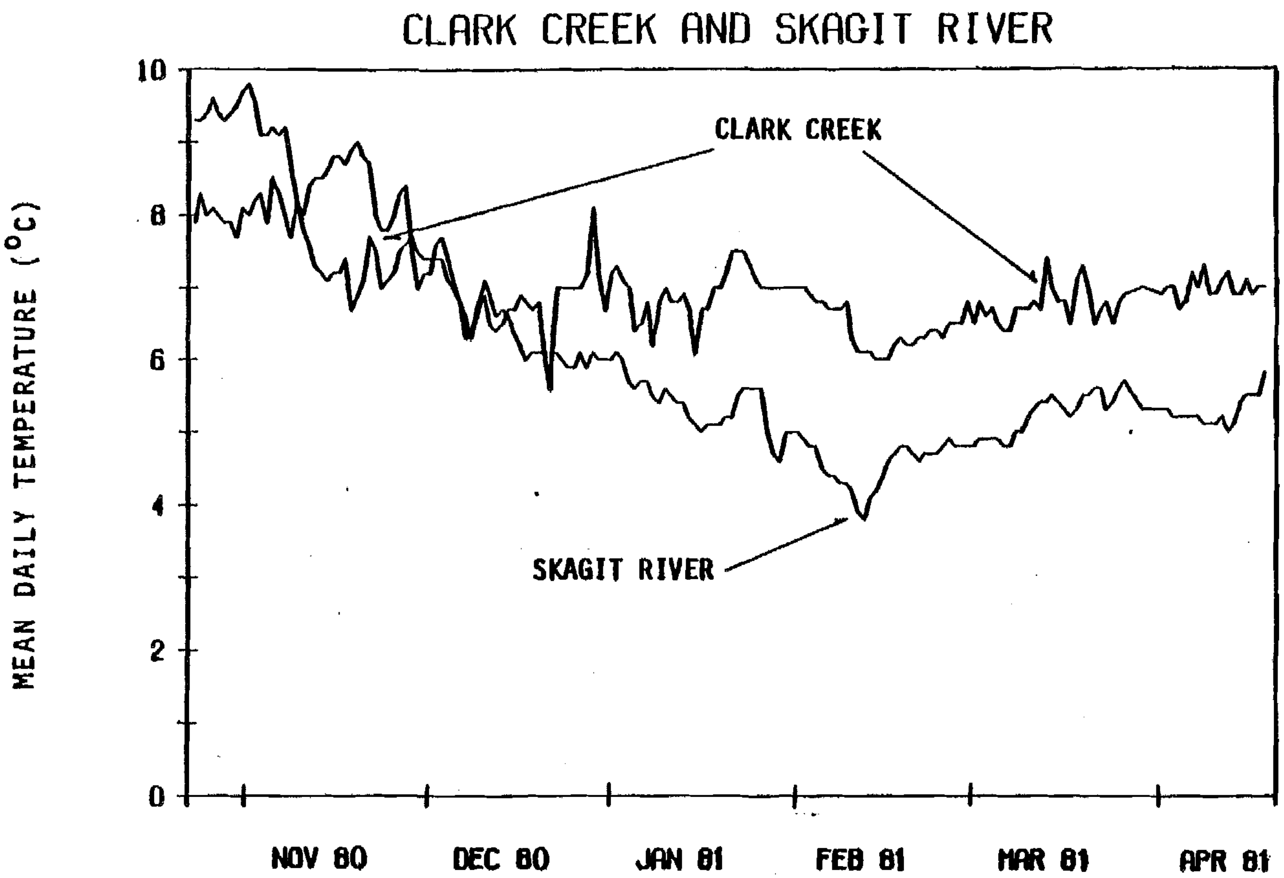

Figure 17. Mean daily temperature of Clark Creek water utilized in the experimental hatchery and the Skagit River at Alma Creek for 1980-81.

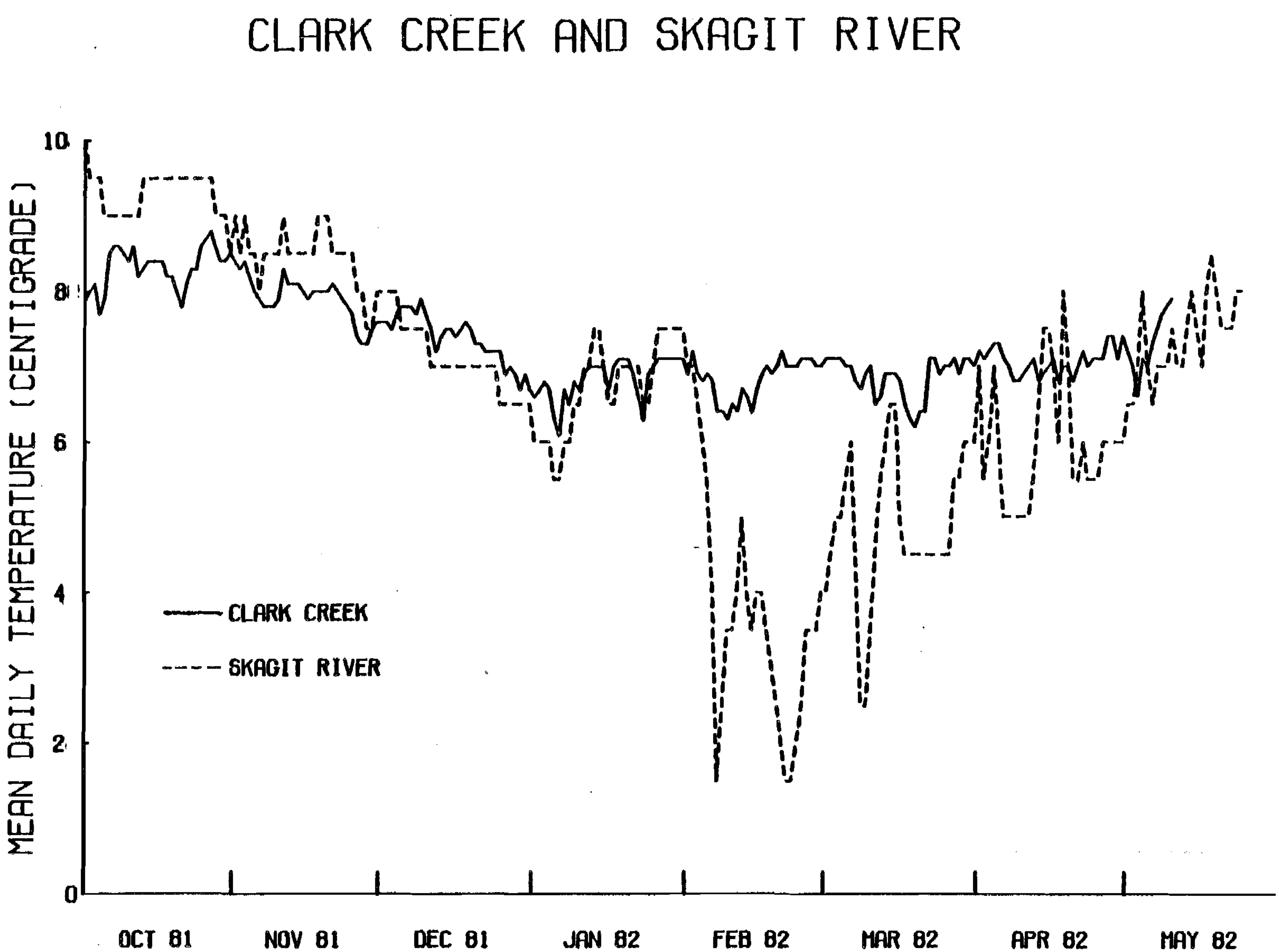

Figure 18. Mean daily temperature of Clark Creek water used in the experimental hatchery and Skagit River at Alma Creek for 1981-82.

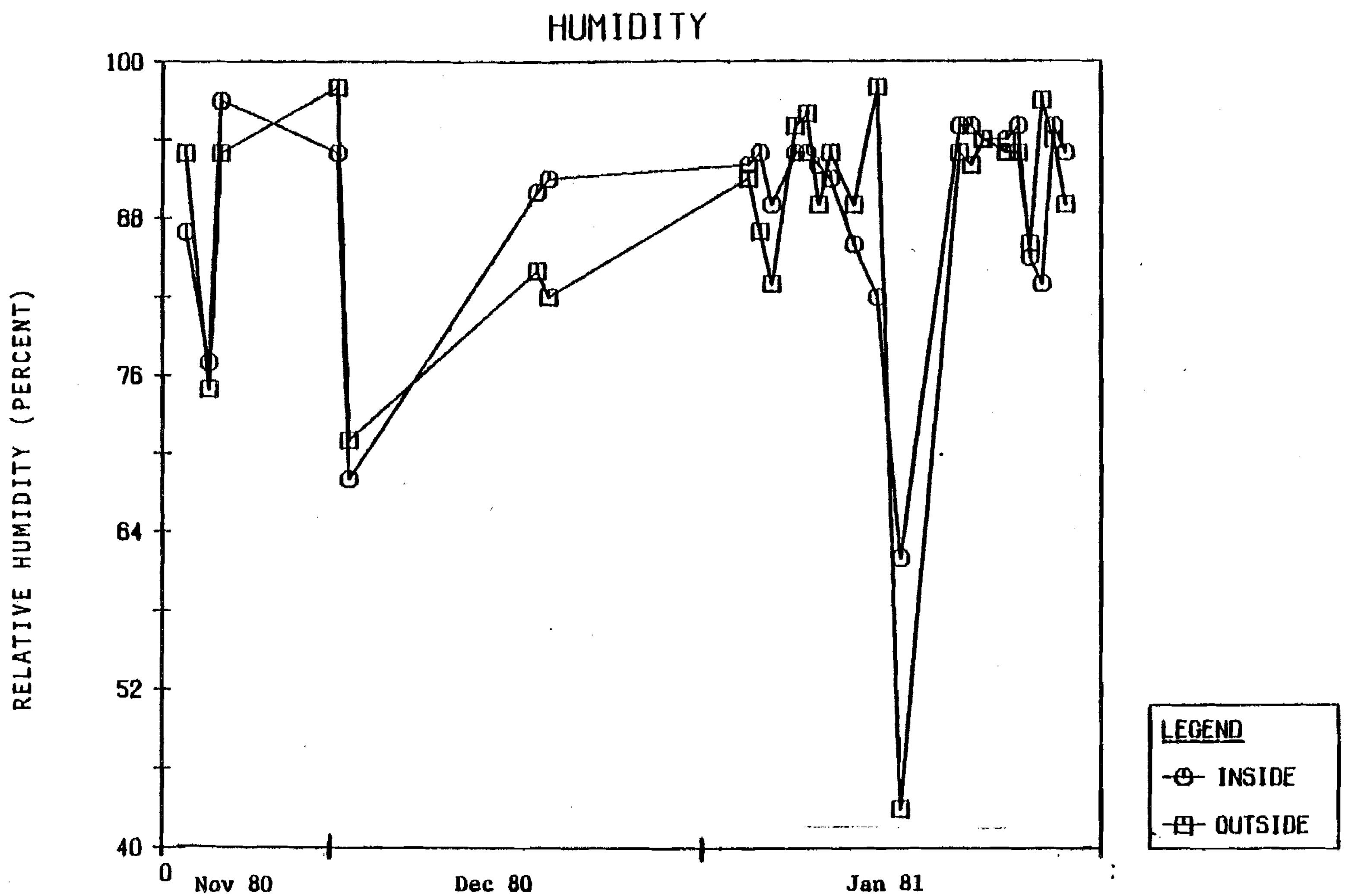

Fig. 19. Relative humidity measured inside and outside of the experimental hatchery building for 1980-81.

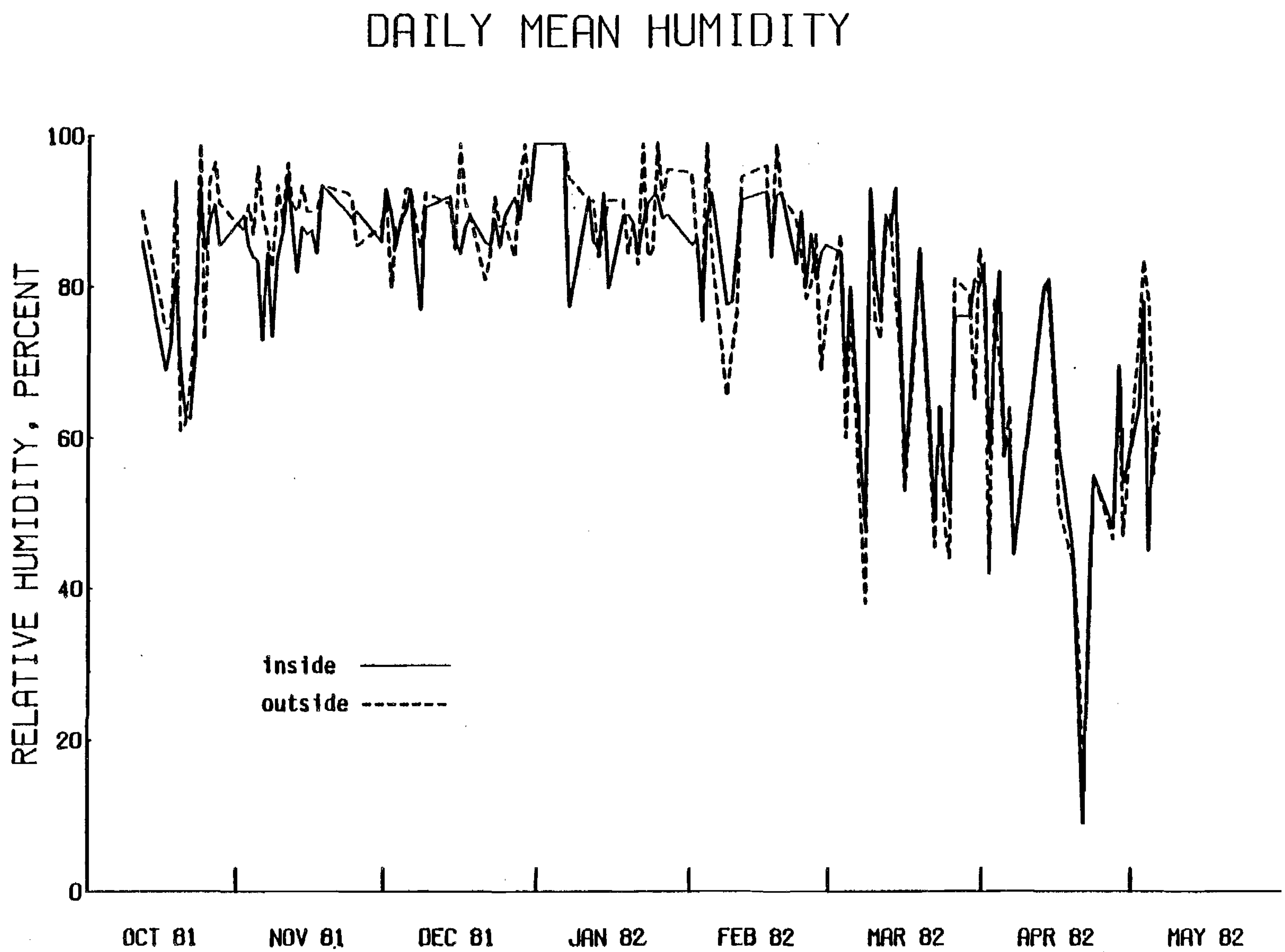

Fig. 20. Relative humidity measured inside and outside of the experimental hatchery building for 1981-82.

4, 8 and 16 hrs/day dropped to average lows of 8.4, 6.9 and 4.1 mg/1, respectively, during the hatching period. The controls remained at air saturation levels.

A particle size analysis of the four artificial substrates tested in the laboratory experiments in 1980-81 is presented in Table 22. The minimum particle size for large, medium and small substrates was greater than 13.5, 6.73 and 3.33 mm, respectively. The mixed substrate had a geometric mean diameter of 7.73 mm. Results of chinook and pink salmon redds sampled in the Skagit River are shown in Table 23. The analyses for both species were averaged to arrive at a substrate composition that was used for these species as well as chum salmon and steelhead trout during the 1981-82 laboratory studies (Table 23).

6.4.2 Dewatering Test

6.4.2.1 Fertilization to Eyed Stage (1980-81)

The comparative survival of eggs from chinook and coho salmon and steelhead trout dewatered for 0 (control) 4, 8, and 16 hrs daily in the large, medium small or mixed gravel sizes was evaluated from fertilization through eyed stage (8 weeks for chinook and coho salmon and 6 weeks for steelhead). Eggs of all species during the development period were highly tolerant to dewatering irrespective of daily dewatering time or substrate type used. Survival in control redds was similar to dewatered redds for each gravel size tested with levels of survival ranging from 65-90%, 85-95%, and 90-100% for chinook and coho salmon and steelhead trout, respectively (See Appendix V, Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11). An exception to the chinook survival ranges was the daily dewatering of 4 hr in small gravel which declined to 40 percent due to flow reduction resulting from the cylinder clogging. Moreover the generally lower survival with chinook salmon as

Table 22. Geometric mean diameter (dg) and substrate particle size by groups representing percent volume passing through sieves of the designated size (mm) for artificial substrates used in 1980-81.

Artificial redd substrates	Sample size	dg (mm)	Sieve size (mm)									
			50.8	26.7	13.5	6.73	3.33	1.68	.833	.419	.211	.106
Large	11	—*	0.0	.469	.463	.004	.002	0	0	0	0	0
Medium	13	—*	0.0	0.0	.403	.563	.023	.007	.002	.001	0.0	.001
Small	10	—*	0.0	0.0	.001	.469	.519	.013	.005	.002	0.0	.001
Mixed	58	7.73	0.0	.254	.393	.196	.057	.039	.030	.018	.01	.003

* Indeterminable

Table 23. Chinook and pink salmon spawning substrate analyses for 1981-82. Geometric mean diameters (dg) and substrate particle size by groups representing percent volume retained on sieves of the designated size (mm) are shown. Artificial substrate particle size distribution is also presented.

Redd substrate	Sample size	dg (mm)	Sieve size (mm)									
			50.8	26.7	13.5	6.73	3.33	1.68	0.833	0.419	0.211	0.106
Chinook	8	31.0	0.544	0.110	0.121	0.079	0.046	0.035	0.032	0.021	0.009	0.003
Pink	9	32.2	0.572	0.133	0.099	0.059	0.049	0.027	0.018	0.025	0.015	0.002
Artificial*	--	31.6	0.557	0.122	0.110	0.069	0.048	0.031	0.025	0.023	0.012	0.003

*Mean of chinook and pink salmon analyses.

compared to coho and steelhead was caused by factors other than dewatering since control redds declined at a similar rate to dewatered redds with this species. Coho salmon eggs were not evaluated in mixed gravel for dewatering times of 4, 8 and 16 hrs/day for the fertilization to eyed staged. However, equivalent data are available from tests evaluating the incubation period from fertilization through hatching (Section 6.4.2.3).

Survival levels of coho salmon eggs dewatered continuously (24 hr/day) from fertilization through eyed stage (approx. 8 weeks) were 80% for large, medium and small gravel substrates and 50% for the mixed substrate (Appendix V, Fig. 12). Control levels for each of the gravel substrates were approximately 90%. This test was not completed for chinook salmon or steelhead trout; however, equivalent data is available from tests evaluating the period from fertilization through hatching (Section 6.4.2.3).

6.4.2.2 Eyed through Hatching

Survival of chinook, coho and chum salmon and steelhead trout was determined for dewatering regimes of 0 (control), 4, 8, 16 and 24 hr/day (continuous) in large, medium and small gravel for the incubation period extending from eyed through hatching. Survival decreased in most tests from the commencement of hatching at a rate directly related to the amount of time dewatered (Appendix V, Figs. 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38). Exceptions to this progressive decrease in survival were found in large gravel in which alevins in some instances moved downward through the gravel and survived in the water retained at the bottom of the cylinder. The use of repetitive sampling without replacement produced fluctuating survival levels between redds. The survival through hatching was summarized by noting the incubation day on which 50 percent mortality occurred for each dewatering regime and gravel size and is presented in Tables 24, 25 and 26 for chinook, coho and steelhead, respectively. Chinook eggs dewatered 4 hrs/day in small gravel reached the 50% mortality level (day 65) prior to the onset of hatching (day 72) due to a decline in flow brought on by clogging and was not due to dewatering.

The chum salmon eggs were obtained as a single lot consisting of mixed fertilization dates, consequently, hatching time was staggered which precluded construction of a time to 50% mortality table. However, the pattern of decreased survival observed with the other species was also evident with chum salmon but in an extended form.

6.4.2.3 Fertilization Through Hatching

In the first year studies, chinook salmon were dewatered for 0 (control), 4, 8, 16, and 24 hr/day (continuous) in large, medium, small and mixed gravel for the incubation period extending from fertilization through hatching (Appendix V, Figs. 39, 40). Coho salmon eggs and alevins were dewatered in mixed gravel for 0, 4, 8 and 16 hrs/day (Appendix Fig. 41) and steelhead trout eggs and alevins were dewatered in large, medium, small and mixed gravel for 0 (control) and 24 hr/day (continuous) for this period (Appendix V, Fig. 42). The same pattern of survival was evident in this longer term testing as was present when this period was divided into fertilization to eyed and eyed through hatching, (i.e., high survival up to the onset of hatching followed by a significant post-hatching decrease in survival directly related to the length of daily dewatering).

In the second year studies, chinook, pink and chum salmon and steelhead trout were dewatered for 0 (control), 2, 4, 8, 16 and 24 hr/day (continuously) in one artificial gravel mixture that approximated natural spawning substrate in the Skagit River. The results for chinook, pink, chum and steelhead confirmed those obtained the first year and are presented in Figs. 21, 22, 23,

CHINOOK DEWATERED

GRAVEL SIZE	Control	4 hr/day	8 hr/day	16 hr/day
Small (0.33 - 1.35 cm)	–	65	76	76
Medium (0.67 - 2.67 cm)	–	79	76	75
Mixed (0.08 - 5.08 cm)	–	78	77	77
Large (1.35 - 5.08 cm)	–	78	76	73

Table 24 . Incubation days to 50 percent mortality for chinook salmon tested under four dewatering regimes and gravel sizes.

COHO DEWATERED

GRAVEL SIZE	Control	4 hr/day	8 hr/day	16 hr/day
Small (0.33 - 1.35 cm)	–	–	75	71
Medium (0.67 - 2.67 cm)	–	–	72	70
Mixed (0.08 - 5.08 cm)	–	73	70	70
Large (1.35 - 5.08 cm)	–	–	–	–

Table 25. Incubation days to 50 percent mortality for coho salmon tested under four dewatering regimes and gravel sizes.

STEELHEAD DEWATERED

GRAVEL SIZE	Control	4 hr/day	8 hr/day	16 hr/day
Small (0.33 - 1.35 cm)	–	55	53	53
Medium (0.67 - 2.67 cm)	–	56	54	53
Mixed (0.08 - 5.08 cm)	–	54	53	53
Large (1.35 - 5.08 cm)	–	58	54	53

Table 26. Incubation days to 50 percent mortality for steelhead trout tested under four dewatering regimes and gravel sizes.

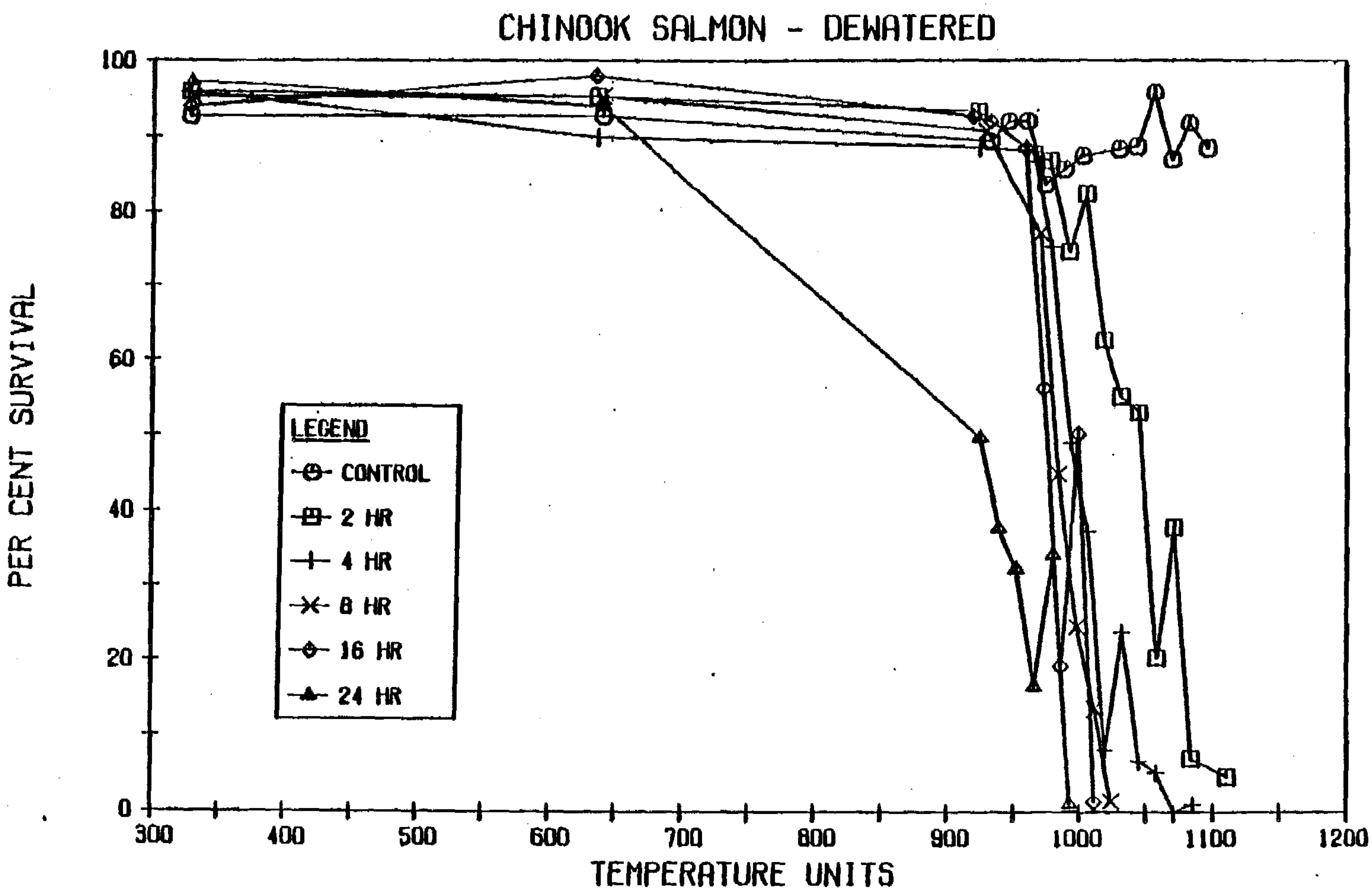

Fig. 21. Percent survival of chinook salmon embryos dewatered for 2, 4, 8, 16, and 24 hrs/day in artificial redds from fertilization through hatching.

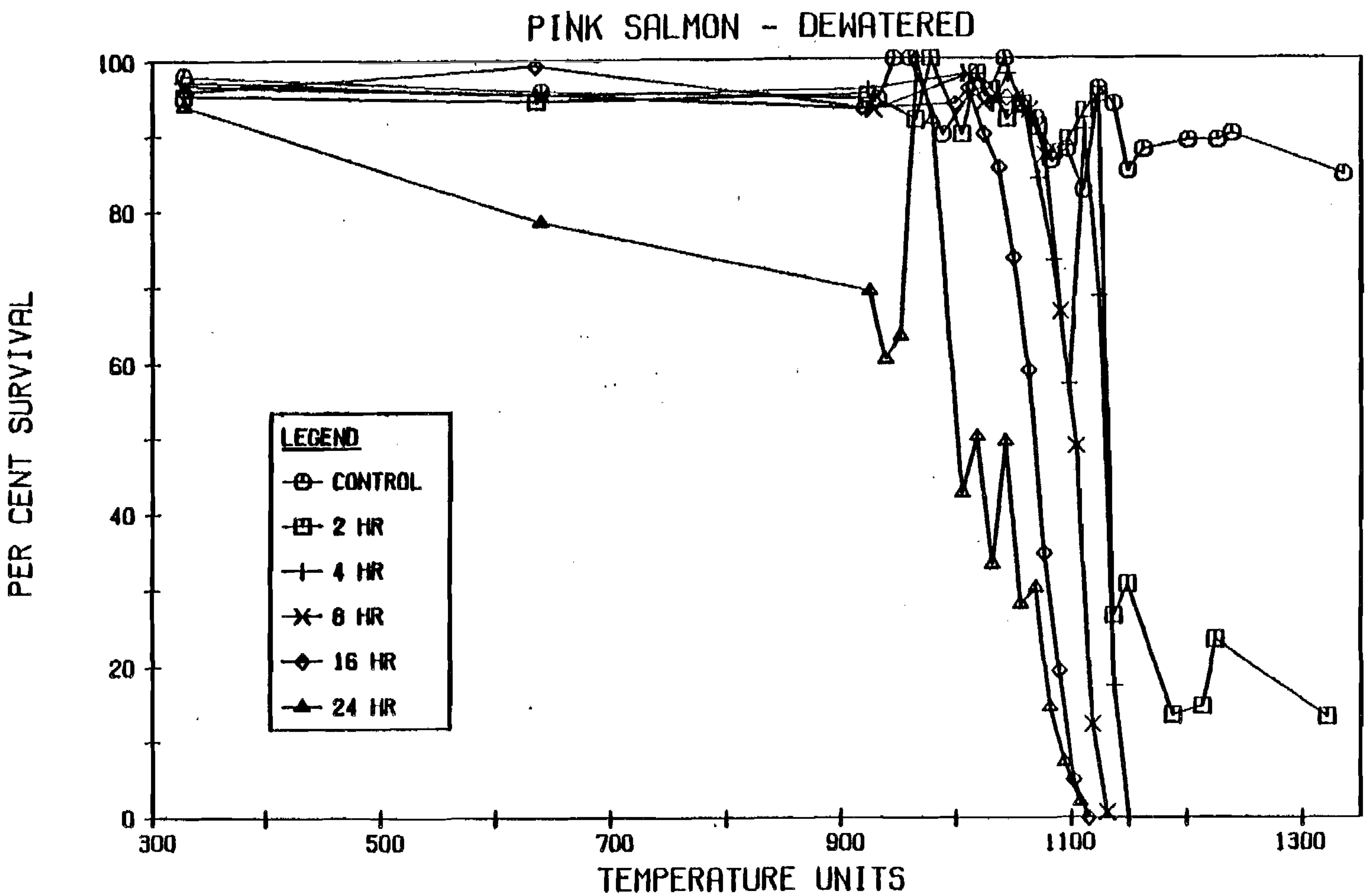

Fig. 22. Percent survival of pink salmon embryos dewatered for 2, 4, 8, 16, and 24 hrs/day in artificial redds from fertilization through hatching.

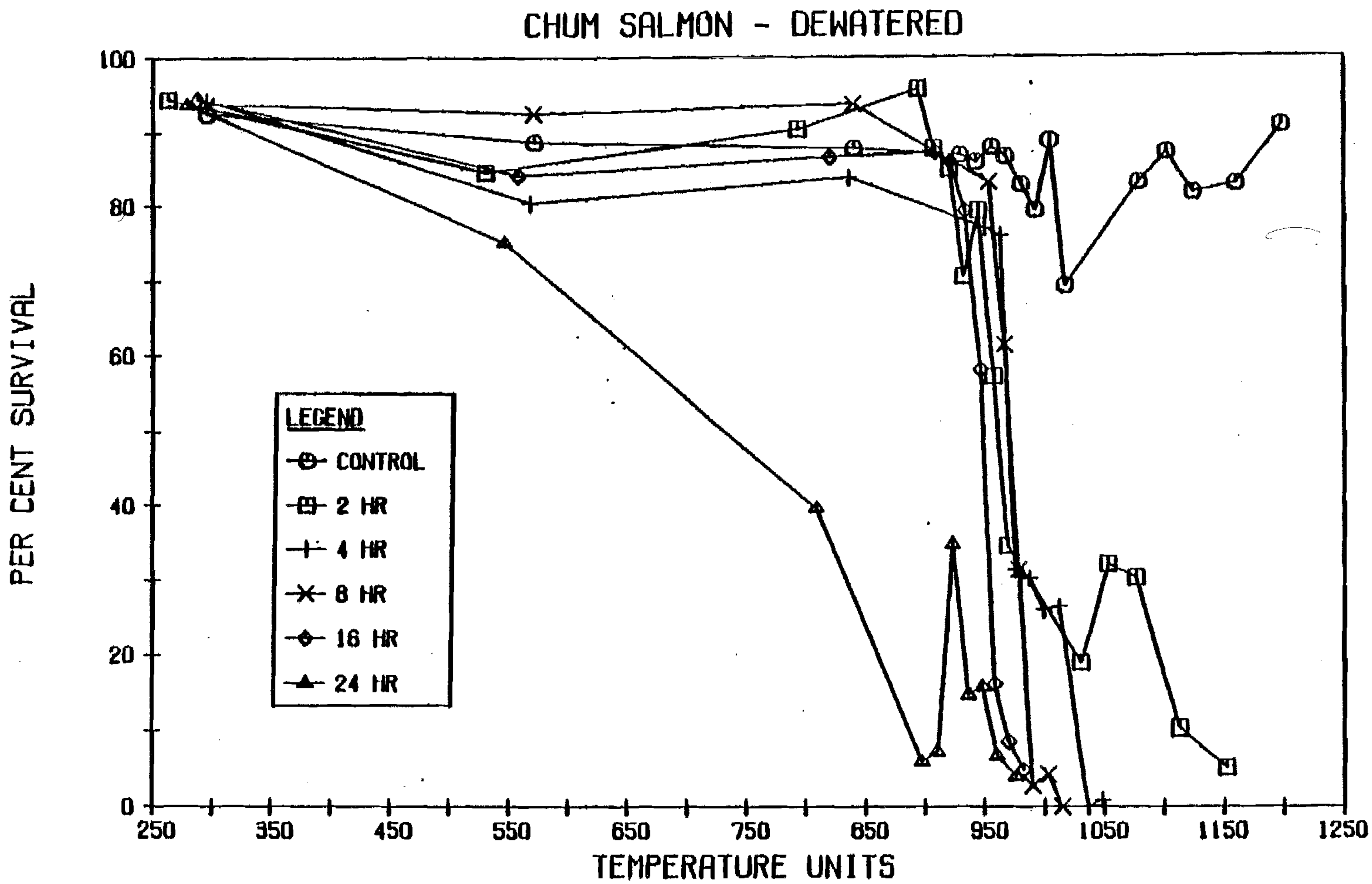

Fig. 23. Percent survival of chum salmon embryos dewatered for 2, 4, 8, 16, and 24 hrs/day in artificial redds from fertilization through hatching.

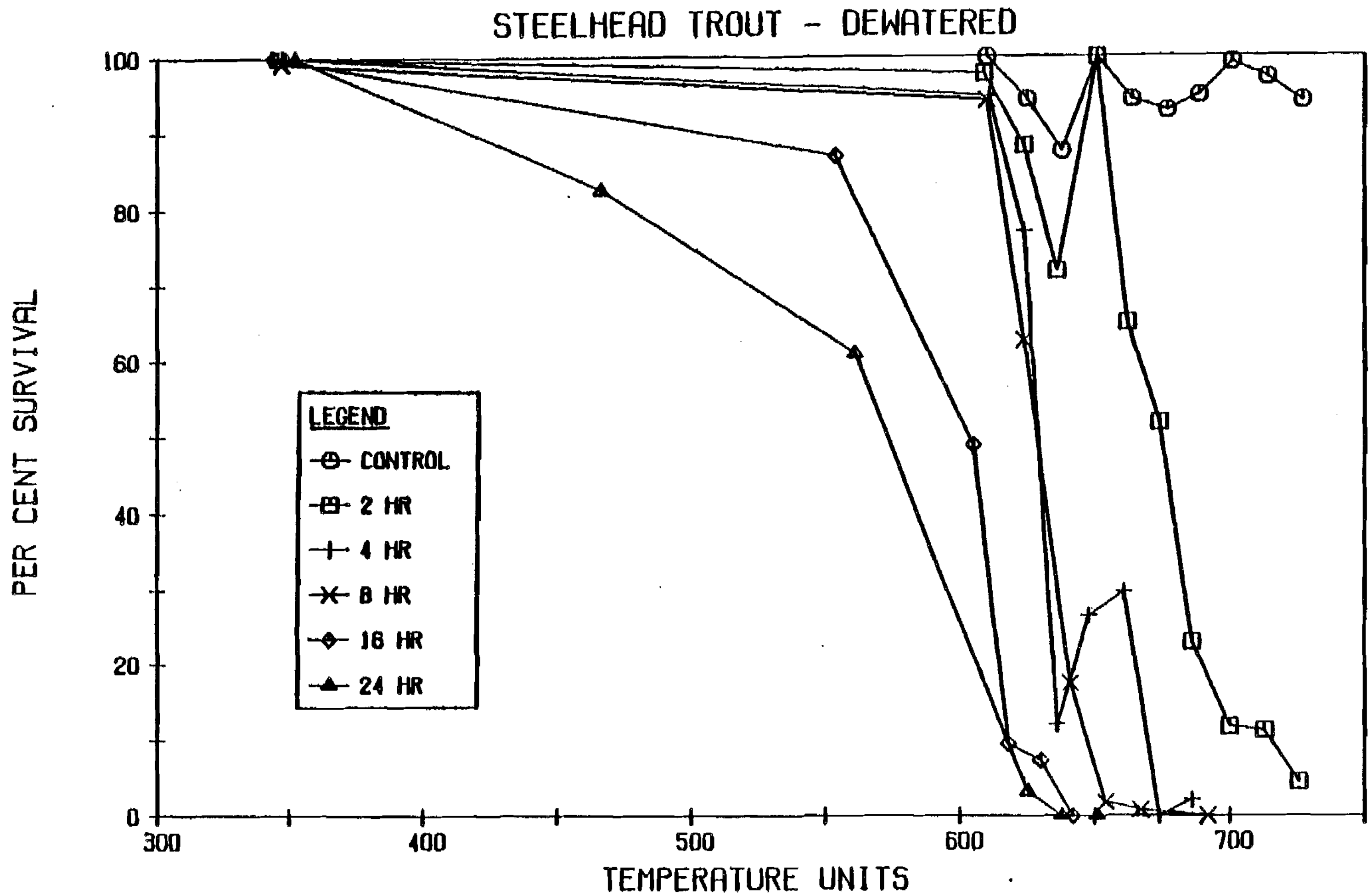

Fig. 24. Percent survival of steelhead trout embryos dewatered for 2, 4, 8, 16, and 24 hrs/day in artificial redds from fertilization through hatching.

24, respectively. Reduction in extraneous sources of mortality and acquisition of reliable temperature monitoring equipment permitted a more detailed analysis of post-hatching survival. The time in incubation days and temperature units required to reach 50% hatching and the 75, 50, and 25% survival marks were estimated for each species and are summarized in Table 27. As evident from these data, the dewatering time of 24 hrs/day, (i.e., continuously dewatered from the time of fertilization) resulted in a mortality of at least 50% of the eggs prior to 50% hatching for all species. Fungus played a major role in this mortality making it difficult to quantitate the effects of dewatering alone.

6.4.3 Static Water Test

6.4.3.1 Fertilization Through Eyed Stage

The comparative survival of coho salmon and steelhead trout eggs was evaluated in the static water condition for daily periods of 0 (control) 4, 8, 16 hrs in large, medium, small and mixed gravel sizes. Survival for both species was high (80-90%) for all static regimes and gravel substrates tested although slightly less than control levels (90-95%) (Appendix V, Figs. 43, 44, 45, 46, 47, 48, 49, 50). The data presented in the steelhead figures extends beyond the eyed stage and approaches hatching at which time survival decreased significantly, particularly in the 8 and 16 hr/day static conditions for all gravel sizes. The dramatic decrease in survival for steelhead on day 47 for the 8 hr test was caused by accidently providing 24 hrs of static conditions rather than 8 hrs.

6.4.3.2 Eyed Through Hatching

The comparative survival of chinook, coho and chum salmon and steelhead trout was evaluated in static water conditions for daily periods of 0

Table 27. Temperature units (incubation days in parentheses) to 50% hatching and 75, 50, and 25% survival for chinook, chum, and pink salmon and steelhead trout embryos dewatered 0 (control), 2, 4, 8, 16, and 24 (continuous) hrs/day in 1981-82.

Species			Dewatering time, hrs/day					
			Control	2	4	8	16	24
Chinook	50% Hatch		1002(70)	978(69)	979(69)	984(69)	973(69)	--
	% Survival	75	--	992(70)	979(69)	970(68)	973(69)	925(65)
		50	--	1058(75)	993(70)	984(69)	986(70)	925(65)
		25	--	1058(75)	1019(72)	998(70)	986(70)	966(68)
Chum	50% Hatch		967(78)	920(78)	963(78)	966(78)	946(78)	--
	% Survival	75	--	932(79)	963(78)	966(78)	946(78)	547(46)
		50	--	969(82)	975(79)	978(79)	958(79)	809(68)
		25	--	1030(87)	1012(82)	990(80)	958(79)	897(75)
Pink	50% Hatch		1082(76)	1071(76)	1071(76)	1077(76)	1063(76)	--
	% Survival	75	--	1136(81)	1085(77)	1091(77)	1050(75)	1005(71)
		50	--	1136(81)	1137(81)	1104(78)	1076(77)	1005(71)
		25	--	1186(85)	1137(81)	1118(79)	1089(78)	1081(77)
Steelhead	50% Hatch		625(49)	636(50)	636(50)	624(49)	618(49)	--
	% Survival	75	--	636(50)	636(50)	624(49)	605(48)	561(44)
		50	--	674(53)	636(50)	641(50)	605(48)	561(48)
		25	--	686(54)	674(53)	641(50)	618(49)	561(48)

(control) 4, 8, 16 and 24 hrs (continous) in large, medium, small and mixed gravel sizes. Due to an insufficient number of chum eggs static conditions were limited to 0 (control), 8, 16 hrs/day for all gravel sizes. Survival of chinook eggs in small, medium and large gravel was poor prior to static water testing for reasons unknown, however, general survival trends were discernable after initiation of the test regimes.

Distinct differences in survival were noted among the various gravel sizes and static water times tested for all the species. The general pattern that emerged consisted of progressively lower post-hatching survival as gravel size decreased, (i.e., large > medium > mixed > small) and time of static conditions increased (Appendix V, Figs. 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72). The effect of gravel size was most evident in the large gravel where survival was significantly higher for all static water conditions when compared to the other gravel sizes tested. Survival levels in the static water time of 4 hr/day were similar to or slightly lower than controls for all species and gravel sizes while static water times of 8, 16, and 24 hr/day were substantially lower. Unlike the dewatering studies, survival often did not reach 0% within the time constraints of the testing.

6.4.3.3 Hatching Through Emergence

The results of preliminary tests designed to determine the tolerance of developing alevins to single event dewaterings of various times are presented in Table 28, for chinook, pink, chum, and coho salmon and steelhead trout, respectively. As evident from the pink and steelhead data, tolerance to dewatering decreased significantly as development proceeded.

Table 28. Percent mortality resulting from single event dewaterings of chinook, pink, chum, and coho salmon and steelhead trout alevins for indicated times in 1981-82. Temperature units (TUs) required for hatching and emergence and number accumulated at the time of testing are presented.

	TUs (F°)			Dewatering time (hr)							
Species	Hatching	Emergence	Test	0.5	1	2	4	6	8	16	24
Chinook	1002	1719	1162				30				
			1175							46	
			1263							70	
			1345						69	72	74
			1419						78	78	81
			1719						100	100	100
Pink	1082	1777	1188						12	28	
			1263								46
			1345						10	32	61
			1419						24	57	64
			1719						84	98	93
			1777						82	87	93
Chum	967	1561	1183								
			1322			71	91	94	98	98	
			1450	100	100	100	100				
Coho	777	1334	1044						83	96	
			1183			93	95	100			
			1334	100	100	100	100				
Steelhead	625	1050	701				59		97	96	
			727		32	64	79				
			782		60	87	92				
			887		99						

6.4.4 Alevin Quality

Mean lengths, weights and condition factors of chinook salmon alevins exposed to 0, 4, 8, 16 and 24 hrs of dewatering per day as eggs in 4 gravel types in 1980-81 are shown in Tables 29, 30 and 31. As apparent from the tables no differences in the measured indices were discernable among the various combinations of time dewatered and gravel type. Similar lack of differences was observed with coho dewatering tests (Tables 32-34). The mixed fertilization times within tested groups of chum salmon did not allow for a standardized sampling time of alevins at button-up to determine fry quality. A water flow interruption to the Heath incubator resulted in the loss of the steelhead alevins which were to be examined for fry quality.

In second year studies (1981-82), the development of alevins was evaluated immediately after hatching to eliminate any influence compensatory mechanisms may have had following testing and prior to calculation of condition factors at the button-up stage. The body and yolk weights at hatching expressed as a proportion of the yolk weight at the time of spawning for chinook, pink, and chum salmon and steelhead trout are presented in Tables 35, 36, 37 and 38, respectively. The estimated energy (ΔE) of metabolism, is also shown. The negative values for ΔE result from the sum of the body and yolks totaling greater than 1.0. This result is puzzling but may be accounted for by inaccuracy in weighing, drying, or loss of initial yolk material. Although not statistically significant, the body to initial yolk weight ratio in the continuously dewatered test was less than controls and other dewatering times for all species evaluated. No other trends were apparent.

6.5 Intragravel Alevin Survival, Movement and Behavior

6.5.1 Intragravel Behavior Studies in 1981

Table 29. Mean and range of lengths for chinook salmon alevins dewatered 0, 4, 8, 16, and 24 hrs/day as eggs in four gravel sizes in 1980-81.

Gravel size (cm)	Incubation days dewatered	Hrs dewatered/day 0	4	8	16	24
Small (0.33-1.35)	56-75	38.9 (36.5-41.0) n=25	38.7 (36.5-40.0) n=16	39.0 (36.7-41.0) n=27	38.6 (36.5-41.0) n=24	38.6 (36.5-40.5) n=10
Medium (0.67-2.67)	56-75	38.5 (37.0-40.5) n=24	38.8 (36.0-41.0) n=17	39.3 (36.7-42.0) n=23	38.7 (37.0-41.0) n=27	38.5 (35.5-41.0) n=10
Large (1.35-5.08)	56-75	38.7 (36.0-40.0) n=24	39.0 (37.0-41.5) n=20	39.5 (37.0-41.5) n=20	39.3 (36.5-42.0) n=30	38.8 (36.7-40.5) n=7
Mixed (0.08-5.08)	58-77	39.7 (36.5-42.0) n=30	39.3 (36.5-40.5) n=13	39.3 (38.0-41.0) n=8	--	39.1 (37.0-41.0) n=21
Mixed (0.08-5.08)	1-54	38.9 (37.0-41.0) n=19	38.1 (35.5-40.5) n=20	38.8 (36.7-41.0) n=21	38.2 (35.0-41.0) n=27	--
Mixed (0.08-5.08)	1-75	38.9 (36.0-41.0) n=23	39.3 (36.5-40.5) n=21	38.4 (35.5-40.0) n=25	39.1 (38.0-41.0) n=18	--

Table 30. Mean and range of weights for chinook salmon alevins dewatered 0, 4, 8, 16, and 24 hrs/day as eggs in four gravel sizes in 1980-81.

Gravel size (cm)	Incubation days dewatered	Hrs dewatered/day 0	4	8	16	24
Small (0.33-1.35)	56-75	47.9 (38-56) n=25	48.6 (40-55) n=16	48.4 (37-55) n=27	47.9 (41-55) n=24	46.7 (39-54) n=10
Medium (0.67-2.67)	56-75	47.3 (38-54) n=24	47.9 (38-54) n=17	48.4 (37-55) n=23	46.3 (39-53) n=27	46.3 (35-52) n=10
Large (1.35-5.08)	56-75	48.8 (40-56) n=24	50.0 (43-56) n=20	50.2 (41-57) n=20	46.1 (35-54) n=30	48.3 (37-54) n=7
Mixed (0.08-5.08)	58-77	50.1 (40-59) n=30	50.9 (42-56) n=13	50.2 (39-55) n=8	--	48.3 (40-55) n=21
Mixed (0.08-5.08)	1-54	47.1 (42-56) n=19	45.6 (39-53) n=20	45.2 (40-54) n=21	46.9 (38-56) n=27	--
Mixed (0.08-5.08)	1-75	48.4 (40-58) n=23	50.6 (43-58) n=21	45.2 (38-53) n=25	46.1 (42-54) n=18	--

Table 31. Mean and range of condition factors for chinook salmon alevins dewatered 0, 4, 8, 16, and 24 hrs, and gravel sizes in 1980-81.

Gravel size (cm)	Incubation days dewatered	Hrs dewatered/day 0	4	8	16	24
Small (0.33-1.35)	56-75	81.3 (72.5-95.1) n=25	83.5 (76.0-91.1) n=16	81.3 (71.3-94.5) n=27	83.1 (76.0-99.4) n=24	81.1 (72.5-95.7) n=10
Medium (0.67-2.67)	56-75	83.1 (72.9-91.6) n=24	82.2 (72.5-95.1) n=17	79.7 (70.8-93.3) n=23	77.1 (62.5-92.0) n=27	82.7 (75.4-88.4) n=10
Large (1.35-5.08)	56-75	84.0 (68.2-94.5) n=24	84.5 (72.8-98.6) n=20	81.1 (74.2-91.6) n=20	77.1 (62.5-92.0) n=30	82.7 (75.4-88.4) n=7
Mixed (0.08-5.08)	58-77	80.0 (72.7-88.9) n=30	84.0 (77.6-97.8) n=13	82.4 (72.5-92.1) n=8	--	80.4 (75.7-86.3) n=21
Mixed (0.08-5.08)	1-54	79.7 (71.4-89.8) n=19	82.6 (72.9-93.8) n=20	77.3 (69.9-86.5) n=21	84.1 (74.0-105.3) n=27	--
Mixed (0.08-5.08)	1-75	82.0 (74.4-88.1) n=23	83.0 (71.4-95.7) n=21	79.9 (68.5-86.5) n=25	77.2 (72.9-83.3) n=18	--

Table 32. Mean and range of lengths for coho salmon alevins dewatered 0, 4, 8, 16, and 24 hrs/day as eggs in four gravel sizes in 1980-81.

Gravel size (cm)	Incubation days dewatered	Hrs dewatered/day				
		0	4	8	16	24
Small (0.33-1.35)	1-56	32.0 (29.0-34.5) n=32	--	--	--	32.4 (29.0-35.0) n=27
Medium (0.67-2.67)	1-56	32.6 (29.0-35.5) n=32	--	--	--	32.3 (29.0-34.5) n=32
Large (1.35-5.08)	1-56	--	--	--	--	32.9 (30.5-34.5) n=31
Mixed (0.08-5.08)	1-56	32.9 (29.0-35.5) n=63	--	--	--	32.6 (29.5-35.0) n=51
Mixed (0.08-5.08)	1-67	32.7 (29.5-34.5) n=31	32.8 (30.0-35.5) n=31	32.4 (29.0-35.0) n=32	32.1 (29.0-34.5) n=32	--

Table 33. Mean and range of weights for coho salmon alevins dewatered 0, 4, 8, 16, and 24 hrs/day as eggs in four gravel sizes in 1980-81.

Gravel size (cm)	Incubation days dewatered	Hrs dewatered/day				
		0	4	8	16	24
Small (0.33-1.35)	1-56	23.0 (16-31) n=32	--	--	--	26.6 (20-23) n=27
Medium (0.67-2.67)	1-56	26.1 (18-32) n=32	--	--	--	25.4 (15-33) n=32
Large (1.35-5.08)	1-56	--	--	--	--	27.2 (21-34) n=31
Mixed (0.08-5.08)	1-56	25.9 (29-36) n=63	--	--	--	26.2 (20-32) n=51
Mixed (0.08-5.08)	1-67	26.4 (20-33) n=31	24.4 (30-36) n=31	25.9 (20-30) n=32	23.2 (15-29) n=32	--

Table 34. Mean and range of condition factors for coho salmon alevins dewatered 0, 4, 8, 16, and 24 hrs/day as eggs in four gravel sizes in 1980-81.

Gravel size (cm)	Incubation days dewatered	Hrs dewatered/day 0	4	8	16	24
Small (0.33-1.35)	1-56	69.5 (58.3-77.7) n=32	--	--	--	78.2 (68.0-97.9) n=27
Medium (0.67-2.67)	1-56	75.5 (64.4-102.9) n=32	--	--	--	74.5 (58.8-87.5) n=32
Large (1.35-5.08)	1-56	--	--	--	--	76.3 (64.8-87.3) n=31
Mixed (0.08-5.08)	1-56	72.8 (59.4-91.9) n=63	--	--	--	77.0 (66.3-90.6) n=51
Mixed (0.08-5.08)	1-67	75.3 (68.8-85.7) n=31	68.5 (59.3-78.9) n=31	76.3 (58.9-89.0) n=32	69.5 (56.0-77.7) n=32	--

Table 35. Mean body (b_1) and yolk-sac (y_1) weights, body weight to initial yolk weight ratio $\frac{b_1}{y_o}$, yolk-sac to initial yolk weight ratio $\frac{y_1}{y_o}$, and energy of metabolism (ΔE) for chinook salmon dewatered for 0 (control), 2, 4, 8, 16 and 24 (continuous) hrs/day from fertilization to hatching.

	N	b_1 (g)	y_1 (g)	$\frac{b_1}{y_o}$	$\frac{y_1}{y_o}$	ΔE
Control	39	.0091	.0898	.105	1.041	-.145
2	75	.0077	.0872	.089	1.011	-.100
4	100	.0080	.0925	.093	1.072	-.165
8	103	.0071	.0787	.082	.913	.005
16	78	.0081	.0833	.094	.965	-.059
24	25	.0062	.0819	.072	.949	-.021

Table 36. Mean body (b_1) and yolk-sac (y_1) weights, body weight to initial yolk weight ratio $\frac{b_1}{y_o}$, yolk-sac to initial yolk weight ratio $\frac{y_1}{y_o}$, and energy of metabolism (ΔE) for pink salmon dewatered for 0 (control), 2, 4, 8, 16 and 24 (continuous) hrs/day from fertilization to hatching.

	N	b_1 (g)	y_1 (g)	$\frac{b_1}{y_o}$	$\frac{y_1}{y_o}$	ΔE
Control	44	.0067	.0590	.103	.907	-.010
2	25	.0053	.0537	.097	.826	.079
4	25	.0075	.0570	.115	.876	.009
8	12	.0052	.0516	.082	.794	.124
16	23	.0069	.0522	.106	.803	.092
24	43	.0047	.0571	.072	.878	.050

Table 37. Mean body (b_1) and yolk-sac (y_1) weights, body weight to initial yolk weight ratio $\frac{b_1}{y_o}$, yolk-sac to initial yolk weight ratio $\frac{y_1}{y_o}$, and energy of metabolism (ΔE) for chum salmon dewatered for 0 (control, 2, 4, 8, 16 and 24 (continuous) hrs/day from fertilization to hatching.

	N	b_1 (g)	y_1 (g)	$\frac{b_1}{y_o}$	$\frac{y_1}{y_o}$	ΔE
Control	78	.0077	.0913	.079	.931	-.010
2	75	.0074	.0933	.075	.951	-.026
4	75	.0073	.0913	.074	.931	-.005
8	109	.0070	.0867	.071	.884	.045
16	32	.0072	.0903	.073	.921	.007
24	25	.0061	.0938	.062	.956	.018

Table 38. Mean body (b_1) and yolk-sac (y_1) weights, body weight to initial yolk weight ratio $\frac{b_1}{y_o}$, yolk-sac to initial yolk weight ratio $\frac{y_1}{y_o}$, and energy of metabolism (ΔE) for steelhead trout dewatered for 0 (control), 2, 4, 8, 16 and 24 (continuous) hrs/day from fertilization to hatching.

	N	b_1 (g)	y_1 (g)	$\frac{b_1}{y_o}$	$\frac{y_1}{y_o}$	ΔE
Control	36	.0044	.0326	.108	.815	.077
2	44	.0048	.0352	.119	.869	.012
4	80	.0050	.0317	.123	.782	.095
8	106	.0036	.0321	.089	.792	.119
16	64	.0032	.0332	.080	.820	.100
24	-	-	-	-	-	-

Data collected in 1981 on intragravel movement of chinook alevins indicated that early stage post-hatching alevins could make successful downward movements in the large gravel (Fig. 25) but not in the three smaller gravel sizes, as illustrated in Fig. 26 for mixed gravel. The survival of chinook in large gravel due to movement during the hatching period was variable from one sampling date to another but did not decrease as hatching progressed (Fig. 25). One hundred percent of the alevins successfully moved downward and survived in one cylinder dewatered for 16 hr/day and sampled near the end of the hatching period.

Chinook alevins were not observed on the bottom in any of the other three gravel sizes tested. The mixed gravel was selected to represent the three smaller gravels (small, medium and mixed). Survival of the controls in mixed gravel remained near 100 percent while survival in the 4, 8 and 16 hr/day dewatered tests decreased with time dewatered (Fig. 26). This was attributed to the inability of chinook alevins to move through smaller gravel sizes.

In studies on later-stage, pre-emergent chinook alevins it was determined that 100 percent of the alevins could make rapid downward migrations through the large gravel to avoid dewatering. No successful migrations were recorded in any of the three smaller gravel sizes.

The post-hatching survival of coho alevins remained high under all dewatered regimes tested in the large gravel (Fig. 27). Survival decreased in the small, medium and mixed gravel with increased time dewatered (Fig. 28, 29 and 30). The decrease in survival in the smaller gravels was directly related to amount of time the alevins had been dewatered. There was no post-hatching survival in the three smaller-sized gravels dewatered for 16 hr/day and 8 hr/day in the mixed gravel.

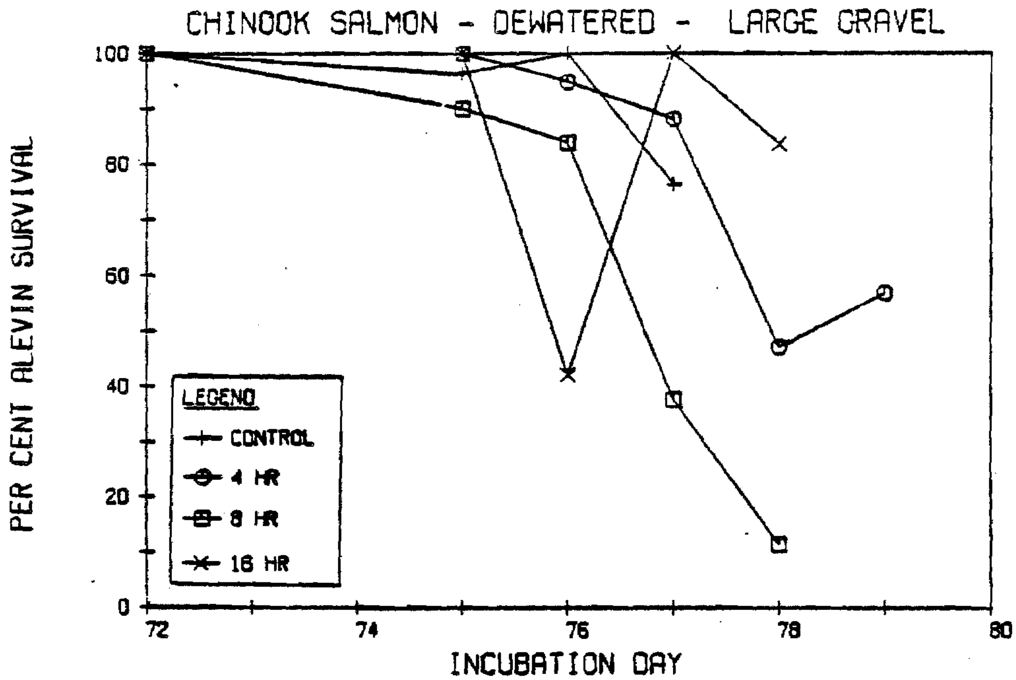

Fig. 25. Percent survival of chinook salmon alevins dewatered for 4, 8 and 16 hrs/day in large gravel through the hatching period.

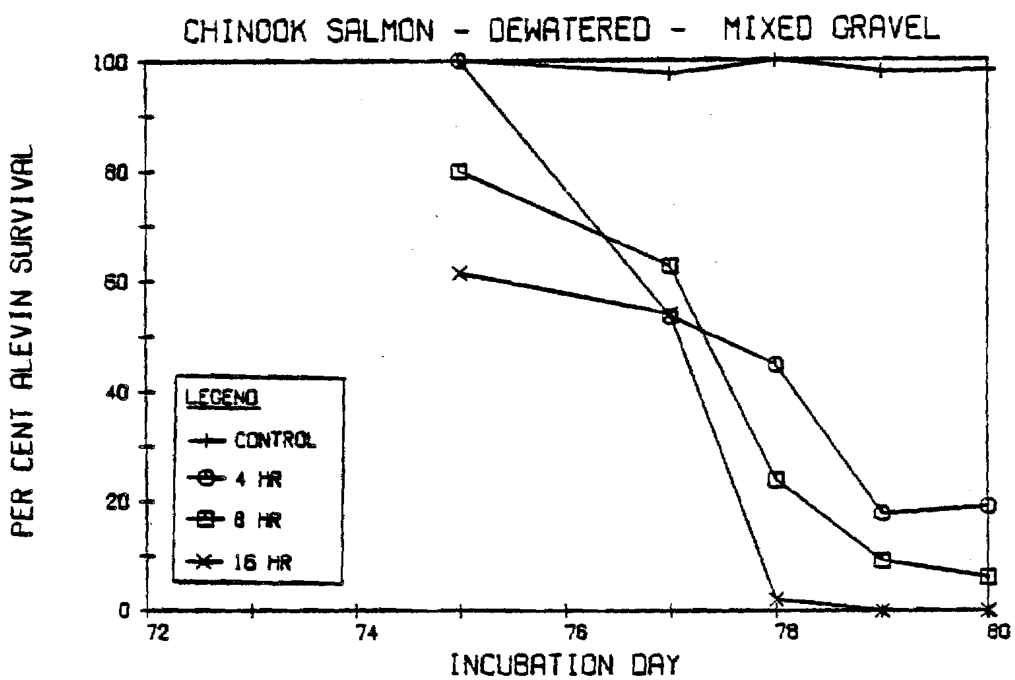

Fig. 26. Percent survival of chinook salmon alevins dewatered for 4, 8 and 16 hrs/day in mixed gravel through the hatching period.

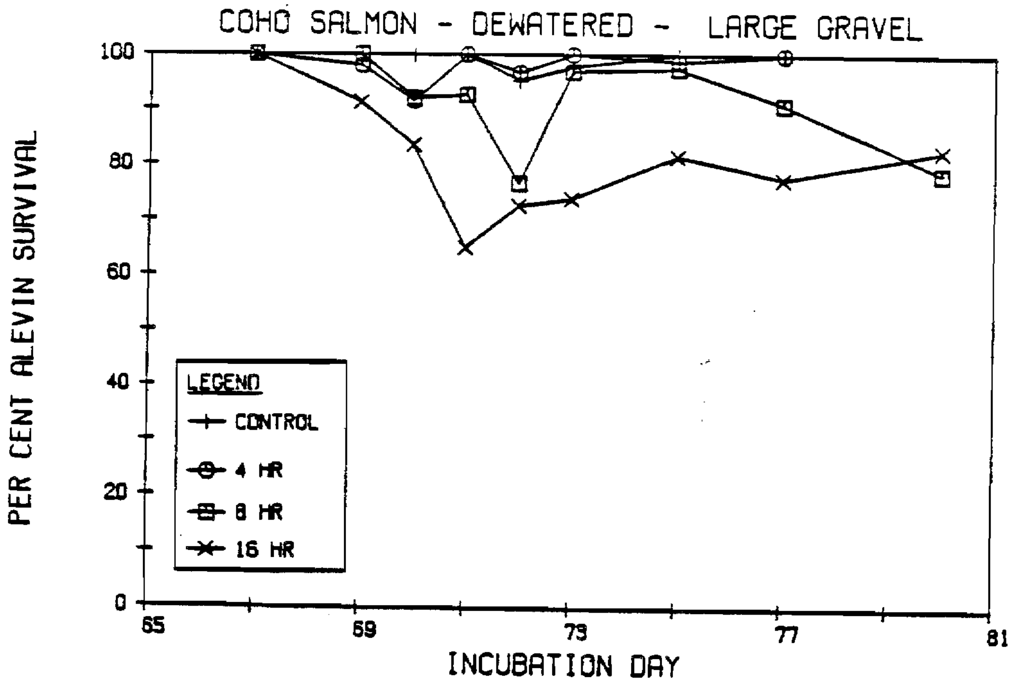

Fig. 27. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in large gravel through the hatching period.

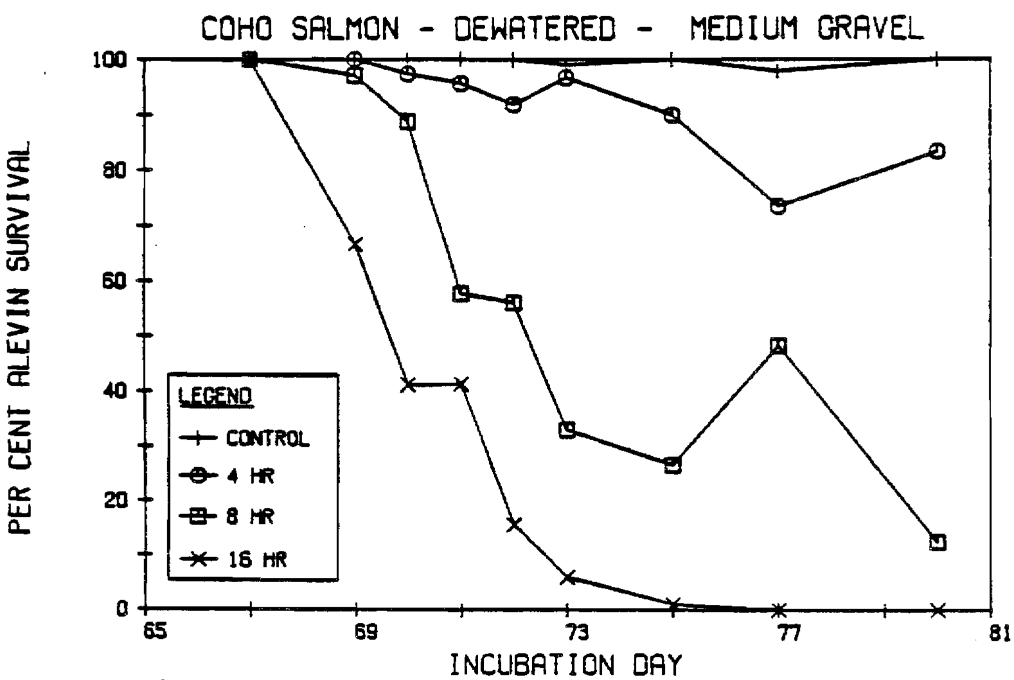

Fig. 28. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in medium gravel through the hatching period.

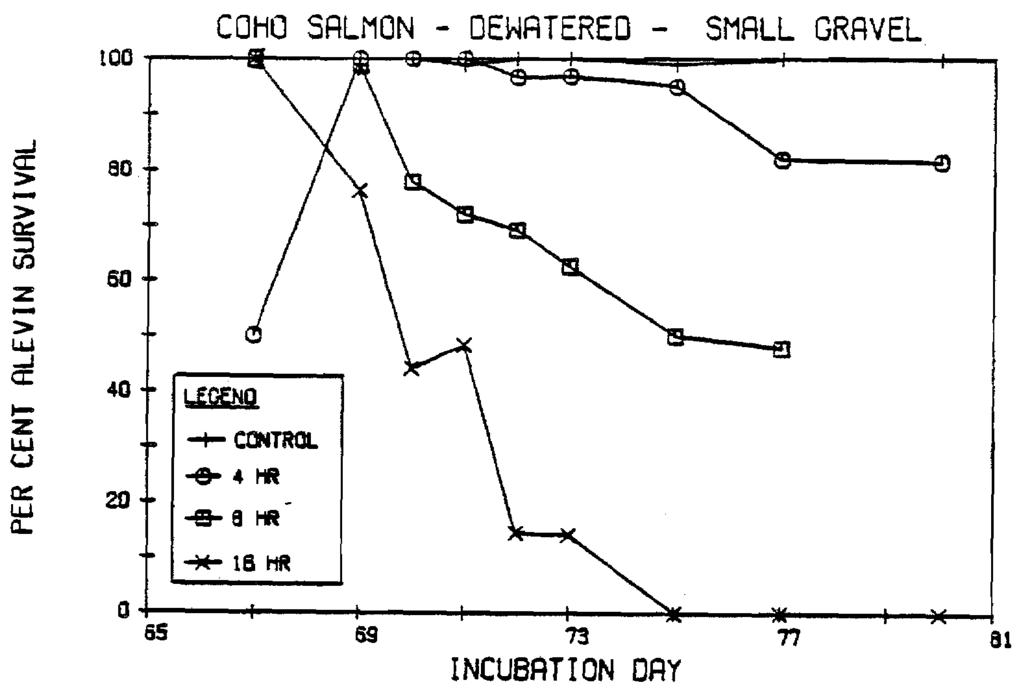

Fig. 29. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in small gravel through the hatching period.

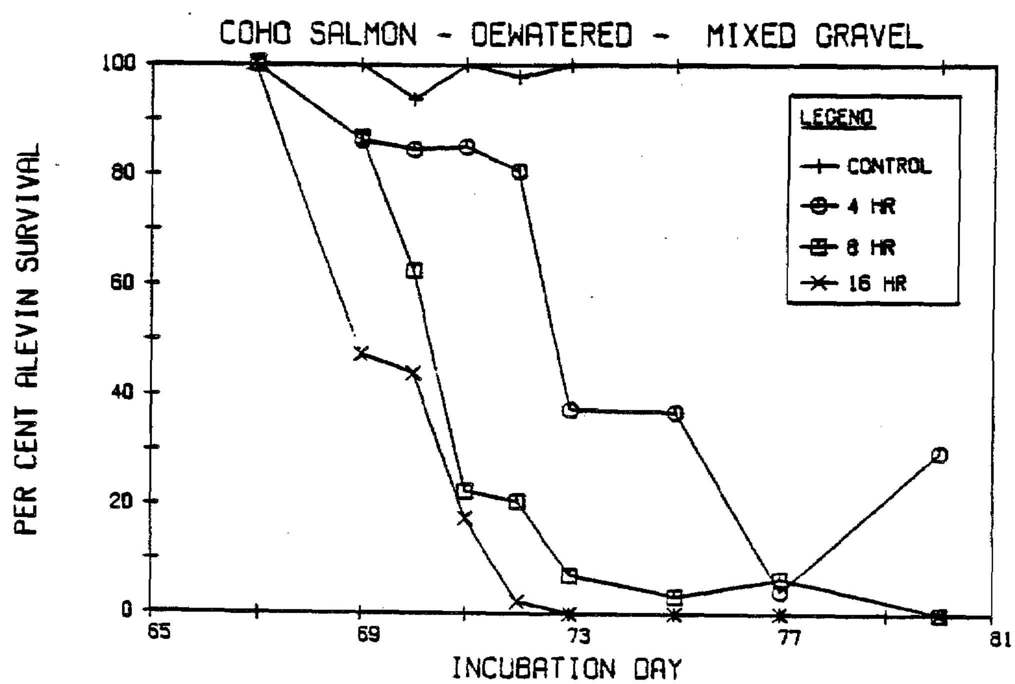

Fig. 30. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in mixed gravel through the hatching period.

Survival of coho through the hatching stage in large gravel (1.35-5.08 cm) is shown graphically in Fig. 27. Length of dewatered period apparently influenced the ability of alevins to migrate. The survival decreased with an increase in the dewatered period. High survival well into the alevin stage indicates that successive daily dewatering of up to 16 hr/day did not increase mortality after the alevins had migrated to the bottom of the cylinder.

Some coho alevins migrated through the small, medium and mixed gravel sizes. The overall number of successful migrations through these smaller sized gravels was lower than in the large gravel. Post-hatching survival of coho in the mixed gravel remained high in the control but declined to zero in the 16 hr/day test before the end of the hatching period (Fig. 30). Survival in the 4 and 8 hr/day tests dropped during hatching in proportion to the length of time dewatered. In studies of later stage pre-emergent coho alevins it was found that the alevins could make rapid migrations through 30 cm of large gravel in one minute. Alevins were also observed to make non-successful migrations of shorter distances through the three smaller gravel sizes. Thus downward movement occurred but was not rapid enough to keep up with a dewatering rate of 30 cm/min so the alevins never reached the 5 cm of water retained at the bottom of the cylinder.

The post-hatching tests of steelhead alevins (Figs. 31, 32, 33 and 34) indicated survival occurred in alevins dewatered for 4 hrs/day in large (Fig. 31), medium (Fig. 32), and small (Fig. 33) gravel. Those exposed 8 hrs/day survived only in the large gravel (Fig. 31). The 16 hr/day exposure resulted in complete mortality in all gravel sizes except about 3 percent survival remained in the large gravel (Fig. 31). Control survival in all four gravel sizes remained near 100 percent throughout these tests. The time to complete mortality in the medium, small and mixed gravels occurred on incubation day 56

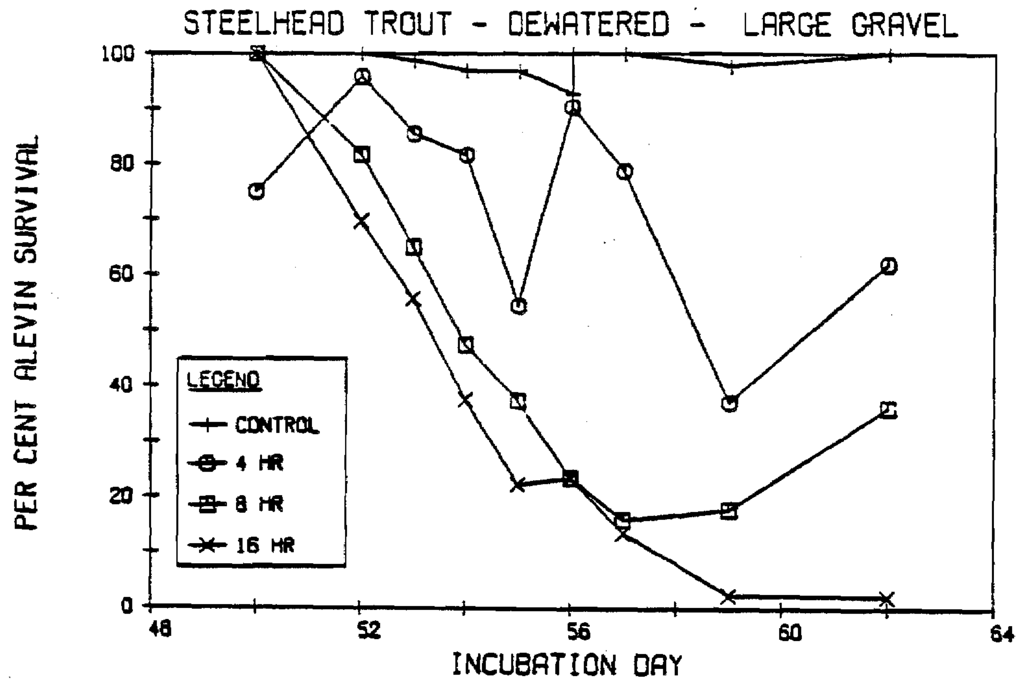

Fig. 31. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in large gravel through the hatching period.

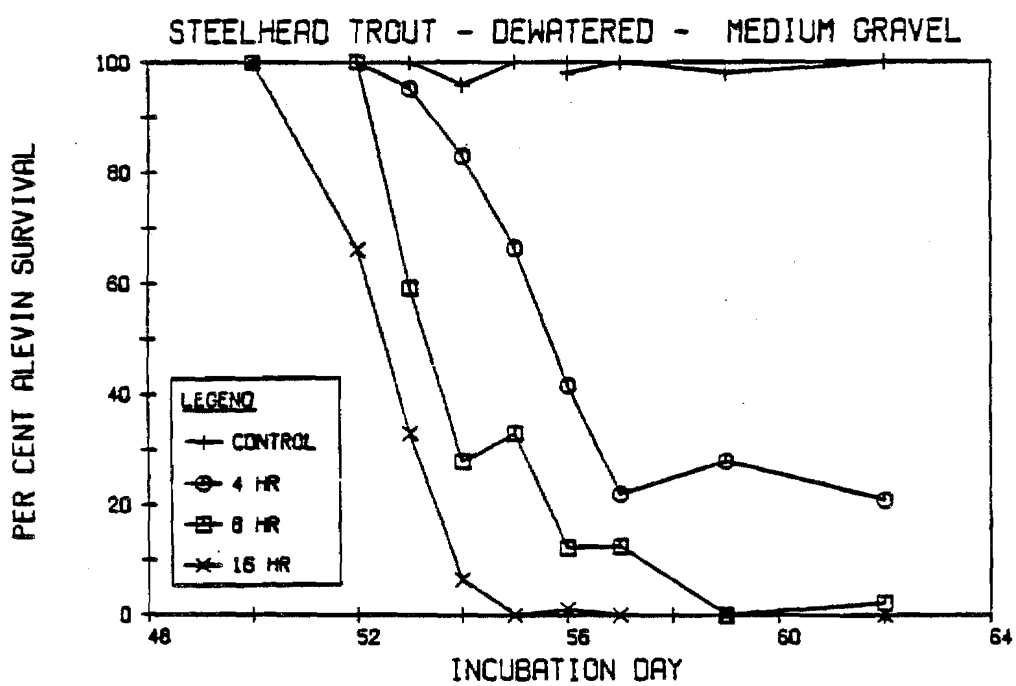

Fig. 32. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in medium gravel through the hatching period.

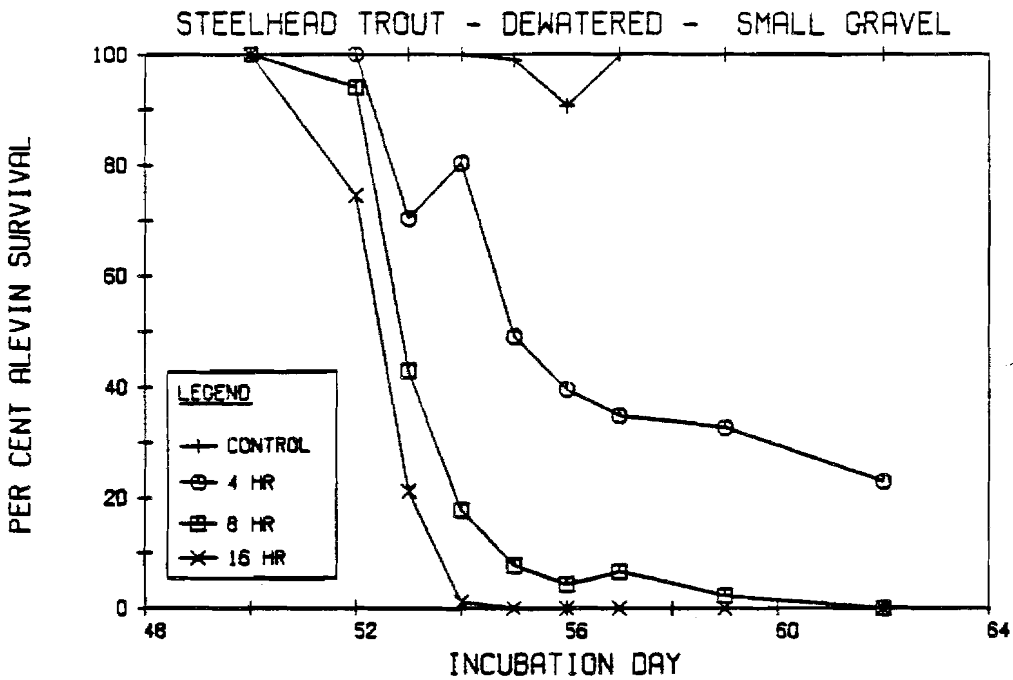

Fig. 33. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in small gravel through the hatching period.

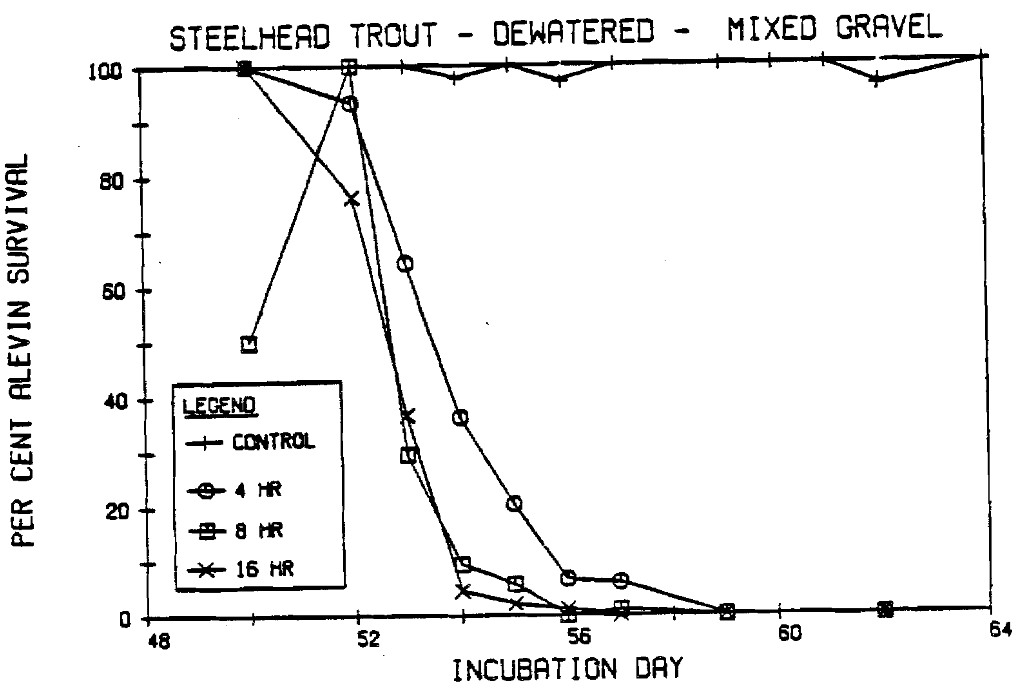

Fig. 34. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in mixed gravel through the hatching period.

while 3 percent survived after 62 days in large gravel.

In aquarium tests it was determined that alevins could make increasingly rapid downward migrations as their development progressed (Table 39). Even very low dewatering rates of from .5 to 5 inches per hour caused mortalities of over 50 percent during the first several weeks after hatching. As the alevins approached the 90 percent button-up stage dewatering rates of up to 48 inches per hour caused less than 30 percent mortality.

6.5.2. Intragravel Behavior Studies in 1982

The 1982 alevin behavior studies were done on campus. The temperature of the Lake Washington water used is plotted in Figure 35.

The dissolved oxygen level of the incubation water was monitored on a regular basis. The level of oxygen in the incoming water did not drop below 9.2 mg/l at any time during the laboratory studies. The dissolved oxygen levels during the steelhead incubation period (May-June) were lower than those reported in coho and chum studies (March-April) due to increasing lake water temperature. These lower dissolved oxygen levels were always at least 2 mg/l above the reported critical level of 7.1 mg/l (Alderdice et al., 1958).

6.5.3 Aquaria Behavior Studies

Observation of early post-hatching alevins indicated that there was a general tendency for both chinook and pink alevins to move downward through the gravel substrate. The distance moved varied from several inches to 15 inches in the first several days after hatching. Movement of individual alevins was impossible to follow as they were often behind the gravel substrate.

Other studies on chinook and pink alevins indicated that the ability to make intragravel movements to avoid dewatering increased in direct relation to the developmental stages of the alevin. The average percent mortality and

Table 39. Percent mortality of steelhead alevins at various dewatering rates.

Date	% button-up	Dewatering rate (inches/hr)	% mortality
June 15	0 (hatch)	—	—
June 24	30–40	.5	52
June 30	40–50	5	58
July 7	60–70	2	0
July 8	60–70	3	16
July 8	60–70	6	38
July 14	80–90	12	12
July 14	80–90	12	26
July 15	80–90	24	20
July 15	80–90	48	28
July 21	90–100	24	10
July 21	90–100	48	30
July 22	90–100	12	12

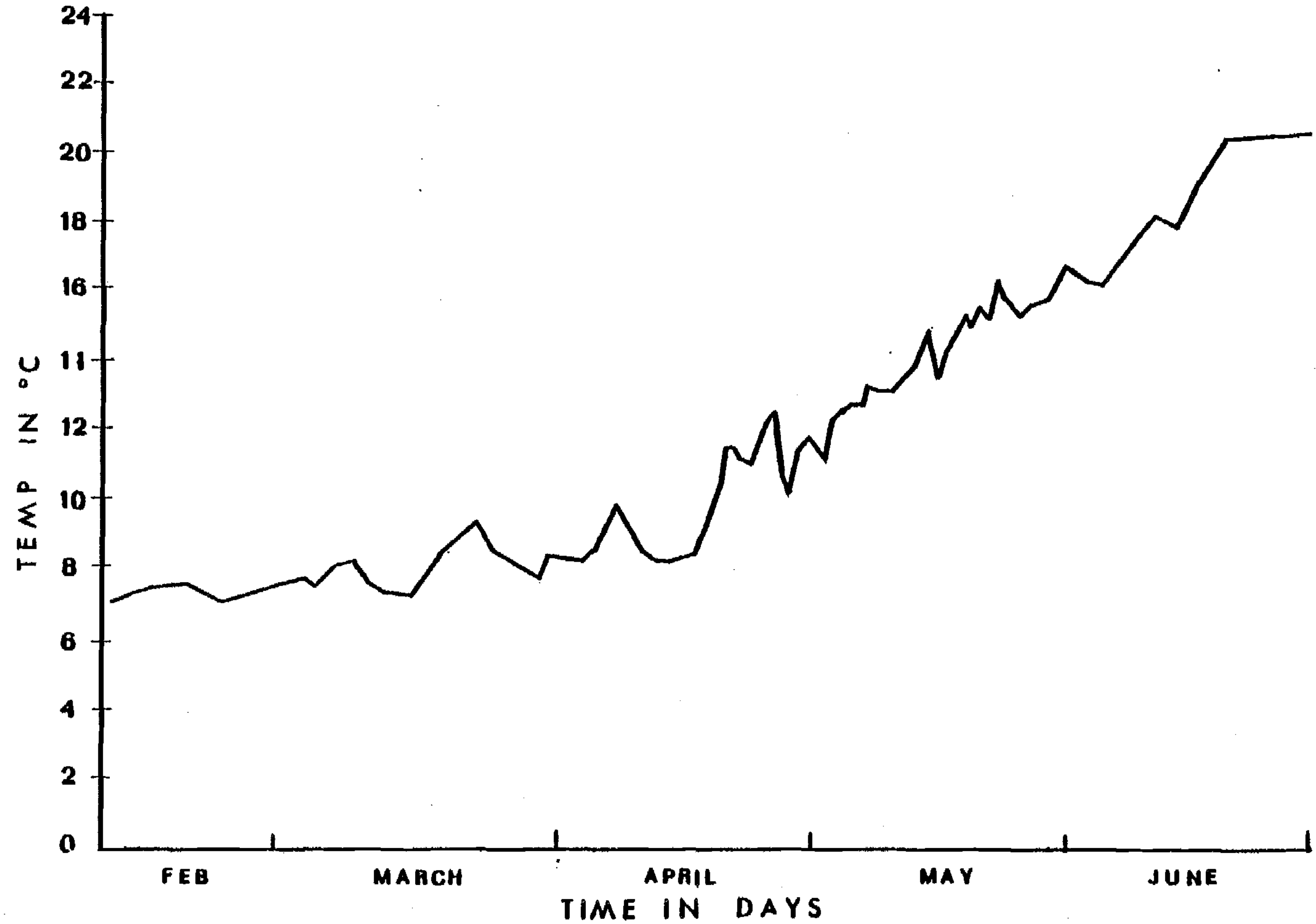

Fig. 35. Temperature of Lake Washington water used in alevin behavior tests.

range during four dewatering tests in each of the three developmental stages tested is reported for chinook (Table 40) and pink (Table 41). At each developmental stage the pink alevins had a higher percentage of alevins surviving by moving downward through the substrate.

Early observations indicated that alevins of both species were moving into the current (positive rheotaxis) as well as downward. The aquarium was divided lengthwise into four sections (upstream to downstream) by alevin barriers and the number of alevins collected in each trap is presented in Figure 36 for chinook and Figure 37 for pink.

6.5.4 Velocity Studies

Data collected during velocity studies on coho, chum and steelhead alevins are presented in Figures 38, 39 and 40, respectively. In the early stage of development very few coho and chum alevins moved from the gravel staging area. Steelhead alevins showed considerable random movement after 16 hours in the 0 velocity experiment. There was also some movement in the medium and high velocity experiments for early stage steelhead.

The middle developmental stage results for all three species showed similar trends. There was random movement (both "upstream" and "downstream") in the 0 velocity tests and little or no downstream movement (negative rheotropism) occurred in medium and high incubation flows. The alevins of all three species studied remained in the gravel staging area when velocity was adequate. When alevins in high velocity experiments did move during the late developmental stages it was generally into the current (positive rheotropic behavior).

In the last developmental stage, shortly before emergence, the results for all three species were similar in the zero velocity tests with the alevins demonstrating random dispersal. There were some differences between the

Table 40. Percent mortality of chinook salmon alevins dewatered at 3 inches/hour.

Date	% Button up	Dewater rate (inches/hour)	Average % mortality (4 tests)	Range
12-26-81	0 (hatch)	—	—	—
1-1-82	5-10	3	95	(88-100)
1-18-82	40-60	3	48	(22-84)
2-1-82	80-90	3	18	(6-32)

Table 41. Percent mortality of pink salmon alevins dewatered at 3 inches/hour.

Date	% Button up	Dewater rate (inches/hour)	Average % mortality (4 tests)	Range
12-29-81	0 (hatch)	—	—	—
1-5-82	5-10	3	88	(72-100)
1-21-82	40-60	3	34	(18-62)
2-5-82	80-90	3	8	(2-24)

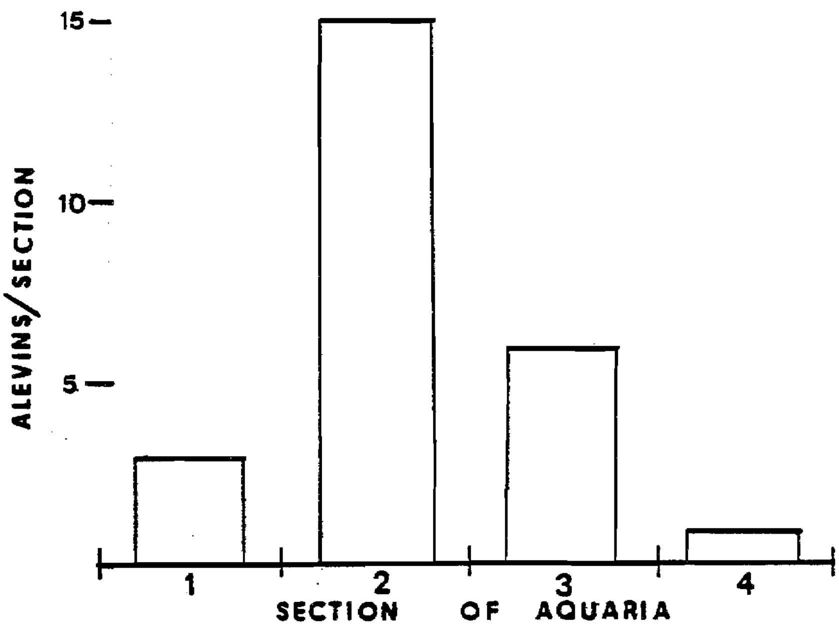

Figure 36. Number of chinook salmon alevins trapped per section after moving toward inlet (1) or outlet (4).

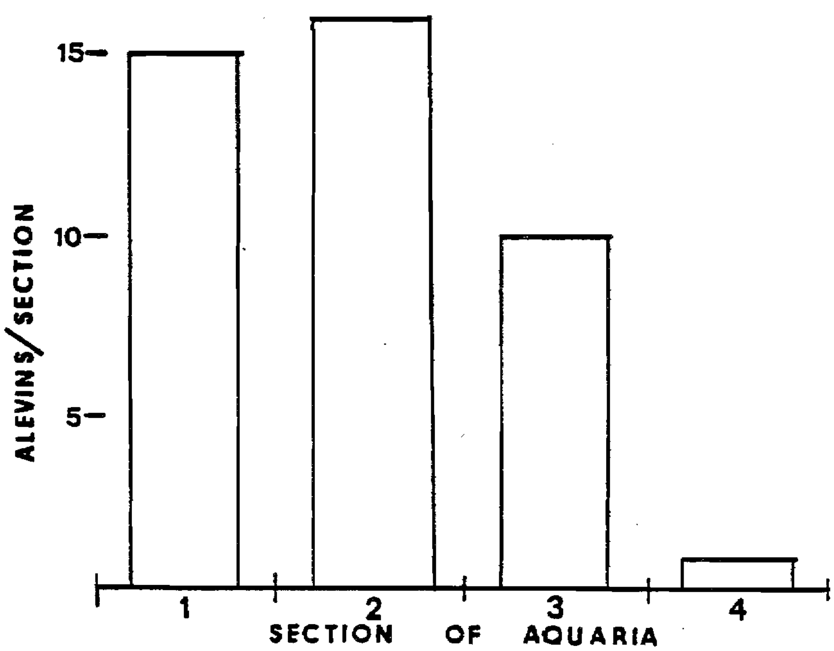

Figure 37. Number of pink salmon alevins trapped per section after moving toward inlet (1) or outlet (4).

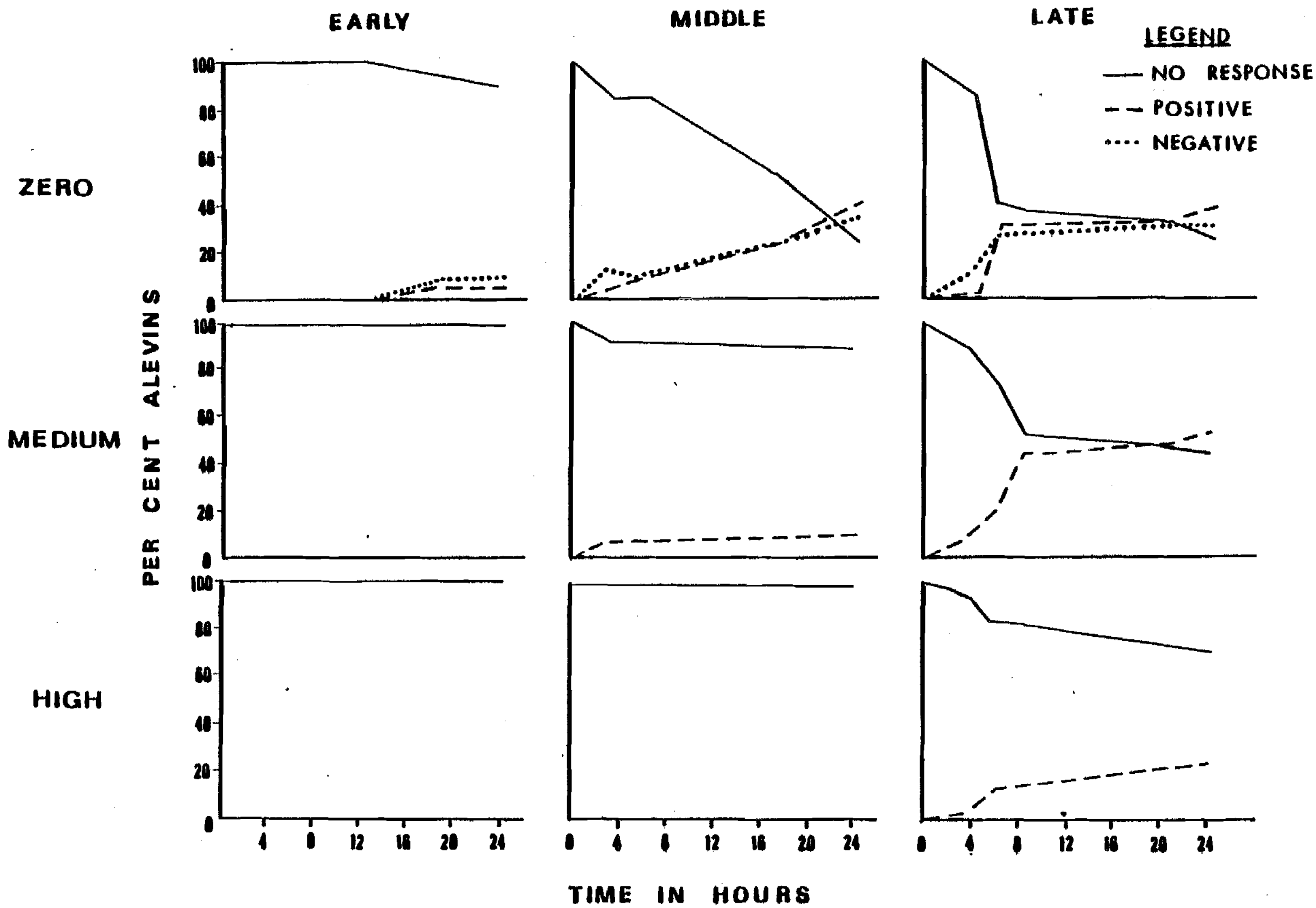

Fig. 38. Coho alevin behavior in zero, medium, and high velocity tests at early, middle, and late developmental stages.

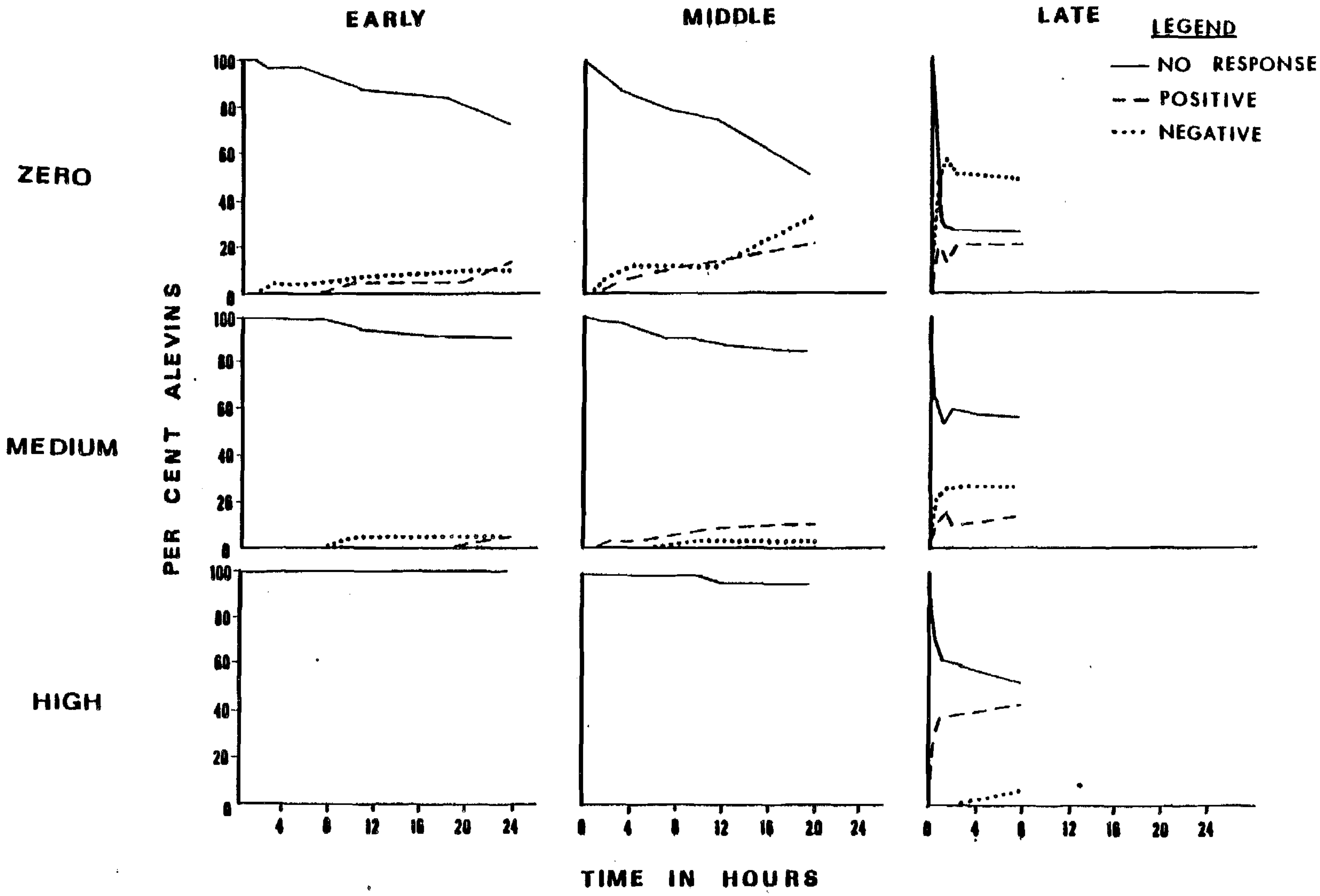

Fig. 39. Chum alevin behavior in zero, medium, and high velocity tests at early, middle, and late developmental stages.

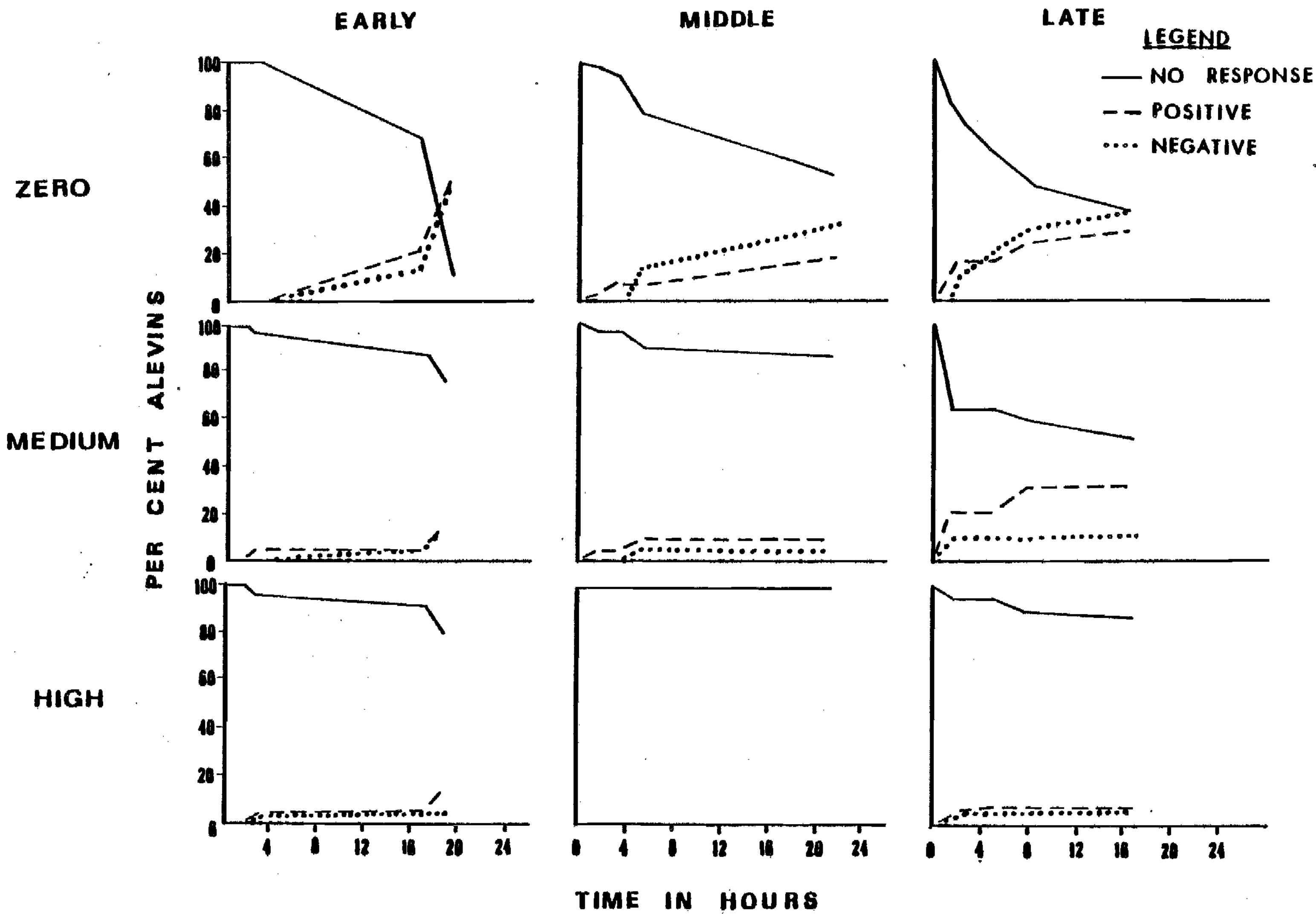

Fig. 40. Steelhead alevin behavior in zero, medium, and high velocity tests at early, middle, and late developmental stages.

species in the tests with medium and high velocity. The coho alevins showed only positively rheotactic responses to both velocity levels with no alevins moving downstream. The chum alevins demonstrated greater negative rheotaxis in the medium velocity but not in the high velocity studies. The steelhead alevins showed some negative rheotaxis but the majority of the alevins moved upstream.

In all three species the alevins responded more quickly to the environmental stimulus as their stage of development progressed from post-hatching to pre-emergent.

6.5.5 Dissolved Oxygen Studies

Y-maze experiments on the effect of dissolved oxygen levels on the movement of alevins were tested on coho and chum (late developmental stages) and all stages of steelhead trout and are presented in Tables 42, 43, and 44, respectively. The level of dissolved oxygen and percentage of alevins remaining or moving into the staging area and each of the arms of the Y-maze are reported. In all cases where movement occurred the greater percentage of alevins moved into the arm with the higher dissolved oxygen level.

6.5.6 Photobehavioral Studies

The results of experiments to determine the behavioral response of alevins to light are reported for coho (Figure 41), chum (Figure 42), and steelhead alevins (Figure 43). Photonegative behavior for all three species increased during the early developmental stages. This avoidance of light was strongest during the middle to late developmental stages with a rapid reversal to neutral or positive photobehavior as time of emergence neared.

Table 42. Percentage of coho salmon alevins remaining in staging area and migrating to high and low dissolved oxygen levels in arms of Y-maze.

Incubation day (after hatching)	Length of test	High DO Arm		Low DO Arm		Staging area	
		% Alevin	DO level	% Alevin	DO level	% Alevin	DO level
35	3 hr	70.0	11.0	3.3	3.5	26.7	6.8
38	2 hr	60.0	11.2	0.00	3.4	40.0	7.3
40	2 hr	70.0	10.2	23.3	7.0	6.6	8.7

Table 43. Percentage of chum salmon alevins remaining in staging area and migrating to high and low dissolved oxygen levels in arms of Y-maze.

Incubation day (after hatching)	Length of test	High DO Arm		Low DO Arm		Staging area	
		% Alevin	DO level	% Alevin	DO level	% Alevin	DO level
39	14 hr	33.3	10.8	0.0	3.2	66.6	7.4
40	3 hr	60.0	11.2	3.33	3.5	36.7	7.3
41	2 hr	70.0	11.2	10.0	5.2	20.0	7.2
42	3 hr	60.0	10.2	33.3	7.0	6.7	8.7
42	2 hr	70.0	11.0	3.33	8.1	26.7	8.9

Table 44. Percentage of steelhead alevins remaining in staging area and migrating to high and low dissolved oxygen levels in arms of Y-maze.

Incubation day (after hatching)	Time of test	High O_2		Low O_2		Not moving	
		% Alevin	DO	% Alevin	DO	% Alevin	DO
6	18 hr	3.3	9.5	3.3	6.0	93.3	7.8
7	3 hr	6.6	9.5	3.3	2.5	90.0	8.5
7	18 hr	33.3	10	0.0	2.0	66.6	5.7
10	8 hr	53.3	10	3.3	2.0	43.4	6.0
12	4 hr	63.3	8.5	0.0	3.0	36.7	5.5
13	2.5 hr	53.3	6.1	0.0	2.3	46.7	4.1
14	1.5 hr	44.0	7.8	28	6.7	28	7.2
14	2.0 hr	33.0	9.9	5.3	7.1	14	8.4
15	2.0 hr	56.7	8.7	16.7	4.5	26.6	6.5

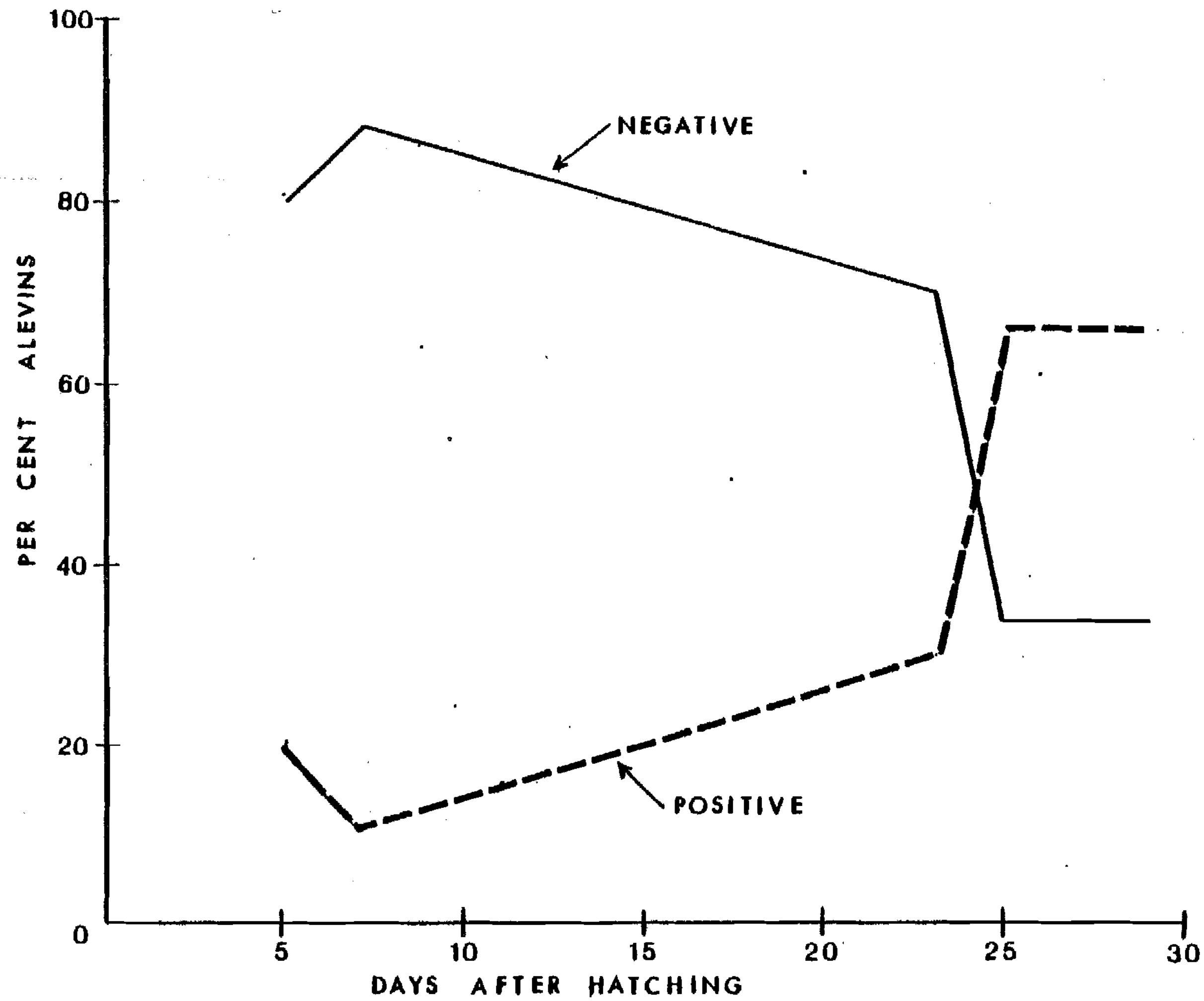

Fig. 41. Coho alevin photobehavior from hatching to emergence.

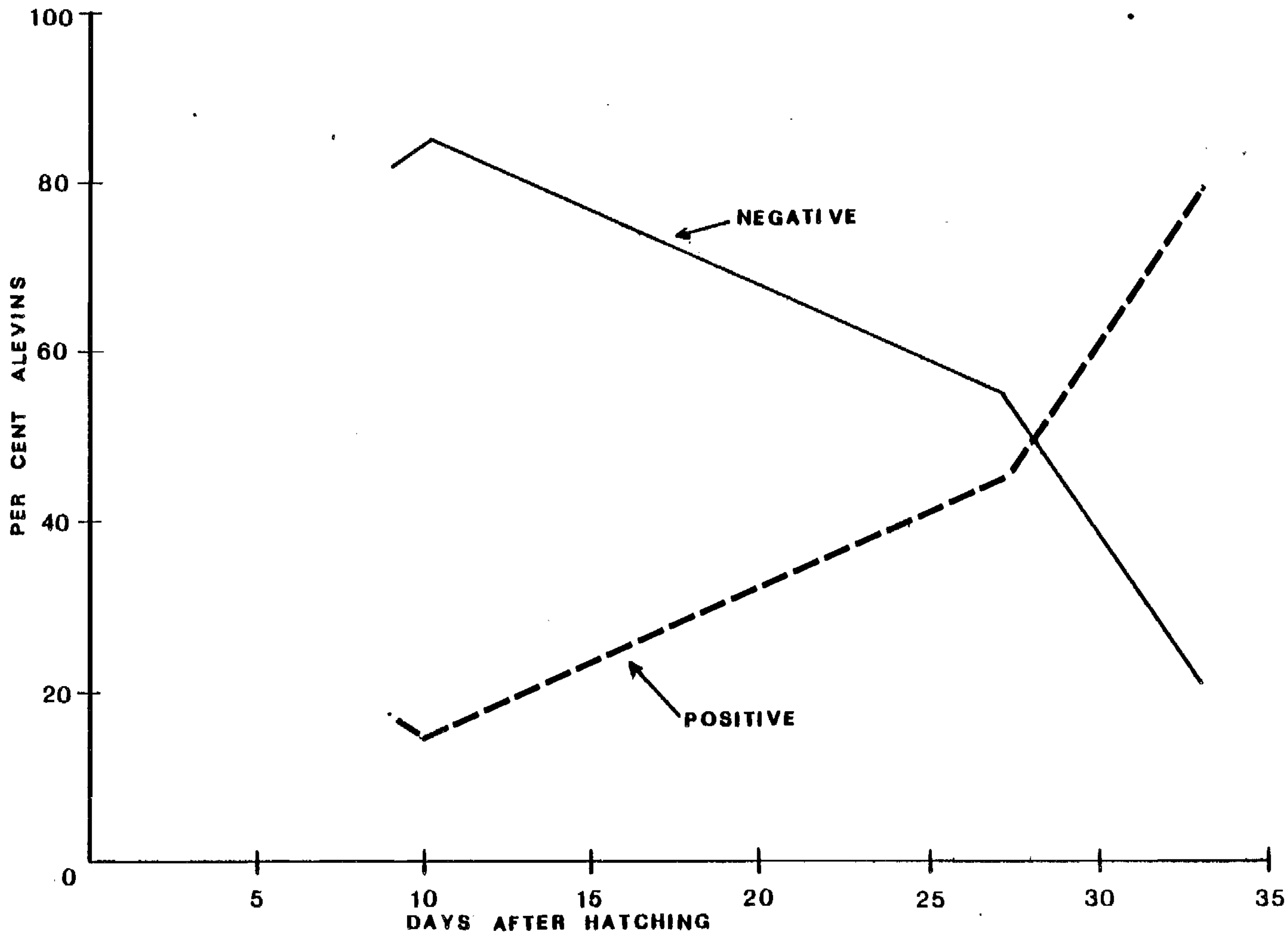

Fig. 42. Chum alevin photobehavior from hatching to emergence.

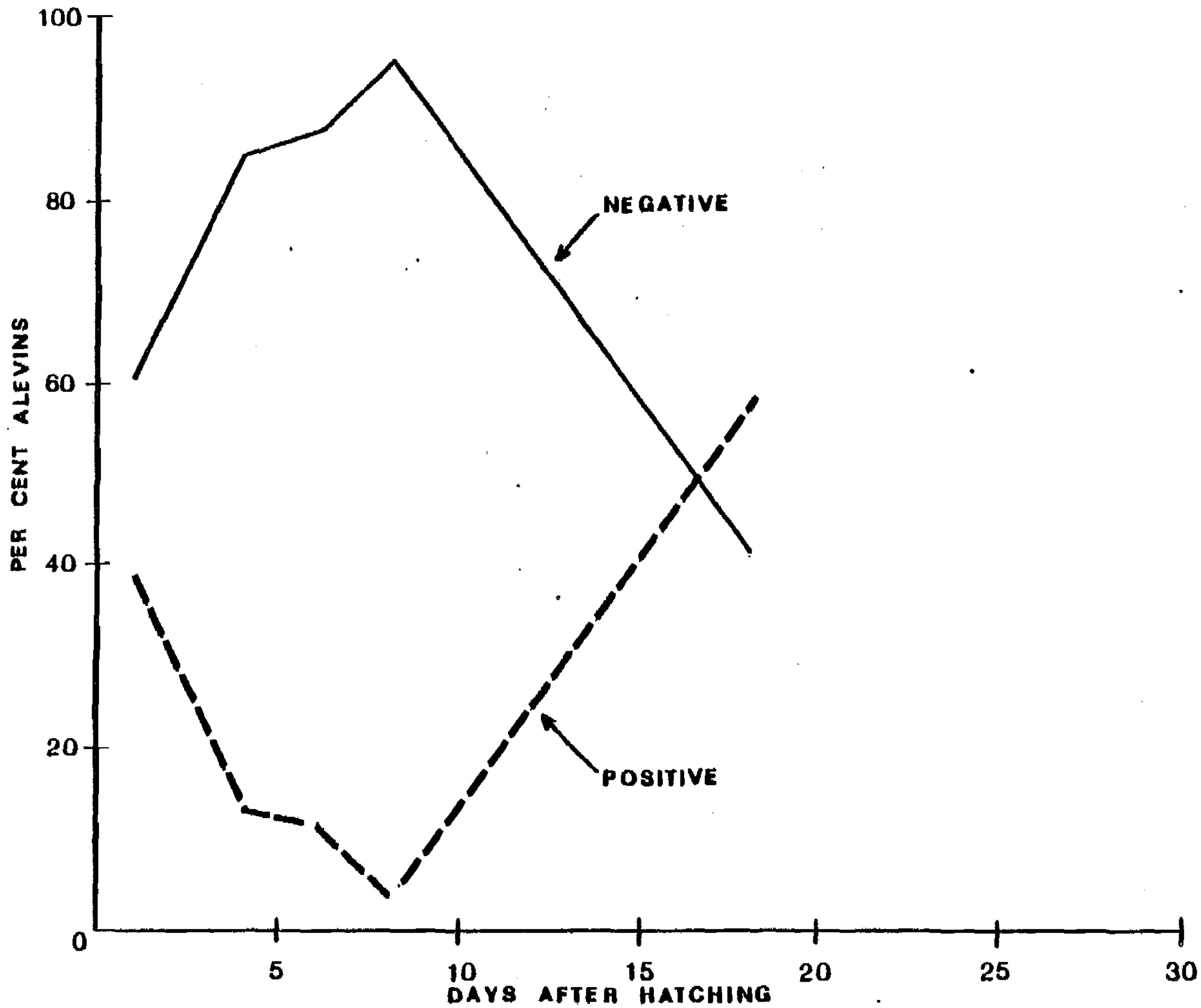

Fig. 43. Steelhead alevin photobehavior from hatching to emergence.

6.6 Fry Stranding

6.6.1 Salmon

6.6.1.1 Abundance of Salmon Fry

The abundance data and indices for sites 1, 2, and 3 are presented in Table 45. The abundance of fry varied significantly between study sites, years and dates within sites and years. The Marblemount site consistently had the highest abundance of fry. These site-specific variances in fry abundance are related to the spawning ground distribution of the adults and the dispersal characteristics of the fry.

6.6.1.2 Stream Flow

The regulated flows which SCL provided for these studies were measured at the Newhalem U.S.G.S. (12-1780) gage. The influence of tributary inflow at Newhalem on daily hourly discharge is illustrated by comparing Figures 44, 45, 46, 47 and 48 with Figures 49, 50, 51, 52 and 53 which give the flows at Marblemount for the same period. Table 46 presents the downramp rate (cfs/hr), downramp (time), time factor by site and tributary inflow.

The regulated flows provided a variety of downramp rates between 360 and 2,760 cfs per hour. During the three year study period the tributary inflow was more variable in 1980 than in 1981 or 1982. During the test done by Phinney in 1973 the tributary inflow was about one-half that experienced in 1980, 1981 and 1982. This is reflected in the average minimum flows for all tests reached each year at the Marblemount gage (12-1810) with a discharge of 2,300 cfs at the Gorge powerhouse (1973, 3,000 cfs; 1980, 3,750 cfs; 1981, 3,470 cfs; 1982, 3,418).

6.6.1.3 Stranding Index vs. Time Factor

The computed stranding indices for the study sites 1, 2 and 3 are

Table 45. Chinook salmon fry abundance and stranding data for 1980, 1981, and 1982.

Date	Study Site No. 1 Electro-fishing No.	Study Site No. 1 Electro-fishing Index	Study Site No. 1 Stranding No.	Study Site No. 1 Stranding Index	Study Site No. 2 Electro-fishing No.	Study Site No. 2 Electro-fishing Index	Study Site No. 2 Stranding No.	Study Site No. 2 Stranding Index	Study Site No. 3 Electro-fishing No.	Study Site No. 3 Electro-fishing Index	Study Site No. 3 Stranding No.	Study Site No. 3 Stranding Index
3/23/80	12	1.20	17	15.00	61	3.21	30	9.66	19	2.71	18	7.01
3/24/80	10	1.00	3	4.00	19	1.00	8	9.00	7	1.00	23	24.00
3/30/80	25	2.50	3	1.60	158	8.32	18	2.28	9	1.29	7	6.20
3/31/80	45	4.50	2	0.67	171	9.00	14	1.67	10	1.43	19	13.99
4/13/80	46	4.60	3	0.87	171	9.00	0	0.11	36	5.14	10	2.14
4/14/80	42	4.20	1	0.48	298	15.68	0	0.06	23	3.29	6	2.13
3/24/81	46	1.48	2	2.03	218	3.11	7	2.57	78	4.88	79	16.39
3/25/81	31	1.00	1	2.00	109	1.56	1	1.28	31	1.94	4	2.58
3/26/81	37	1.19	1	0.84	70	1.00	26	27.00	20	1.25	49	40.00
3/27/81	61	1.97	3	2.03	122	1.74	2	1.72	16	1.00	15	16.00
3/31/81	127	4.10	0	0.24	162	2.31	5	2.60	68	4.25	6	1.65
3/10/82	192	6.62	8	1.36	86	1.48	2	2.03	130	4.48	10	2.46
3/11/82	101	3.48	--	--	92	1.59	1	1.26	63	2.17	0	0.46
3/12/82	79	2.72	3	1.47	134	2.31	5	2.60	43	1.48	6	4.73
3/17/82	97	3.34	2	0.90	104	1.79	5	3.35	35	1.21	27	23.14
3/18/82	55	1.90	1	1.05	105	1.81	3	2.21	56	1.93	62	32.64
3/19/82	29	1.00	0	1.00	62	1.07	5	5.61	37	1.28	35	28.13
3/30/82	134	4.62	6	1.52	163	2.81	8	3.20	61	2.10	68	32.86
3/31/82	--	--	3	0.89	87	1.50	3	2.67	57	1.97	27	14.21
4/1/82	129	4.45	1	0.45	58	1.00	11	11.00	74	2.55	62	24.71
4/2/82	76	2.62	0	0.38	97	1.67	2	1.80	35	1.21	9	8.26
4/7/82	--	--	--	--	117	2.02	3	1.98	35	1.21	15	13.22
4/8/82	--	--	--	--	122	2.10	38	18.57	29	1.00	98	99.00

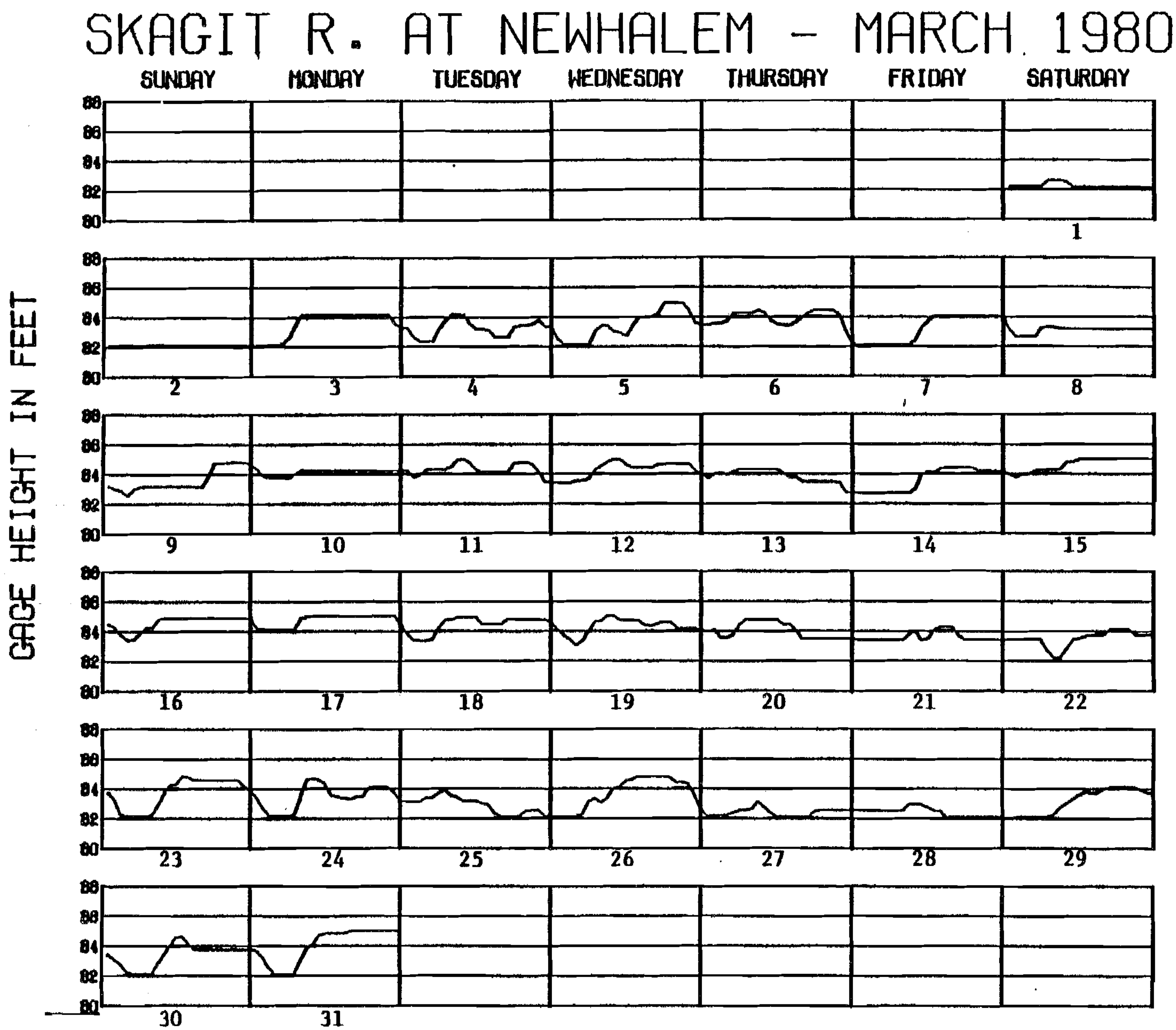

Figure 44. Hourly gage height data for Skagit River at Newhalem (USGS), March 1980.

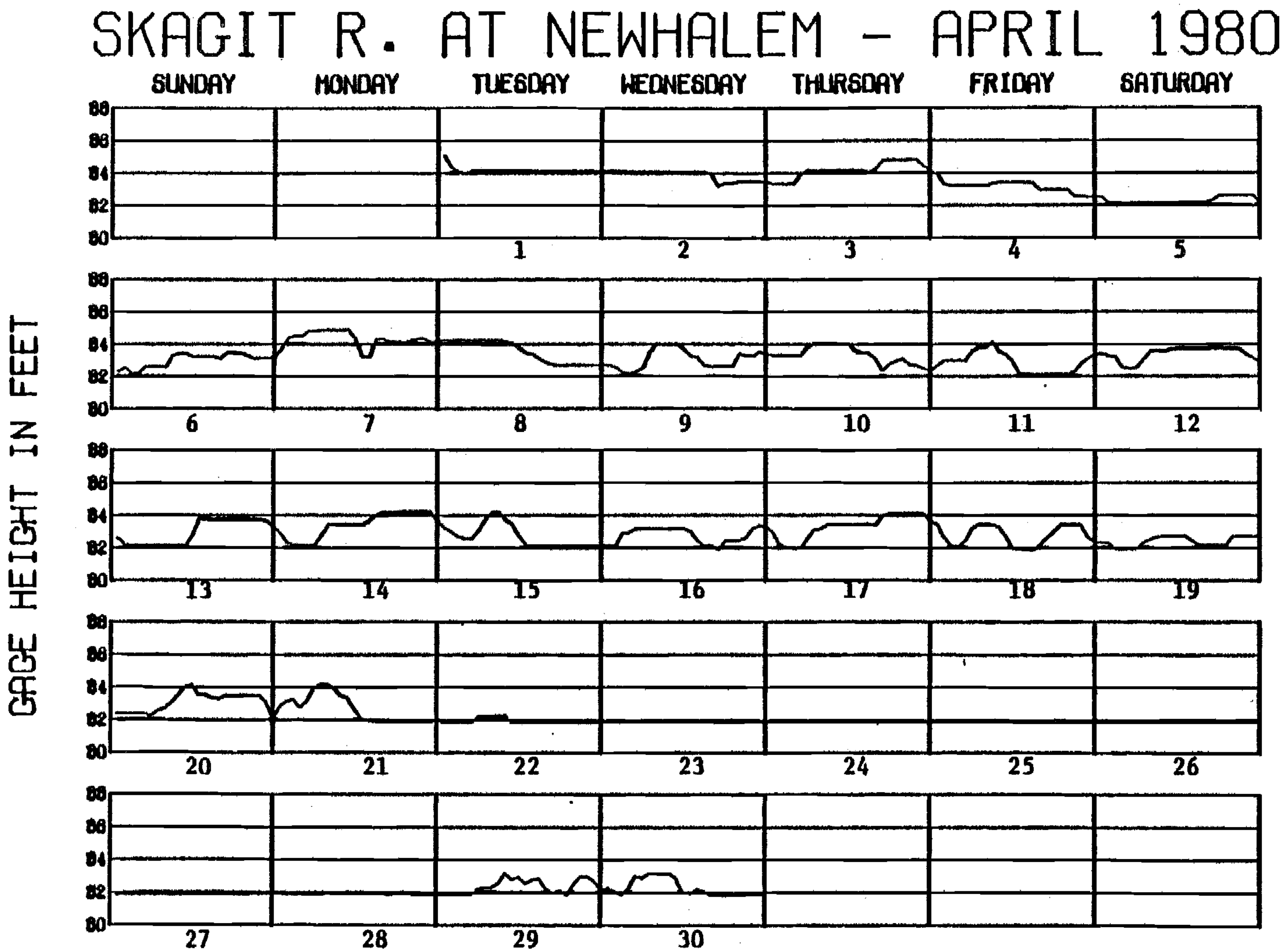

Figure 45. Hourly gage height data for Skagit River at Newhalem (USGS), April 1980.

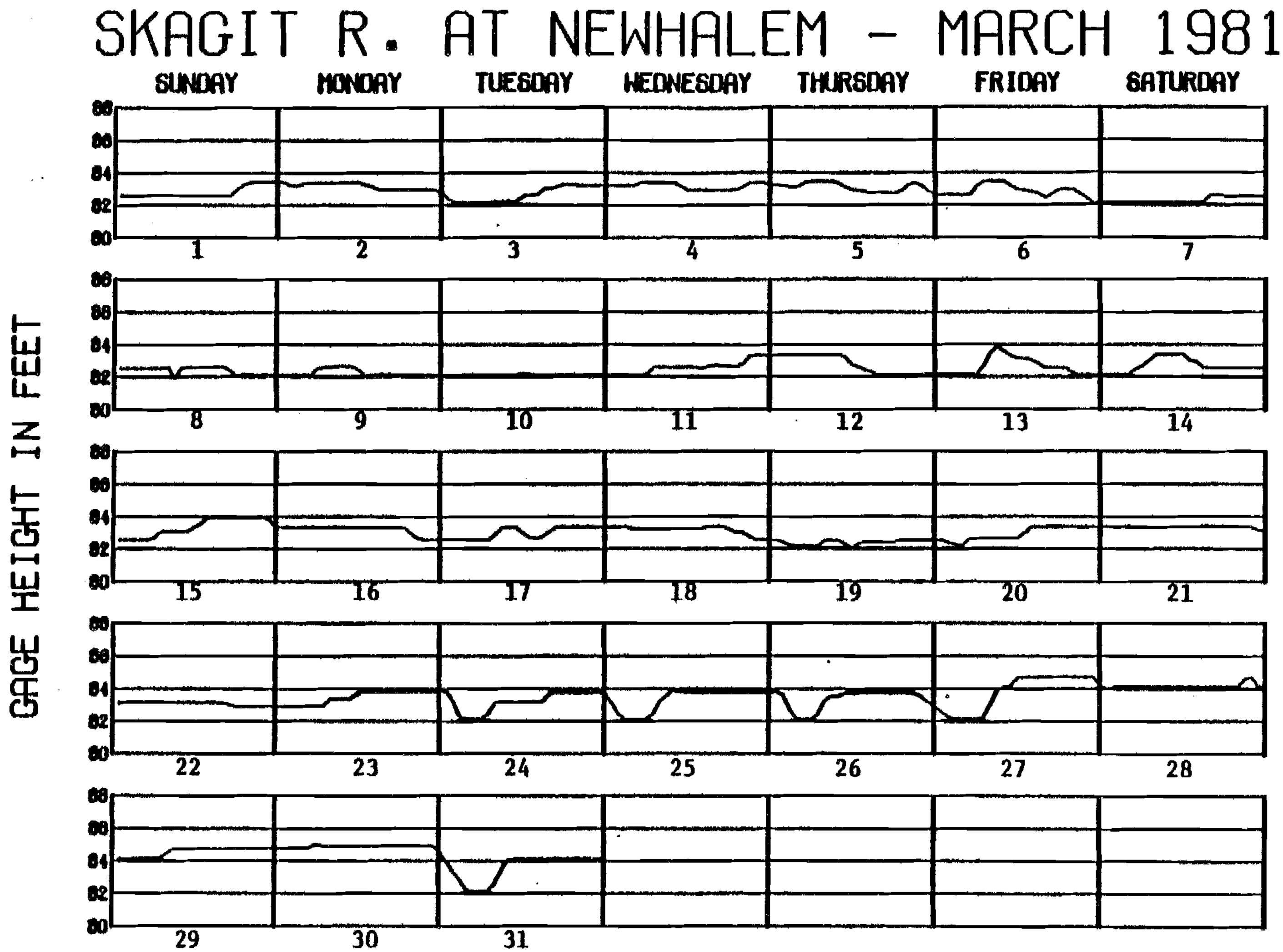

Figure 46. Hourly gage height data for Skagit River at Newhalem (USGS), March 1981.

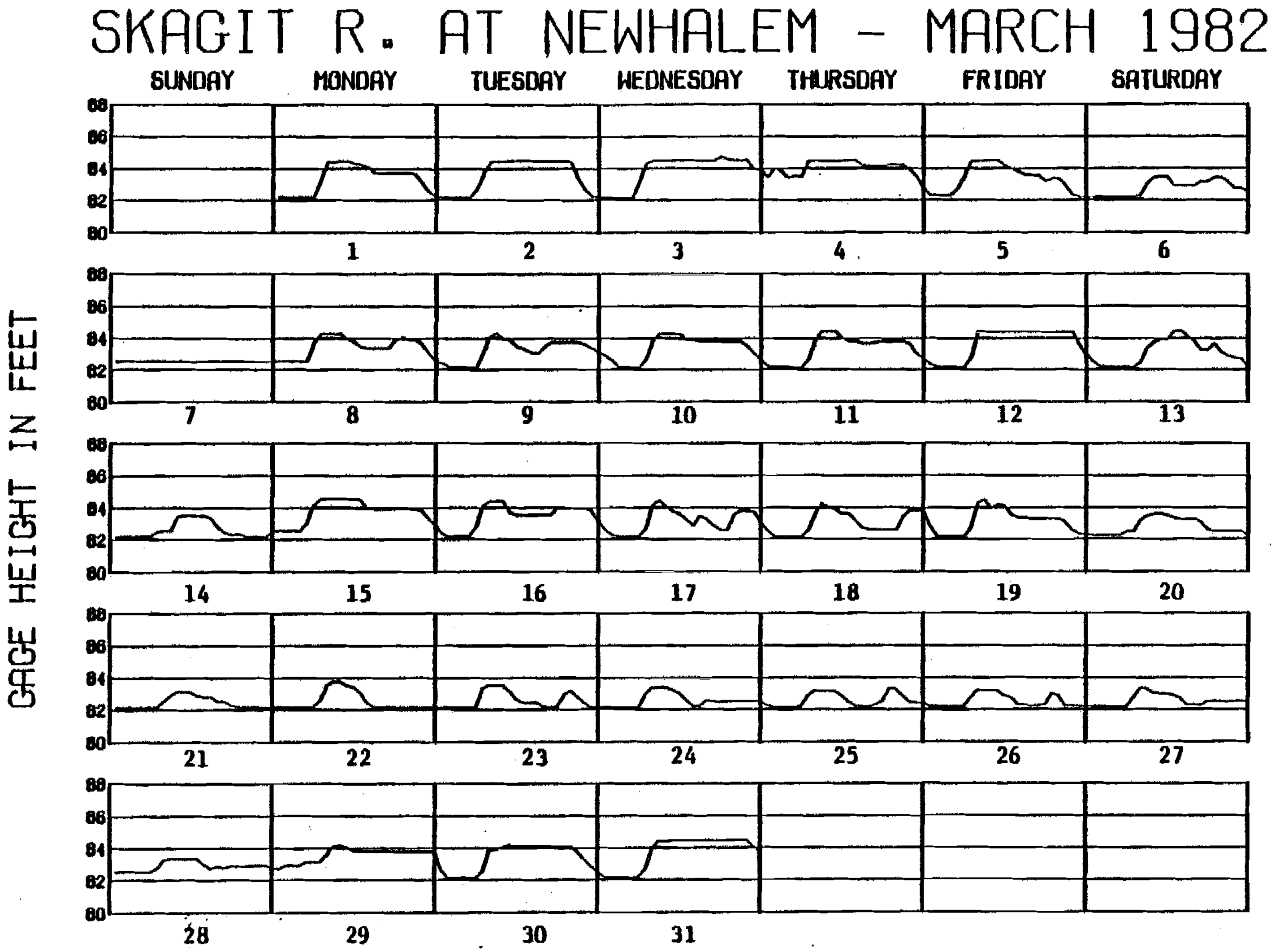

Figure 47. Hourly gage height data for Skagit River at Newhalem (USGS).

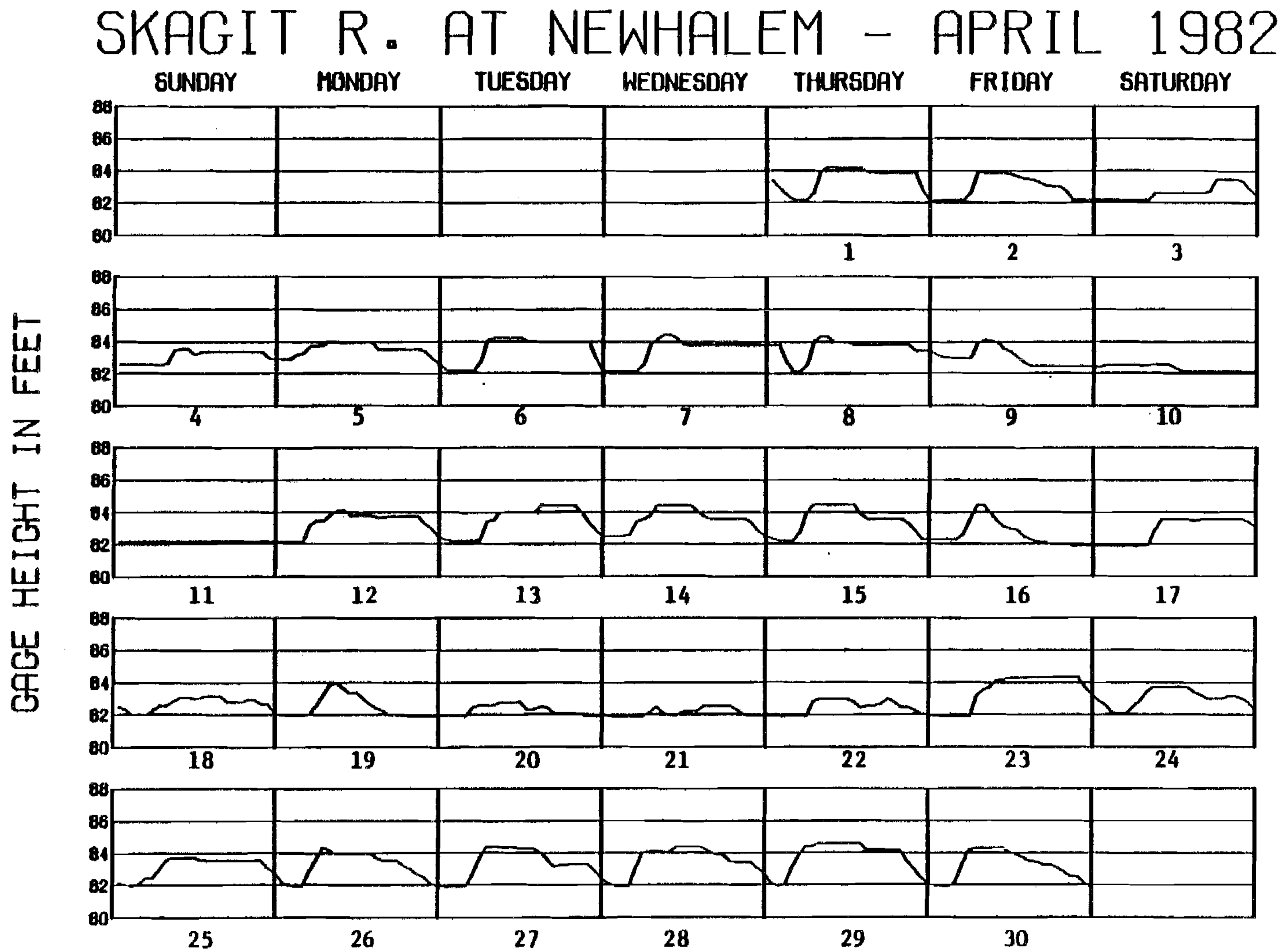

Figure 48. Hourly gage height data for Skagit River at Newhalem (USGS),

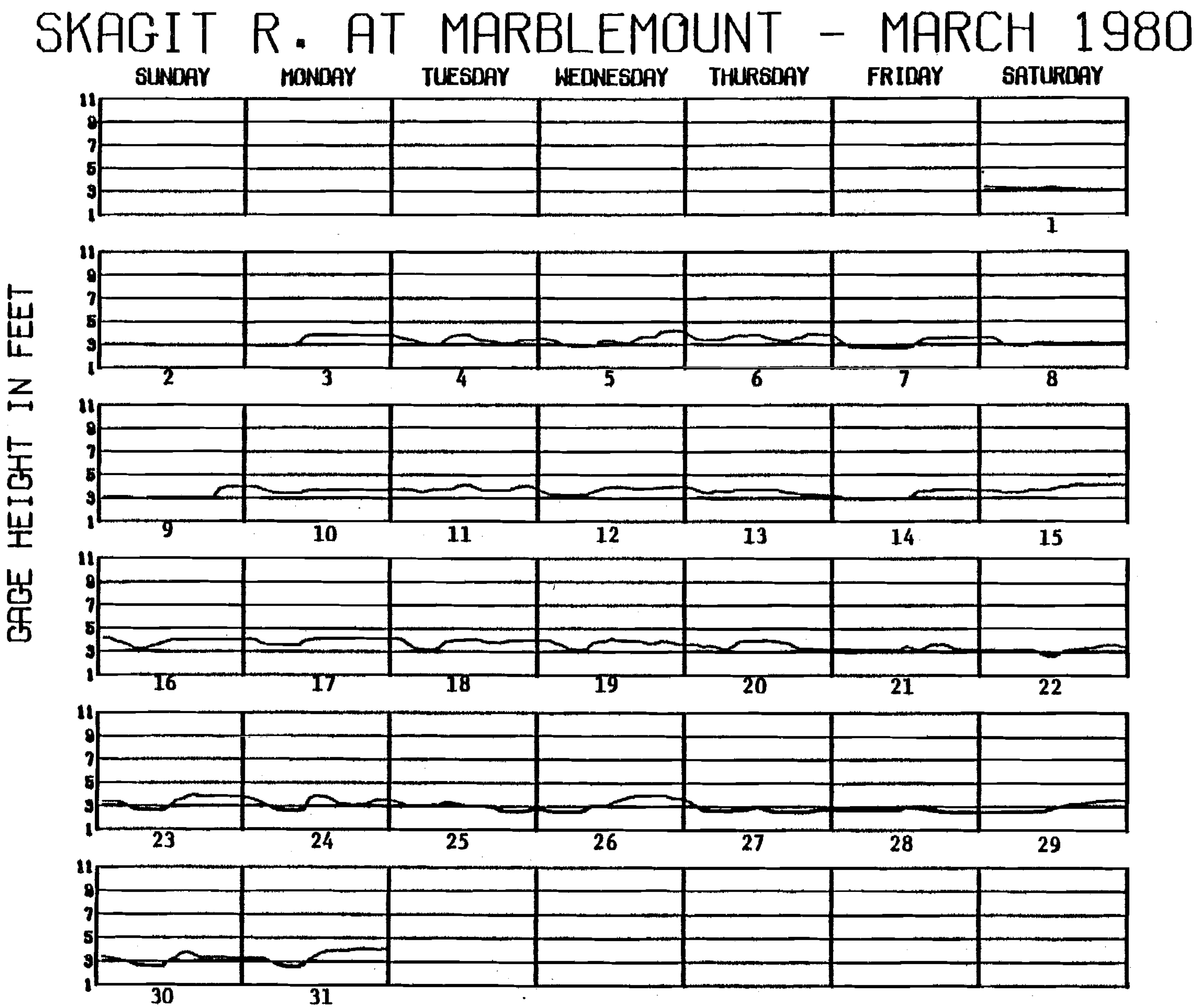

Figure 49. Hourly gage height data for Skagit River at Marblemount (USGS), March 1980.

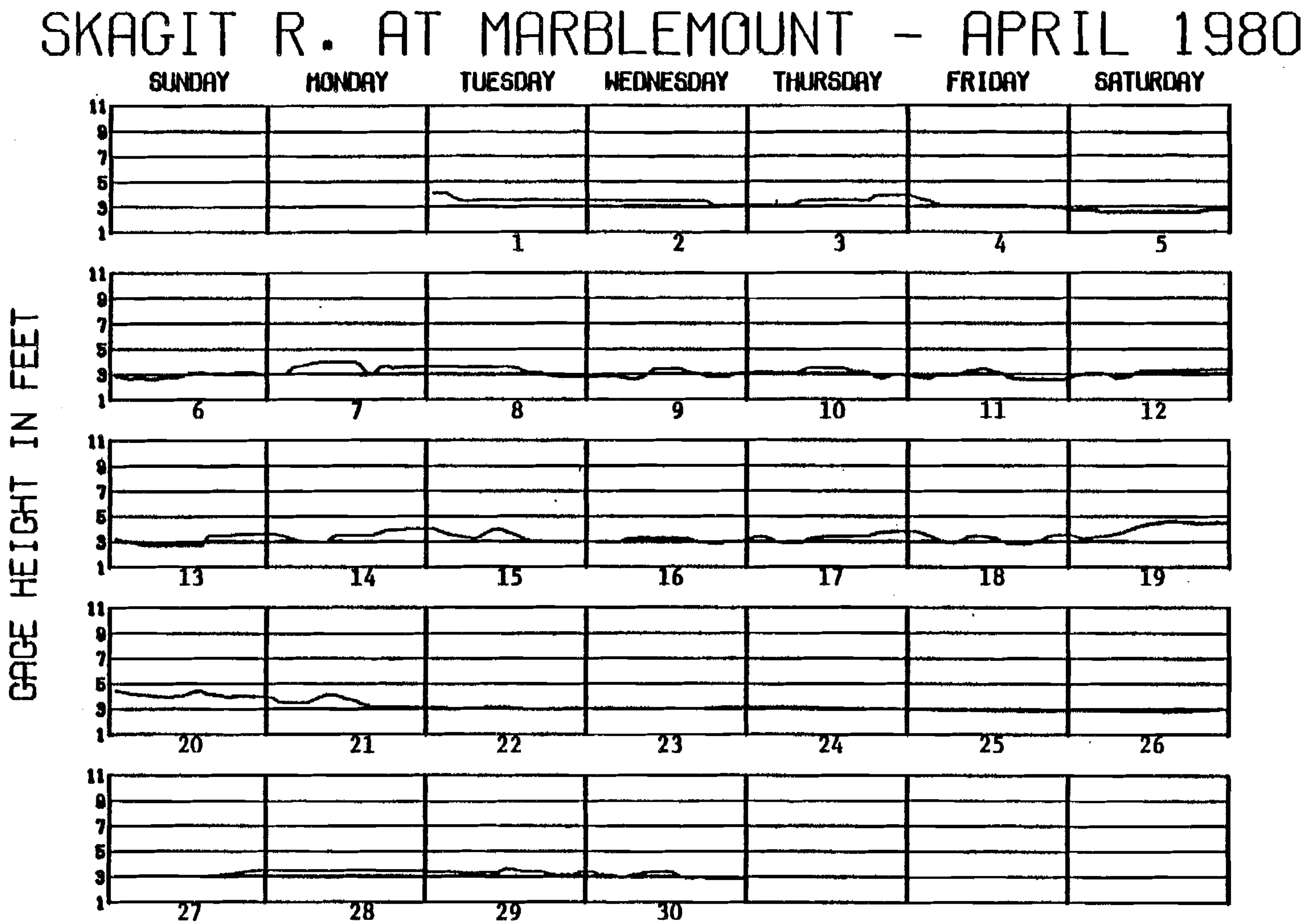

Figure 50. Hourly gage height data for Skagit River at Marblemount (USGS), April 1980.

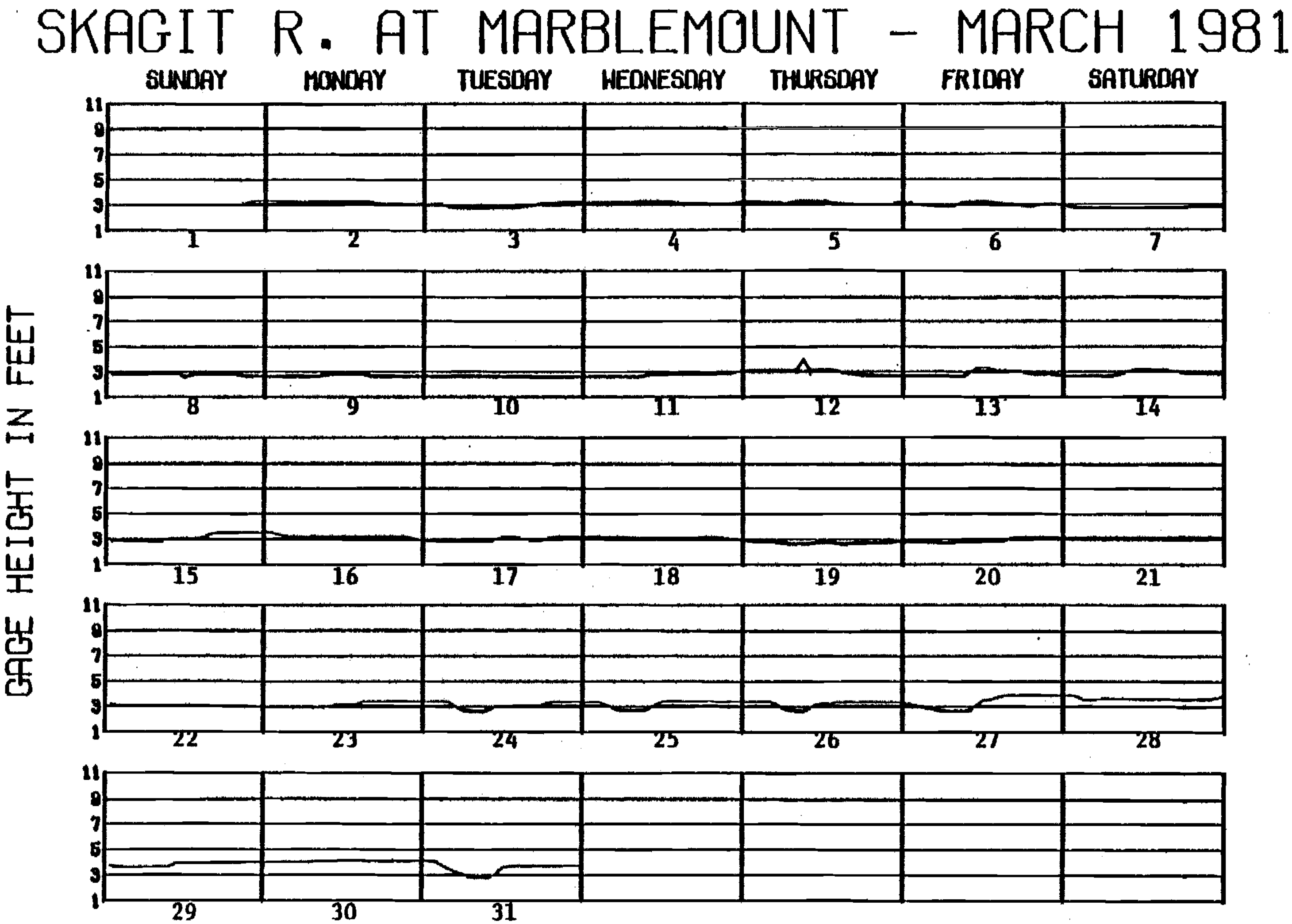

Figure 51. Hourly gage height data for Skagit River at Marblemount (USGS), March 1981.

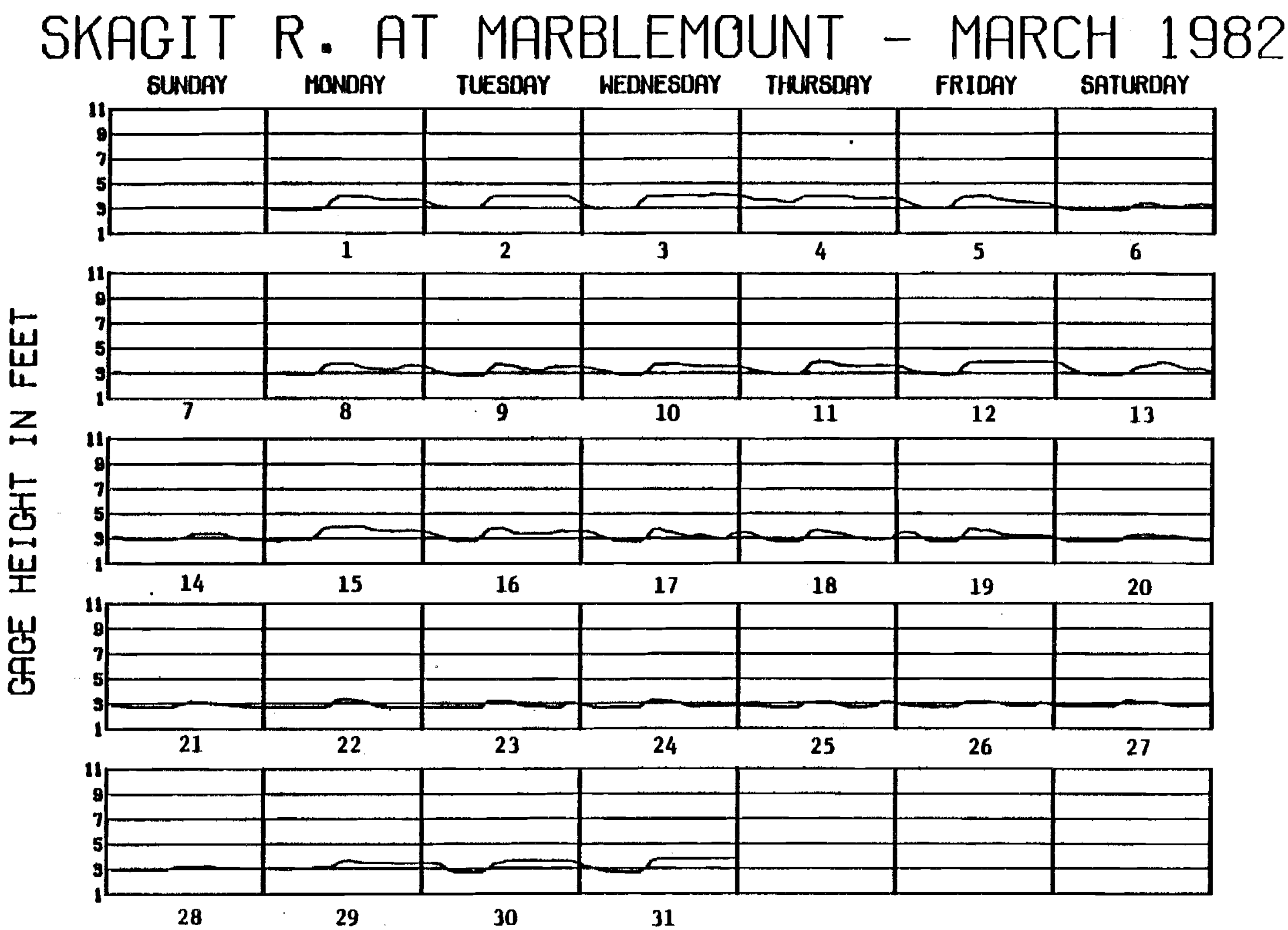

Figure 52. Hourly gage height data for Skagit River at Marblemount (USGS),

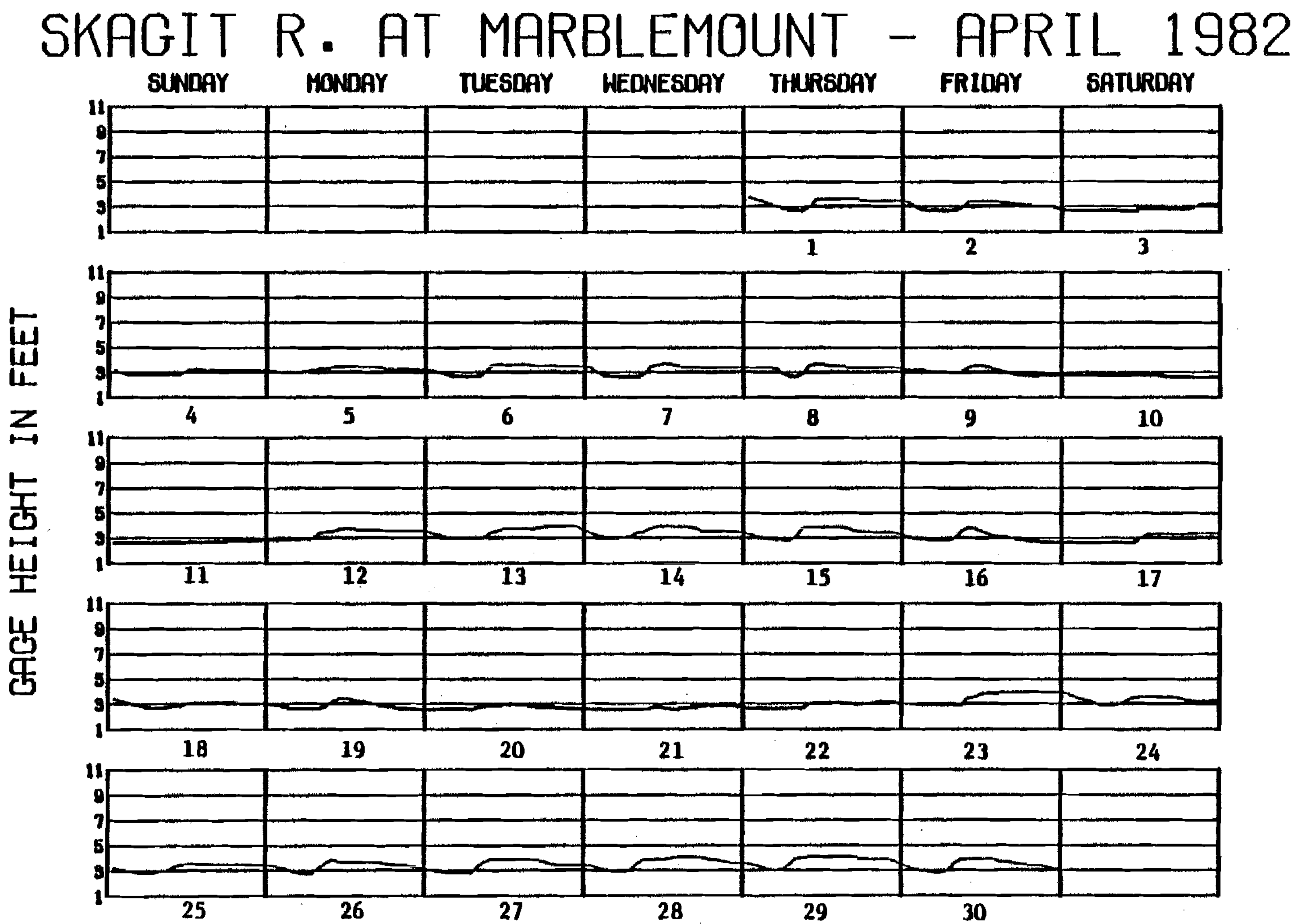

Figure 53. Hourly gage height data for Skagit River at Marblemount (USGS).

Table 46. Stream flow data during the downramping studies, 1980, 1981, and 1982.

Date	Ramp rate cfs/hr	Start time	End time	Time factor Site 1	Site 2	Site 3	Tributary inflow, cfs
3/23/80	1,454	1:15 AM	2:45 AM	1.13	4.63	7.63	1,164
3/24/80	603	10:00 PM	2:20 AM	1.00	4.25	7.25	1,092
3/30/80	357	8:30 PM	3:45 AM	2.37	5.87	8.87	1,066
3/31/80	870	12:30 AM	3:10 AM	1.82	5.32	8.32	997
4/13/80	436	8:30 PM	1:30 AM	1.00	4.08	7.08	1,320
4/14/80	714	10:20 PM	1:45 AM	1.00	4.37	7.37	1,973
3/24/81	941	11:00 PM	1:30 AM	1.00	3.42	6.42	1,077
3/25/81	836	9:50 PM	12:40 AM	1.00	2.62	5.62	1,138
3/26/81	966	11:40 PM	2:00 AM	1.00	4.00	7.00	1,066
3/27/81	402	7:00 PM	12:15 AM	1.00	2.25	5.25	1,066
3/31/81	889[a]	9:15 PM	2:30 AM	1.15	4.65	7.65	1,523
3/10/82	384[a]	9:00 PM	2:30 AM	1.00	3.95	6.95	1,509
3/11/82	624[a]	9:00 PM	12:30 AM	1.00	2.00	5.00	1,853
3/12/82	583[a]	9:20 PM	1:05 AM	1.00	2.52	5.52	1,661
3/17/82	715	10:30 PM	2:00 AM	1.00	3.62	6.62	1,317
3/18/82	747	10:30 PM	1:30 AM	1.00	3.16	6.16	1,242
3/19/82	2,100	12:01 AM	1:05 AM	1.00	2.83	5.83	1,231
3/30/82	2,179[b]	12:00 PM	1:00 AM	1.00	2.88	5.88	1,190
3/31/82	560[b]	8:00 PM	1:00 AM	1.00	2.85	5.85	1,120
4/1/82	700[b]	10:00 PM	3:00 AM	1.68	5.18	8.18	1,155
4/2/82	2,757[b]	10:00 PM	11:06 PM	1.00	1.32	4.32	1,083
4/7/82	1,987	10:00 PM	11:15 PM	1.00	1.63	4.63	1,000
4/8/82	2,070	2:00 AM	3:03 AM	1.97	4.47	8.47	1,033

[a] Variable ramp rate per the Skagit interim flow agreement, number is the average rate.

[b] Variable ramp rate due to ramping at a stage per hour rate, number is the average rate.

presented in Table 45. There is considerable variance in stranding indices both within and between sites. The stranding index relates to all salmon fry.

The apparent relationship between the occurrence of gravel bar dewatering during daylight hours as a result of downramping and the incidence of fry stranding for 1980-81 and 82 tests was examined by plotting the computed time factors versus the stranding indices for study sites 1, 2 and 3 (Figures 54, 55 and 56), respectively. The length of time dewatering occurred at each site during daylight hours for any given downramp was related to the completion time of downramping at Newhalem and the distance of the site downstream. At study site 1, Figure 54, nearest Newhalem the majority of dewatering was completed at or prior to dawn; at site 2, Figure 55, an intermediate distance downstream completion generally ranged from 1-5 hours after dawn; and at site 3, Figure 56, the farthest downstream from Newhalem completion occurred approximately 3-8 hours after dawn.

Coincident with a greater amount of daylight dewatering at sites farther downstream from Newhalem was a progressively higher incidence of stranded fry. The stranding indices for sites 1, 2 and 3 were generally less than 5, 10, and 40 at each respective site progressing downstream.

Two other factors, ramp rate and tributary inflow, were examined within the framework of the time factor vs stranding analysis to gain insight on the influence of these factors on the incidence of stranding. The ramp rate corresponding to each of the time factors was categorized as either high >1400 cfs or moderate <1000 cfs as indicated in the Figures 54-56 by the appropriate symbol. Inspection of these figures indicates a tendency of higher ramp rates to be associated with higher incidences of fry stranding. This, however, may be an artifact of test conditions since downramping at lower rates requires initiation at earlier times at night when compared to higher rates. The net

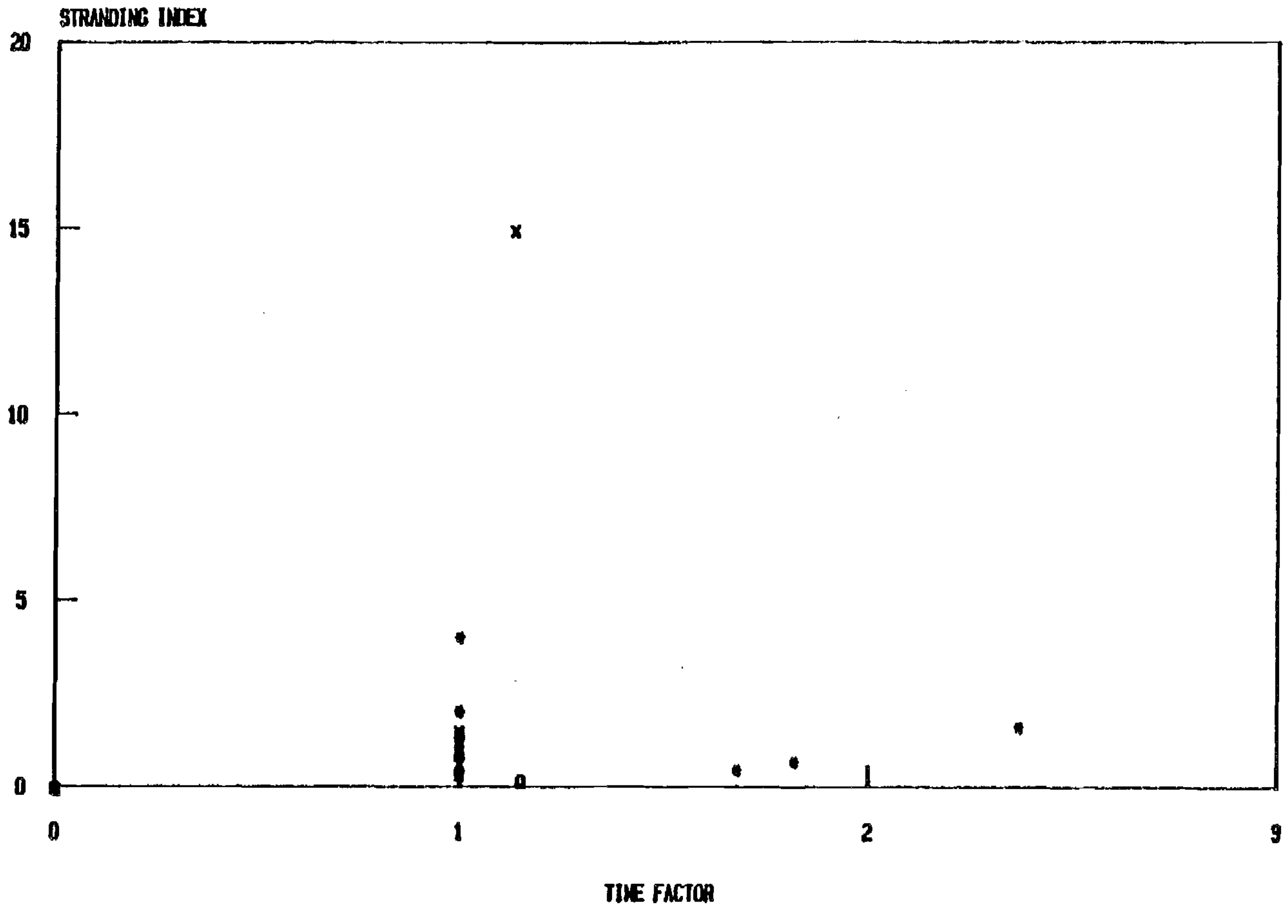

Figure 54. Stranding index vs. time factor for study site no. 1, 1980, 81, 82 data combined. X = high ramp rate >1400 cfs/hr; * = moderate ramp rate <1000 cfs/hr; 0 = high tributary inflow >1300 cfs and moderate ramp rate.

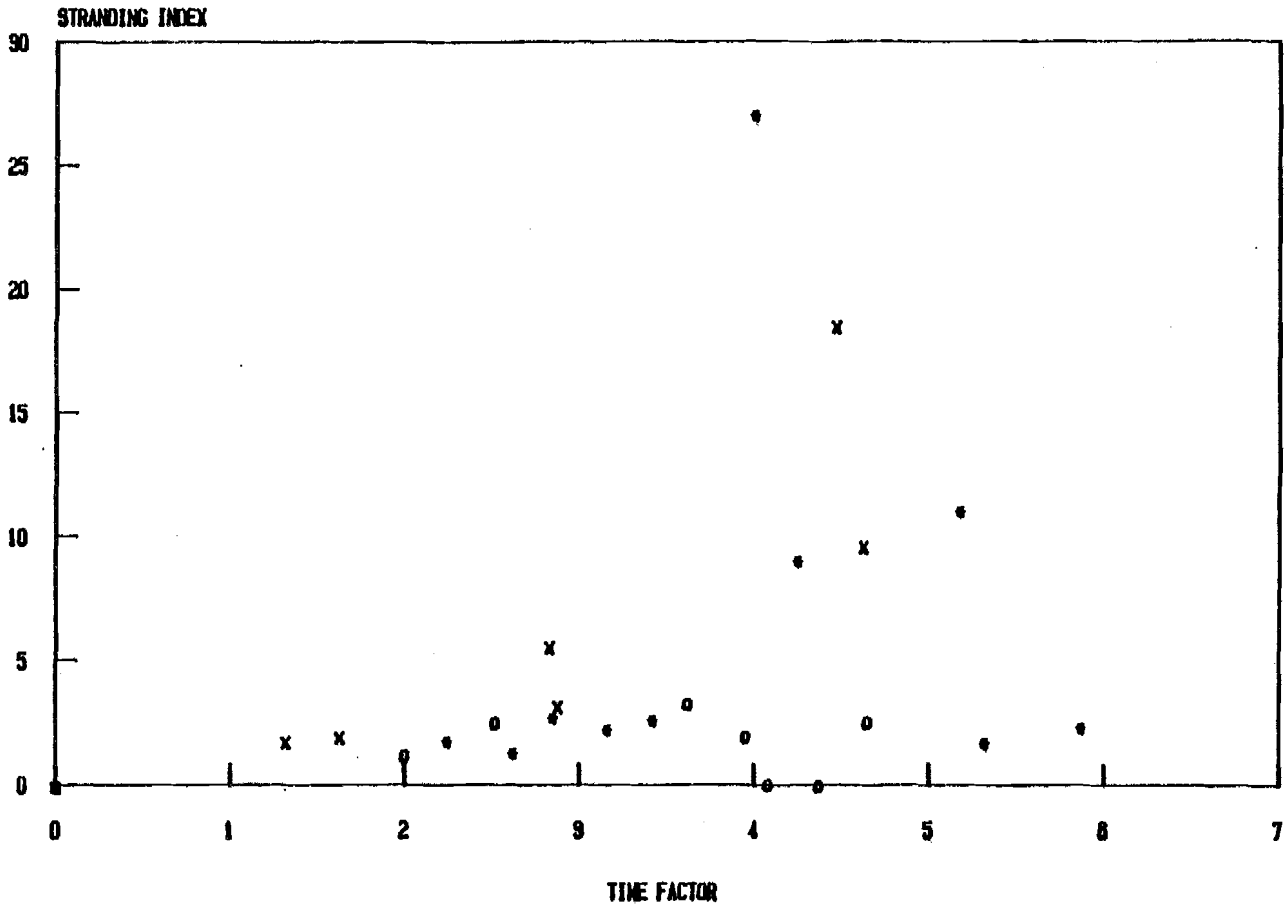

Figure 55. Stranding index vs. time factor for study site no. 2, 1980, 81, 82 data combined. X = high ramp rate >1400 cfs/hr; * = moderate ramp rate <1000 cfs/hr; 0 = high tributary inflow >1300 cfs and moderate ramp rate.

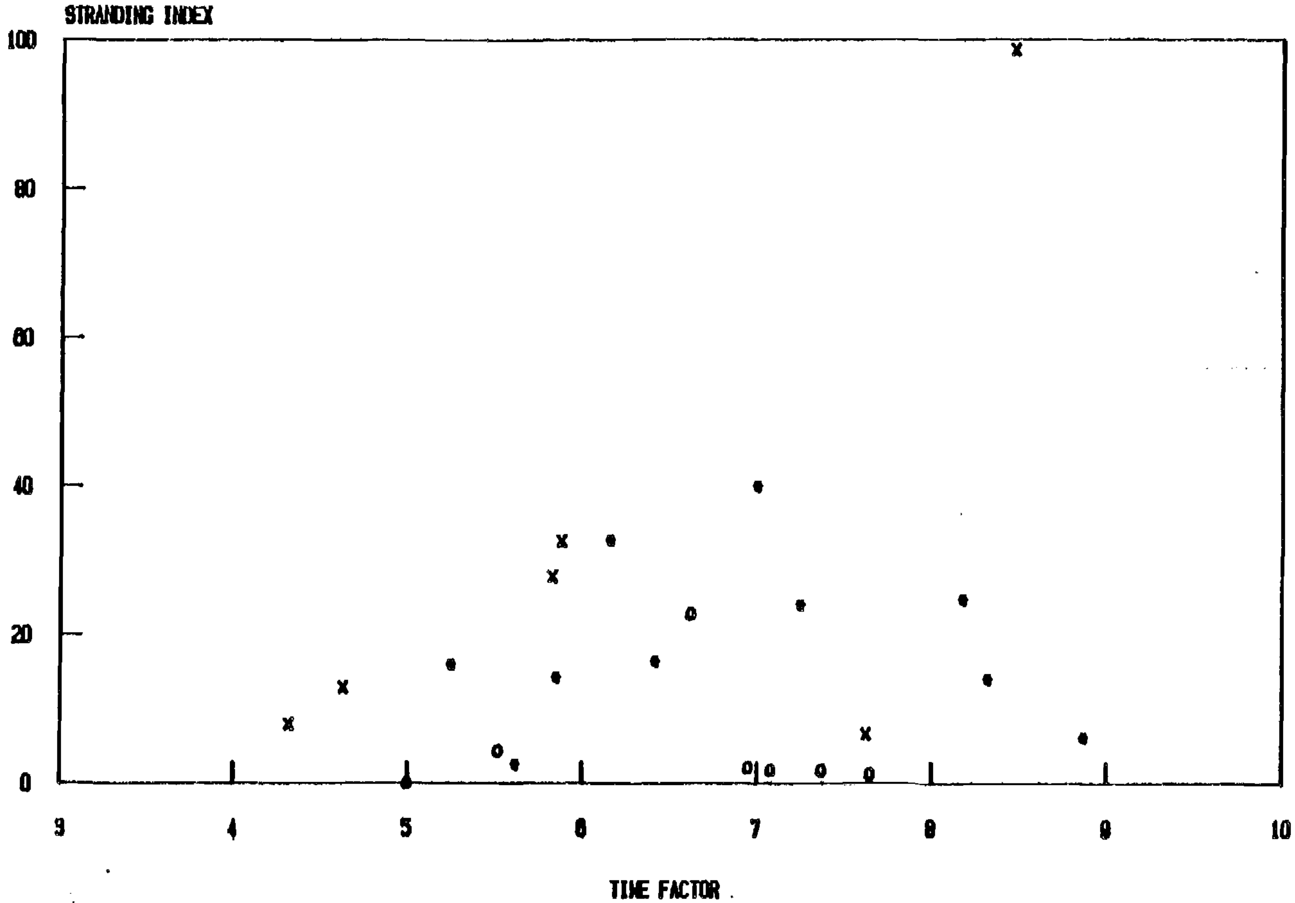

Figure 56. Stranding index vs. time factor for study site no. 3, 1980, 81, data combined. X = high ramp rate >1400 cfs/hr; * = moderate ramp rate <1000 cfs/hr; 0 = high tributary inflow >1300 cfs and moderate ramp rate.

effect is that with a low ramp rate much of the dewatering occurs at night although the completion time may extend well into daylight hours.

With tests during periods of higher tributary inflow the stranding index vs. time factor data point was indicated by a third symbol. The majority of ramping rates during the tests with higher tributary inflow were of the variable type and the moderate ramp rate category. Figures 55 and 56 indicate markedly reduced stranding indices as a result of higher tributary inflow even at higher time factor values.

A degree of caution should be exercised when evaluating the combined 1980-82 data with particular reference to the stranding indices. The stranding indices were computed independently for each year since the area sampled for abundance estimates was changed at each of the sites.

This raises the question as to the validity of combining the data for all three years for a single analysis. As a case in point, the 1980 test data in Table 46 indicate low abundance estimates of fry and consequently low stranding indices for many of the tests when compared to 1981 and 1982 test data. Insufficient numbers of fish potentially susceptible to stranding makes evaluation of factors such as daylight, tributary inflow or ramping rate difficult to identify. If the 1980 test data and high tributary inflow data points are removed from Figures 55 and 56 a clearer relationship of increased incidence of stranding with increased daylight dewatering emerges.

A regression of the stranding indices associated with high ramp rates, above 1900 cfs/hr against the corresponding time factors resulted in R-squared values of 0.821 and 0.973 for sites 2 and 3, respectively. A similar regression for moderate ramp rates 550-750 cfs/hr resulted in R-squared values of 0.157 and 0.867 at study sites 2 and 3, respectively (Appendix II, Table 2).

6.6.2 Steelhead

The results of the 1982 steelhead fry stranding studies are summarized in Table 47. These results indicate that more fry were stranded during darkness than in daylight hours, however, only two daylight stranding tests were conducted. In samples where large numbers of fry were stranded (19 and 24 fry/300 feet) the majority of the fry were trapped in a large pothole area.

Table 47. Results of 1982 Skagit River steelhead fry stranding studies.

Date	Ramp Rate	Location	No. of Stranded Fry	Avg. Length	Electrofishing Catch	Avg. Length	Comment
8-24	--	Rockport	--	--	156 fry/150 feet	34 mm	1
8-25	2000cfs/hr	Rockport	7 fry/425 feet	31.3 mm	--	--	2
8-26	2000cfs/hr	Rockport	7 fry/425 feet	33.9 mm	90 fry/75 feet	32 mm	
9-1	2000cfs/hr	Rockport	8 fry/425 feet	32.3 mm	53 fry/100 feet	32.9 mm	
9-1	2000cfs/hr	Rockport	1 fry/425 feet	34 mm	--	--	3
9-2	--	Rockport	--	--	41 fry/100 feet	34.1 mm	
9-2	2000cfs/hr	Rockport	no fry found	--	--	--	3
9-8	2000cfs/hr	Marblemount	19 fry/300 feet	36.9 mm	130 fry/100 feet	34.7 mm	4
9-8	2000cfs/hr	Rockport	6 fry/450 feet	32.7 mm	63 fry/100 feet	36 mm	
9-9	2000cfs/hr	Marblemount	24 fry/300 feet	36.6 mm	--	--	5
9-9	2000cfs/hr	Rockport	7 fry/425 feet	33.9 mm	--	--	
9-14	2000cfs/hr	Marblemount	1 fry/300 feet	50 mm	65 fry/100 feet	36 mm	6
9-14	2000cfs/hr	Rockport	1 fry/425 feet	36 mm	--	--	
9-15	2000cfs/hr	Marblemount	4 fry/300 feet	35.8 mm	--	--	6
9-15	2000cfs/hr	Rockport	no fry found	--	--	--	6
9-21	2000cfs/hr	Marblemount	4 fry/300 feet	37.3 mm	--	--	
9-22	1000cfs/hr	Marblemount	no fry found	--	--	--	7
9-23	1000cfs/hr	Marblemount	1 fry/300 feet	39 mm	67 fry/100 feet	38.9 mm	

1. Fry moved nearshore on rising water, offshore on dropping water levels
2. Stranded fry found near high water mark
3. Daylight downramping; peak 11:00 am to 1495 cfs by 2:00 pm at Gorge
4. Most stranded fry from large pothole area at downstream end at study site
5. 16 of 24 stranded fry from pothole area
6. No fry found in pothole area or near study site
7. Nearshore area disturbed by spawning chinook salmon

7.0 DISCUSSION

7.1 Escapements, Spawner Distribution and Area Spawned

The boat and aerial surveys performed by WDF and WDG during the past few years provide a valuable data base that has been and will be used in evaluation of the effects of flow fluctuation on the salmonid resource in the Skagit River. The spawning distribution for each species obtained from these surveys will aid in establishing the degree to which the percentage of the spawning population (and subsequent life stages) using each river section is affected by flow fluctuations. Determination of the timing of spawning allows prediction, based on temperature unit accumulation, of the occurrence of later life stages and the critical times when these stages may be subjected to adverse flow fluctuations. The documentation of spawning activity by aerial photos was also instrumental in the selection of representative reaches for the current IFIM study.

7.2 Adult Spawning Behavior-Flow Fluctuation Relationship

An adverse relationship between flow fluctuation and spawning adults has thus far not been demonstrated at least for a significant segment of the population of any salmonid species in the Skagit River. This results from the temporary nature of dewatering and the flexible behavioral response of the adult females. In addition, it has been difficult to demonstrate that spawning habitat is a limiting factor but is more likely augmented by the present interim minimum flow agreement. The problem which exists is the timing of the increase in river discharge which dictates the level of spawning in the channel and sets the level of the discharge regime to be maintained throughout the remaining incubation period. One of the objectives of the IFIM study being initiated is to determine the flows which begin to limit the habitat for spawning. Flow fluctuations occurring during habitat limiting discharges may then be of significance and need to be expressed as loss of habitat.

7.3 Instream Incubation Tests

Steelhead trout eggs were incubated in the Skagit River to determine the temperature units required to reach emergence. This information, when coupled with timing of spawning and the Skagit River temperature regime, will be used to predict periods during incubation when embryonic development is sensitive to fluctuations that result in temporary dewatering, when fry emergence from the gravel occurs or when emigrant fry are susceptible to stranding.

An attempt was made to monitor the effects of flow fluctuations, in particular, dewatering on the survival of chum salmon embryos placed in artificial redds in the Skagit River. The very low survival rates encountered in both control and test incubation containers rendered the experiments inconclusive. A flood in late January followed by moderate widely fluctuating flows in February and March resulted in a progressive intrusion of sediment into the incubation boxes which was the chief component causing mortality of the embryos. Beseta and Jackson (1978) have shown that transport of fine sediment occurs during periods of high flows followed by sediment deposition and intrusion during periods of low flow. The present study demonstrated that sediment became solidly packed in both freezer containers and W-V boxes smothering the eggs and/or alevins.

The difficulty experienced in attempting to incubate artificially enclosed eggs in the Skagit River prompted the initiation of studies on the effects of flow reduction on eggs and alevins under laboratory conditions where such physical parameters as flow, sedimentation and temperature could be controlled.

7.4 Laboratory Incubation Tests

Evaluations of the comparative survival of eggs and alevins from chinook, chum, coho, and pink salmon and steelhead trout subjected to various daily dewatering times in several substrate types indicated a high prehatching survival for all species and a decrease in post-hatching survival in direct relation to the length of successive daily dewaterings. Moreover, tolerance to single dewatering events of various times decreased as development of alevins progressed.

Recent laboratory studies by Reiser and White (1981) with chinook salmon and steelhead trout and Becker et al. (1982) with chinook salmon afford some comparison with these results. Reiser and White, for example, concluded from their studies that salmonid eggs are extremely tolerant to long periods of dewatering (1-5 weeks) without any significant effect on hatching. These findings are confirmed by field observations in which high prehatching survival was reported for brown trout (*Salmo trutta*) (Hobbs 1937) and chinook salmon redds dewatered for 3 to 5 weeks (Hawke, 1978). In contrast, Becker et al. 1980 found that survival of "cleavage" eggs, the developmental period extending from fertilization to eyed stage, declined to nearly 30% when dewatered daily for 16 hrs. The authors suggested this mortality was not due to dewatering alone but also to high temperatures resulting from insolation encountered during the testing. In light of the high survival found in our studies, those of Reiser and White (1981) and the field observations, it appears that temperature was a major contributing factor in the mortality observed in Becker's experiments.

The abrupt decrease in survival following hatching observed in our studies differs substantially from that reported by Becker et al 1982 for erythroembryos, the developmental phase extending from hatching to advanced yolk-sac alevins. The survival levels in their studies after 20 successive dewaterings of 2 and 4 hours daily were surprisingly high at 90 and 56%, respectively. In our studies survival had declined to less than 10% within 10 days for the same daily dewatering times for all species and gravel sizes tested. Surviving alevins in our studies were those that migrated downward through the substrate to the water retained at the bottom of the redd.

It is difficult to account for the differences in results when one considers that the size range of gravel substrates used in our experiments bracketed those of Becker et al. and furthermore that the same general pattern of survival was repeated for all species tested over different temperature regimes. No explanation for this difference is presently available.

A marked decrease in tolerance to single dewatering events was evident as alevin development progressed from hatching to emergence in the present studies. Immediately following hatching, survival after dewatering a single time for 2 hr was on the order of 90%; however, when alevins were dewatered for one hour just prior to emergence mortality was often greater than 90%.

The relatively high tolerance of prehatching developmental stages (eggs) to dewatered and static water conditions when compared to the high susceptability of post-hatching stages (alevins) may be explained in terms of the morphological and physiological changes that occur at the time of hatching. Prior to hatching the chorionic membrane provides the embryo with a protective barrier against adverse environmental conditions and yet allows for the diffusion of oxygen and elimination of metabolic wastes. When the egg hatches, this protective barrier is lost and the alevin becomes progressively more dependent on branchial respiration as the yolk sac is absorbed. Coincident with alevin development is decreased survival in dewatered conditions and increased survival in static water conditions. Increases in physical activity that accompany alevin development apparently allow alevins in advanced stages, when subjected to static water, to either increase water circulation across the gills and/or move from a microenvironment of depleted oxygen to one of more favorable conditions. This was most evident in the differential survival observed in the static water tests employing a range of gravel sizes. Survival was highest in the largest gravel size which facilitated movement and lowest in the smallest gravel size which greatly restricted physical activity of the alevins.

Mortality resulting from dewatering is readily detected under experimental conditions; however, sublethal effects which may be of ecological significance are less obvious. In determination of condition factors for chinook and coho salmon, the alevins were incubated under optium conditions in a compartmentalized Heath incubator for 6 to 10 weeks following testing. This time may have allowed the alevins to compensate for any deviations from normal development present immediately after testing.

Reiser (1981) in a similar study found that embryos that were continuously watered produced alevins that were significantly longer and heavier than dewatered embryos. However, after two months of rearing he found that fry produced from dewatered embryos were significantly longer and heavier and had higher condition factors than fry from watered embryos. Although no explanations of these results was provided, it appears that the conditions under which alevins or fry are reared may significantly alter differences in the condition factors, lengths or weights present immediately following testing.

The development of embryos was evaluated within a few days following hatching during studies in the second year. Consequently, the stress of dewatering was exerted primarily on the egg phase which may in part explain the lack of significance between control and test regimes. Since alevins within all test groups died soon after hatching it was not possible to evaluate the effects of dewatering on alevins alone. However, in the study by Becker et al. (1982), in which mortality was not as rapid, dewatering of alevins resulted in statistically significant decreases in lengths and weights. The importance of these decreases in condition factors particularly if the alevins are returned to optimum environment, are unknown.

Caution should be exercised if these laboratory data are to be applied to actual field situations. In these studies environmental parameters which may significantly affect survival of embryos such as freezing, insolation by the sun or intrusion of sediments, were controlled. Application of the laboratory studies to the field are further complicated when one considers the protracted nature of the spawning season for some of the species. Instances during incubation will arise when highly tolerant eggs of one species and highly susceptible alevins of another are dewatered concurrently. Moreover, the tolerance of alevins to dewatering varies with development. Considering the asynchrony of spawning and the range in susceptibility of the various phases of embryonic development to dewatering, it becomes apparent that a conservative approach is required to predict the consequences of dewatering events to the most sensitive phase.

7.5 Intragravel Alevin Survival, Movement and Behavior

7.5.1 Dewatering Behavior Studies (1981 and 82)

Preliminary experiments in 1981 indicated that chinook, coho and steelhead alevins were capable of making rapid downward migrations through selected gravel sizes to avoid dewatered environments. The difference in numbers of alevins of each species capable of making downward migrations can probably be attributed to size differences between the species. The larger chinook alevins made fewer successful migrations than smaller coho and steelhead through the large gravel and no recorded migrations in the small, medium or mixed gravels. Other laboratory studies (Bjornn 1969, Phillips et al. 1973) have shown that steelhead alevins have a higher survival to emergence than chinook or coho when incubated in the same size gravel. The smaller steelhead alevins were believed to be better able to migrate through the restricted interstices than the chinook or coho alevins.

The aquaria dewatering studies of steelhead alevins in 1981 indicated that rate of dewatering and developmental stage of the alevin were directly related to the percentage of alevins making successful downward migration.

The results of the 1982 dewatering studies on chinook and pink alevins again demonstrated that the size and the stage of development of the alevin are critical factors in ability to migrate through the gravel. As the alevins absorb their yolk sacs and become more fusiform in shape they are capable of migrating through gravel interstices more rapidly. The development of fins and musculature allows for better swimming ability. Other studies on yolk sac fry of chinook salmon indicate an increased swimming ability with a reduction in yolk sac size (Thomas et al. 1977). Early stage yolk sac alevins were found to be hydrodynamically inferior to streamlined fry with less yolk.

These studies, while not carried out in gravel substrates, suggest that movement may increase with advancing development of the alevin.

Aquaria studies in 1982 on chinook and pink alevins indicated there was a general tendency for both species to move downward through the gravel substrate within the first 48 hours after hatching.

Dill (1969) also observed an immediate post-hatching downward movement in aquarium studies of coho alevins. The extent of the downward movement was greater in large gravel (3.2.-6.3 cm) than in small gravel (1.9-3.2 cm). Downward movement was also reported in a study of brown trout (Salmo trutta) alevins (Roth and Geiger, 1963). However, in both these studies the downward movement was believed to result from negative phototactic behavior.

Intragravel movement is an adaptation demonstrated by alevins to avoid stress. Hatching, normal or premature, gives the organism mobility previously lacking in the embryo stage. Bams (1969), in observations on sockeye alevins, reports that under favorable conditions there is no intragravel migration until emergence. Young alevins could be induced to migrate in random directions through the gravel by reducing the flow of water. Random dispersal may potentially reduce stress by increasing the distance between alevins and by relocation of some alevins in more favorable areas. Older sockeye alevins demonstrated normal emergence behavior and migrated to open water to avoid low intergravel oxygen levels. Bams also found that both experimentally increased CO_2 levels and increased numbers of alevins per crevice greatly increased the activity level of alevins. He felt that changes in the micro-environment due to the number of fish present was a factor. Very high sediment levels in the intragravel water also caused movement of the alevins.

The aquaria dewatering studies indicated there was a direct relationship between the number of alevins making successful migrations and the size of the gravel substrate studied. Interstitial spaces in larger gravel allowed greater movement of alevins through the substrate. Numerous field and laboratory studies have been conducted on the relationship between emergence of salmonid alevins and the composition of the gravel substrate in the redds (Wickett, 1958; Cobel, 1961; McNeil and Ahnell, 1964; Koski, 1966; Hall and Lantz, 1969; Bjornn, 1969 in Reiser and Bjornn, 1979; Hausel, 1973; Phillips et al, 1975; and McCuddin, 1977 in Reiser and Bjornn, 1979). These studies demonstrate that fine sediment, usually less than 3 mm in diameter is inversely related to salmonid survival to emergence. Timing of emergence varied considerably between these studies. Phillips, et al., (1975), reported premature emergence of smaller fry with increasing concentrations of fines. Hausle and Coble (1976) found that increasing fines slowed emergence. Dill and Northcote (1970) noted that survival to emergence and timing of emergence were not affected when testing several larger gravel sizes without fines. Koski (1975) in studies of chum alevins emerging from sand gravel mixtures found that smaller fry emerged from gravel containing a high percentage of sand. He suggested that there was a selective mortality against the larger fry in high sand substrates.

Coho alevins in some instances demonstrated the ability to migrate downward through the medium, small and standard mix gravel samples. This ability was attributed to their smaller size. The ability to migrate downward through smaller gravels becomes significant, especially in the mixed gravel which contained sand. Bams (1969) in studies of sockeye emergence noted that alevins migrating upward when confronted with a sand barrier exhibited a "butting" behavior. The alevins thrust headfirst upward loosening the sand grains which fell downward past the fish allowing it to tunnel out. This behavior would be of little utility in downward migrations.

7.5.2 Velocity Studies

The 1982 studies on the effect of velocity on the movement of coho, chum and steelhead alevins revealed four trends. First, alevins in zero velocity studies had no current to orient to and they dispersed randomly through the three sections of the test aparatus. Second, alevins tested in medium and high velocity studies generally stayed in the central gravel staging area indicating they had adequate incubation conditions. Third, if movement did occur in medium and high velocity experiments the alevins generally demonstrated a positive rheotactic response by moving upstream into the current. Finally, the length of time after stress is imposed before movement occurred decreased with advancing stage of alevin development. The difference in rheotactic response between coho and chum in the pre-emergent developmental stage is probably the result of differences in early life history strategies. The coho remain in the river for one year after emerging, thus a positive rheotactic response would be expected. The chum fry migrate downstream to the ocean after emerging. This would explain why pre-emergent chum alevins demonstrated a high degree of negative rheotropism while the coho showed none. The steelhead pre-emergent fry should be similar to the coho as they have similar early life histories. They demonstrated a mixed behavior however, with positive rheotactic response about twice as large as negative response.

Several other studies have reported on lateral movements of alevins in the gravel. Dill (1969) in recording the vertical and lateral movements of coho alevins found a negative rheotactic behavior in the downward movement and a positive rheotaxis during the emergent upward phase. He also suggested that alevins were dispersing through the gravel to increase the distance between alevins. Other studies of salmonid alevins have shown that brown trout are negatively rheotactic during the downward phase (Bishai, 1960; Stuart, 1953), brook trout (Salvelinus fontinalis) are positively rheotactic at hatching (White, 1915), and brown trout are positively rheotactic during the entire alevin stage (Roth and Geiger, 1963). Bams (1969) demonstrated that sockeye and pink salmon (O. gorbuscha) alevins are positively rheotactic in the presence of light. As can be seen from these studies there is some controversy as to the direction of lateral movement of alevins. The positive or negative rheotaxic component of movement may be of considerable importance in locating areas that have not had dissolved oxygen lowered and metabolic wastes increased due to water reuse by sibling alevins.

Chapman (1962) found that the coho moved downstream in small numbers shortly after emerging from the gravel. He did not determine if this downstream movement was an inate migratory urge or just displacement by current. Other studies by Mason and Chapman (1965) indicated that the earliest emerging coho fry occupied the most upstream areas of the study stream. Later studies by Mason (1976) indicated that coho fry showed a positive current reponse with 68-82% moving upstream following emergence. Neave (1955) and Hoar (1956) showed that pink, chum, and sockeye salmon fry usually migrated as individuals and were negatively rheotactic. Thus results of these studies on pre-emergent alevins generally are in agreement with results of other studies on early emergent fry of the same species or early life history strategies.

7.5.3 Dissolved Oxygen Studies

Experiments on the effect of dissolved oxygen levels on movement indicated that alevins were capable of detecting an oxygen gradient and migrating into the arm of the Y-maze with the higher dissolved oxygen level. The ability to detect and migrate to the higher oxygen level could be important to the growth and ultimate survival of the alevin as several studies have shown. After hatching the oxygen demand of larval fishes increases markedly with age (Sharmardina 1954, from Davis, 1975). Nikiforou (1952, from Davis, 1975) found better growth in yolk sac fry of Atlantic salmon (*Salmo salar*) reared at 6.8-7.5 mg O_2/liter compared with those reared at 4.5-5.0 mg O_2/liter. The latter group weighed less than one-half of the high oxygen group.

Brannon (1965) studied the effects of water velocity, dissolved oxygen, and light on the development and weight of sockeye (*O. nerka*) embryos and alevins. The embryos were affected by low oxygen and light but not by velocity. The rate of alevin growth was affected by both oxygen level and velocity. These studies were conducted under hatchery conditions so the lack of gravel substrate and the high range of velocities studied reduce their application to the intragravel environment.

Larmoyeux and Piper (1973) found that growth was significantly reduced when O_2 was less than 5.0 ppm and ammonia greater than 0.5 ppm. They report however that growth rate was not affected when oxygen was in excess of 7 ppm and ammonia was as high as 0.8 to 1.0 ppm. This study suggested that low oxygen affected growth more than the ammonia levels tested. With low water flows through salmon redds a combination of low oxygen and high metabolic waste levels can occur. Movement of alevins to areas of higher dissolved oxygen levels could be critical to their survival.

7.5.4 Photobehavioral Studies

The results of the experiments to determine behavioral response of alevins to light indicated that photo-negative behavior for all three species increased during the early developmental stages. This avoidance of light reached a peak during the middle to late stages of the alevins development. As time of emergence approached there was a rapid reversal to positive phototactic behavior. This photo-negative response of newly hatched alevins has long been known (White, 1915; Gray, 1928). Some studies have indicated a progressive weakening of this initial photo-negativity (Stuart, 1953, Woodhead, 1957; Mason, 1976; and Dill, 1977). Bams (1969) found that sockeye salmon were negatively phototactic throughout their entire intragravel incubation and that any light inhibited emergence. Early studies by Neave (1955) and Hoar (1956) showed that pink, chum, and sockeye fry were negatively phototactic and that these initial responses eventually give way to rapid dramatic changes to neutral or positive photobehavior.

Mason (1976) in studies on coho fry found that the pronounced photo-negative behavior was suddenly lessened at time of emergence but remained photo-negative. Mason refers to this retention of photo-negative response as hiding behavior in which fry use the gravel bed as a refuge.

The recent studies of Carey and Noakes (1981) on rainbow trout indicated the occurrence of a rapid photo response shift from negative to positive occurring at the onset of emergence and the depletion of 85% (by volume) of the yolk reserve.

The negative photobehavior of the alevins prior to emergence is probably an adaptation to keep them in the gravel during development when they would be most susceptable to predation. Carey and Noakes (1981) found that alevins initiated downward movements in an artificial turf substrate incubation system whenever light was applied above the substrate. The rapid reversal of this photobehavior at emergence allows the alevins to enter the water column above the substrate and take up the next stage of their life histories as free swimming fry.

7.6 Fry Stranding

The stranding of salmon fry (*Oncorhynchus* spp.) on gravel and sand bars and in shallow sloughs below hydroelectric dams as water levels recede following a peak in power production has been well documented in Washington State (Thompson 1970; Graybill et al. 1979; Phinney 1974; Bauersfeld 1977, 1978; Becker et al. 1981). The relationship of hydroelectric power peaking and stranding kills of salmon fry on the Skagit River has been examined periodically in cooperative studies involving Seattle City Light, Washington Department of Fisheries and the University of Washington Fisheries Research Institute since 1969 (Thompson 1970, Phinney 1974, Graybill et al. 1979). The thrust of these studies has been to identify flow manipulation conditions which are least detrimental to Skagit River populations of salmon fry. The early studies (Thompson 1970) demonstrated that reduction in flow at Gorge Dam from greater than 5,000 cfs to 1,100 cfs stranded many more fry than did reduction from greater than 5,000 cfs to 2,500 cfs.

During Thompson's study the reduction in flow was accomplished in a matter of minutes. The thrust of Phinney's study was to determine if reducing the rate of flow reduction to 400 cfs per 6 minutes would significantly reduce the loss of salmon fry due to stranding. The modified down-ramping rate still resulted in substantial fry mortality particularly when the flow was reduced to about 1,000 cfs at Gorge powerhouse.

The relationship between ramping rates ranging from 357 to 2,757 cfs/hr and fry stranding mortality was investigated at three sites along the Skagit River. The relationship appeared very weak until the additional variable of daylight during the downramping period was examined and factored into the analysis. The inclusion of the daylight data in the form of a time factor accounted for a significant portion of the variability in stranding observed at the Marblemount and Rockport study sites. There is an interaction between daylight and downramping which needs further evaluation to determine how to coordinate downramping rate with the occurrence of daylight to minimize stranding mortality.

The tendency of salmon fry stranding to increase from one site to the next moving downstream independent of ramp rate was apparently not associated with salmon fry density because the Marblemount site had the highest densities and was generally intermediate in stranding. The trend may be a function of the physical characteristics of the study sites such as substrate composition and gravel bar gradient.

However, the observation and analysis of the time data indicates that the time factor is at least partially responsible. The time lag in flow reductions as the flow change proceeds downstream results in an increase in occurrence of downramping during daylight hours as the distance downstream from Newhalem increases.

Downramping rate has in the past been considered one of the major factors responsible for fry stranding mortality and consequently analysis has focused on developing a stranding-downramping relationship. As a result of recent fry stranding studies several other factors thought to influence stranding have emerged. Among these are time of day, tributary inflow, abundance of fry, and substrate. The degree to which some of these factors modified stranding was estimated in the current analytical procedure.

Alternative methodologies in evaluating fry stranding mortality might include 1) refinement of the stranding index vs. time factor analysis or 2) stranding index versus habitat.

In the first methodology the time factor would represent the time at which the water level (stage) at a given site dropped to a predetermined level that critically impacted the habitat of the fry. The advantages of such a method are that the critical drop in stage may occur prior to the maximum dewatering for a given ramp rate and thus low ramp rate requiring many hours for a downramp may be more easily compared to higher rates. Furthermore, since drop in stage is being evaluated the tributary inflow would be incorporated in the analysis.

A second methodology that could directly account for many of these factors might describe stranding as a function of habitat (i.e., preferred depth, substrate) and also the duration the habitat was available. A habitat-stranding relationship could then be evaluated for flow reductions in terms of time of day, rate, etc. Since depth is used in describing the habitat tributary inflow would be taken into consideration.

The decrease in the incidence of steelhead fry stranding during daylight hours appears opposite to that obtained with salmon. An explanation of these differences may be found in the behavioral patterns of fry noted during the studies. Steelhead fry in the nearshore areas during daylight hours appear to be easily frightened and readily leave the area at the slightest disturbance. Large numbers could be observed moving into shallow water as river levels rose each day. These fish would flee at the sight of a person approaching the water's edge. Even the wake from passing boats caused fry to leave the area for several minutes. This behavior was observed throughout the stranding study. Care had to be taken while electrofishing not to approach the water's edge in the inventory area to avoid scaring the fish away. Considering that steelhead fry normally emerge from the gravel at times when natural river flows are apt to be dropping may be the reason for what was observed during the stranding study. These fish may be genetically keyed to protect themselves from dropping water levels. The finding of most of the stranded fry near the high water line is possibly explained because the water's edge moved across this area during hours of darkness when visual cues were not as apparent to the fish. This can also explain the scarcity of fish in the nearshore area during a decline in the water level and the tendency to flee at any disturbance. This is supported by the small number of stranded fry found after the daylight downramping. Two factors probably affected the daylight downramp stranding. The river began dropping as soon as it reached high water at Rockport. There may not have been enough time for the fry to establish territories (feeding or spatial) before the flows started to drop. And since this downramp took place completely during daylight, the visual cues were such that the fish avoided stranding.

In 1981, steelhead fry became scarce in the nearshore area by the time the mean length of a sample reached 47 mm. The 1982 observations indicate that while the fry may be present in the nearshore area they appear to be less susceptible to stranding once they reach a length of about 40 mm. Fry growth rates were similar but somewhat slower in 1982. In 1981 on September 9, fry samples from the Marblemount area averaged 40.3 mm in length, while samples from the Rockport area averaged 39.3 mm. In 1982, samples from the same areas averaged 36.0 and 34.9 mm, respectively, on the same date. Average length of steelhead fry taken from the Skagit River at both locations was 39.7 mm in 1981 and 35.6 mm in 1982. This data does not suggest any major differences between 1981 and 1982 as far as when fry are no longer susceptible to stranding. By about the first of October each year fry appear to have grown to the point where their habitat preferences move them from the nearshore areas to deeper water.

8.0 SUMMARY AND CONCLUSIONS

8.1 Escapements, Spawner Distribution and Area Spawned

Boat and aerial surveys were conducted by WDF to estimate the Skagit system natural spawning escapements for chinook (summer-fall) pink, chum and coho salmon. The escapement levels of summer-fall chinook, pink and coho salmon for 1978-1981 were comparable to those for previous years. A particularly strong high cycle (even-year) escapement was estimated for chum salmon in 1978 (115,200) and a less than average return in 1980 (21,350). As in past years, the most heavily used section of the mainstem Skagit above the Sauk for summer-fall chinook on a per-mile basis was the section between Diobsud Creek and the Cascade River. The area spawned per river mile in this section as determined from aerial photographs taken on October 6, 1980 was 5,365 m^2 and represented approximately 375 redds.

Helicopter surveys were conducted by WDG to estimate the Skagit system natural spawning escapements of steelhead trout. The distribution of steelhead spawners per various river section was determined by plotting the locations of the redds on recent aerial photographs. The 1977-1978 to 1981-1982 spawning periods were the first for which escapement estimates were available, so comparison with previous years was not possible. Steelhead escapement for the mainstem Skagit for these years ranged from 913 to 3,362. The section of the Skagit mainstem most heavily spawned extended from the Cascade River to the Sauk River.

8.2 Adult Spawning Behavior

The spawning behavior of female chinook and chum salmon was observed in relation to fluctuating flows. Individual female chinook salmon which had commenced their spawning activity were marked as were redds in the initial stages of construction. During moderate changes in flow females remained at their redds; however, during flow reductions which approached dewatering the females left the redds but returned later at increased flows. Only two redds out of twenty-five marked were judged not to be completed.

The general pattern of activity indicated that the female chinook would complete their redds if the flow levels provided adequate flows over the redd site for at least several hours each day.

The moderately high and stable flows during the chum observation period precluded establishing any relationship between flow fluctuations and spawning behavior.

The 1981 observations of marked redds for both chinook and pink salmon confirmed the 1980 observation that females are forced off redds by flow reductions and return to complete their redds if a reasonable opportunity occurs.

8.3 Instream Incubation Tests

Steelhead eggs were incubated in the Skagit River at several sites to determine temperature unit requirements for emergence. All groups appeared to require approximately 1050 temperature units to reach the button-up stage of development.

Chum salmon eggs enclosed in either freezer containers or Witlock-Vibert boxes were buried in the streambed at various depths and locations to determine the effect of dewatering on egg or alevin survival. Unfortunately, the incubation boxes functioned as sediment traps and the eggs and alevins experienced severe mortality. Correlations between egg and alevin survival and dewatering events therefore were not possible.

8.4 Laboratory Incubation Tests

The effects of dewatered or static water conditions on the survival of incubating chinook, coho and chum salmon and steelhead trout eggs and alevins in selected gravel environments were examined. A 9 x 4 factorial design was employed in the first year studies with 5 dewatered or static conditions (0, 4, 8, 16 and 24 hrs (continuous) per day) and 4 gravel sizes (0.33-1.35 cm, 0.67-2.67 cm, 1.35-5.08 cm, and 0.08-5.08 cm) as the environmental variables. In the second year studies a single gravel composition representative of Skagit River substrate was used with dewatering times of 0, 2, 4, 8, 16 and 24 hrs/day. Eggs were tested from the time of fertilization through hatching.

Prehatching survival generally was high for all species, gravel sizes and dewatering or static regimes tested. Posthatching survival for all species and gravel sizes generally decreased in direct relation to the amount of time dewatered or in static condition. For all species, gravel size and dewatering regimes, at least 50 percent of the alevins had died within a week after hatching.

8.5 Alevin Behavior Studies

The alevin behavior studies have shown that salmonid alevins are capable of making downward migrations through some gravel substrates to avoid dewatering. The size of the gravel substrate is directly related to the number of successful migrations with smaller gravel sizes restricting alevin movement. Studies on the effect of velocity on alevin behavior indicated that alevins dispersed randomly when placed in zero velocity flow troughs but remained in the staging area or were positively rheotactic if placed in flow tanks with adequate velocity. Dissolved oxygen studies demonstrated that alevins could distinguish between two water sources with high and low dissolved oxygen levels and would migrate toward the higher oxygen source. Alevin photo behavior studies have shown that an initial post-hatching photo negativity increased during incubation then reversed sharply to photo positive behavior as time of emergence approached. In all of the preceeding experiments the response time of the alevin decreased as the stage of development increased from post-hatching alevin to pre-emergent fry.

8.6 Fry Stranding

The relationship between ramping rates ranging from 357 to 2,757 cfs/hr and salmon fry stranding mortality was investigated at three sites along the Skagit River. The relationship appeared very weak until the additional variable of daylight during the downramping period was examined and factored into the analysis. The inclusion of the daylight data in the form of a time factor accounted for a significant portion of the variability in stranding observed at the Marblemount and Rockport study sites. There is an interaction between daylight and downramping which needs further evaluation to determine how to coordinate downramping rate with the occurrence of daylight to minimize stranding mortality.

Steelhead fry stranding studies evaluated the effects of day vs night downramping on the incidence of stranded fry. The number of stranded fry was significantly less in the daylight test when compared to the nighttime downramping, however, only a limited number of daylight tests were conducted. This may have resulted from insufficient time for the fry to establish territories during the daylight flow regime or an avoidance behavior dependent on daylight conditions.

9.0 RECOMMENDATIONS

Efforts to minimize the adverse effects of hydroelectric flow fluctuation in the Skagit River on the salmonid resource can be aided by the development and use of a habitat model that focuses on maintenance of physical habitat requirements for each salmonid species/life history stage. Specific effects of flow fluctuations on spawning (harrassment), incubation (dewatering), and fry rearing (stranding) have been determined and need to be incorporated into such a habitat model. A model would focus on two basic problems: 1) determination of the minimal annual flow regime required by the mix of salmonid species/life history stages present in the river and 2) the effects of short-term rapid fluctuation in discharge due to hydroelectric peaking on the most sensitive salmonid life stages. The instream flow incremental method (IFIM) has been developed to deal with the first problem by providing a predictive model of available habitat based on river discharge. The IFIM can be extended to model the second problem, short-term fluctuations to predict various biological responses to short term and cumulative habitat perturbations. It is in this second area that additional research and methods development are required.

The specific objectives and tasks required for this model development are outlined as follows:

Objective I. A quantitative instream flow analysis of the Skagit River (Newhalem to Rockport) using the instream flow incremental method (IFIM) of analysis to determine the physical habitat and associated flow requirements for each salmonid species/life history stage under natural and present power generating regimes is needed.

Tasks A. Cross-sectional transect measurements of depth, velocity and substrate would be made at low (1500 cfs), medium (3000cfs), and high (6000-7000cfs) discharges at seven study reaches.

B. Low, medium and high flow data sets would be used to calibrate the IFG-4 hydraulic simulation model which would then be used to predict discharges and associated hydraulic parameters within and outside the range of the calibration flows.

C. Habitat suitability criteria:

a. Spawning - Criteria for chinook, pink and chum salmon and steelhead trout would be developed using previously collected Skagit River data. These criteria would then be compared to published curves for selection of the final curves to be used in the analysis.

b. Incubation - New criteria for chinook, pink and chum salmon and steelhead trout which is being developed by Milhous (US FWS-IFG) would be utilized or the assumption made that these criteria are equal to spawning flows.

c. Fry - Published values would be relied upon for steelhead trout, none are available for salmon.

d. Juveniles - Chinook and steelhead published criteria would be compared to data developed during the fry stranding studies on the Skagit River.

e. Adults - Published values will be applied to steelhead trout.

D. The computer program HABTAT would be used to determine the weighted usable area values for each species/life stage utilizing the habitat suitability criteria, over the range of discharges simulated using the depth, velocity and substrate data predicted by the hydraulic model.

E. Develop instream flow recommendations for the Skagit River from Newhalem to Rockport using the following steps:

a. simulation of a range of discharges at each study reach to determine WUA values for each species/life history stage;

b. calculate combined WUA indices for each species/life stage for the Skagit River by extrapolating individual reaches to each associated river segment;

c. identify discharges for the various species/life stages on the basis of the peak habitat efficiency values (i.e., the discharge (Q_E) associated with the <u>maximum percentage of WUA</u> within the wetted perimeter) and the maximum habitat availability values (i.e., the discharge (Q_M) resulting in the <u>maximum WUA</u>);

d. determination of salmonid life stages and species to be given preferential consideration in the development of instream flow recommendations; the preference assigned would be based on numerical abundance, sensitivity to habitat perturbation and critical or limiting periods of life history;

e. combine the Q_M and Q_E flow information and stochastic projections of monthly discharge based on historical records to determine minimum flow recommendations for each species/life stage during normal and critical water years;

f. recommend comparable alternative minimum and critical water year instream flows for natural and present power generation regimes based on City Light and USGS river gaging records.

Objective II. Determine the effects that the rate, frequency and amplitude of flow fluctuation have on chinook, chum and pink salmon and steelhead trout incubation habitat.

Task a. A phenology chart for each species to establish incubation timing, developmental rates, emergence and emigration periods would be developed from existing data.

Task b. Hourly discharge data for each developmental period would be examined under natural and two selected post-operational discharge periods.

Task c. Results of the laboratory dewatering and intragravel behavioral studies would be incorporated into an analysis of the calculated and actual incubation habitat affected by dewatering in a time-dependent habitat model.

Objective III. Develop a time-dependent habitat model capable of predicting the availability and probability of use of juvenile habitat affected by various ramping rate and flow duration events.

Task a. Field measurements to develop criteria relevant to fry stranding (i.e., beach slope, hydraulic gradient, depth, velocity, substrate, time of day and fry abundance) would be made during the chinook and steelhead fry stranding studies.

Task b. A survey of the number of representative stranding bars would be made from Newhalem to Rockport to determine the relationship of the sample fry stranding bars to the entire river channel.

Objective IV. Determine the intragravel survival, movement, and behavior of salmonid alevins in response to variations in velocity, dissolved oxygen and metabolic wastes resulting from flow fluctuations. Additional research on this topic is required because the results have not been sufficiently developed for incorporation in the model.

Task A. The occurrence of intragravel movement of salmonid alevins under conditions of adequate velocity, dissolved oxygen, low metabolic wastes and darkness would be determined.

B. The level of water velocity that would stimulate movement of alevins would be established and determination of whether or not the movement is random or demonstrated a positive or negative rheotactic response made.

C. The ability of alevins to make downward intragravel migrations to avoid dewatering would be tested using different dewatering rates and substrate sizes.

D. The survival and movement of alevins in response to various levels of dissolved oxygen and metabolic waste would be recorded.

E. The direction and magnitude of photoresponse of alevins would be established.

F. The influence of the developmental stage of an alevin in altering its response to the preceding environmental stimuli would be determined.

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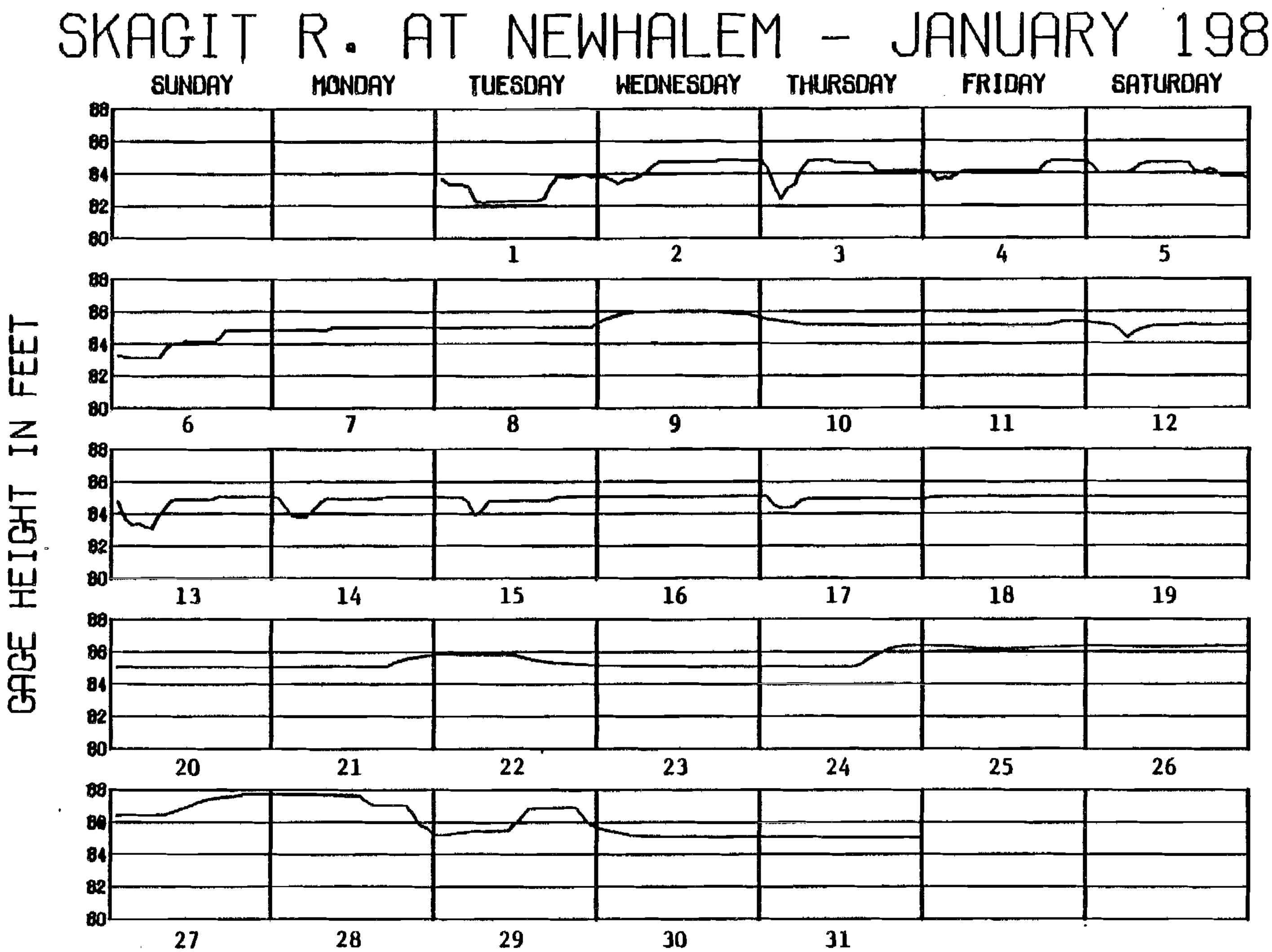
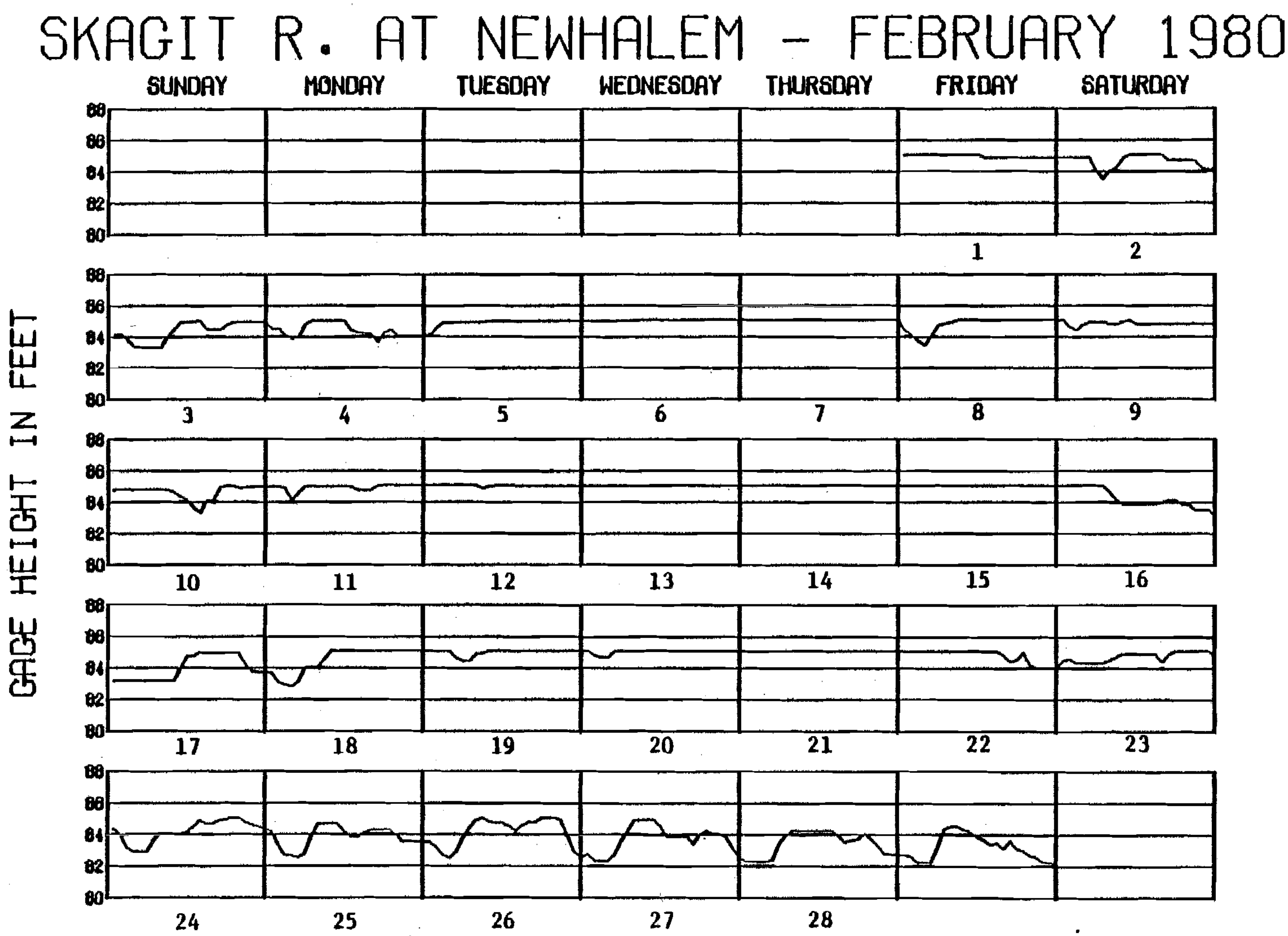
11.0 APPENDICES



Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December, 1980.



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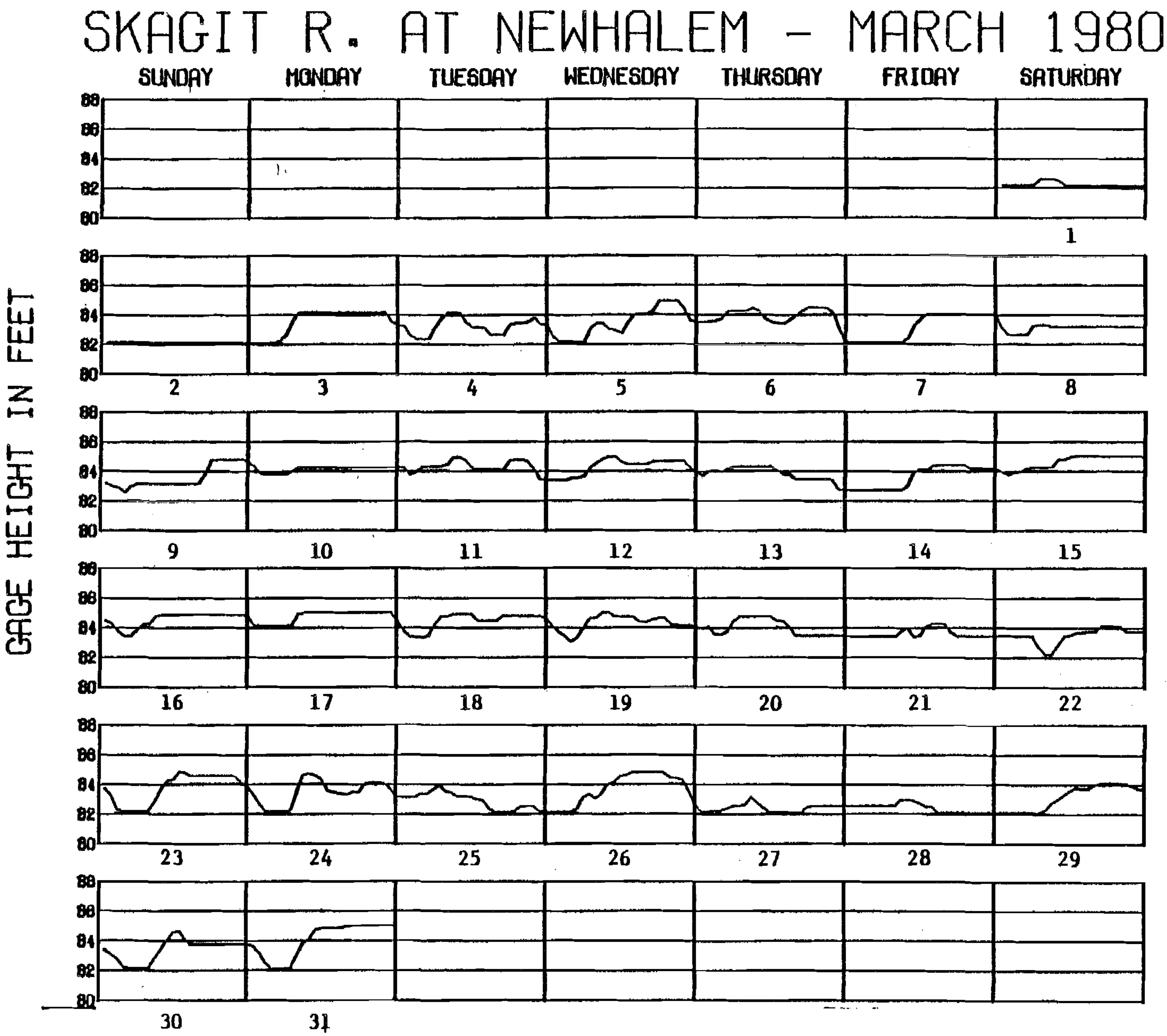

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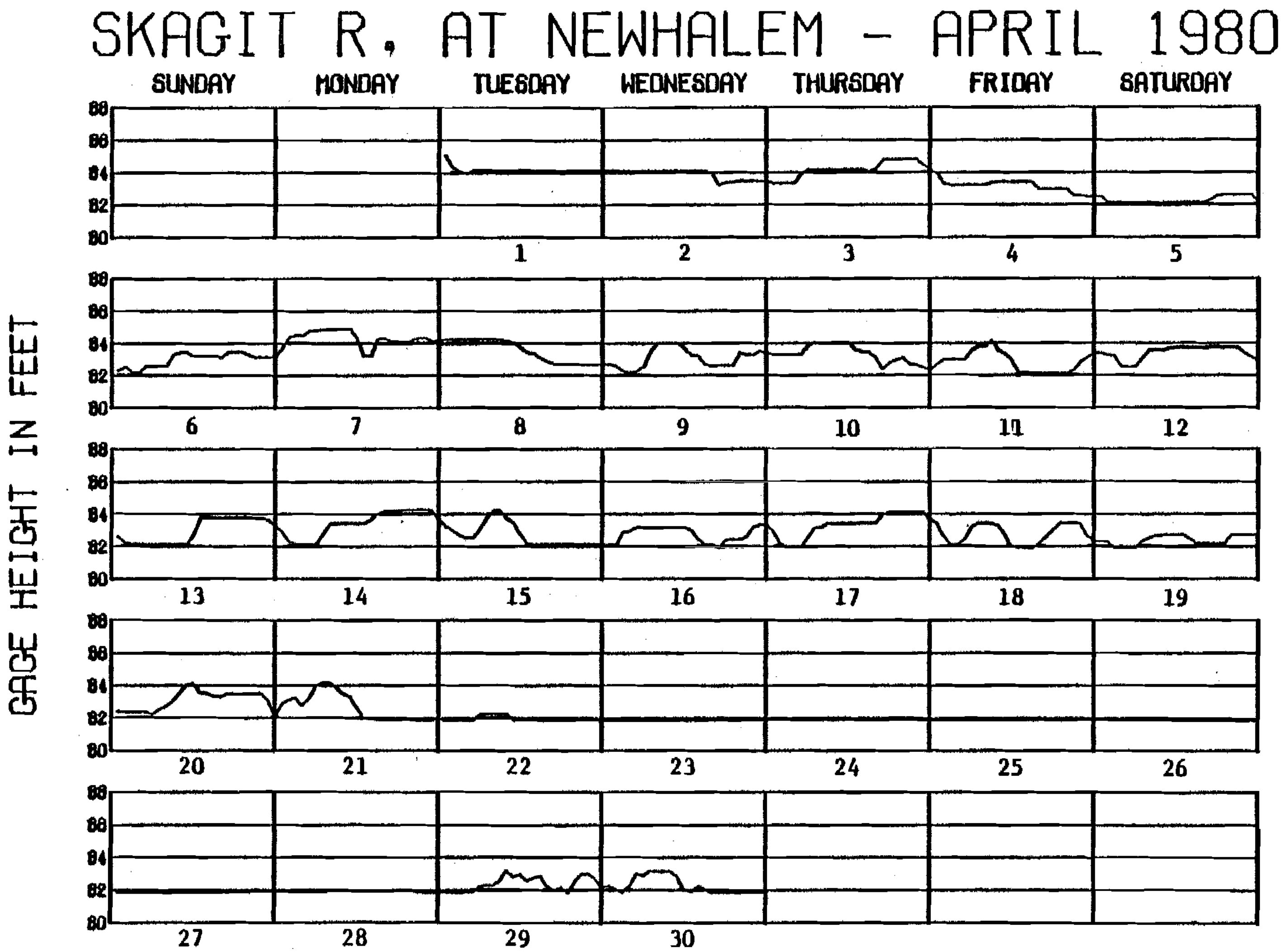
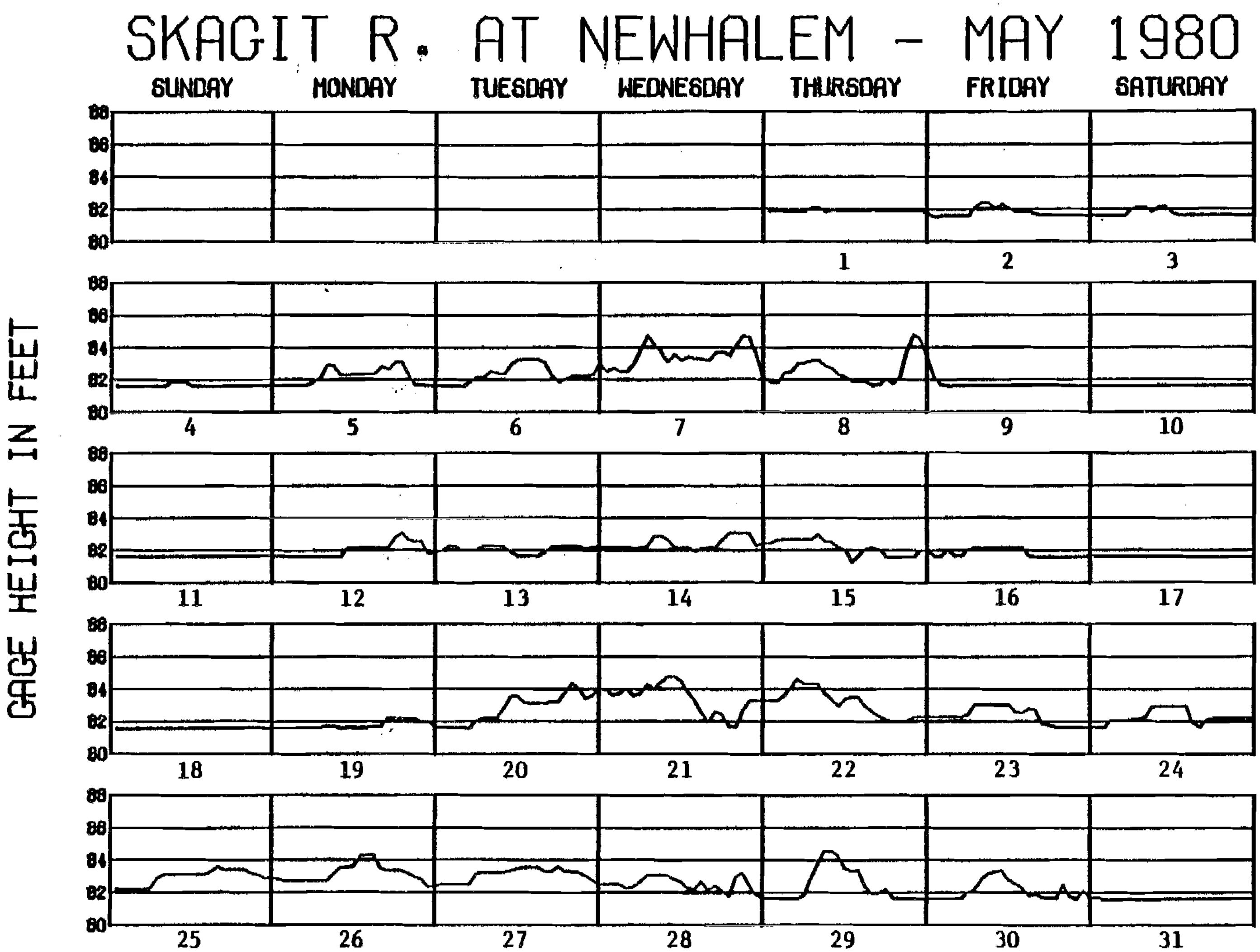


Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1980 (continued).



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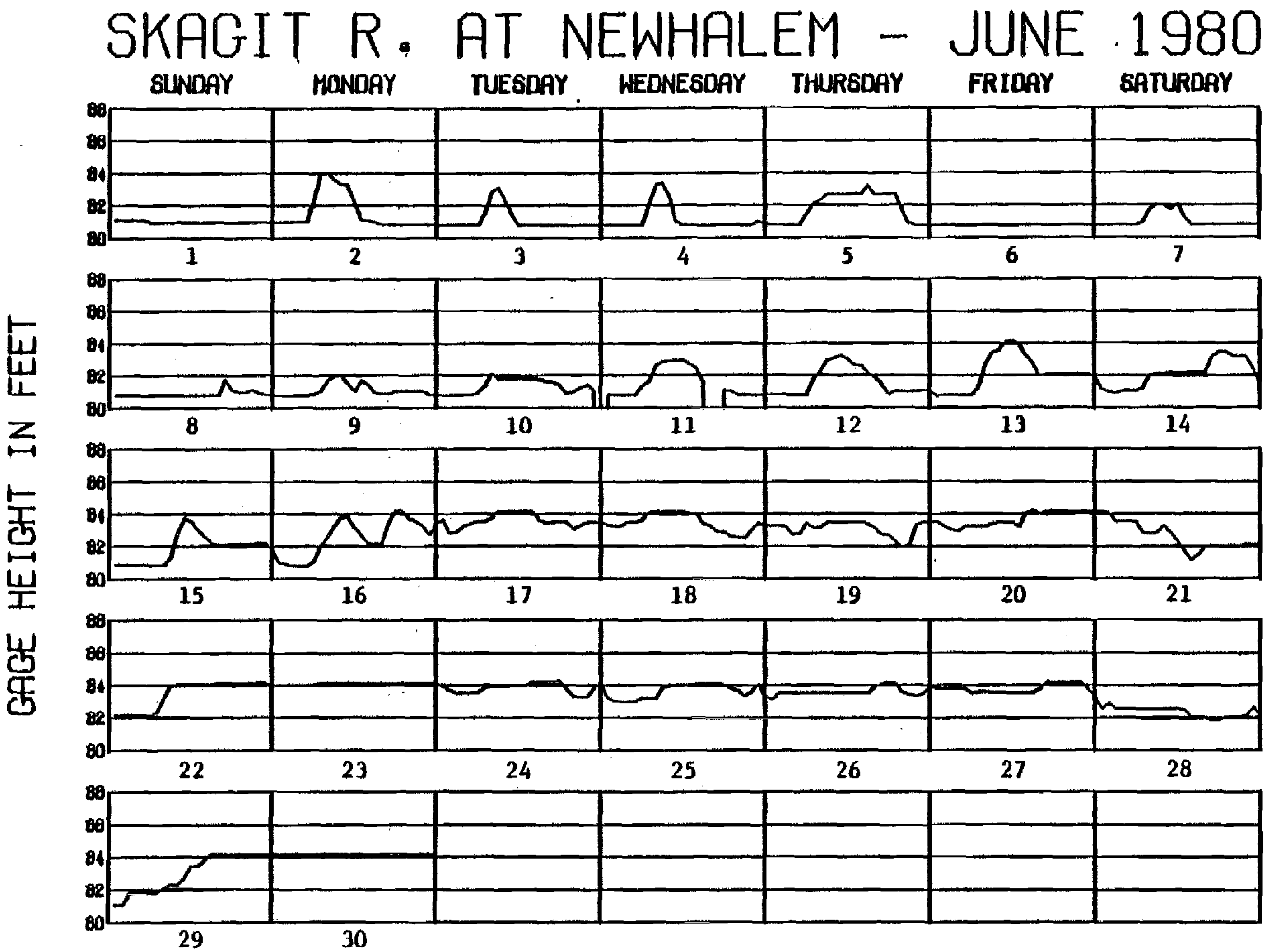

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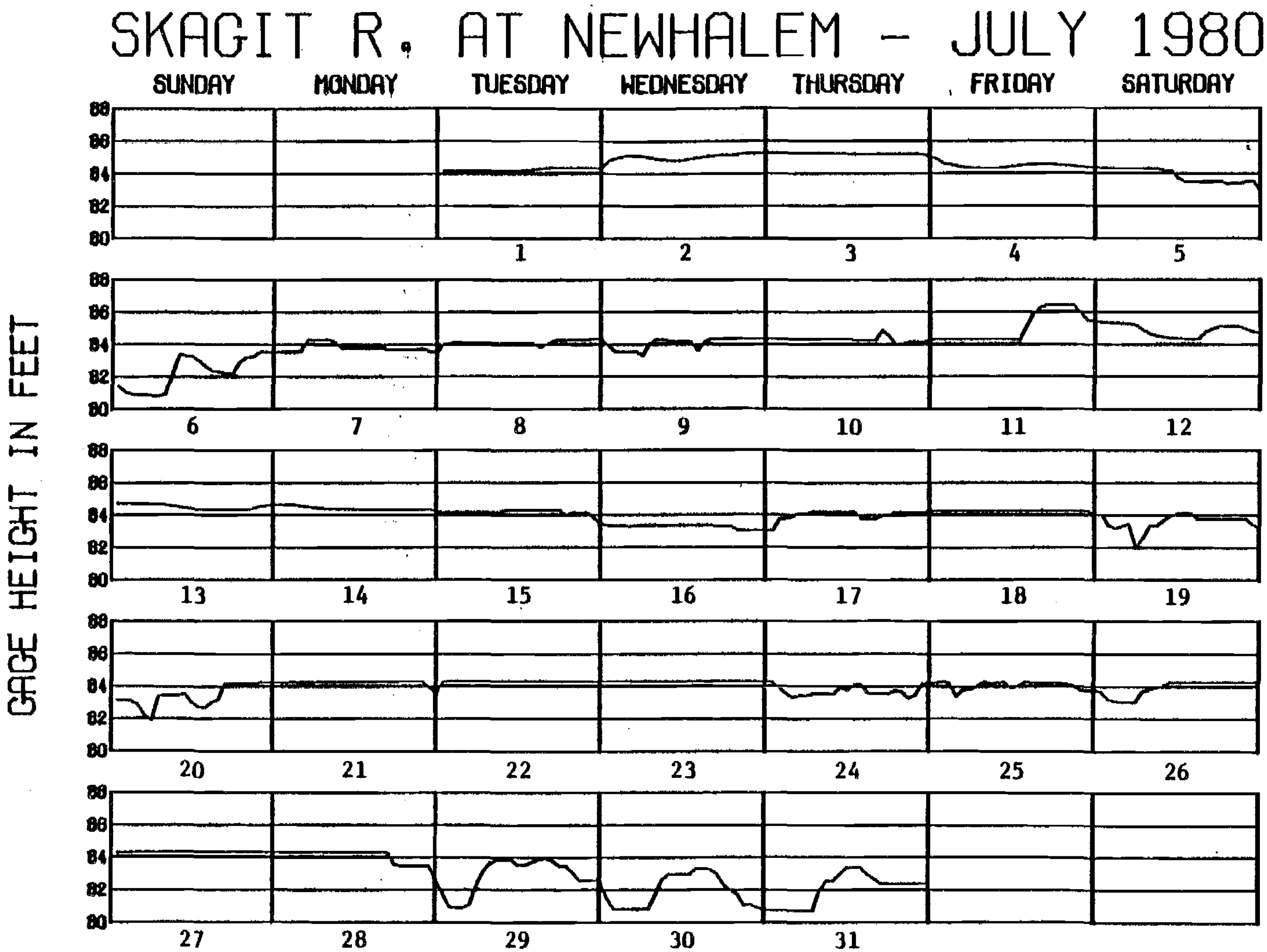
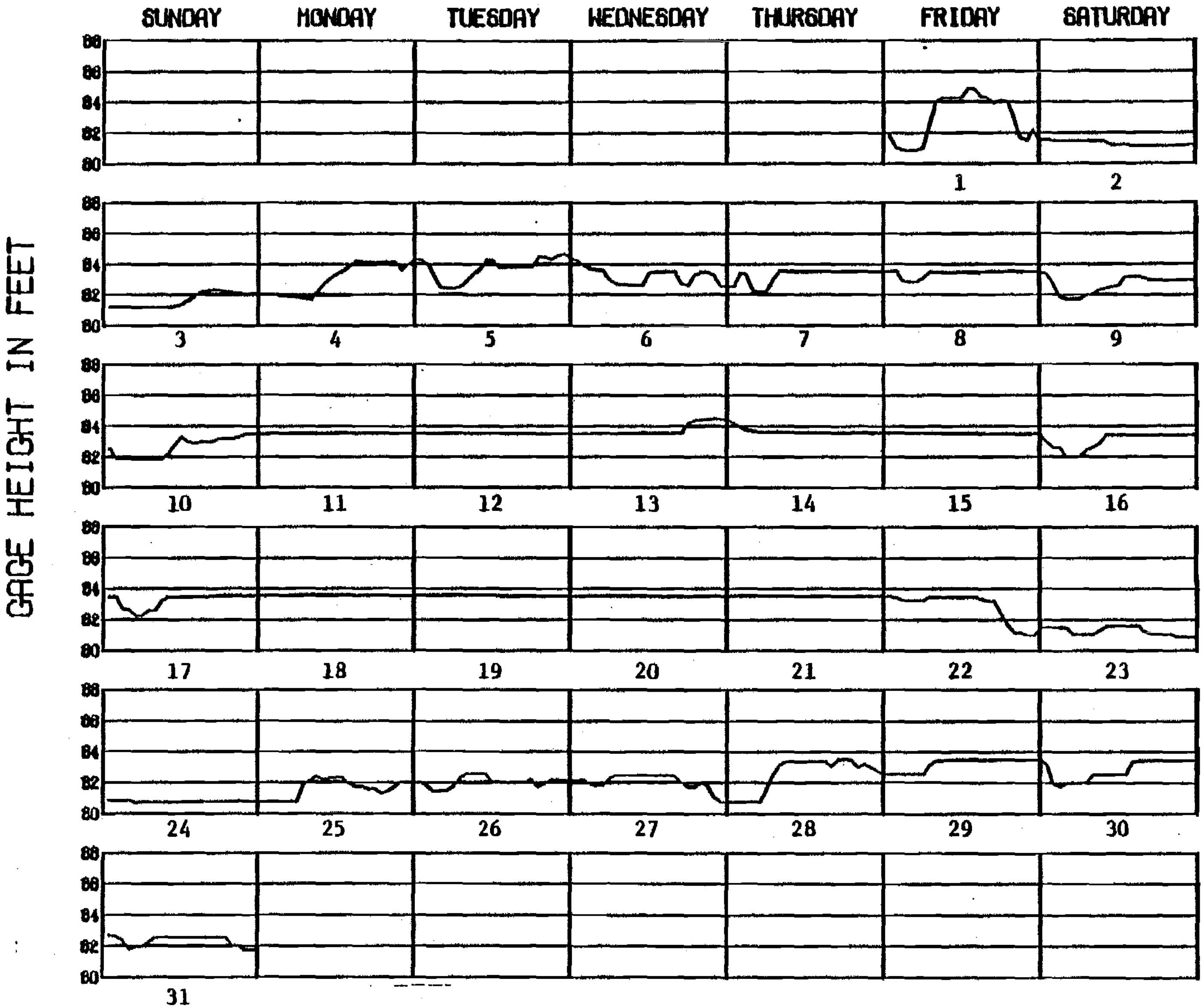
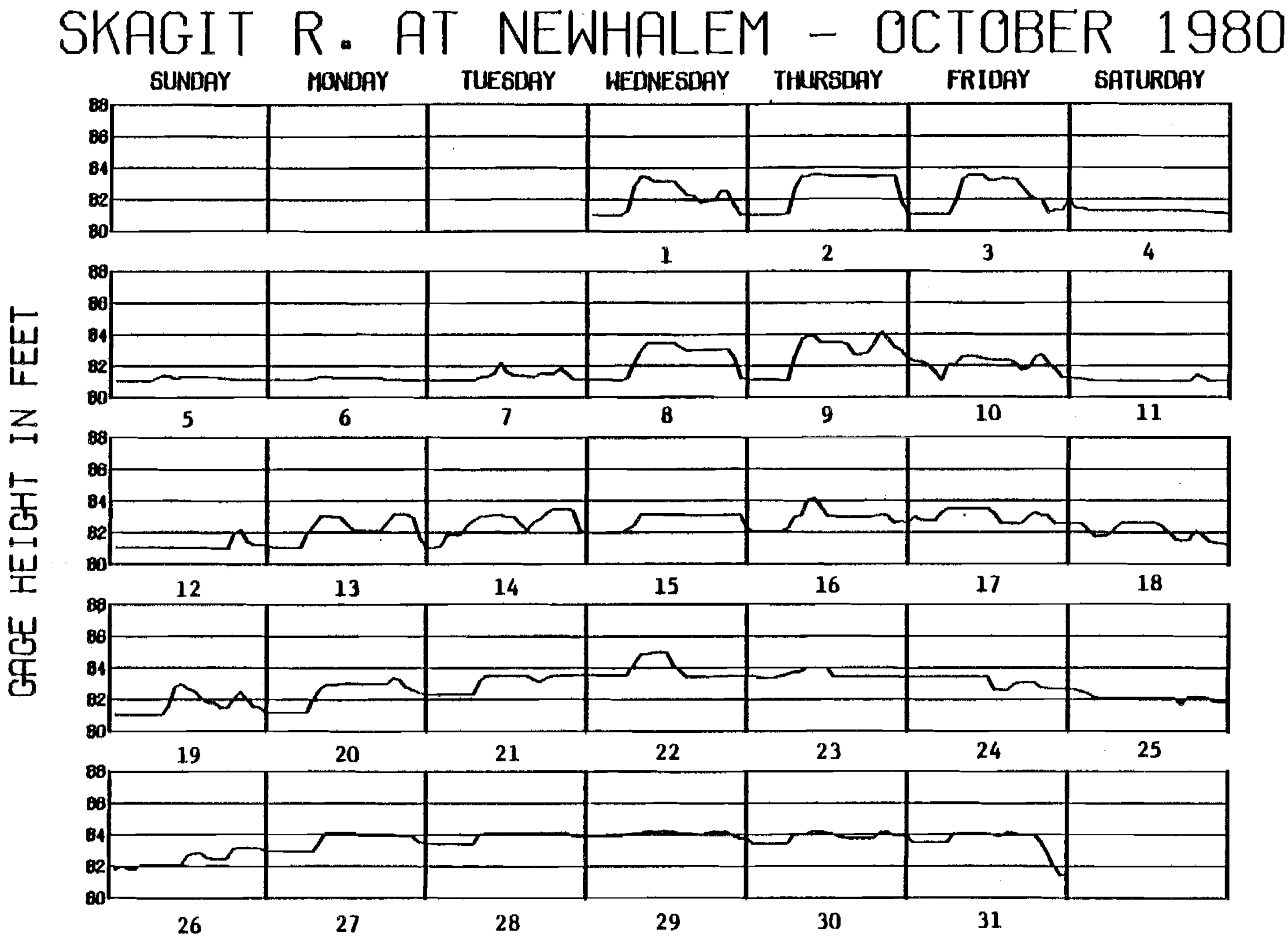


Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1980 (continued).

SKAGIT R. AT NEWHALEM - AUGUST 1980

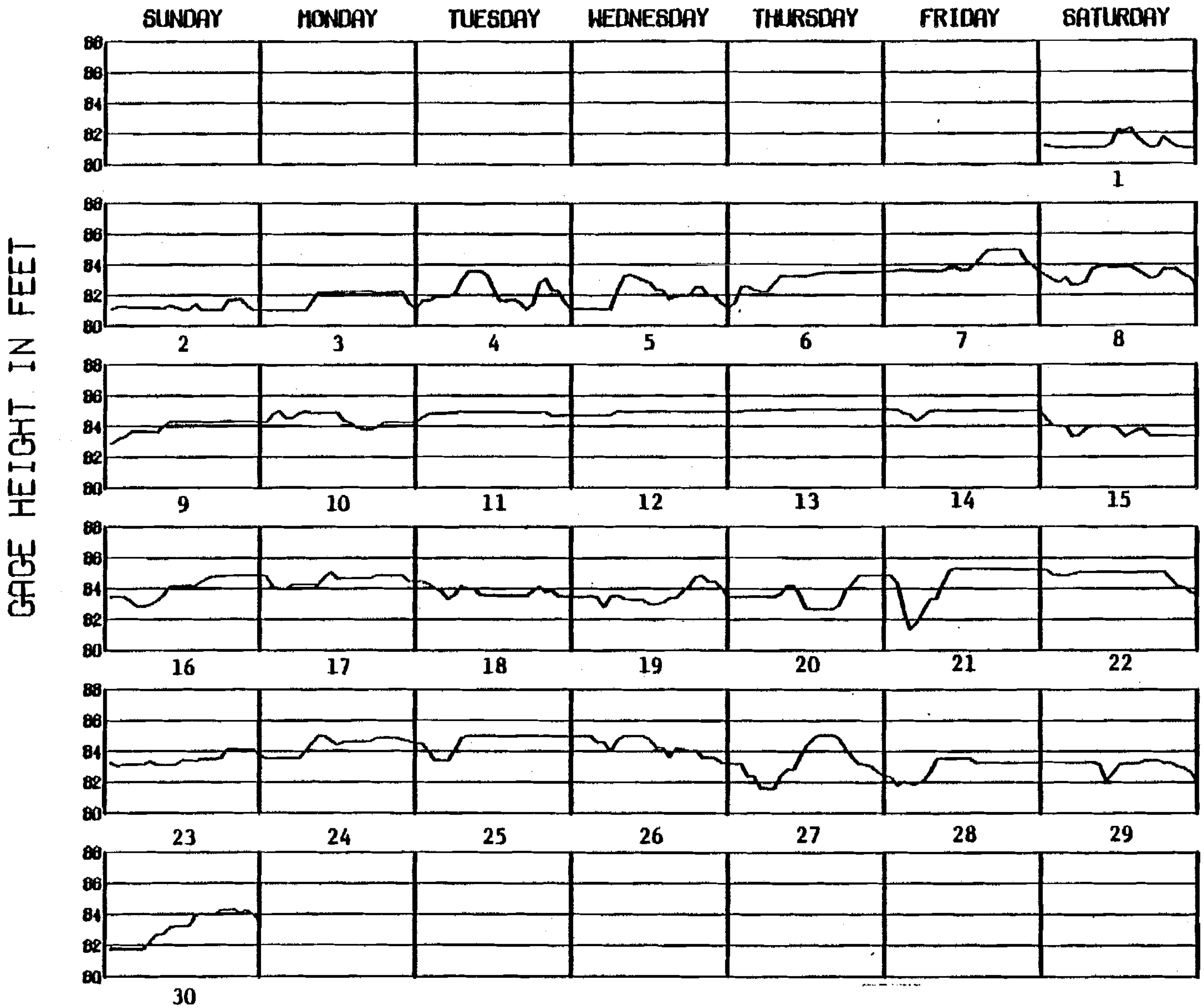


Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1980 (continued).

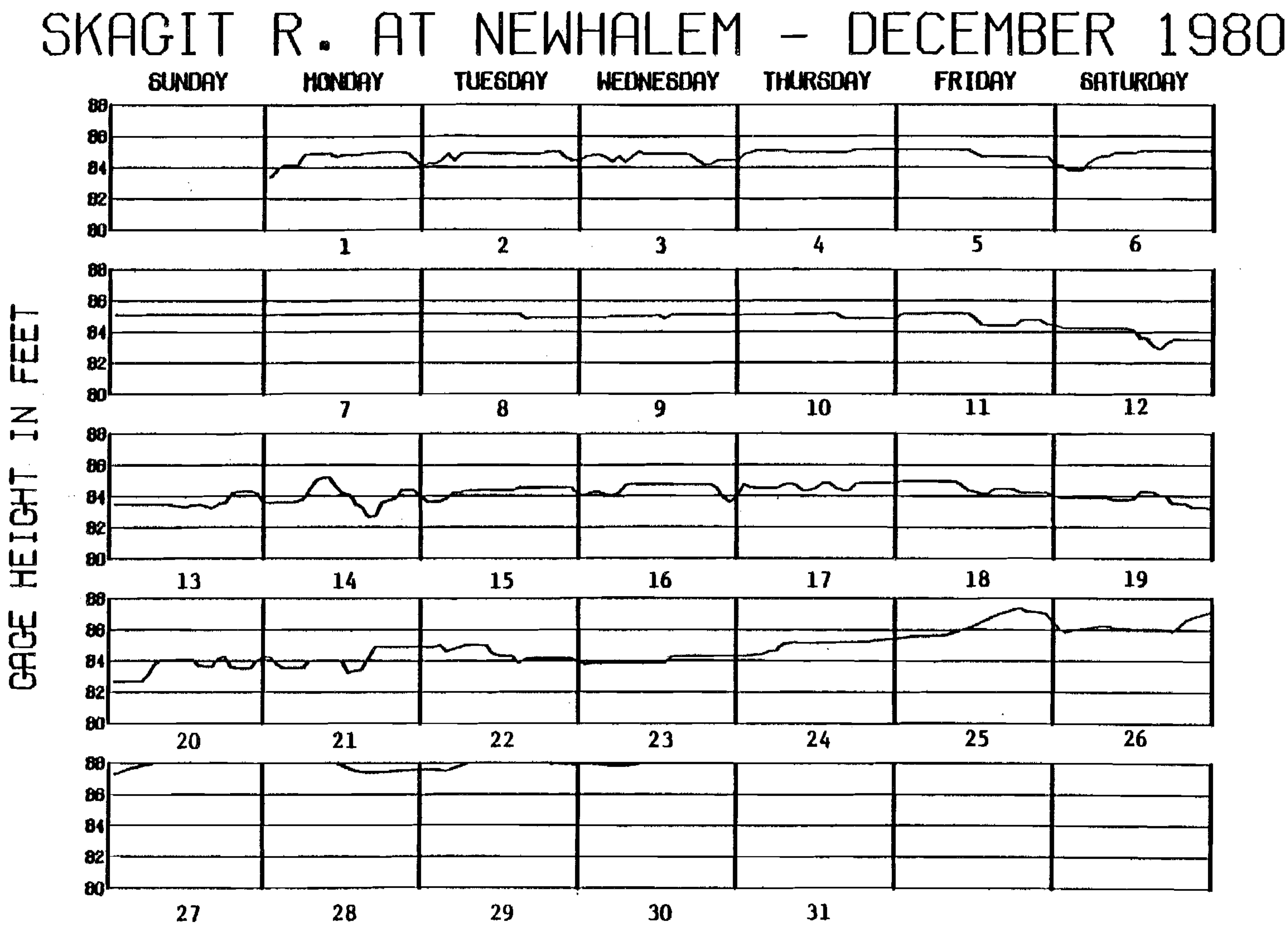


Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1980 (continued).

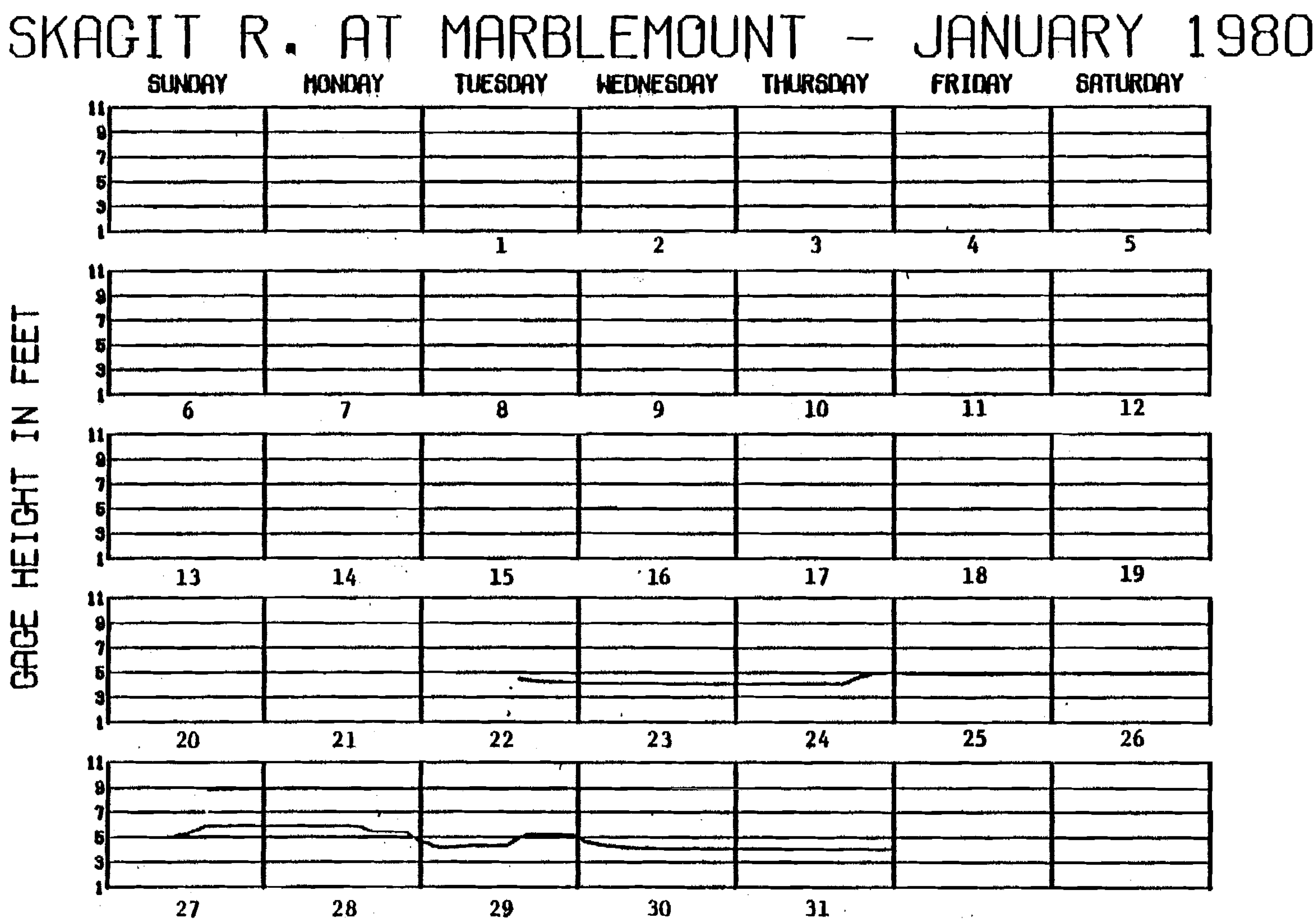
SKAGIT R. AT NEWHALEM - NOVEMBER 1980



Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1980 (continued).

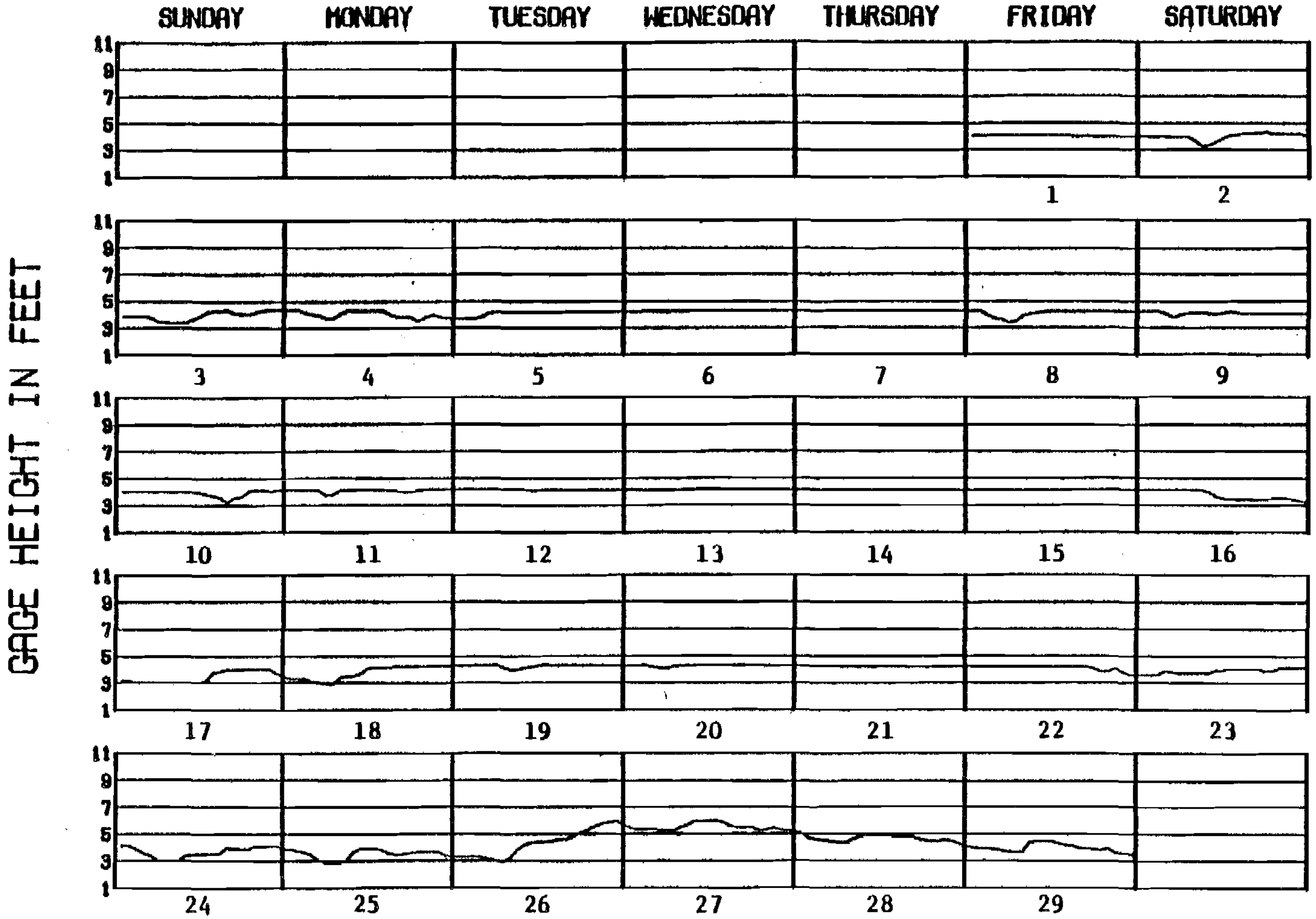


Appendix I, Figure 1. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1980 (continued).

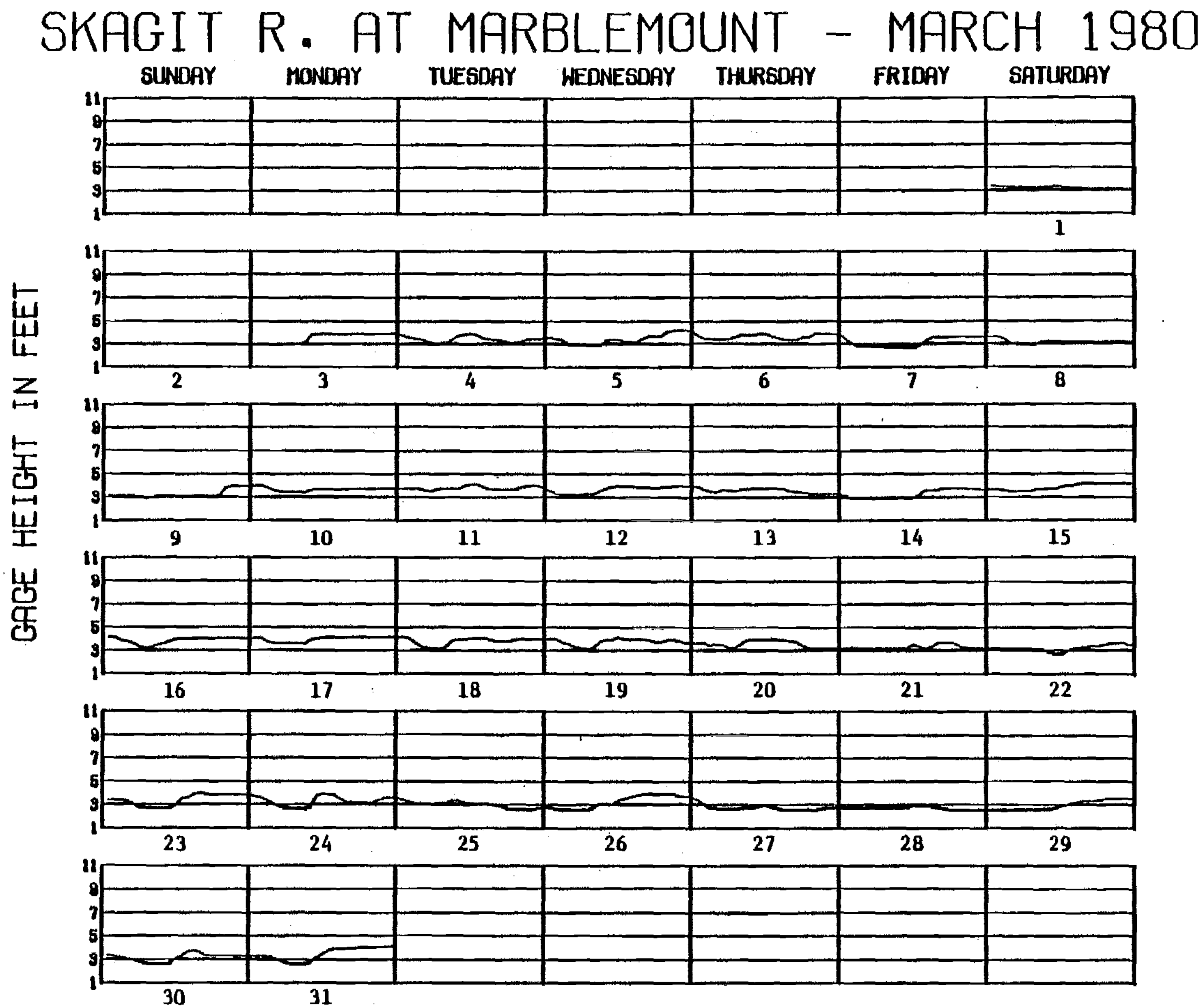


Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980.

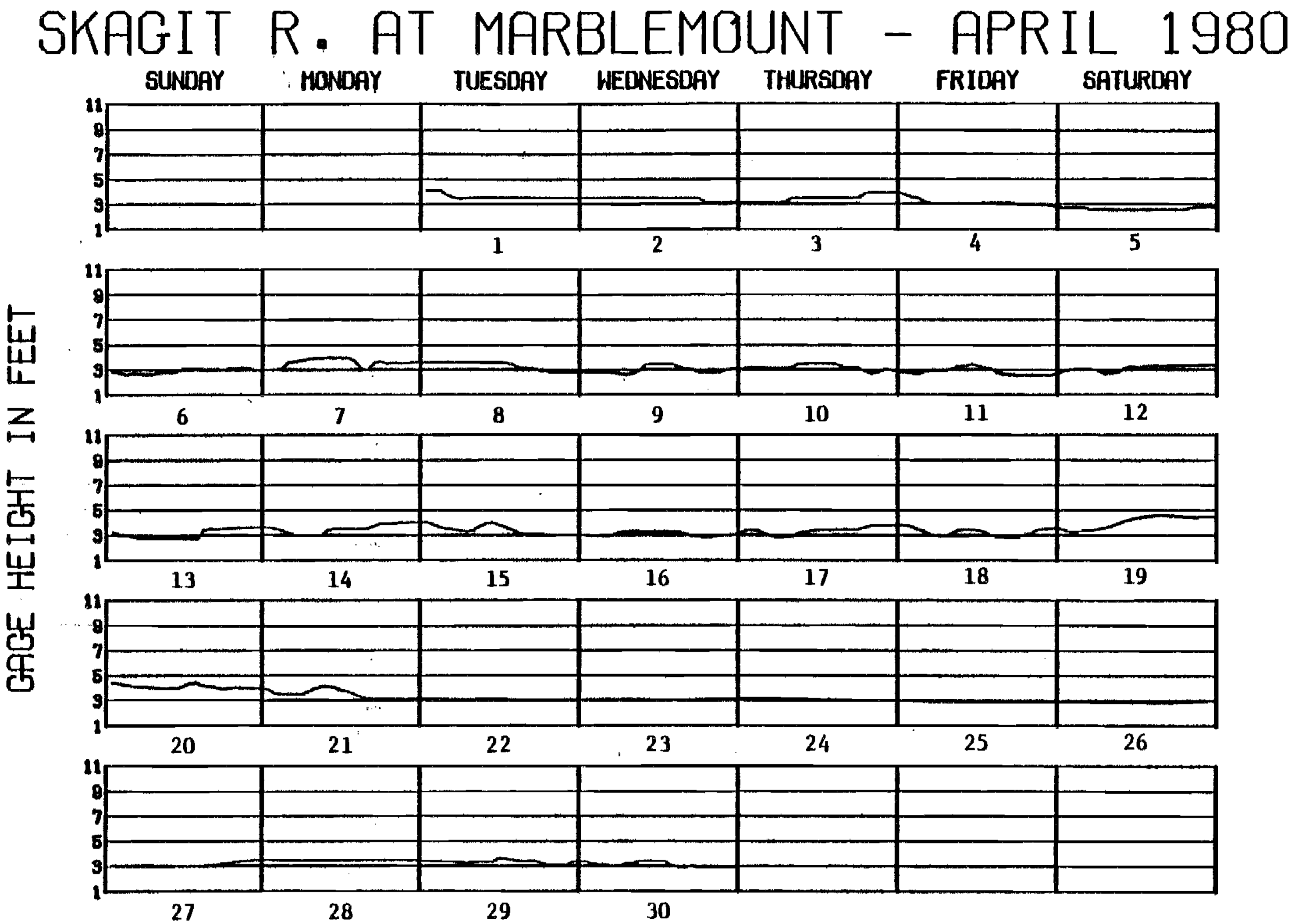
SKAGIT R. AT MARBLEMOUNT - FEBRUARY 1980



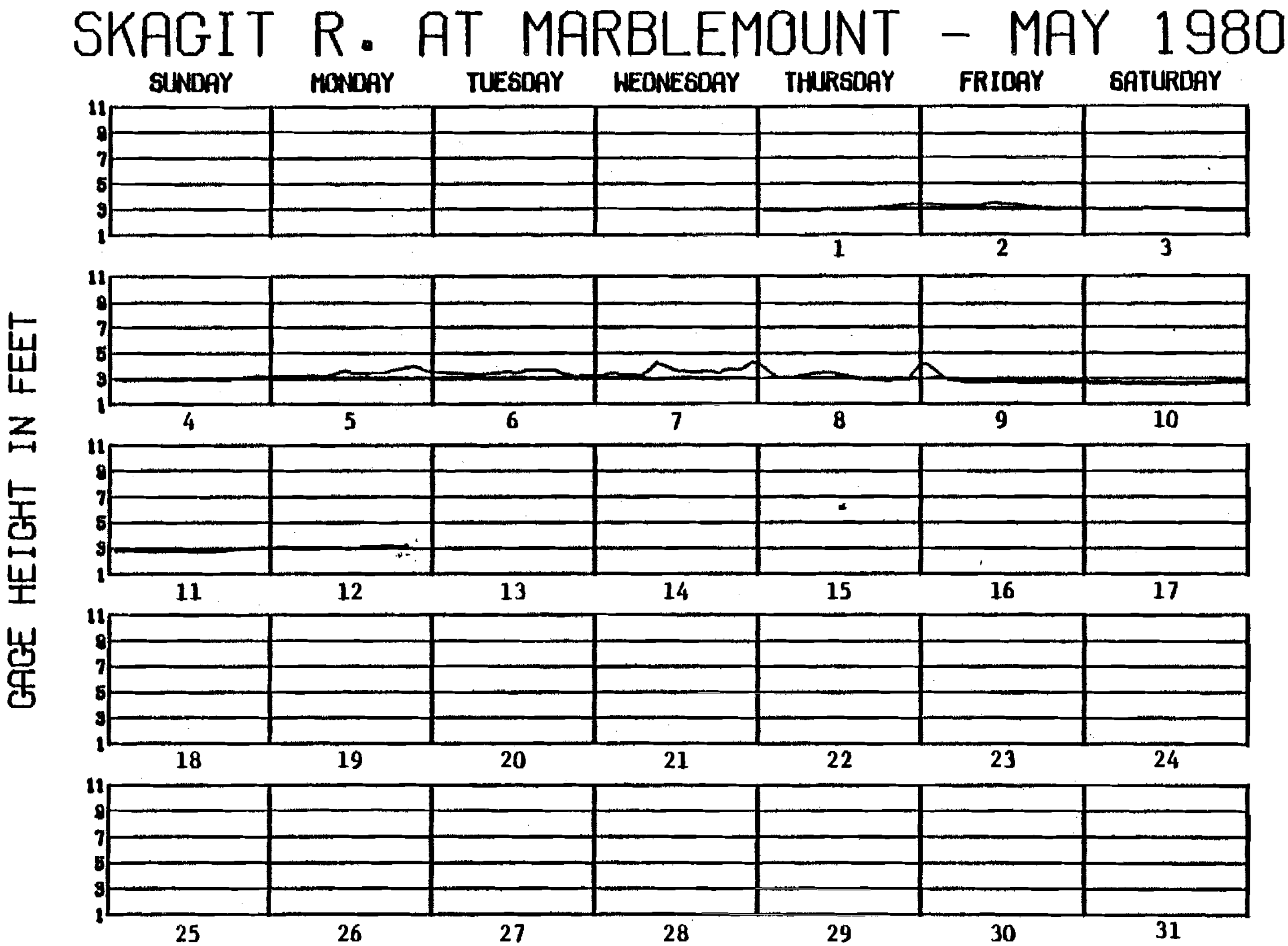
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).



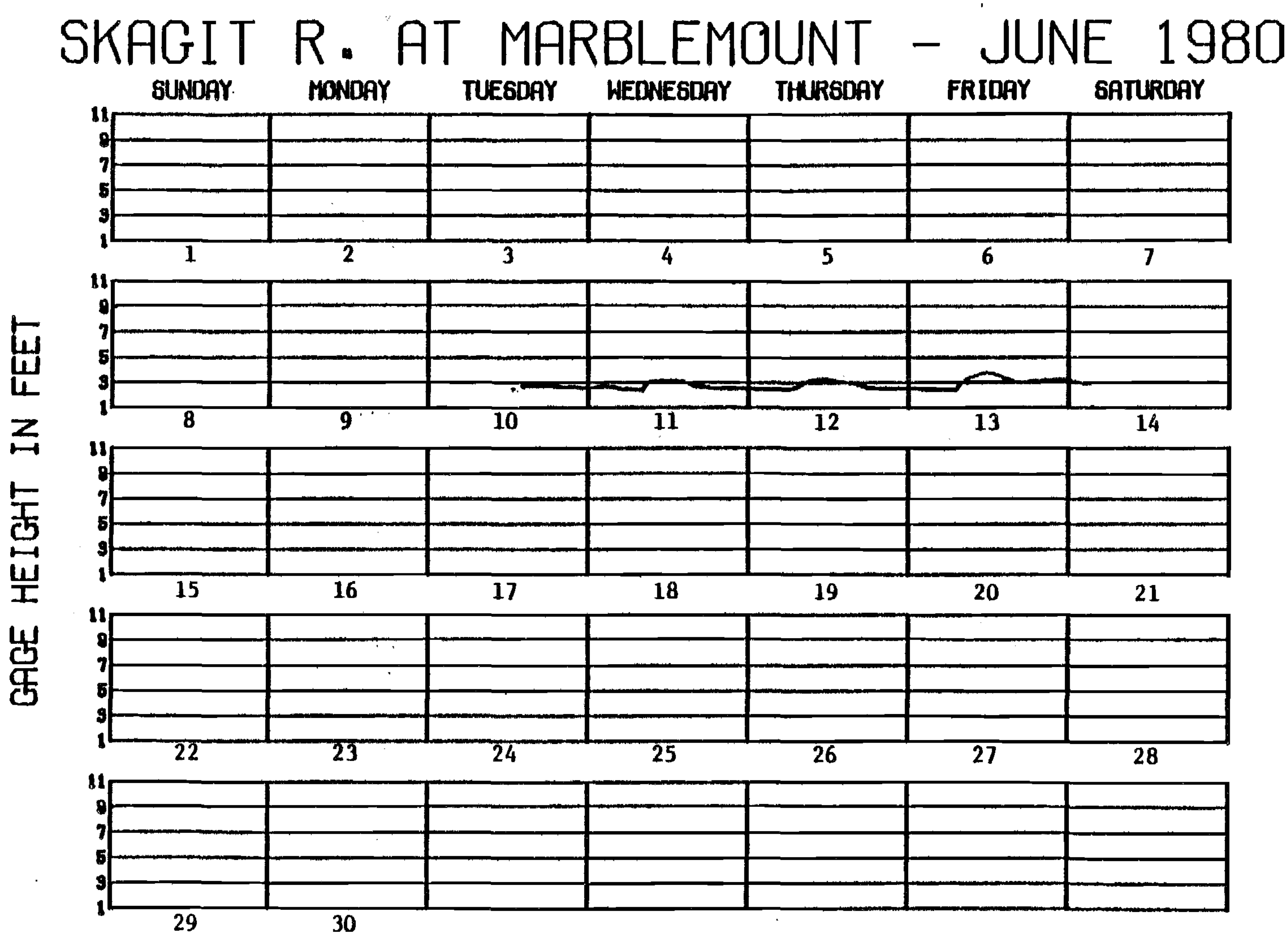
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).



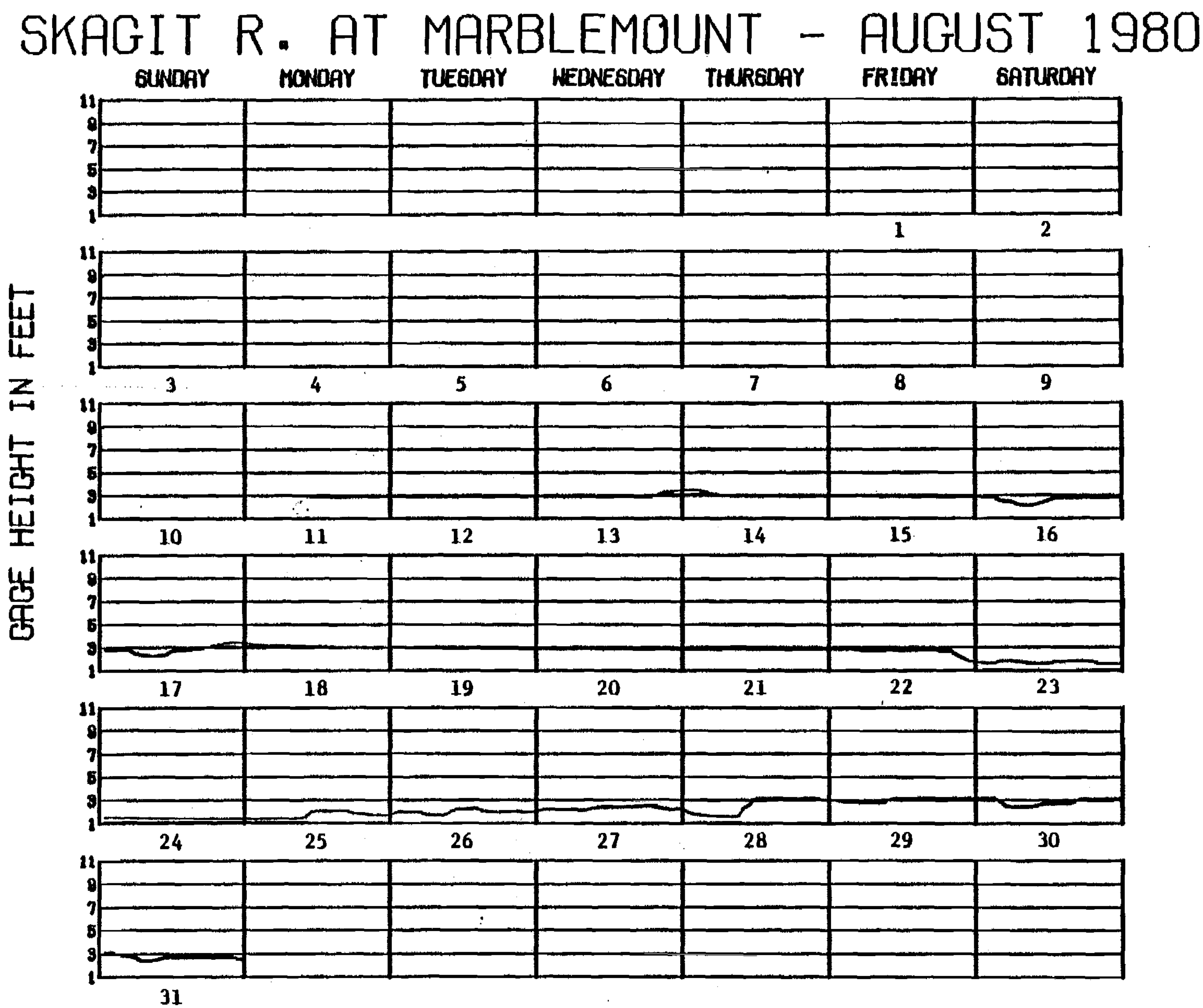
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).



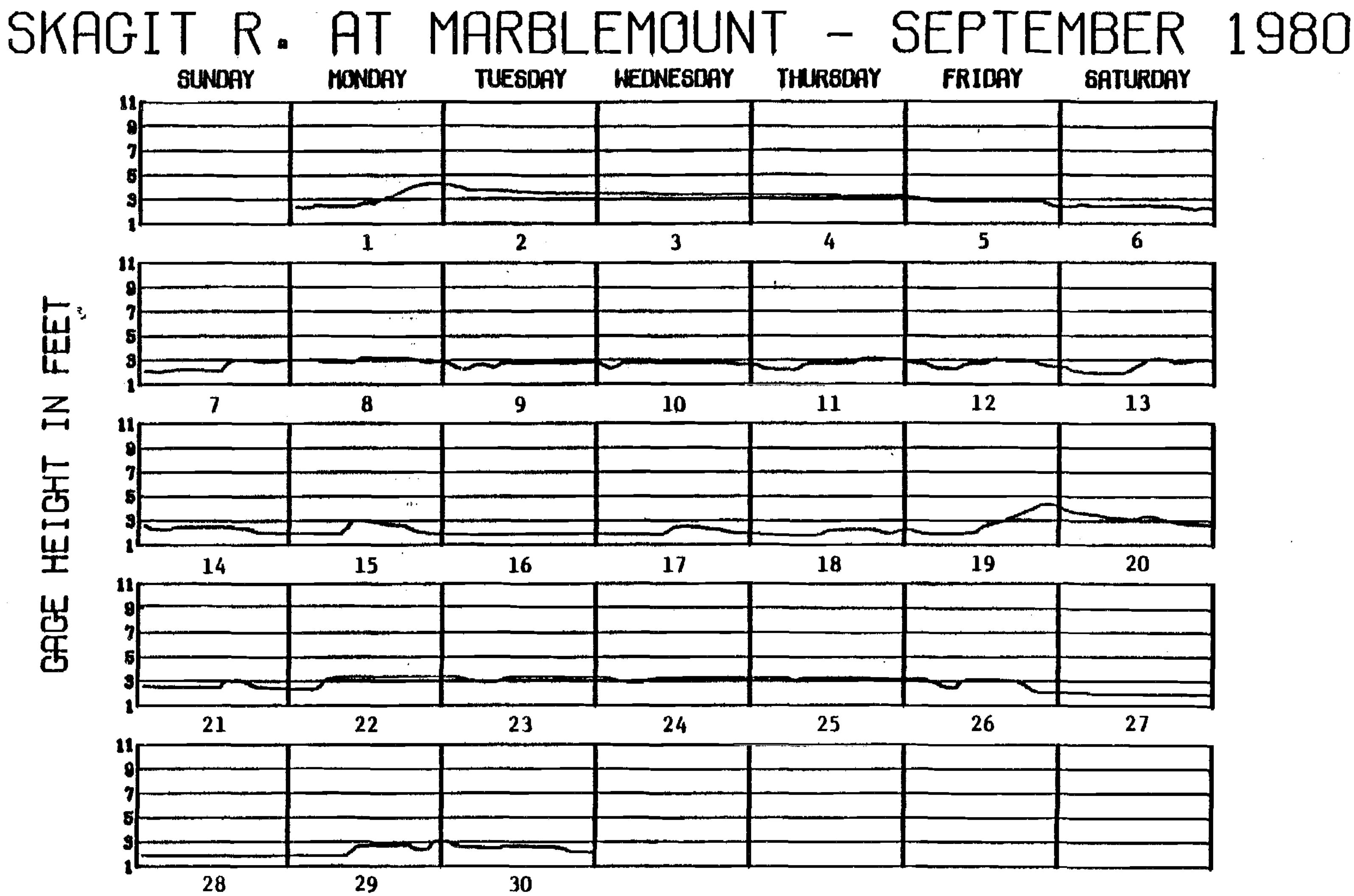
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).



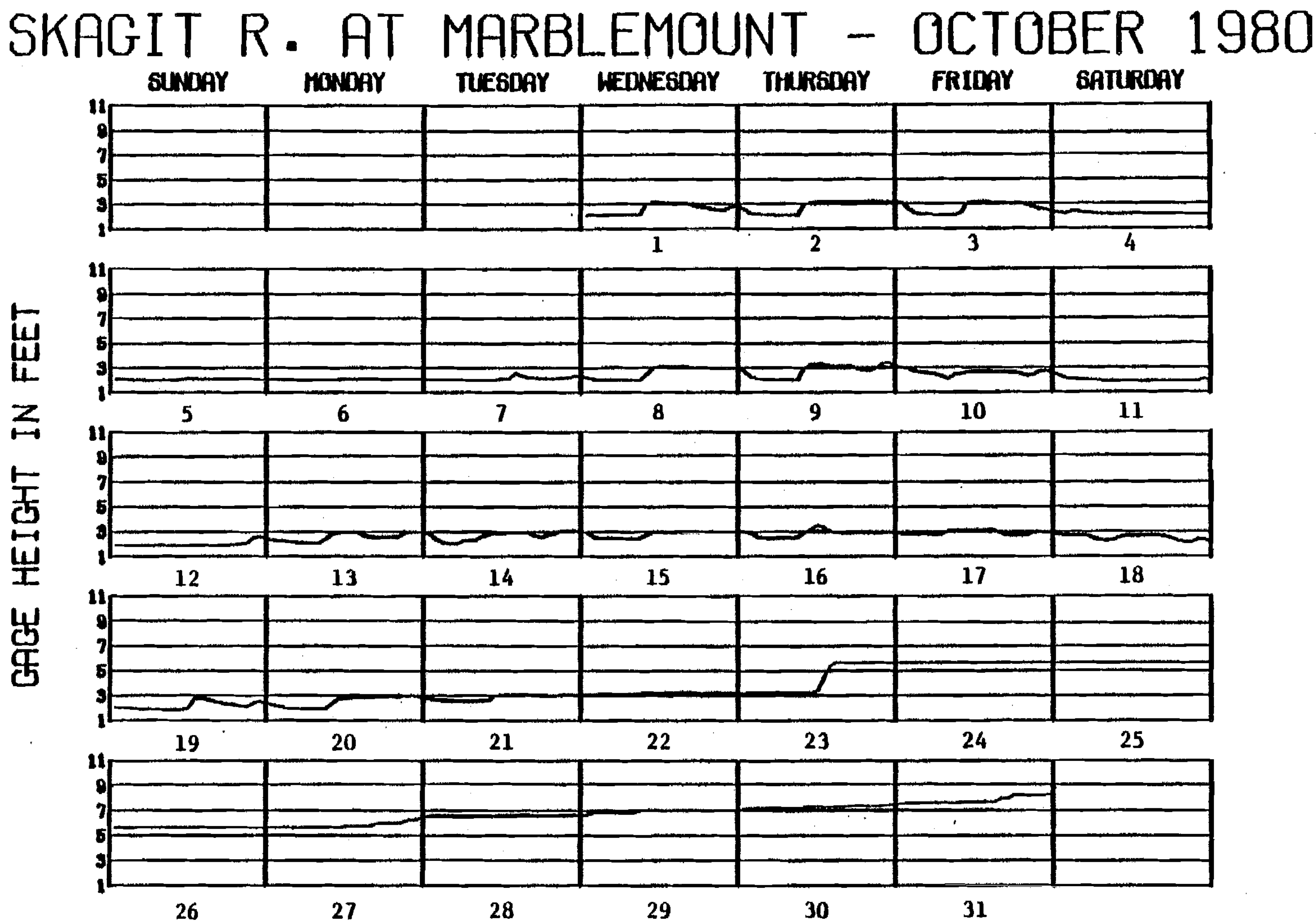
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).



Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).

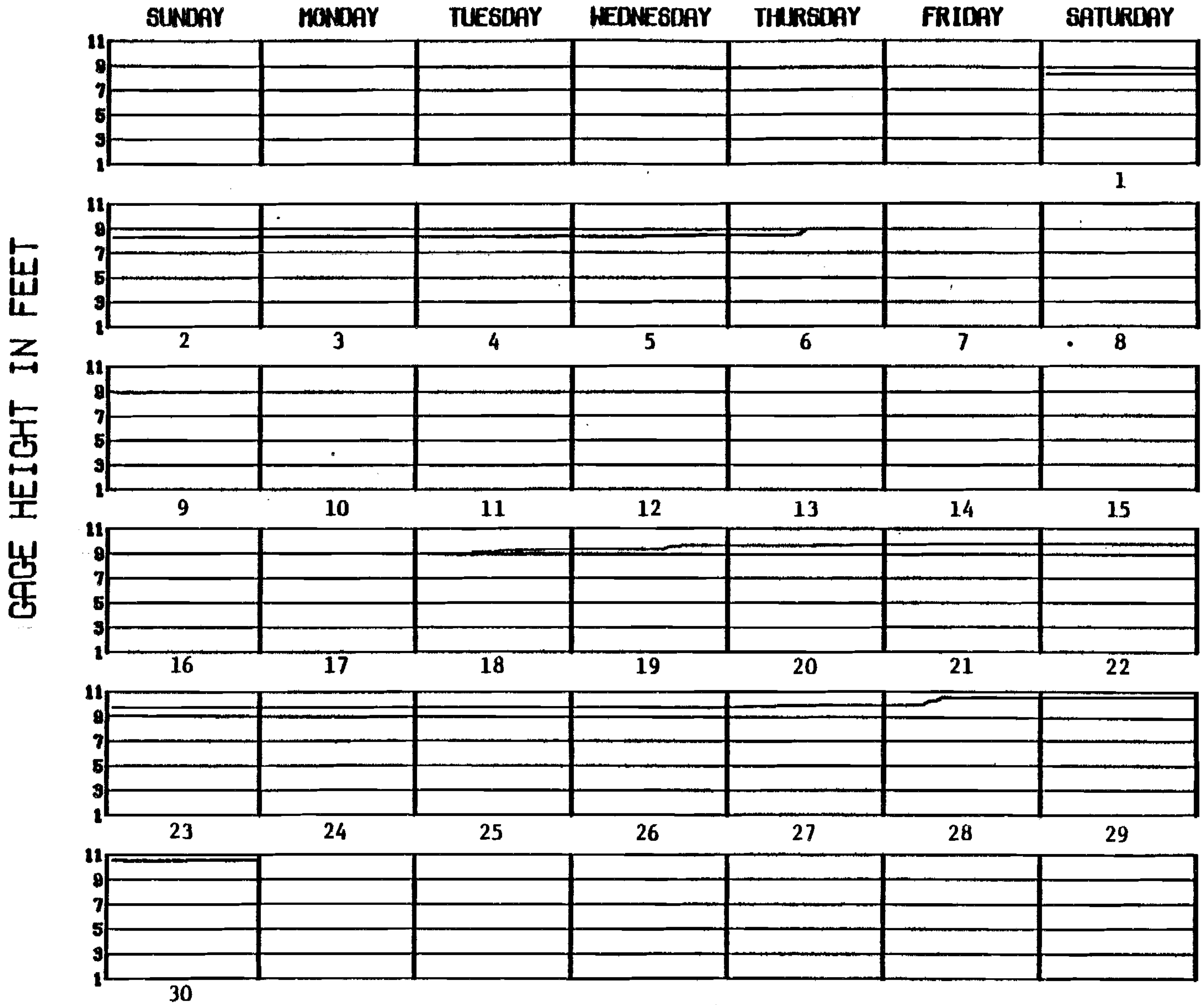


Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).



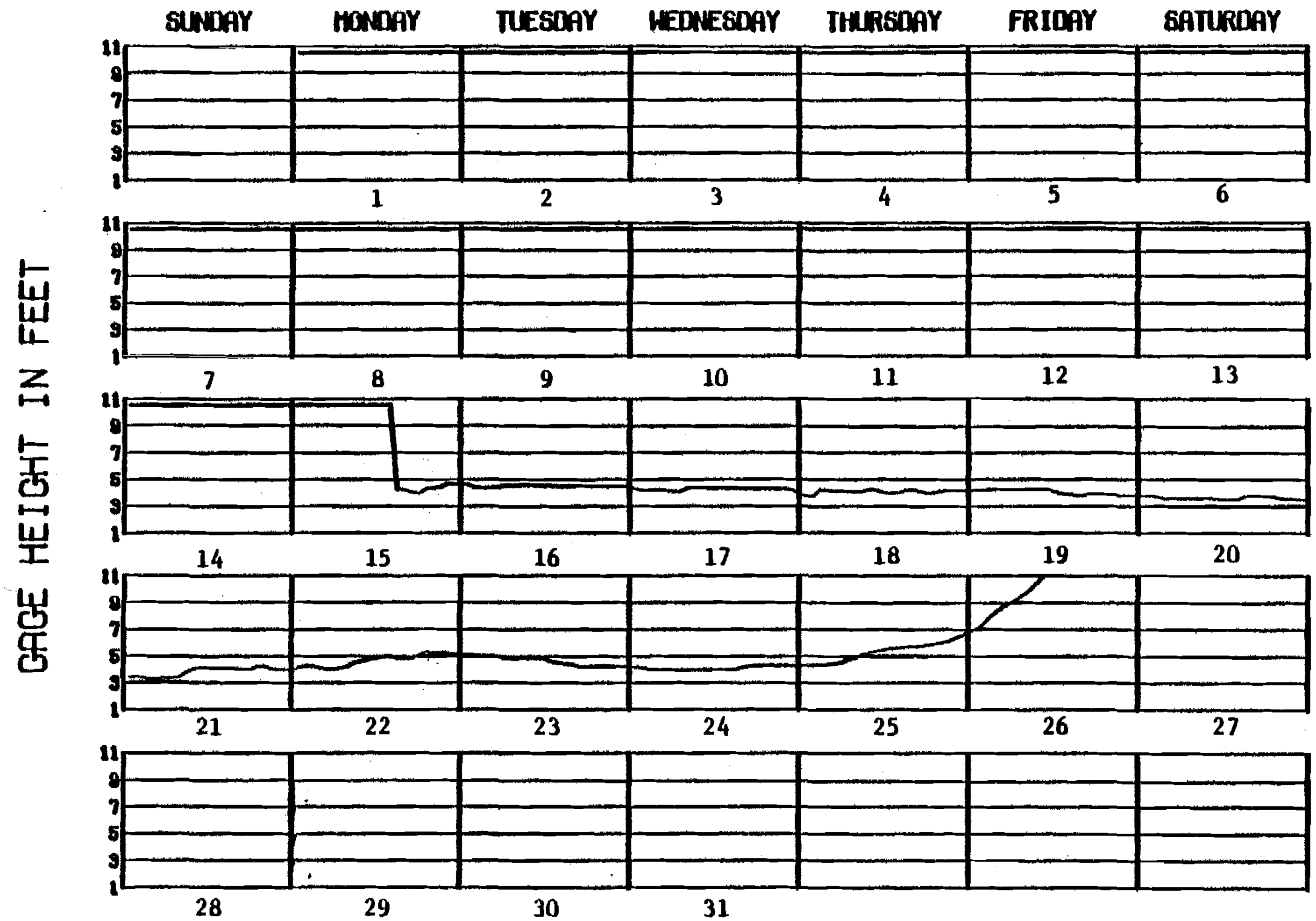
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).

SKAGIT R. AT MARBLEMOUNT - NOVEMBER 1980



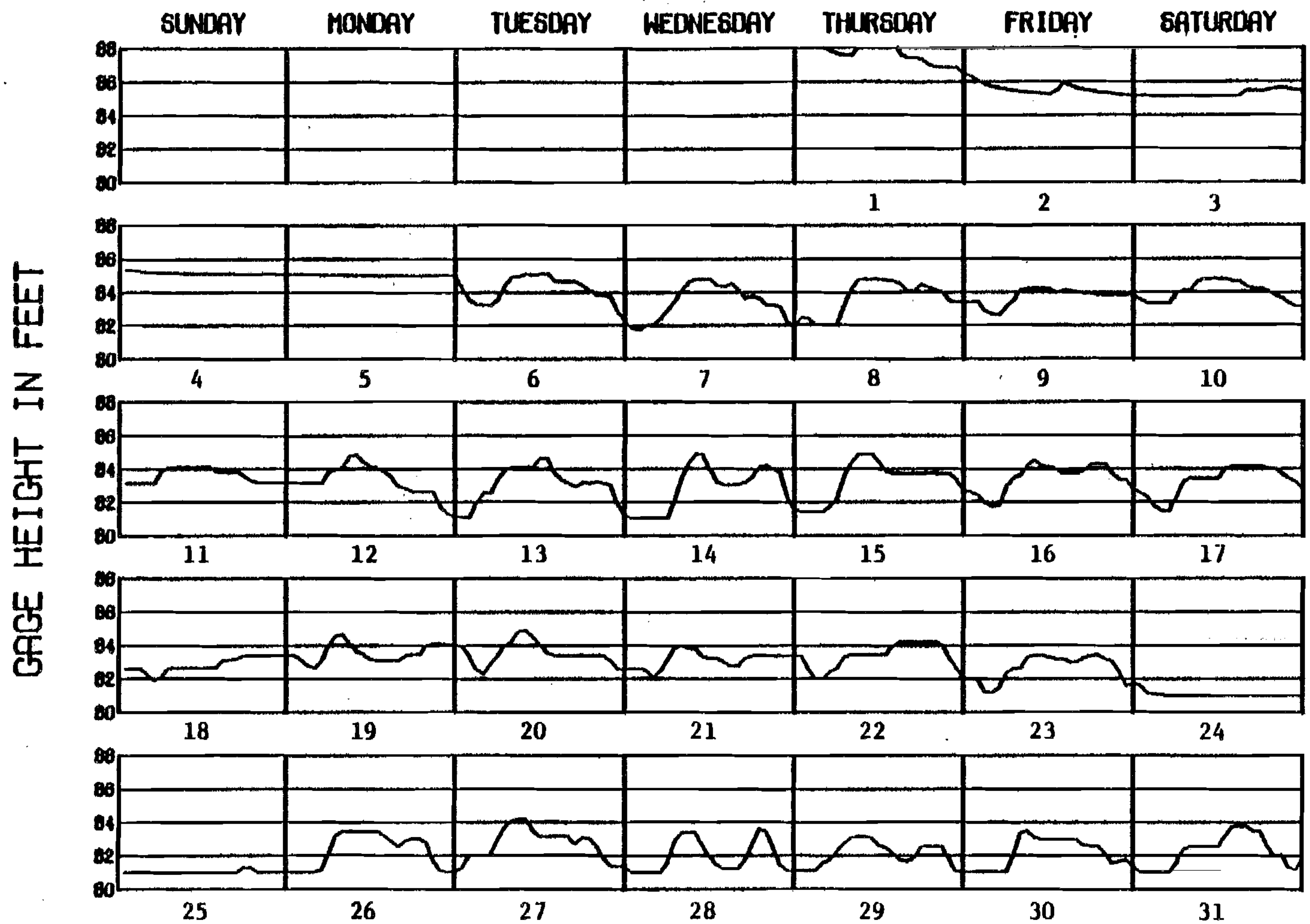
Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).

SKAGIT R. AT MARBLEMOUNT - DECEMBER 1980



Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980 (continued).

SKAGIT R. AT NEWHALEM - JANUARY 1981



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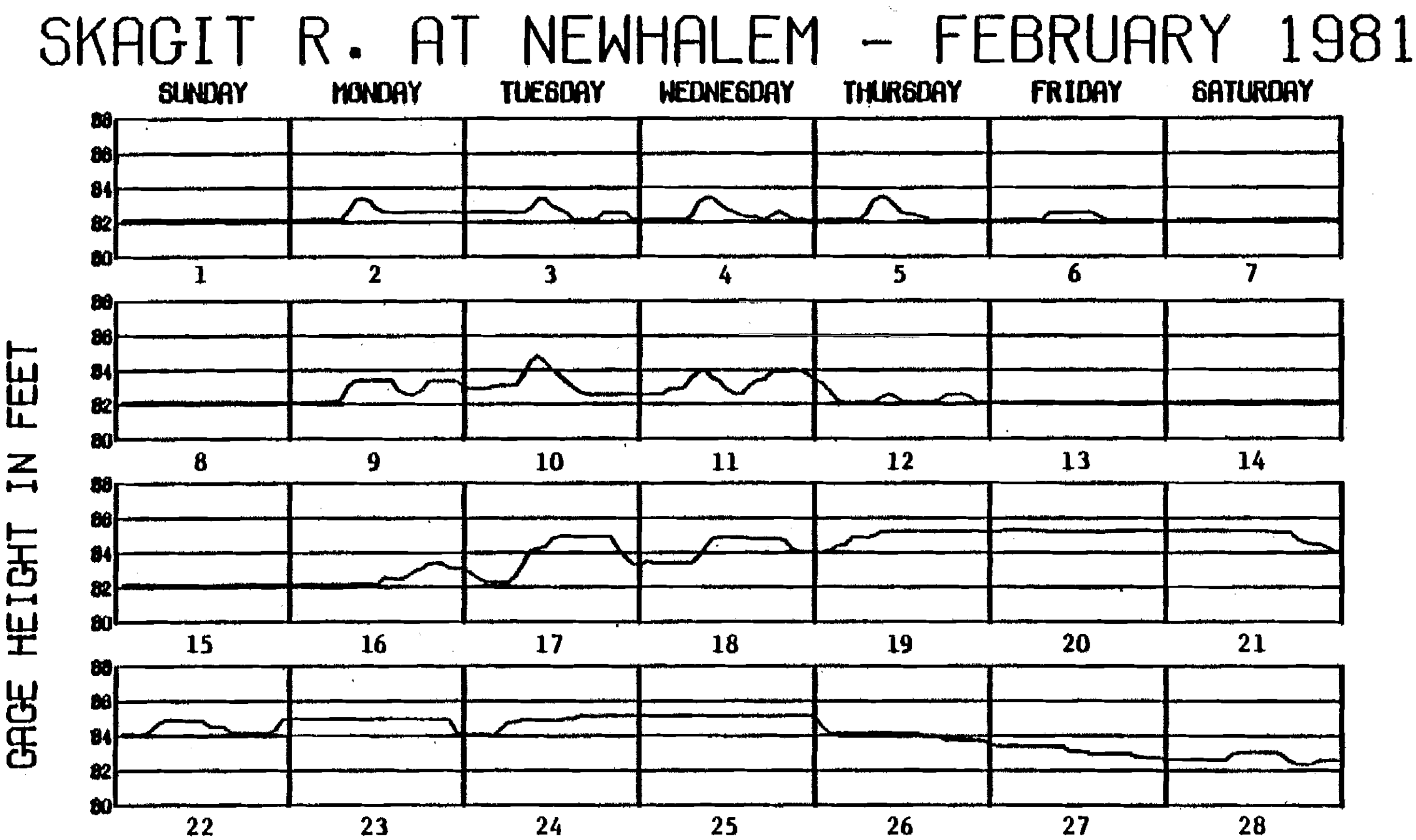
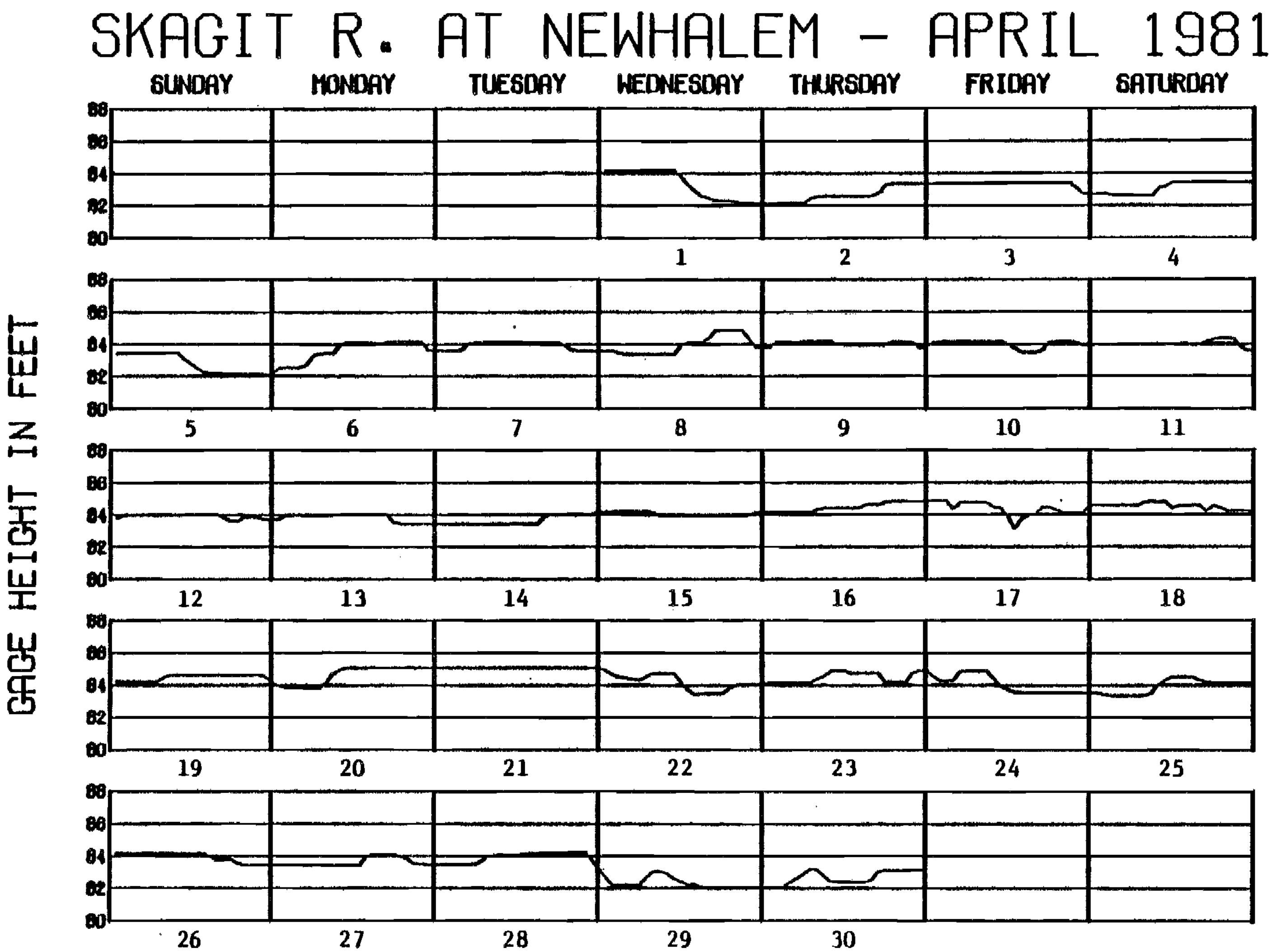


Appendix I, Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (continued).



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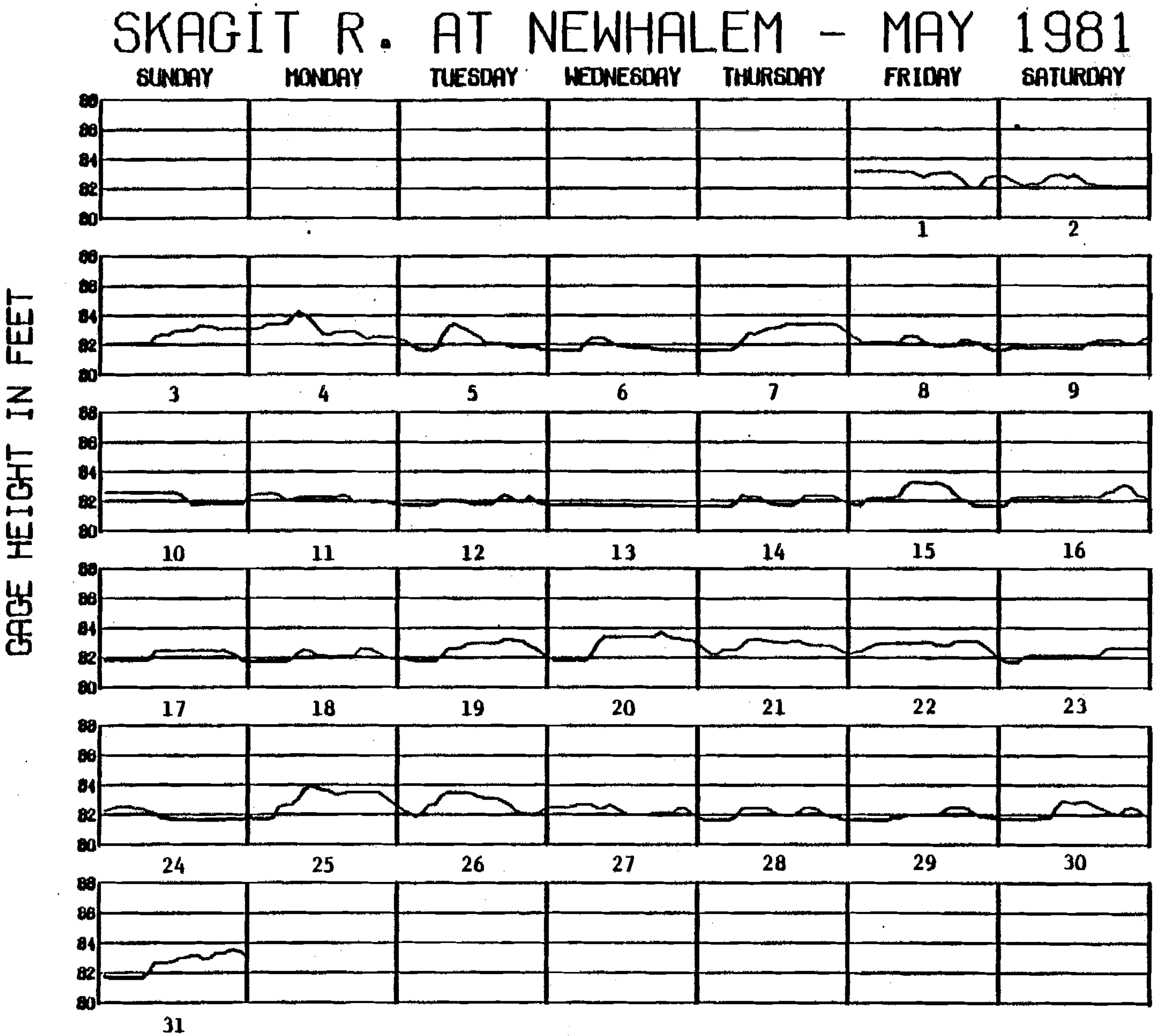
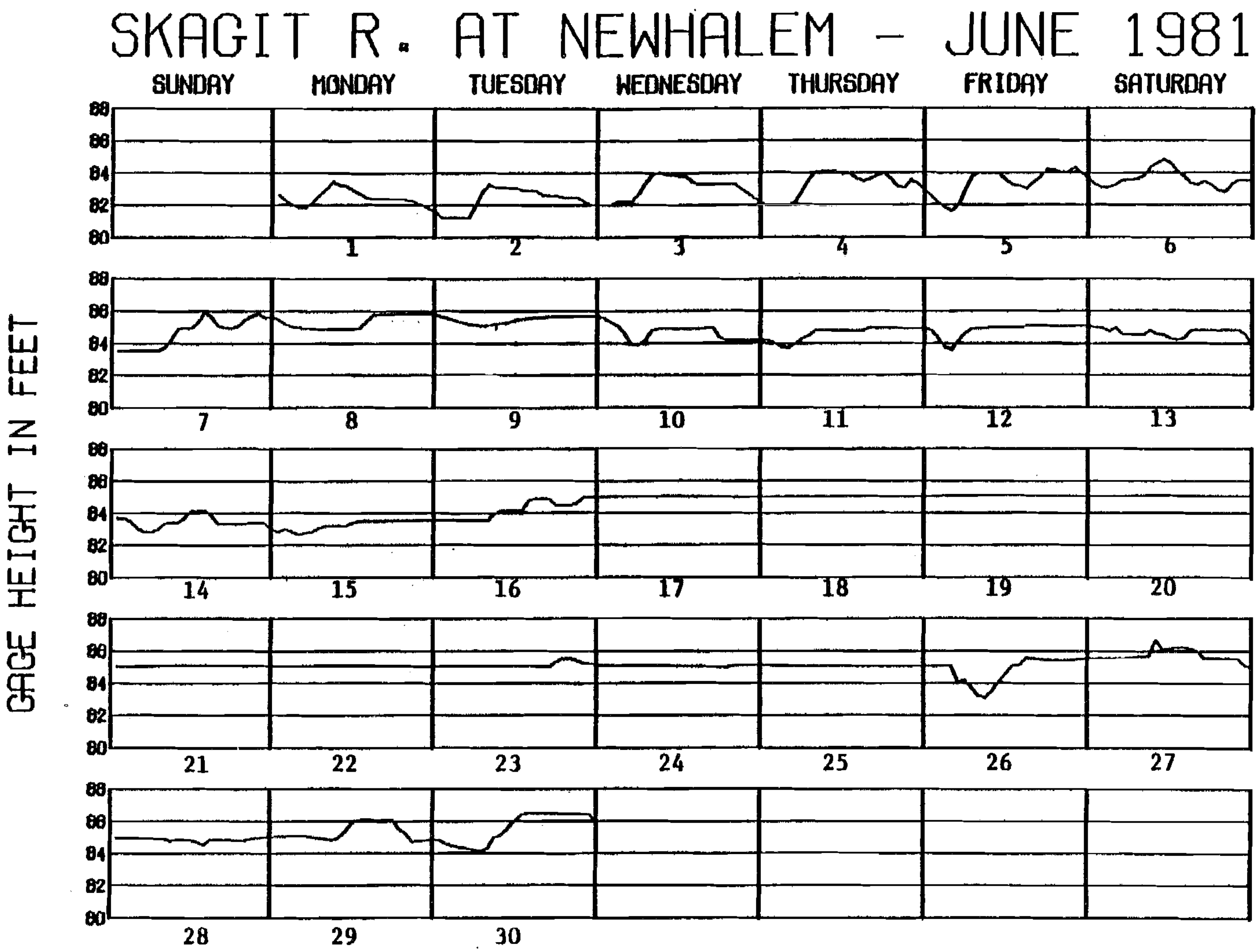
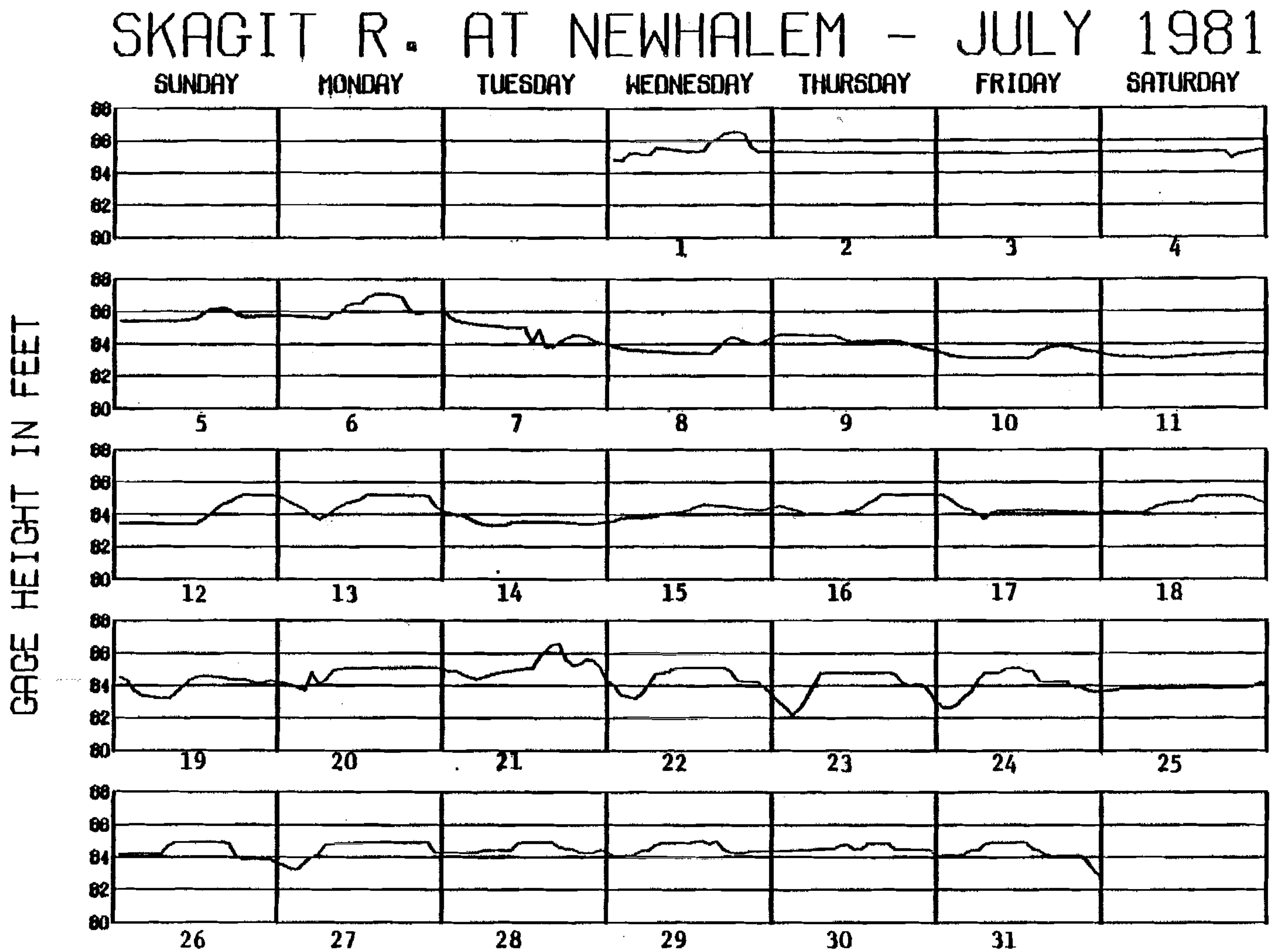


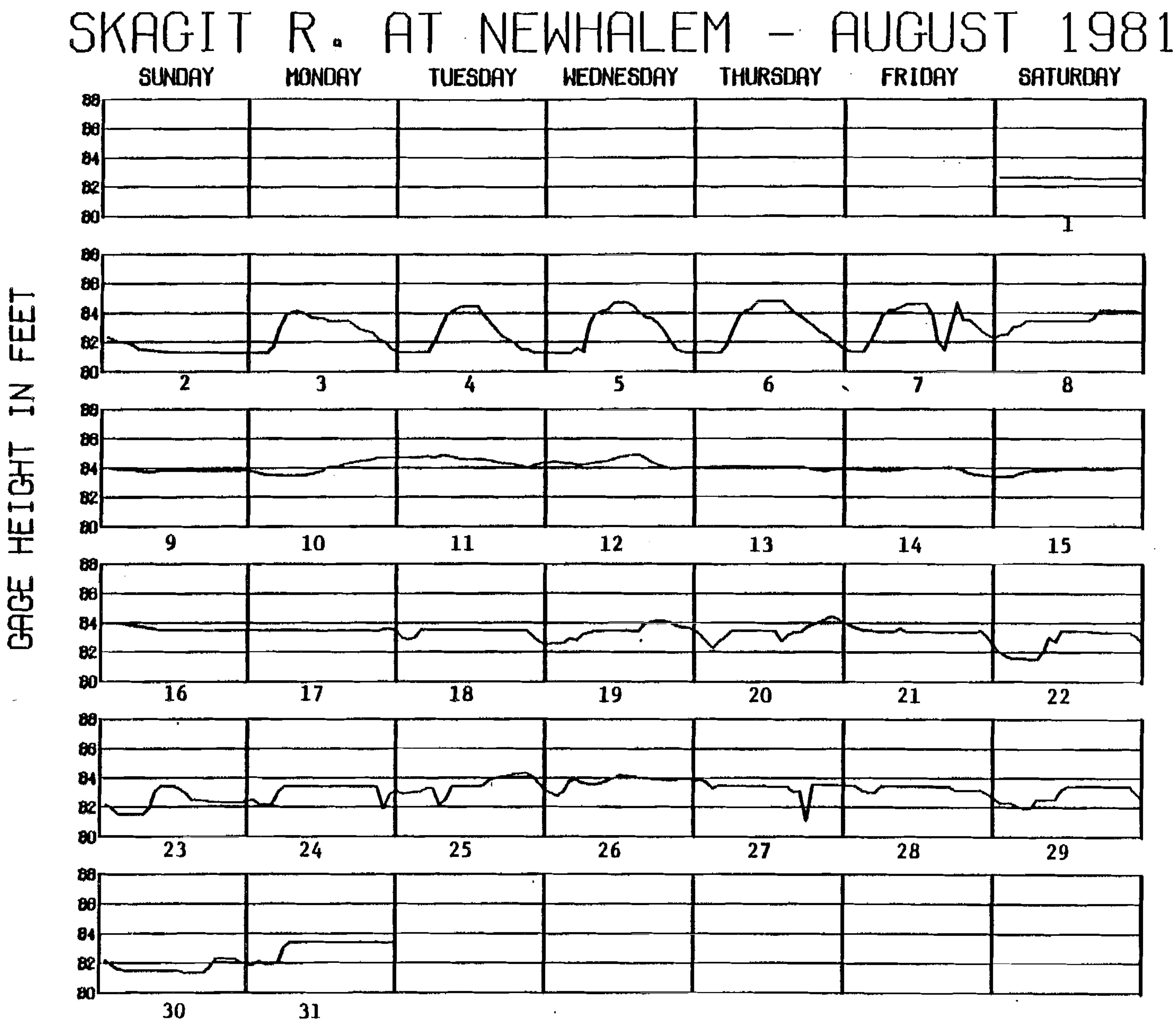
Appendix I, Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (continued).



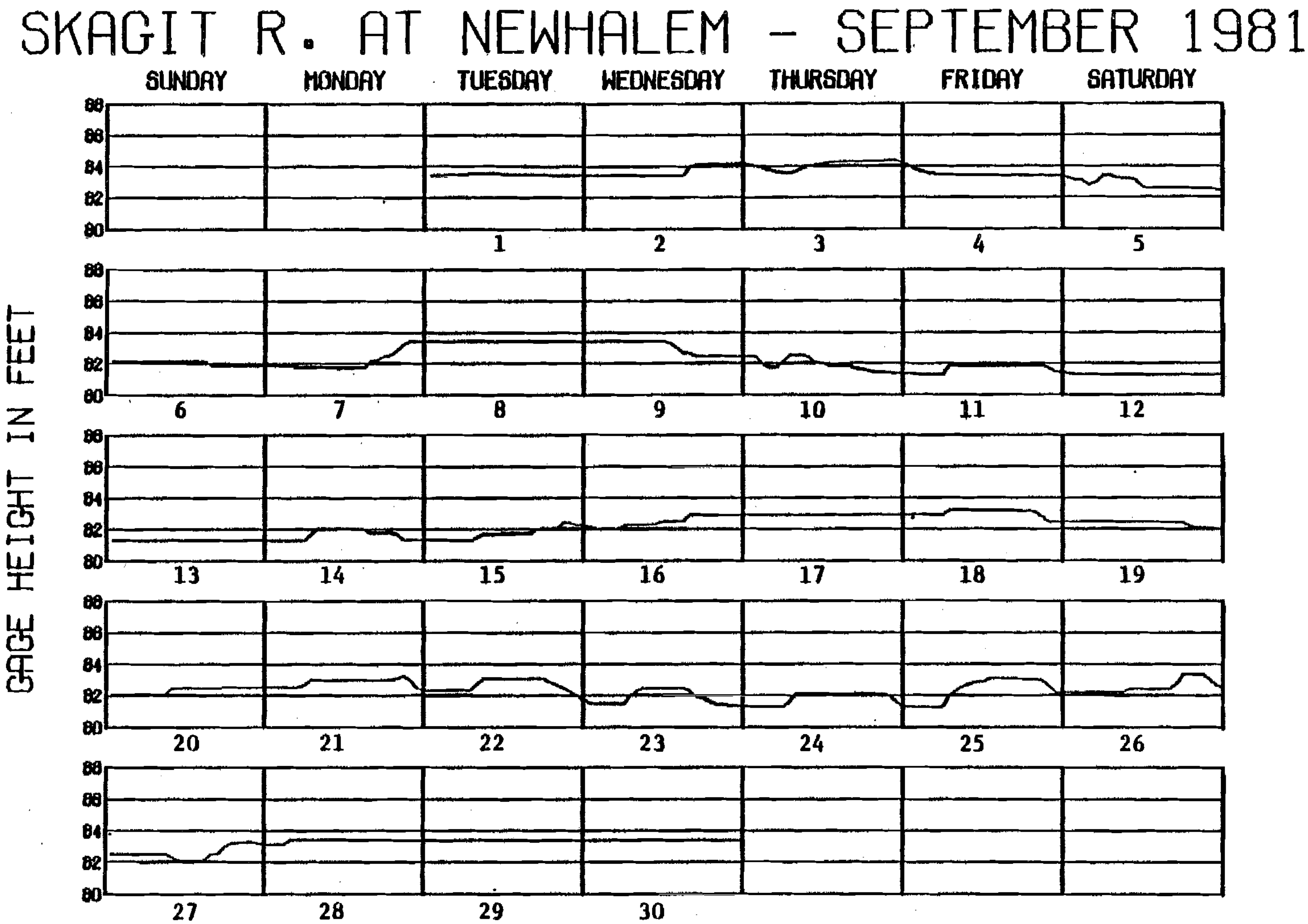
Appendix I Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (Continued).



Appendix I Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (Continued).

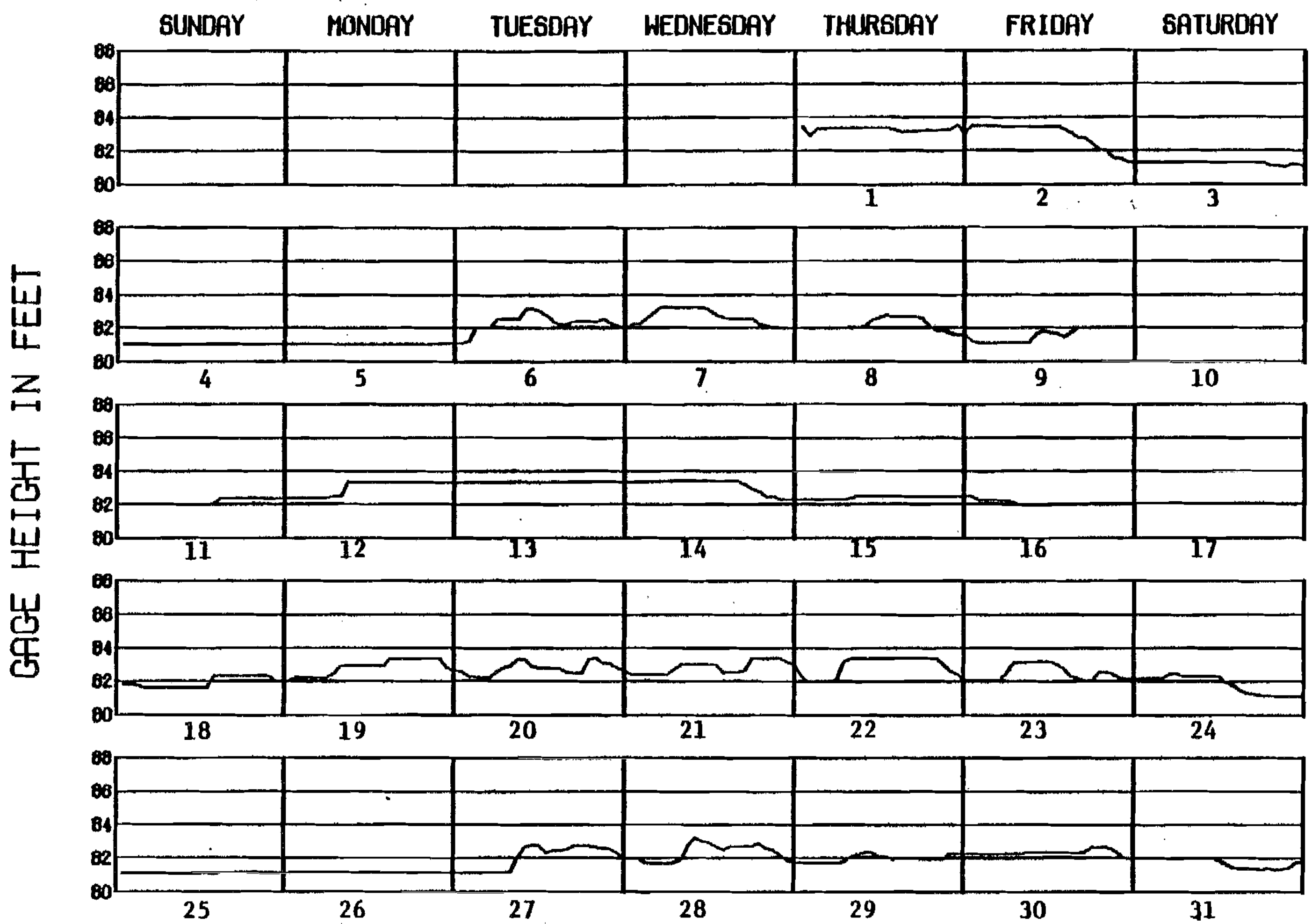


Appendix I Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (Continued).

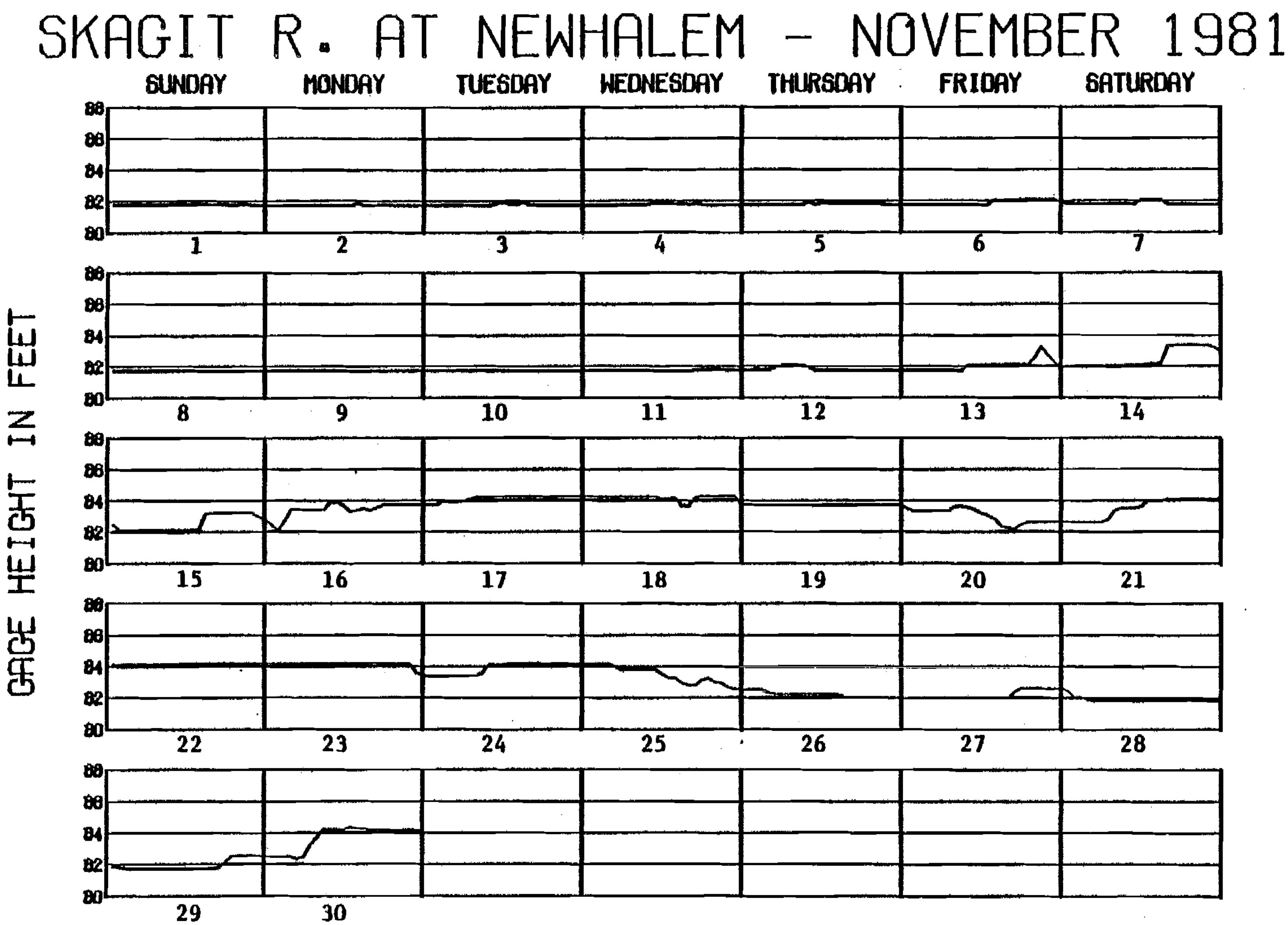


Appendix I Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (Continued).

SKAGIT R. AT NEWHALEM - OCTOBER 1981



Appendix I Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (Continued).



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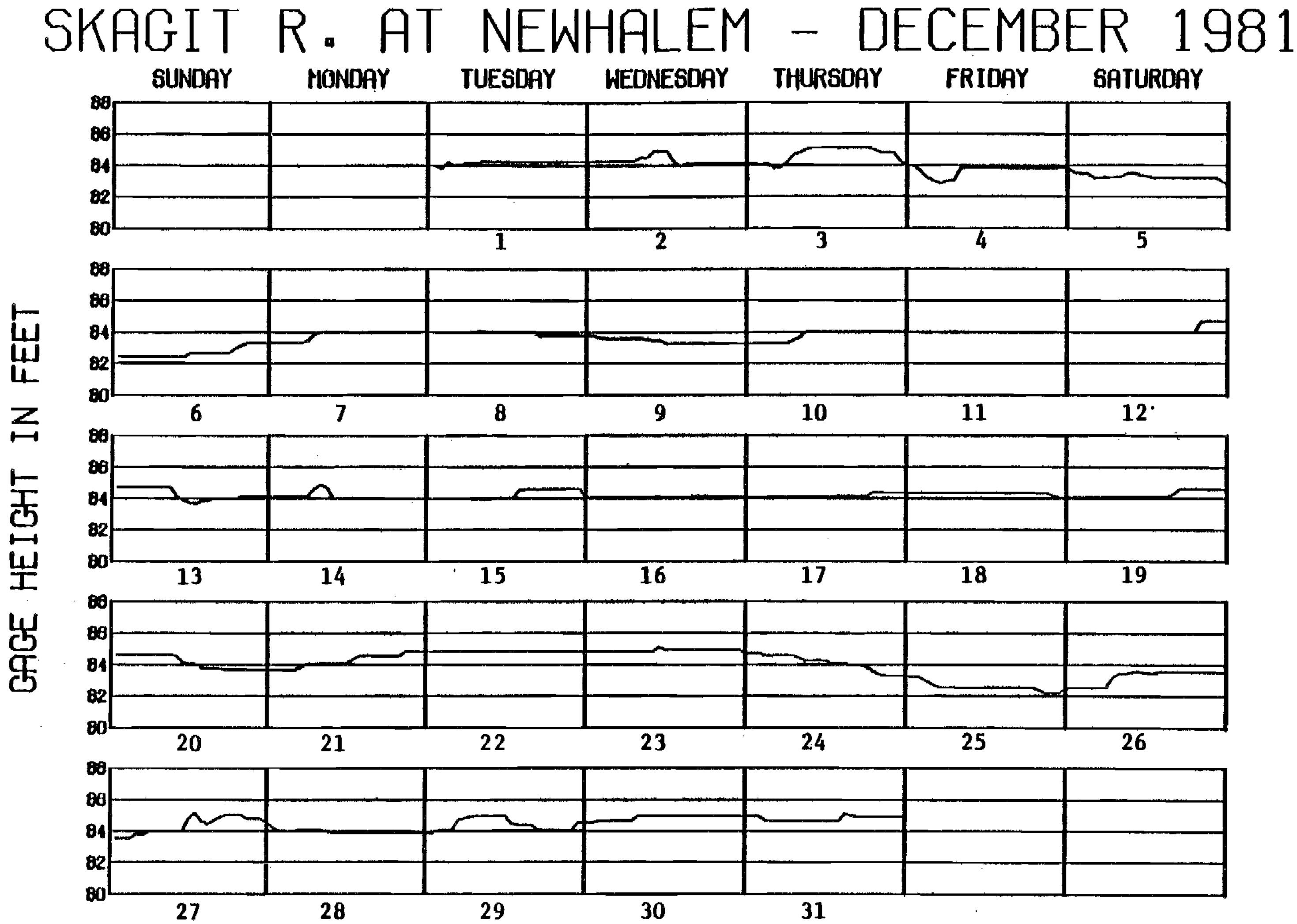
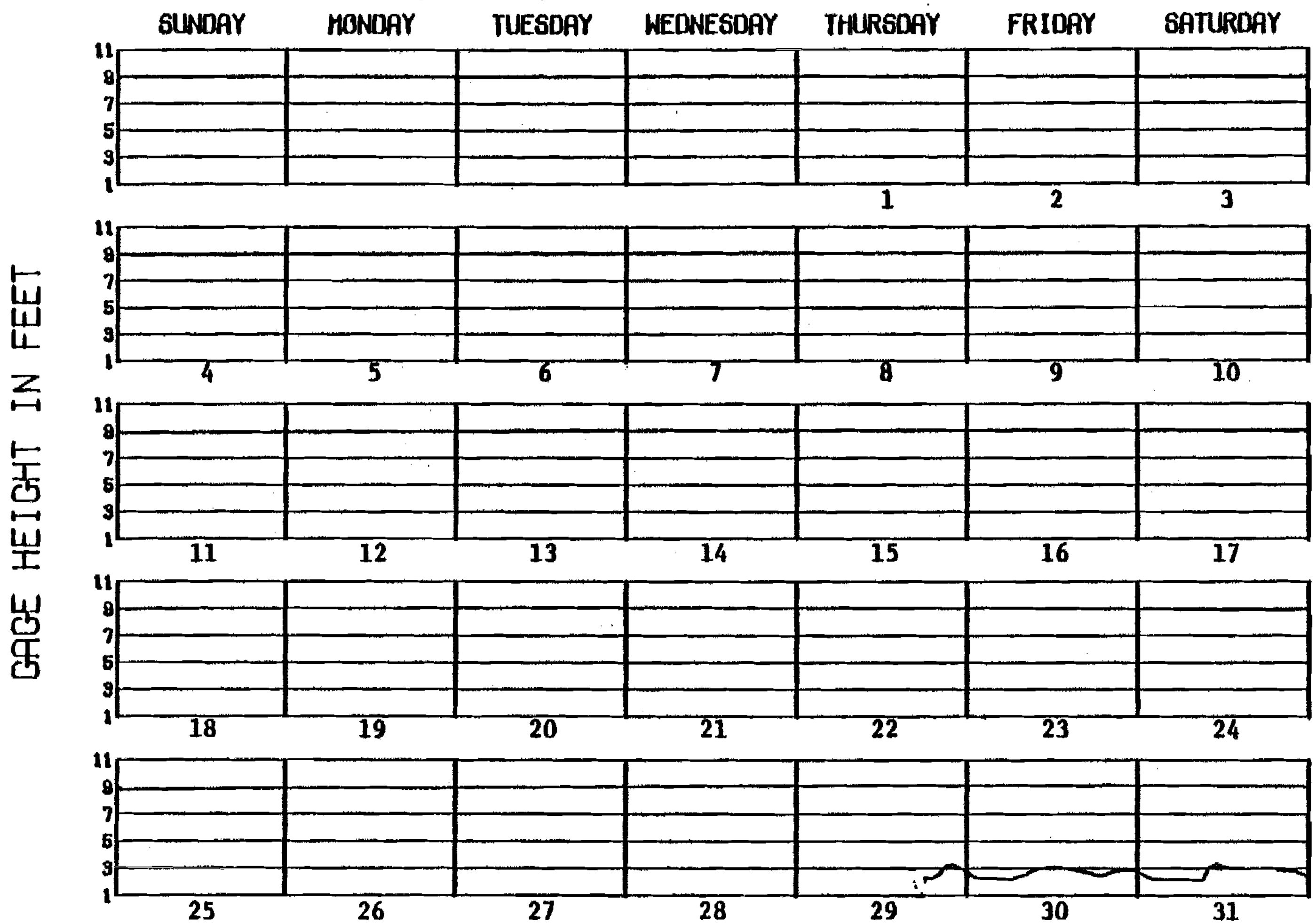
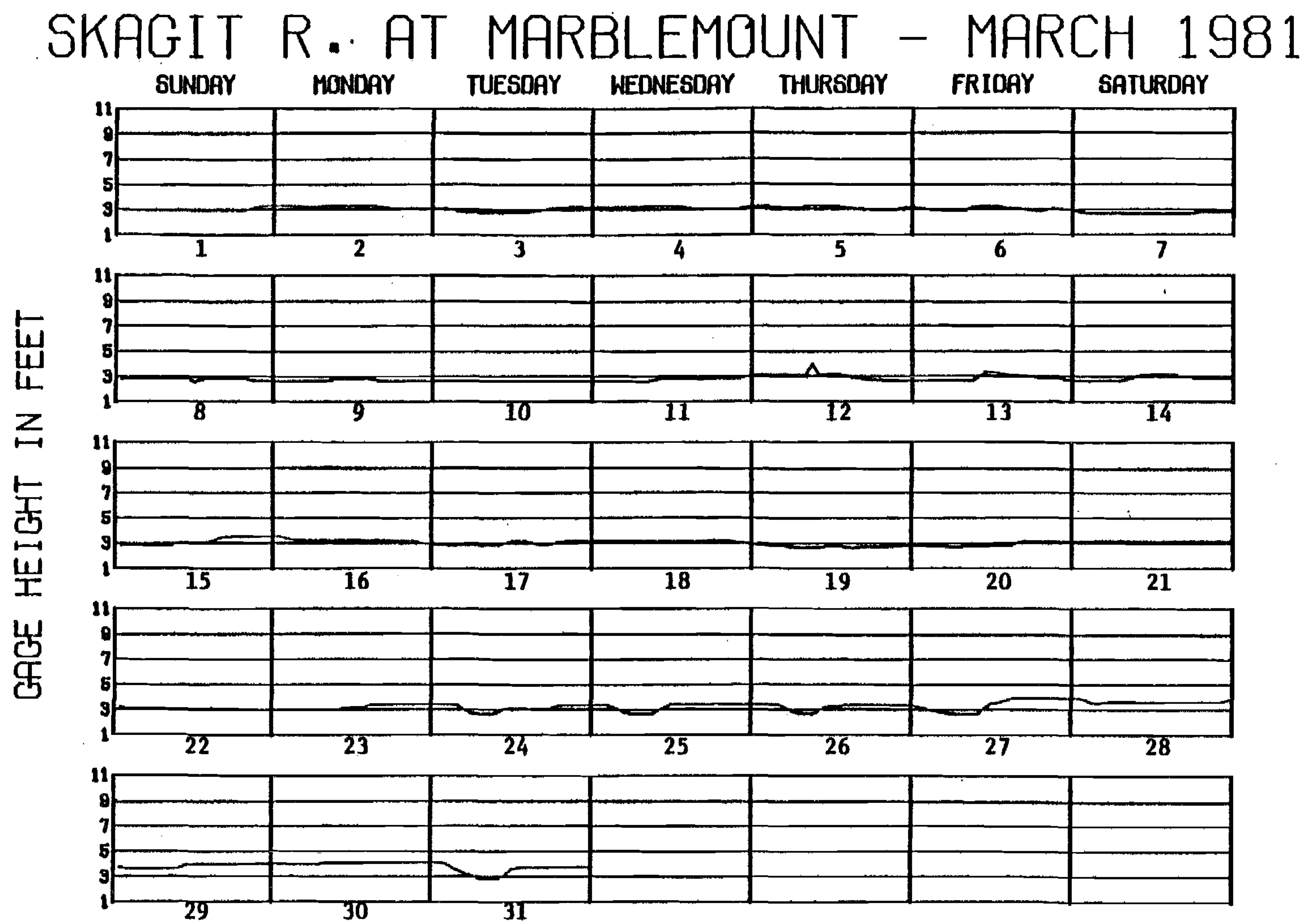


Appendix I. Figure 3. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1981 (Continued).

SKAGIT R. AT MARBLEMOUNT - JANUARY 1981



Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981.



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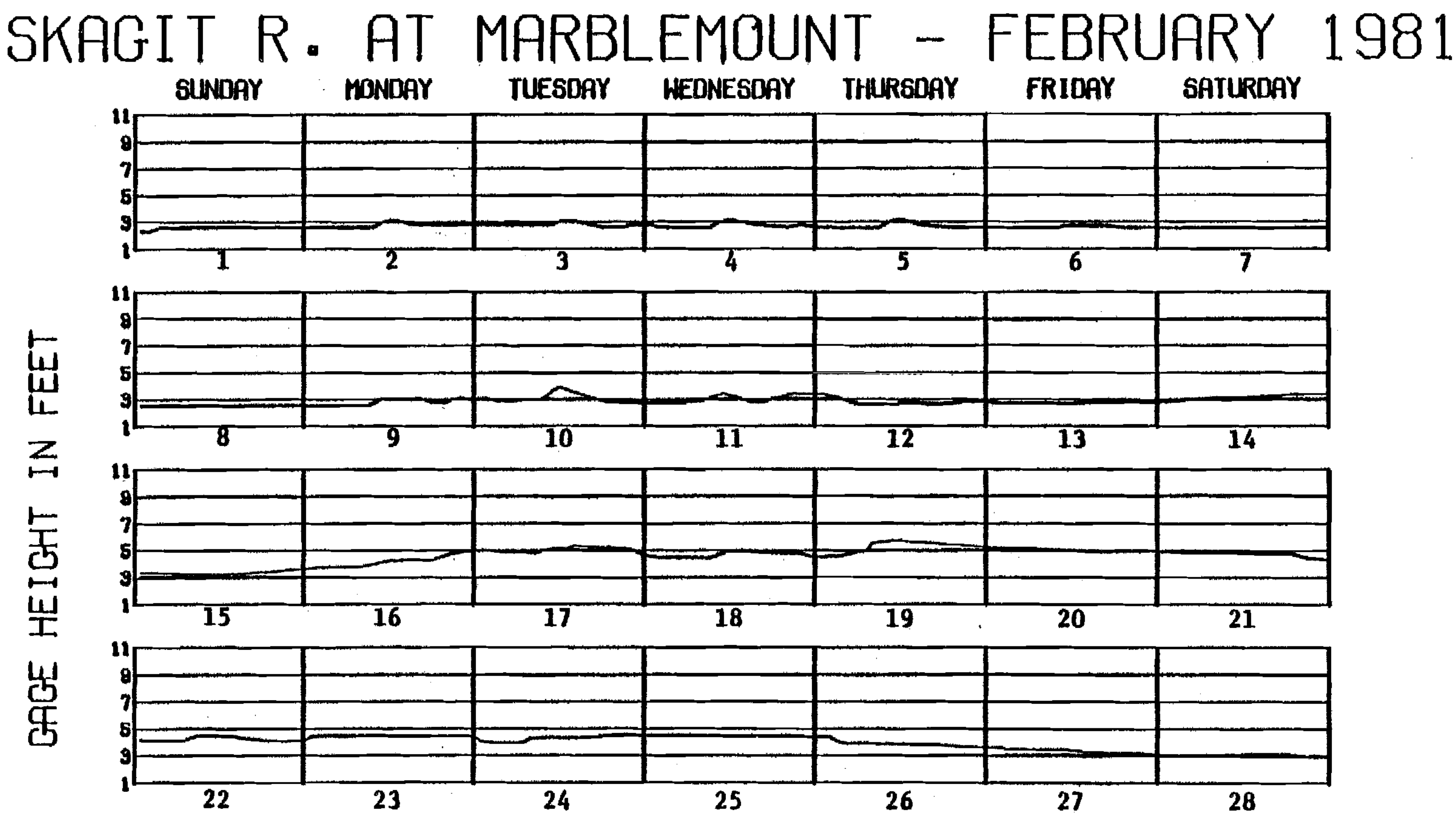

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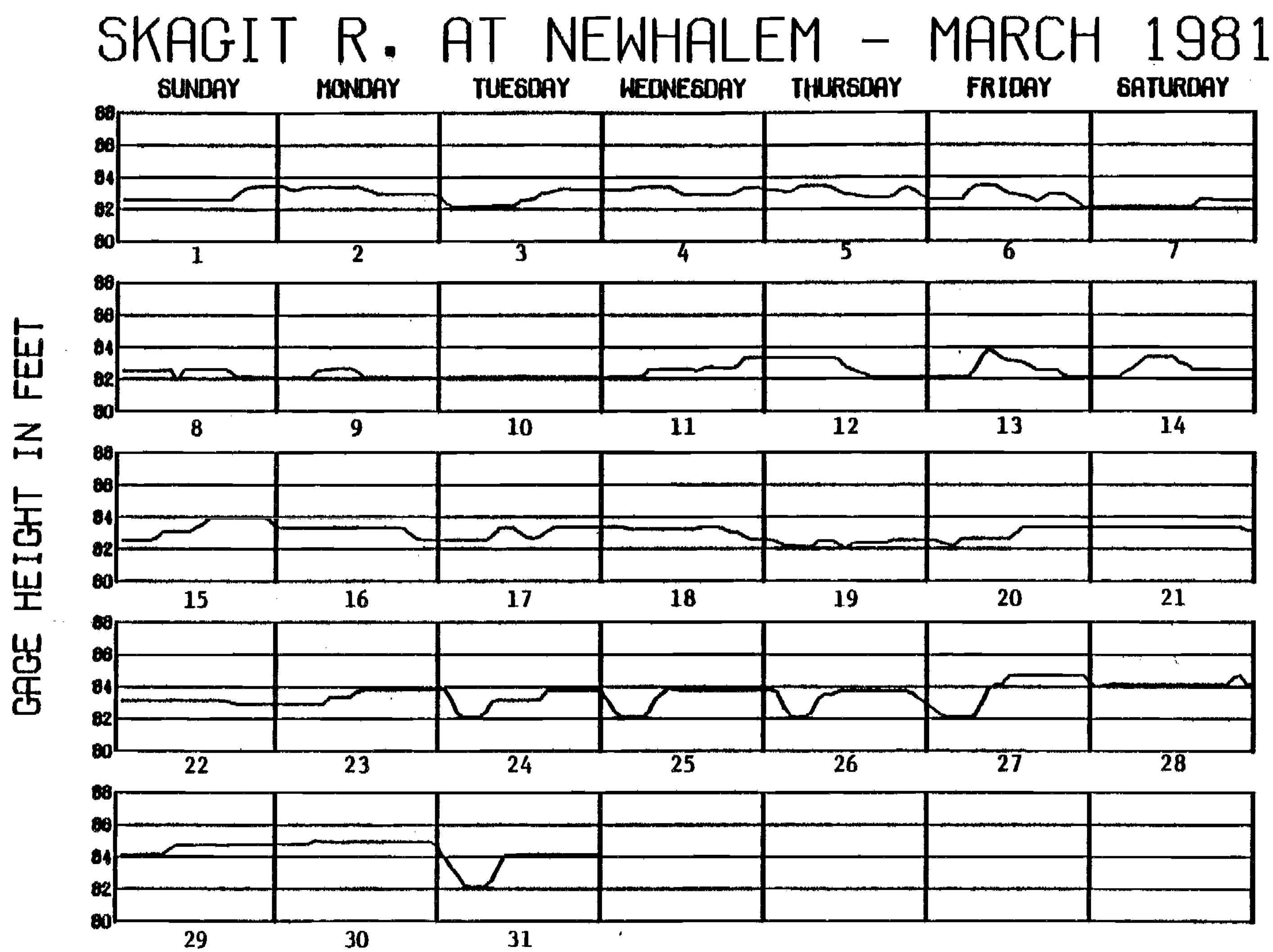
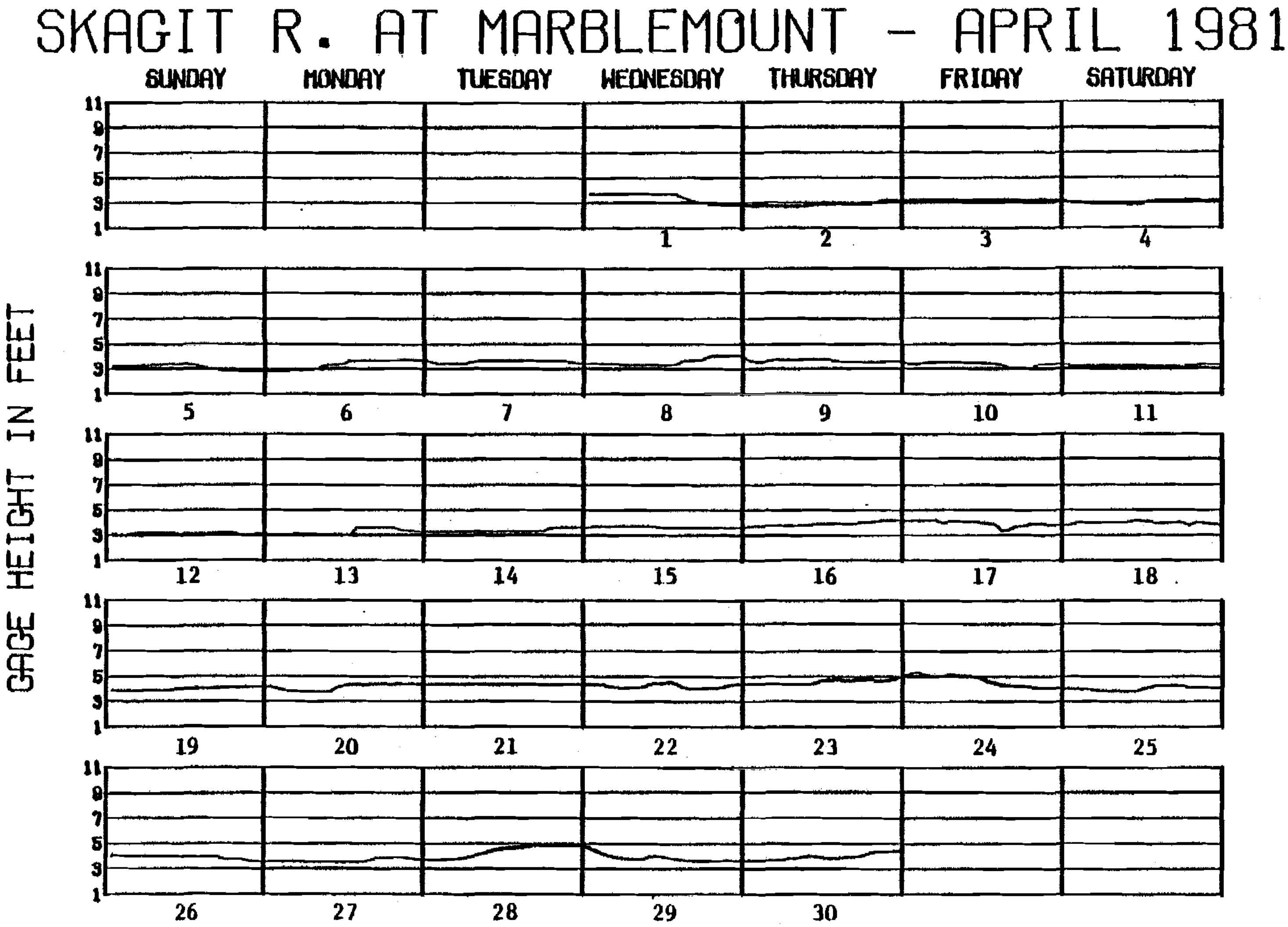


Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



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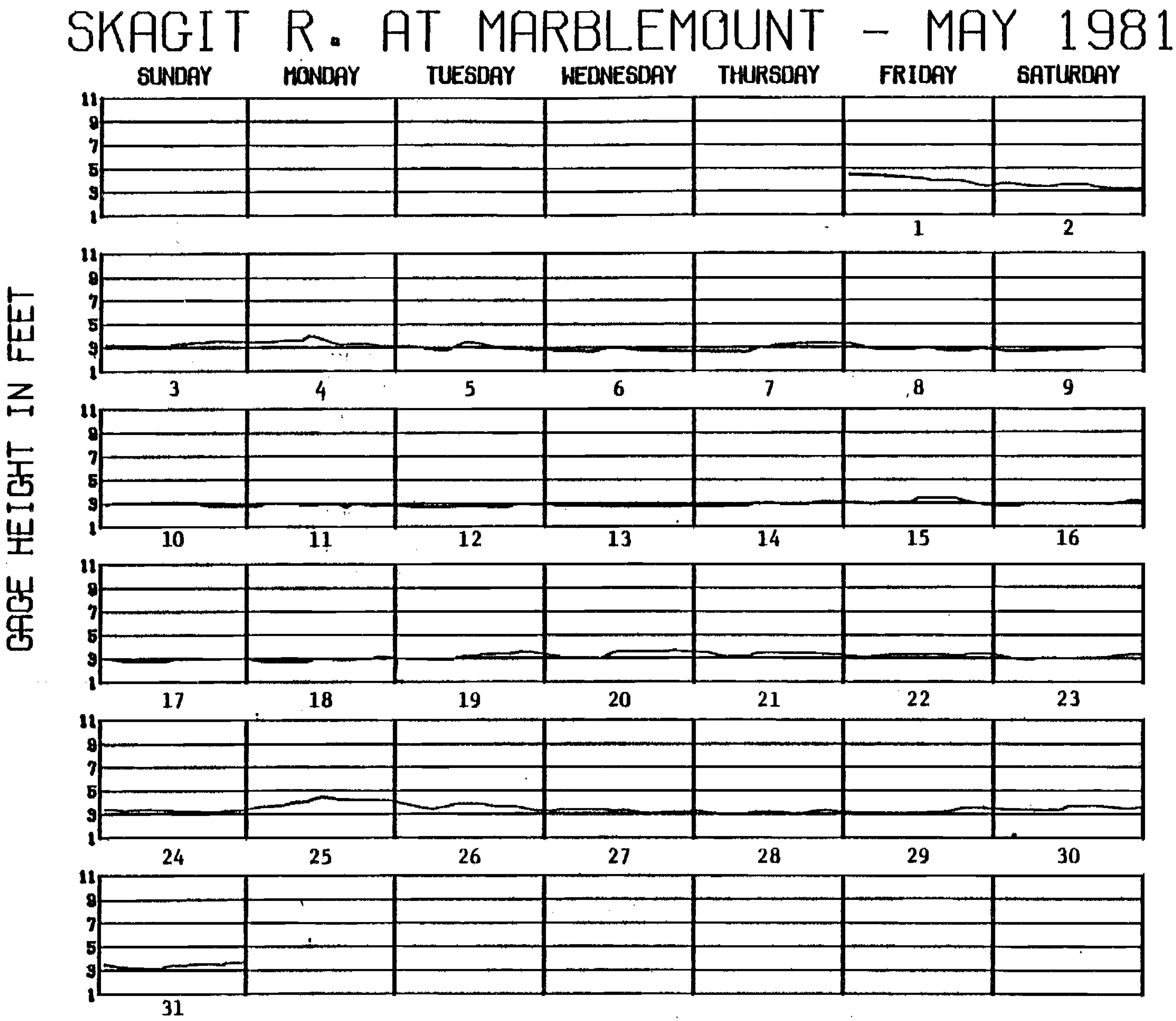

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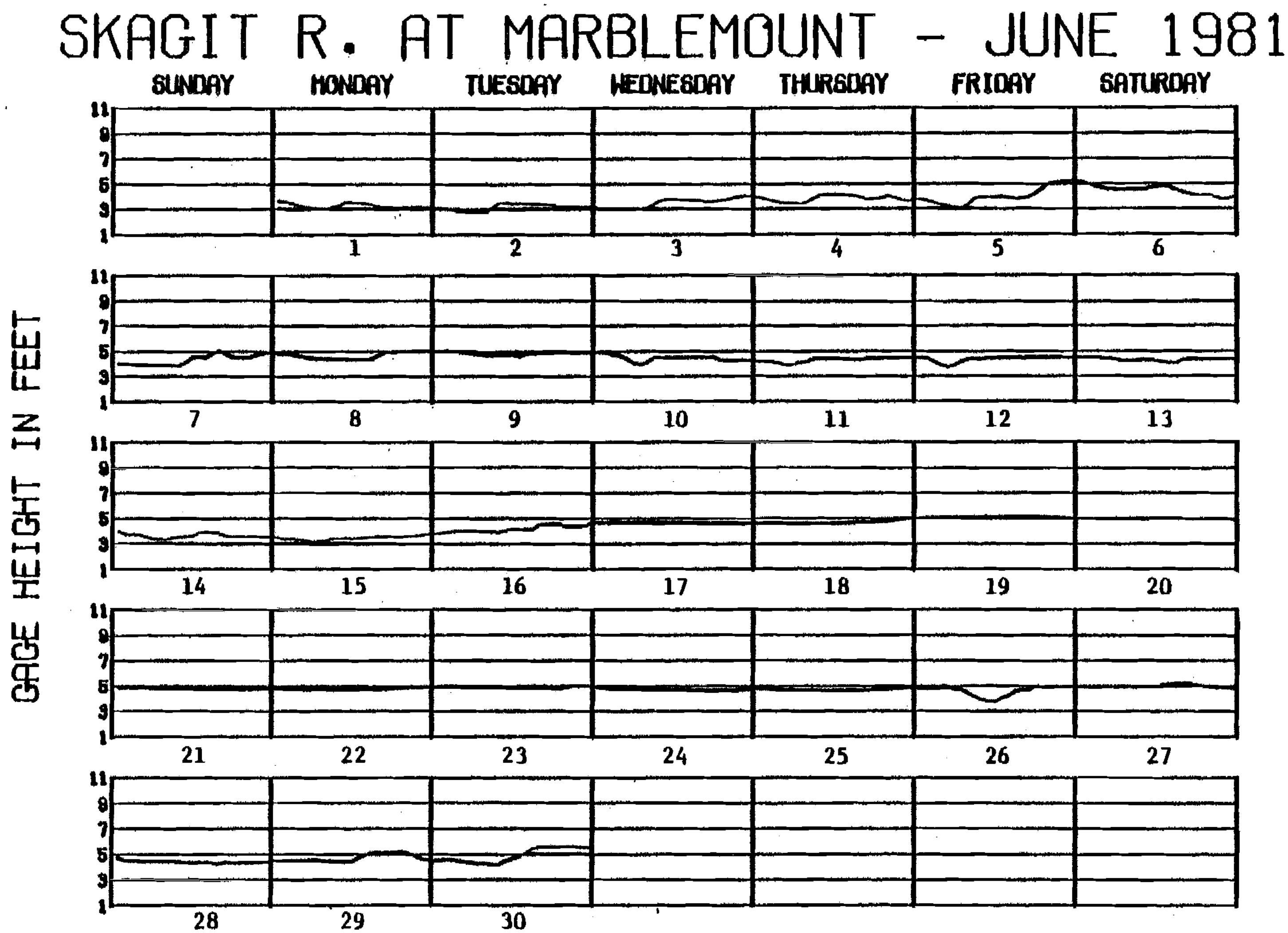
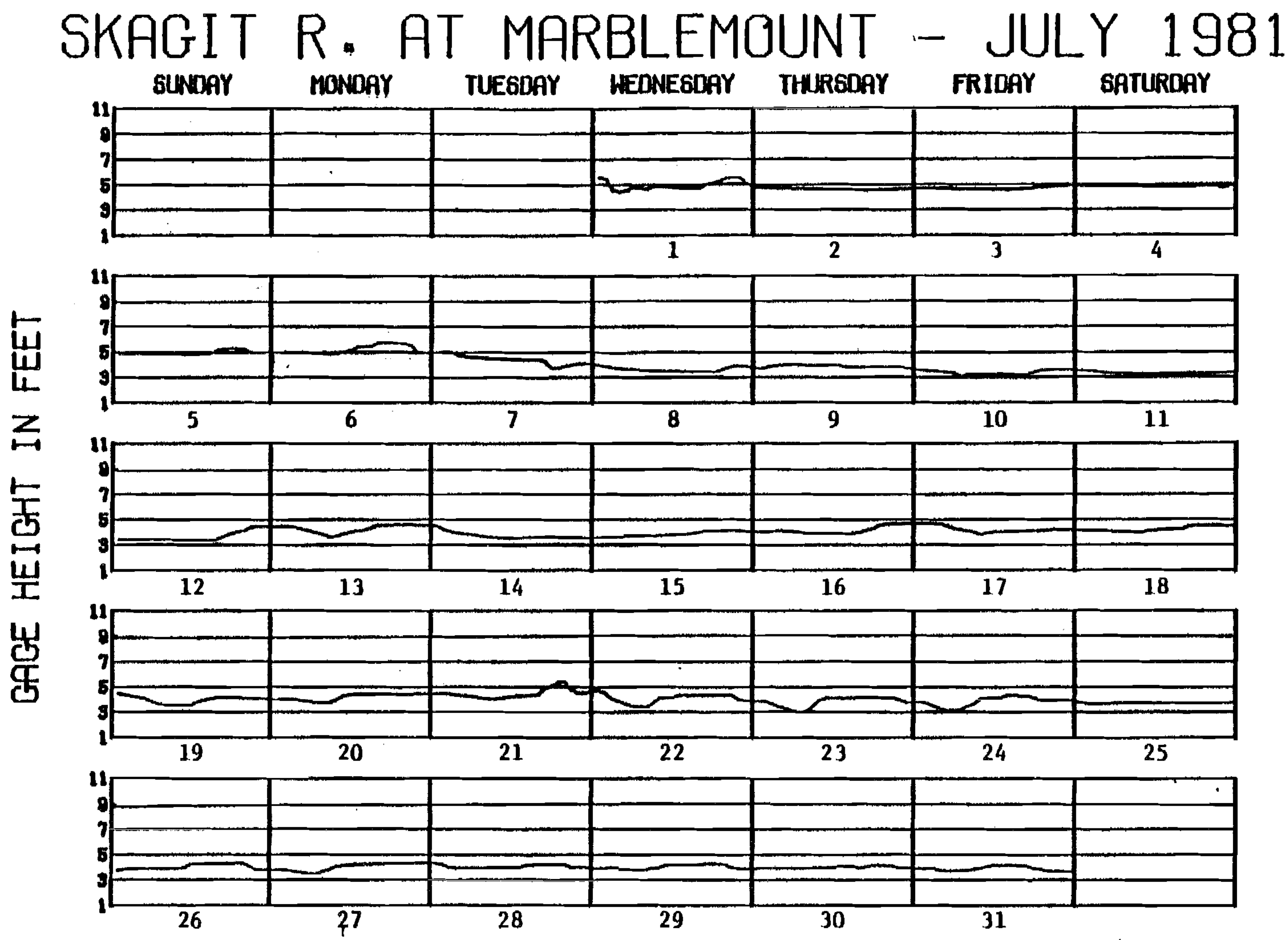


Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



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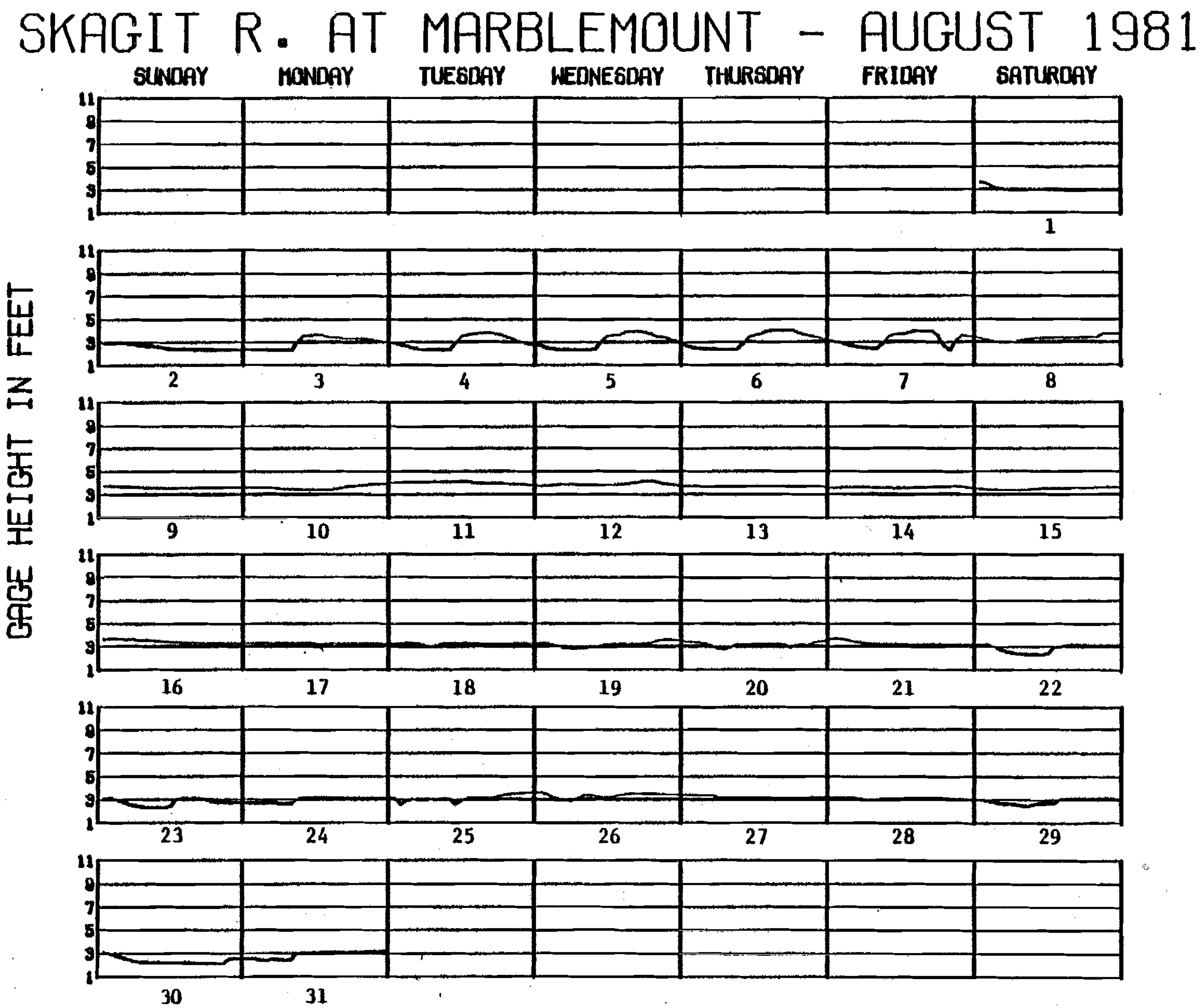
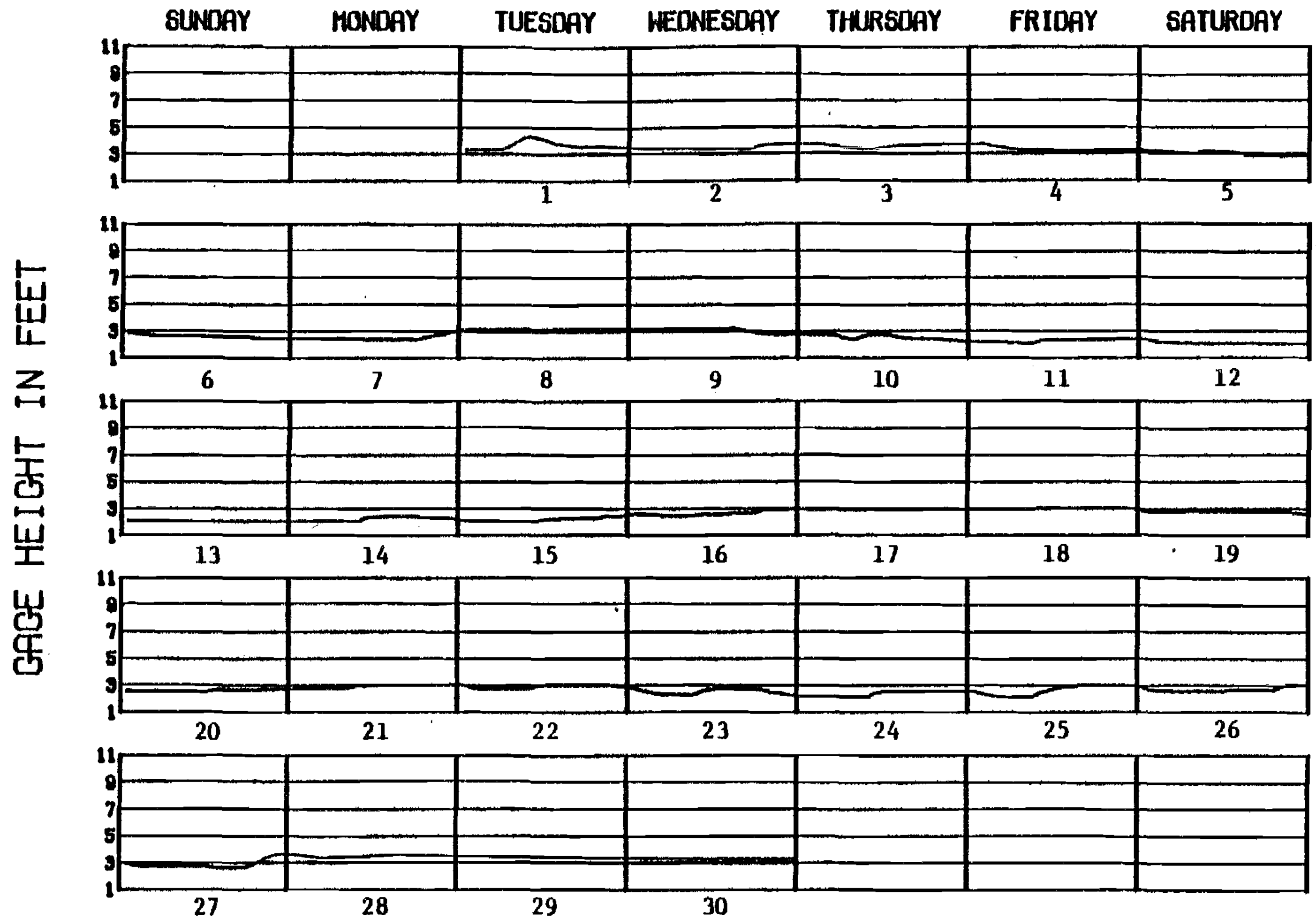
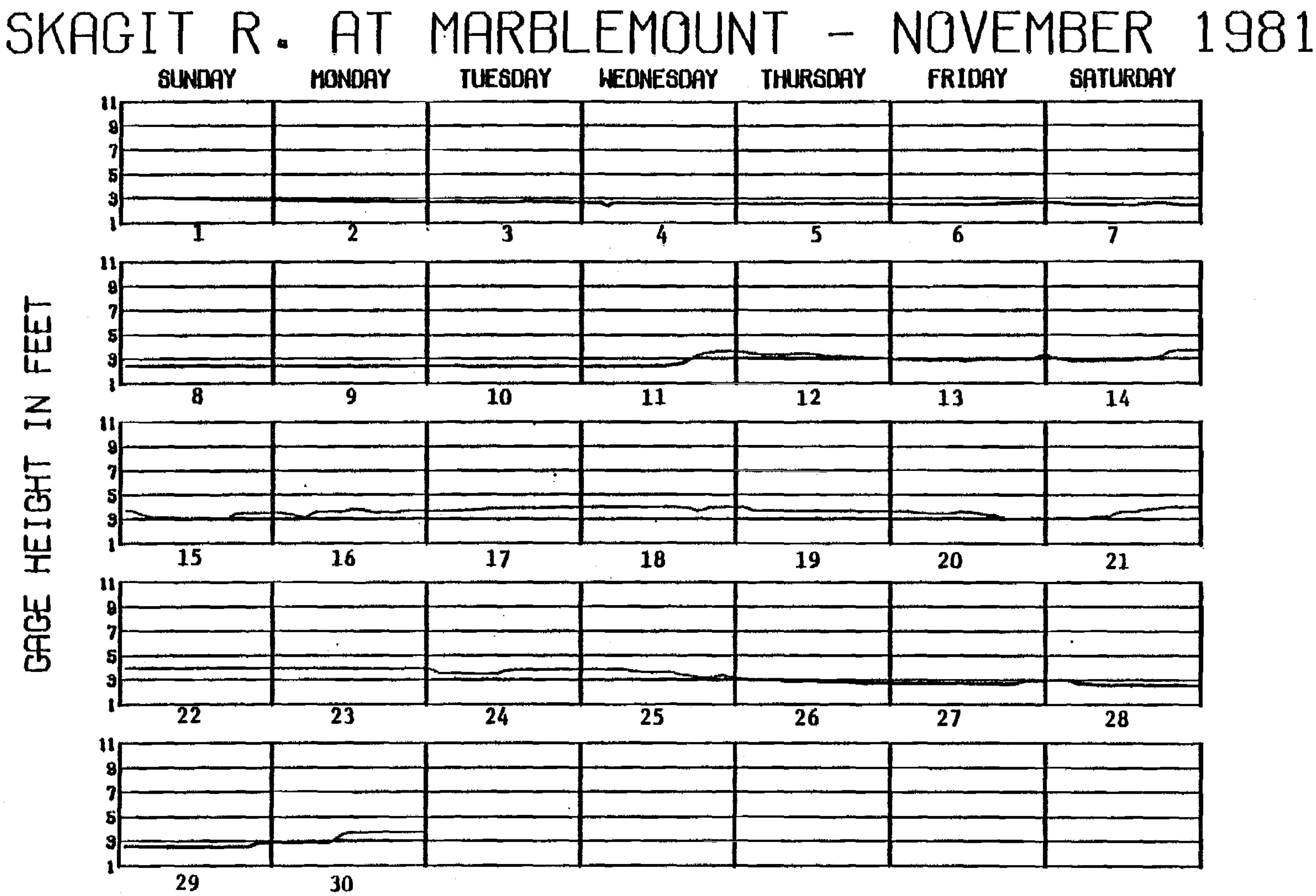


Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).

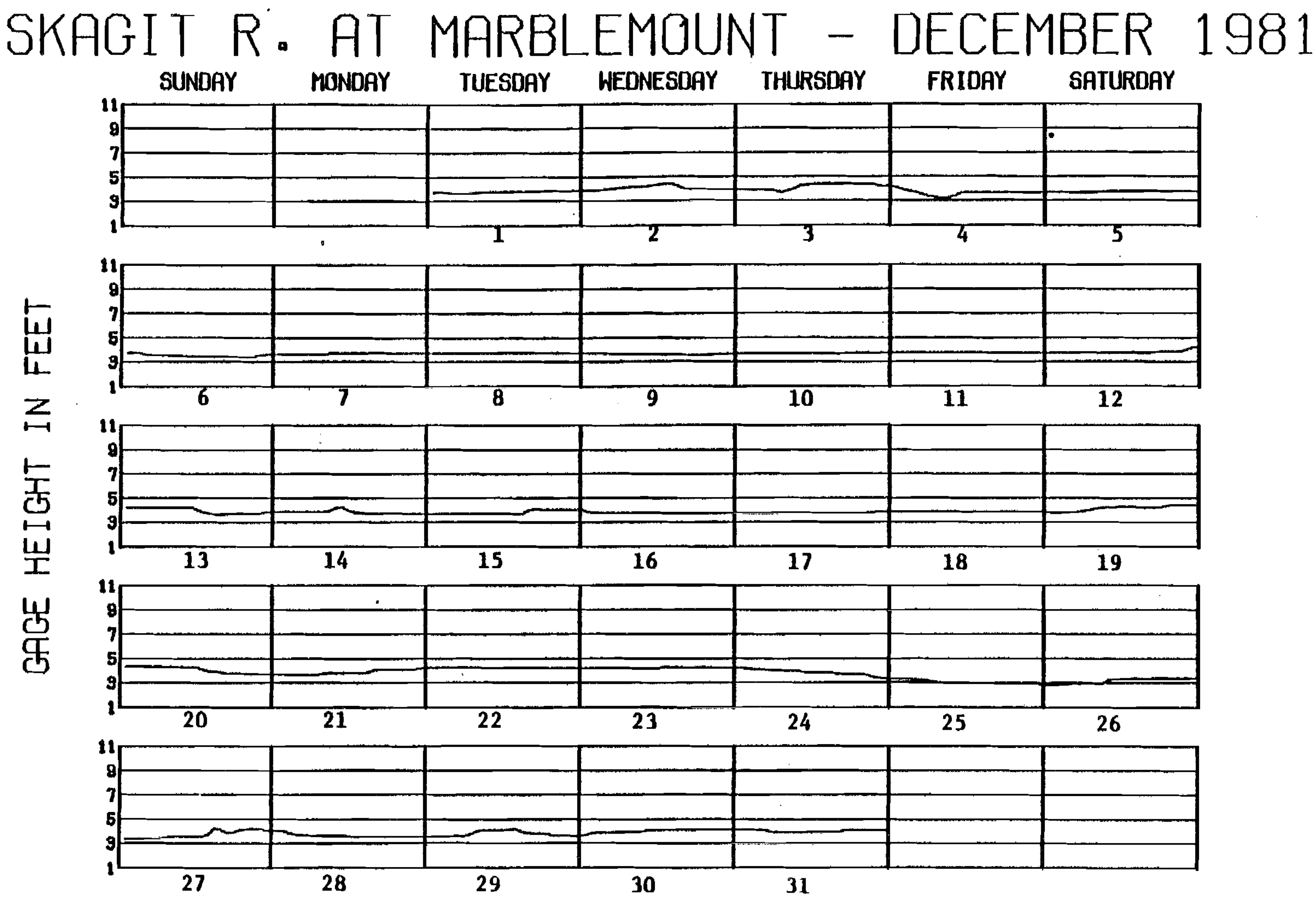
SKAGIT R. AT MARBLEMOUNT - SEPTEMBER 1981



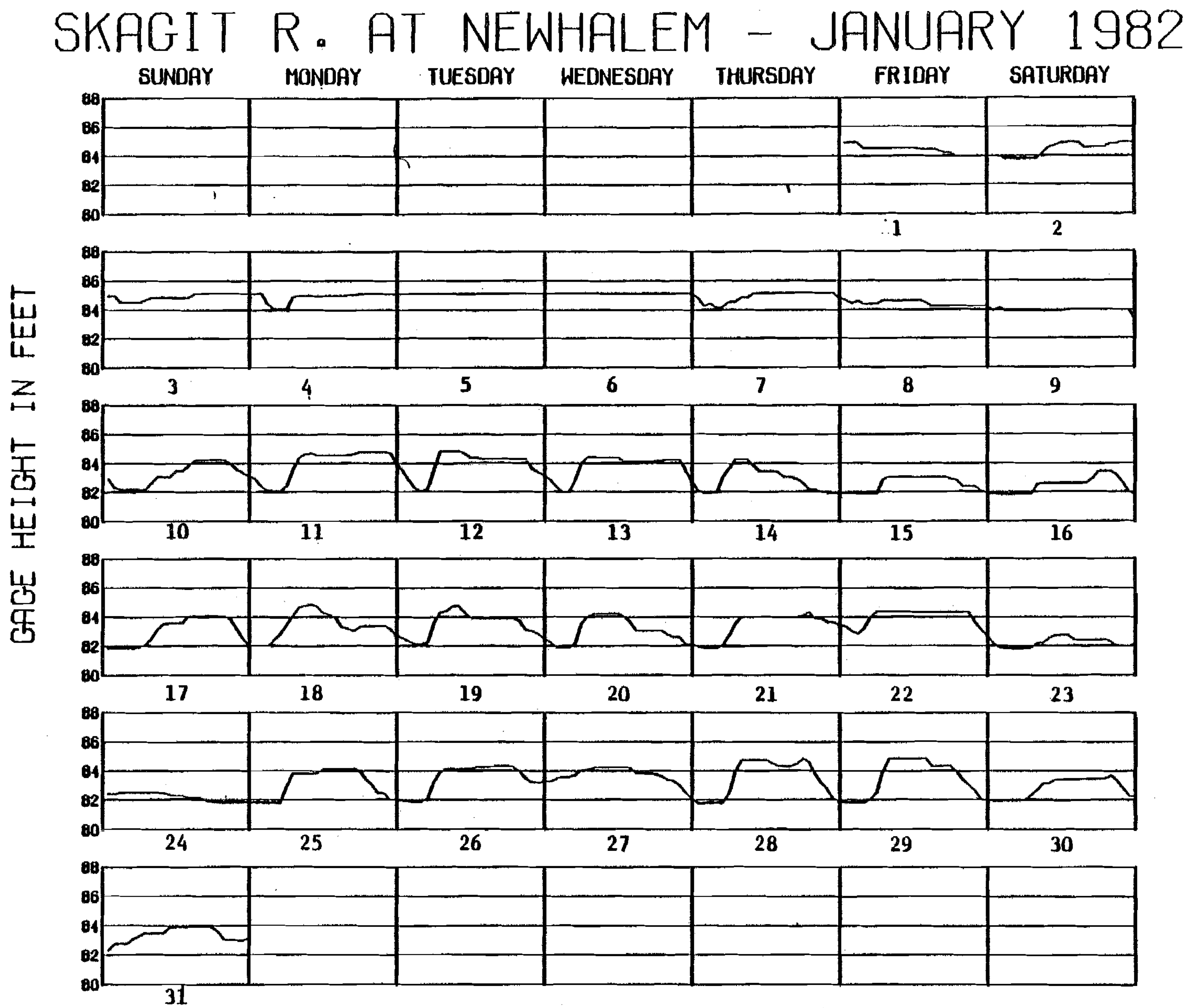
Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



Appendix I. Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1981 (Continued).

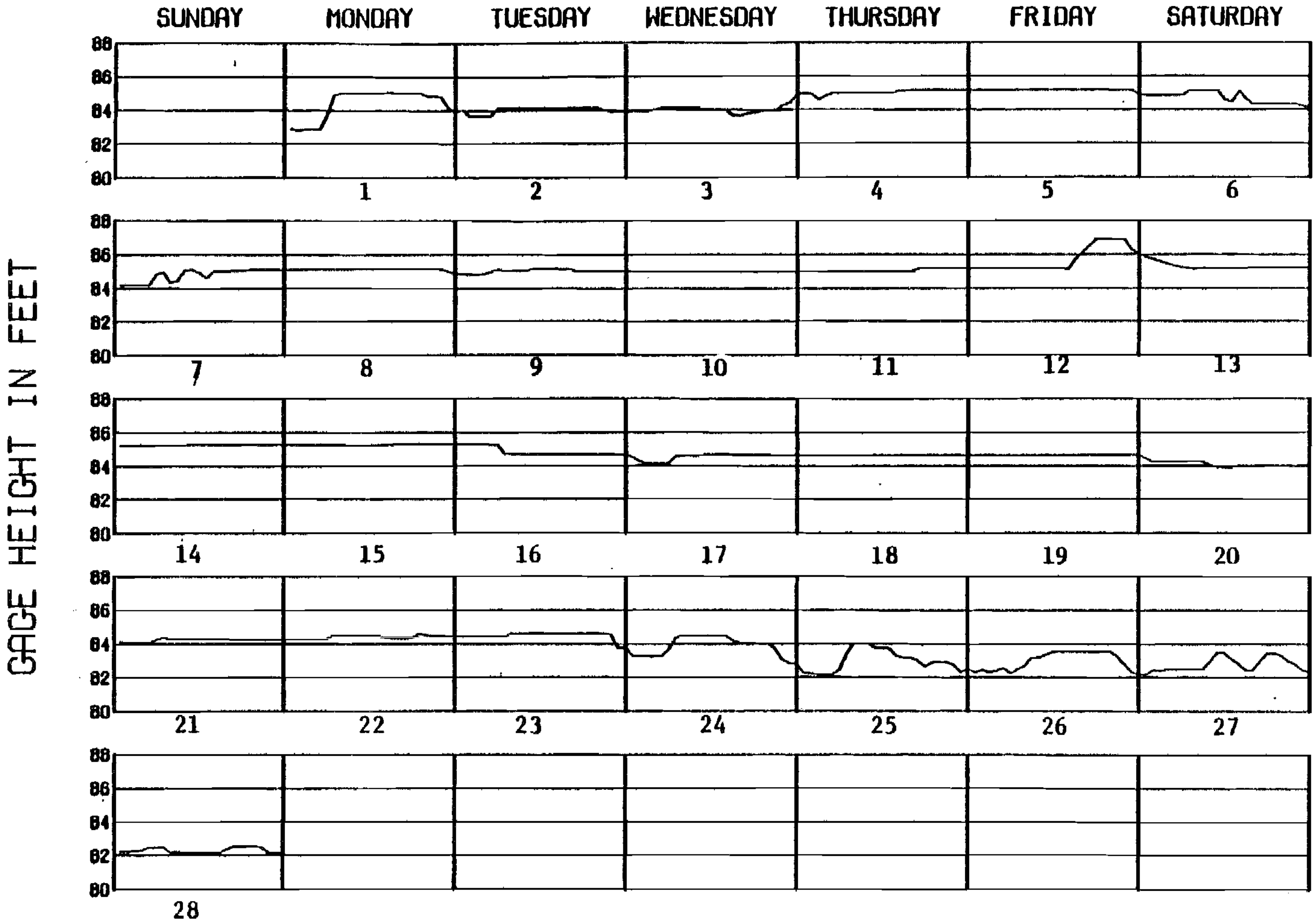


Appendix I Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1981 (Continued).

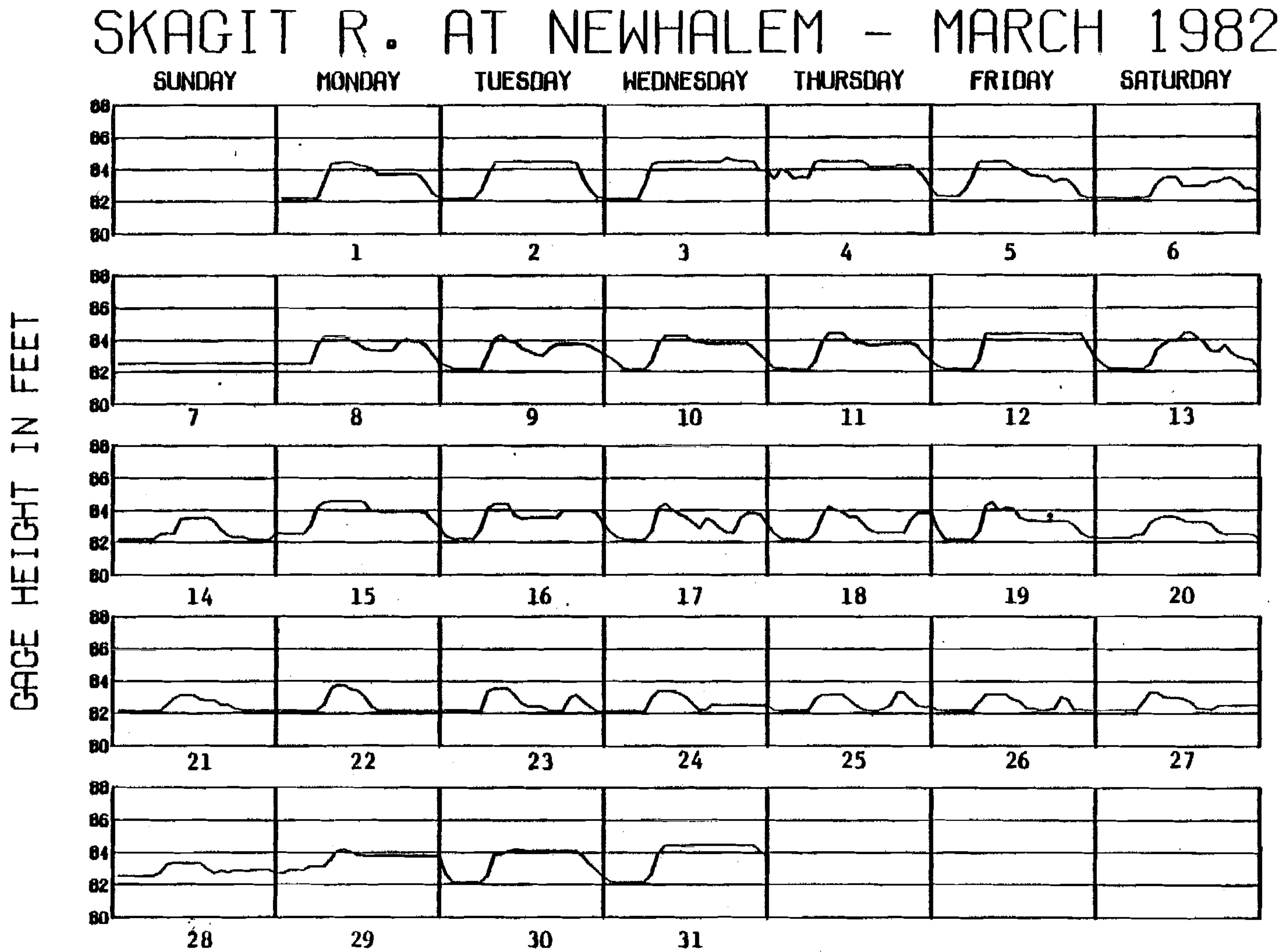


Appendix I Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982.

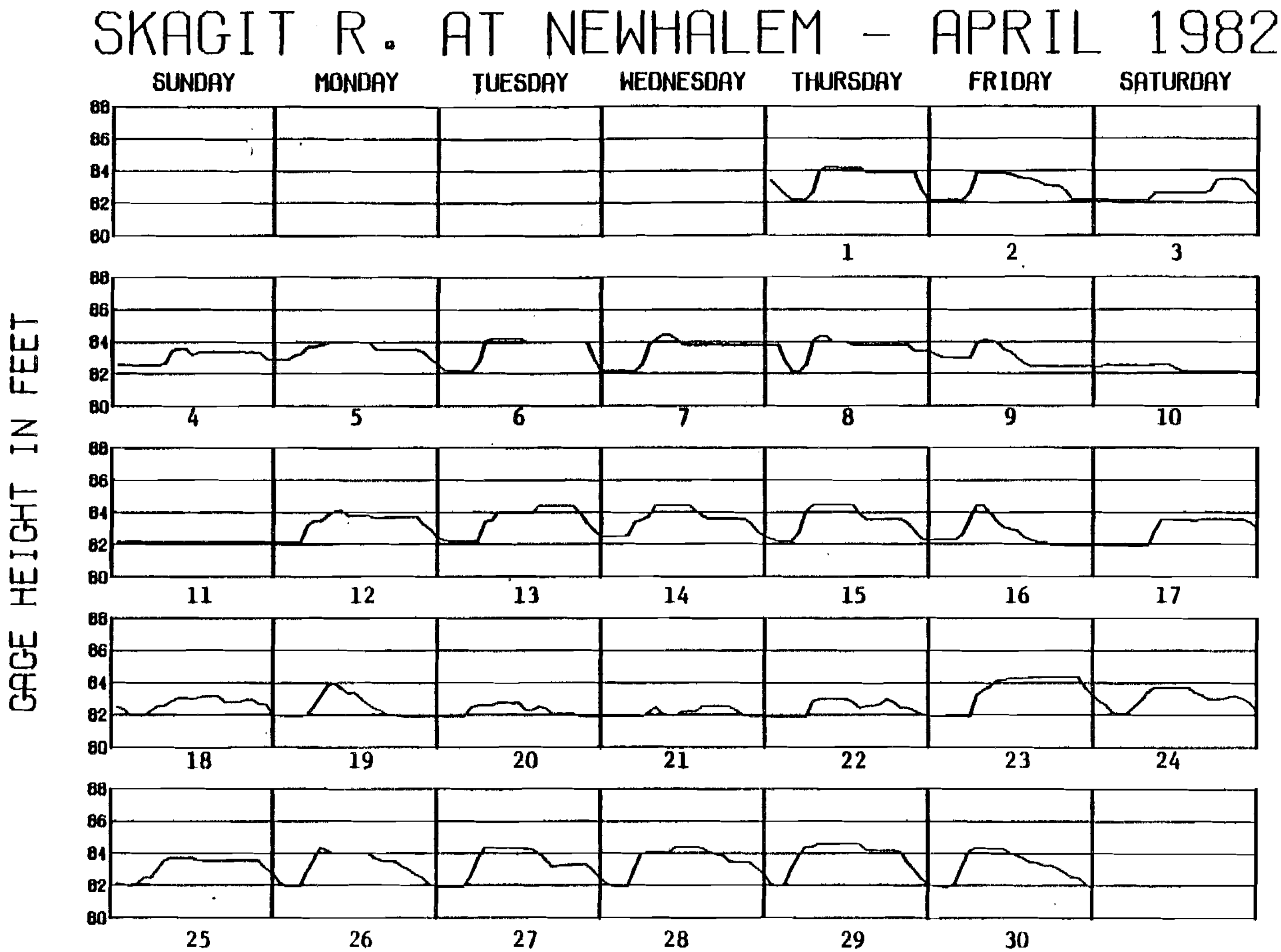
SKAGIT R. AT NEWHALEM - FEBRUARY 1982



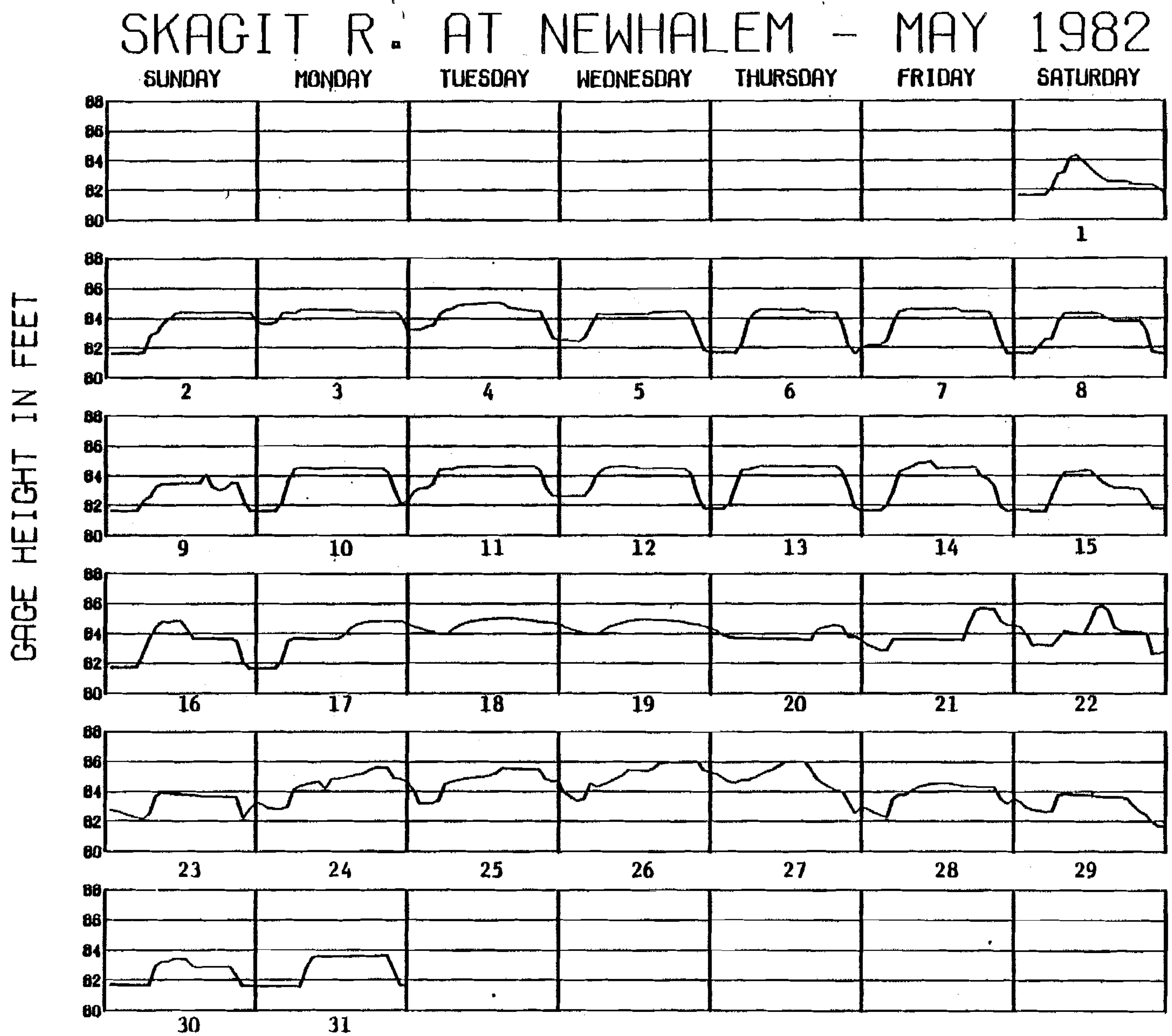
Appendix I, Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).



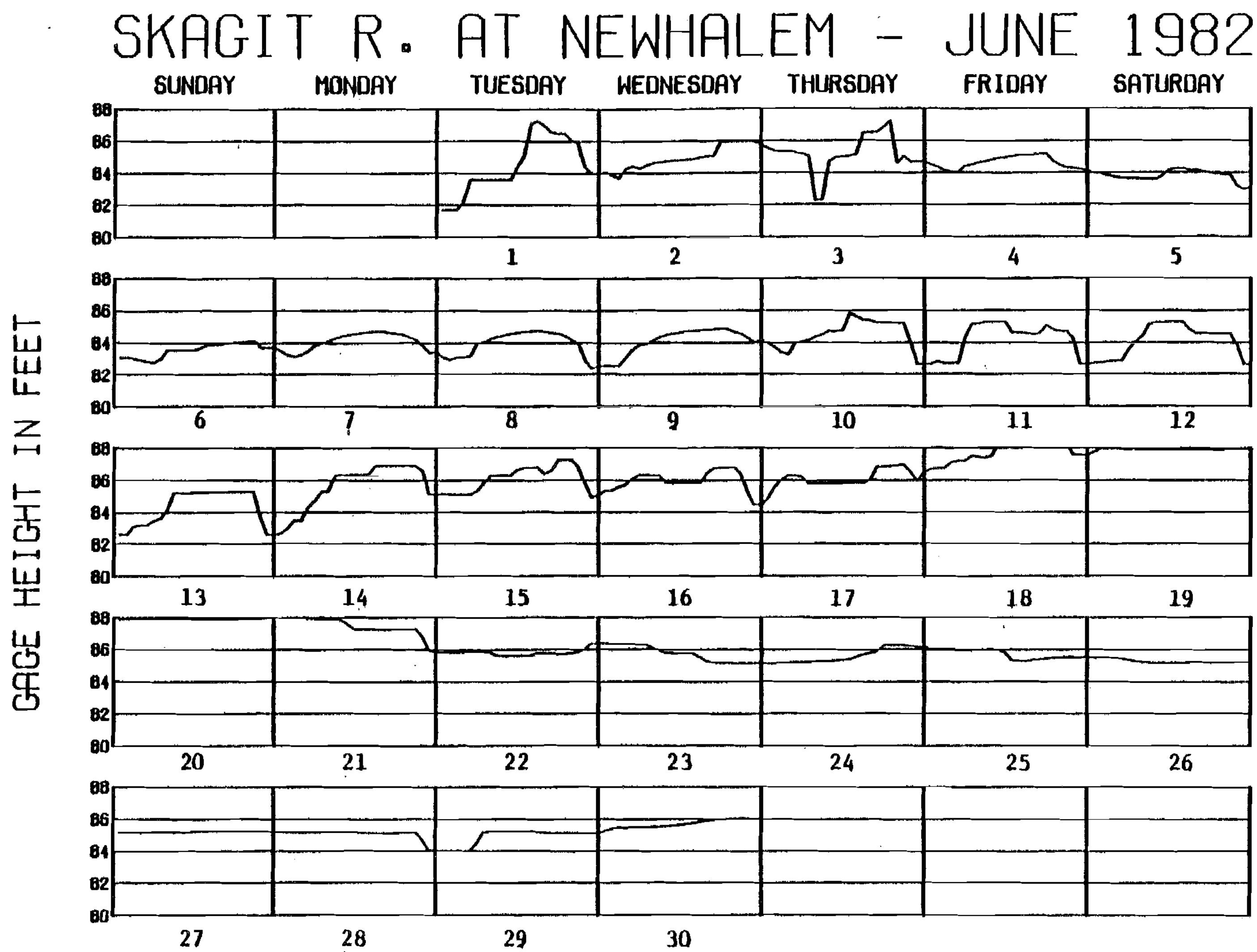
Appendix I. Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).



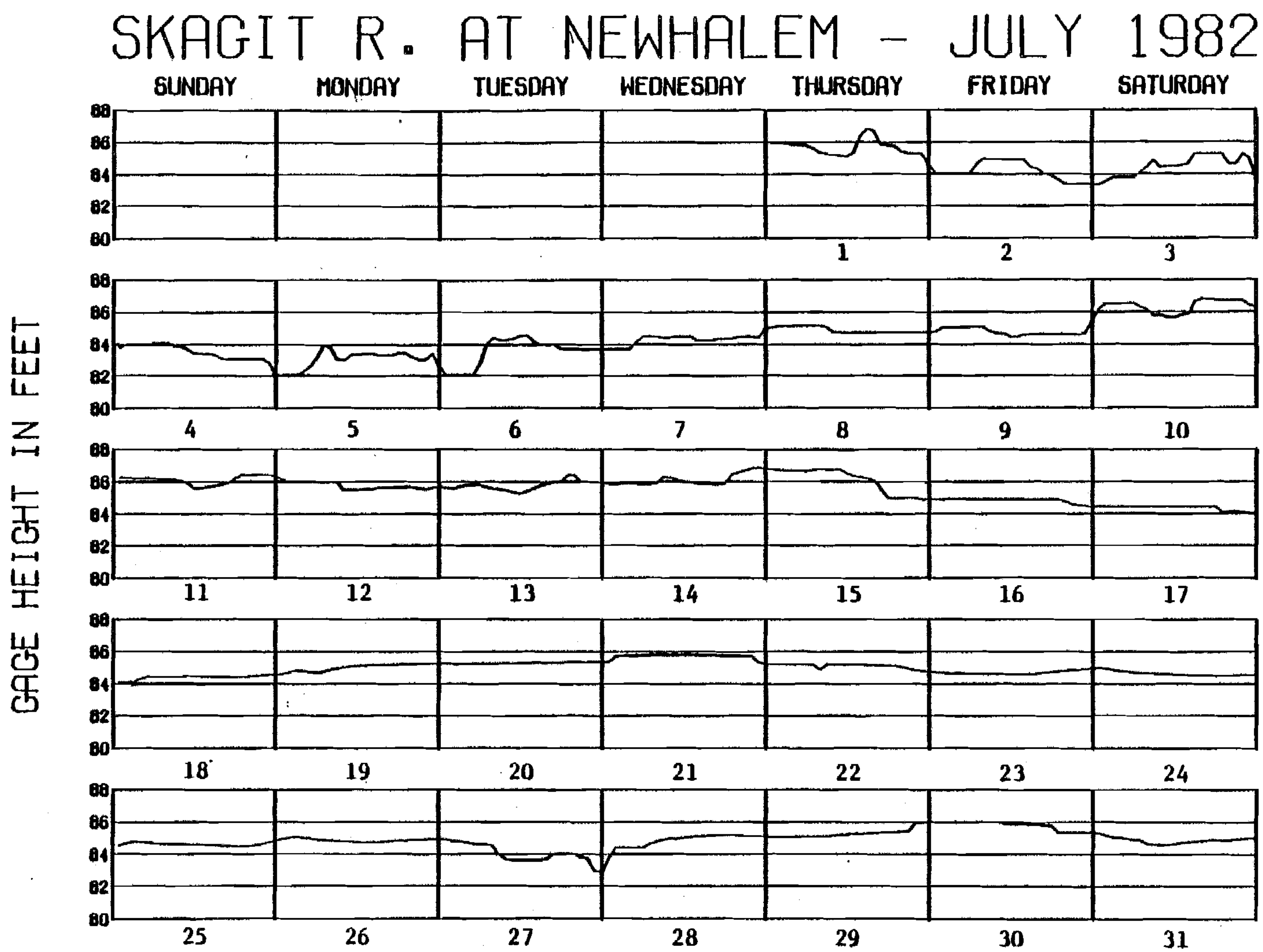
Appendix I. Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).



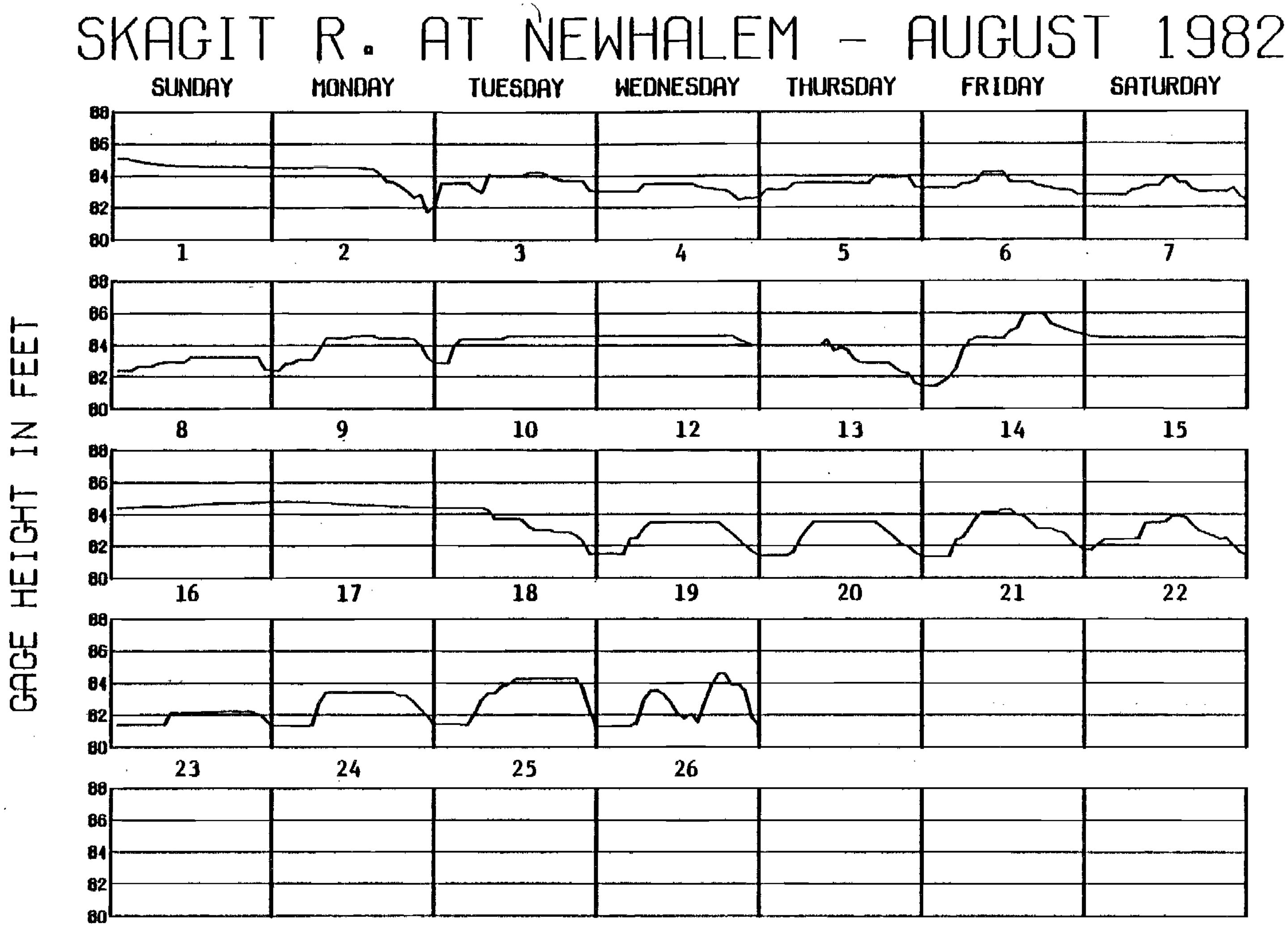
Appendix I. Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).



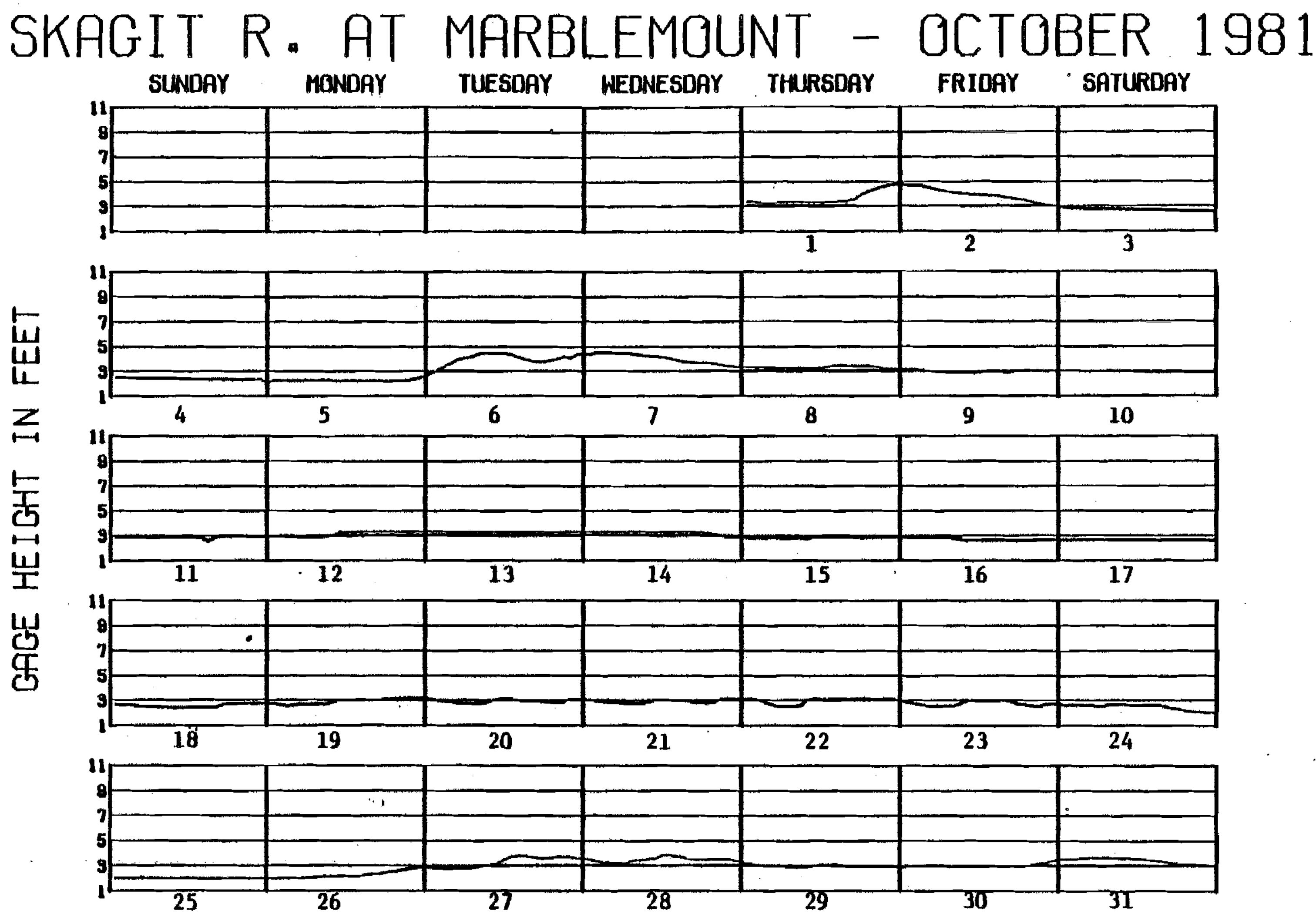
Appendix I. Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).



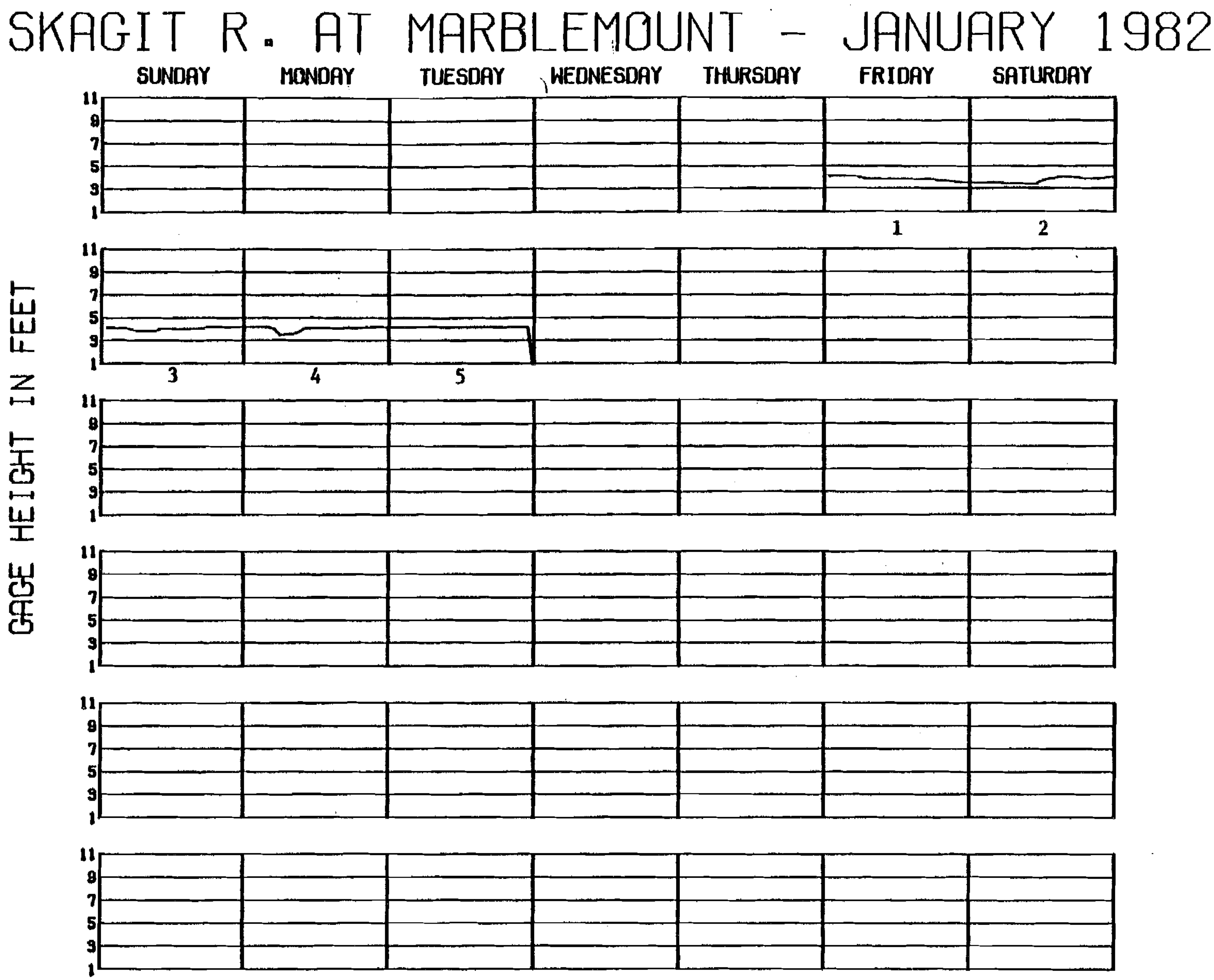
Appendix I. Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).



Appendix I. Figure 5. Hourly gage height data for Skagit River at Newhalem (USGS), January-December 1982 (continued).

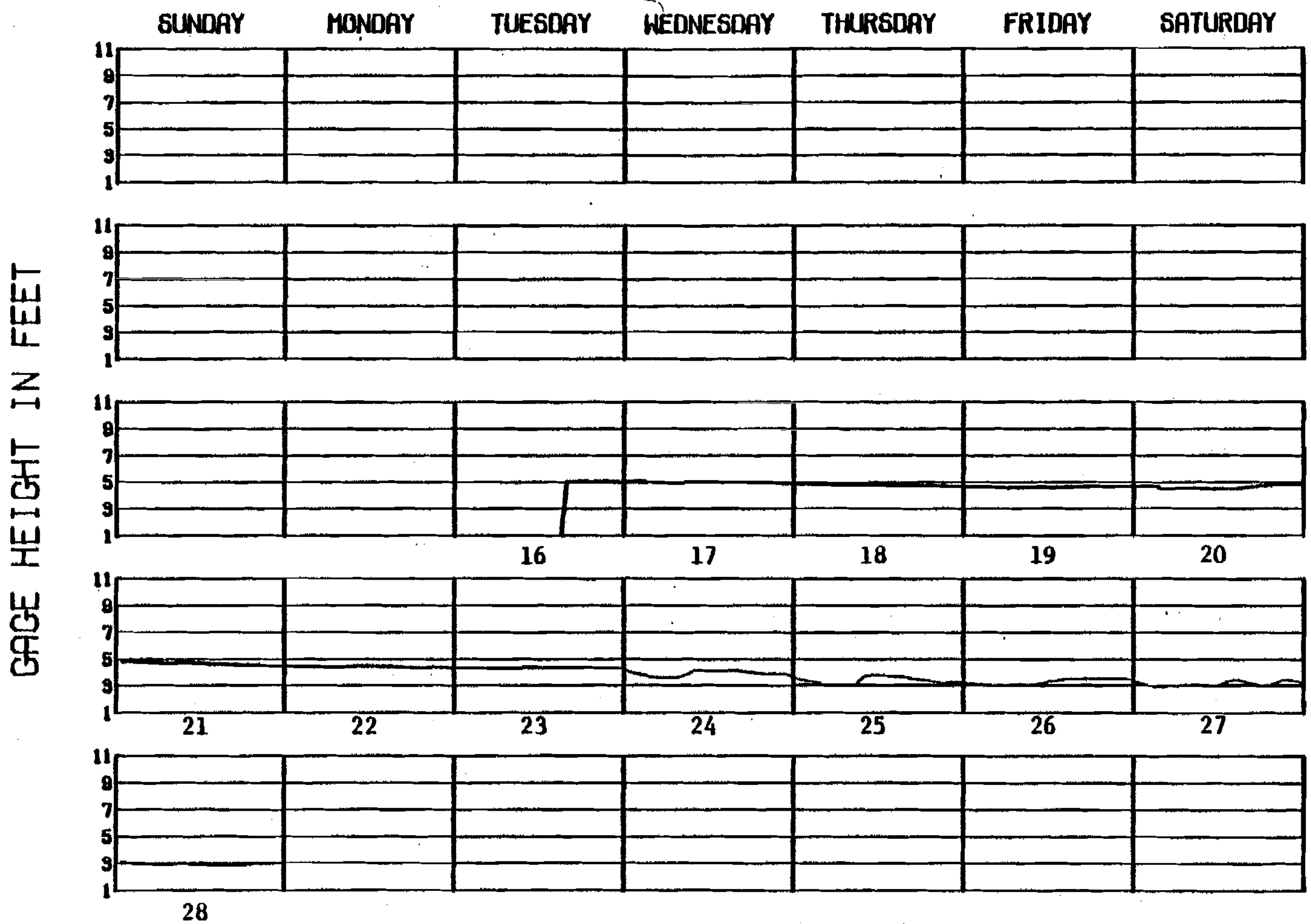


Appendix I Figure 5. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1981 (continued).



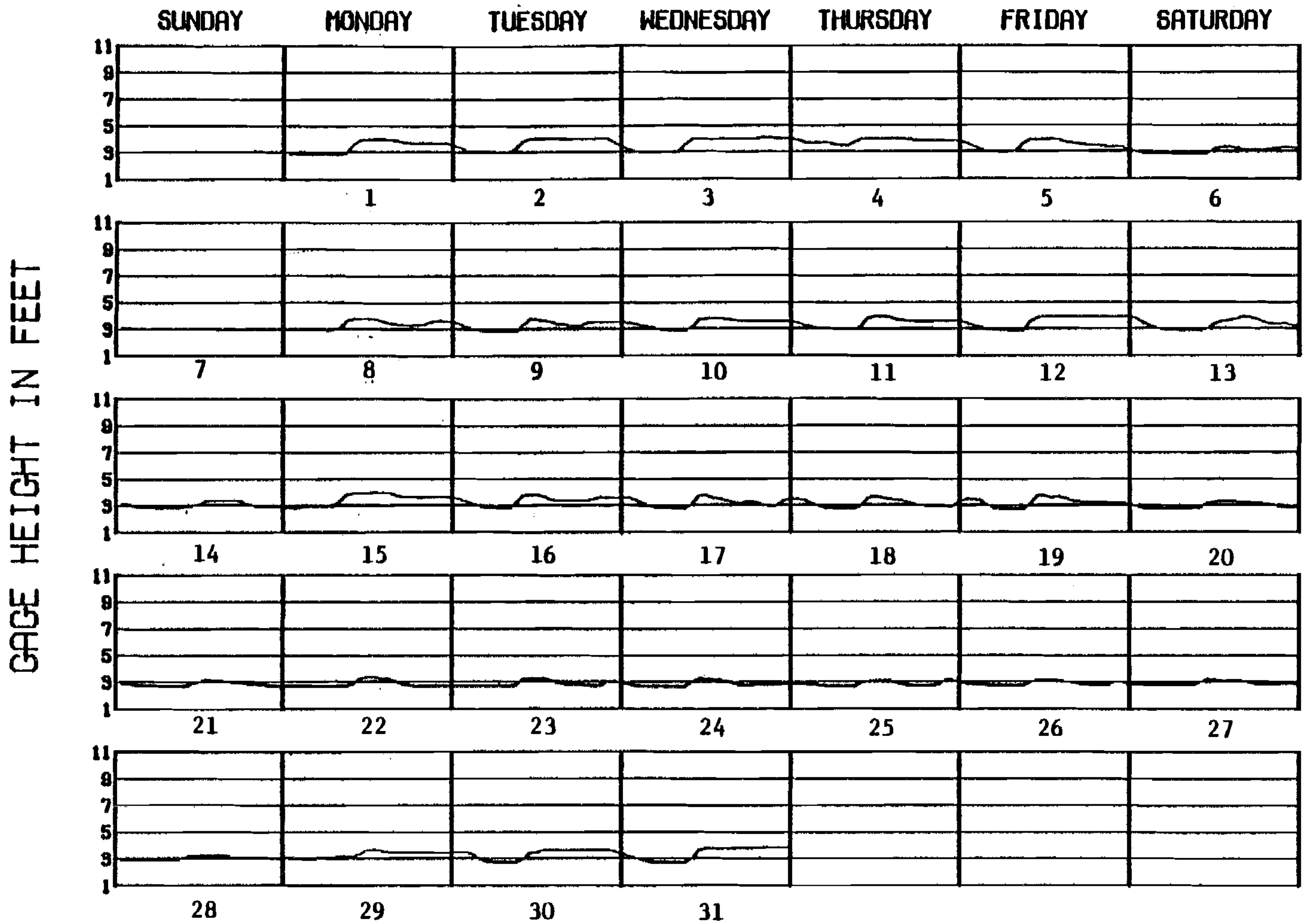
Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982.

SKAGIT R. AT MARBLEMOUNT - FEBRUARY 1982

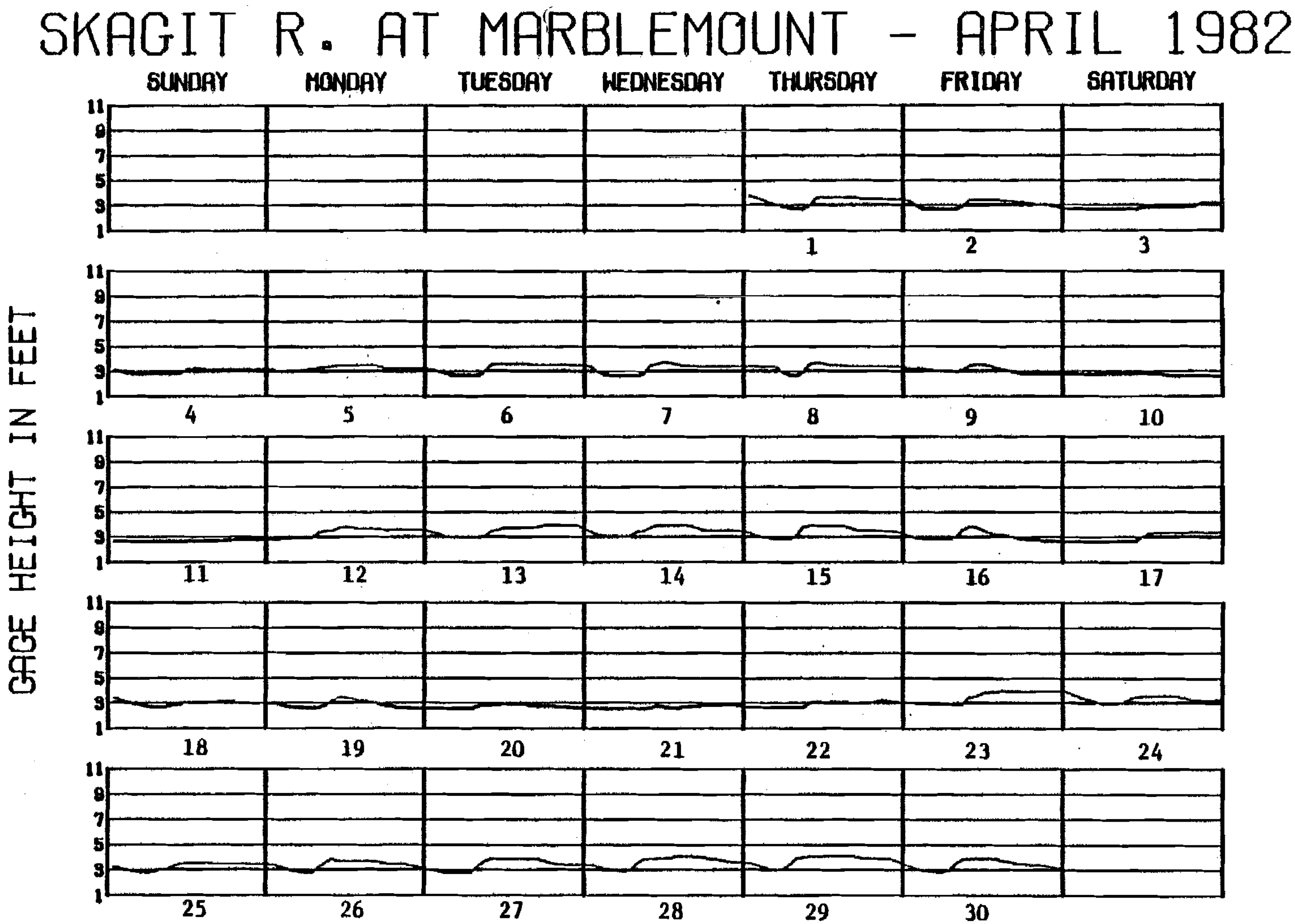


Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982 (continued).

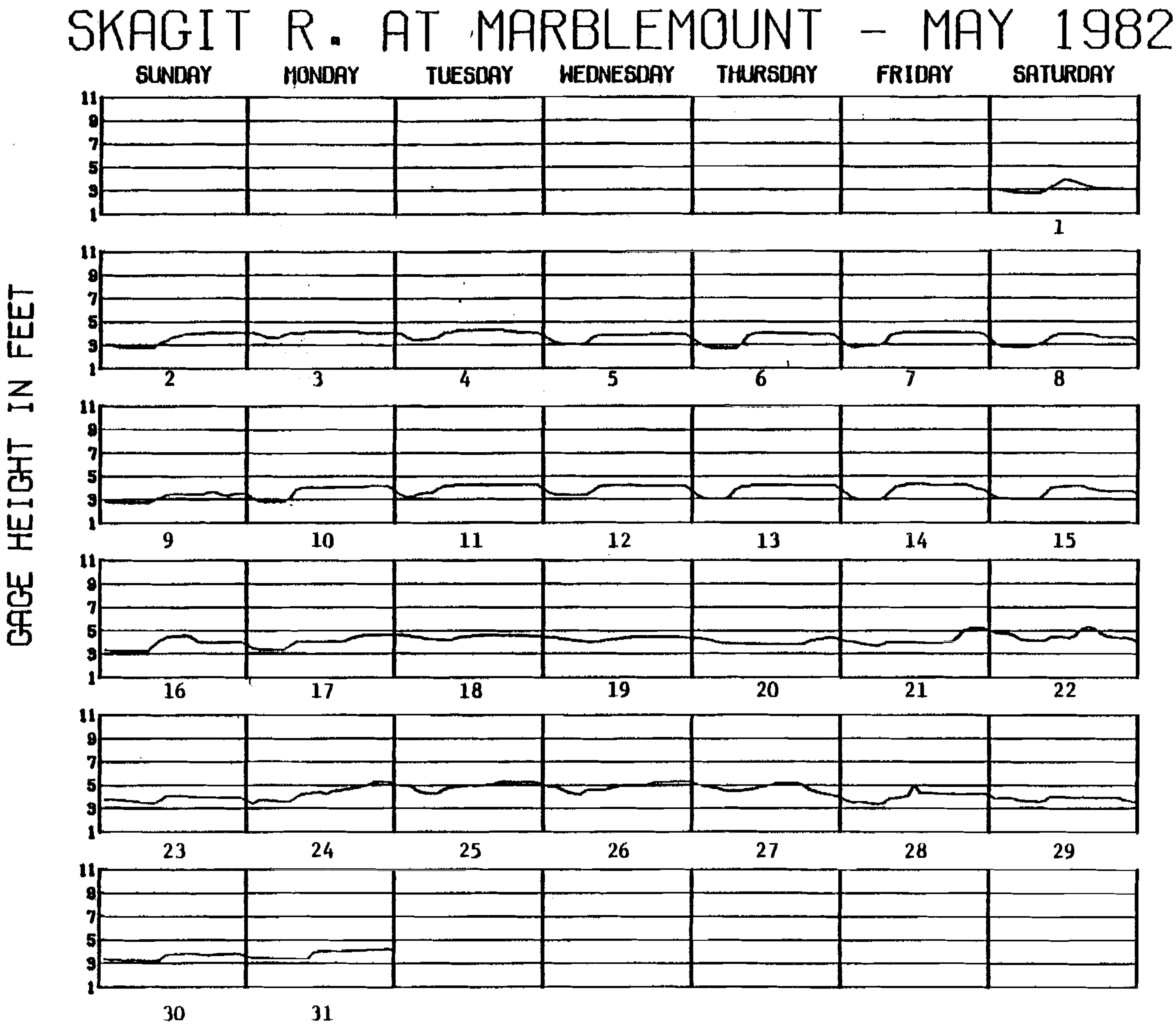
SKAGIT R. AT MARBLEMOUNT - MARCH 1982



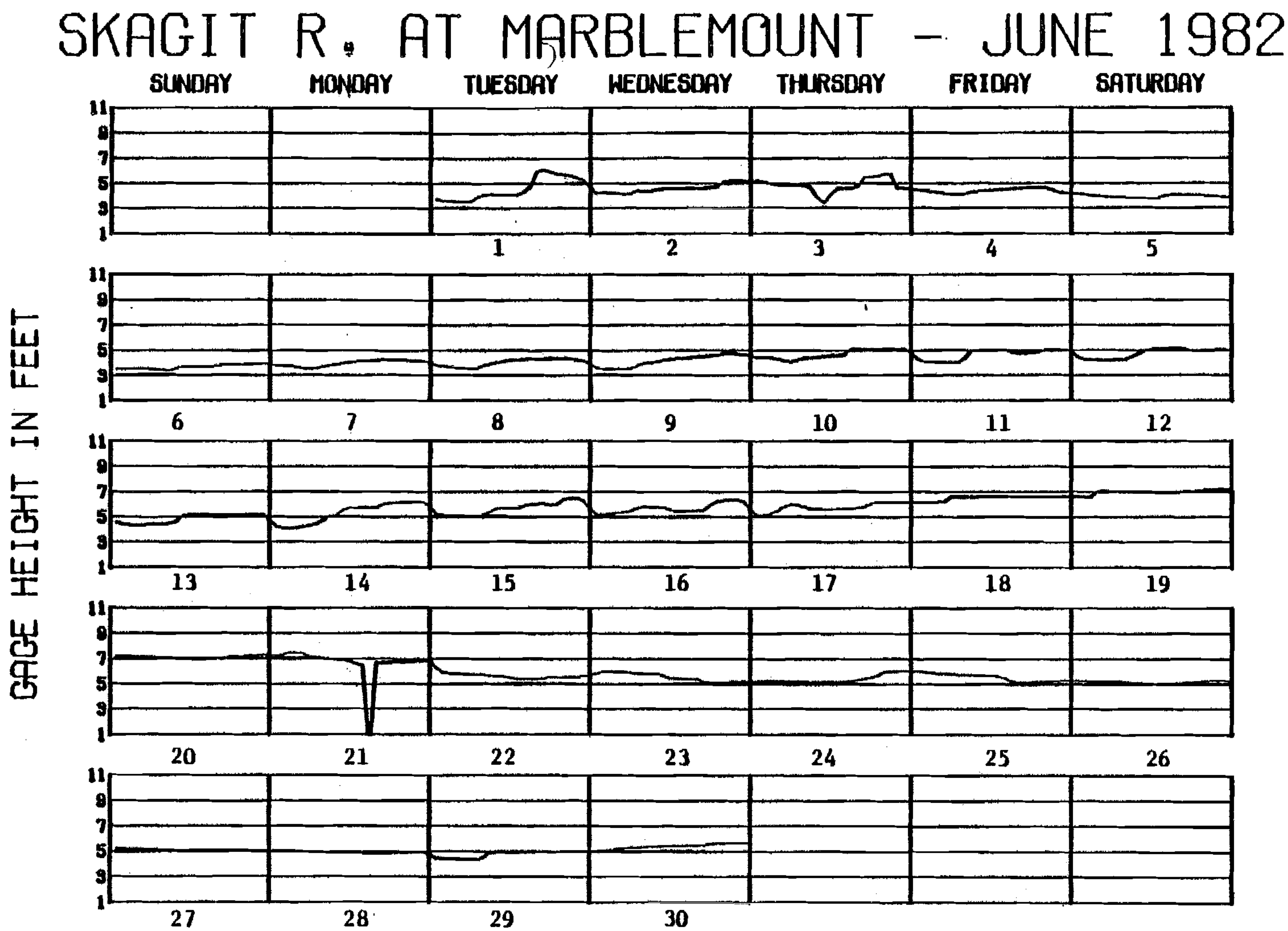
Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982 (continued).



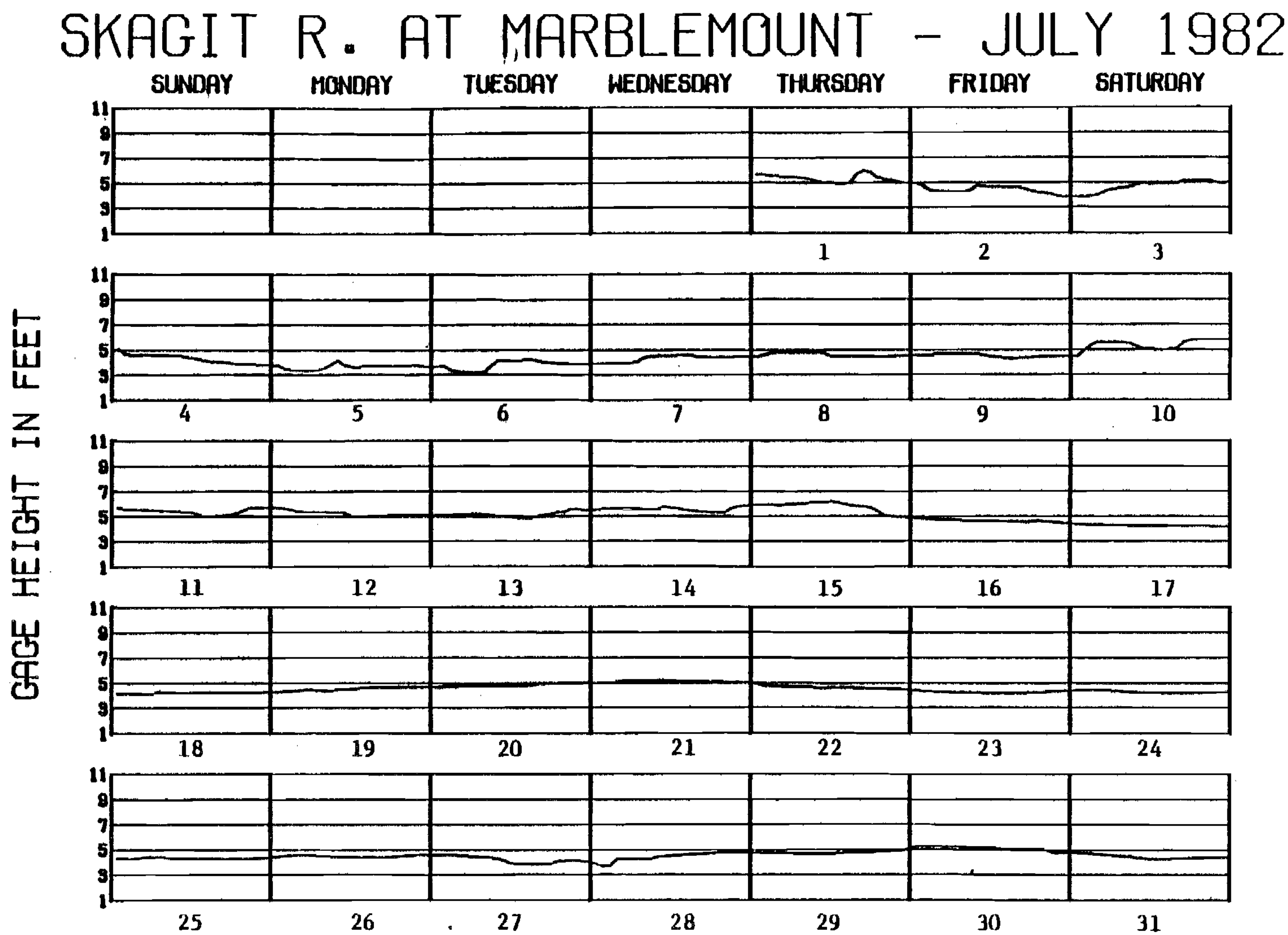
Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982 (continued).



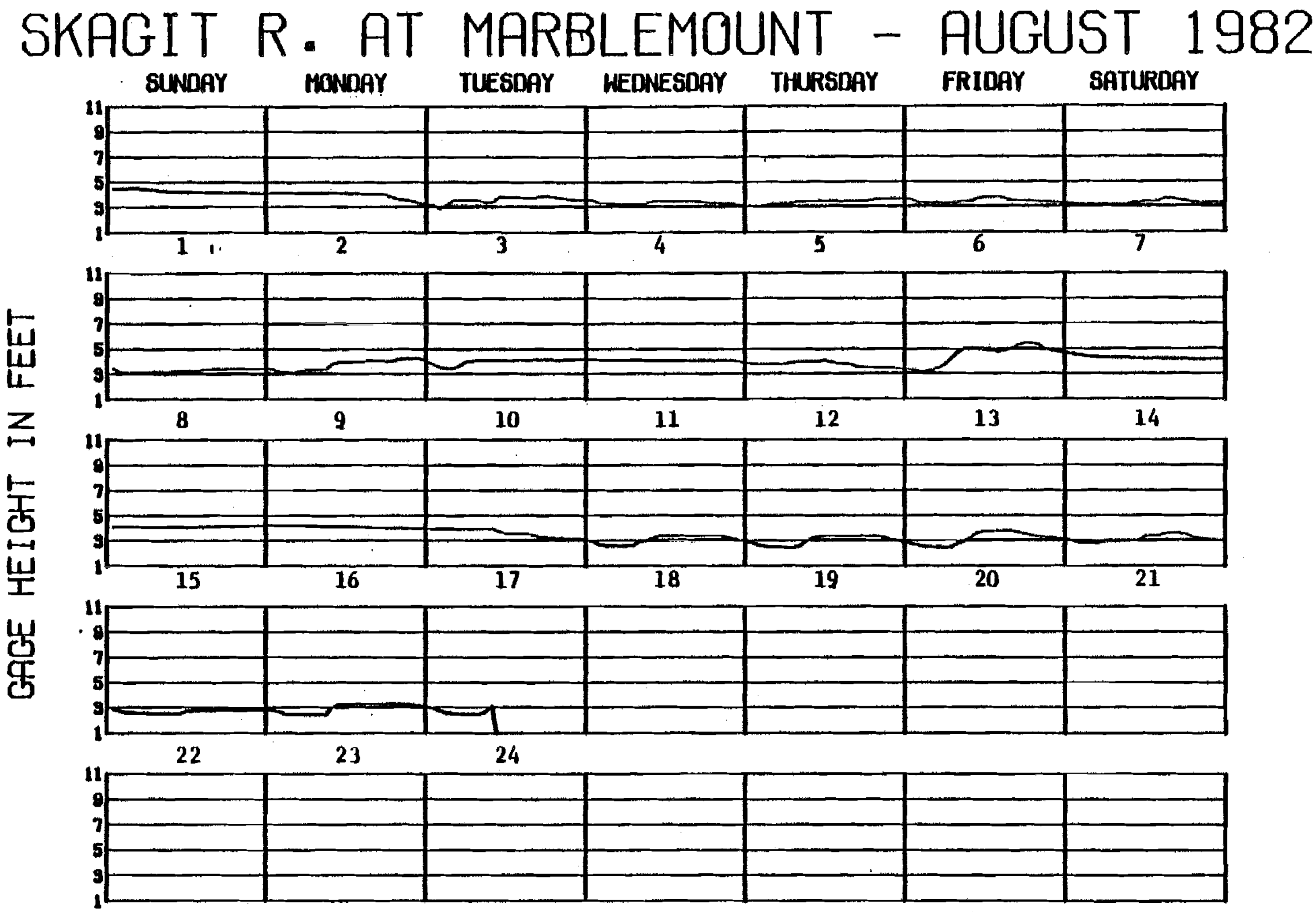
Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount, (USGS) January-December 1982 (continued).



Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982 (continued).



Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982 (continued).



Appendix I. Figure 6. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1982 (continued).

Appendix II. Table 1A. Site specific downramping data for 19 March 1982 (in feet).

USGS Newhalem gage		County line		USGS Marblemount gage		Marblemount		Rockport	
Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.
12:00 M	83.81	12:30 AM	4.60	2:00 AM	3.48	3:10 AM	4.72	4:30 AM	4.16
1:00 AM	82.86	12:45 AM	4.60	3:00 AM	3.39	3:20 AM	4.66	5:00 AM	4.12
2:00 AM	82.20	1:00 AM	4.50	4:00 AM	3.01	3:40 AM	4.50	5:27 AM	4.03
3:00 AM	82.19	1:15 AM	4.36	5:00 AM	2.78	4:00 AM	4.34	5:50 AM	3.92
4:00 AM	82.19	1:30 AM	4.20	6:00 AM	2.74	4:20 AM	4.20	6:00 AM	3.86
		1:50 AM	4.04	7:00 AM	2.72	4:40 AM	4.08	6:55 AM	3.68
		2:00 AM	3.96			4:50 AM	4.06	7:55 AM	3.56
		2:10 AM	3.90			6:00 AM	3.92	8:10 AM	3.54
		2:15 AM	3.89					8:30 AM	3.53

Appendix II. Table 1B. Site specific downramping data for 30 March 1982.

USGS Newhalem gage		County line		USGS Marblemount gage		Marblemount		Rockport	
Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.
12:00 M	83.75	1:00 AM	4.48	2:00 AM	3.47	2:54 AM	4.74	4:40 AM	3.98
1:00 AM	82.65	1:18 AM	4.24	3:00 AM	3.33	3:00 AM	4.70	5:00 AM	3.94
2:00 AM	82.16	1:30 AM	4.12	4:00 AM	2.94	3:18 AM	4.58	5:15 AM	3.90
3:00 AM	82.16	1:48 AM	3.96	5:00 AM	2.74	3:30 AM	4.50	5:30 AM	3.86
		2:00 AM	3.88	6:00 AM	2.71	3:42 AM	4.38	5:45 AM	3.78
		2:06 AM	3.86	7:00 AM	2.70	4:00 AM	4.26	6:00 AM	3.72
		2:12 AM	3.86			4:18 AM	4.12	6:15 AM	3.64
						4:30 AM	4.06	6:40 AM	3.54
						4:42 AM	4.02	7:00 AM	3.46
						5:00 AM	3.96	7:25 AM	3.42
						5:18 AM	3.91	8:00 AM	3.38
						5:30 AM	3.90	8:30 AM	3.34
								8:45 AM	3.32
								9:00 AM	3.32

Appendix II. Table 2.
Regression of stranding index at grouped ramping rates, high (A) and moderate (B) vs. time factor.

Site 2 (A)

The regression equation is Y = 1.63 = 0.160 x 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	—	1.6304	0.3823	4.26
x 1	C2	0.15976	0.04309	3.71

The St. Dev. of Y about regression line is S = 0.6086 with (5-2) = 3 degrees of freedom.

R squared = 82.1 percent
R squared = 76.1 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	5.0929	5.0929
Residual	3	1.1113	0.3704
Total	4	6.2041	

Site 3 (A)

The regression equation is Y = 4.22 + 0.0442 x 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	—	4.2228	0.2093	20.17
x 1	C4	0.044174	0.004288	10.30

The St. Dev. of Y about regression line is S = 0.3130 with (5-2) = 3 degrees of freedom.

R squared = 97.3 percent
R squared = 96.3 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	10.39812	10.39812
Residual	3	0.29400	0.09800
Total	4	10.69212	

Site 2 (B)

The regression equation is Y = 1.96 + 0.114 x 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	—	1.956	2.656	0.74
x 1	C4	0.1137	0.1318	0.86

The St. Dev. of Y about regression line is S = 3.665 with (6-2) = 4 degrees of freedom.

R squared = 15.7 percent
R squared = -5.4 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	9.99	9.99
Residual	4	53.74	13.43
Total	5	63.73	

Site 3 (B)

The regression equation is Y = 2.11 + 0.288 x 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	—	2.1115	0.2855	7.40
x 1	C3	0.28849	0.05661	5.10

The St. Dev. of Y about regression line is S = 0.4519 with (6-2) = 4 degrees of freedom.

R squared = 86.7 percent
R squared = 83.3 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	5.3035	5.3035
Residual	4	0.8170	0.2043
Total	5	6.1205	

Appendix III. Table 1. Skagit summer-fall chinook tagging data, 1980.

Date	Location	Ref. No.	Side	Tagging Data		
				Disk	Tab	Flagging
9/3/80	Right bank riffle at R.M. 81.2	1	R L	none none	none none	pink none
				*"Snag tag" used Uncertain of sex of fish		
9/3/80	Right bank riffle at R.M. 78.1	2	R L	none none	none none	blue none
				*"Snag tag" used Uncertain of sex of fish		
9/3/80	Left bank riffle at R.M. 78.7	3	R L	none none	none none	Orange none
				*"Snag tag" used Uncertain of sex of fish		
9/8/80	Right bank riffle at R.M. 78.1	4	R L	pink pink	pink pink	pink pink
				Fish was nearly spawned out		
9/8/80	Right bank riffle at R.M. 78.1	5	R L	red red	red red	white white
				Fish was unspawned		
9/8/80	Left bank riffle at R.M. 78.3	6	R L	yellow yellow	yellow yellow	yellow yellow
				Fish was one-half spawned out		
9/8/80	Left bank riffle at R.M. 82.5	7	R L	pink pink	pink pink	pink pink
				Fish was three-fourths spawned out		
9/8/80	Right bank riffle at R.M. 78.1	8	R L	yellow yellow	yellow yellow	yellow yellow
				Fish was one-fourth spawned out		

Appendix III. Table 1 (continued)

Date	Location	Ref. No.	Side	Tagging Data		
				Disk	Tab	Flagging
9/8/80	Right bank riffle at R.M. 78.1	9	R L	pink yellow	pink yellow	pink yellow
				Fish was one-fourth spawned out		
9/9/80	Right bank riffle at R.M. 78.3	10	R L	orange orange	red red	orange orange
				Fish was three-fourths spawned out		
9/9/80	Left bank riffle at R.M. 78.7	11	R L	pink pink	pink pink	pink pink
				Fish was three-fourths spawned out		
9/15/80	Left bank riffle at R.M. 78.6	12	R L	pink pink	yellow yellow	yellow yellow
				Fish was one-fourth spawned out		
9/15/80	Left bank riffle at R.M. 78.6	13	R L	orange orange	white white	white white
				Fish was one-fourth spawned out		
9/15/80	Left bank riffle at R.M. 78.3	14	R L	orange orange	red red	orange orange
				Fish was unspawned		
9/15/80	Right bank riffle at R.M. 78.1	15	R L	yellow yellow	yellow yellow	yellow yellow
				Fish was three-fourths spawned out.		
9/16/80	Left bank riffle at R.M. 81.9	16	R L	pink pink	pink pink	pink pink
				Fish was unspawned		
9/16/80	Left bank riffle at R.M. 82.5	17	R L	orange orange	red red	orange orange
				Fish was unspawned		
9/16/80	Left bank riffle at R.M. 82.5	18	R L	orange orange	red red	white white
				Fish was one-fourth spawned out		
9/16/80	Right bank riffle at R.M. 81.2	19	R L	yellow yellow	yellow yellow	yellow yellow
				Fish was one-half spawned out		

Appendix III. Table 1 (continued)

Date	Location	Ref. No.	Side	Tagging Data Disk	Tab	Flagging
9/16/80	Left bank riffle at R.M. 79.0	20	R L	yellow yellow	red red	none none
				Fish was unspawned		
9/16/80	Left bank riffle at R.M. 79.0	21	R L	pink pink	pink pink	pink pink
				Fish was nearly spawned out		
9/16/80	Right bank riffle at R.M. 78.3	22	R L	white white	red red	none none
				Fish was unspawned		
9/16/80	Right bank riffle at R.M. 78.1	23	R L	white white	red red	none none
				Fish was unspawned		
9/16/80	Right bank riffle at R.M. 78.1	24	R L	pink pink	pink pink	none none
				Fish was unspawned		
9/16/80	Right bank riffle at R.M. 78.1	25	R L	yellow yellow	red red	none none
				Fish was one-fourth spawned out		
9/16/80	Right bank riffle at R.M. 78.1	26	R L	orange orange	yellow yellow	none none
				Fish was one-half spawned out		
9/16/80	Right bank riffle at R.M. 78.1	27	R L	white white	blue blue	none none
				Fish was three-fourths spawned out		
9/16/80	Right bank riffle at R.M. 78.1	28	R L	orange orange	green green	none none
				Fish was three-fourths spawned out		
9/16/80	Right bank riffle at R.M. 78.1	29	R L	orange orange	white white	none none
				Fish was unspawned		

Appendix III. Table 2. Observation data for Skagit summer-fall chinook, 1980.

Fish Ref. No.	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior
1.	9/3/80 RB at RM 81.2 Spawning, Initial marking	9/6/80 RB at RM 81.0 resting in about 2' of water					
2.	9/3/80 RB at RM 78.1 Spawning, Initial marking	9/12/80 RB at RM 78.1 Tag found in streambed					
3.	9/3/80 LB at 78.7 Spawning, Initial marking						
4.	9/8/80 RB at RM 78.1 Spawning, Initial marking	9/14/80 RB at RM 78.3 Holding in ~2 ft. of Water					
5.	9/8/80 RB at RM 78.1 Spawning, Initial marking	9/9/80 RB at RM 78.3 Spawning	9/11/80 RB at RM 78.1 Spawning	9/15/80 RB at RM 78.3 Holding below redd Spawned out			
6.	9/8/80 LB at RM 78.3 Spawning, Initial marking	9/9/80 LB at RM 78.3 Spawning	9/11/80 LB at RM 78.3 protecting redd	9/12/80 LB at RM 78.3 protecting redd	9/13/80 LB at RM 78.3 protecting redd	9/14/80 LB at RM 78.3 holding below redd	9/15/80 LB at RM 78.3 Found dead just below redd

Appendix III.

Table 2. Observation data for Skagit summer-fall chinook, 1980 (continued).

Fish Ref. No.	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior
7.	9/8/80 LB at RM 82.5 Spawning, Initial marking	9/11/80 LB at RM 82.5 resting near redd	9/12/80 LB at RM 82.5 Protecting redd	9/16/80 LB at RM 82.3 Resting in shallow water spawned out	9/18/80 LB at RM 82.5 Spawned out		
8.	9/8/80 RB at RM 78.1 Spawning, Initial marking	9/12/80 RB at RM 78.1 Spawning					
9.	9/8/80 RB at RM 78.1 Spawning, Initial marking	9/15/80 RB at RM 78.1 Recovered in net spawned out	9/16/80 RB at RM 78.1 Still hanging around-spawned out				
10.	9/9/80 RB at RM 78.3 Spawning, Initial marking	9/16/80 RB at RM 78.2 Found dead Completely spawned out					
11.	9/9/80 LB at RM 78.7 Spawning, Initial marking	9/11/80 LB at RM 78.7 Spawning					

Appendix III.

Table 2. Observation data for Skagit summer-fall chinook, 1980 (continued).

Fish Ref. No.	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior
12.	9/15/80 LB at RM 78.6 Spawning, Initial marking	9/16/80 LB at RM 78.6 Spawning	9/18/80 LB at RM 78.6 Spawned out				
13.	9/15/80 LB at RM 78.6 Spawning Initial marking	9/16/80 LB at RM 78.6 Spawning	9/17/80 LB at RM 78.6 Spawning				
14.	9/15/80 LB at RM 78.3 Spawning Initial marking	9/16/80 RB at RM 78.3 Spawned out	9/17/80 RB at RM 78.3 Spawned out	9/18/80 RB at RM 78.3 Spawned out	9/19/80 RB at RM 78.2 Holding in shallow water below redd	9/21/80 RB at RM 78.2 Just barely hanging on	
15.	9/15/80 RB at RM 78.1 Spawning Initial marking	9/16/80 RB at RM 78.1 Spawning	9/17/80 RB at RM 78.1 Spawning				
16.	9/16/80 LB at RM 81.9 Spawning Initial marking	9/17/80 LB at RM 81.9 Spawning	9/18/80 LB at RM 81.9 Spawning	9/19/80 LB at RM 81.9 Holding below redd, spawned out			
17.	9/16/80 LB at RM 82.5 Spawning Initial marking	9/17/80 LB at RM 82.5 Spawning	9/18/80 LB at RM 79.0 holding in ~ 2' of water				

Appendix III.

Table 2. Observation data for Skagit summer-fall chinook, 1980 (continued).

Fish Ref. No.	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior
18.	9/16/80 LB at RM 82.5 Spawning Initial marking						
19.	9/16/80 RB at RM 81.2 Spawning Initial Marking	9/17/80 RB at RM 81.2 Spawning	9/18/80 RB at RM 81.2 Holding below redd	9/19/80 RB at RM 81.2 Spawned out below redd			
20.	9/16/80 LB at RM 79.0 Spawning Initial marking	9/17/80 LB at RM 79.0 Spawning	9/18/80 LB at RM 79.0 Holding near redd	9/21/80 LB at RM 79.0 Holding below redd			
21.	9/16/80 LB at RM 79.0 Spawning Initial marking	9/17/80 LB at RM 79.0 Spawning					
22.	9/16/80 RB at RM 78.3 Spawning Initial marking						
23.	9/16/80 RB at RM 78.1 Spawning Initial marking	9/17/80 RB at RM 78.1 Spawning	9/18/80 RB at RM 78.1 Spawning	9/21/80 RB at RM 78.1 Holding near redd			

Appendix III.

Table 2. Observation data for Skagit summer-fall chinook, 1980 (continued).

	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior	Date Location Behavior
24.	9/16/80 RB at RM 78.1 Spawning Initial marking	9/18/80 RB at RM 78.1 Spawning					
25.	9/16/80 RB at RM 78.1 Spawning Initial marking	9/18/80 RB at RM 78.1 Spawning					
26.	9/16/80 RB at RM 78.1 Spawning Initial marking						
27.	9/16/80 RB at RM 78.1 Spawning Initial marking						
28.	9/16/80 RB at RM 78.1 Spawning Initial marking						
29.	9/16/80 RB at RM 78.1 Spawning Initial marking	9/17/80 RB at RM 78.1 Spawning	9/18/80 RB at RM 78.1 Spawning				

Appendix III

Table 3. Observation dates and conditions for Skagit summer-fall chinook, 1980.

Date	Type Survey	Location(s)	Observation Conditions
9/3/80	Boat Survey	RM 78 to RM 85	Good, flow moderate, water clear, weather clear
9/4/80	Boat Survey	RM 78 to 83	Good, flow moderate, water clear, weather clear
9/5/80	Boat Survey	RM 78 to 83	Good, flow moderate, water clear, weather clear
9/6/80	Foot Survey Spot Checks	RM 78.1 to RM 78.3 RM 78.5 to RM 78.6 RM 78.65 to RM 78.75	Good, flow low, water clear, weather clear
9/7/80	Foot Survey Spot Checks	RM 78.1 to RM 78.3 RM 78.5 to RM 78.6 RM 78.65 to 78.75	Fair, flow low, water clear, weather overcast and raining
9/8/80	Boat Survey	RM 78.0 to RM 83.0	Good, flow moderate, water clear, weather clear
9/9/80	Boat Survey	RM 78.0 to RM 83.0	Good, flow moderate, water clear, weather clear
9/10/80	Foot Survey	RM 78.1 to RM 78.2	Good, flow moderate, water clear, weather clear
9/11/80	Foot Survey Boat Survey	RM 78.1 to RM 78.2 RM 78.0 to RM 83.0	Good, flow moderate, water clear, weather clear
9/12/80	Boat Survey	RM 78.0 to RM 83.0	Fair, flow moderate, water clear, weather overcast
9/13/80	Boat Survey	RM 78.0 to 83.0	Good, flow low, water clear, weather clear
9/14/80	Boat Survey	RM 78.0 to 83.0	Good, flow low, water clear, weather clear
9/15/80	Boat Survey	RM 78.0 to 84.0	Good, flow moderate, water clear, weather clear
9/16/80	Boat Survey	RM 76.0 to 83.0	Good, flow moderate, water clear, weather clear
9/17/80	Boat Survey	RM 78.0 to 83.0	Good, flow low, water clear, weather clear
9/18/80	Boat Survey	RM 78.0 to 83.0	Fair, flow moderate, water clear, weather cloudy and raining

Appendix III.
Table 3. Observation dates and conditions for Skagit summer-fall chinook, 1980 (continued).

Date	Type Survey	Location(s)	Observation Conditions
9/19/80	Boat Survey	RM 78.0 to 83.0	Poor, flow moderate, water slightly turbid, weather overcast and raining hard
9/21/80	Boat Survey	RM 78.0 to 83.0	Poor, flow moderate, water moderately turbid, weather cloudy and raining

Appendix III. Table 4. Skagit summer-fall chinook tagging data, 1980.
Observation dates, September 1980.

Fish Reference Number	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20 1/	21
1	*	-	-	@	-	-	-	-	-	-	-	-	-	-	-	-	-		-
2	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
3	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
4						*	-	-	-	-	-	@	-	-	-	-	-		-
5						*	0	-	0	-	-	-	X	-	-	-	-		-
6						*	0	-	0	0	0	0	#						
7						*	-	-	0	0	-	-	-	X	-	X	-		-
8						*	-	-	-	0	-	-	-	-	-	-	-		-
9						*	-	-	-	-	-	-	X	X	-	-	-		-
10							*	-	-	-	-	-	-	#					
11							*	-	0	-	-	-	-	-	-	-	-		-
12													*	0	-	X	-		-
13													*	0	0	-	-		-
14													*	X	X	X	X		X
15													*	0	0	-	-		-
16														*	0	0	X		-
17														*	0	@	-		-
18														*	-	-	-		-
19														*	0	0	X		-
20														*	0	0	-		0
21														*	0	-	-		-
22														*	-	-	-		-
23														*	0	0	-		0
24														*	-	0	-		-
25														*	-	0	-		-
26														*	-	-	-		-
27														*	-	-	-		-
28														*	-	-	-		-
29														*	0	0	-		-

Key:
- * initial marking
- 0 observed in vicinity or redd
- - not seen during observation period
- X recovered spawned out
- # recovered dead
- @ observed away from red
- 1/ No observation conducted

Appendix III

Table 5. Skagit chum salmon tagging data, 1980.

Date Time	Location	Ref. No.	Tagging Data: Color – Disk	Tagging Data: Color – Tab	Tagging Data: No.
12/1/80 1900 hrs	Mouth of Marblemount Slough	1	White	Orange	3946
12/1/80 1930 hrs	Mouth of Marblemount Slough	2	White	Pink	3943
12/3/80 1600 hrs	Marblemount Slough 100 yds above mouth	3	Orange	Yellow	1074
12/3/80 1630 hrs	Marblemount Slough 100 yds above mouth	4	Orange	White	1073
12/3/80 1730 hrs	Marblemount Slough 100 yds above mouth	5	Orange	Orange	1072
12/7/80 1130 hrs	Marblemount Slough 120 yds above mouth	6	Orange	Pink	1071
12/7/80 1830 hrs	Marblemount Slough 120 yds above mouth	7	Yellow	White	4959

Appendix III.

Table 6. Observation data for Skagit chum salmon, 1980.

Ref. No.	Date - Time Location Behavior	Date - Time Location Behavior	Date - Time Location Behavior	Date - Time Location Behavior
1	12/1/80 - 1900 Mouth of Marblemount Slough entering slough to spawn, initial marking			
2	12/1/80 - 1930 Mouth of Marblemount Slough entering slough to spawn, initial marking	12/7/80 - 1200 130 yds above mouth of Marblemount Slough, holding on riffle subsequently caught in net, was spawned out	12/8/80 - 1400 115 yds above mouth of Marblemount Slough, resting in fairly deep water	12/15/80 100 yds above mouth of Marblemount Slough, dead
3	12/3/80 - 1600 100 yds above mouth of Marblemount Slough, chased off riffle into net, initial marking	12/4/80 - 0840 130 yds above mouth of Marblemount Slough, holding just above spawning riffle	12/7/80 - 150 yds above mouth of Marblemount Slough, digging on redd in center of slough attended by one (1) male	
4	12/3/80 - 1630 100 yds above mouth of Marblemount Slough, moving up slough to spawn initial marking	12/8/80 - 1430 Mouth of Marblemount Slough milling with a group of 8 chums. All looked like post spawners	12/8/80 - 1700 100 yds above mouth of Marblemount Slough, recaptured in net while moving up slough, spawned out	12/12/80 - 1515 120 yds above mouth of Marblemount Slough, holding in riffle, no males present
5	12/3/80 - 1730 100 yds above mouth of Marblemount Slough, moving up slough to spawn, Initial marking	12/4/80 - 0840 115 yds above mouth of Marblemount Slough, digging on redd, attended by two (2) males	12/8/80 - 1400 115 yds above mouth of Marblemount Slough, holding on redd, no males around	12/8/80 - 1700 100 yds above mouth of Marblemount Slough, recaptured in net while moving up slough, spawned out
6	12/7/80 - 1130 120 yds above mouth of Marblemount Slough, chased off riffle into net, Initial marking	12/8/80 - 1700 100 yds above mouth of Marblemount Slough, recaptured in net while moving up slough, spawned out	12/10/80 - 1000 118 yds above mouth of Marblemount Slough, digging on a redd. No males around	2/15/80 - 1630 118 yds above mouth of Marblemount Slough, holding position, no males around.

Appendix III. Table 6. Observation data for Skagit chum salmon, 1980 (continued).

Ref. No.	Date - Time Location Behavior	Date - Time Location Behavior	Date - Time Location Behavior	
6	12/16/80 - 1030 110 yds above mouth of Marblemount Slough, holding position, no males around	12/17/80 - 0800 110 yds above mouth of Marblemount Slough, holding position, no males around		
7	12/7/80 - 1830 120 yds above mouth of Marblemount Slough, moving up slough to spawn. Initial marking	12/12/80 - 1500 155 yds above mouth of Marblemount Slough, guarding redd, no males around	12/14/80 - 0930 155 yds above mouth of Marblemount Slough, digging on a redd, No males present	

Appendix III.

Table 7. Observation dates and conditions for Skagit chum salmon, 1980.

Date	Type Survey	Location	Observation Conditions
12/1/80	Foot Survey	Marblemount Slough Mouth of Slough only	Night tagging operation, not a real observation. flow high, water clear
12/2/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/3/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/4/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/5/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/7/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/8/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/9/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy and snowing
12/10/80	Foot Survey	Marblemount Slough	Good, flow moderate, water slightly turbid, weather cloudy and raining
12/12/80	Foot Survey	Marblemount Slough	Fair, flow moderately high, water slightly turbid, weather overcast and raining
12/14/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather cloudy
12/15/80	Foot Survey	Marblemount Slough	Fair, flow moderate, water moderately turbid, weather cloudy
12/16/80	Foot Survey	Marblemount Slough	Fair, flow moderately high, water clear, weather cloudy
12/17/80	Foot Survey	Marblemount Slough	Excellent, flow moderate, water clear, weather clear
12/18/80	Foot Survey	Marblemount Slough	Good, flow moderate, water clear, weather overcast

Appendix III.

Table 7. Observation dates and conditions for Skagit chum salmon, 1980 (continued).

Date	Type of Survey	Location	Observation Conditions
12/19/80	Foot Survey	Marblemount Slough	Fair, flow moderate, water clear, weather overcast and raining
12/20/80	Foot Survey	Marblemount Slough	Fair, flow moderate, water clear, weather overcast and raining

Appendix III. Table 8. Skagit chum tagging data, 1980. Observation dates, December 1980.

Fish Reference Number	1	2	3	4	5	6 1/	7	8	9	10	11 1/	12	13 1/	14	15	16	17	18	19	20
1	*	-	-	-	-		-	-	-	-		-		-	-	-	-	-	-	-
2	*	-	-	-	-		X	X	-	-		-		-	#					
3			*	@	-		0	-	-	-		-		-	-	-	-	-	-	-
4			*	-	-		-	X	-	-		X		-	-	-	-	-	-	-
5			*	0	-		-	X	-	-		-		-	-	-	-	-	-	-
6							*	X	-	X		-		-	X	X	X	-	-	-
7							*	-	-	-		0		0	-	-	-	-	-	-

Key:
- * initial marking
- 0 observed in vicinity of redd
- \- not seen during observation period
- X recovered spawned out
- # recovered dead
- @ observed away from redd
- 1/ No observation conducted

Appendix IV Table 1. Steelhead Redd Depths Marblemount Area 1982. All measurements in feet.

Date	5–18	6–4	8–20	9–11	9–30
Newhalem Staff	482.2	484.8	482.3	483.5	481.3
Marblemount Staff	4.3	4.4	2.3	3.1	2.1
Depths	4.0				
	4.5				
	4.5				1.3
	4.0				
	3.25				
	2.25				
	3.0				
	2.75				-0.4
	2.75				-0.5
	3.0				
	3.0				
	4.0				
	3.0		0.0	0.4	-0.5
	3.5		1.25		
	3.25				1.3
	2.5		0.5		
	3.0				
	2.0				
	2.5				
	2.5				-0.2
	2.5				
	2.5		0.2		-0.3
	2.25		0.25		-0.35
	2.25		0.25		-0.3
	2.0				
		2.1			
		2.4			
		2.2			-0.5
		2.2			
		2.2			-0.4

Appendix IV Table 2. Steelhead Redd Depths Illabot-Corkingdale Area 1982. All measurements in feet.

Date	4-28	5-18	6-4	8-3	9-30
Newhalem Staff	484.1	481.7	484.5	483.5	481.3
Marblemount Staff	3.1	4.3	4.4	2.3	2.1
Depths	3.5	4.0			
	2.75	3.25			
	3.0	3.5			
	2.5	3.0			
	1.75	2.0			
	2.25	2.75		1.5	0.4
	1.5	2.0			
		2.75			
		2.25			
		2.0			
			2.7		
			2.0		0.0
			1.9		
			1.8		
			1.6		

Appendix IV Table 3. Steelhead Redd Depths Upper Rockport Area 1982. All measurements in feet.

Date	4-28	5-18	6-4
Newhalem Staff	483.3	481.9	484.4
Marblemount Staff	3.1	4.3	4.3
Depths	2.9		
	3.0		
	2.75	4.25	
	2.25	3.0	
	2.0	3.75	
	2.25	3.0	
	1.5		
	2.75	3.25	
	2.0		
	2.0	4.25	
	3.25	3.0	
	2.25	2.75	
			1.7
			2.2
			2.0
			2.2
			2.9

APPENDIX V

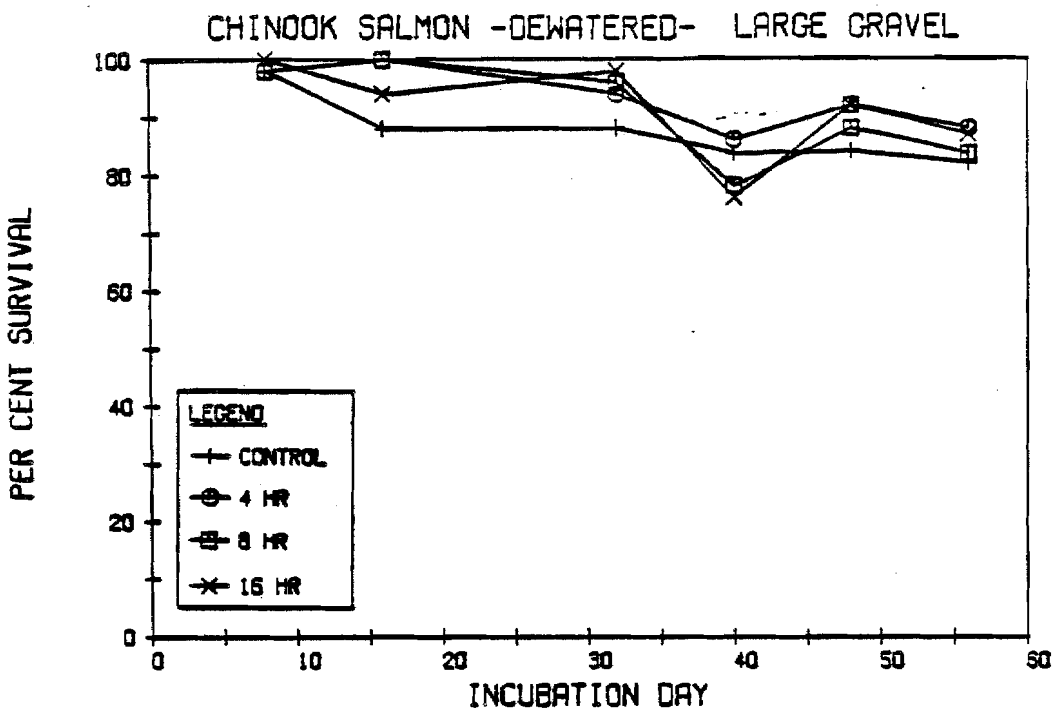


Fig. 1. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

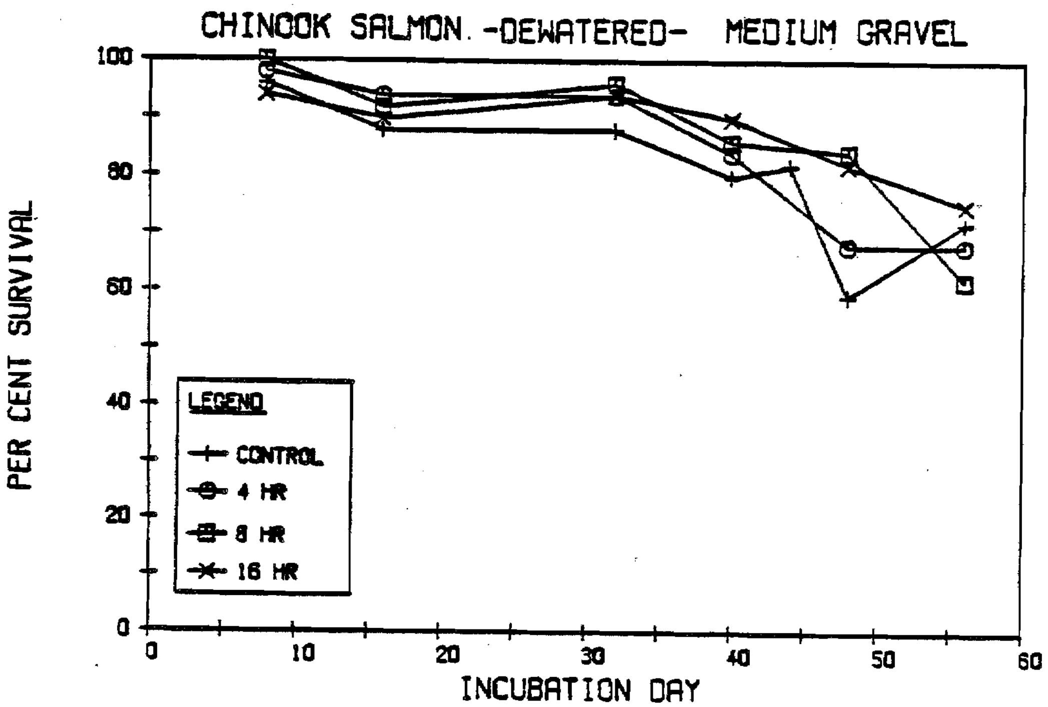


Fig. 2. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

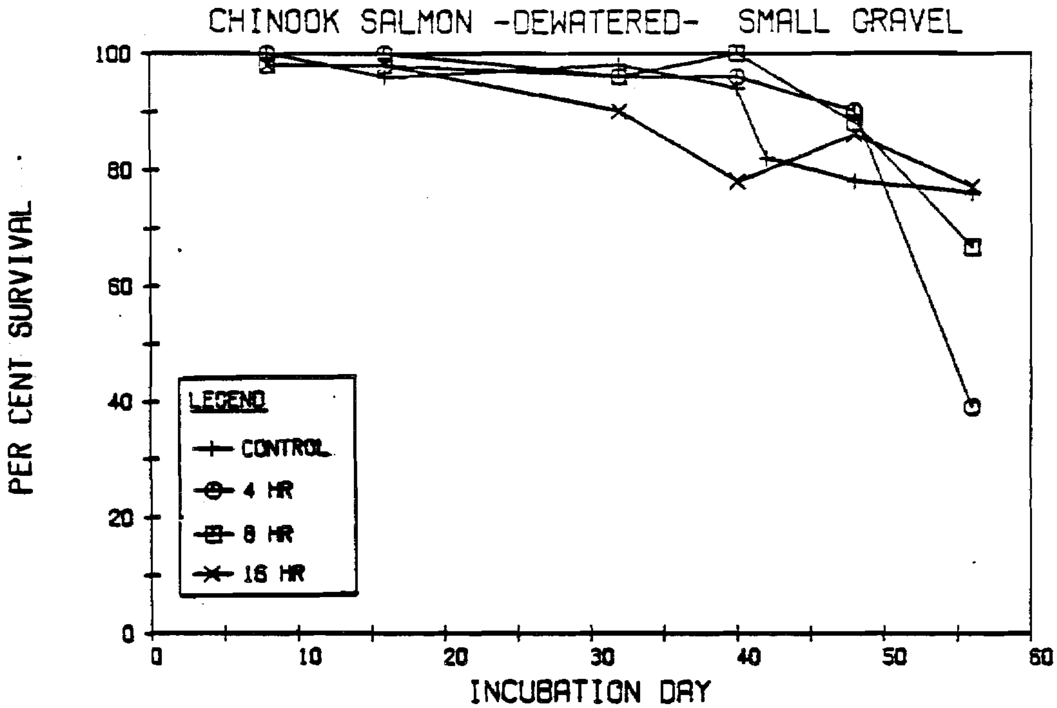


Fig. 3. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

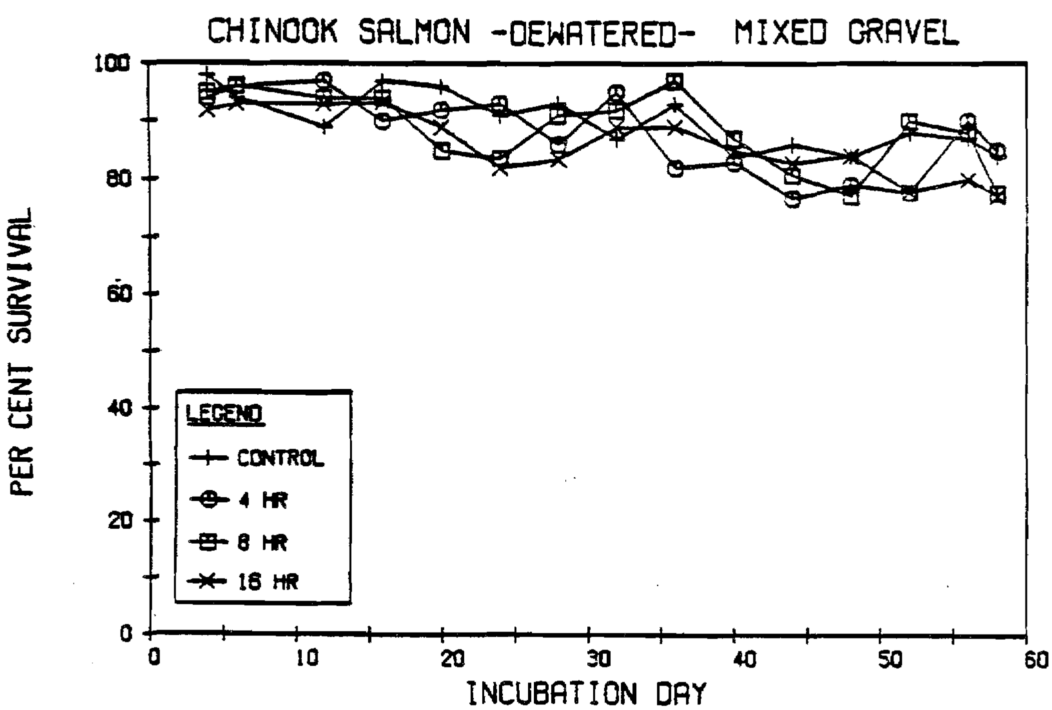


Fig. 4. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

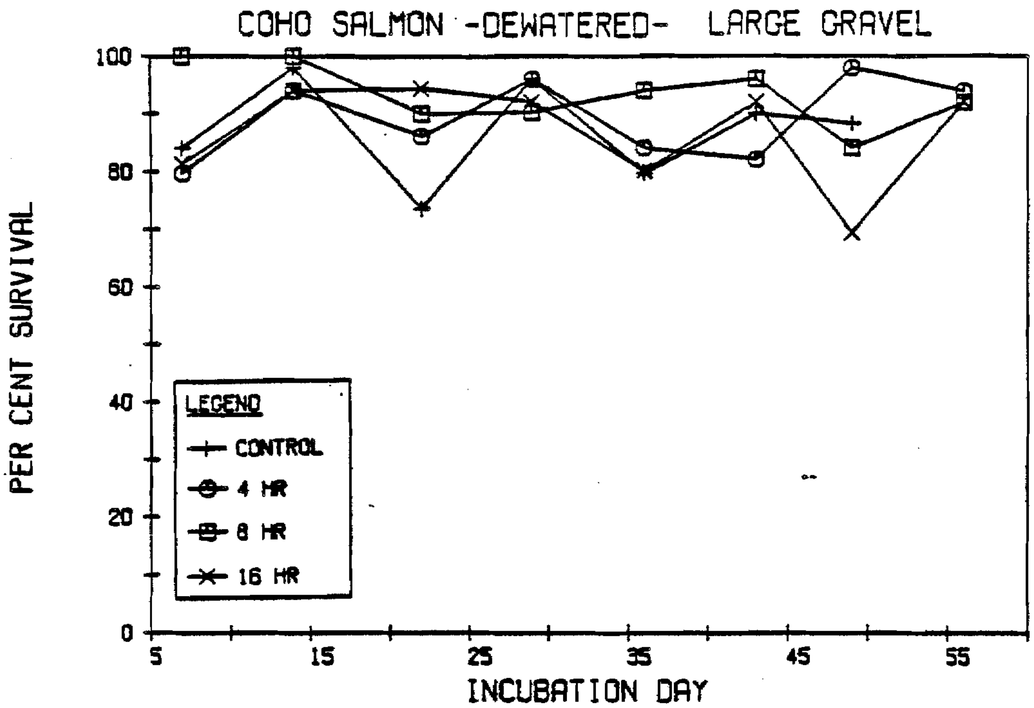


Fig. 5. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

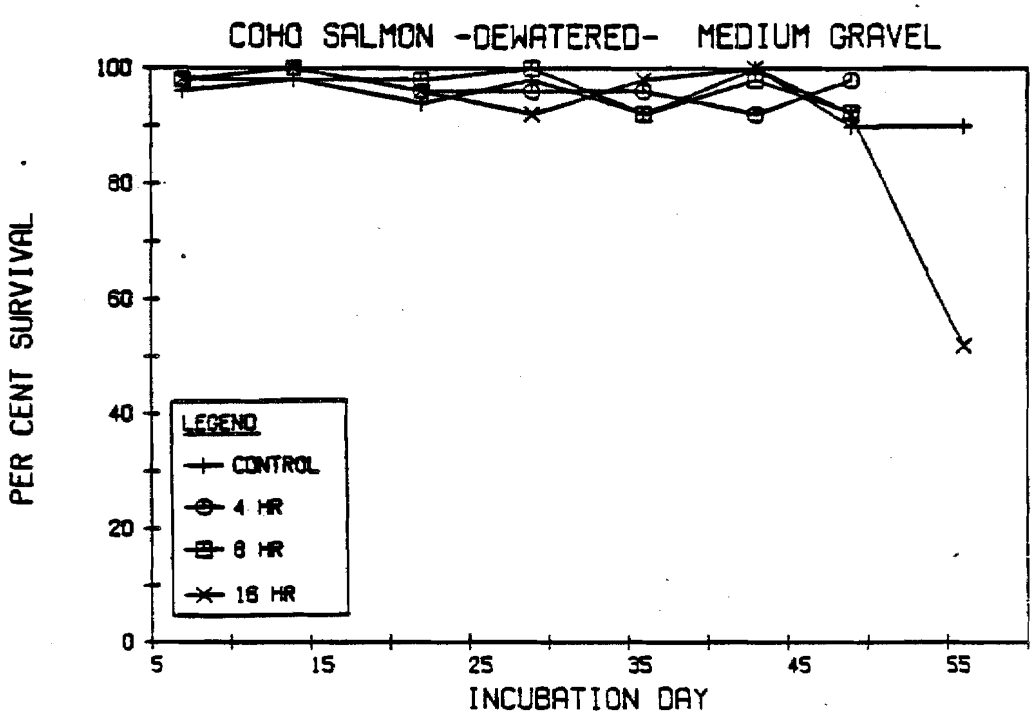


Fig. 6. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

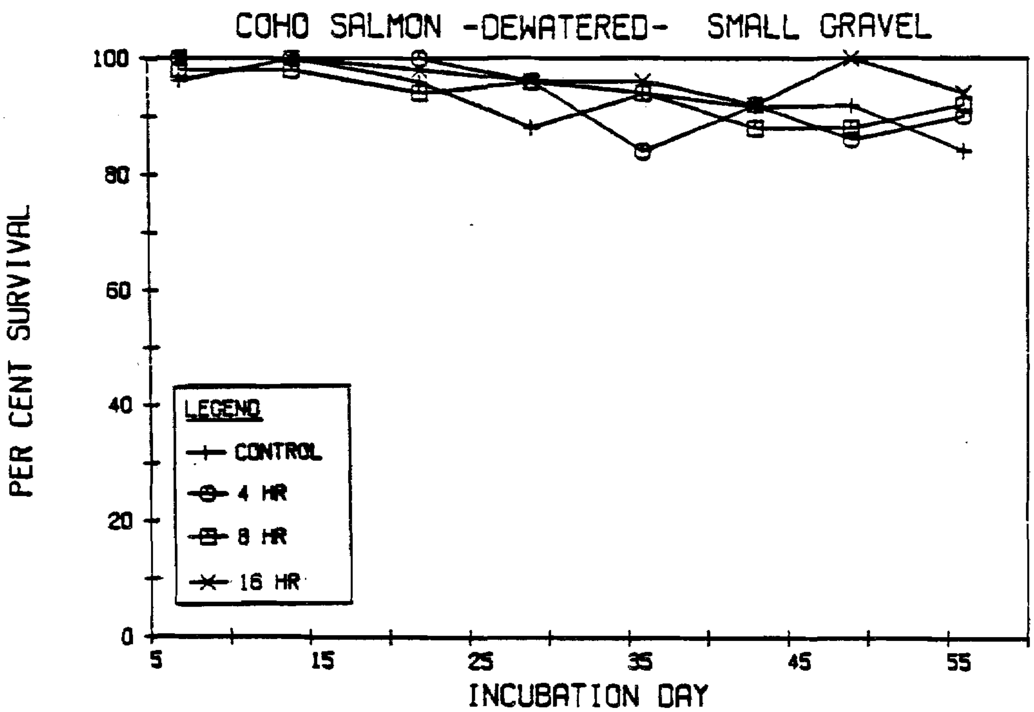


Fig. 7. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

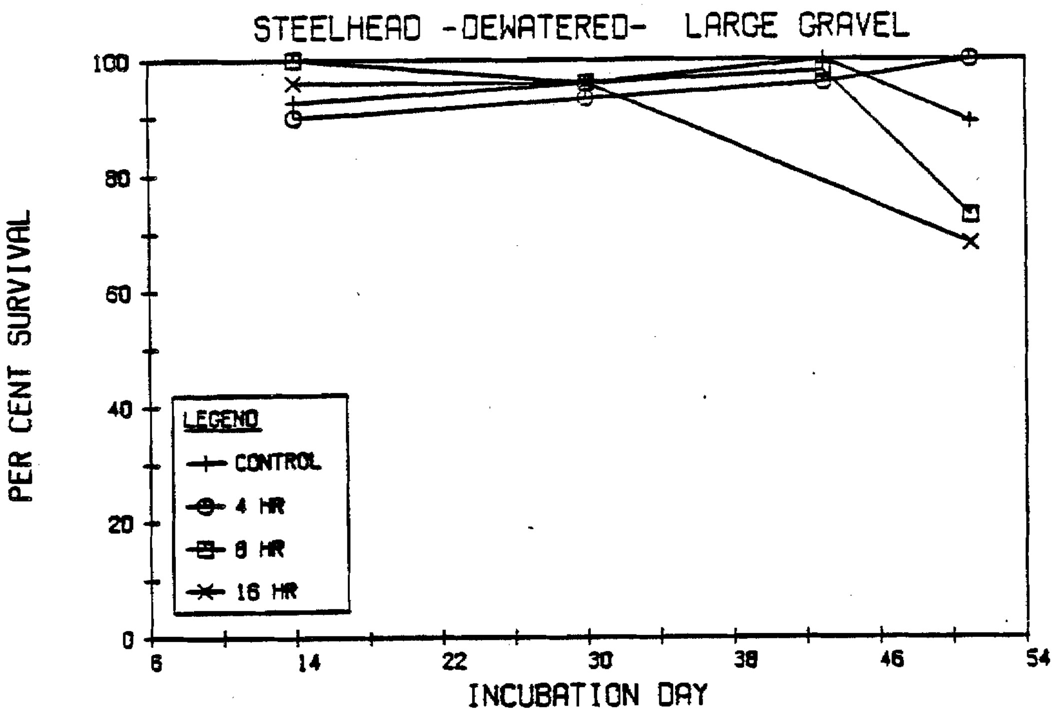


Fig. 8. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

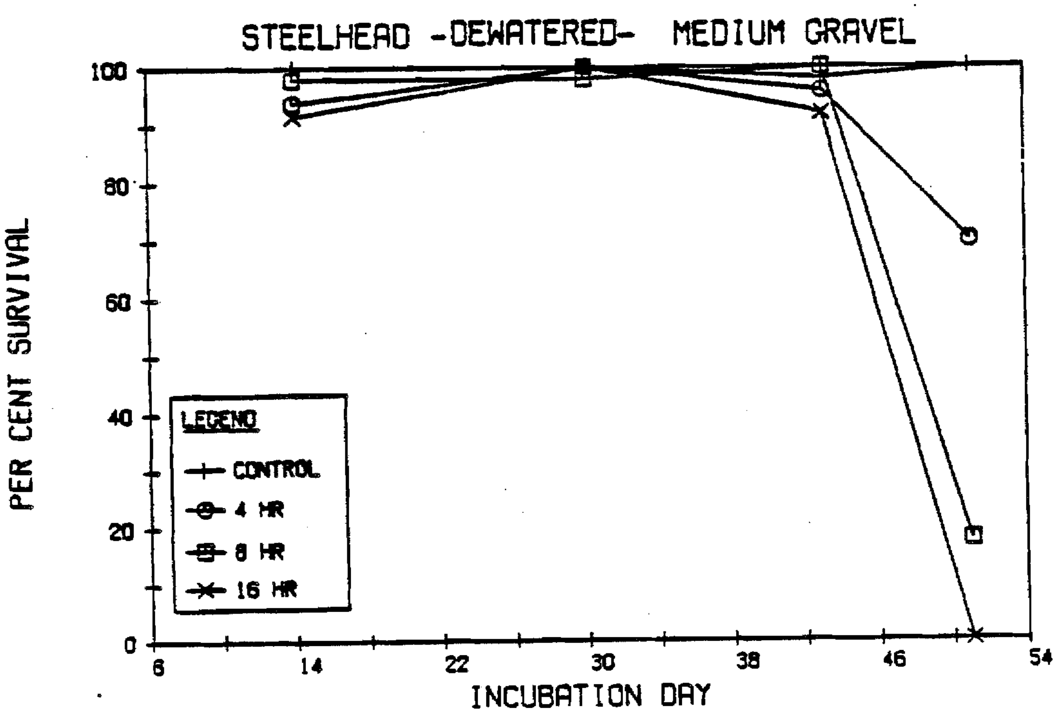


Fig. 9. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

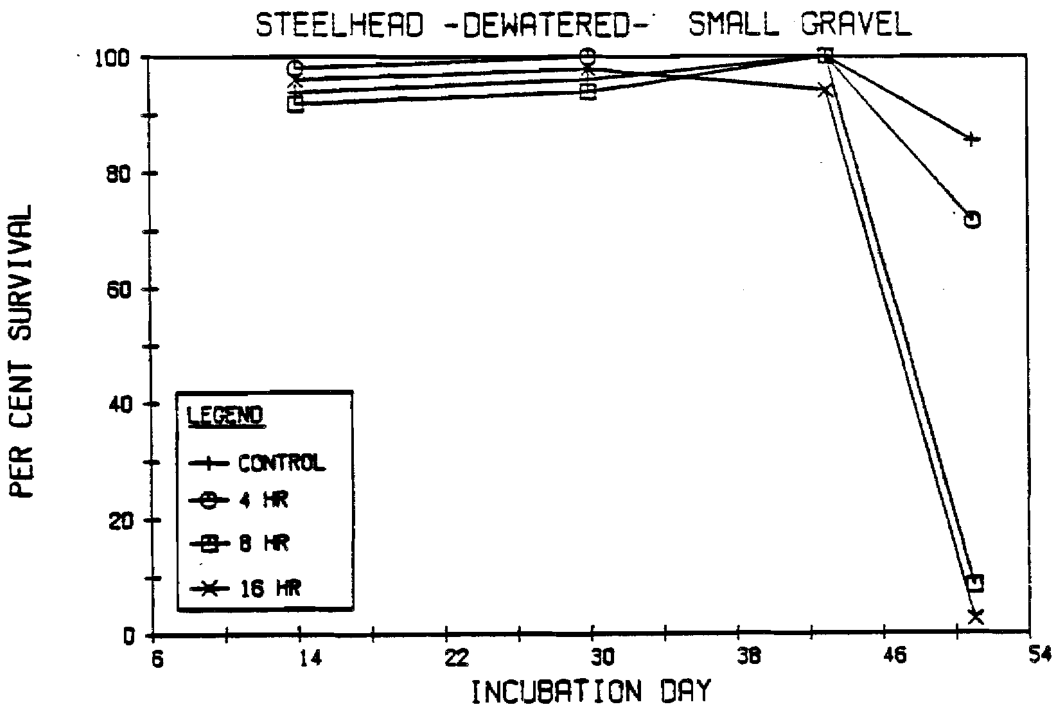


Fig. 10. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

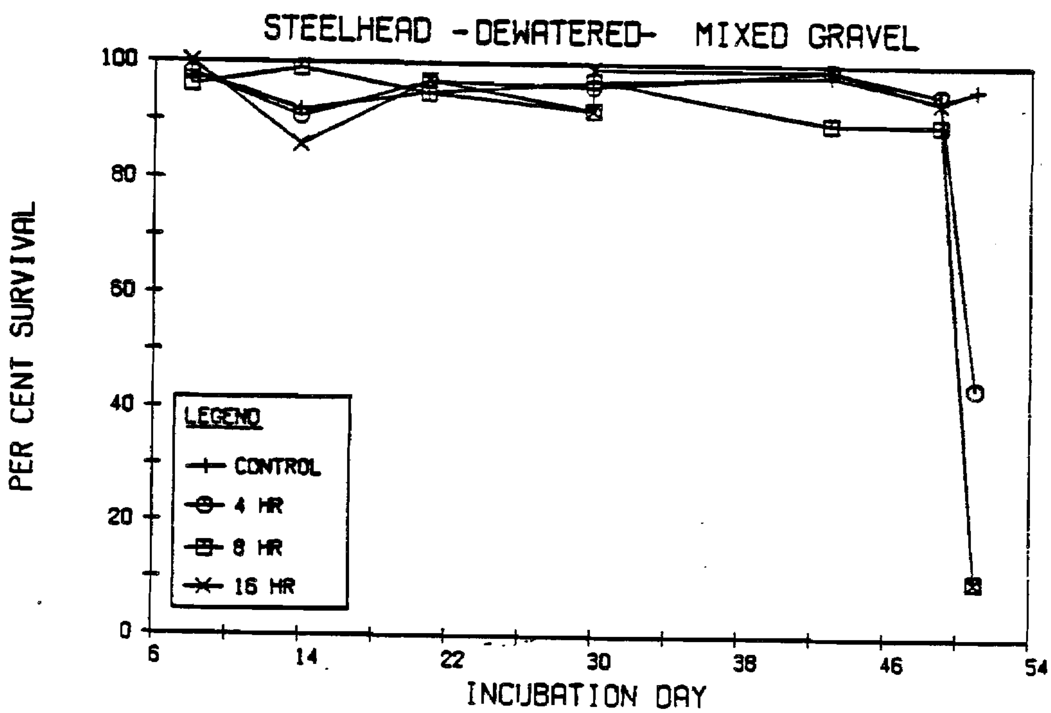


Fig. 11. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

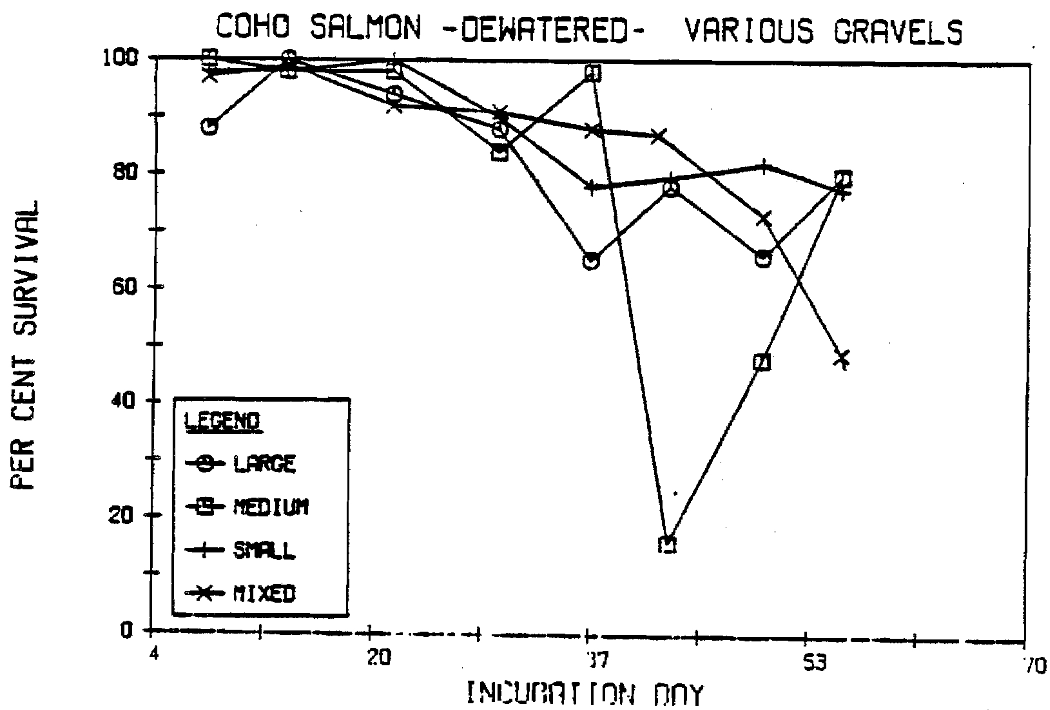


Fig. 12. Percent survival of coho salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from fertilization through eyed.

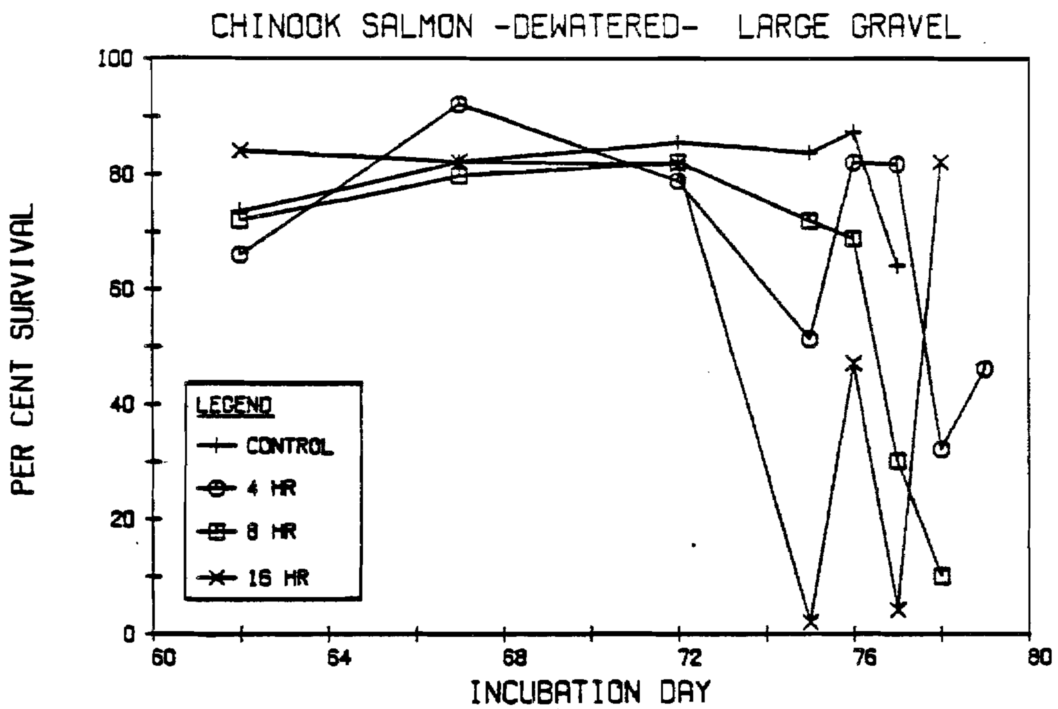


Fig. 13. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

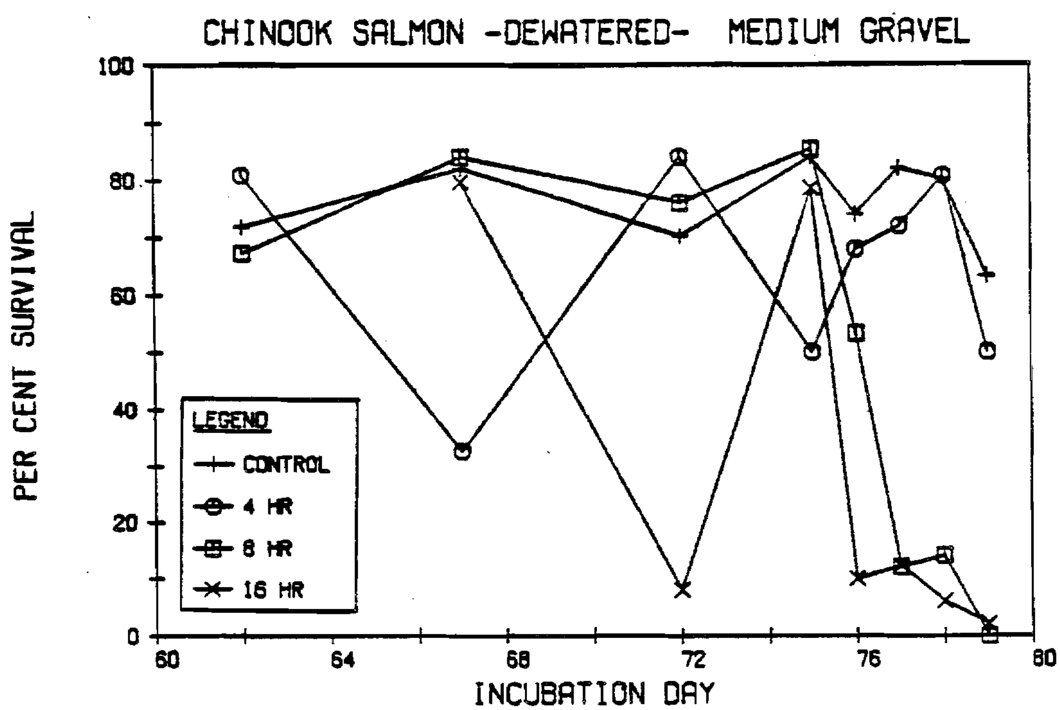


Fig. 14. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

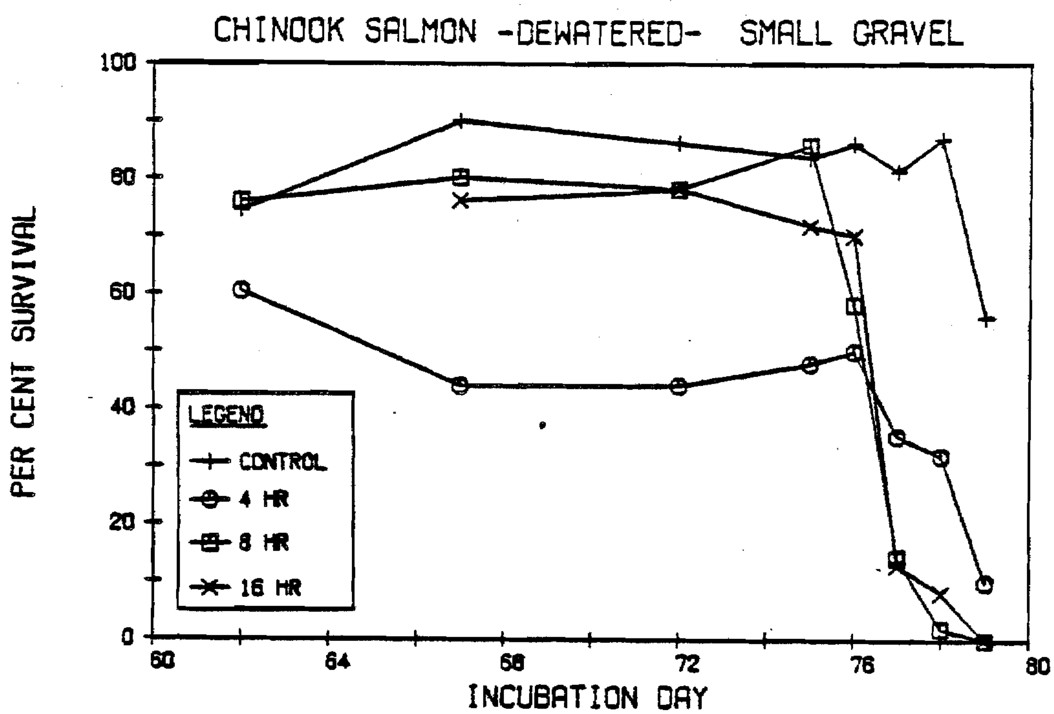


Fig. 15. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

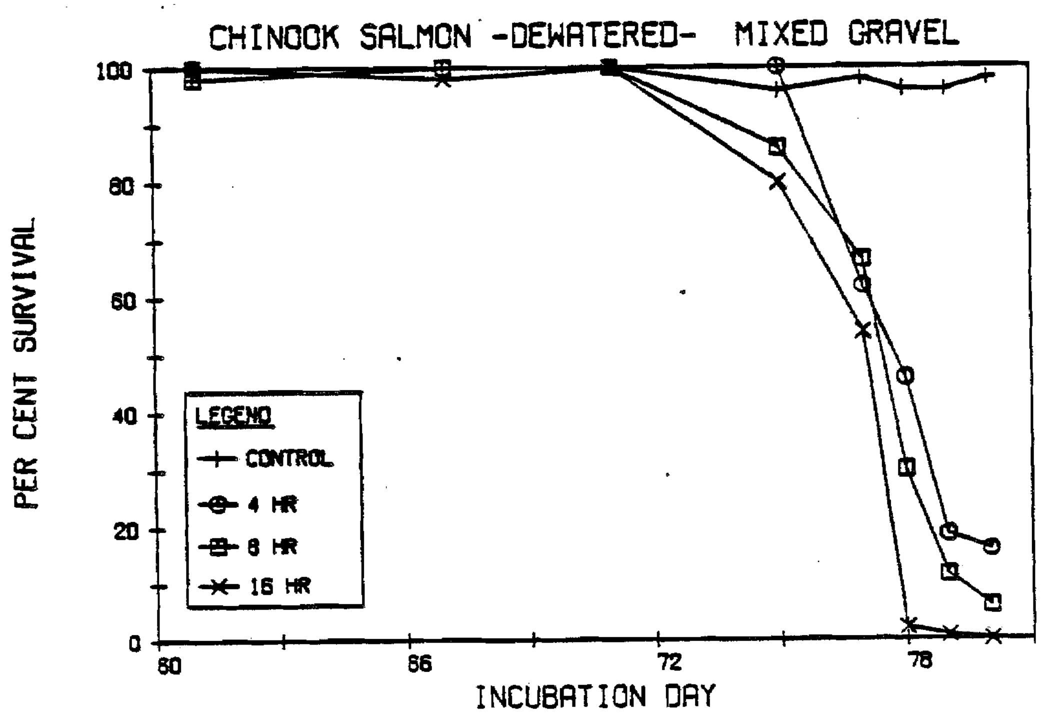


Fig. 16. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

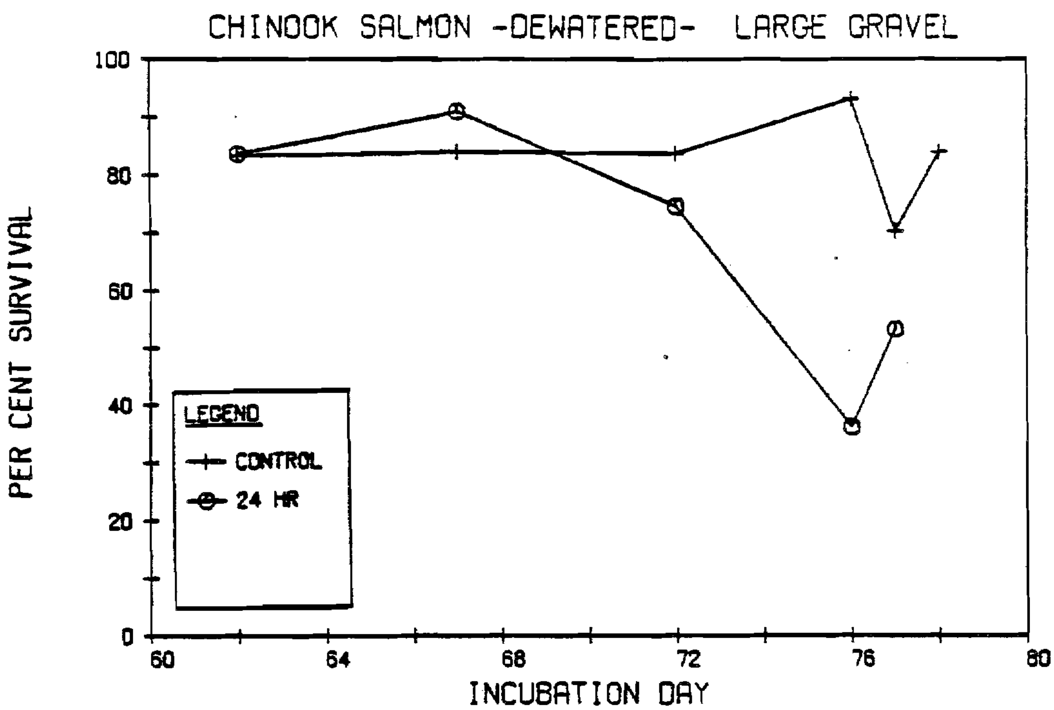


Fig. 17. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in large gravel from eyed through hatching.

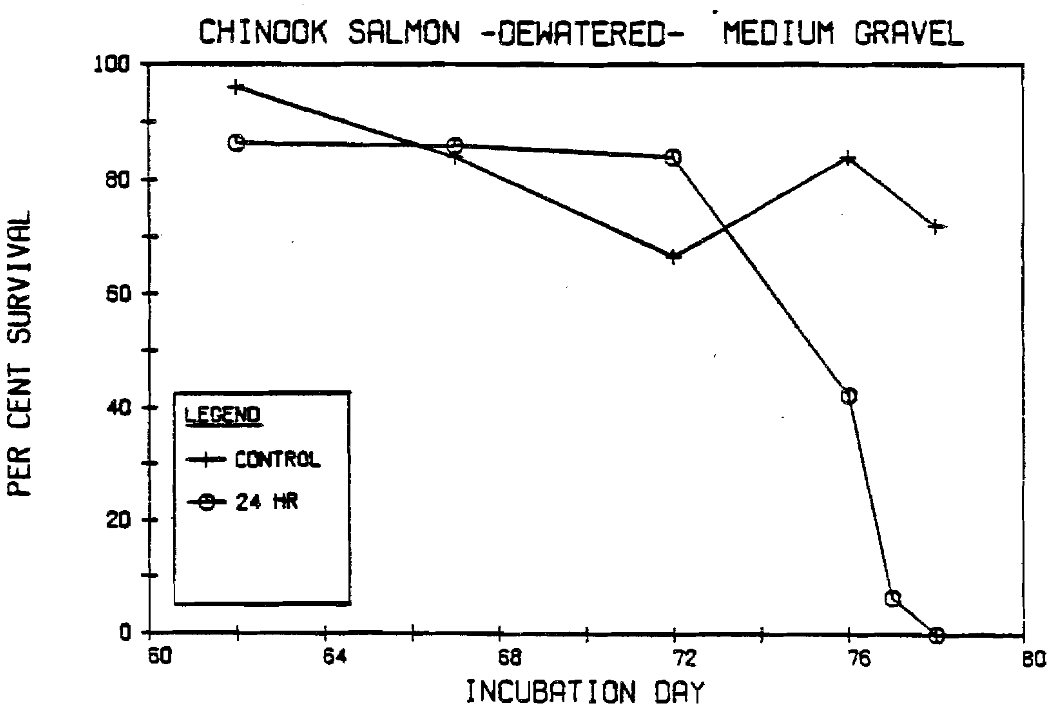


Fig. 18. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in medium gravel from eyed through hatching.

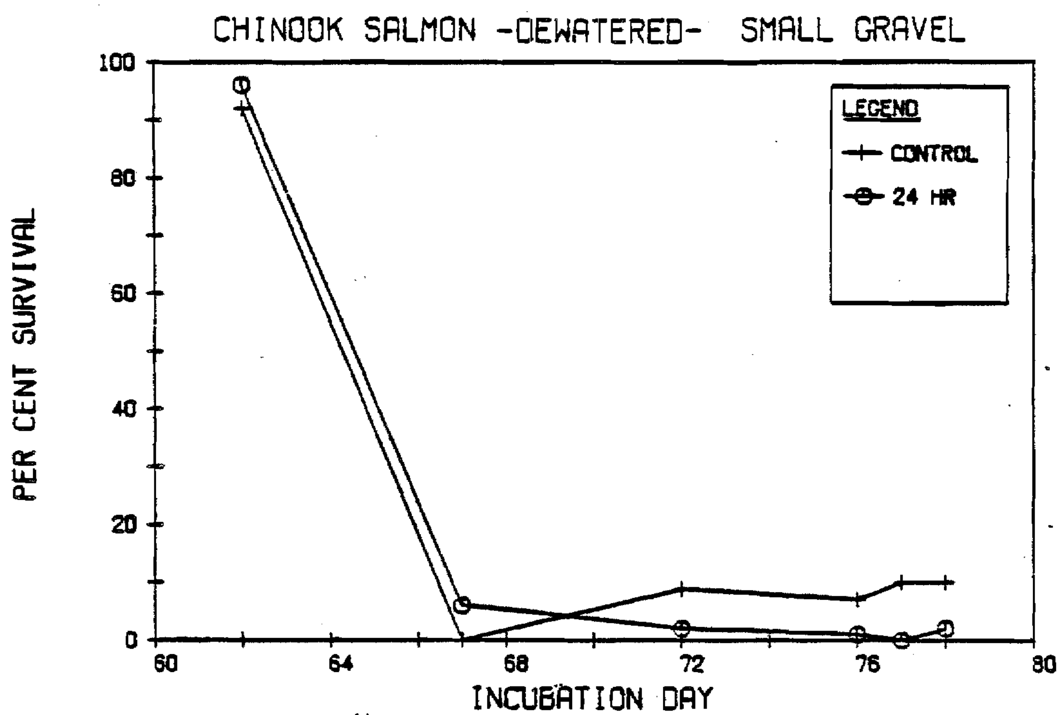


Fig. 19. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in small gravel from eyed through hatching.

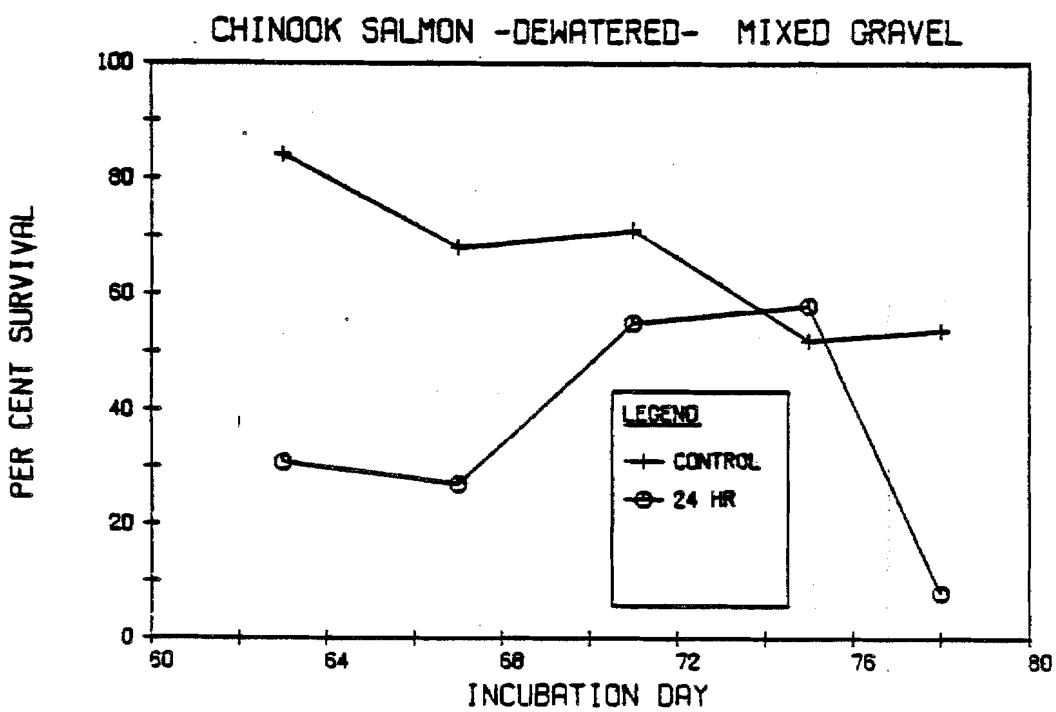


Fig. 20. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in mixed gravel from eyed through hatching.

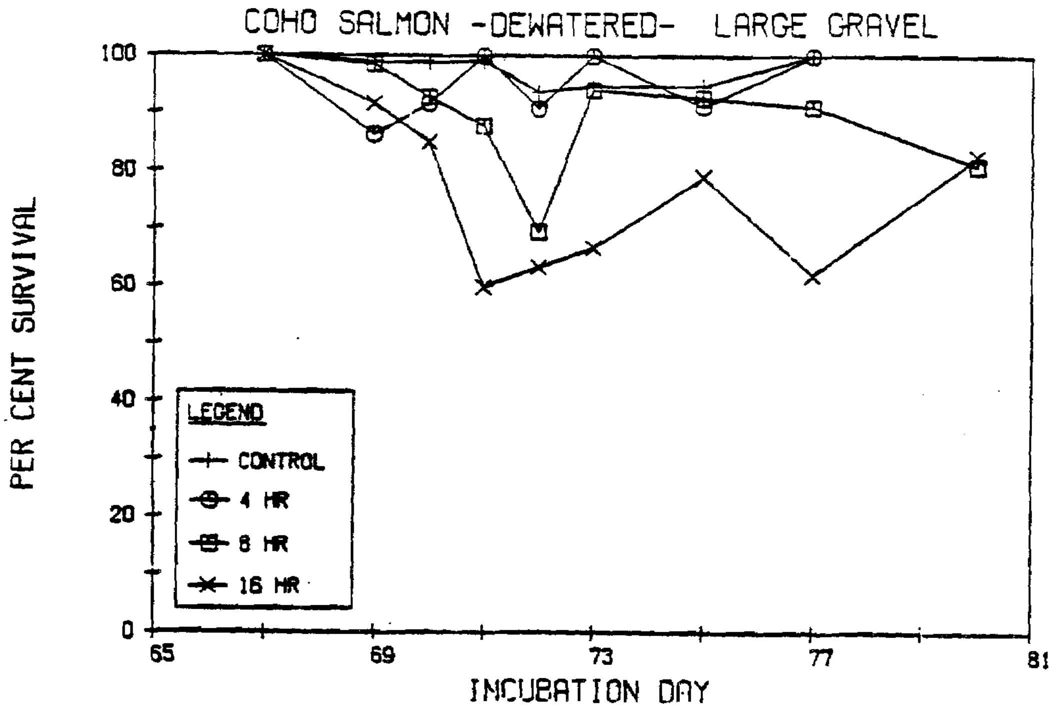


Fig. 21. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

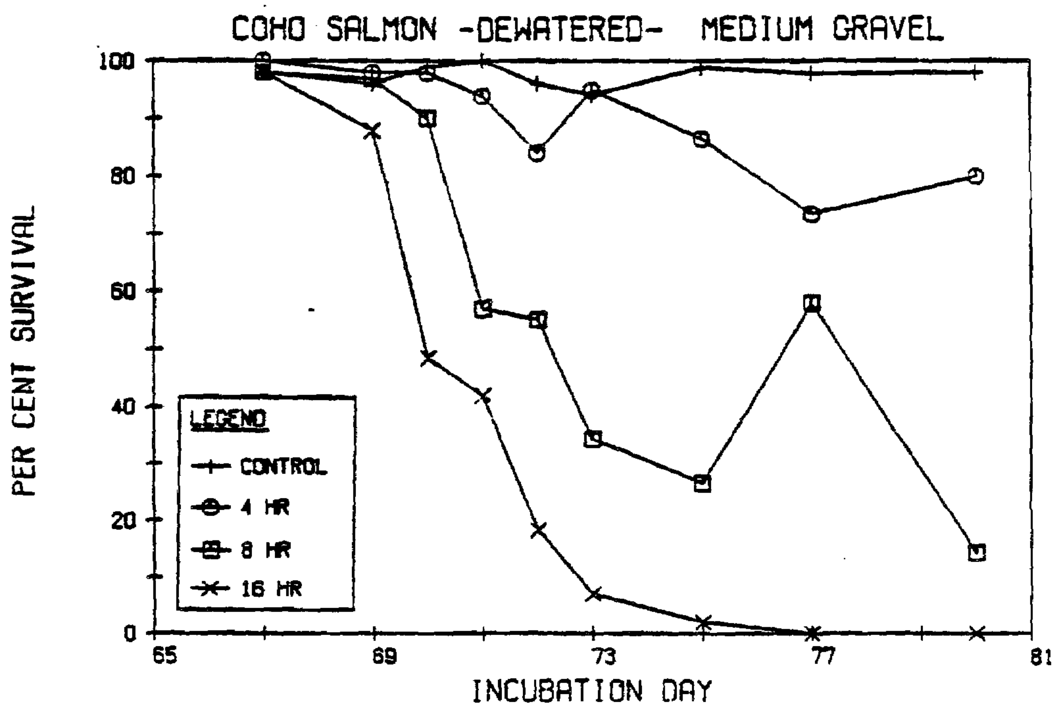


Fig. 22, Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

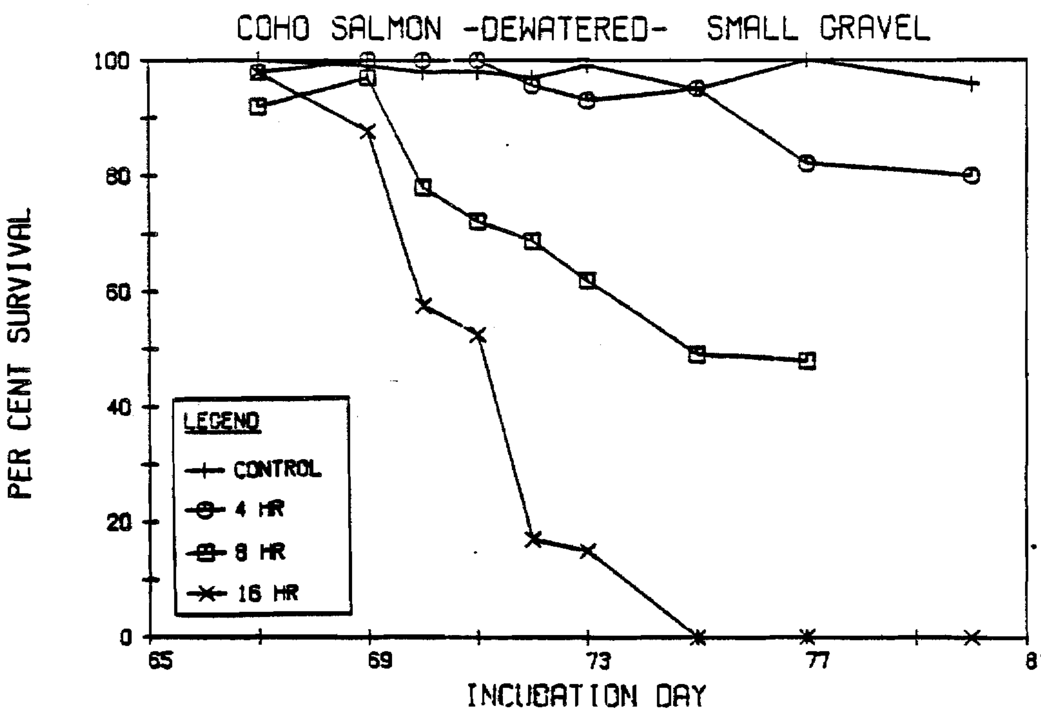


Fig. 23. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

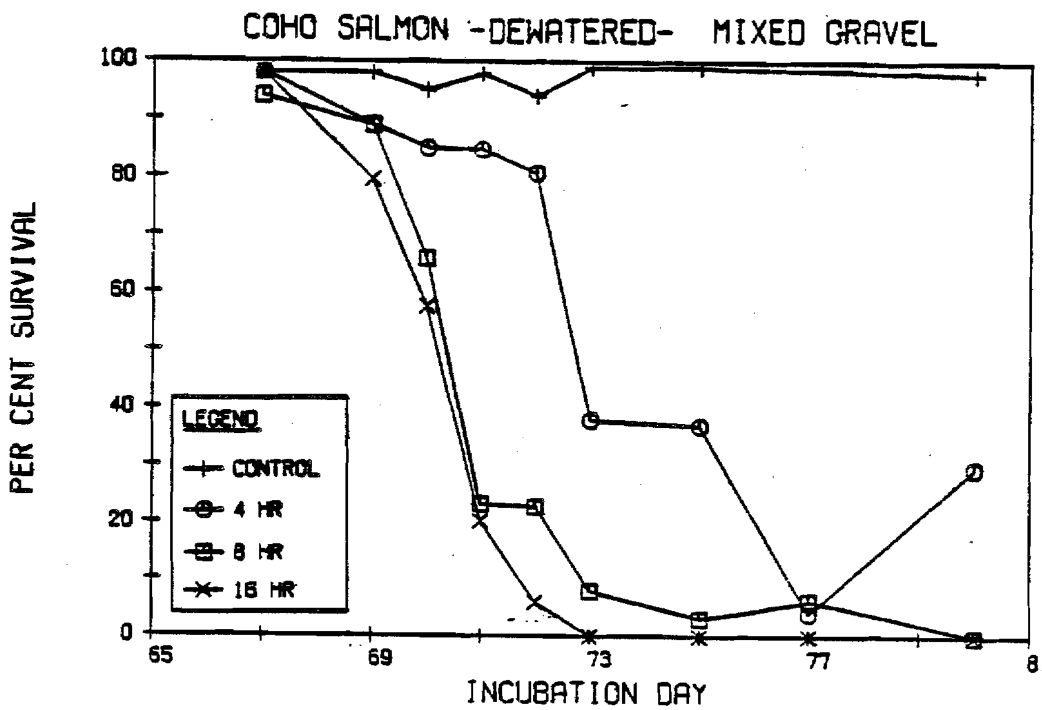


Fig. 24. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

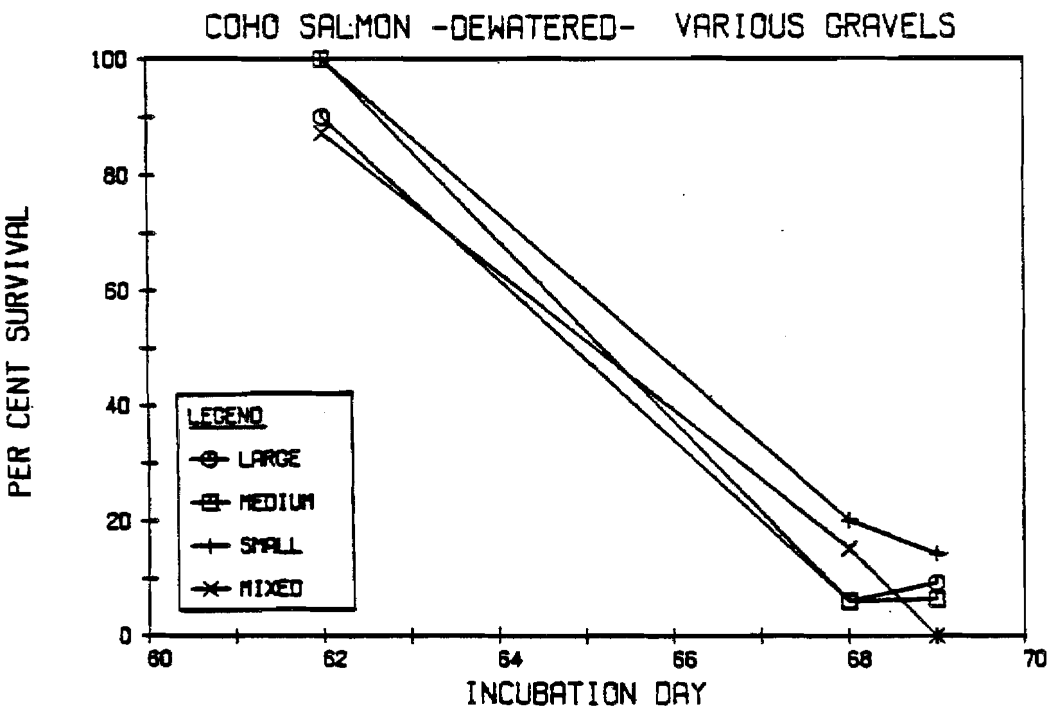


Fig. 25. Percent survival of coho salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from eyed through hatching.

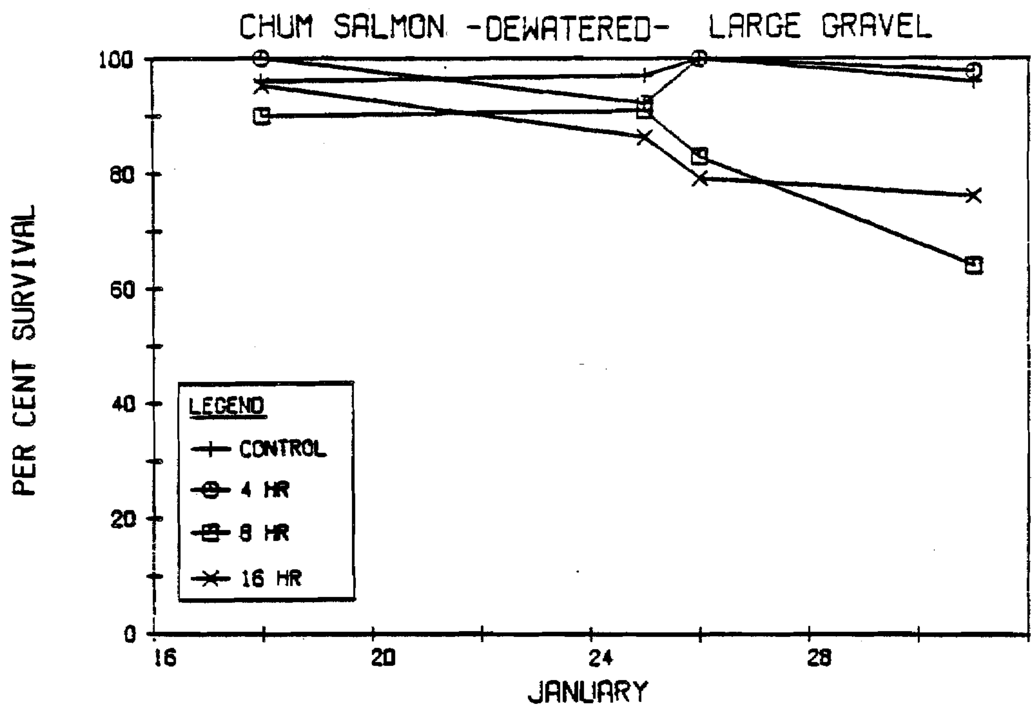


Fig. 26. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

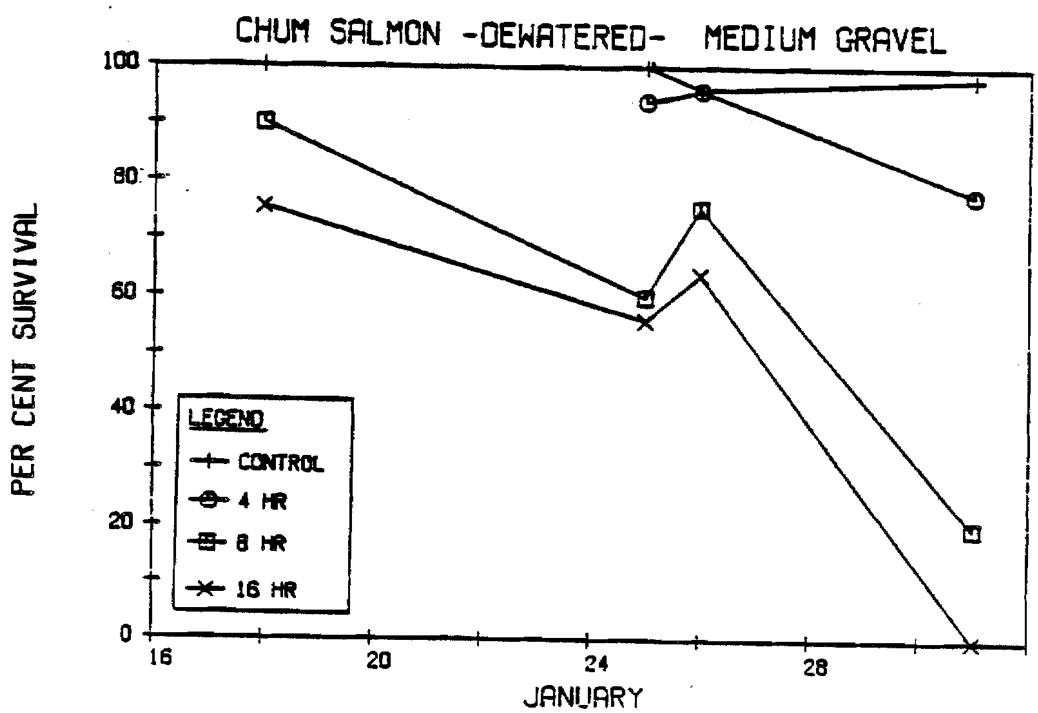


Fig. 27. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

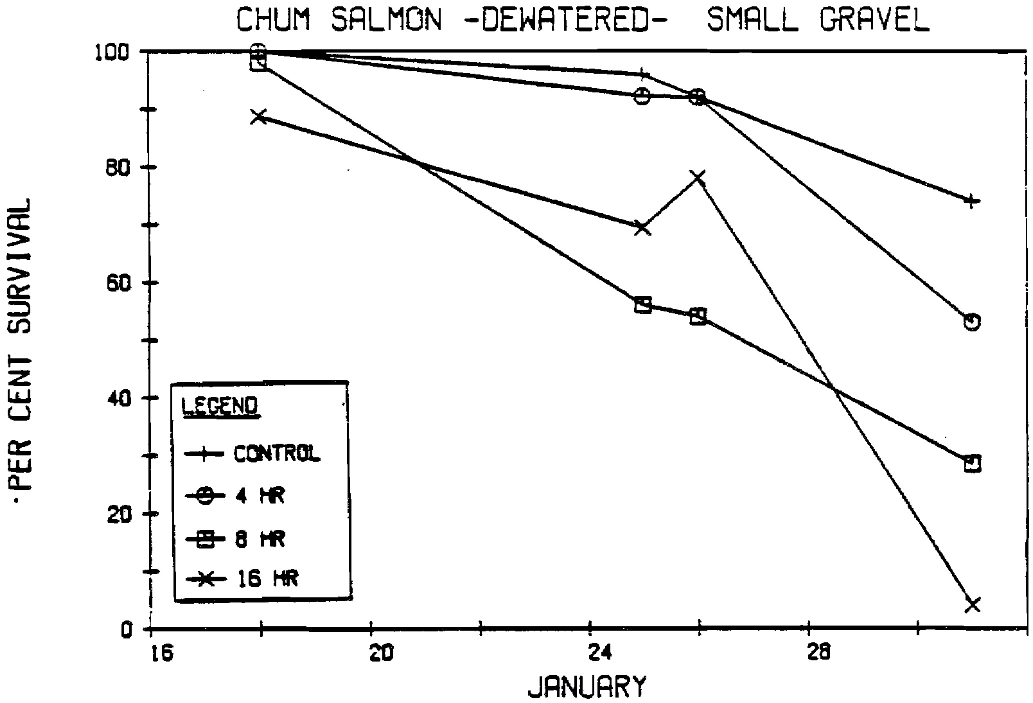


Fig. 28. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

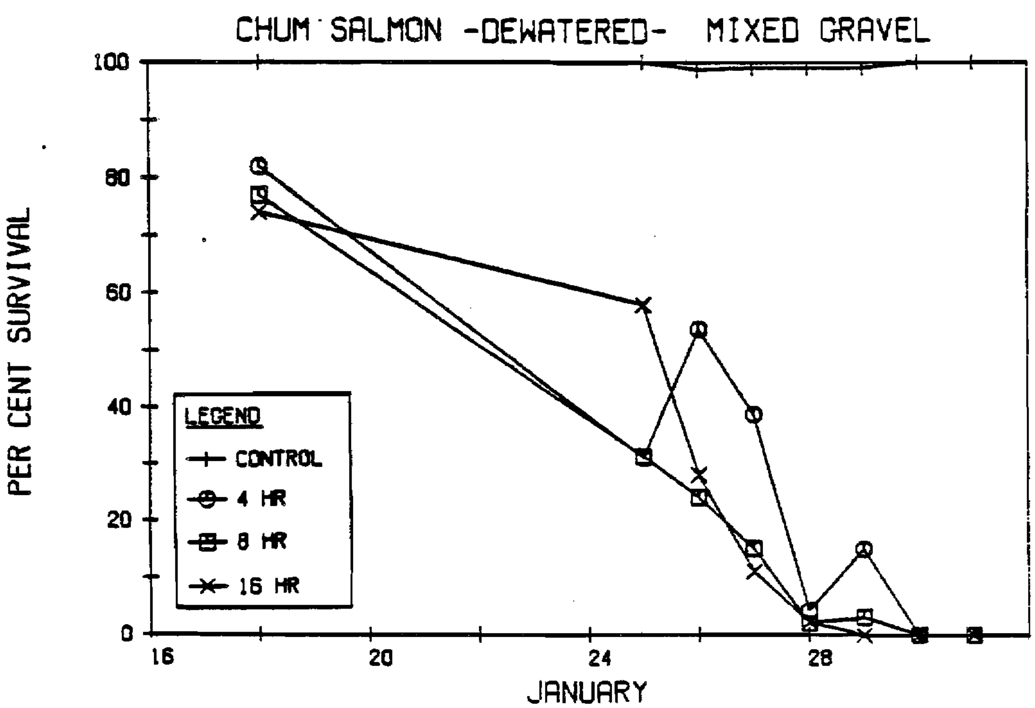


Fig. 29. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

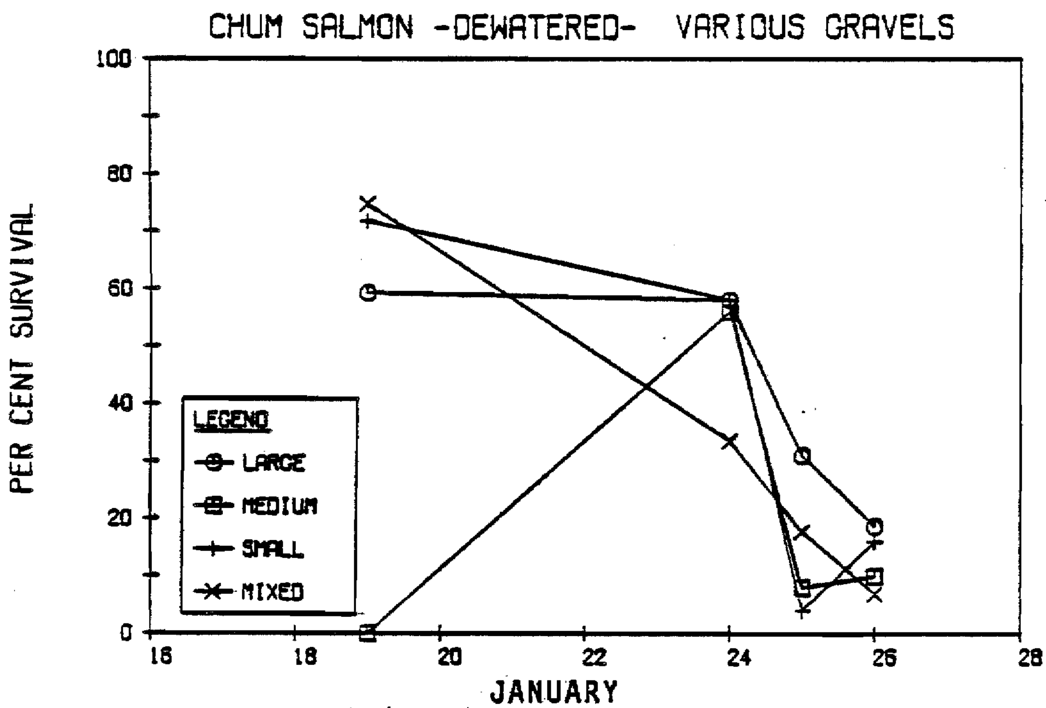


Fig. 30. Percent survival of chum salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from eyed through hatching.

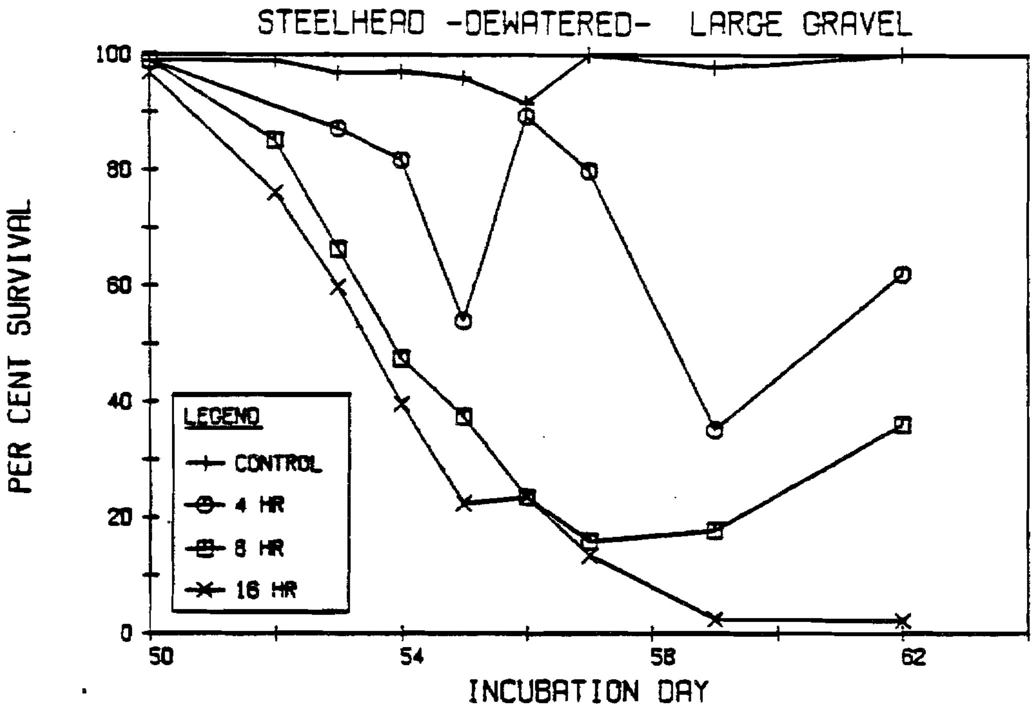


Fig. 31. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

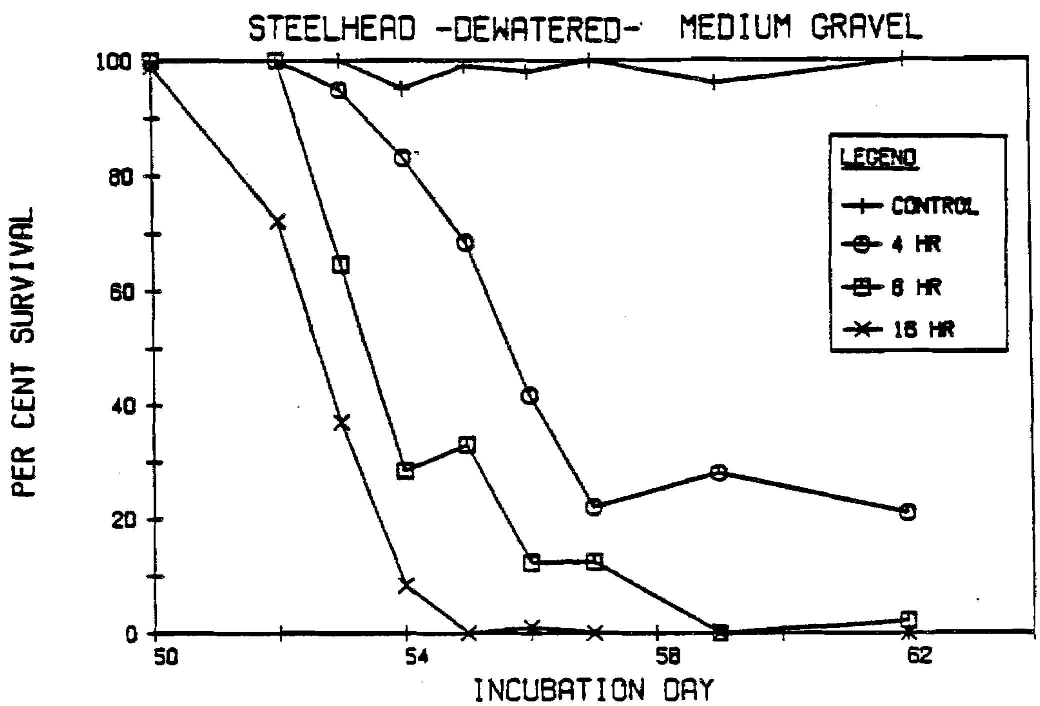


Fig. 32. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

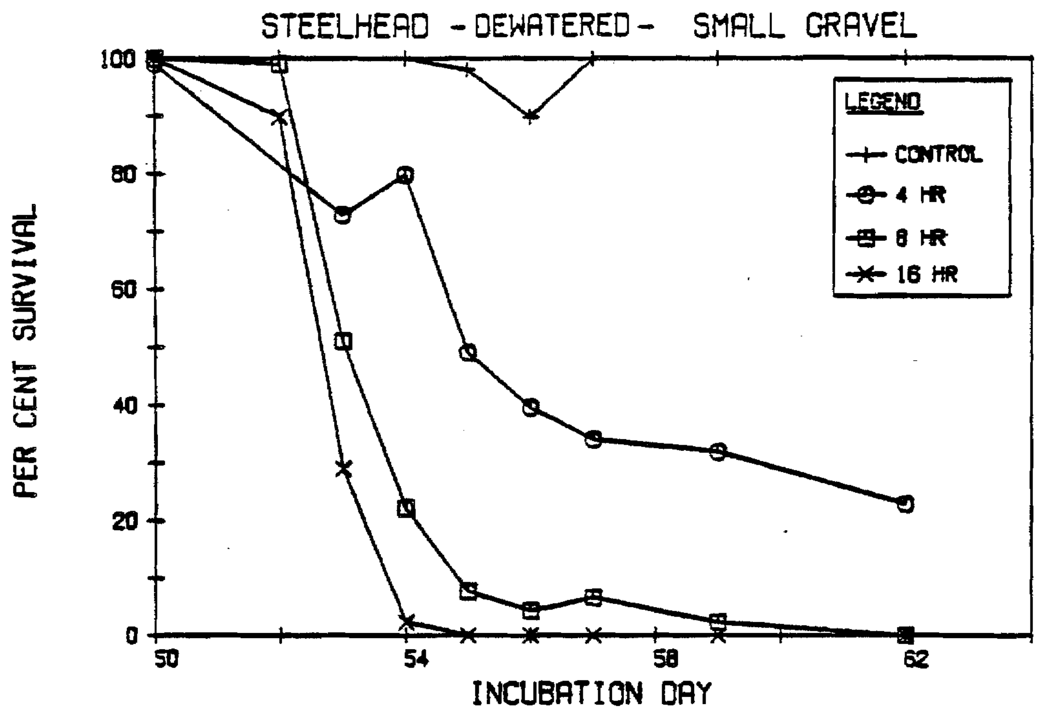


Fig. 33. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

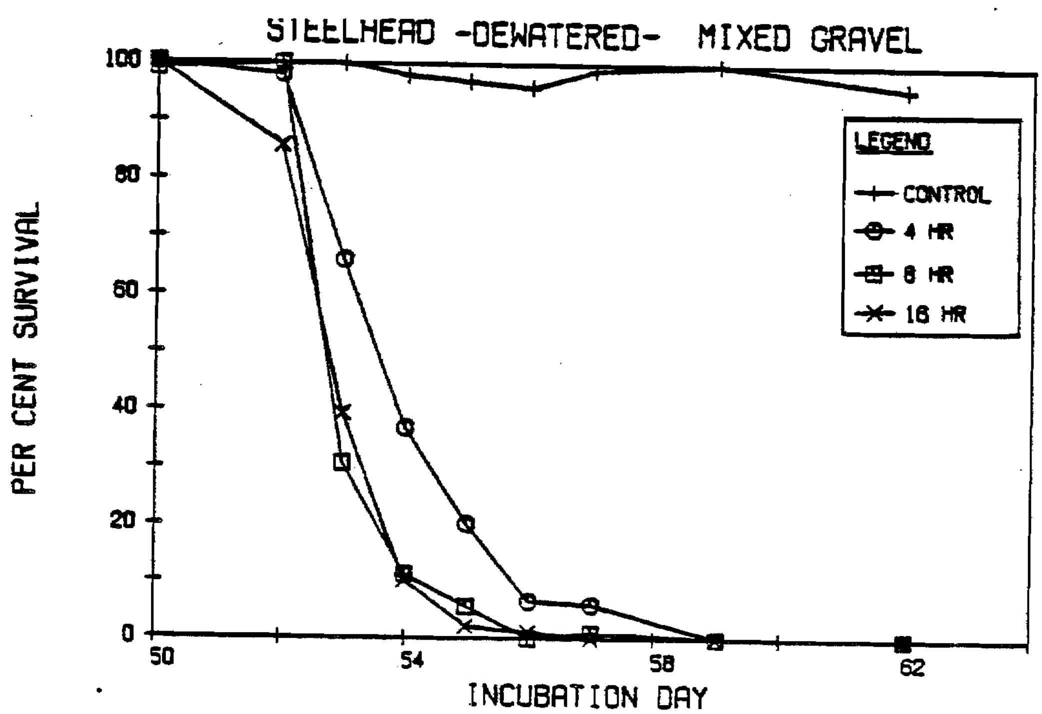


Fig. 34. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

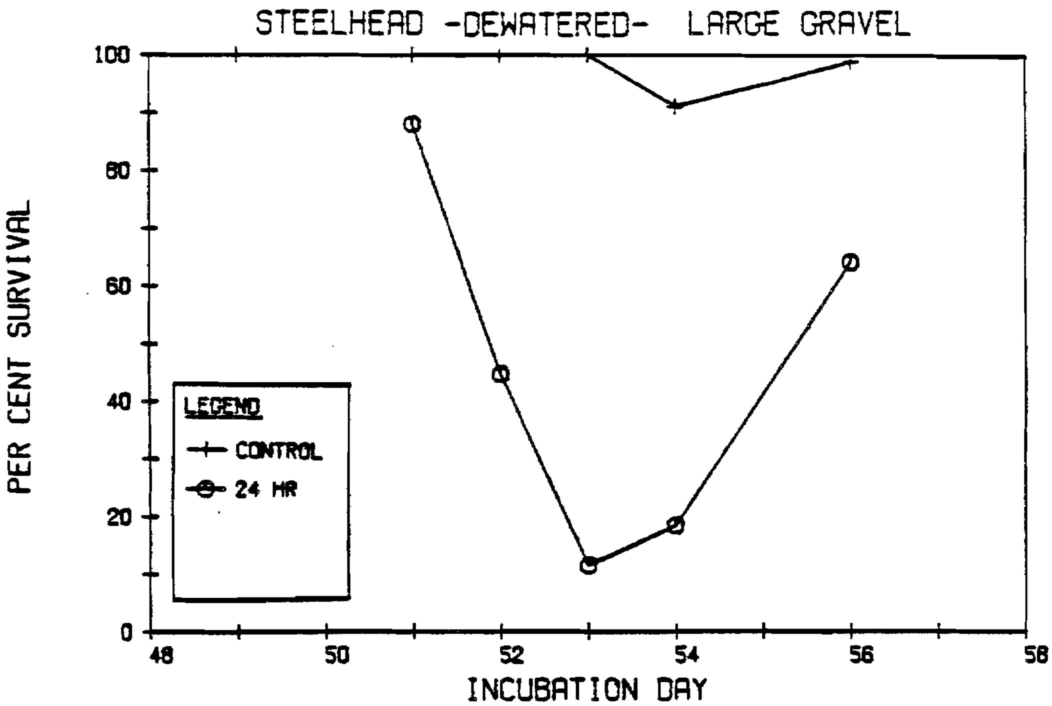


Fig. 35. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in large gravel from eyed through hatching.

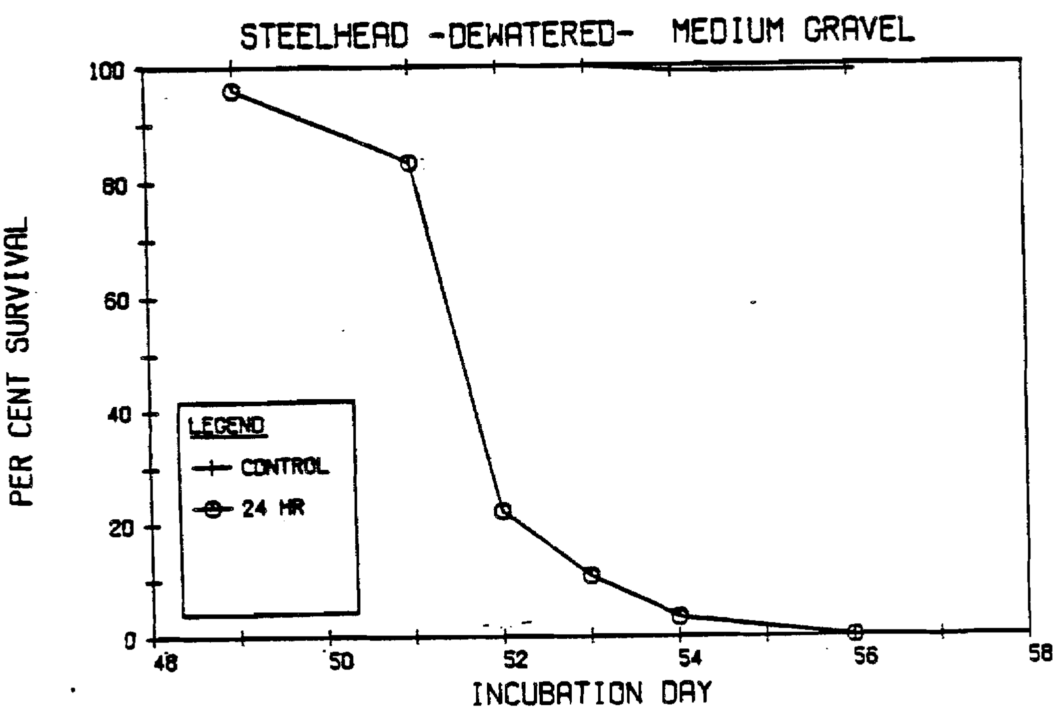


Fig. 36. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in medium gravel from eyed through hatching.

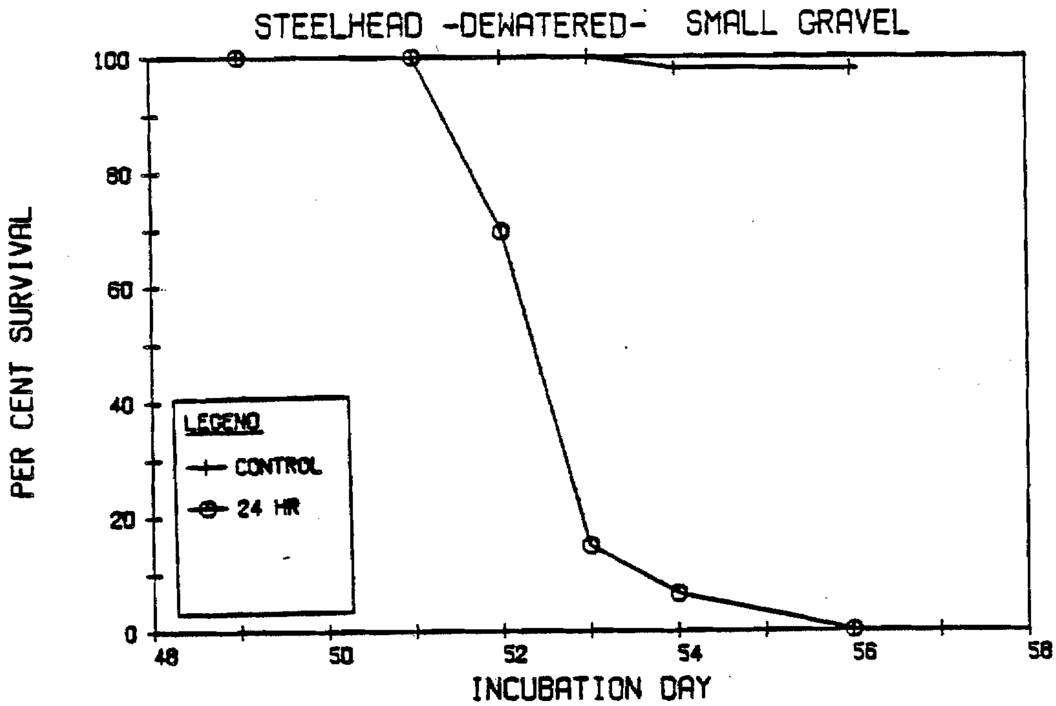


Fig. 37. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in small gravel from eyed through hatching.

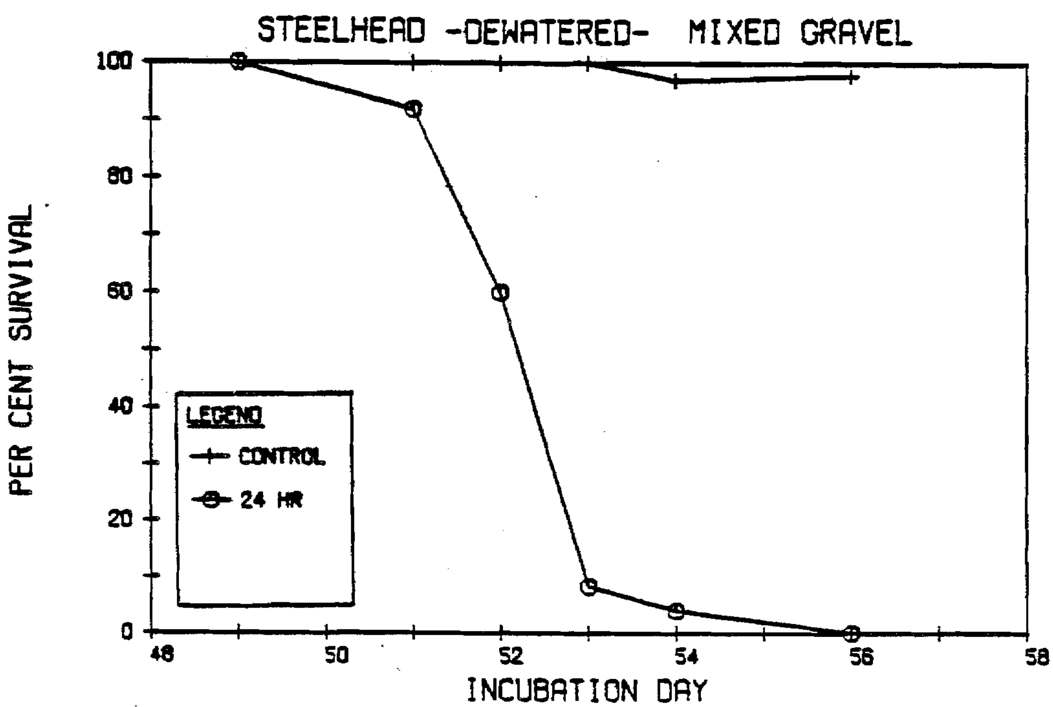


Fig. 38. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in mixed gravel from eyed through hatching.

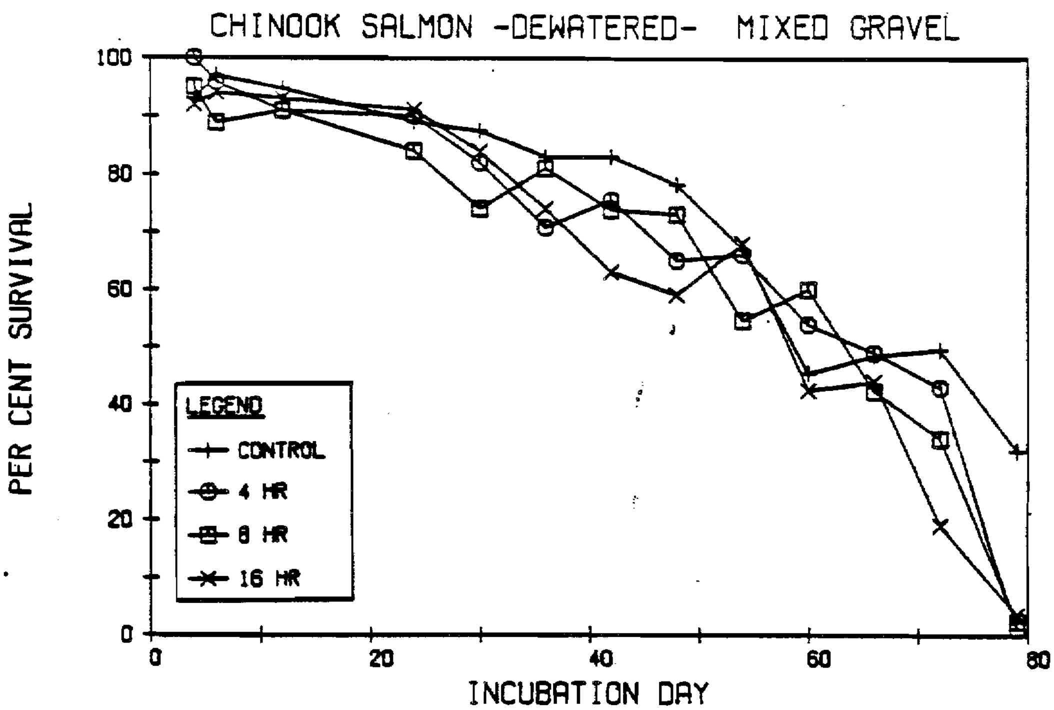


Fig. 39. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization through hatching.

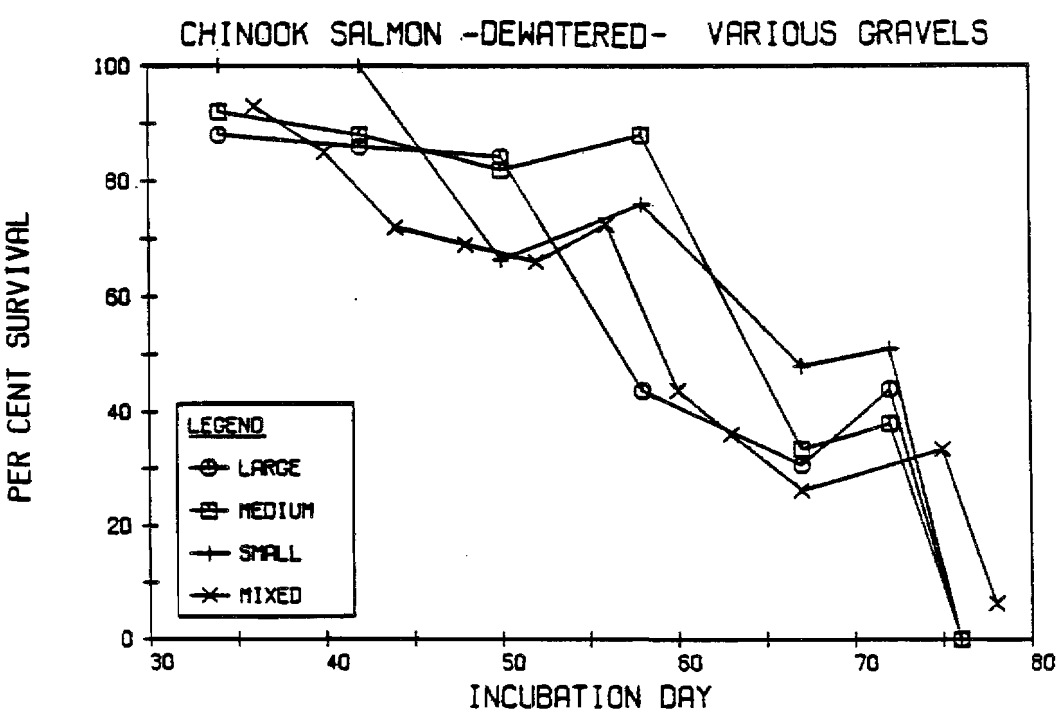


Fig. 40. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravel from fertilization through hatching.

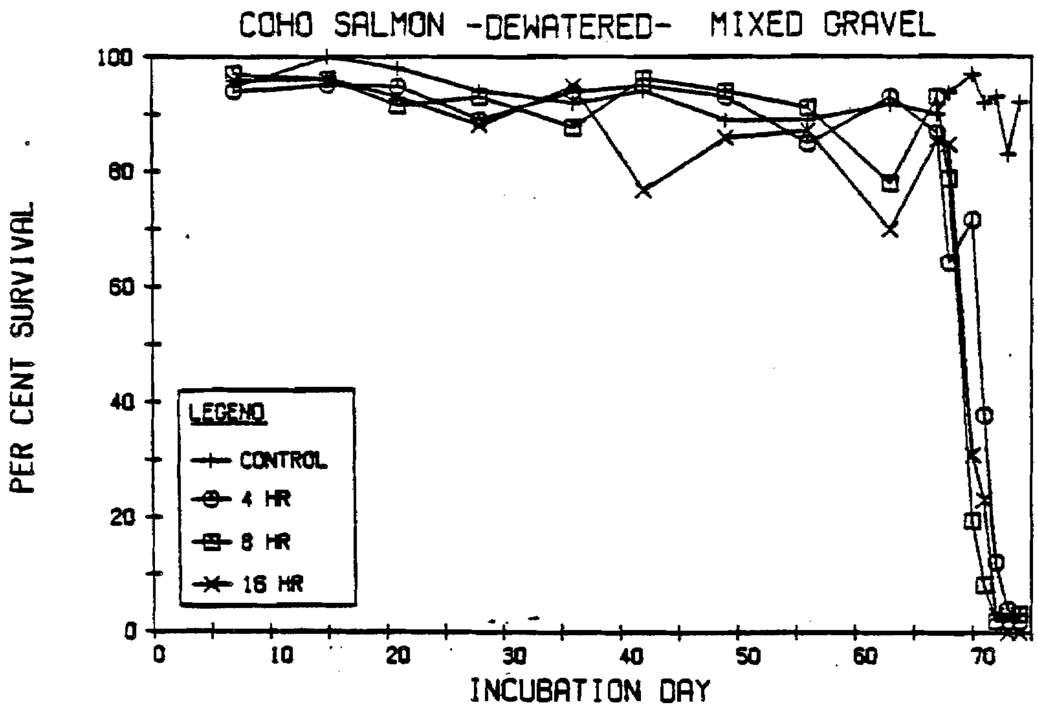


Fig. 41. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization through hatching.

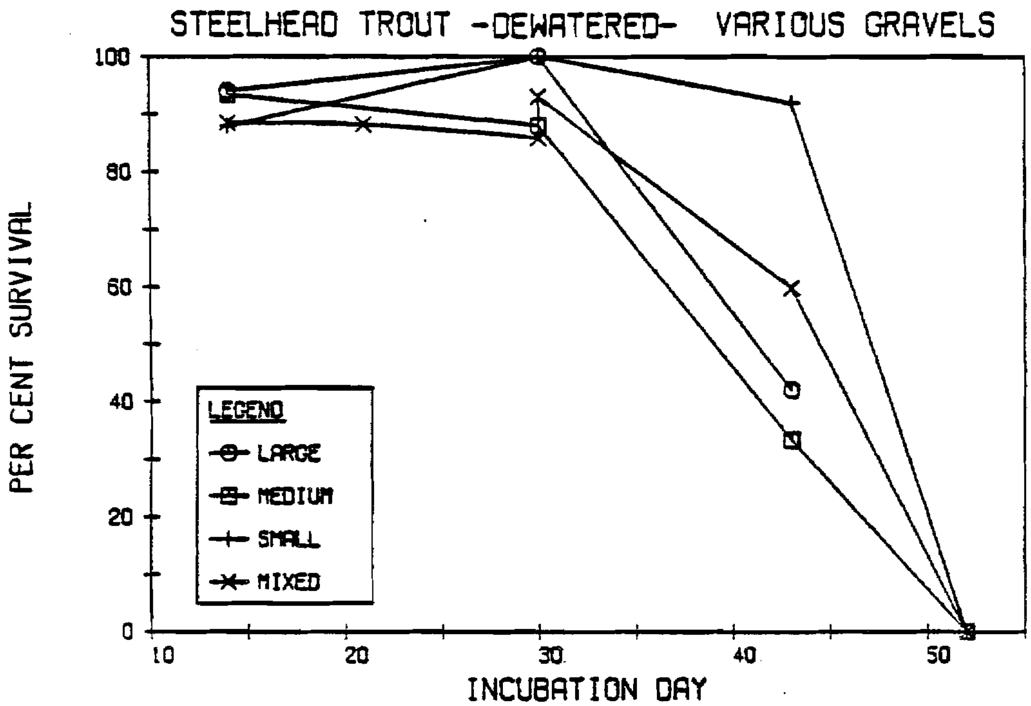


Fig. 42. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from fertilization through hatching.

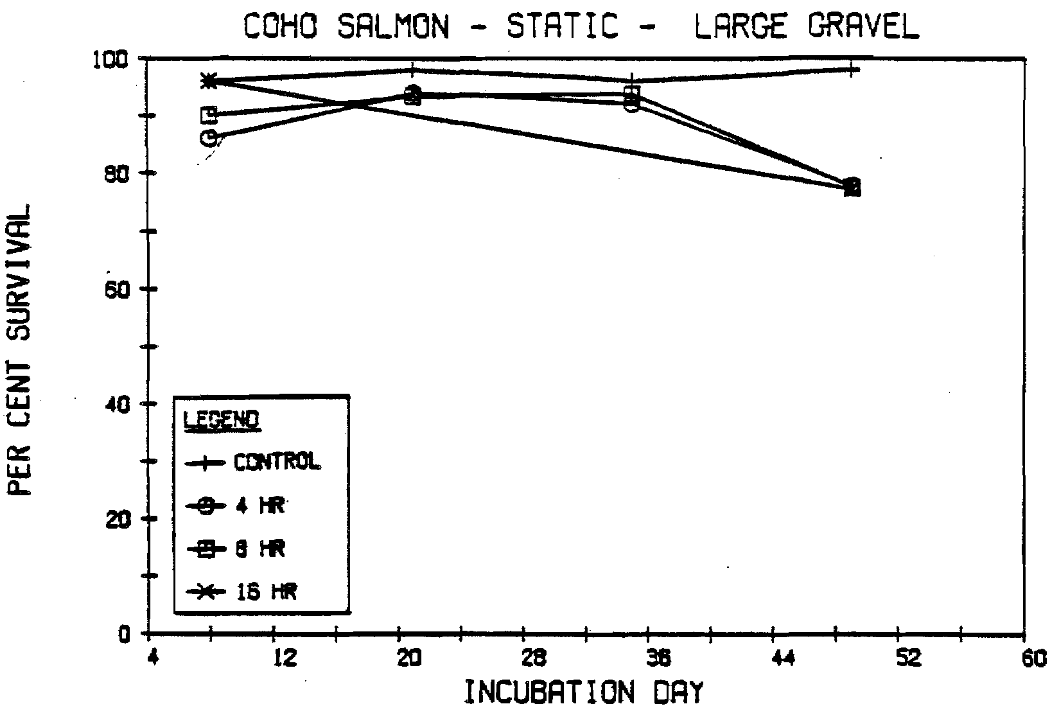


Fig. 43. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

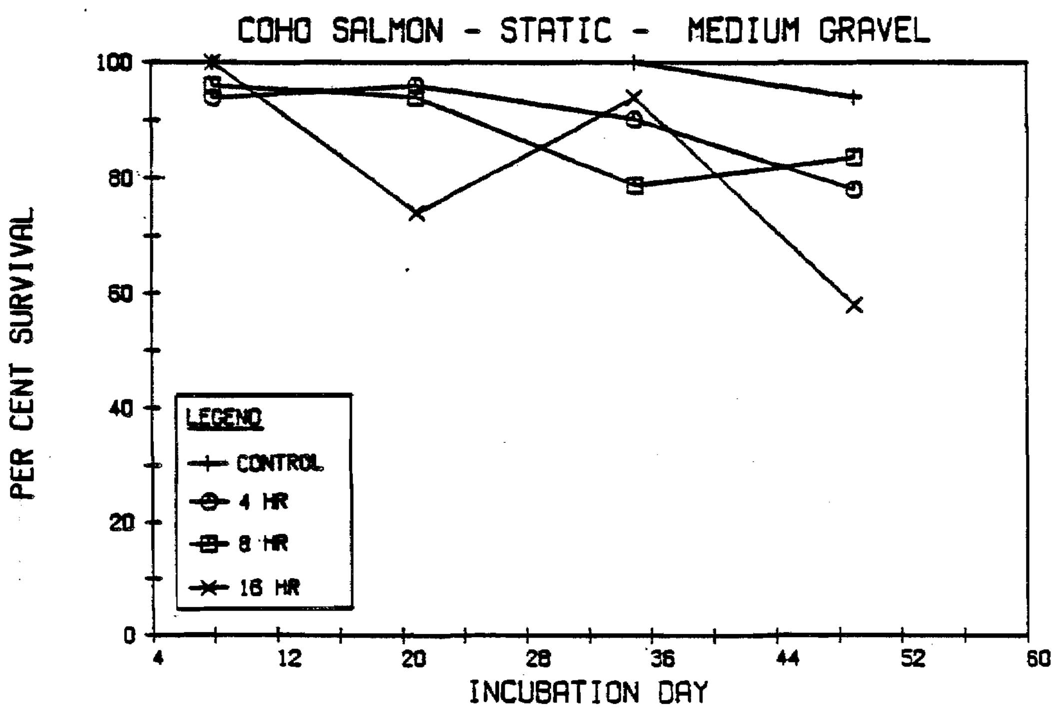


Fig. 44. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

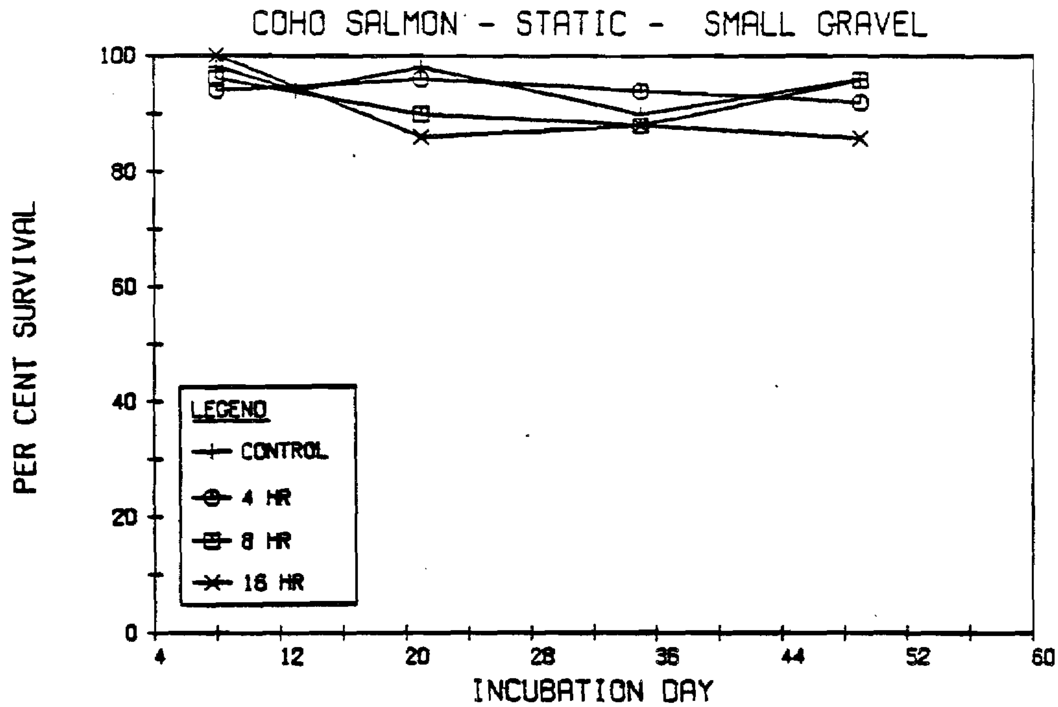


Fig. 45. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

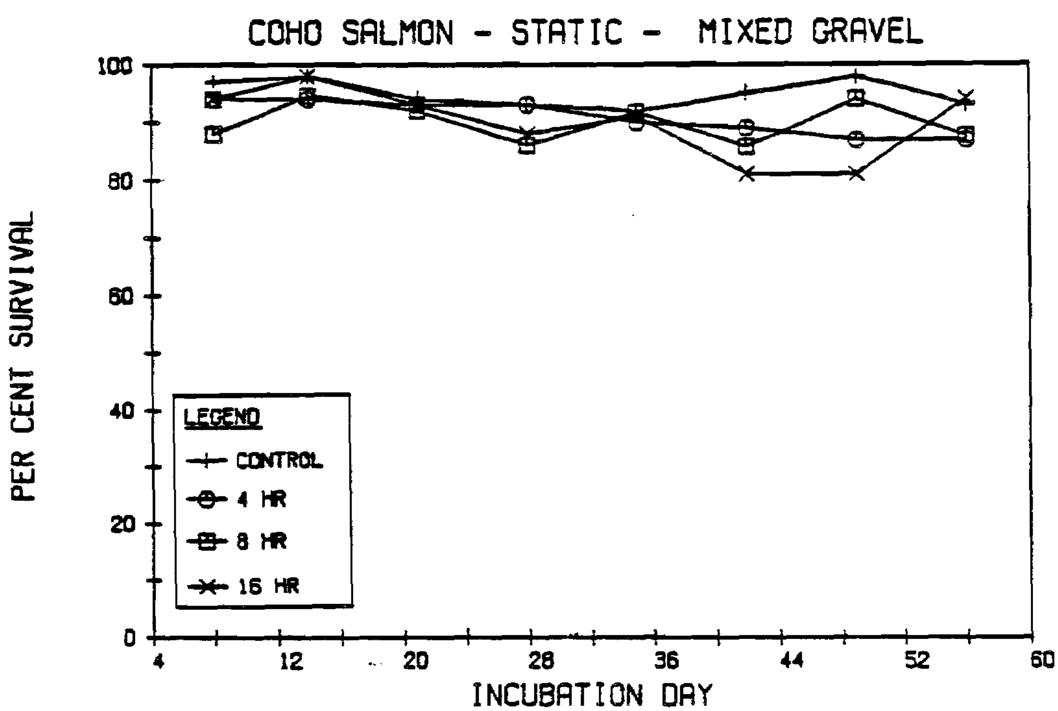


Fig. 46. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

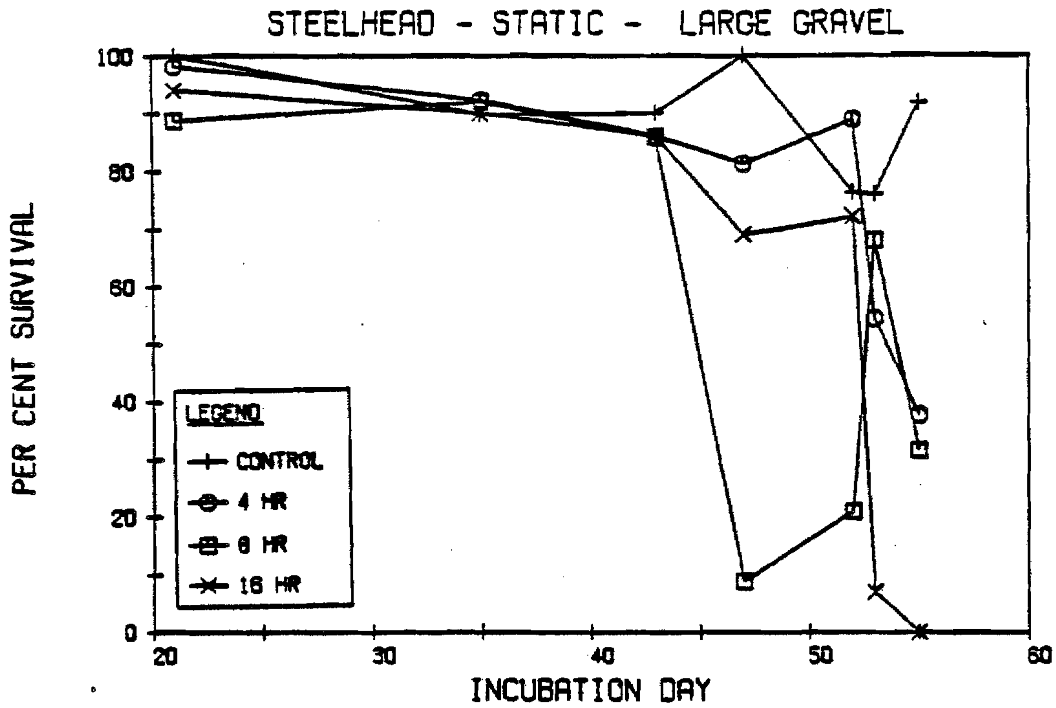


Fig. 47. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

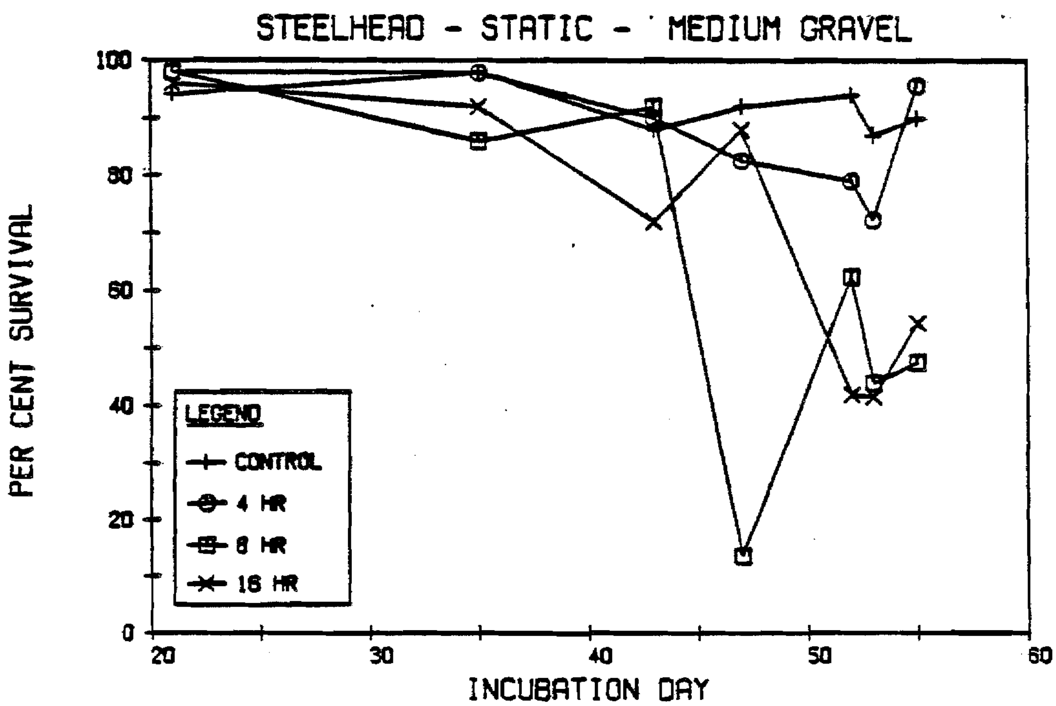


Fig. 48. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

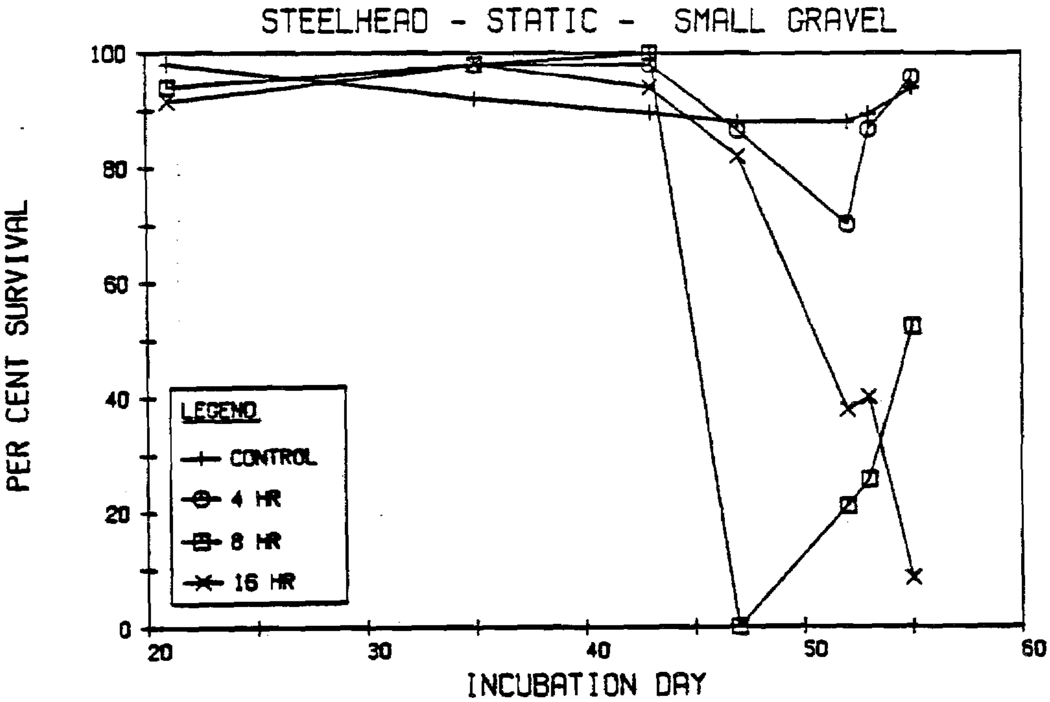


Fig. 49. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

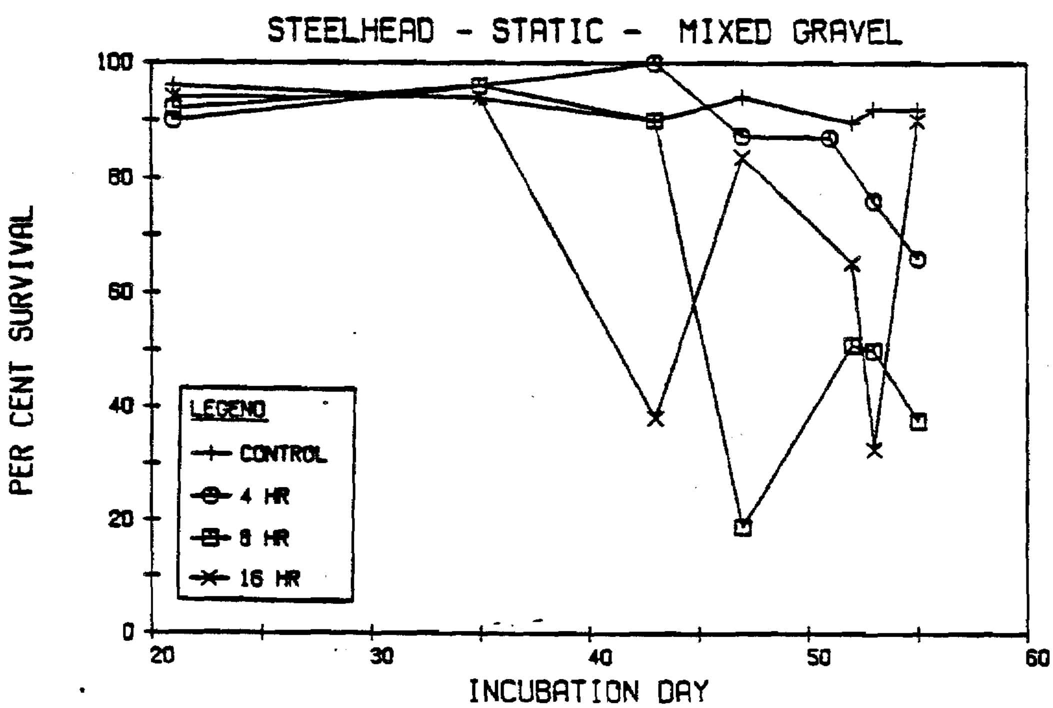


Fig. 50. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

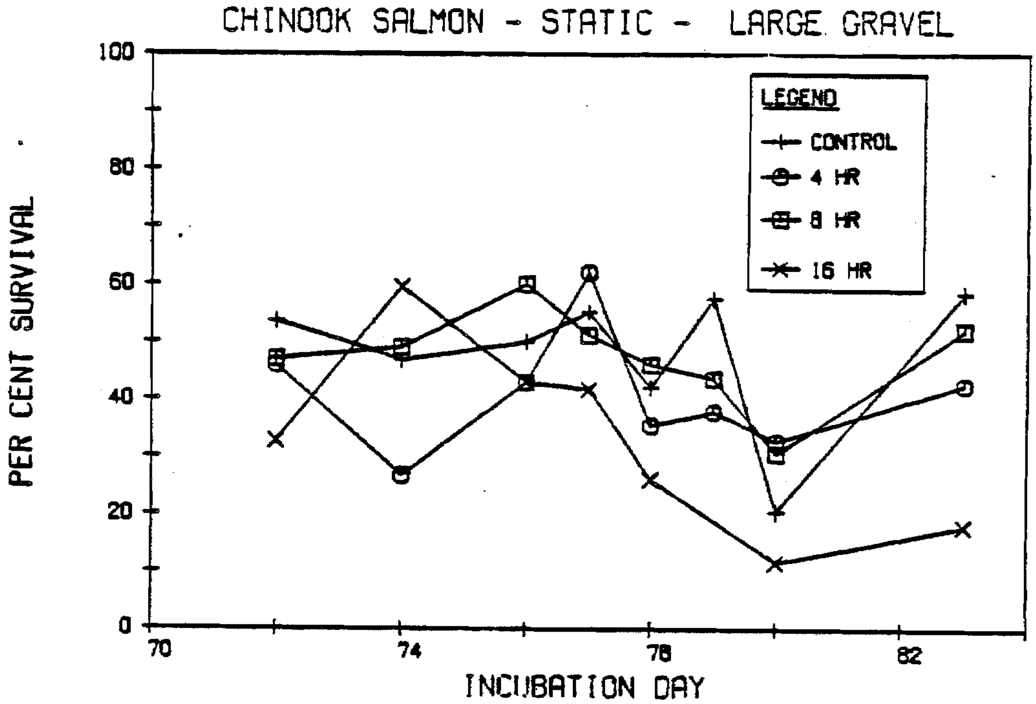


Fig. 51. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

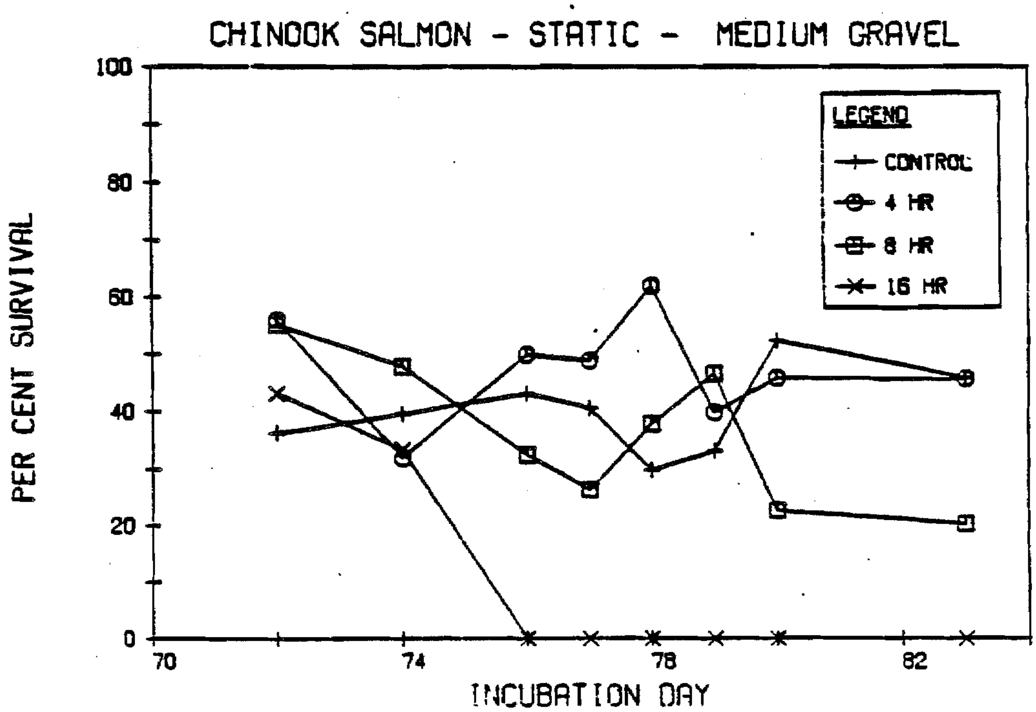


Fig. 52. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

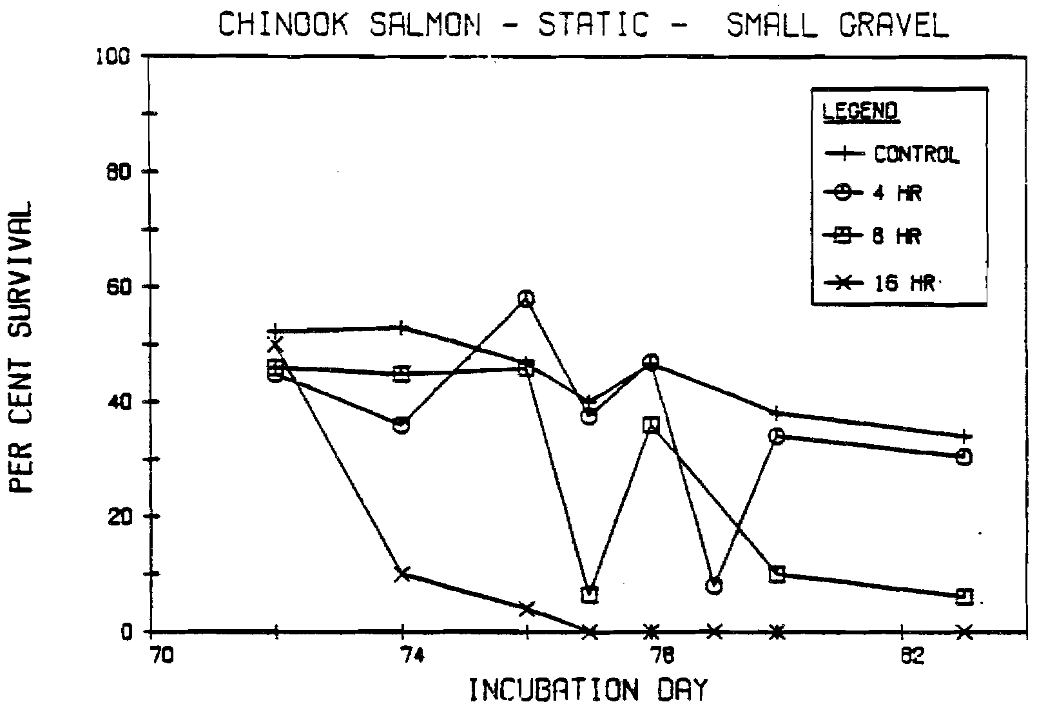


Fig. 53. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

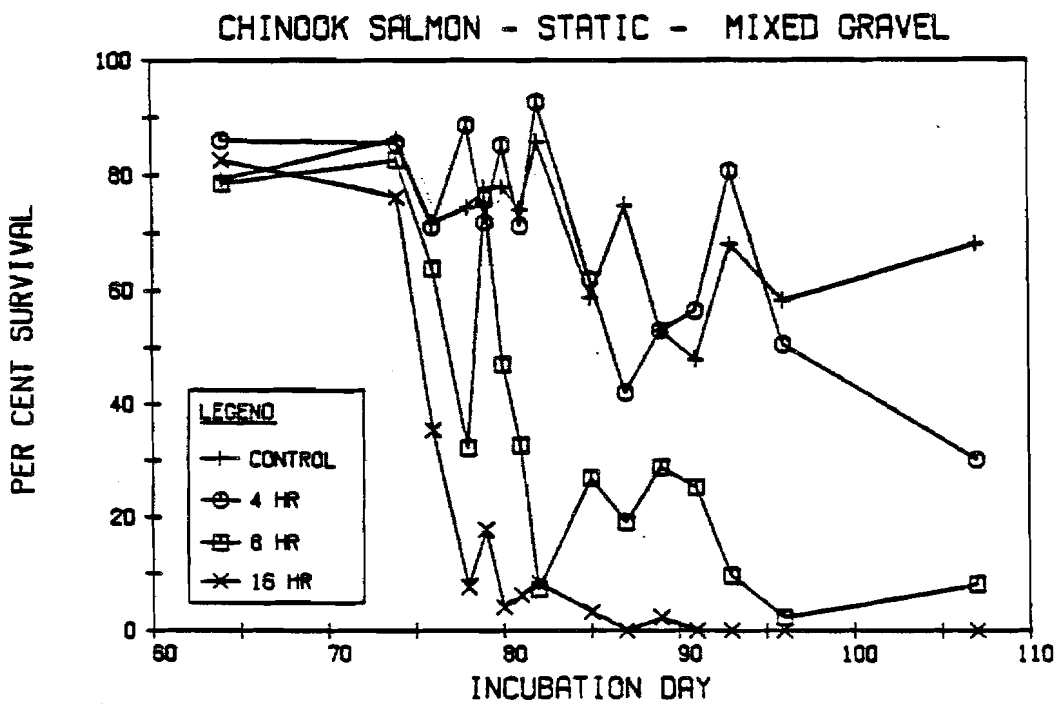


Fig. 54. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

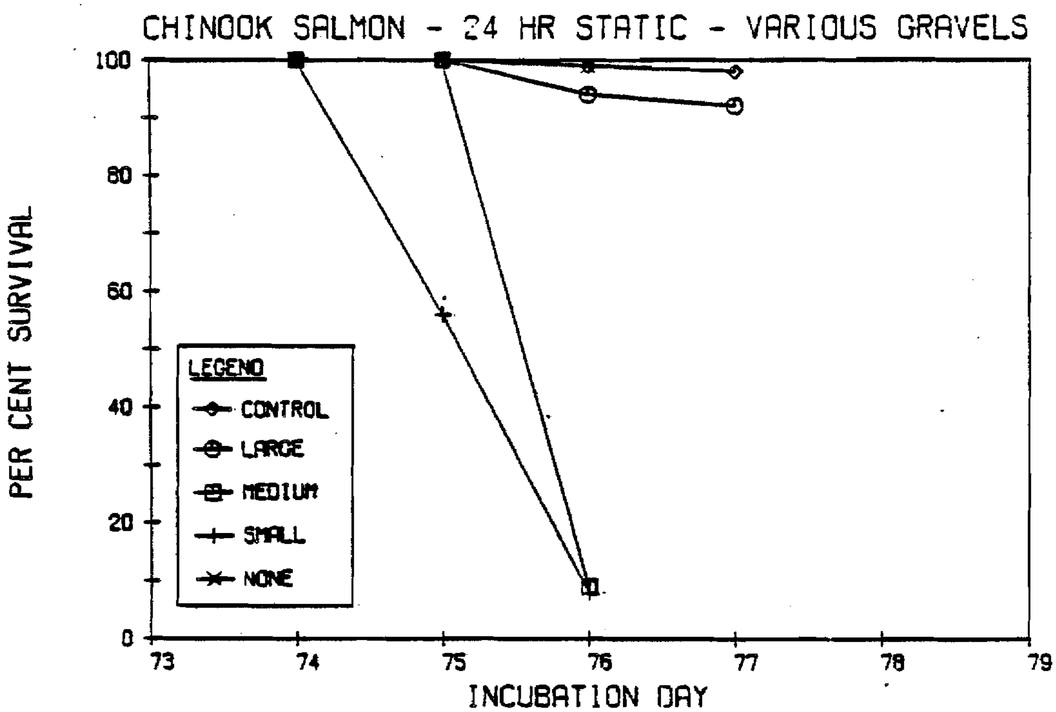


Fig. 55. Percent survival of chinook salmon embryos in static water for 24 hrs/day in large, medium and small gravels from eyed through hatching.

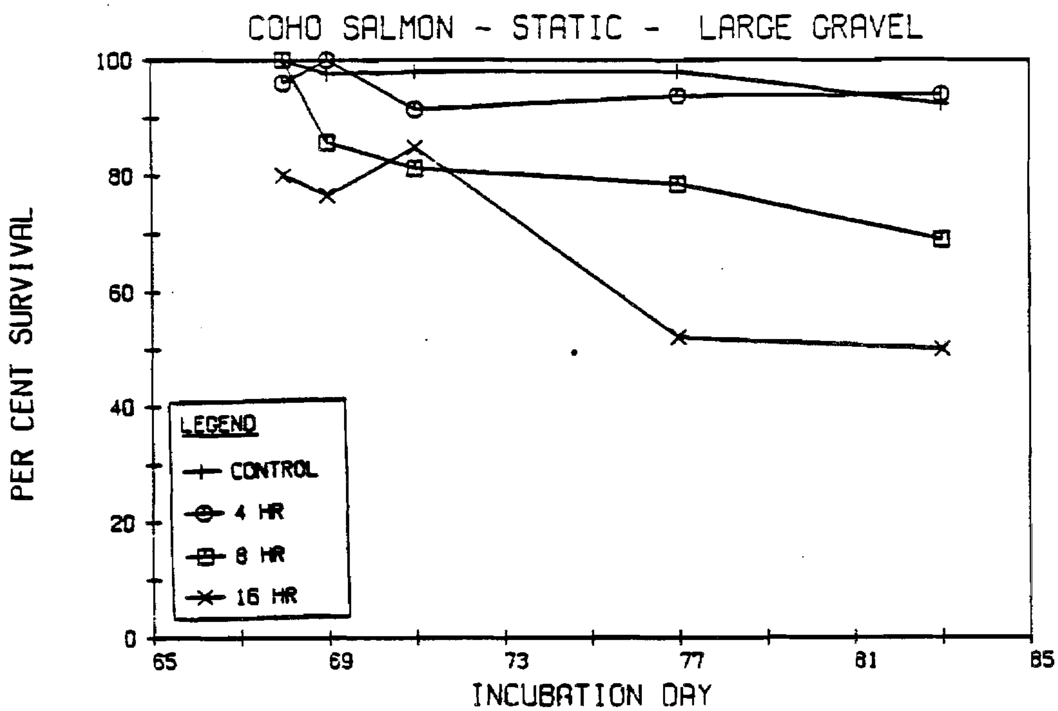


Fig. 56. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

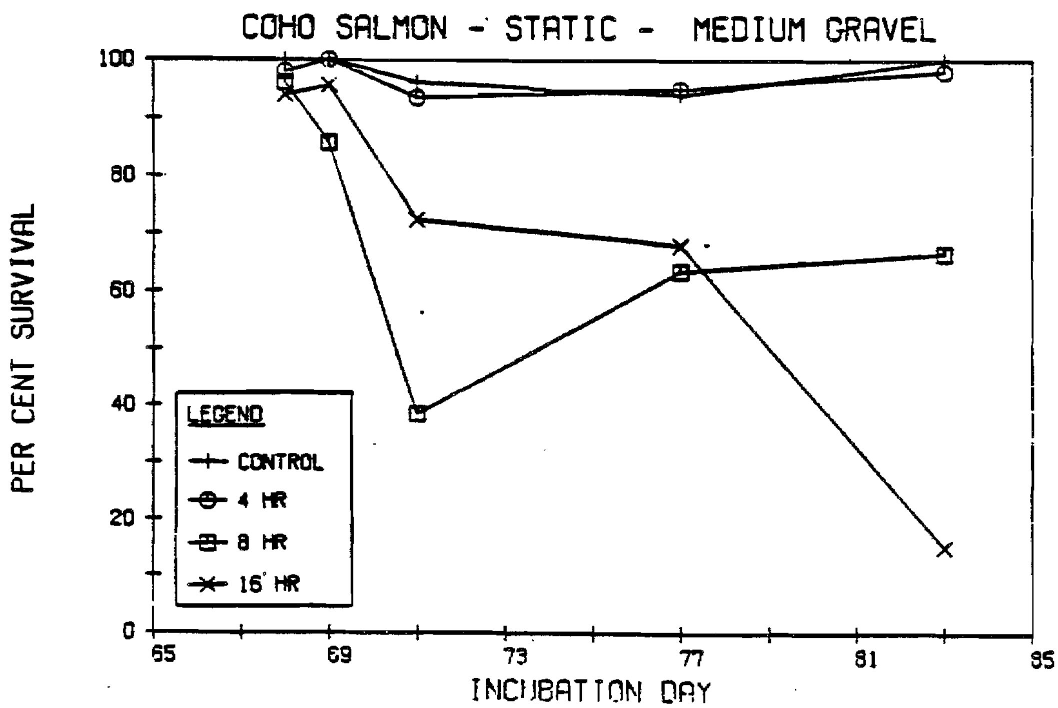


Fig. 57. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

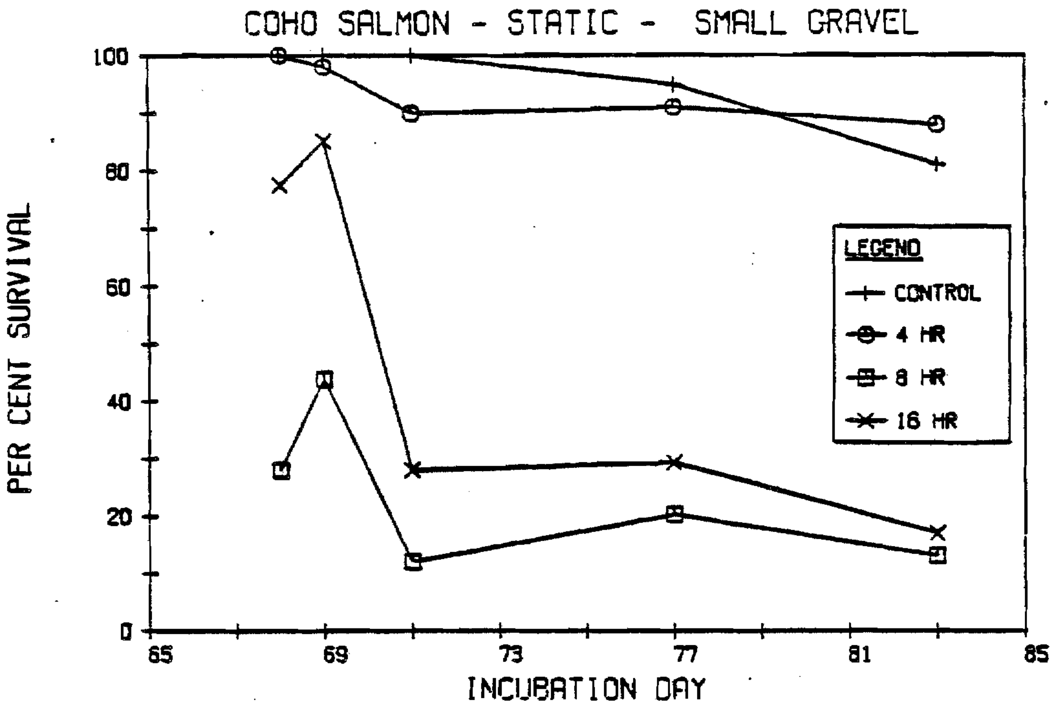


Fig. 58. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

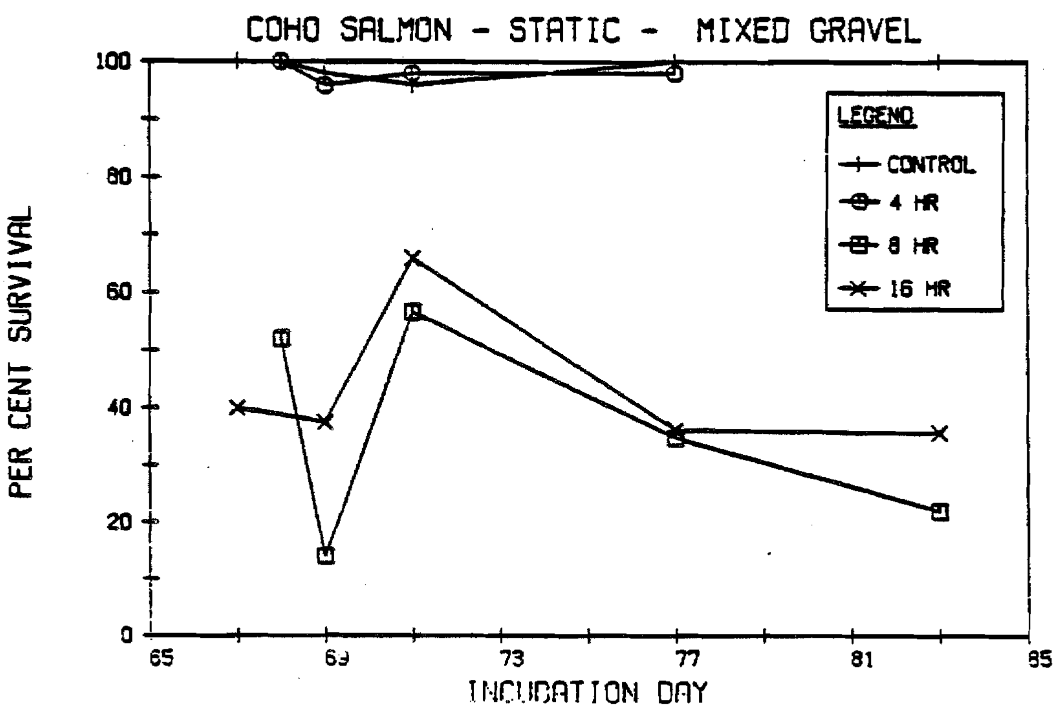


Fig. 59. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

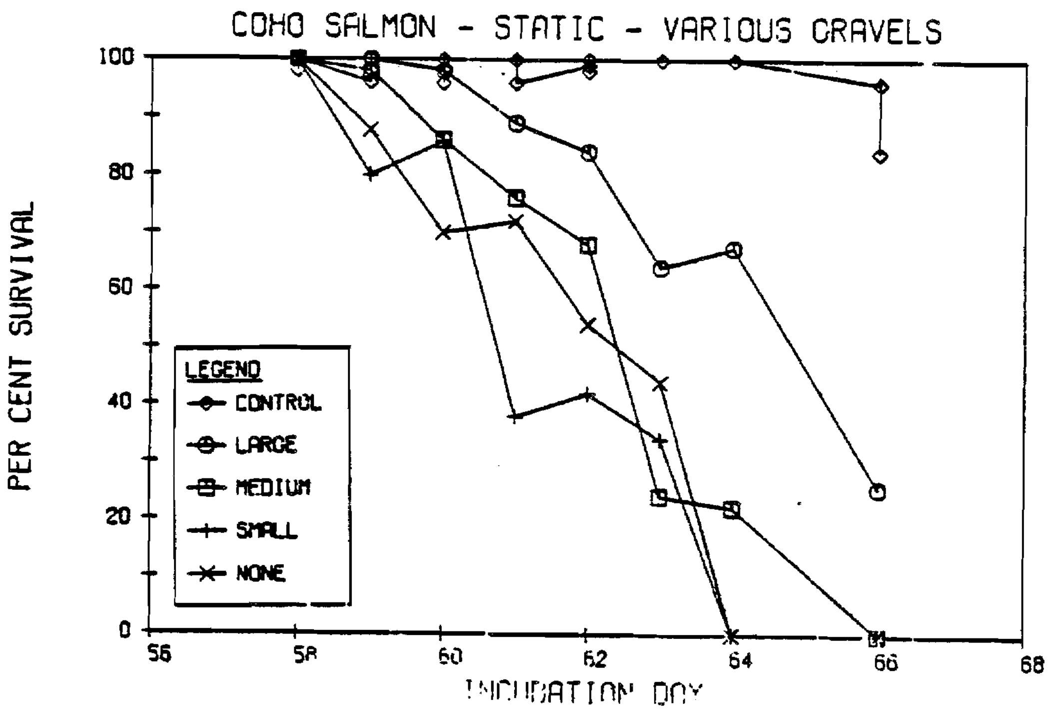


Fig. 60. Percent survival of coho salmon embryos in static water for 24 hrs/day in large, medium and small gravels from eyed through hatching.

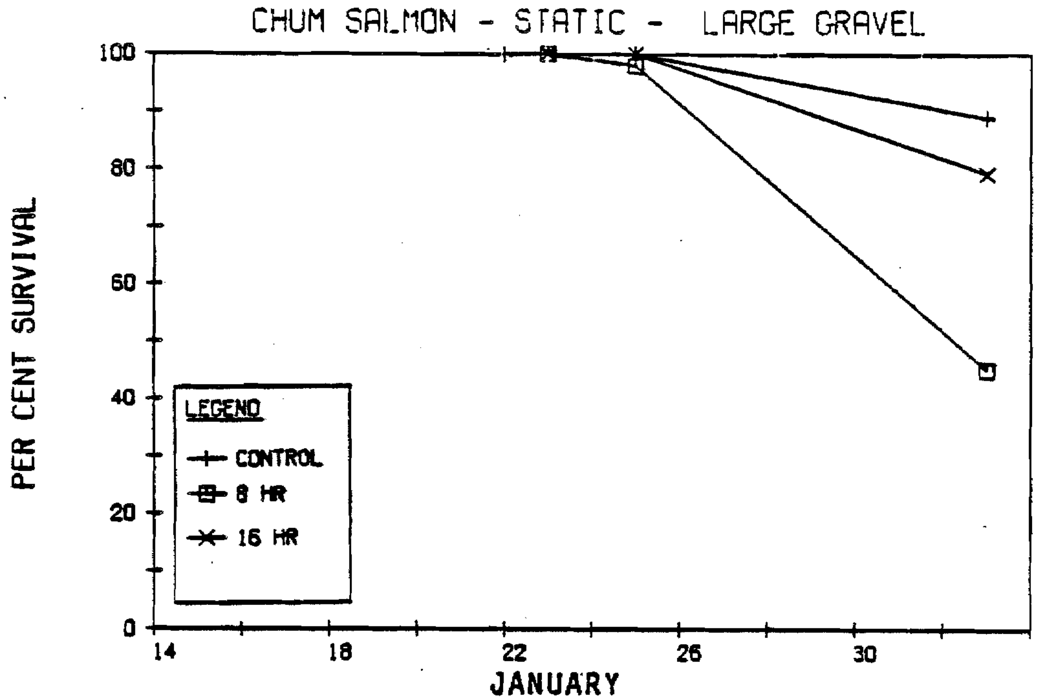


Fig. 61. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in large gravel from eyed through hatching.

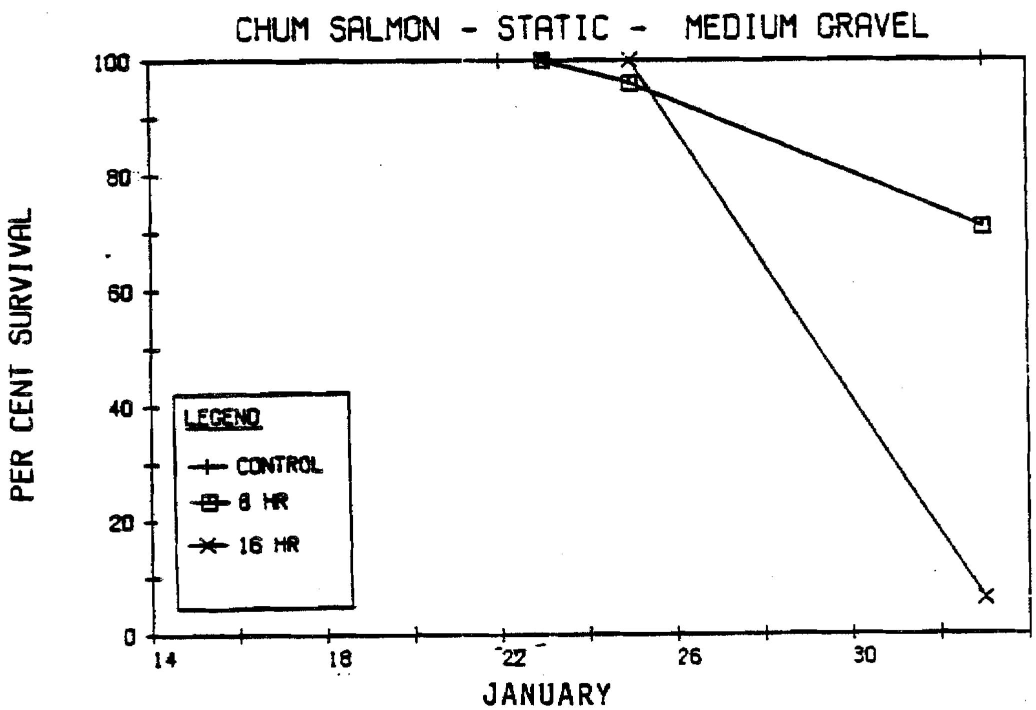


Fig. 62. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in medium gravel from eyed through hatching.

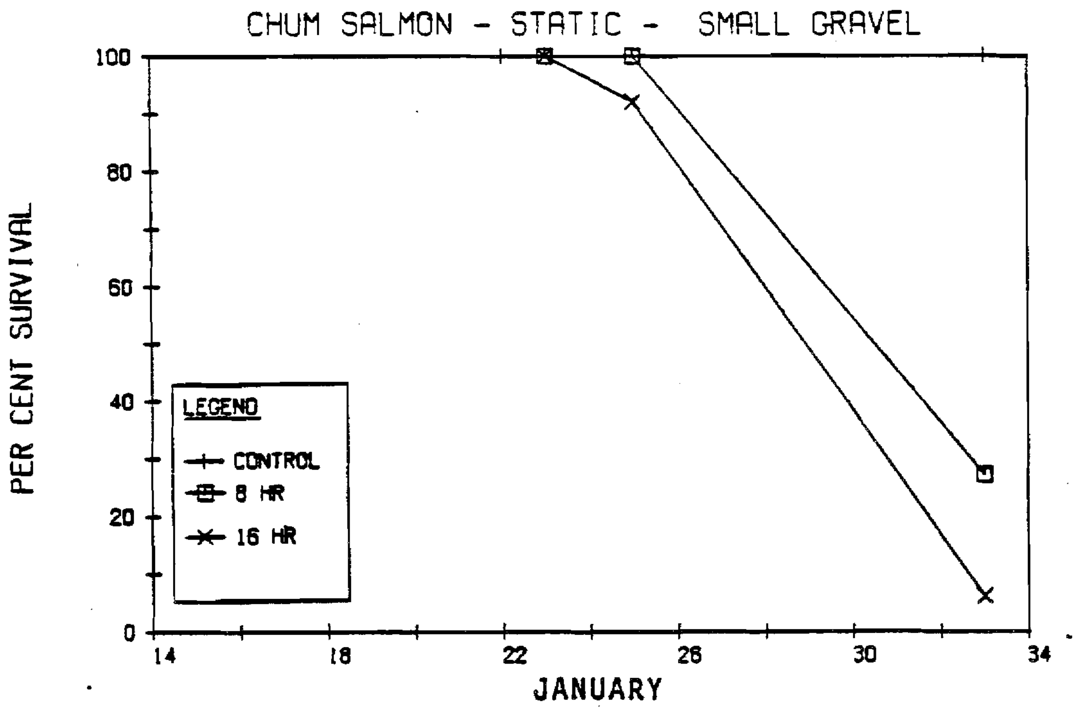


Fig. 63. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in small gravel from eyed through hatching.

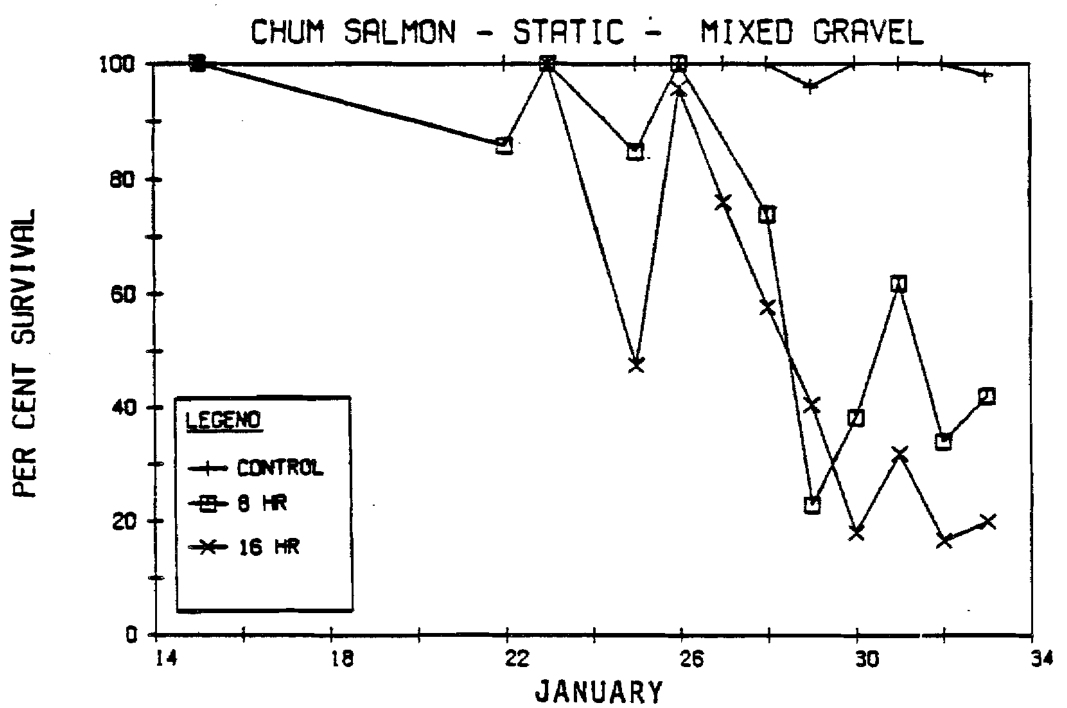


Fig. 64. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in mixed gravel from eyed through hatching.

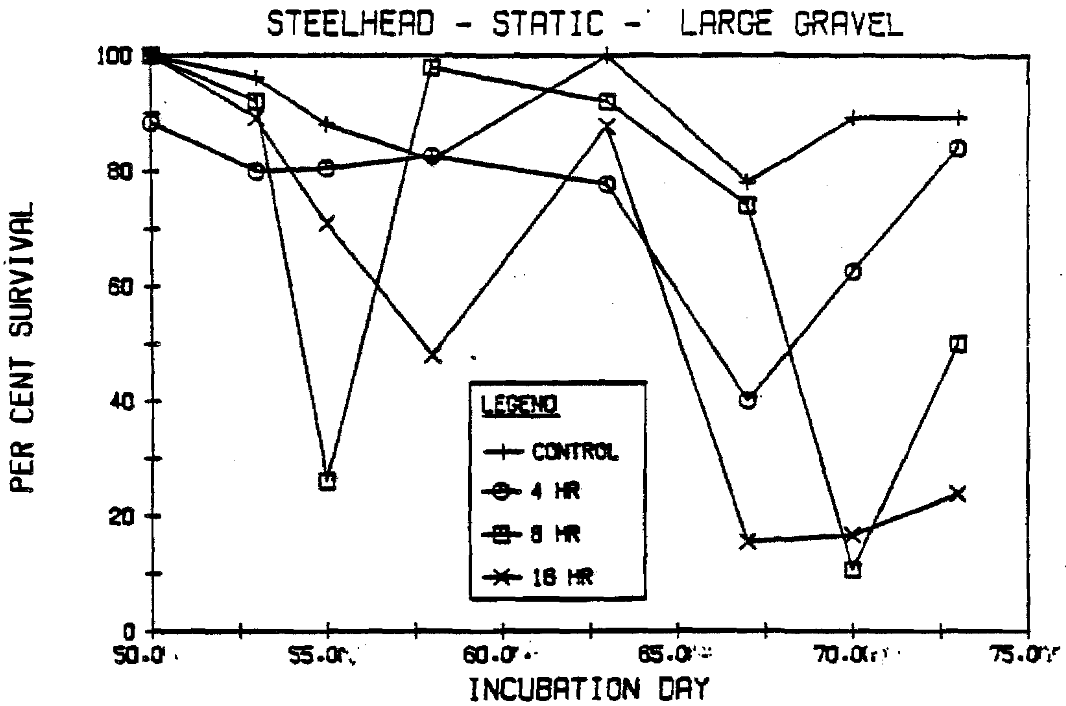


Fig. 65. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

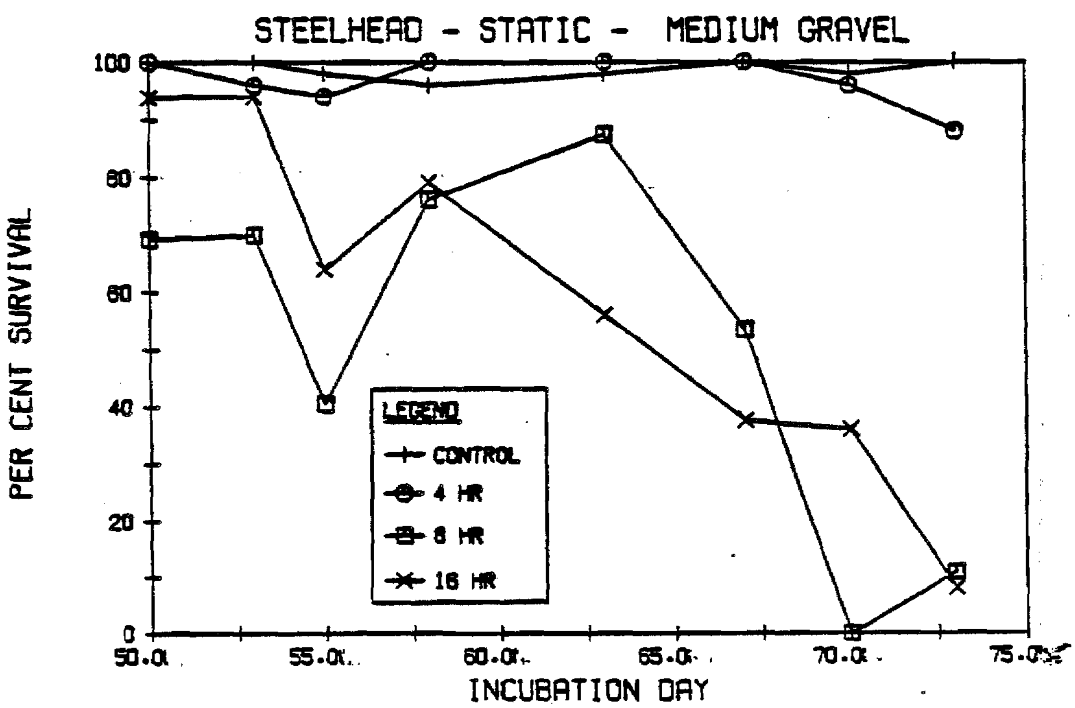


Fig. 66. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

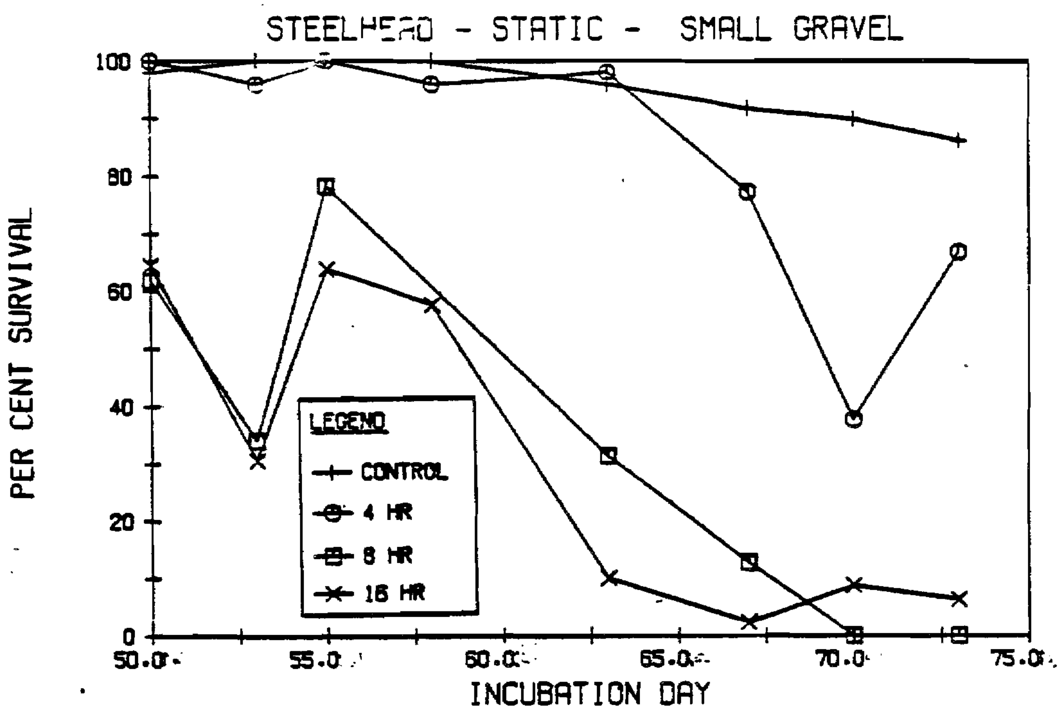


Fig. 67. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

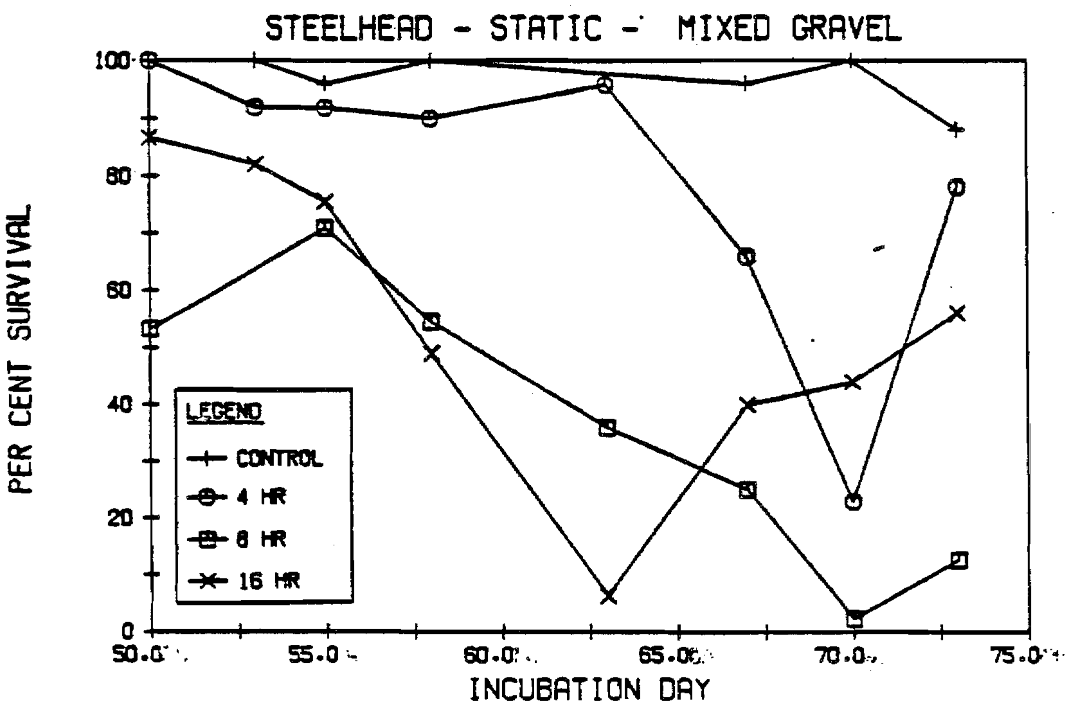


Fig. 68. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

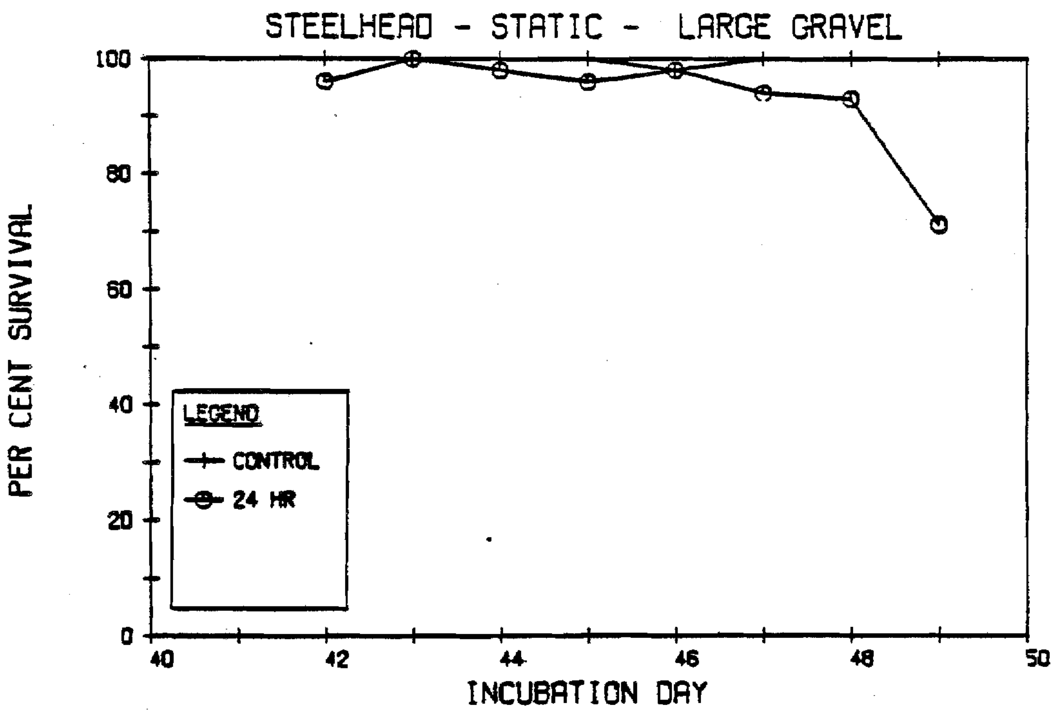


Fig. 69. Percent survival of steelhead trout embryos in static water for 24 hrs/day in large gravel from eyed to hatching.

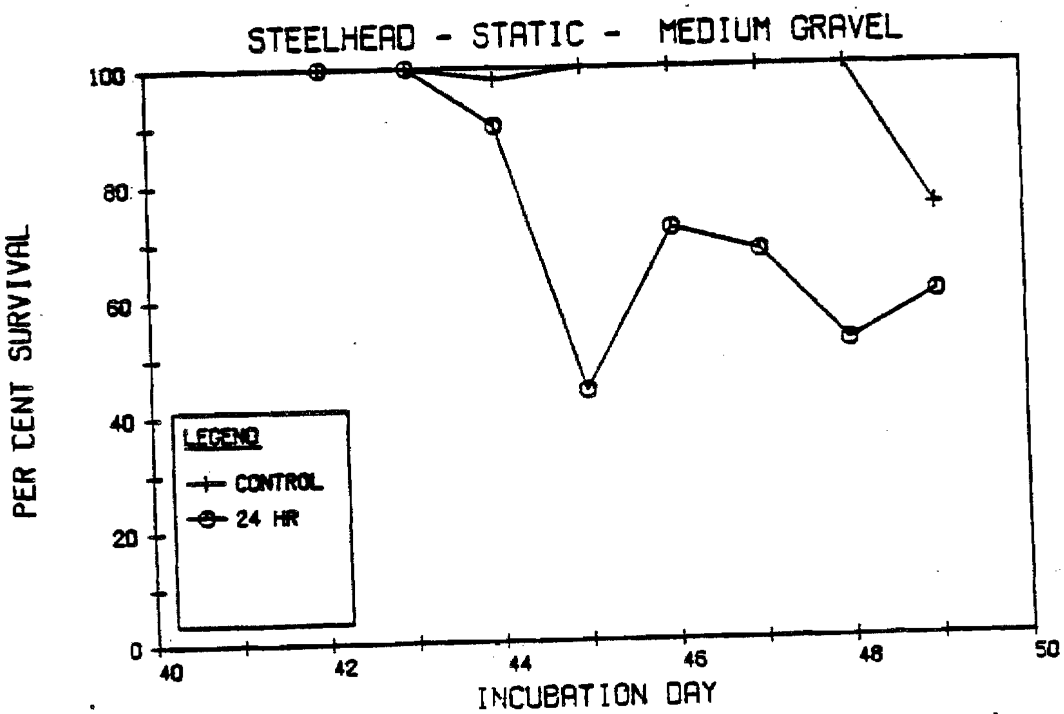


Fig. 70. Percent survival of steelhead trout embryos in static water for 24 hrs/day in medium gravel from eyed to hatching.

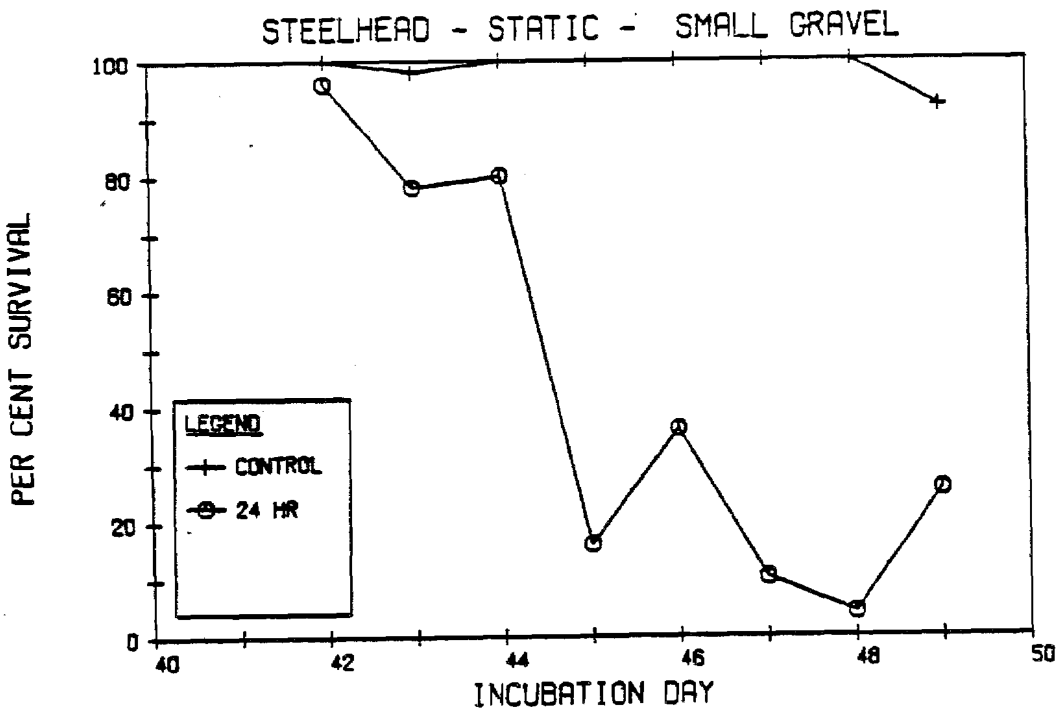


Fig. 71. Percent survival of steelhead trout embryos in static water for 24 hrs/day in small gravel from eyed to hatching.

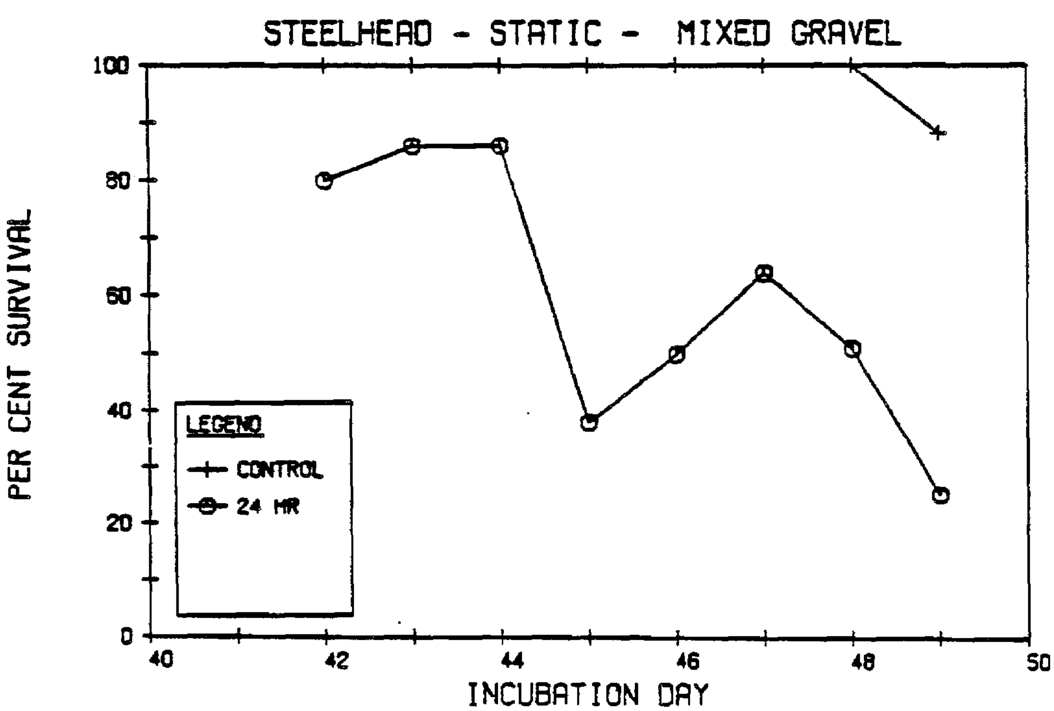


Fig. 72. Percent survival of steelhead trout embryos in static water for 24 hrs/day in mixed gravel from eyed to hatching.