FRI-UW-8127
December 1981

Fisheries Research Institute
School of Fisheries
University of Washington
Seattle, Washington 98195

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

by

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ANNUAL PROGRESS REPORT

for

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

Approved:

Submitted December 11, 1981

Director

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1.0 ABSTRACT

The escapement levels of summer-fall chinook, pink, and coho salmon for 1978-80 were comparable to those of previous years. A large escapement of chum salmon occurred in 1978 with a less than average return in 1980. The most heavily used section of the mainstem Skagit River for summer-fall chinook was between Diobsud Creek and the Cascade River. The number and distribution of returning steelhead trout was determined from aerial surveys. The most heavily spawned area extended from the Cascade River to the Sauk River.

The behavioral study of spawning chinook salmon showed a general pattern of activity indicating that females would complete redds if fluctuating discharge provided adequate flows over a redd site for at least several hours each day. High and stable flows during the chum spawning period prevented meaningful observations of this species.

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 4 x 4 factorial design was employed with 4 dewatered or static conditions (4, 8, 16, and 24 hrs) 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. 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 sizes, and dewatering regimes, at least 50 percent of the alevins had died within a week after hatching.

The relationship between ramping rates ranging from 357 to 1588 cfs/hr and fry stranding mortality was investigated at three Skagit River sites. A significant relationship does not yet exist with these data.

Specific recommendations leading to the conceptualization of a quantitative habitat model are outlined.

2.0 ACKNOWLEDGMENTS

This study is sponsored by the City of Seattle Department of Lighting, Office of Environmental Affairs, Seattle, Washington. Field and laboratory studies are being conducted as a cooperative effort between the following agencies and associated personnel:

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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 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, 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 McDowell 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 study objectives were to 1) determine the tolerance to continuous dewatering on pre- and posthatching egg-alevin developmental stages for chinook, coho, chum and pink salmon and steelhead trout; 2) determine the tolerance to multiple dewatering regimes (4, 8, 16 and 24 hrs daily) on pre- and posthatching stages of each species; 3) determine the tolerance to cumulative multiple dewatering regimes (4, 8 and 16 hours daily) throughout all developmental stages; 4) determine survival rates for each of the above dewatering regimes in specific gravel substrates; 5) determine the quality of fry surviving each dewatering regime and 6) determine the intragravel behavior of pre-emergent fry to dewatering in selected gravel substrates.

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 salt water near Mount Vernon, Washington. The Skagit is one of the largest rivers flowing into Puget 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 daily maximum, minimum and mean gage heights at Newhalem and Marblemount are presented in Figs. 2 and 3, respectively. The gage heights have been converted into discharge in cubic feet per second.

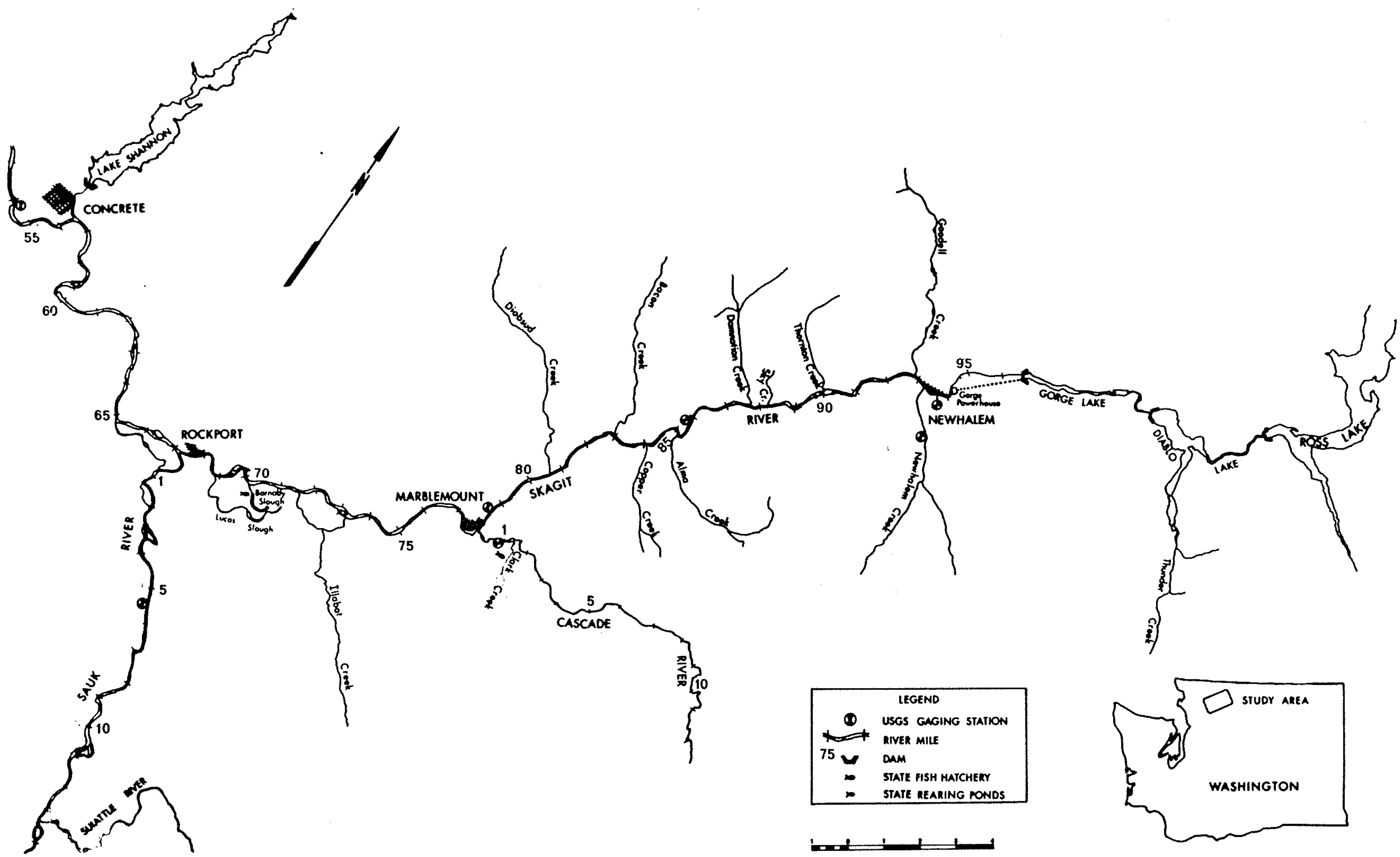

Fig. 1. Skagit Basin study area.

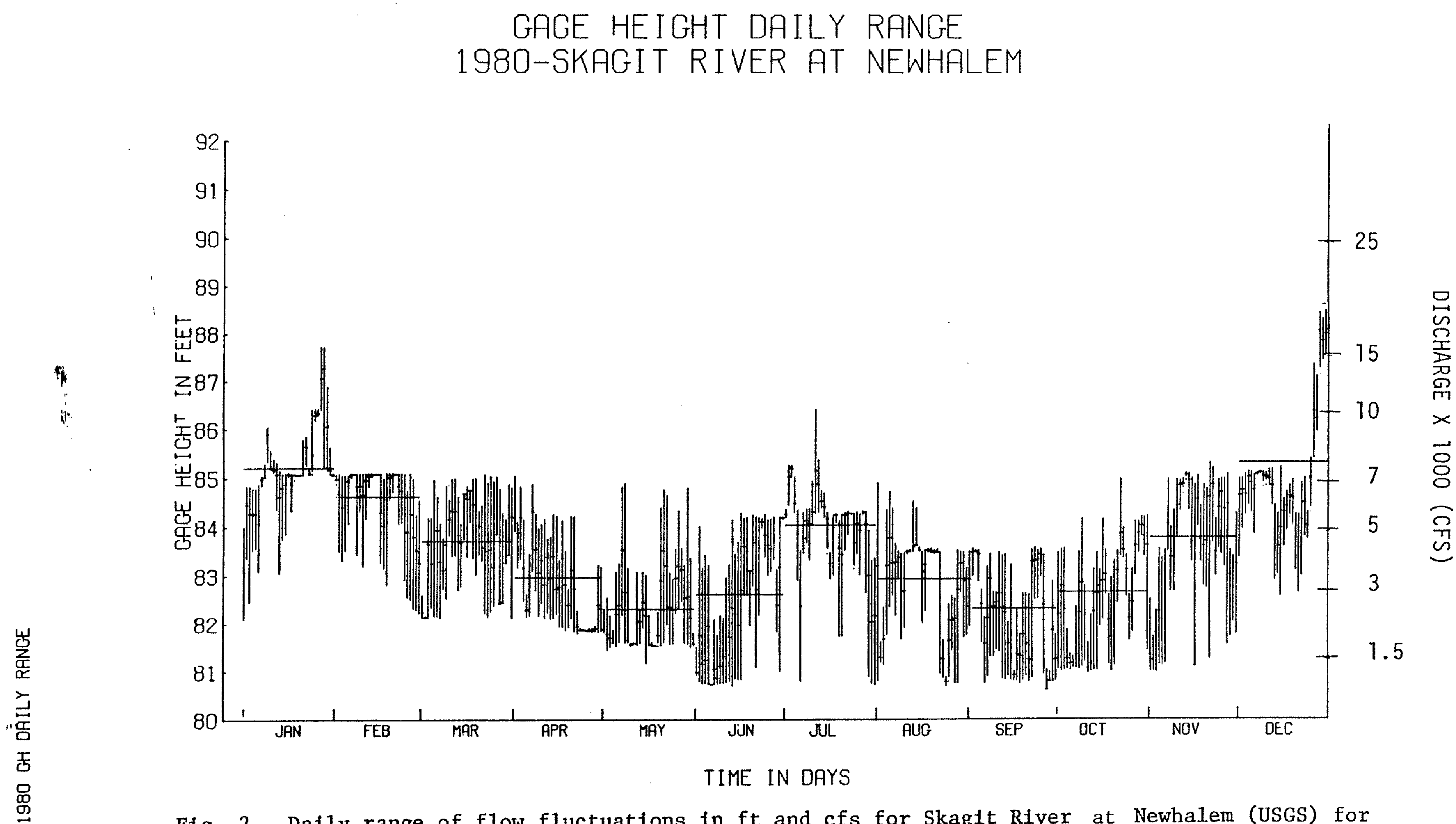

Fig. 2. Daily range of flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for 1980. The mean daily and monthly discharges are also shown.

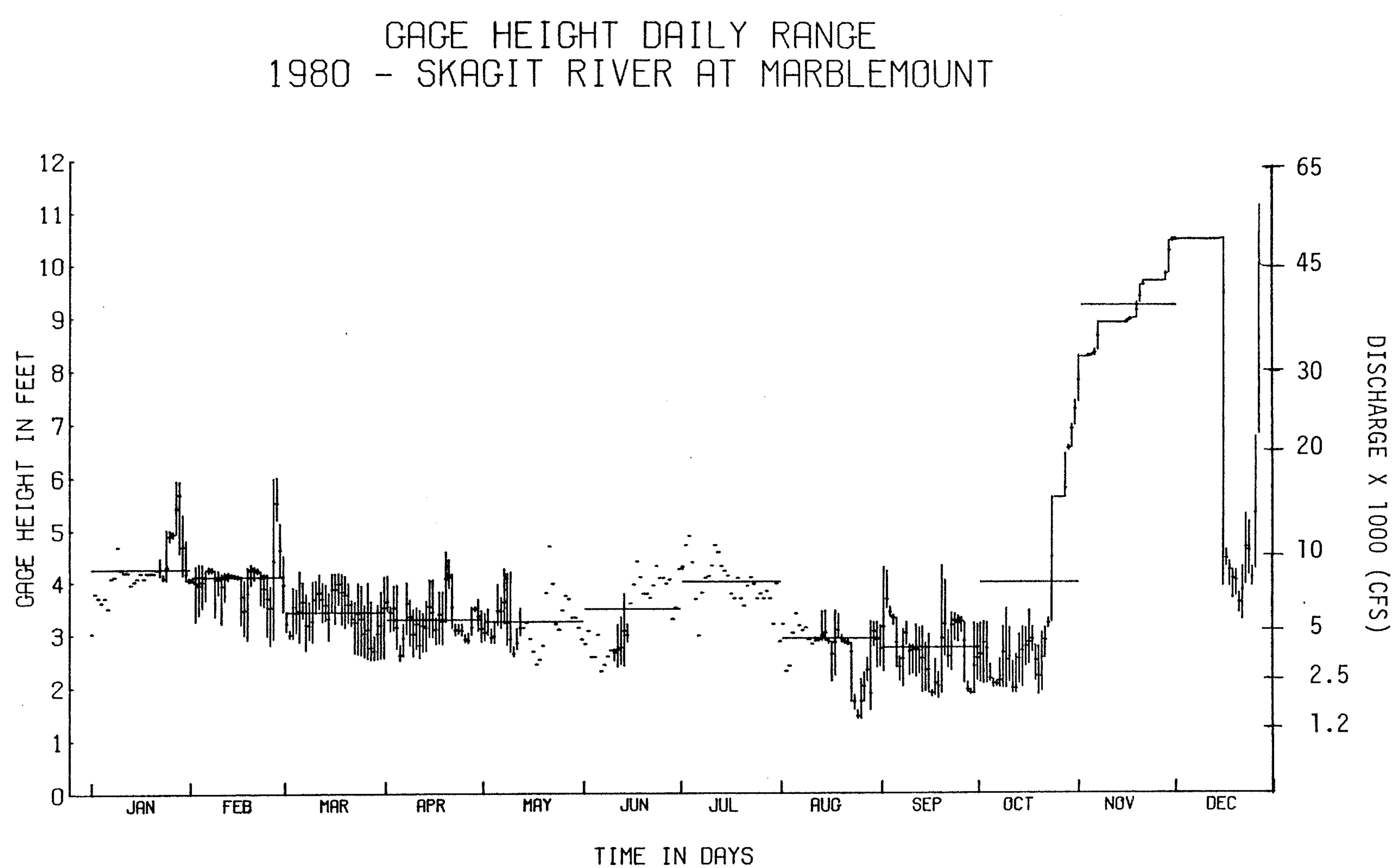

Fig. 3. Daily range of flow fluctuations in ft and cfs for Skagit River at Marblemount (USGS) for 1980. The mean daily and monthly discharges are also shown.

1980 GH DAILY RANGE

5.0 METHODS AND MATERIALS

5.1 Escapements, Spawner Distribution and Area Spawned

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 and by WDG to estimate the steelhead trout escapement. The distribution of steelhead spawners per various river section was determined by plotting the general locations of the redds on recent aerial photos of the river.

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. This date corresponded to a time of relatively low flow and provided an opportunity to document the potential exposure of chinook redds to dewatering. Since most of the redds remained visible on this date the area spawned and spawner distribution were determined more accurately.

5.2 Adult Spawning Behavior

Chinook salmon females selecting redd locations 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 their initial stages of construction. In the first few days of the study, chinook females were spotted digging redds in shallow water and were marked by snagging them on the back with a trebble hook, to which a flag of surveyor's tape had been 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 1980.

For chum salmon two sampling locations were selected for the marking of females and observation of their spawning activity. These sites were the Thornton Creek side channel at RM 9.0 and Marblemount Slough at RM 78. These discrete spawning areas were selected because it was believed that they offered the best opportunity to mark unspawned females entering a spawning area where they could be subsequently observed.

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.

5.3 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.

5.4 Instream Incubation Tests

Field incubation studies were initiated with chum salmon in two side channels of the Skagit River in which this species is 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 Witlock-Vibert (W-V) boxes. Ten freezer containers were positioned double-file, in 8-inch deep trenches and covered with substrate at each of four depths. The staff gage heights of these 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' staff gage height ($\approx$ 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 dwatering event.

Following planting, a freezer container and/or W-V box was removed every two weeks from each redd depth and the developmental 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.

5.5 Laboratory Incubation Tests

5.5.1 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 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. 4) 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. 4). Water entered a

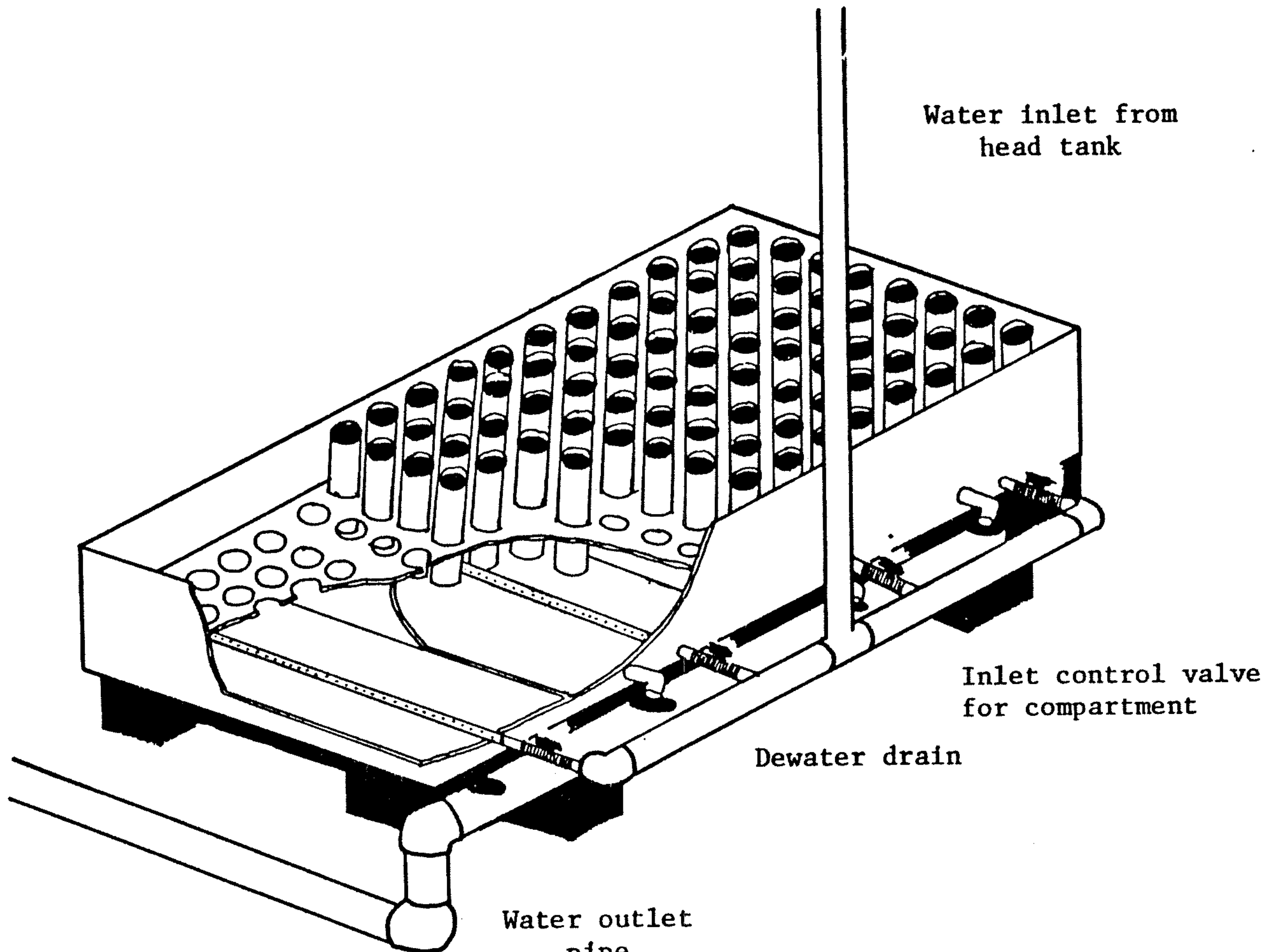

Fig. 4. Diagram of experimental water table with section of false bottom and sides removed to show water flow to several separately controlled compartments.

false bottom on 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.

5.5.2 Artificial Redds

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 of chum salmon were acquired at the eyed egg stage from the Skagit Hatchery.

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. The four gravel sizes used in the various tests 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 gravel (0.08 to 5.08 cm). The mixed gravel approximated the gravel composition found in chinook redds sampled in the Skagit River. 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 in the natural environment.

5.5.3 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 the nine selected experimental redds were monitored by 9 probes connected to an Applied Research Austin (ARA) electronic thermometer and Scanner (SO-20) and recorded on an ARA recorder (Model 400). Relative humidity inside and outside the laboratory was measured daily with a Taylor sling psychrometer.

5.5.4 Experimental Design

Experiments designed to test the effects of static or dewatered conditions caused by flow reduction or cessation utilized a 4 x 4 factorial design. Static or dewater stresses of 4, 8, 16 or 24 hrs (continuous) per day and the four gravel sizes previously described were tested. Each table was designed to test four different static or dewatered conditions and four gravel sizes as the environmental variables. Individual sections were dewatered for 4, 8 or 16 hrs/day. The remaining section was used as a control which received a continuous flow of water. Sections in another table were used for the continuous (24 hr/day) dewatering test and control. These experimental stresses were tested over two life 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 (Stages 1 and 2). 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.

A large number of replicates were designed into each treatment to allow repetitive sampling without replacement. Sampling consisted of removing a series of cylinders each week from the test compartments. The contents of individual cylinders were emptied onto a sampling table and mortalities were recorded. Sampling frequency was increased as hatching began. All live embyros were placed in a compartmentalized Heath incubator and allowed to develop at normal water flow.

5.5.5 Fry Quality

At button-up stage a sample of 30 alevins, or if less, as many as were available, was removed from the Heath incubator from selected test conditions and preserved in 10 percent formalin. To establish a correction factor for the effect of preservation on length and weight changes over time, four groups of 30 untested and Heath incubated alevins were 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 in the fresh state and on subsequent dates in the preserved state. The formula used in computing condition factors was

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

5.5.6 Intragravel Behavior

Intragravel behavior studies were conducted in two different experimental chambers. Early studies on chinook were conducted in clear plexiglas 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. 5).

In posthatching 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, 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 also 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 alevins.

Immediate posthatching 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.

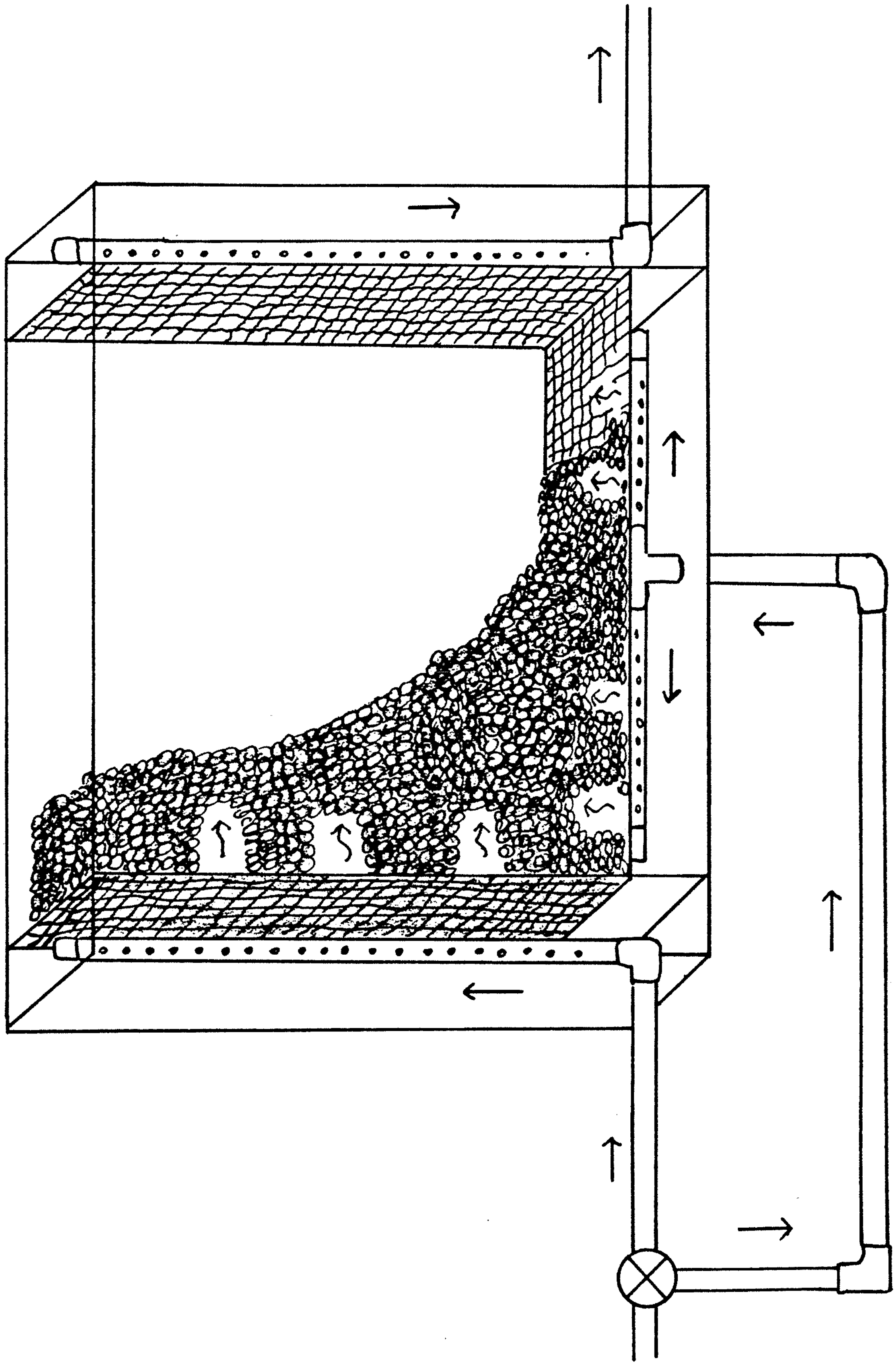

Fig. 5. Alevin behavior chamber.

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. Three gravel sizes tested ranged in size from 1.25 to 1.9 cm, 1.9 to 2.5 cm, and 2.5 to 3.9 cm in diameter. Laminar flow was used in all tests.

5.6 Fry Stranding

5.6.1 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 (RM 90.2), Marblemount Bar (RM 78.2) and Rockport Bar (RM 67.7) (Fig. 1). 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 first and the areas between transects were then examined. 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 as we gained experience it required only one person per bar to collect the data. All observations began at daybreak to prevent loss of fry on the study sites due to scavenging by birds. The samplers were instructed to collect 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.

5.6.2 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 sample period the area electrofished was a continuous two hundred foot section of each gravel bar.

5.6.3 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.

5.6.4 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 chinook fry was converted to an index number by the following steps:

1) Adding one to the count and multiplying by ten. This data transformation created numbers which could be adjusted for the abundance and tributary inflow factors and still result in an integer value, which facilitated presentation and comparison of stranding indices.
2) Dividing by the chinook fry abundance factor. This was done to adjust for fluctuating fry abundance. Assuming all other variables being 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 abundance.
3) Multiplying by the tributary inflow factor. This was done to adjust for fluctuations in tributary inflow. Assuming all other variables being equal, a change in tributary inflow would cause a directly proportional change in stranding rate.

The abundance and tributary inflow factors were computed by dividing all the observations in each data set by the lowest value in each set. Thus the day with the lowest chinook abundance for a given site in a give year has a factor of 1.0. Similarly, the day with the lowest tributary inflow has a factor of 1.0. The tributary inflow was factored over both years because the basic river channel and study bars had only minor changes in configuration between years. However, the abundance factor was computed independently for each year because the locations for electrofishing within each study site were changed between years.

Although all fry found stranded were enumerated only the chinook fry were utilized for the fry abundance and stranding index calculations because their populations were considered to be of a more stable "resident" nature than the pink and chum fry.

5.6.5 Downramp Rate vs. Stranding

The stranding indices for chinook fry at each study site were compared to the rates of downramping with graphic display. The actual downramp rates achieved on each observation date were computed utilizing change-in-flow records from the U.S.G.S. Newhalem gage and the time frame for the flow change from Seattle City Light power generation strip charts for the Gorge powerhouse output. The SCL time data were utilized because they were on a finer scale than U.S.G.S. data allowing greater accuracy in determining the start and end of a power/flow reduction cycle. Power generation at Gorge powerhouse and flow at the Newhalem gage changed simultaneously because the gage is located immediately downstream from the Gorge powerhouse tailrace.

When all the actual downramp rate data are available the functional relationships between downramp rate and fry stranding will be explored. Preliminary analysis indicates that variance in downramp rates will account for a significant portion of the observed variance in fry stranding.

6.0 RESULTS AND DISCUSSION

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 1978-1980 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 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 1980 are shown in Table 2.

Tables 3 and 4 list chinook salmon redd counts made by WDF from helicopter and fixed wing surveys from 1977-1980. 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 the helicopter and fixed-wing surveys (Table 5). The total area spawned as determined from the photographs was 58,810m^2 or 2,162 m^2/mi. The river section with the greatest area spawned per river

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

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

[2] Revised from 1976 and 1977 tagging studies.

Table 2. Salmon escapement to the Skagit Hatchery racks 1978-1980.[1]

Year	Coho	Chinook	Pink	Chum
1978	11,078	88		284
1979	11,792	267	384	8
1980	21,893	1,010		17

[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 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

mile, 5,365 m^2, was Diobsud Creek to Cascade River (Table 6). The date on which 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 flow level. 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 0.26 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 7 for the period 1978 to 1981. 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 1980-1981 estimated by WDG are summarized in Table 8. 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 1981 steelhead spawning season for the Skagit and Sauk rivers by WDG. Steelhead redd counts from

Table 6. 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 x 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

Table 7. Fish production of the Skagit Hatchery and fish plants by WDF in the Skagit system from Boyd Creek (river mile 44.7) to Newhalem, 1978-1981.

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
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
	*Plant as of July 29, 1981				
	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 8. 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

these surveys are presented in Tables 9-11. Spawning generally commenced in mid-March and extended through June. Peak counts of 67 and 427 in the mainstem Skagit and 73 and 23 in the Sauk occurred on June 9, 1980 and May 22, 1981 respectively. In 1979 surveys were not conducted beyond April, so a peak count could not be obtained.

Based on the 1980 and 1981 peak counts approximately 80 percent of the redds were located in the mainstem Skagit (from Sedro Woolley to Newhalem) with 20 percent in the mainstem Sauk (primarily from the mouth to Darrington). The section of the Skagit mainstem most heavily spawned extended from the Cascade River to the Sauk River.

Catch statistics for the Skagit River system, calculated and compiled by WDG, are presented for 1977 to 1981 in Tables 12-14.

Table 9. 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 10. 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 11. 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		

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

Table 12. Sport harvest of Skagit system winter-run (November-April) steelhead trout, 1977-1978 through 1980-1981 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

Table 13. Sport harvest of Skagit system summer run (May-October) steelhead trout, 1977-1980 (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

Table 14. Skagit system Treaty Indian harvest of winter-run steelhead, 1977-1978 through 1980-1981 (WDG).

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

6.2 Adult Spawning Behavior

6.2.1 Chinook

The flows during the chinook observation period were relatively stable. The change in flow conditions is reflected in the daily changes in stream height at the Marblemount gage (Figs. 6 and 7). The mean change in stream height 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 stream 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 Table 15. 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 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 Table 16. The general conditions for observation of the chinook spawning activity and marked females were generally good (Table 17). A chronological summary of tagging and observation dates is presented in Table 18. 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

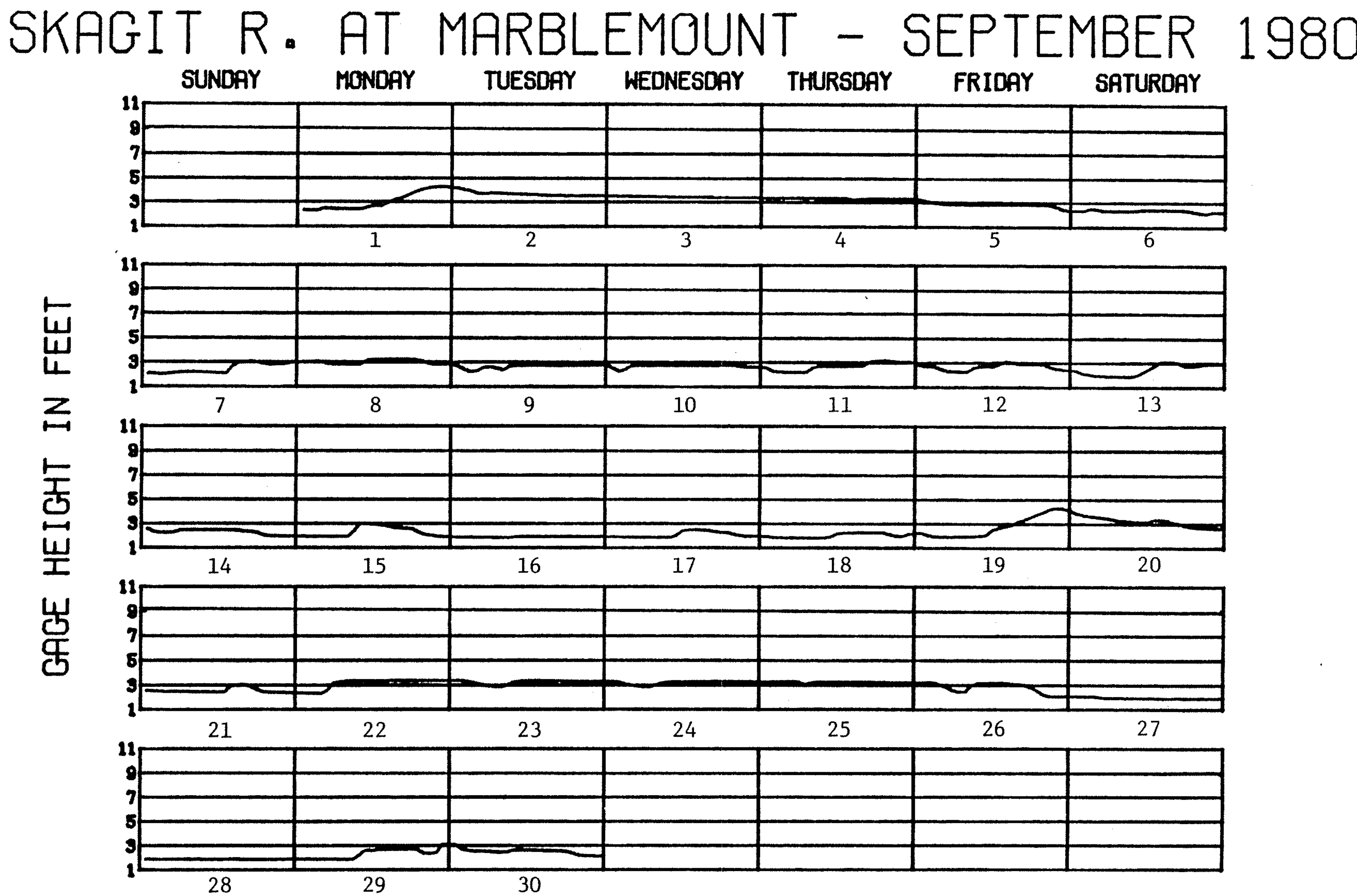

Fig. 6. Hourly gage height data for Skagit River at Marblemount (USGS), September 1980.

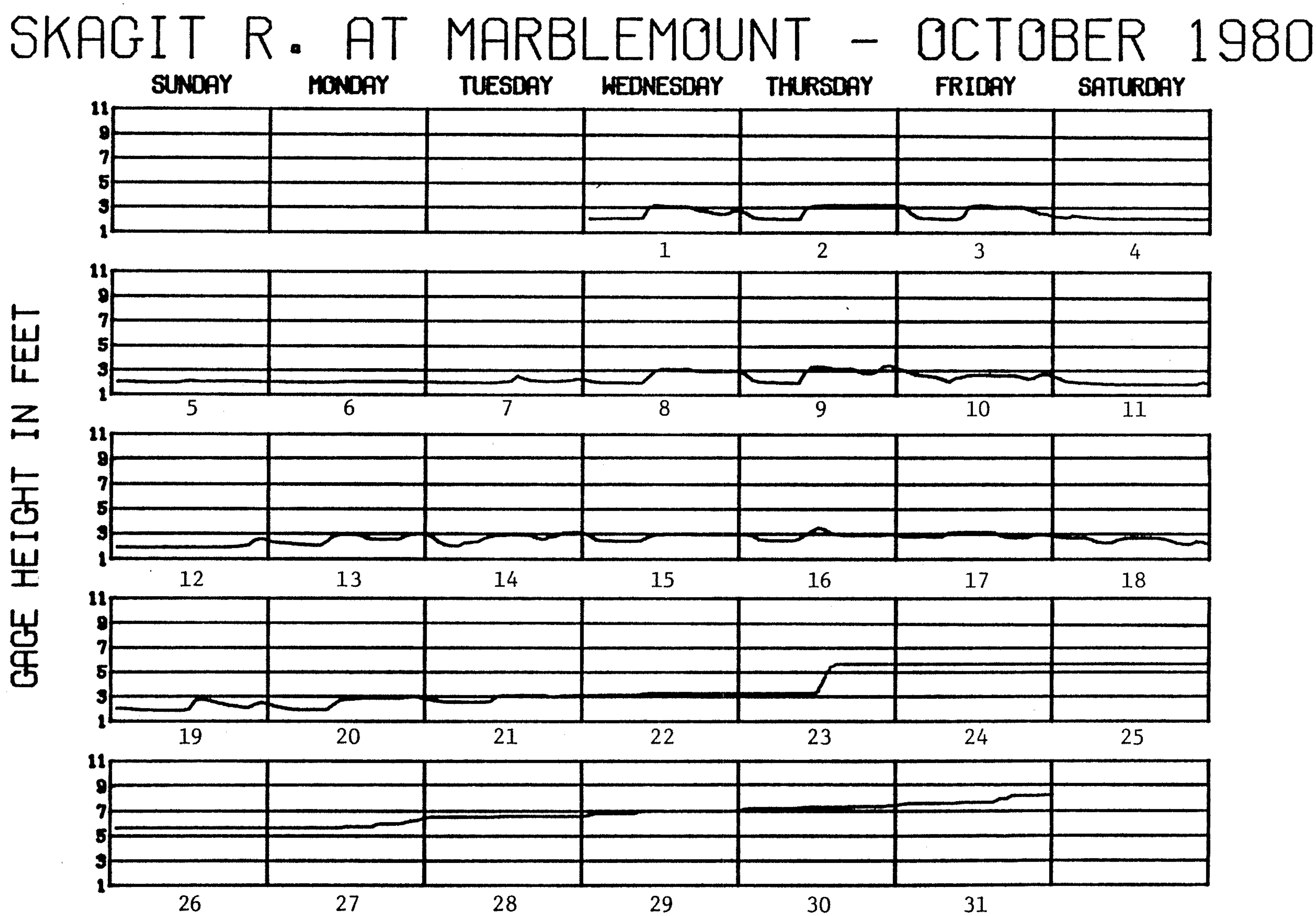

Fig. 7. Hourly gage height data for Skagit River at Marblemount (USGS), October 1980.

Table 15. 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		

Table 15. Skagit summer-fall chinook tagging data, 1980 (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		

Table 15. Skagit summer-fall chinook tagging data, 1980 (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 Fish was unspawned	red red	none none
9/16/80	Left bank riffle at R.M. 79.0	21	R L	pink pink Fish was nearly spawned out	pink pink	pink pink
9/16/80	Right bank riffle at R.M. 78.3	22	R L	white white Fish was unspawned	red red	none none
9/16/80	Right bank riffle at R.M. 78.1	23	R L	white white Fish was unspawned	red red	none none
9/16/80	Right bank riffle at R.M. 78.1	24	R L	pink pink Fish was unspawned	pink pink	none none
9/16/80	Right bank riffle at R.M. 78.1	25	R L	yellow yellow Fish was one-fourth spawned out	red red	none none
9/16/80	Right bank riffle at R.M. 78.1	26	R L	orange orange Fish was one-half spawned out	yellow yellow	none none
9/16/80	Right bank riffle at R.M. 78.1	27	R L	white white Fish was three-fourths spawned out	blue blue	none none
9/16/80	Right bank riffle at R.M. 78.1	28	R L	orange orange Fish was three-fourths spawned out	green green	none none
9/16/80	Right bank riffle at R.M. 78.1	29	R L	orange orange Fish was unspawned	white white	none none

Table 16. 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

Table 16. 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					

Table 16. 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				

Table 16. 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 mark-...	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			

Table 16. 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 mark- ing	9/18/80 RB at RM 78.1 Spawning					
25.	9/16/80 RB at RM 78.1 Spawning Initial mark- ing	9/18/80 RB at RM 78.1 Spawning					
26.	9/16/80 RB at RM 78.1 Spawning Initial mark- ing						
27.	9/16/80 RB at RM 78.1 Spawning Initial mark- ing						
28.	9/16/80 RB at RM 78.1 Spawning Initial mark- ing						
29.	9/16/80 RB at RM 78.1 Spawning Initial mark- ing	9/17/80 RB at RM 78.1 Spawning	9/18/80 RB at RM 78.1 Spawning				

Table 17. 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

Table 17. 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

Table 18. 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														*	-	-	-		-

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

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 at increased flows.

While observing redds marked with painted rocks we observed only two redds out of twenty-five that were not judged to be 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.

6.2.2 Chum

The flows during the chum observation period were moderately high and very stable (Figs. 8 and 9). Spot checks of the Marblemount gage indicated flows ranging between 5,950 cfs and 8,950 cfs over the entire observation period, which represents a stream height fluctuation of 0.80 feet. The U.S.G.S. records were not examined for this period because there were no

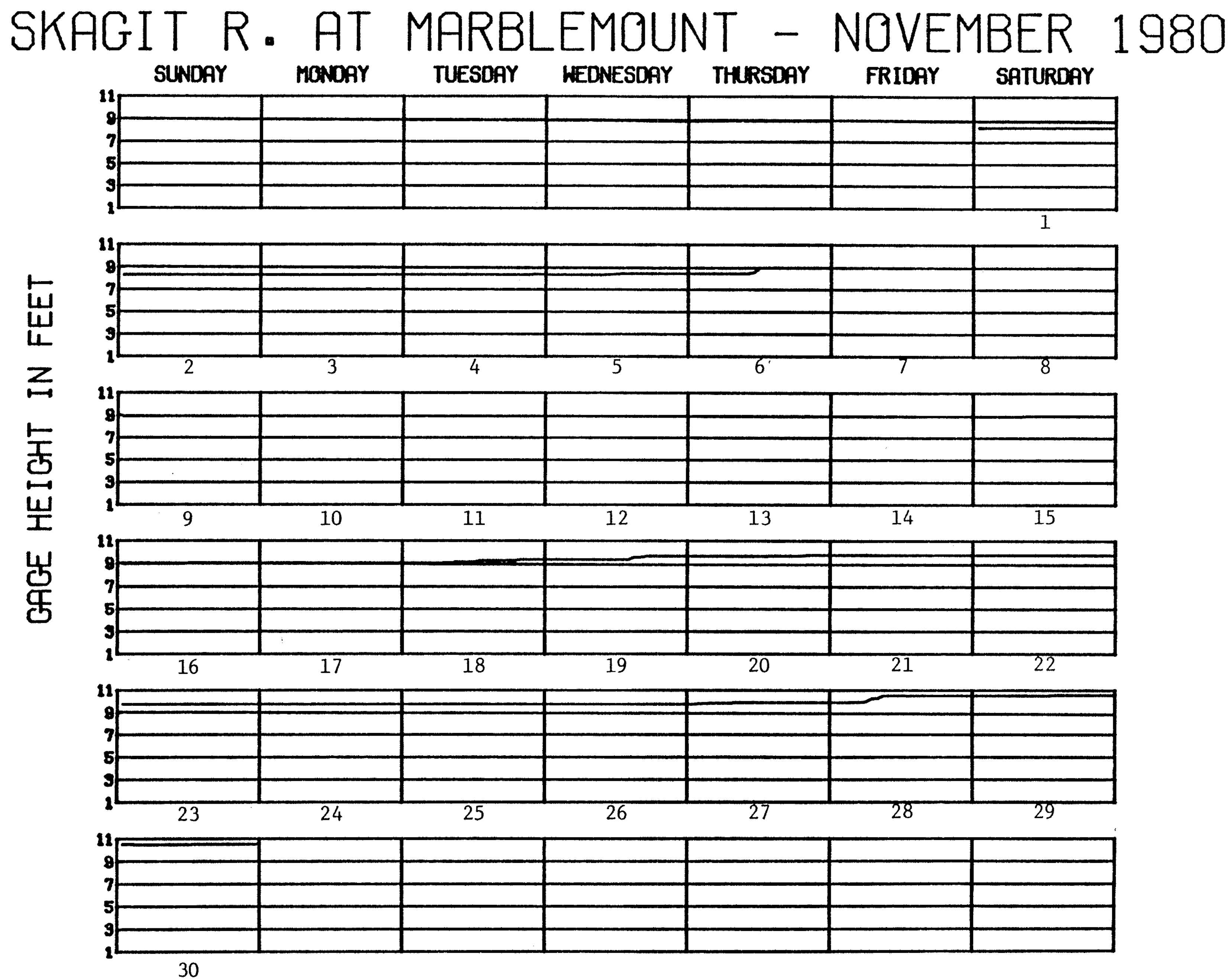

Fig. 8. Hourly gage height data for Skagit River at Marblemount (USGS), November 1980.

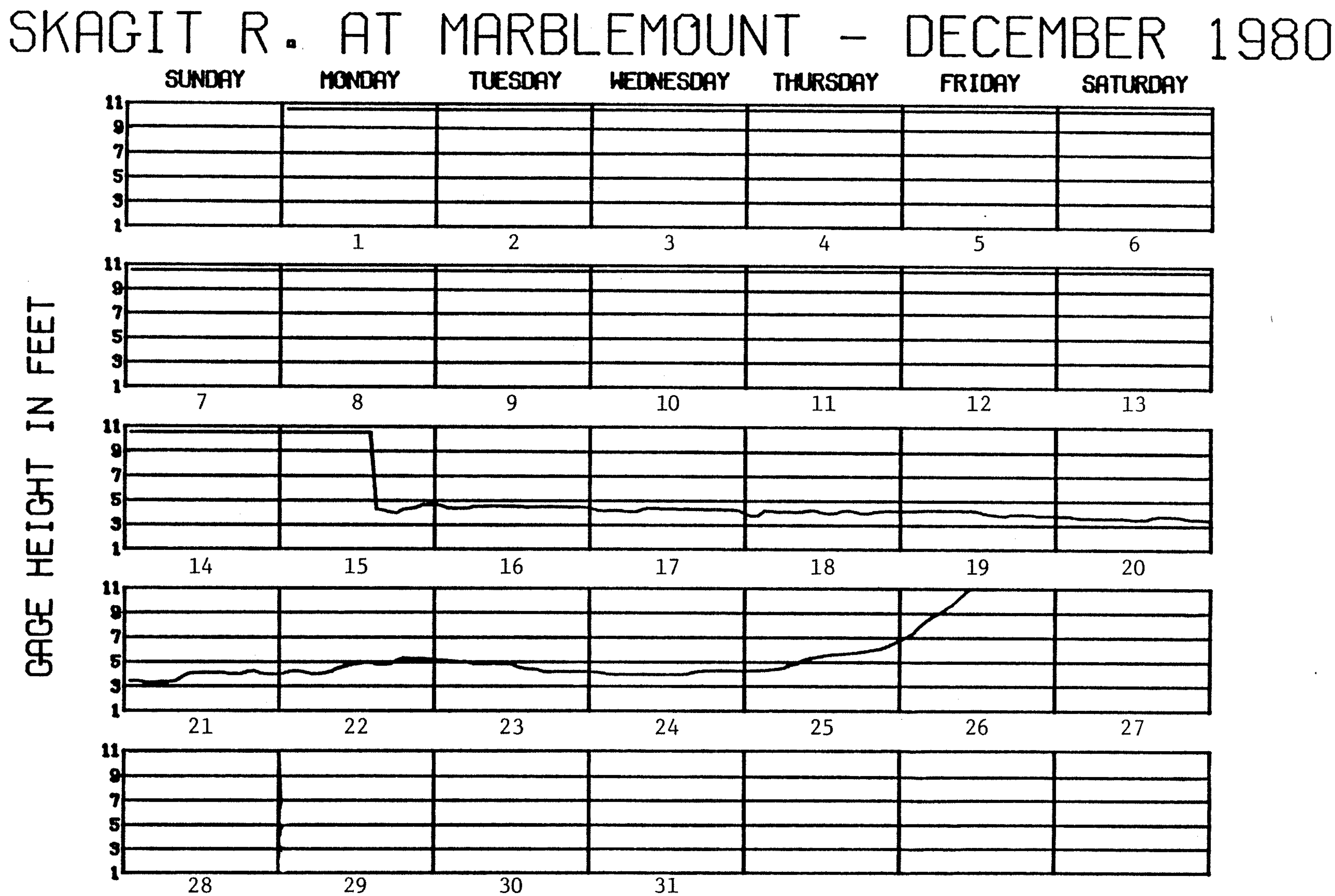

Fig. 9. Hourly gage height data for Skagit River at Marblemount (USGS), December 1980.

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 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 Table 19 and a chronological summary of tagging and observation dates are presented in Table 20. The general conditions for observation of chum spawning activity and marked females (Table 21) were fair to excellent. A chronological summary of tagging and observation dates is presented in Table 22. 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 from 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 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.

Table 19. 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

Table 20. 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 Marble-mount Slough, holding on riffle subsequently caught in net, was spawned out	12/8/80 - 1400 115 yds above mouth of Marble-mount 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 Marble-mount Slough, holding just above spawning riffle	12/7/80 - 150 yds above mouth of Marble-mount 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 Marble-mount 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 Marble-mount Slough, digging on redd, attended by two (2) males	12/8/80 - 1400 115 yds above mouth of Marble-mount 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 Marble-mount Slough, chased off riffle into net, Initial marking	12/8/80 - 1700 100 yds above mouth of Marble-mount Slough, recaptured in net while moving up slough, spawned out	12/10/80 - 1000 118 yds above mouth of Marble-mount Slough, digging on a redd. No males around	2/15/80 - 1630 118 yds above mouth of Marblemount Slough, holding position, no males around.

Table 20. 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	

Table 21. 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 clea 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

Table 21. 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

Table 22. 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

6.3 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 TU's.

The unavailability of additional fish at later dates precluded incubation studies at the warmer temperature regimes of the Skagit River experienced by the peak of the natural spawning run in mid- to late-May. These gaps in information will be filled by electrofishing and hydraulic sampling data to be acquired in summer of 1981.

6.4 Instream Incubation Tests

Egg boxes used to test instream flow fluctuation effects on chum salmon were planted on January 19, 1980 and removed at biweekly intervals from the gravel 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 23 and 24, respectively. Similar data for the Whitlock-Vibert boxes at the Thornton Creek site are presented in Table 25. 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 incubator boxes appeared to provide slightly higher

Table 23. 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 24. 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 25. 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.

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.

Newhalem and Marblemount gage hydrographs showed a period of high discharge in late January followed by moderate yet widely fluctuating flows in February and March. Coincident with this decreasing yet fluctuating flow regime was a progressive intrusion of sediment into the incubation boxes which was probably 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 supports these findings as the freezer containers and W-V boxes became solidly intruded with sediment in accordance with fluctuating river discharge. The accumulation of sediment in these boxes was no doubt responsible for the poor survival of newly hatched alevins. Indeed the adverse effect of fine sediments on egg and alevin survival is well documented.

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.

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. These studies are addressed in the following section.

6.5 Laboratory Incubation Tests

6.5.1 Environmental Parameters

The temperature of the Clark Creek water used in the laboratory experiments is plotted with the temperature of the Skagit River at Newhalem in Fig. 10. The spring-fed Clark Creek water had a more stable temperature than the Skagit River and thus was colder in the fall and warmer through the winter than the Skagit River.

The relative humidity measured inside and outside the laboratory is shown in Fig. 11. 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 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. Thus the 4 hr/day static dissolved oxygen level did not drop to 7.1 mg/1, the level that was considered critical in studies by Alderdice et al. (1958) and Hayes et al. (1951). The 8 hr/day static level was just below this level and the 16 hr/day static dissolved oxygen level was well below critical levels.

A particle size analysis of the four artificial substrates tested in the

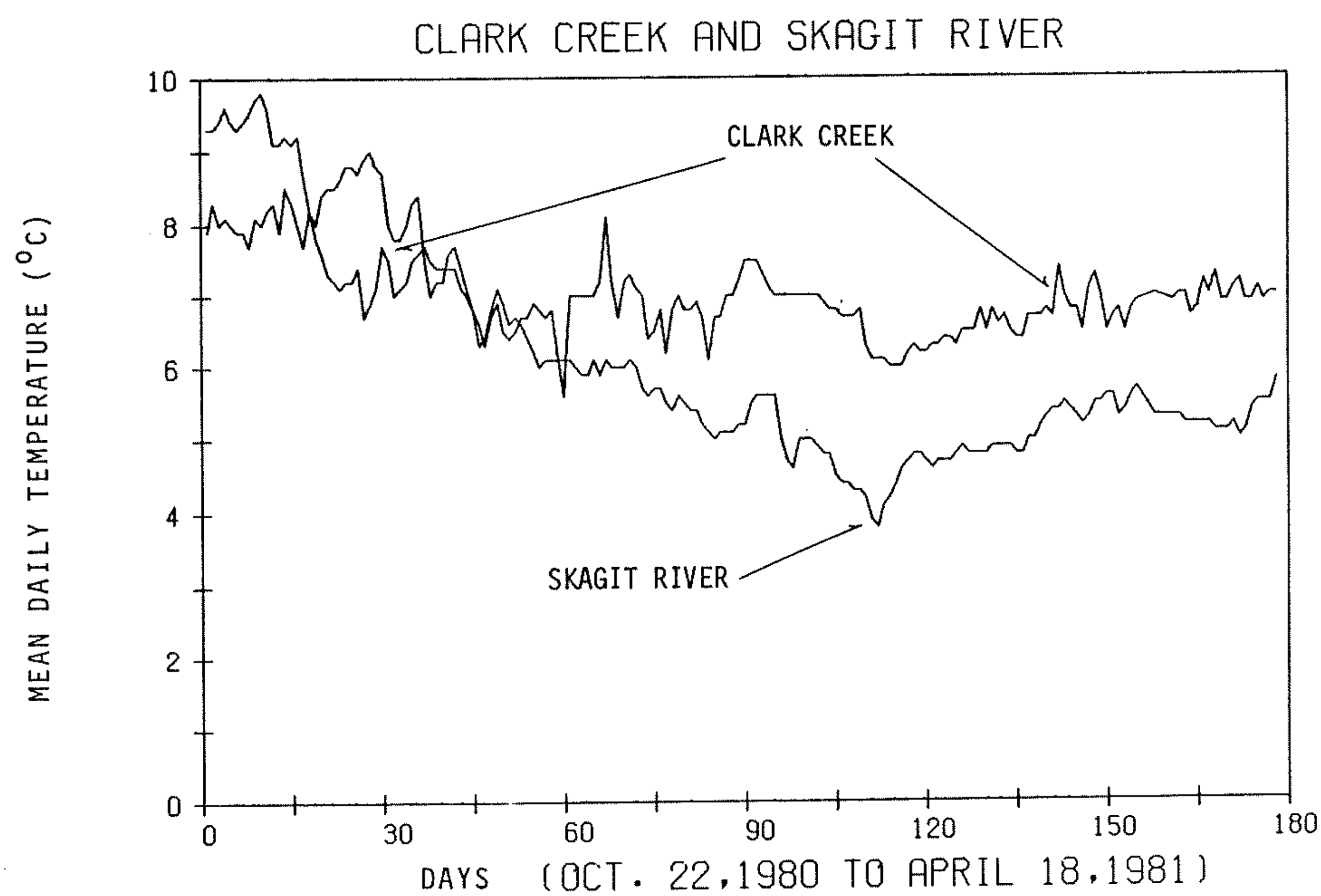

Fig. 10. Mean daily temperature of Clark Creek water utilized in the experimental hatchery and the Skagit River at Newhalem.

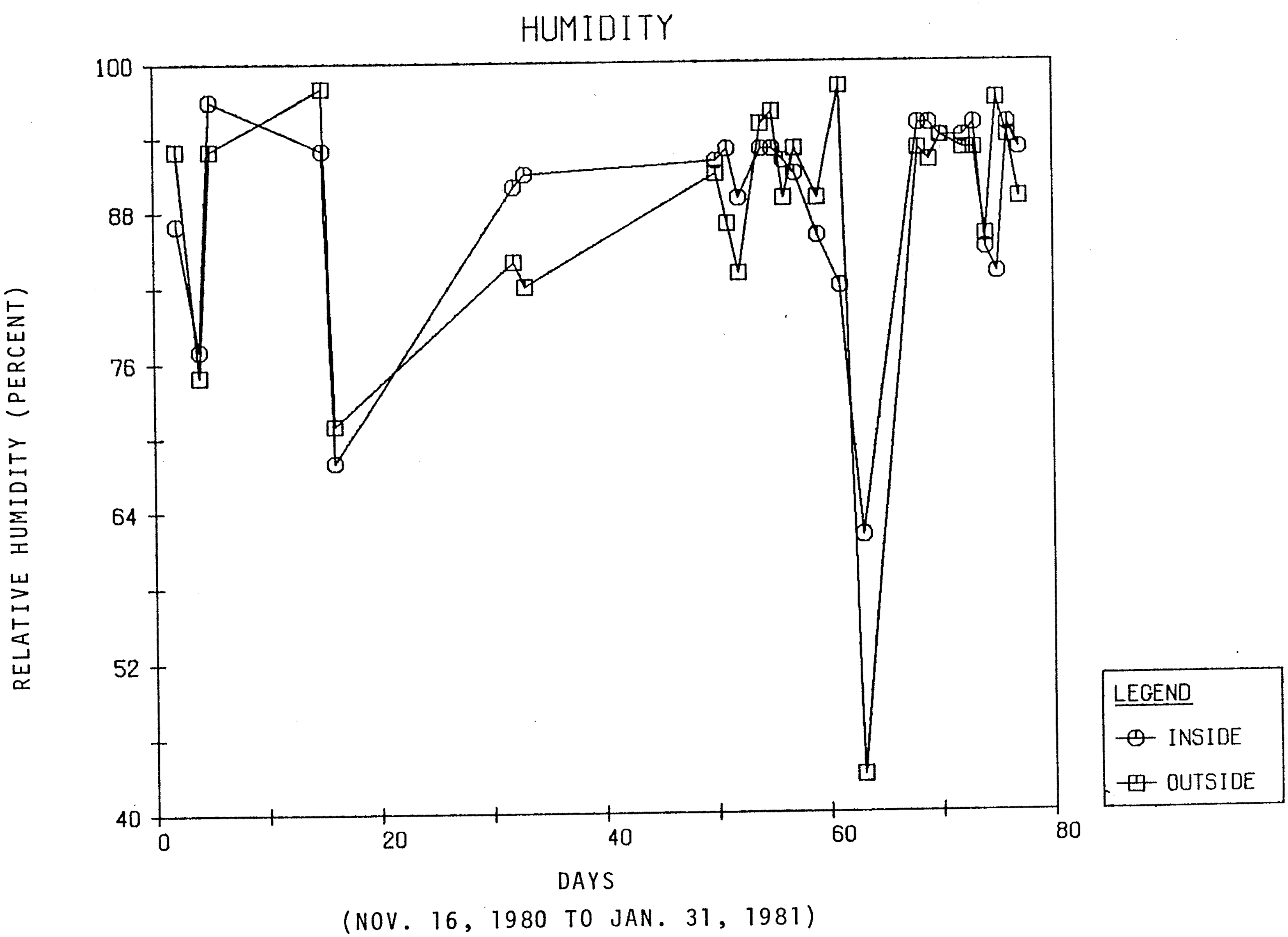

Fig. 11. Relative humidity measured inside and outside of the experimental hatchery building.

laboratory experiments is presented in Table 26. The large, medium and small sizes were greater than 13.5, 6.73 and 3.33 mm, respectively. The mixed substrate had a geometric mean diameter of 7.73 mm.

Table 26. Geometric mean diameter (dg) and substrate particle size by groups representing percent volume passing through sieves of the designated size (mm).

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	—*	100	53.1	.6	.2	0	0	0	0	0	0
Medium	13	—*	100	100	59.7	3.4	1.1	.4	.2	.1	.1	0
Small	10	—*	100	100	99.9	54.0	2.1	.8	.3	.1	.1	0
Mixed	58	7.73	100	74.6	35.3	15.7	10.0	6.1	3.1	1.3	.3	0

* Indeterminable

6.5.2 Dewatered and Static Water Tests

6.5.2.1 Chinook salmon

Figs. 12, 13, 14 and 15 illustrate the comparative prehatching survival (stage 1 — fertilization to eyed) for chinook salmon embryos dewatered for 4, 8 and 16 hr daily in large, medium, small and mixed gravel, respectively. The fertilization to eyed stage extended through the first 60 days of incubation. Prehatching survival was high in the four gravel sizes and three dewatering regimes tested with the exception of the 4 hr/day dewatered regime in the small gravel (Fig. 14) which declined to 40 percent. All other tests remained above 50 percent.

Embryo survival of the eyed through hatching stage (2) was evaluated over the period from incubation day 60 to 80 and is illustrated in Figs. 16, 17, 18 and 19. Chinook hatching began on incubation day 72 and continued to day 80. The survival decreased in most tests from the beginning of hatching in direct relation to the amount of time dewatered. Exceptions to this decrease in survival were found in large gravel where survival was variable and fluctuated due to the number of alevins moving downward through the gravel (Fig. 16). These alevins survived in the water retained at the bottom of each cylinder. The survival through hatching was summarized by compiling the number of incubation days prior to the occurrence of 50 percent mortality for each dewatered regime and gravel size (Fig. 20). The survival of controls did not decline below 50 percent. The length of time to 50 percent survival in 4, 8 and 16 hr/day tests was inversely related to the length of time dewatered except in the 4 hr/day test in small gravel. The minimum survival in the 4 hr/day dewatered small gravel was a continuation of the 4 hr/day

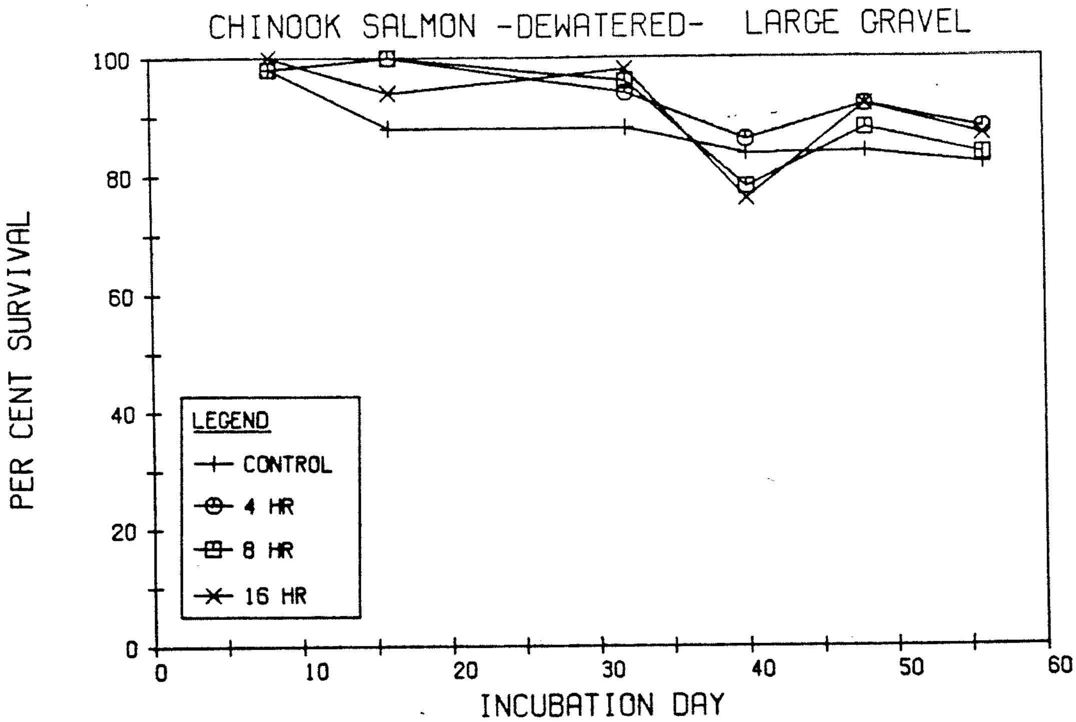

Fig. 12. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

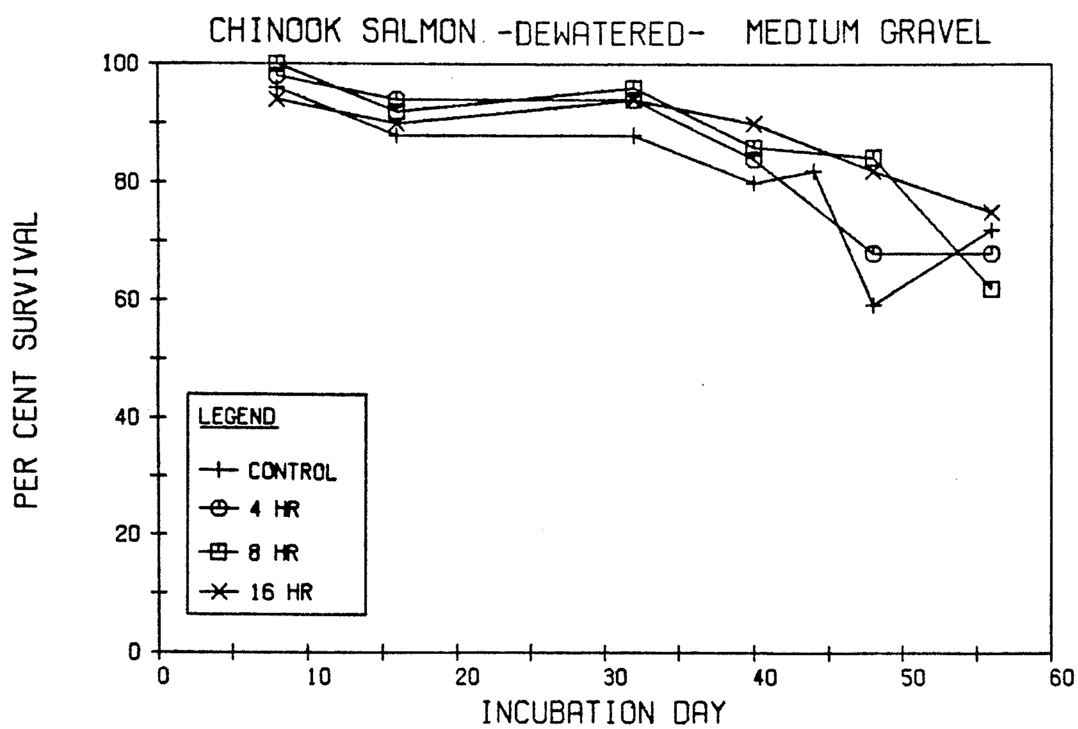

Fig. 13. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

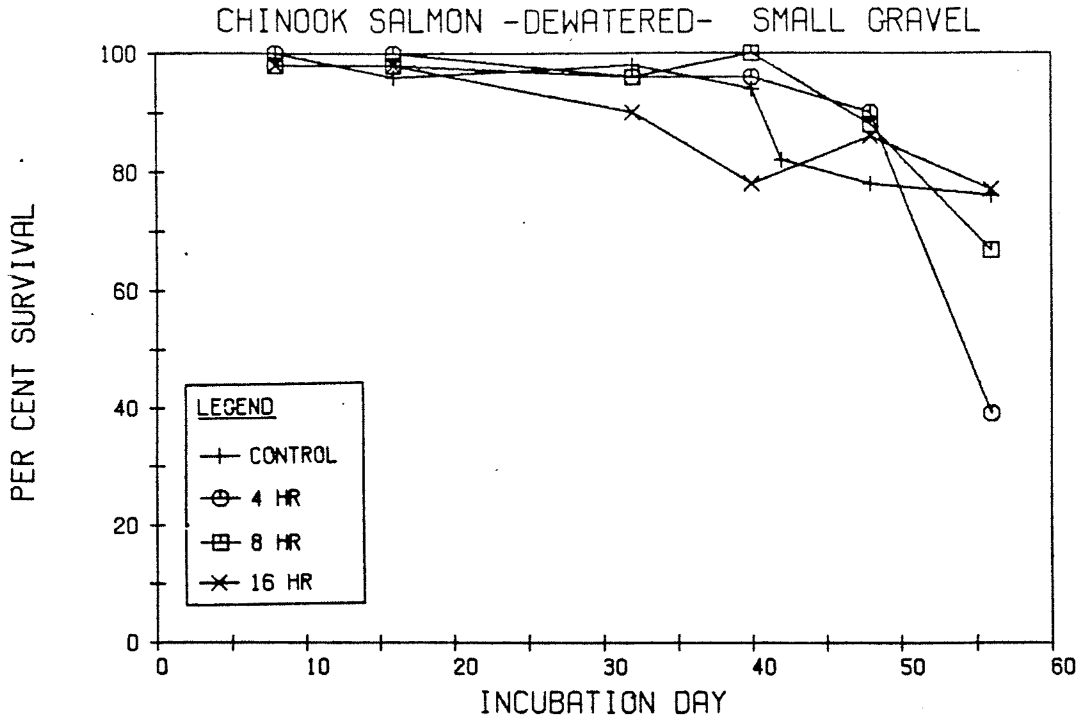

Fig. 14. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

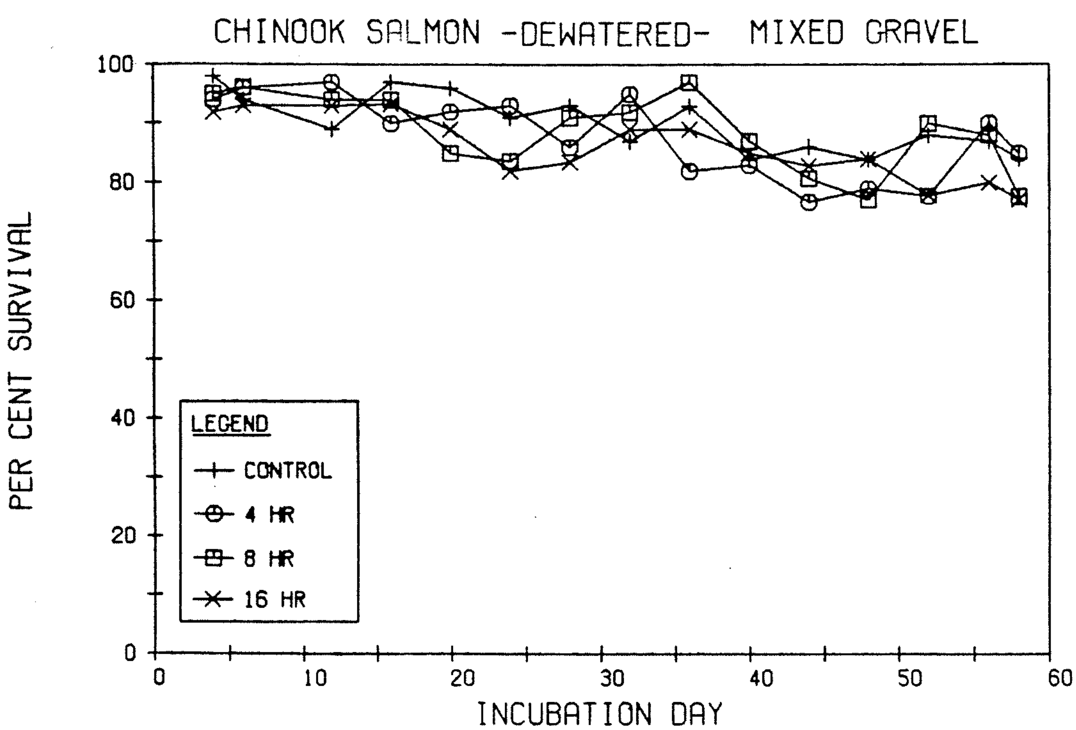

Fig. 15. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

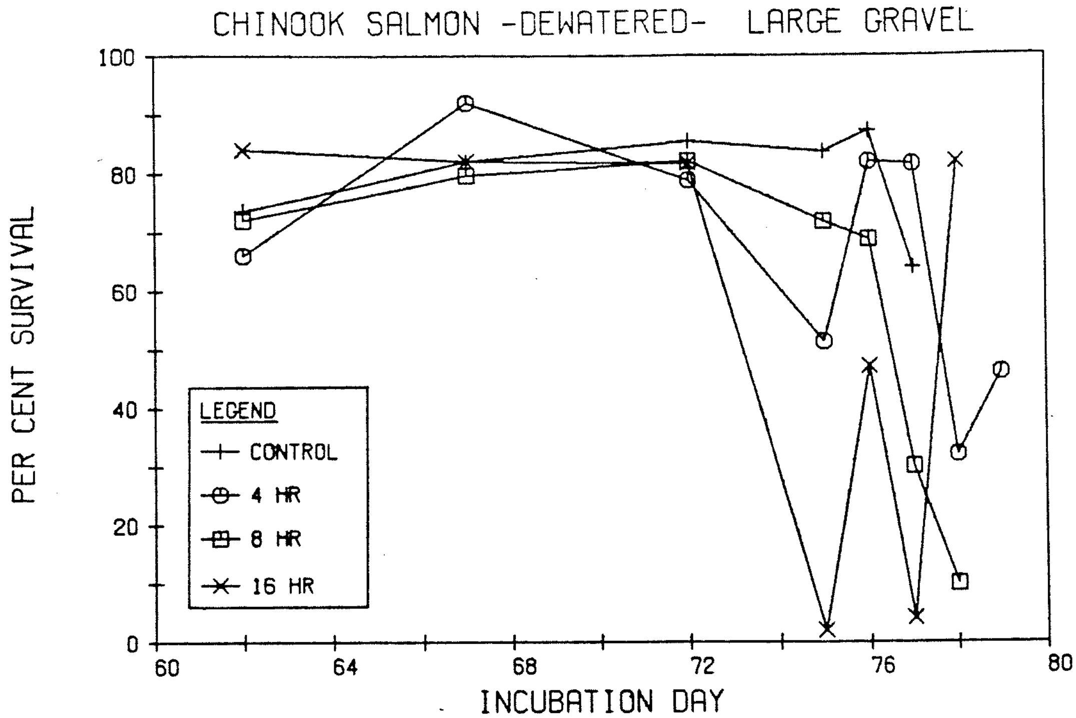

Fig. 16. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

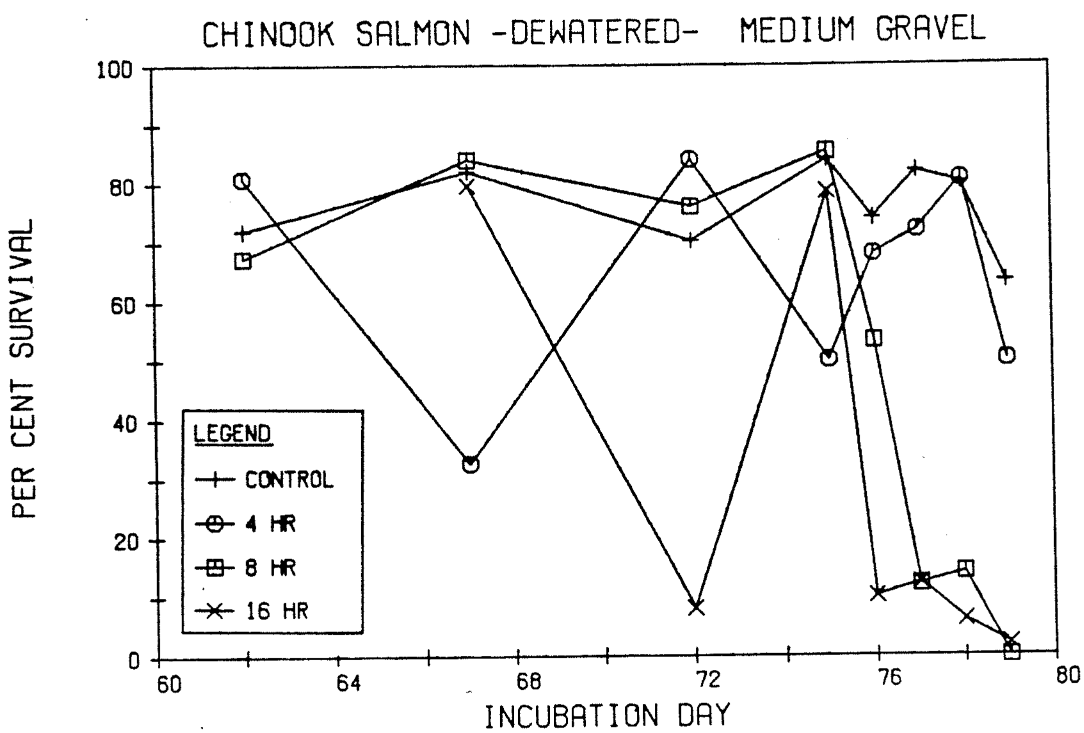

Fig. 17. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

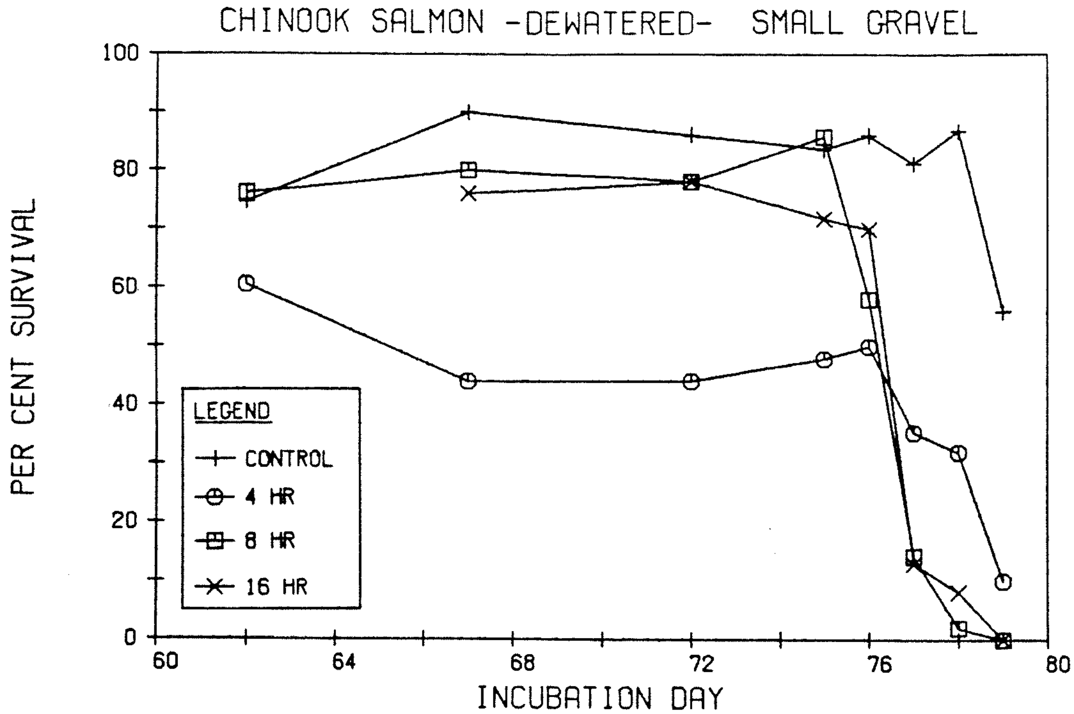

Fig. 18. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

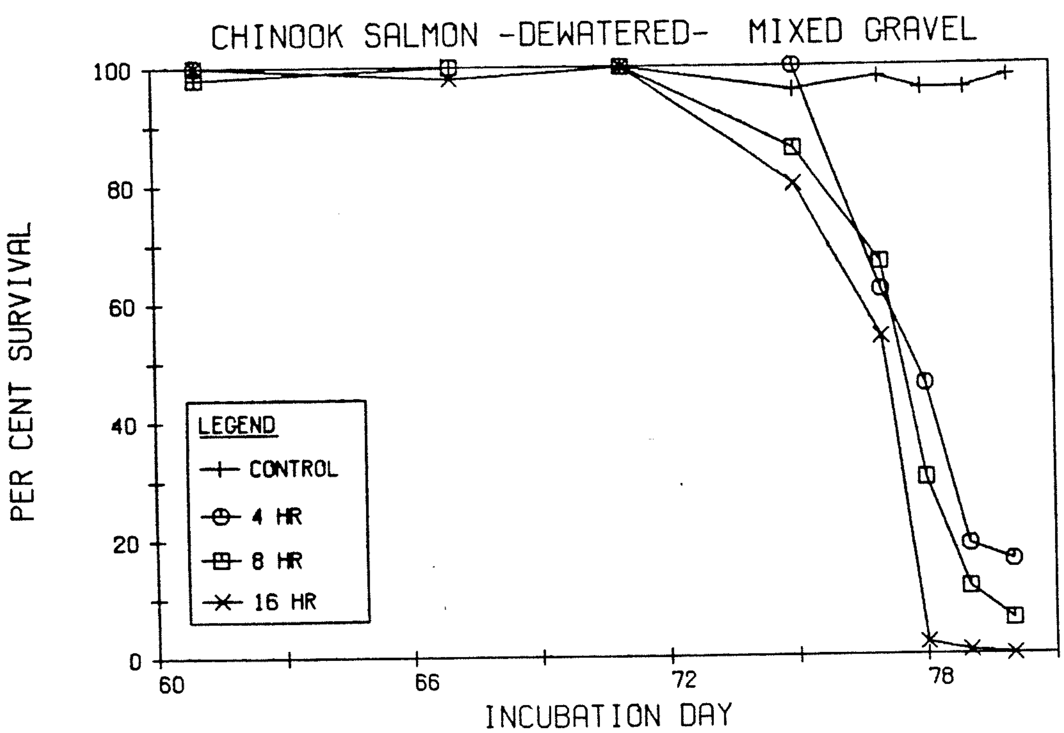

Fig. 19. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

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

Fig. 20. Incubation days to 50 percent mortality for chinook salmon tested under four dewatering regimes and gravel sizes.

results found in the stage 1 tests (Fig. 14) which occurred due to clogging of the gravel.

Dewatering experiments on survival from fertilization through hatching (Stage 3) in mixed gravel showed a continual decrease in prehatching survival (Fig. 21). Posthatching survival in the control remained near the prehatching level while the 4, 8 and 16 hr/day survival dropped to near zero. The nearly equivalent prehatching decrease in survival of both the dewatered tests and the control indicate that some factor (handling, incomplete fertilization, fungus) other than dewatering stress was the cause of mortality.

The continuous 24 hr/day dewatering tests for life stage 3 (fertilization through hatching) demonstrated a similar decrease in prehatching survival (Fig. 22). The posthatching survival dropped to zero in all but the mixed gravel. The 24 hr/day dewatering tests in life stage 2 (eyed through hatching) in large gravel indicated a posthatching decrease in survival (Fig. 23). Percent survival did not drop to zero but sampling was terminated in these tests before hatching was completed. Survival in the medium-sized gravel 24 hr/day tests did drop to zero (Fig. 24). In the small gravel both the control and the test survival fell below 10 percent before hatching began (Fig. 25). Factors other than dewatering stress were probably the cause of this decrease in survival. Low survival in the early samples in mixed gravel was also attributed to factors other than dewatering (Fig. 26). In later samples in mixed gravel the prehatching test survival approximated the control then decreased rapidly as hatching progressed while control survival remained high.

Prehatching survival in static water tests was generally lower than in the dewatered tests (Figs. 27, 28, 29 and 30). Posthatching survival was

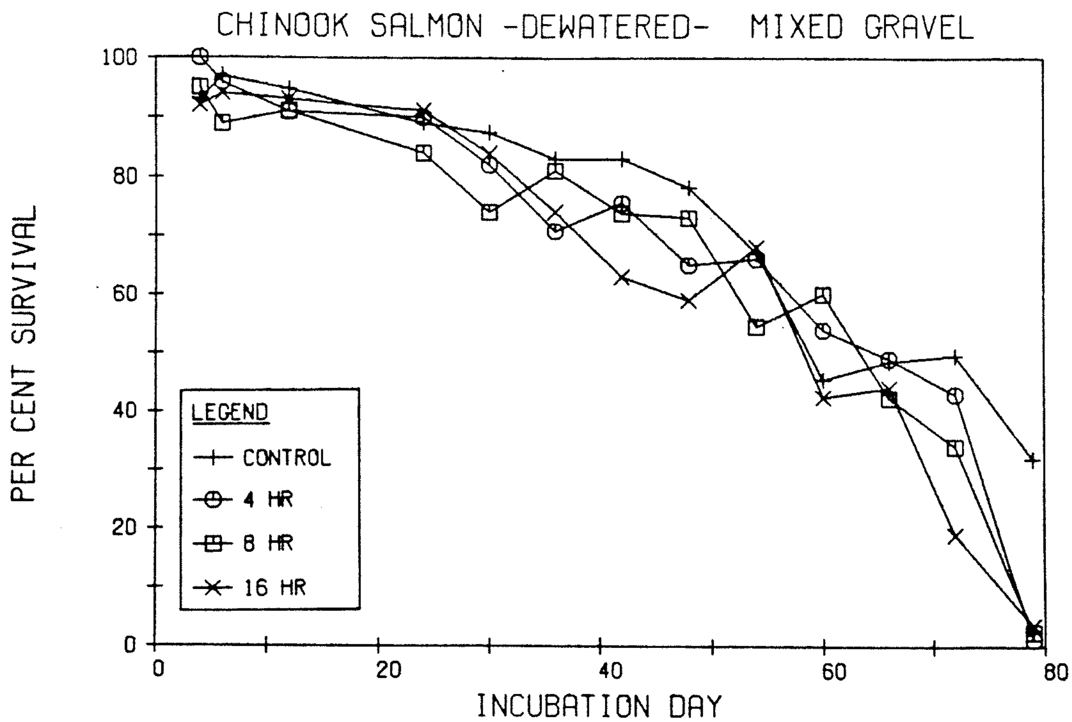

Fig. 21. Percent survival of chinook salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization through hatching.

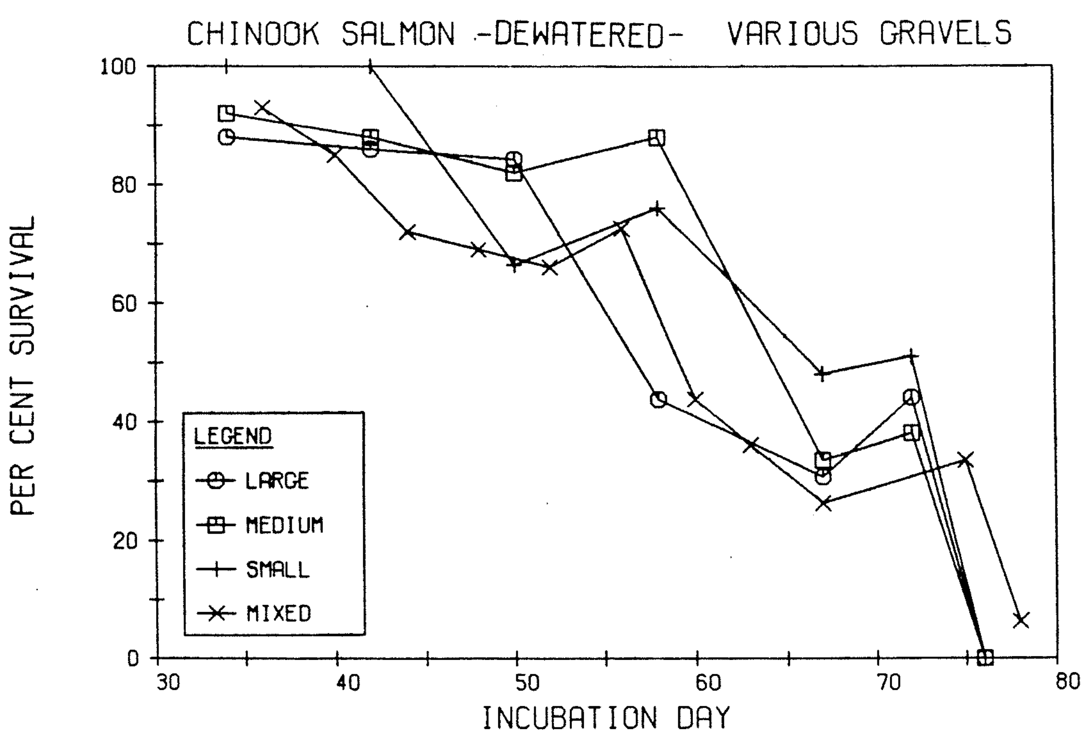

Fig. 22. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravel from fertilization through hatching.

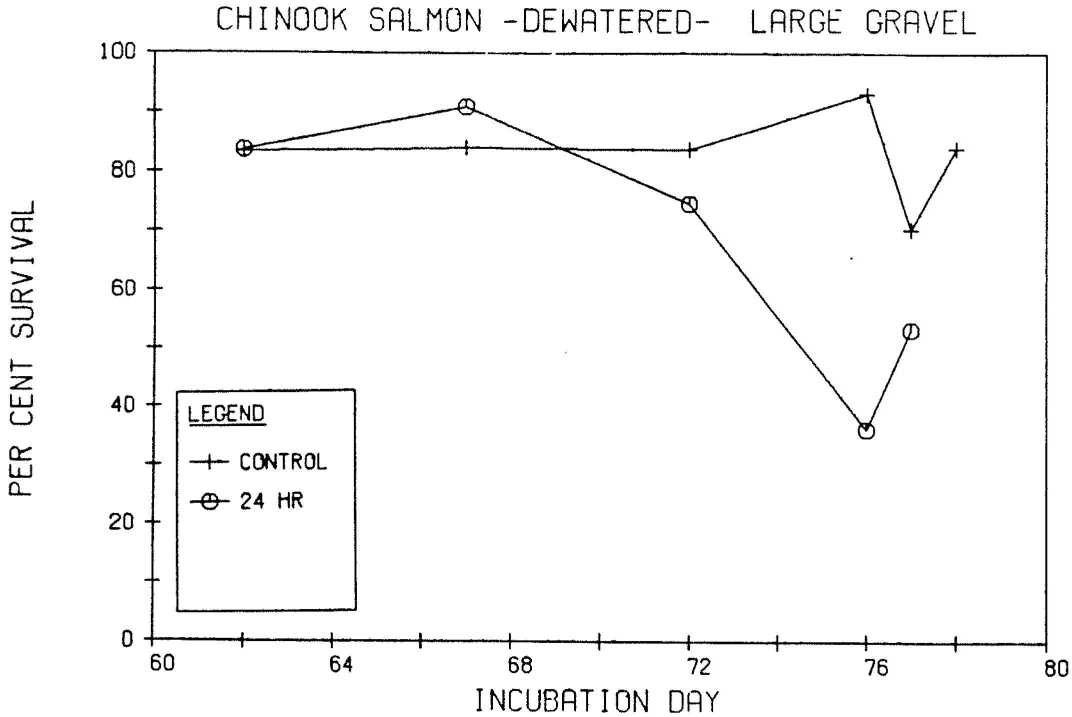

Fig. 23. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in large gravel from eyed through hatching.

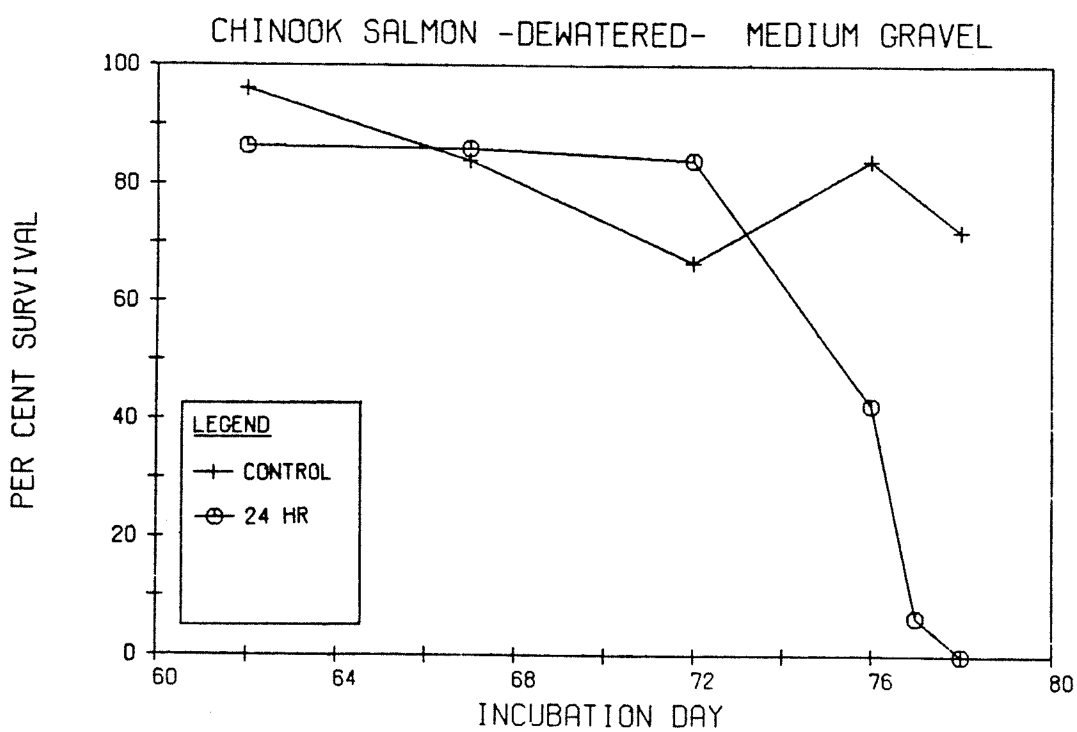

Fig. 24. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in medium gravel from eyed through hatching.

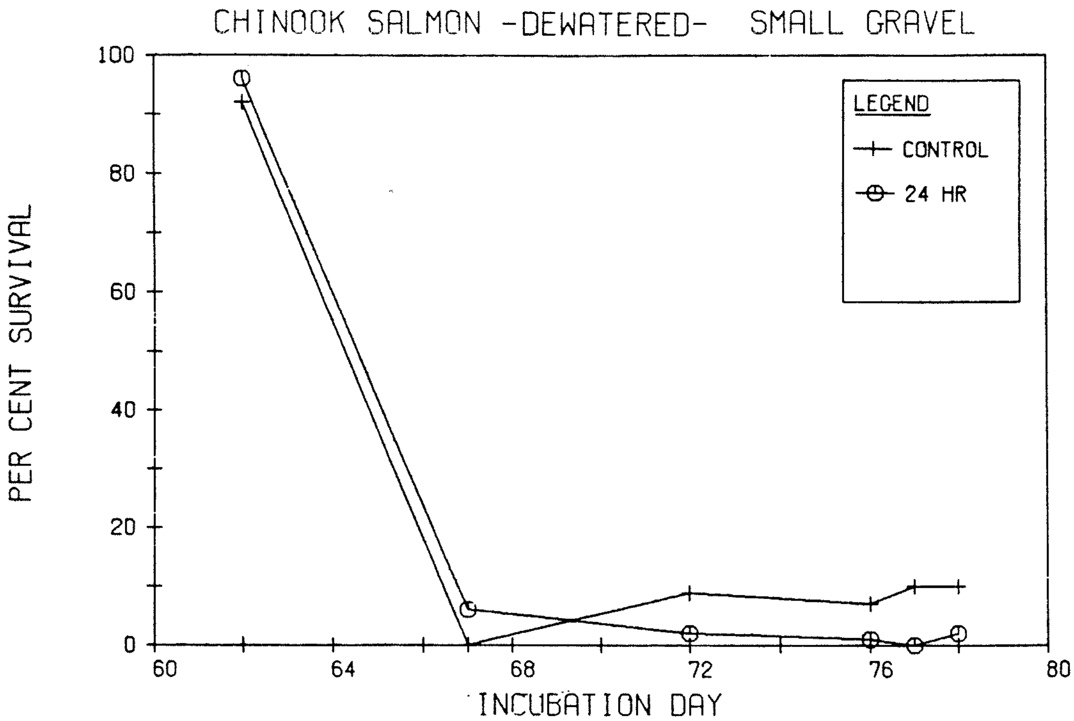

Fig. 25. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in small gravel from eyed through hatching.

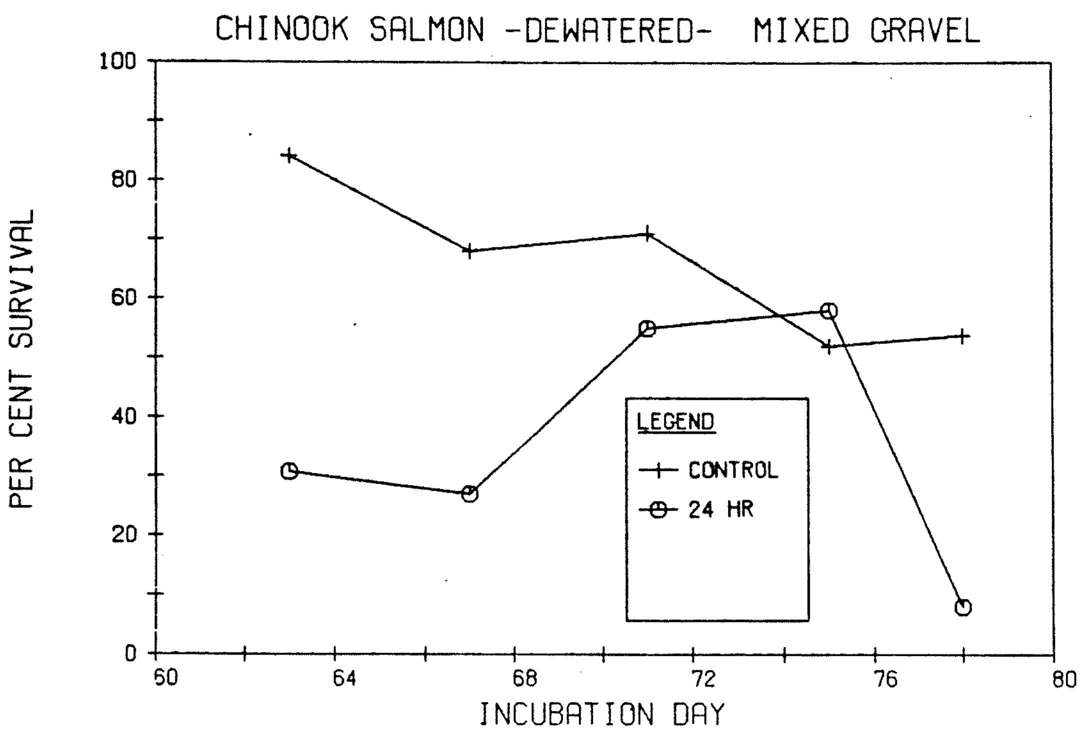

Fig. 26. Percent survival of chinook salmon embryos dewatered for 24 hrs/day in mixed gravel from eyed through hatching.

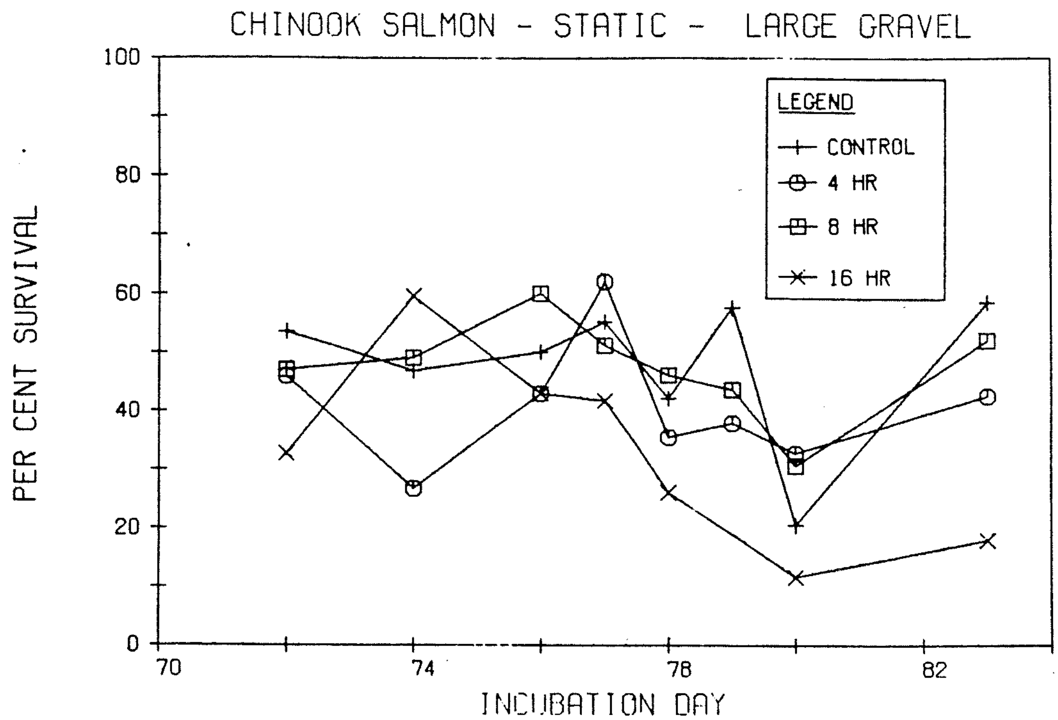

Fig. 27. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

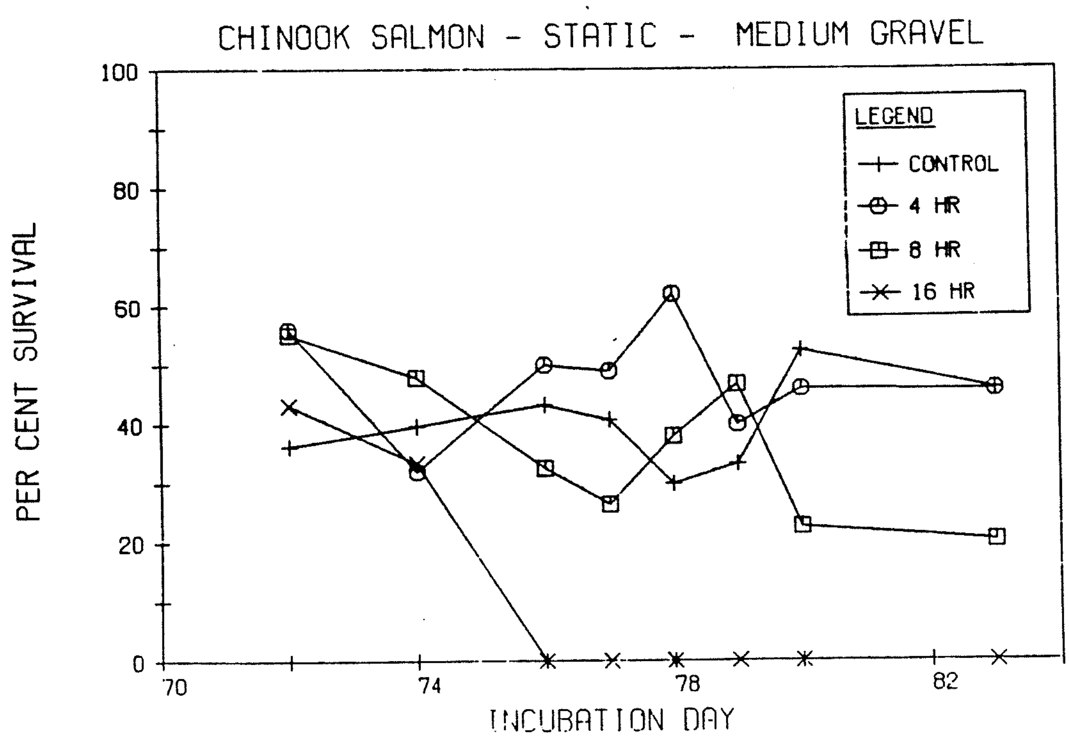

Fig. 28. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

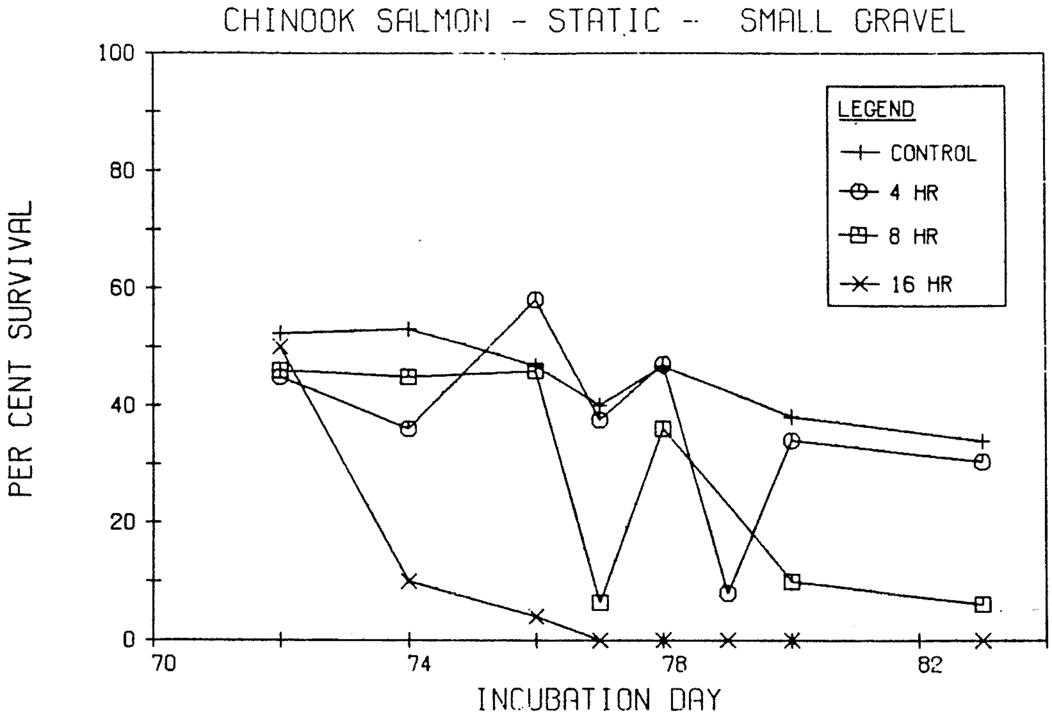

Fig. 29. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

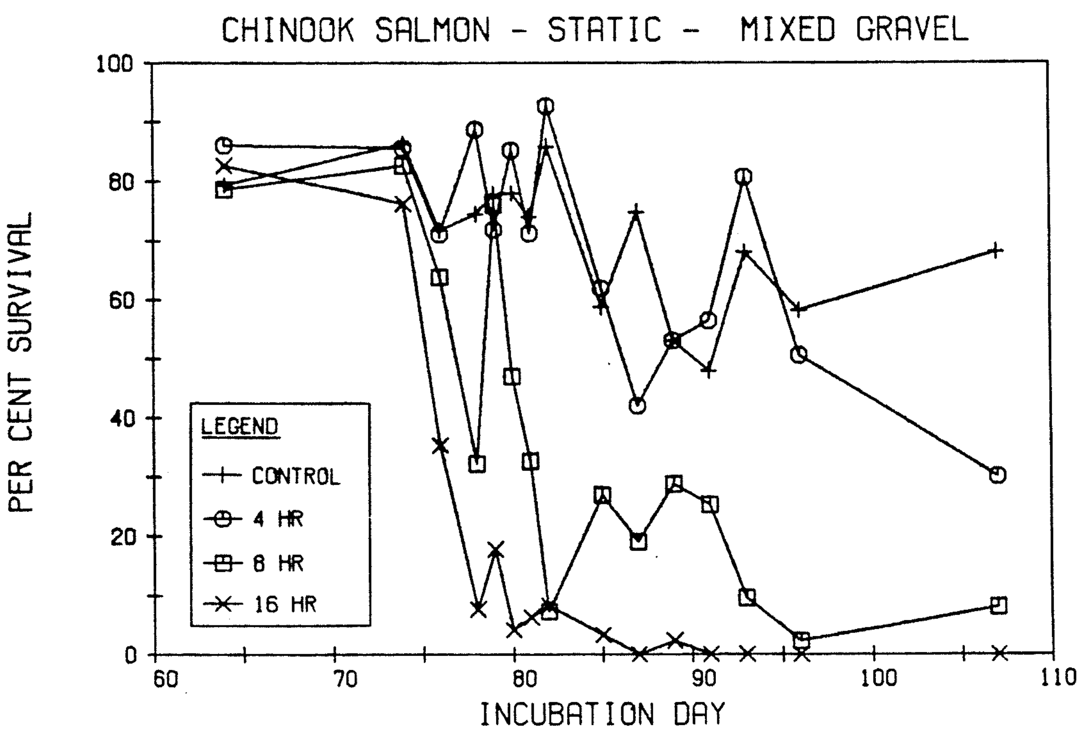

Fig. 30. Percent survival of chinook salmon embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

higher than in the dewatered tests and was directly related to the amount of time the static conditions were imposed on the test organisms. Survival in the 16 hr/day static tests decreased to zero in all gravel sizes but large. Posthatching survival in large gravel and control remained high in continuous 24 hr/day static tests while survival in small and medium gravel decreased (Fig. 31). Experiments not performed on chinook salmon were static tests on the fertilization to eyed stage (1) and continuous 24 hr/day static tests on eyed through hatching for mixed gravel (stage 2).

6.5.2.2 Coho salmon

Prehatching survival (stage 1 eggs) remained high for large, medium and small gravel sizes and all dewatering regimes tested (Fig. 32, 33 and 34). Hatching in coho began on incubation day 67 and continued to day 74. Posthatching survival decreased in all coho dewatering tests in direct relation to the amount of time dewatered (Figs. 35, 36, 37 and 38). Survival remained high in the large gravel (Fig. 35) due to alevins moving downward through the gravel and surviving in the water retained at the bottom of the cylinder. The length of time to 50 percent survival was inversely related to day 74. Prehatching survival approximated the control in stage 3 (fertilization through hatching) dewatered tests in mixed gravel (Fig. 40). Posthatching survival in the control remained high while the 4, 8 and 16 hr/day test survival decreased rapidly to near zero.

Survival in stage 1 (fertilization through eyed) continuous 24 hr/day dewatered experiments remained high with several exceptions where medium and mixed gravel survival fell below 50 percent (Fig. 41). Continuous 24 hr/day dewatering tests on stage two embryos indicate a posthatching

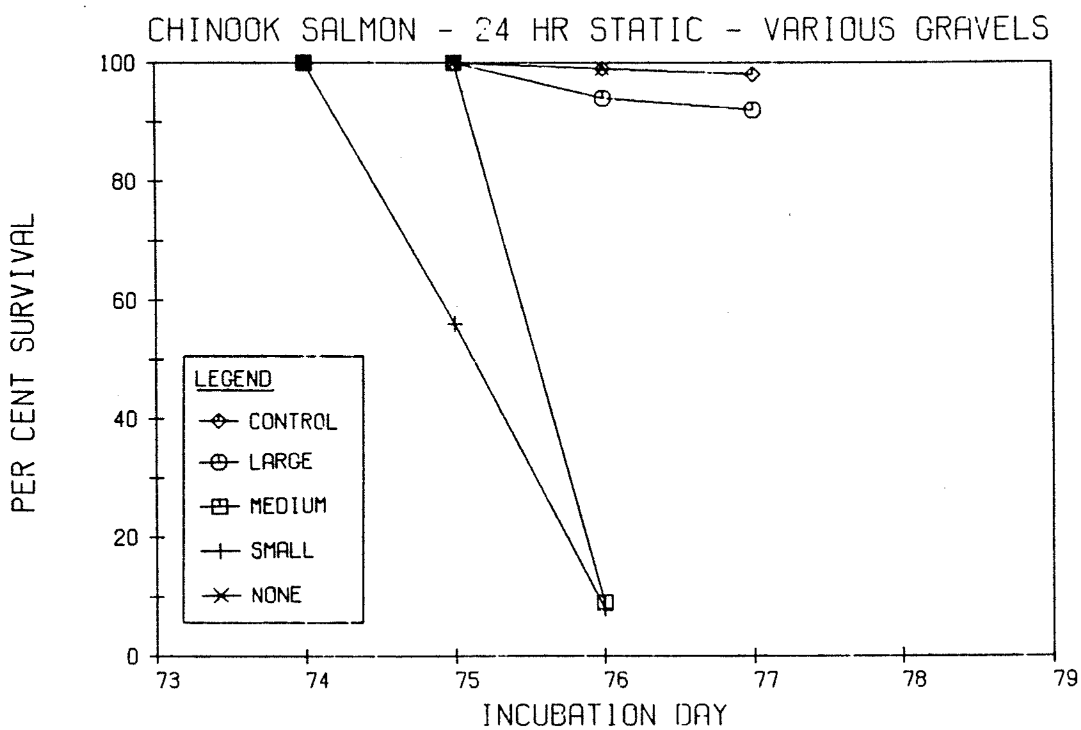

Fig. 31. Percent survival of chinook salmon embryos in static water for 24 hrs/day in large, medium and small gravels from eyed through hatching.

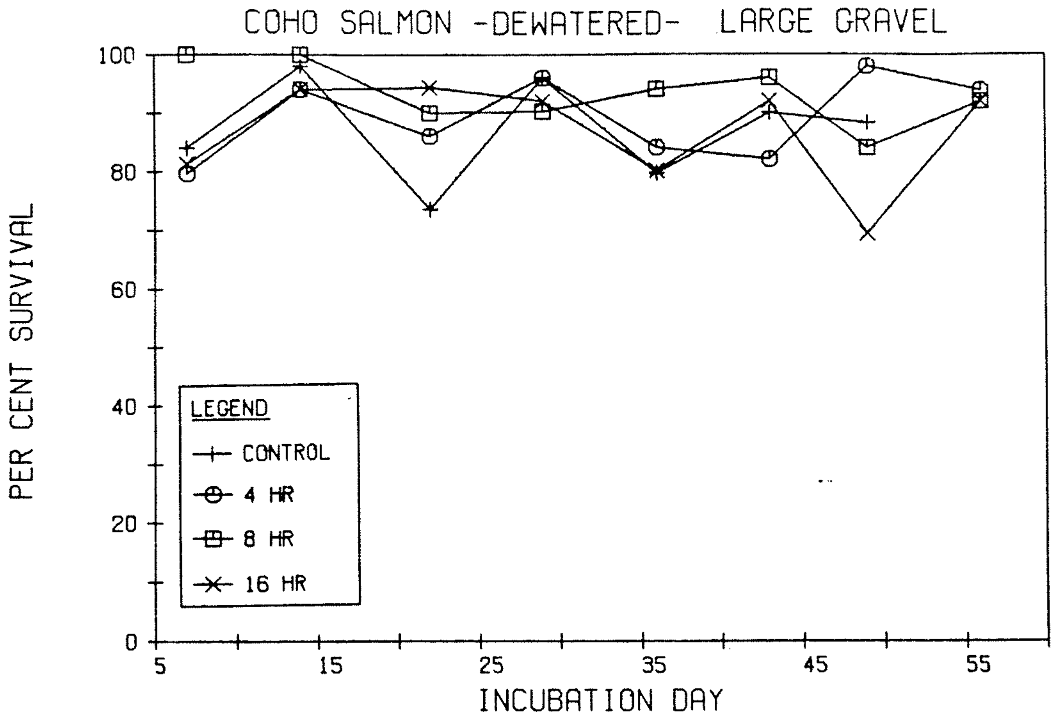

Fig. 32. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/ day in large gravel from fertilization to the eyed stage.

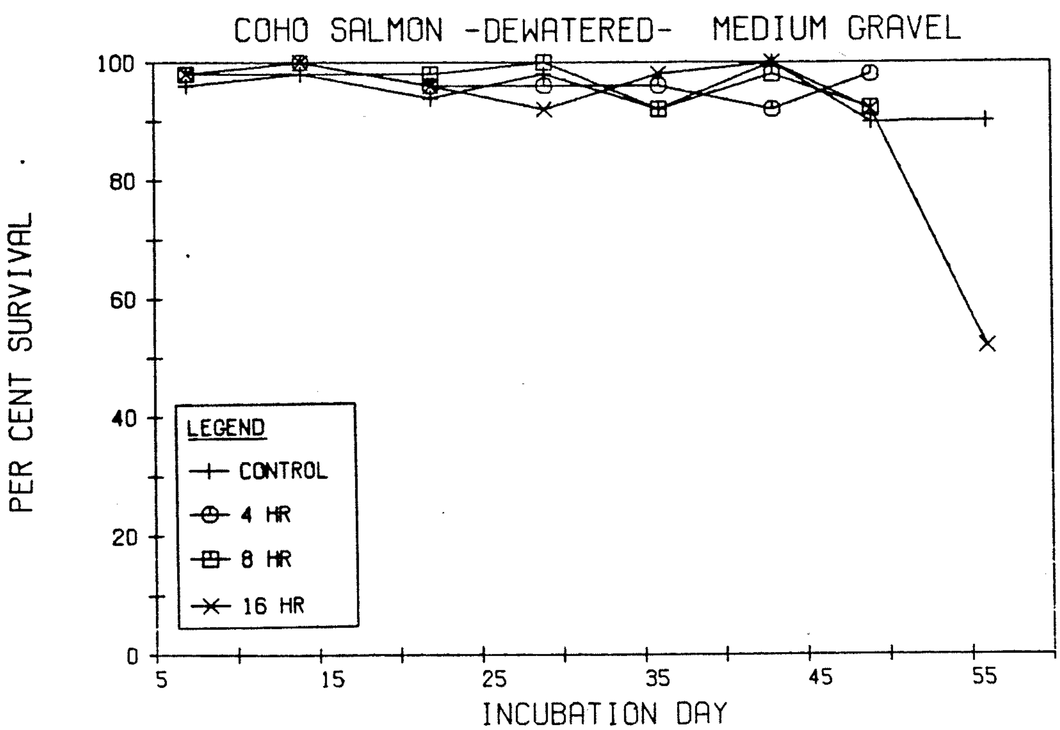

Fig. 33. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/ day in medium gravel from fertilization to the eyed stage.

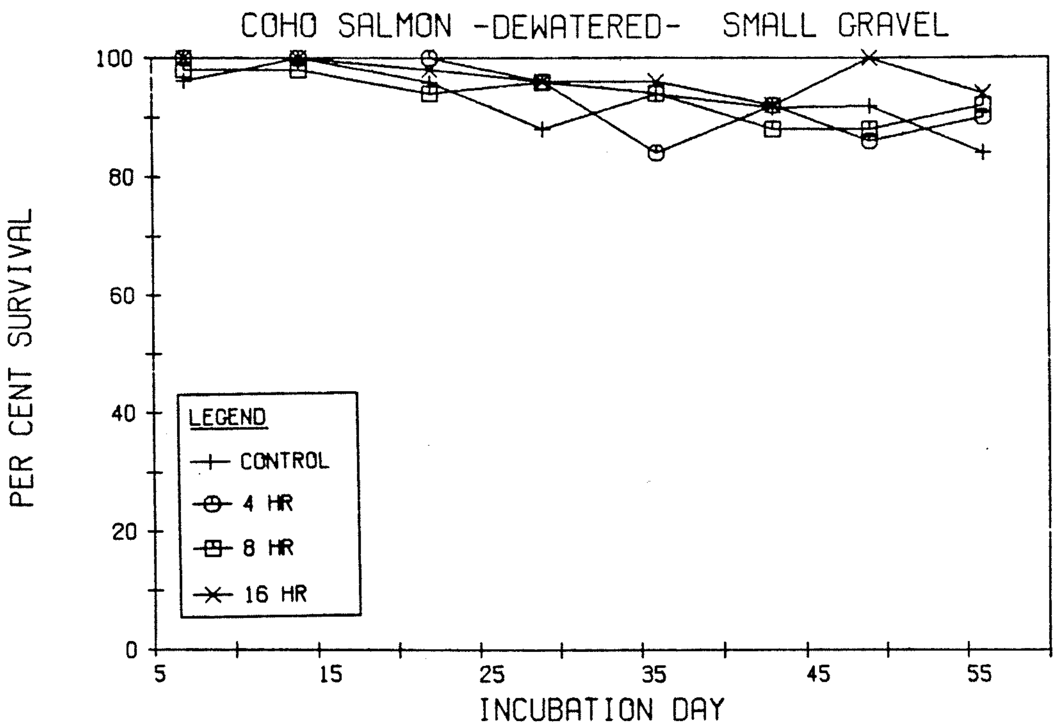

Fig. 34. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

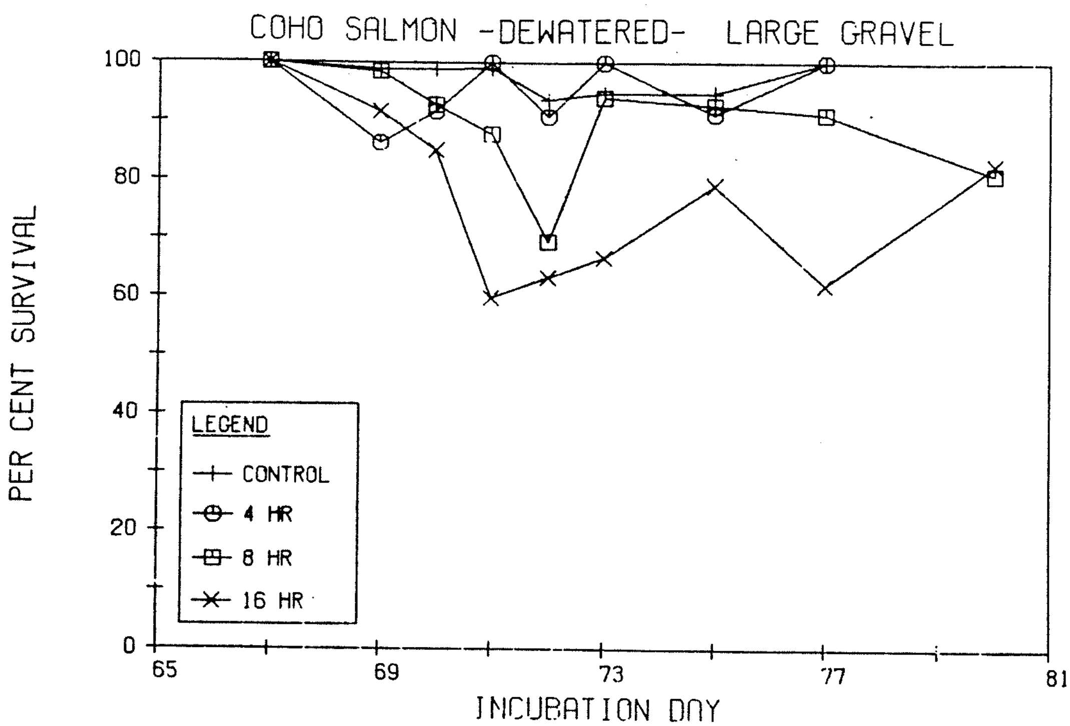

Fig. 35. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

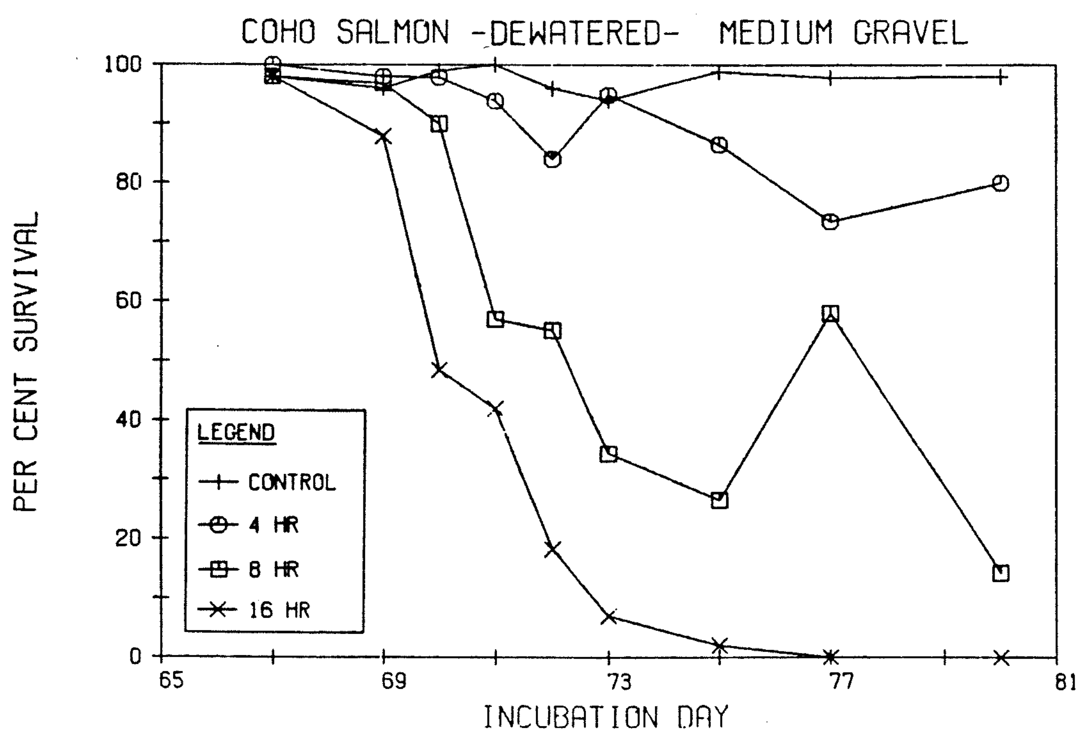

Fig. 36. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

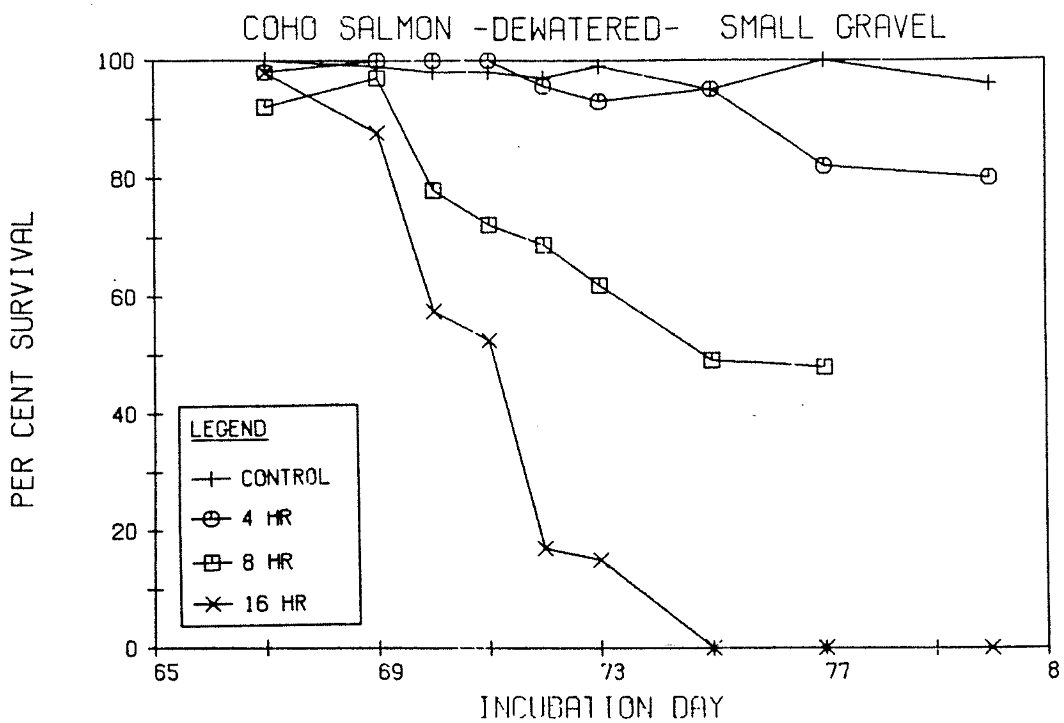

Fig. 37. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

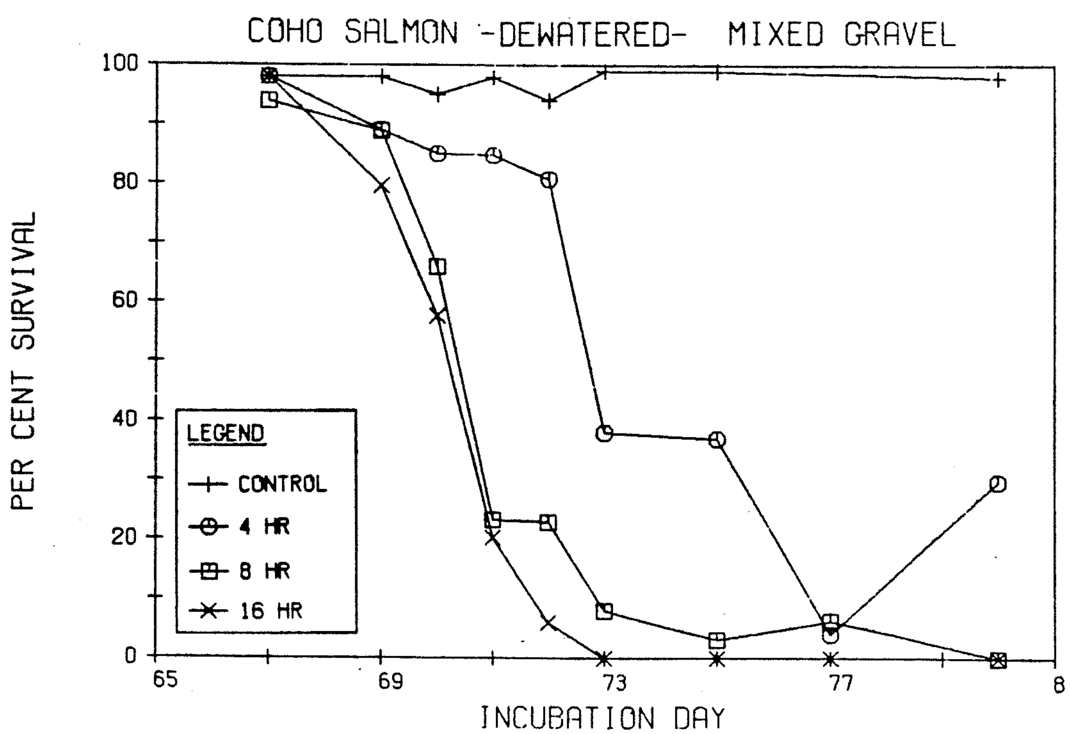

Fig. 38. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

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)	—	—	—	—

Fig. 39. Incubation days to 50 percent mortality for coho salmon tested under four dewatering regimes and gravel sizes.

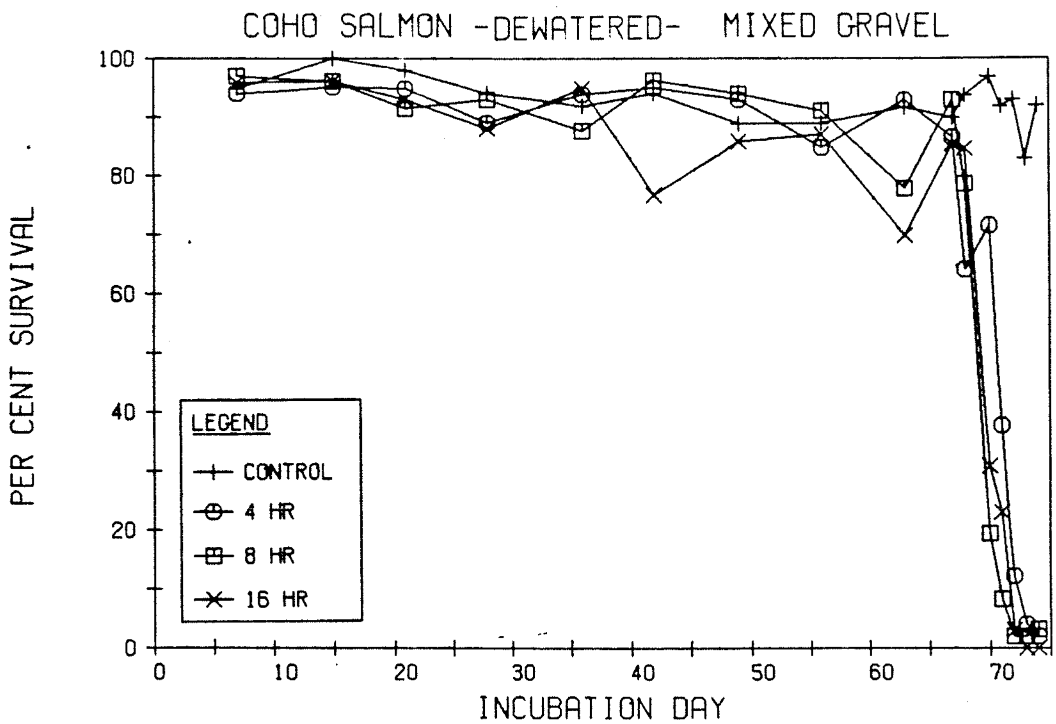

Fig. 40. Percent survival of coho salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization through hatching.

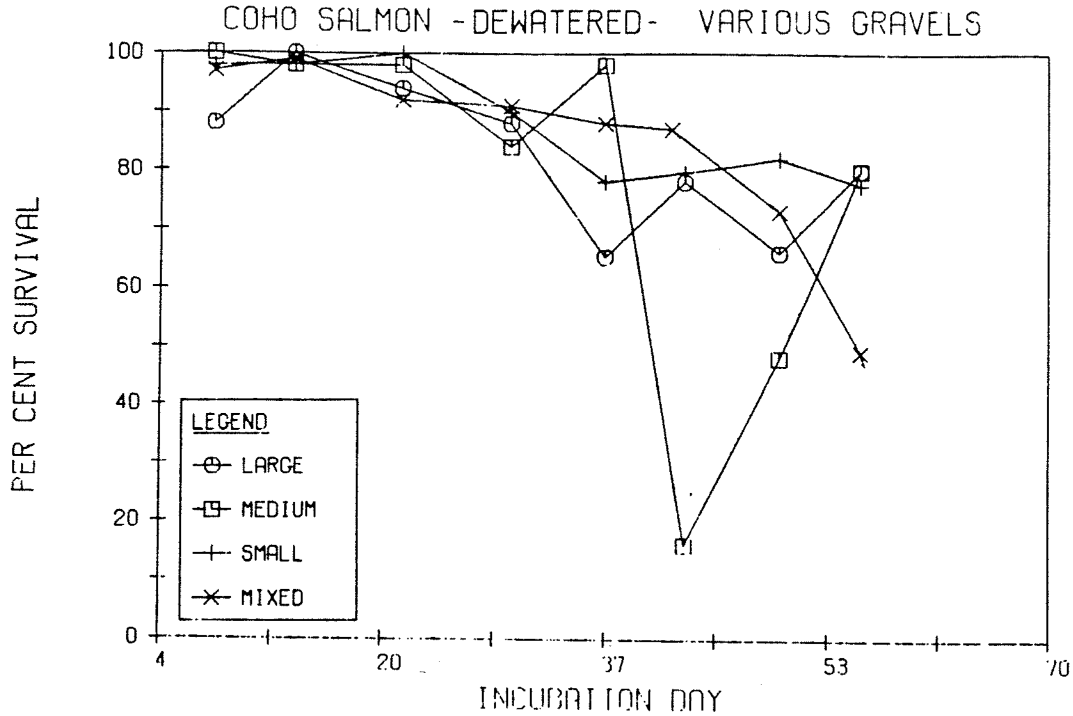

Fig. 41. Percent survival of coho salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from fertilization through hatching.

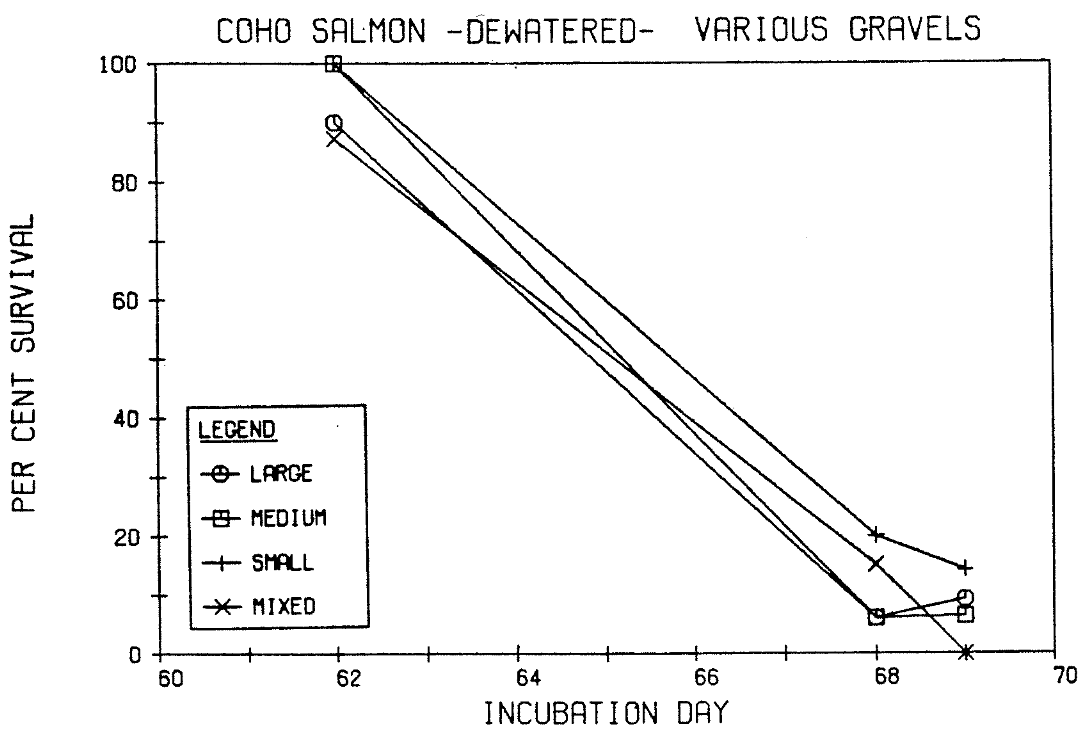

Fig. 42. Percent survival of coho salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from eyed through hatching.

decrease in survival (Fig. 42). Intermediate sampling dates would have probably indicated a higher survival to the hatching date and a more rapid decrease in survival after hatching.

Prehatching survival in stage 1 static tests remained high for all gravel sizes and static regimes tested (Fig. 43, 44, 45 and 46). Posthatching survival in static tests demonstrated variability between gravel sizes (Figs. 47, 48, 49 and 50). Posthatching survival was higher in large gravel where alevins could move through gravel. Survival was directly related to the amount of time static water conditions were imposed. Survival was similar in 8 and 16 hr/day static water regimes while the 4 hr/day static tests approximated the higher survival of the control. The low survival in the 8 and 16 hr/day static tests in small and mixed gravels was due to a decrease in survival of eggs prior to hatching because of low dissolved oxygen in the aquatic microenvironment (Figs. 49 and 50).

Continuous 24 hr/day stage 2 static tests demonstrated a similar decrease in prehatching survival due to low dissolved oxygen especially in the smaller gravel sizes (Fig. 51). There was a direct relation between gravel size and incubation day at which survival fell below 50 percent (small = day 61, medium = day 62, and large = day 65).

Experiments not performed on coho were the 24 hr/day static for all gravels in the fertilization to eyed stage and the 24 hr/day static in mixed gravel in the eyed through hatching stage.

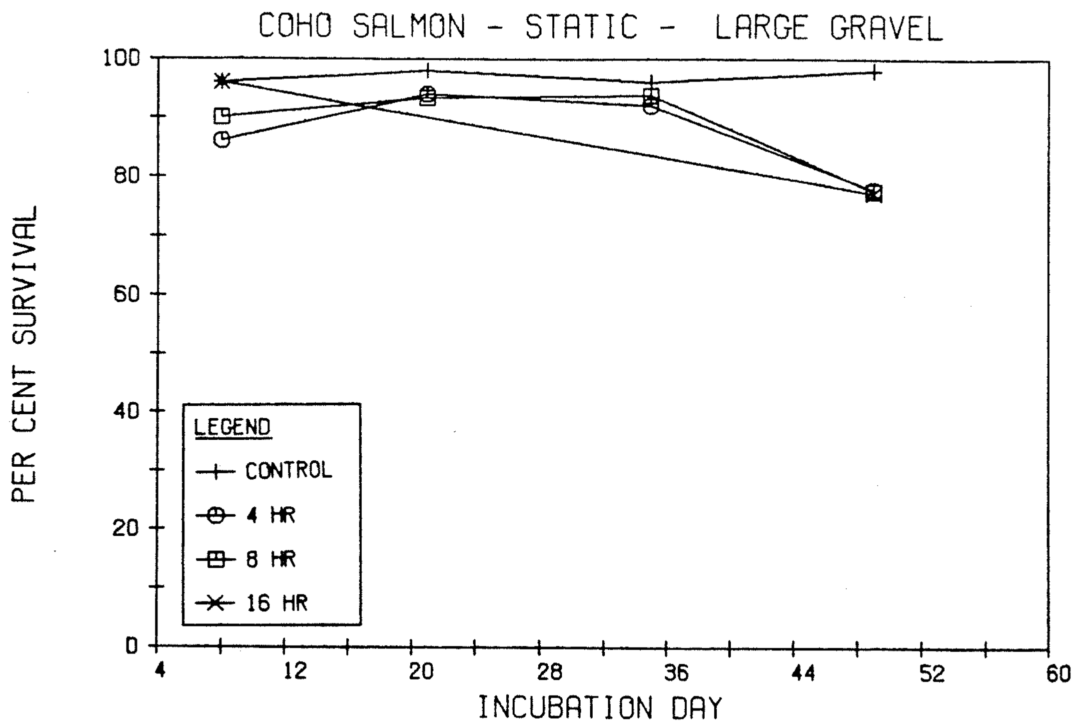

Fig. 43. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

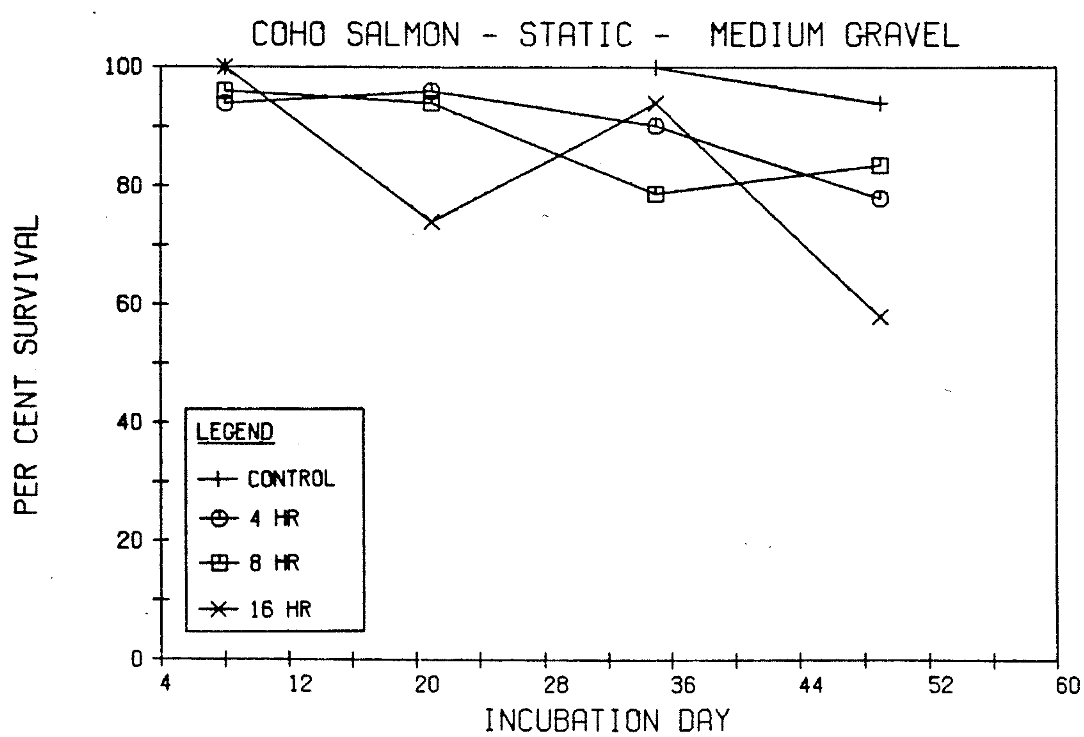

Fig. 44. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

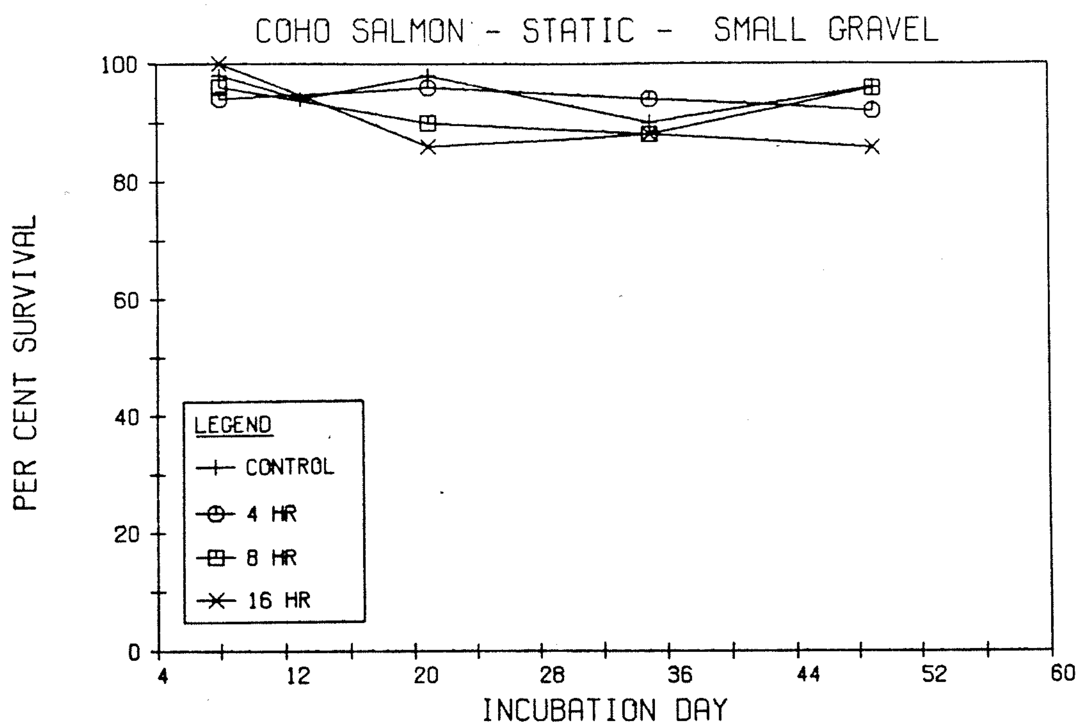

Fig. 45. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

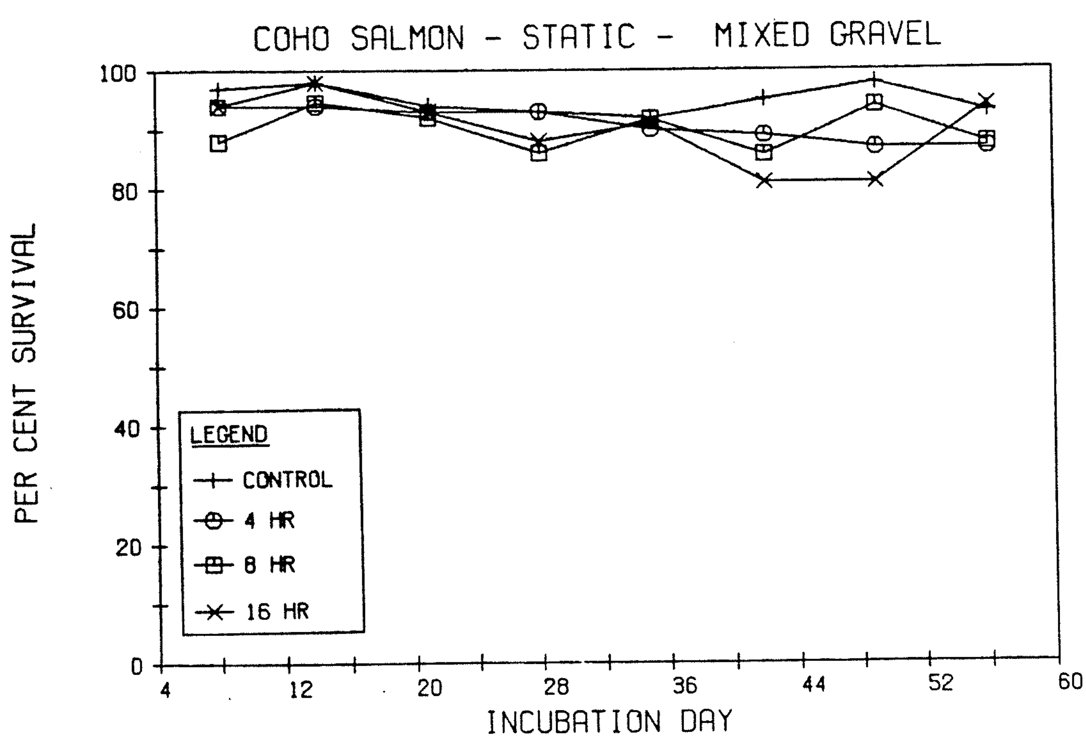

Fig. 46. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

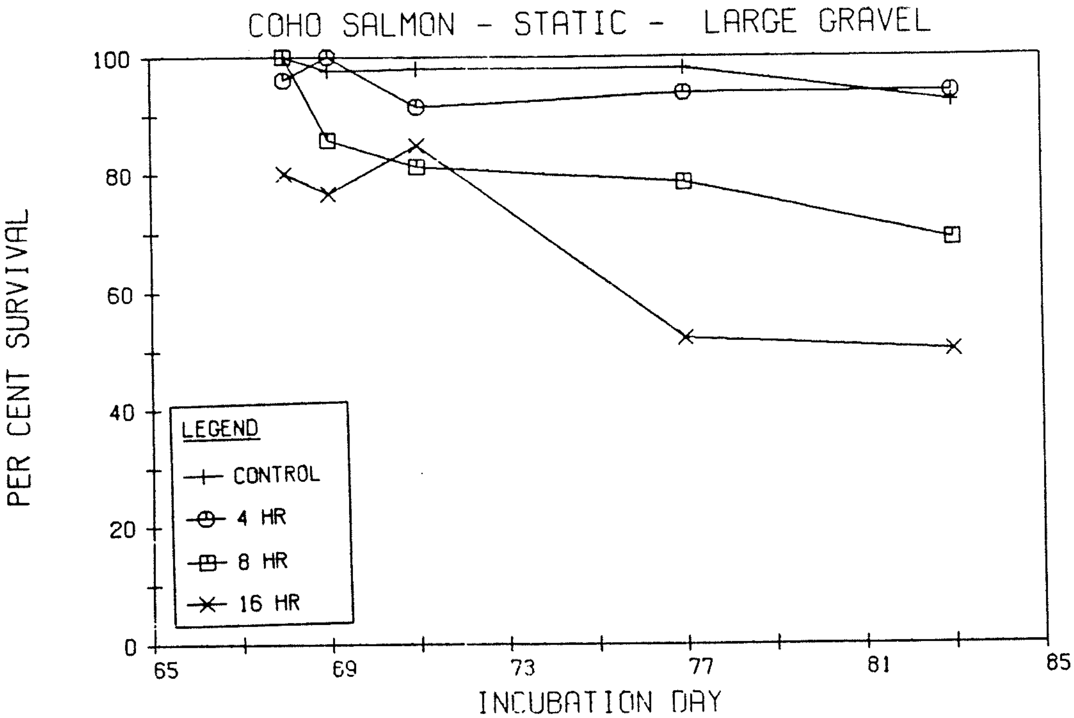

Fig. 47. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

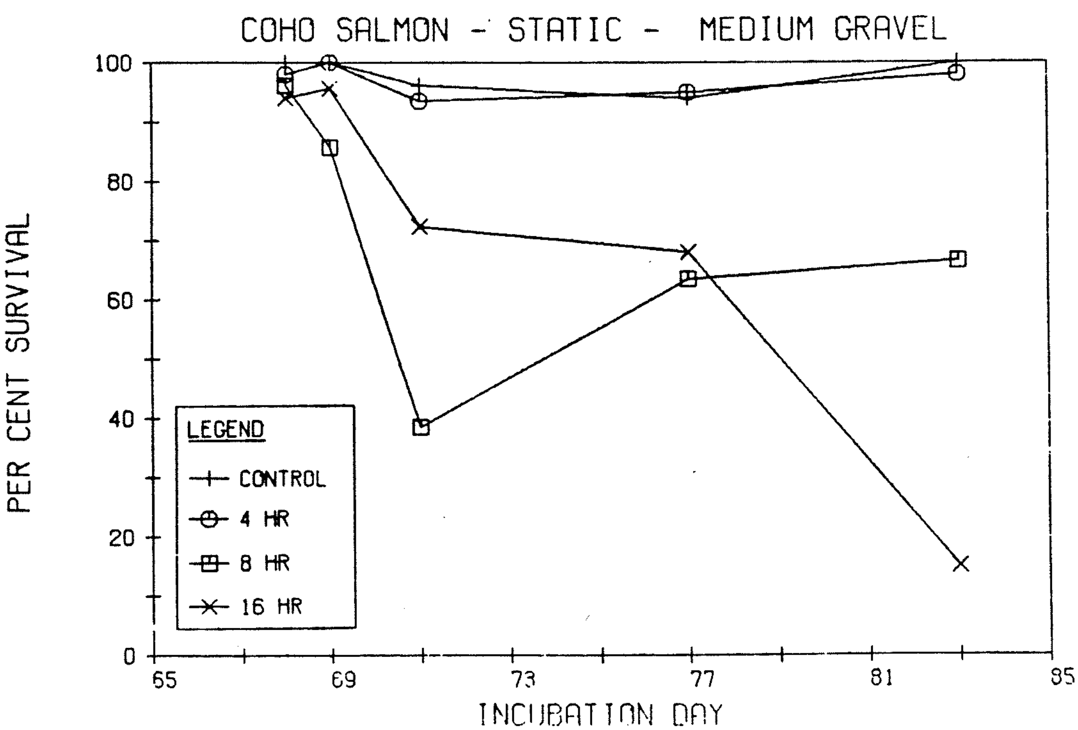

Fig. 48. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

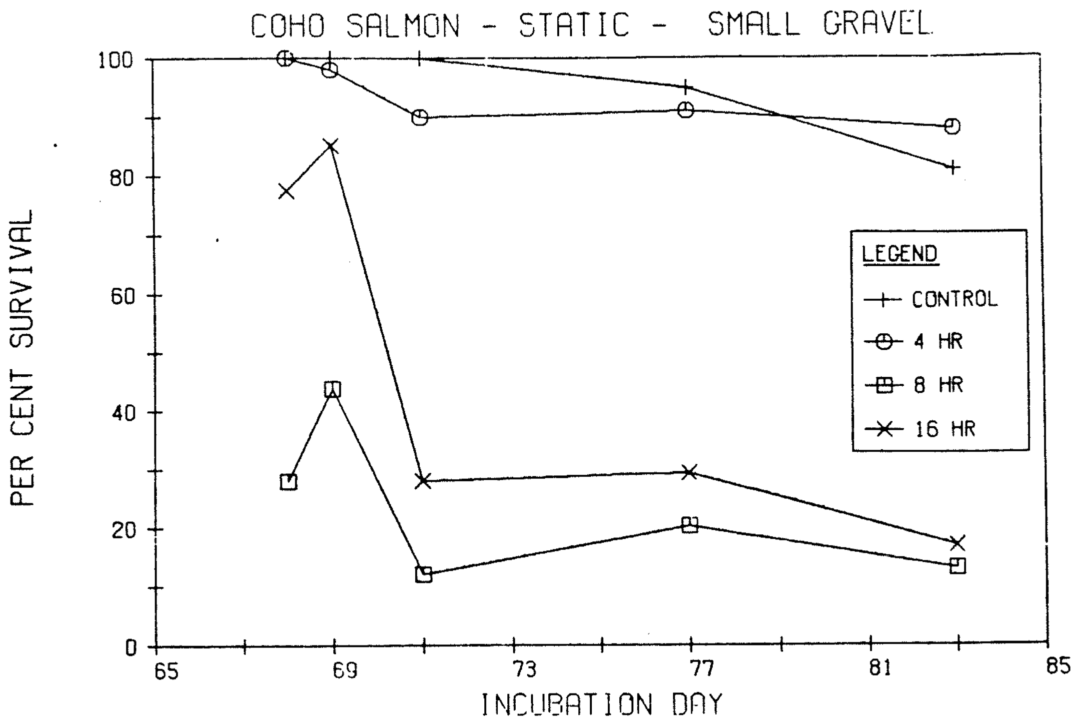

Fig. 49. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

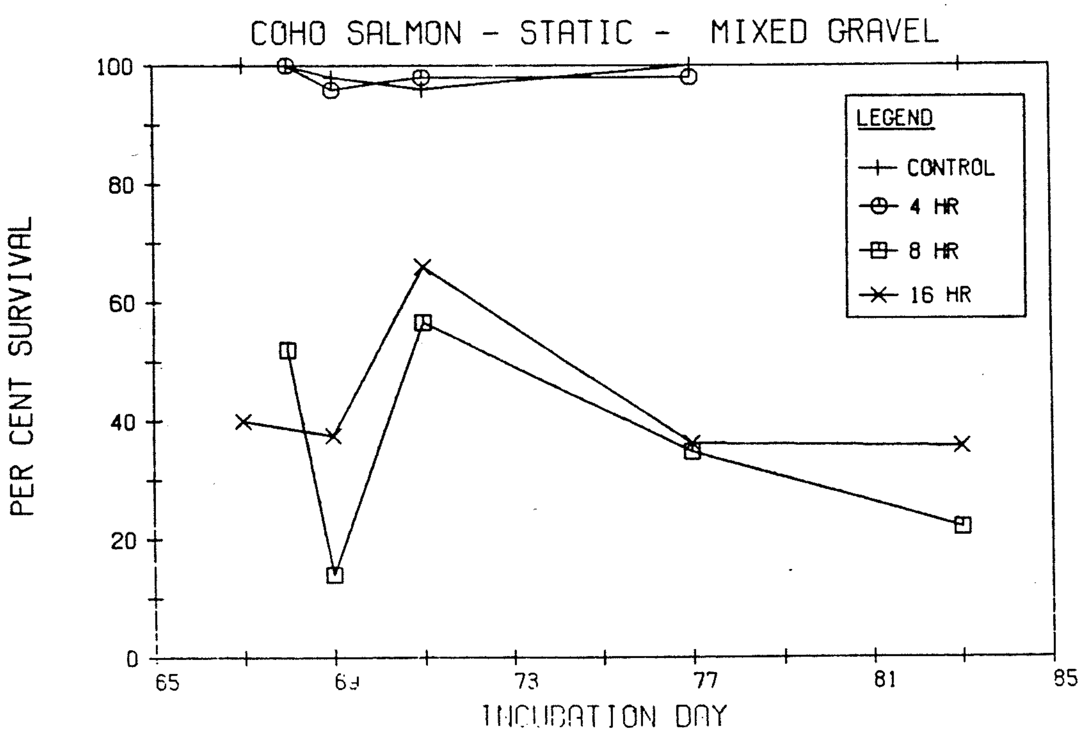

Fig. 50. Percent survival of coho salmon embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

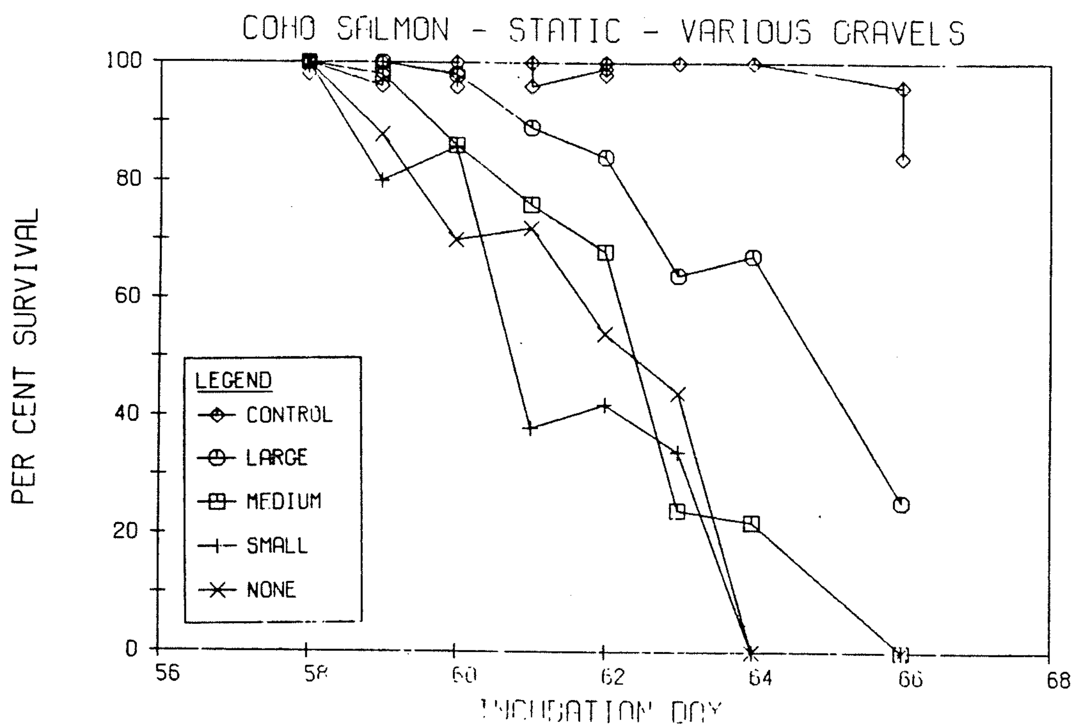

Fig. 51. Percent survival of coho salmon embryos in static water for 24 hrs/day in large, medium and small gravels from eyed through hatching.

6.5.2.3 Chum salmon

Chum salmon eggs were obtained from the Skagit Hatchery as a single lot consisting of mixed fertilization dates. The calendar date was utilized to report the developmental time for chum salmon. Hatching began on January 14 and extended through the 28th. This extended hatching period was caused by the variable development of the different groups of eggs used.

Survival in the dewatered tests in large gravel remained high throughout the hatching period (Fig. 52). In the medium gravel the 8 and 16 hr/day dewatering survival declined while the 4 hr/day and the control remained high (Fig. 53). In the small gravel the survival decreased in direct relation to the amount of time the embryos were dewatered (Fig. 54). In mixed gravel the posthatching survival for all three test regimes decreased to zero while the control survival remained at or near 100 percent (Fig. 55).

Continuous 24 hr/day dewatering tests demonstrated moderate survival to January 24 with a subsequent decrease in survival (Fig. 56). This was probably the hatching date of eggs from the second egg take date which may explain the decline in survival. An unexplained total mortality of eggs on January 19 in medium gravel occurred. Survival on the next sampling date rose to equal survival from the other gravels tested.

Static tests on chum salmon demonstrated a direct relation between survival and length of static stress imposed (Figs. 56, 58, 59 and 60). Survival in large gravel was higher than in the other three gravel sizes (Fig. 57). Control survival in all four gravel sizes remained high throughout the duration of these experiments. No 4 hr/day static tests were done due to the shortage

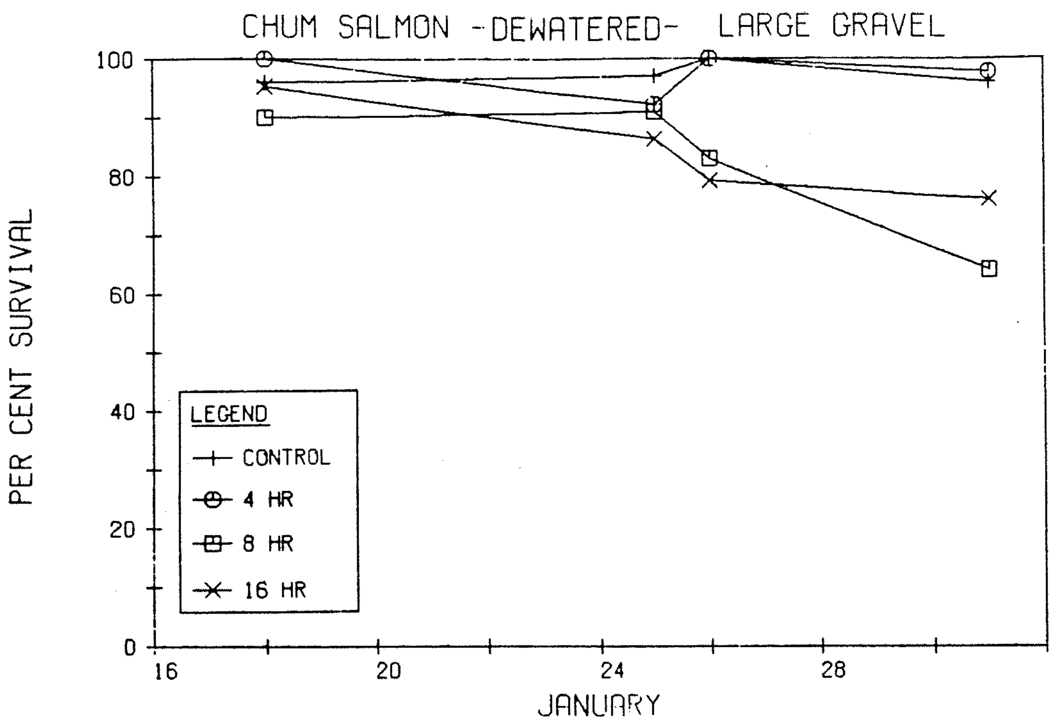

Fig. 52. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

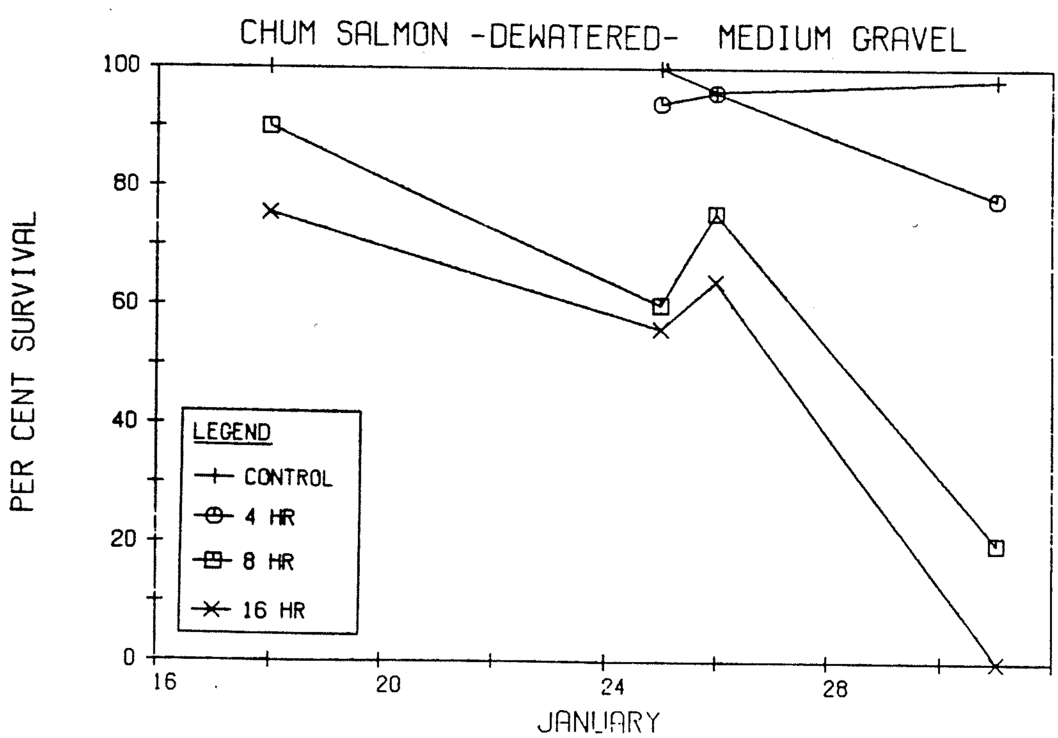

Fig. 53. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

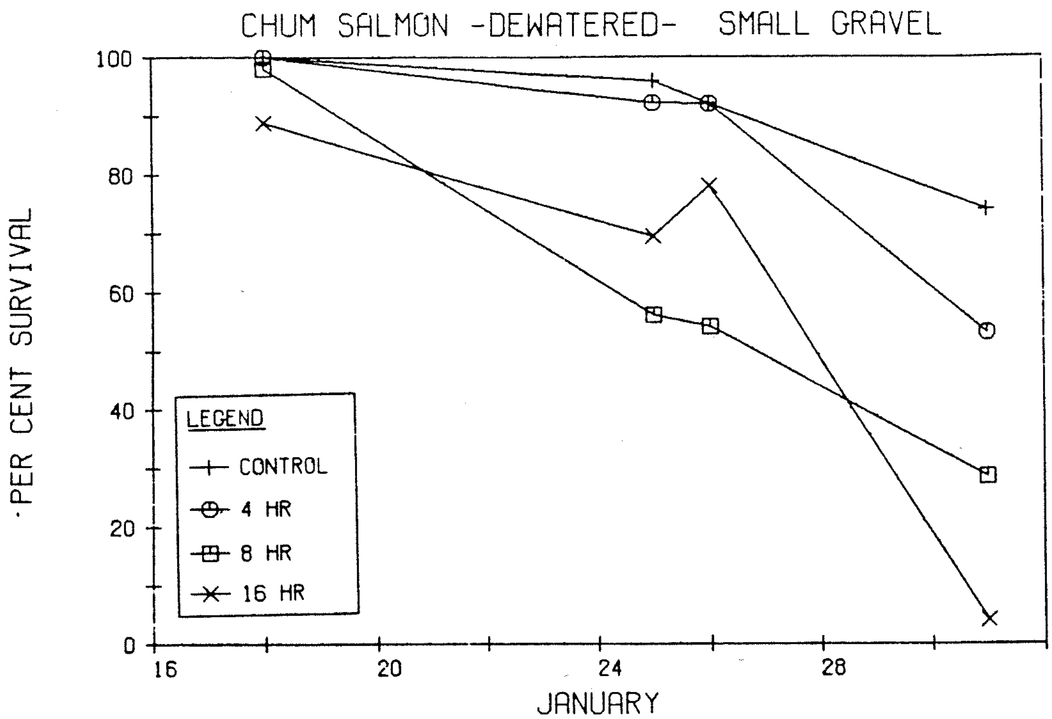

Fig. 54. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

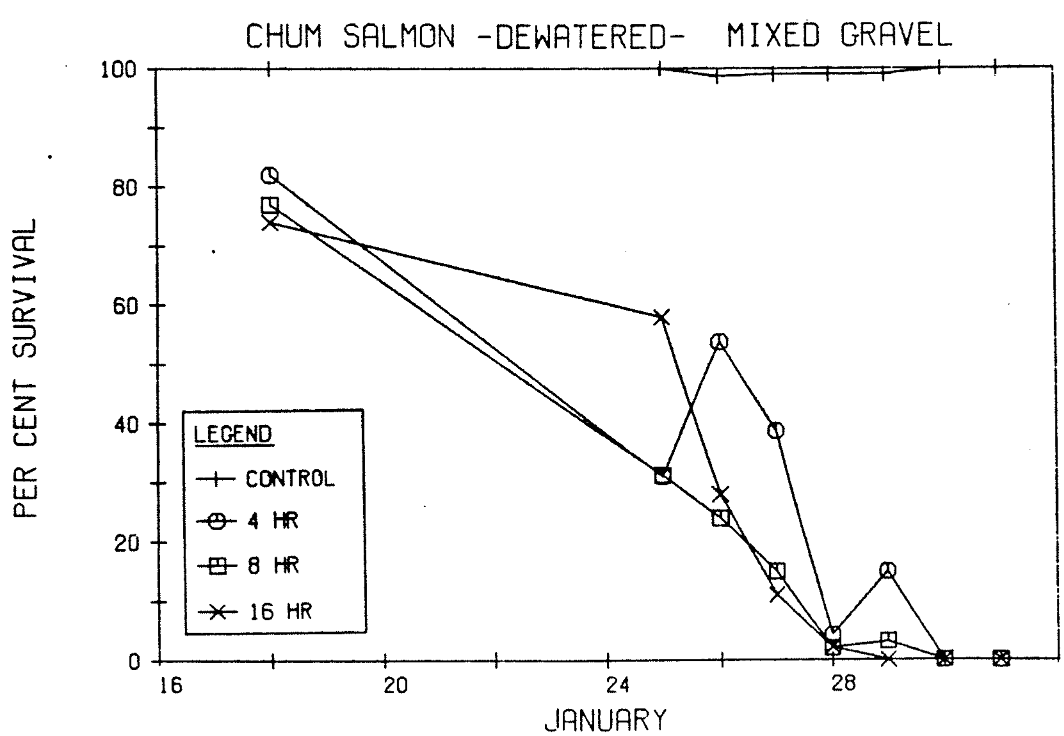

Fig. 55. Percent survival of chum salmon embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

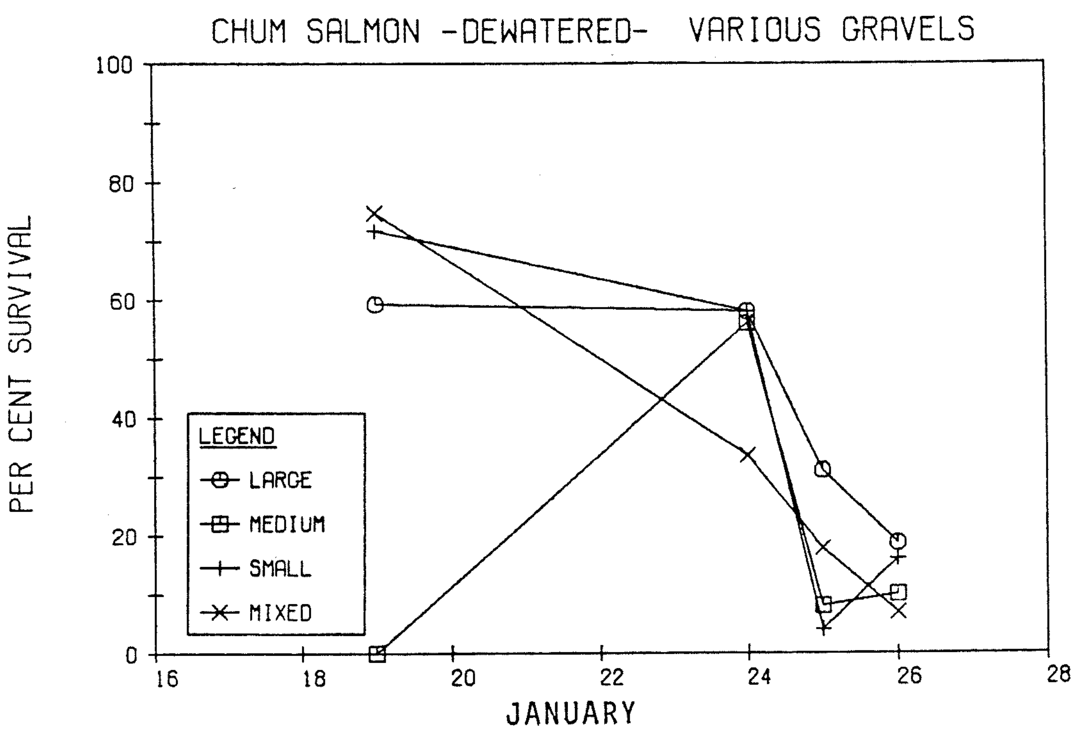

Fig. 56. Percent survival of chum salmon embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from eyed through hatching.

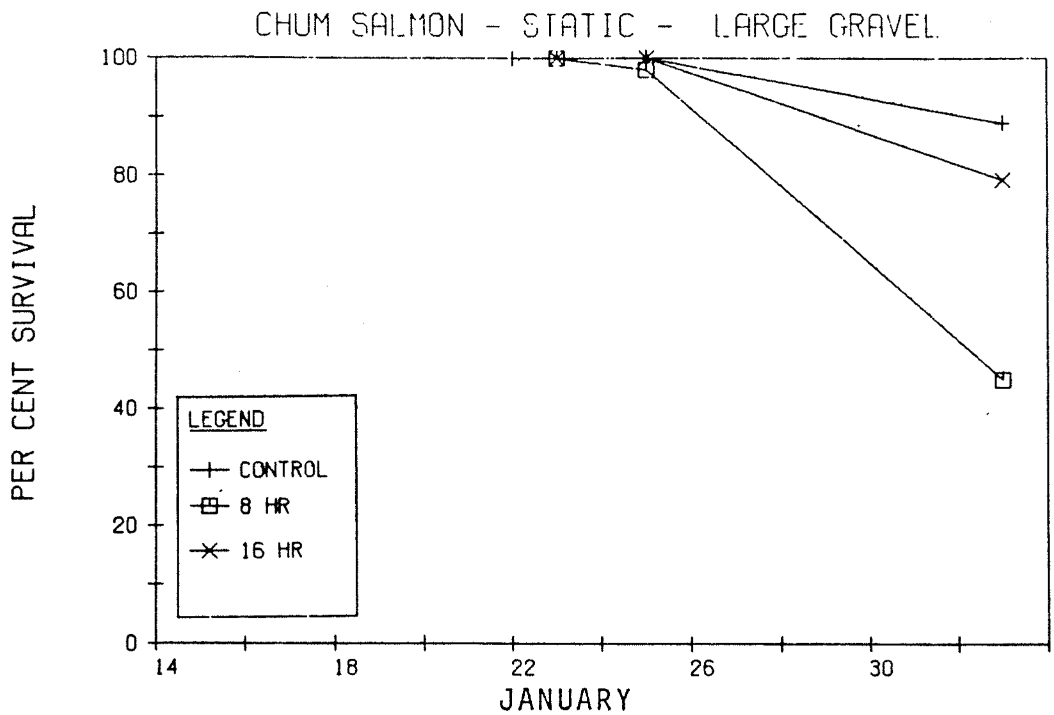

Fig. 57. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in large gravel from eyed through hatching.

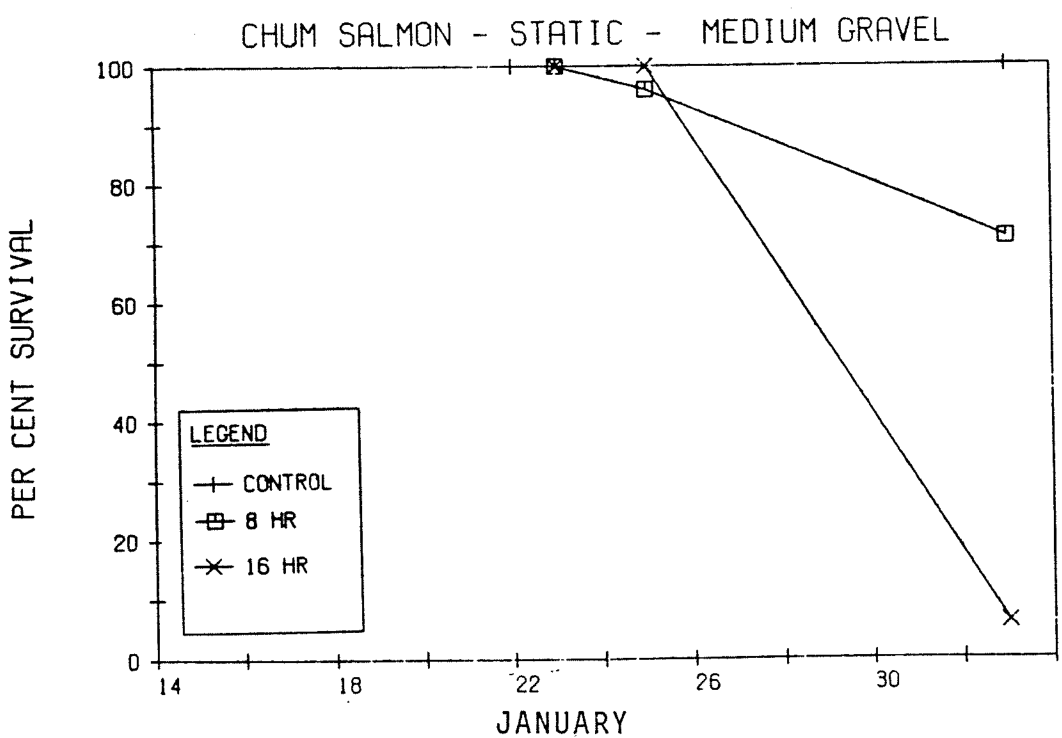

Fig. 58. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in medium gravel from eyed through hatching.

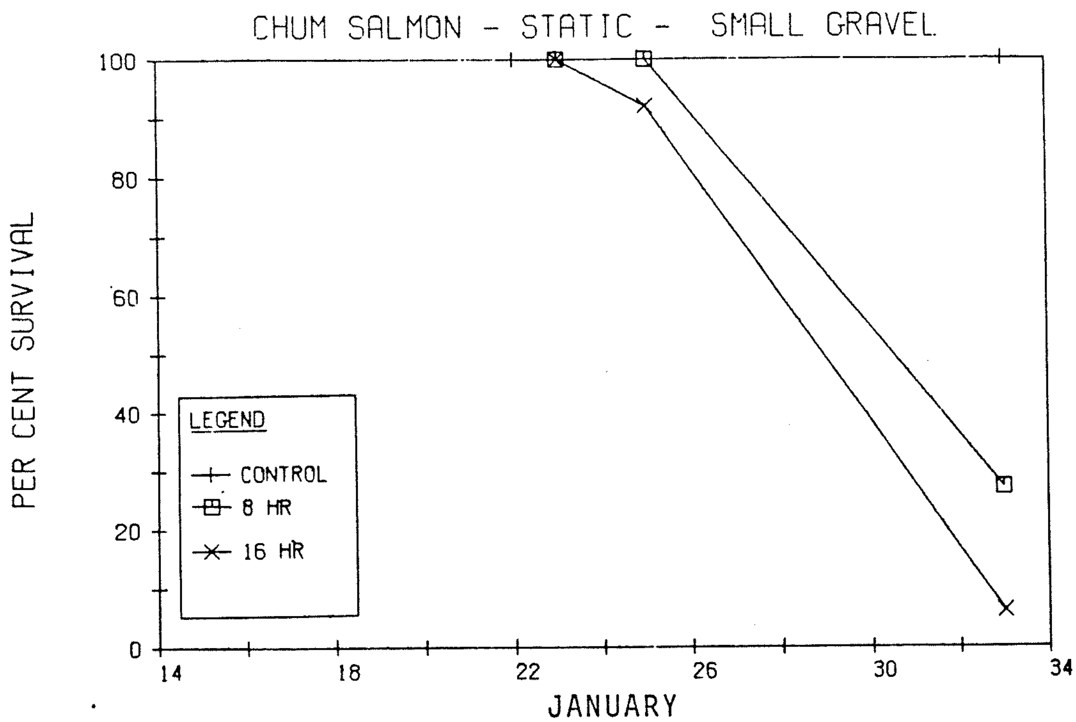

Fig. 59. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in small gravel from eyed through hatching.

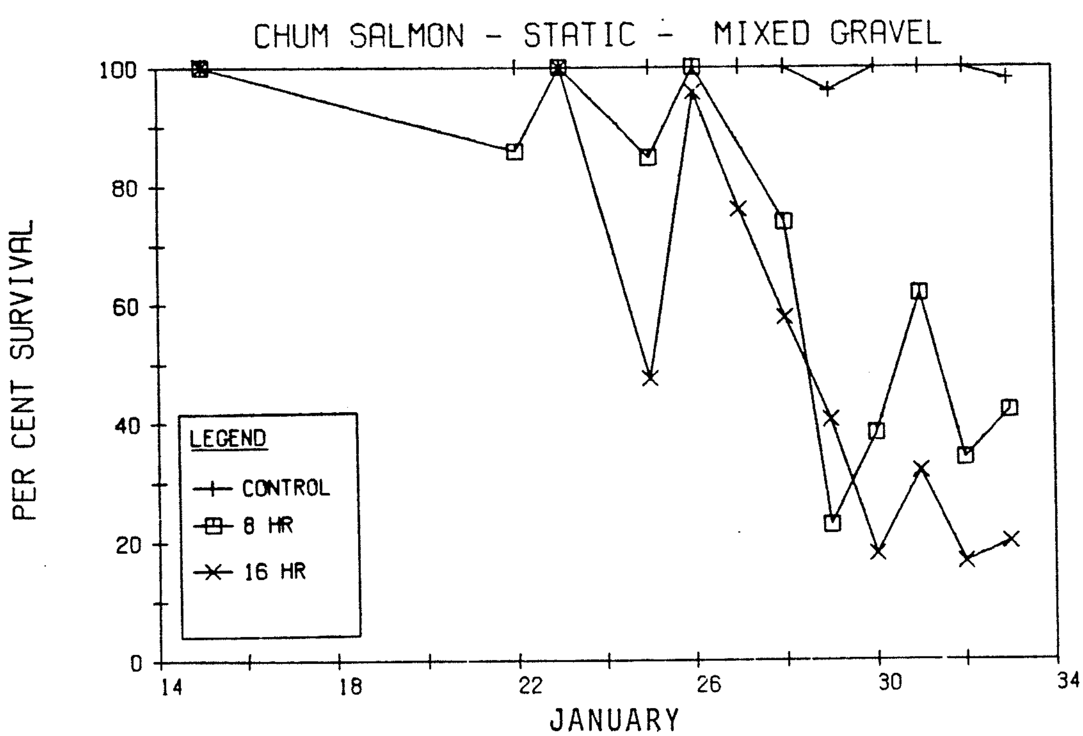

Fig. 60. Percent survival of chum salmon embryos in static water for 8 and 16 hrs/day in mixed gravel from eyed through hatching.

of eggs.

No experiments were performed on the stage 1 (fertilization to eyed) chum eggs. Continuous 24 hr/day static tests in large, medium and small gravels were also not done due to the shortage of eggs and the late date at which we could obtain them.

6.5.2.4 Steelhead trout

Prehatching survival of steelhead remained high for all gravel sizes and all dewatering regimes tested (Figs. 61, 62, 63 and 64). Hatching in steelhead began on incubation day 48 and went through day 53. Posthatching survival decreased in direct relation to the amount of time dewatered (Figs. 65, 66, 67 and 68). Survival in the 4 and 8 hr/day dewatering tests in large gravel was higher than in the other three gravels due to downward movement of alevins through the gravel. The length of time from fertilization to 50 percent survival was inversely related to the length of time dewatered (Fig. 69).

Survival in stage two continuous 24 hr/day dewatering tests decreased to zero by incubation day 56 in all but the large gravel (Figs. 70, 71, 72 and 73). Survival in the large gravel decreased initially but on the final sample date had gone to 64 percent due to downward movement of alevins in the cylinders. Control survival in all these tests remained at or near 100 percent. Continuous 24 hr/day dewatering tests on stage three organisms indicated a decrease in prehatching survival (Fig. 74). Survival in all tests had decreased to zero by incubation day 52.

Prehatching survival in stage three static water tests remained high for all gravel sizes and all static water regimes tested except 8 hrs/day (Figs. 75,

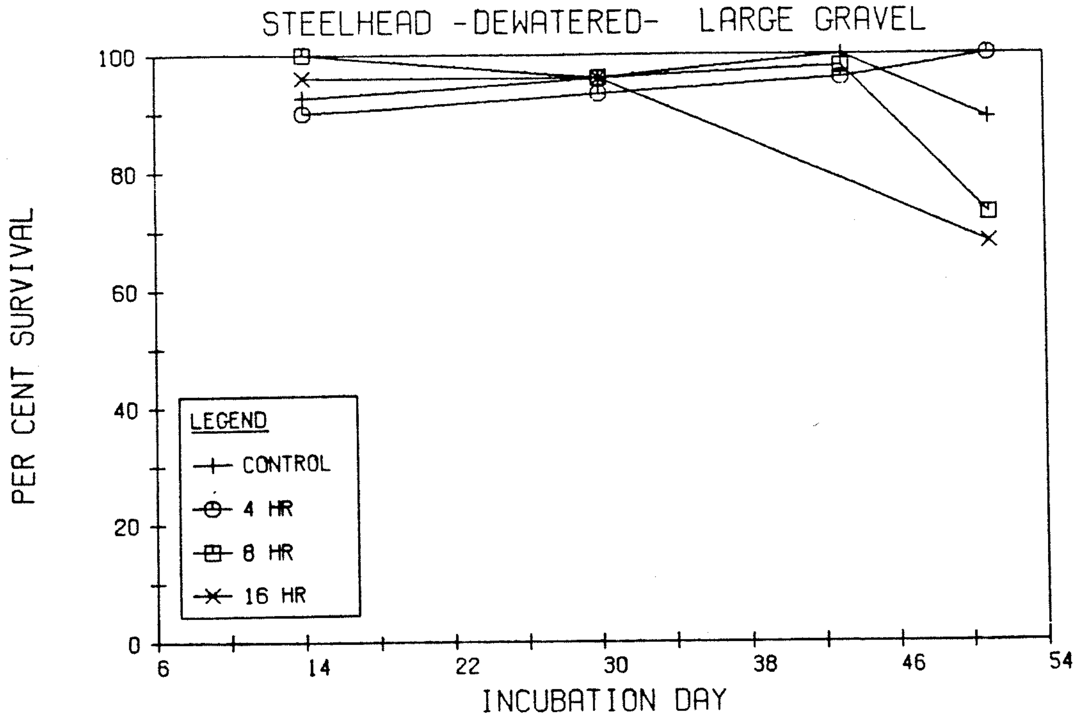

Fig. 61. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

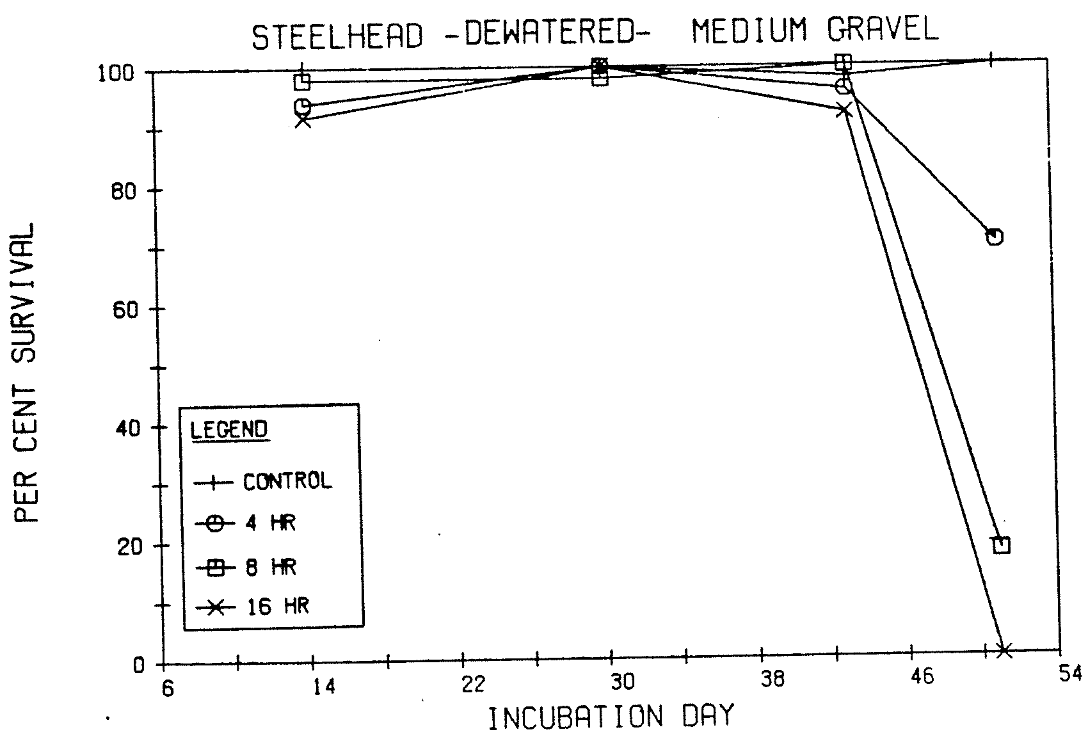

Fig. 62. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

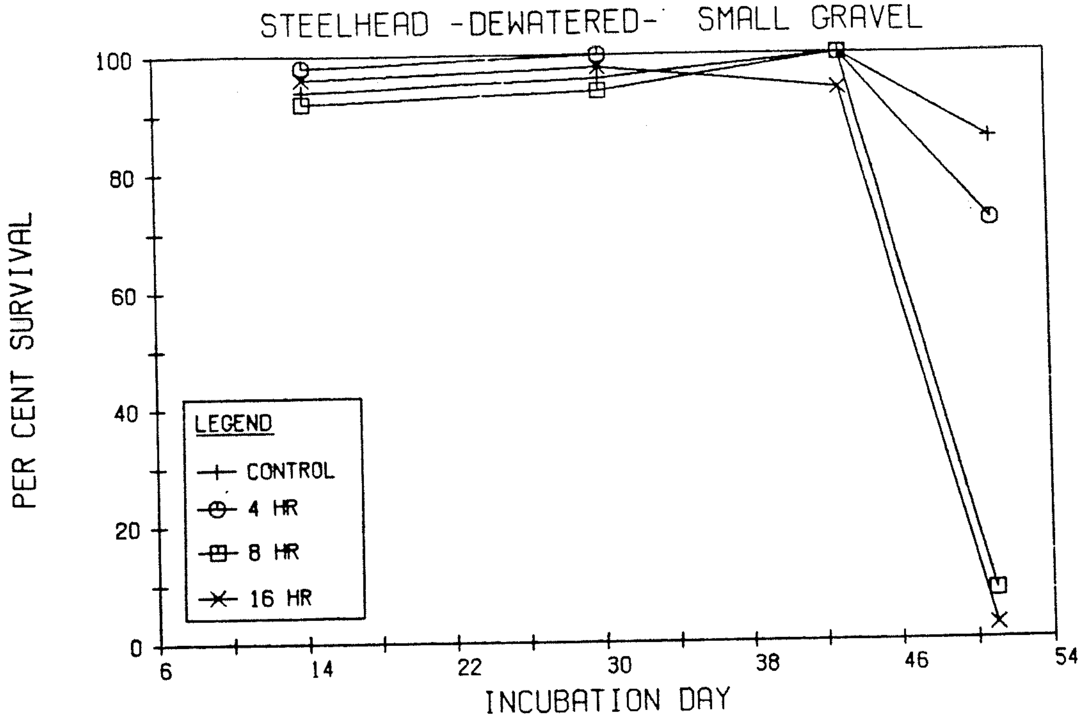

Fig. 63. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

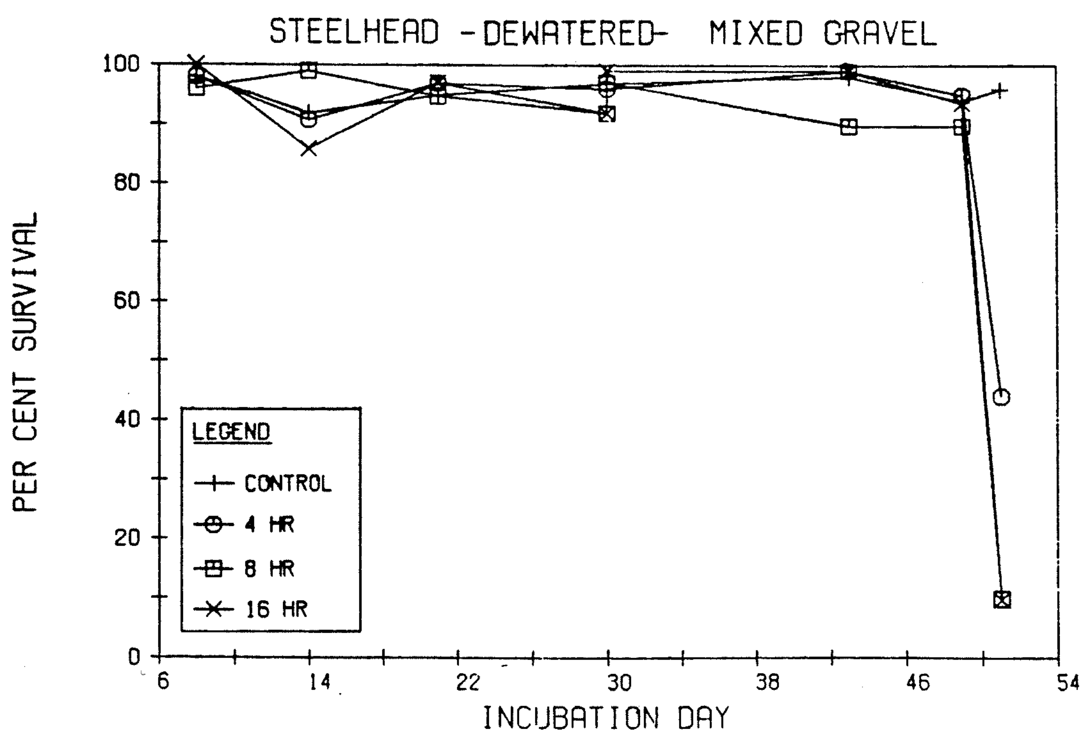

Fig. 64. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

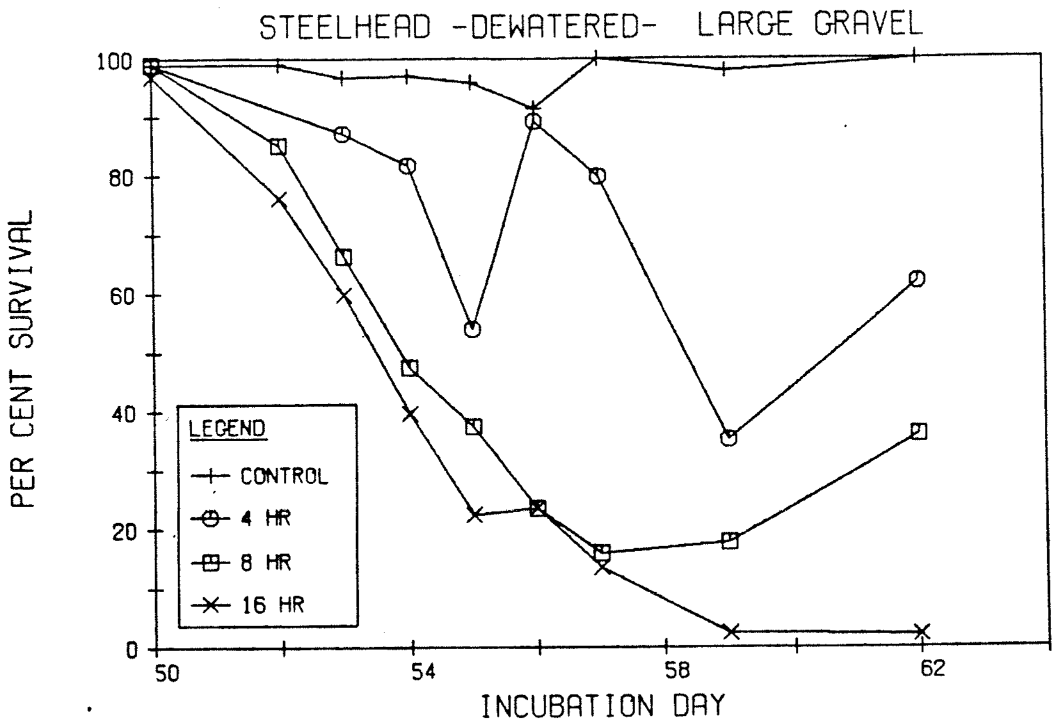

Fig. 65. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

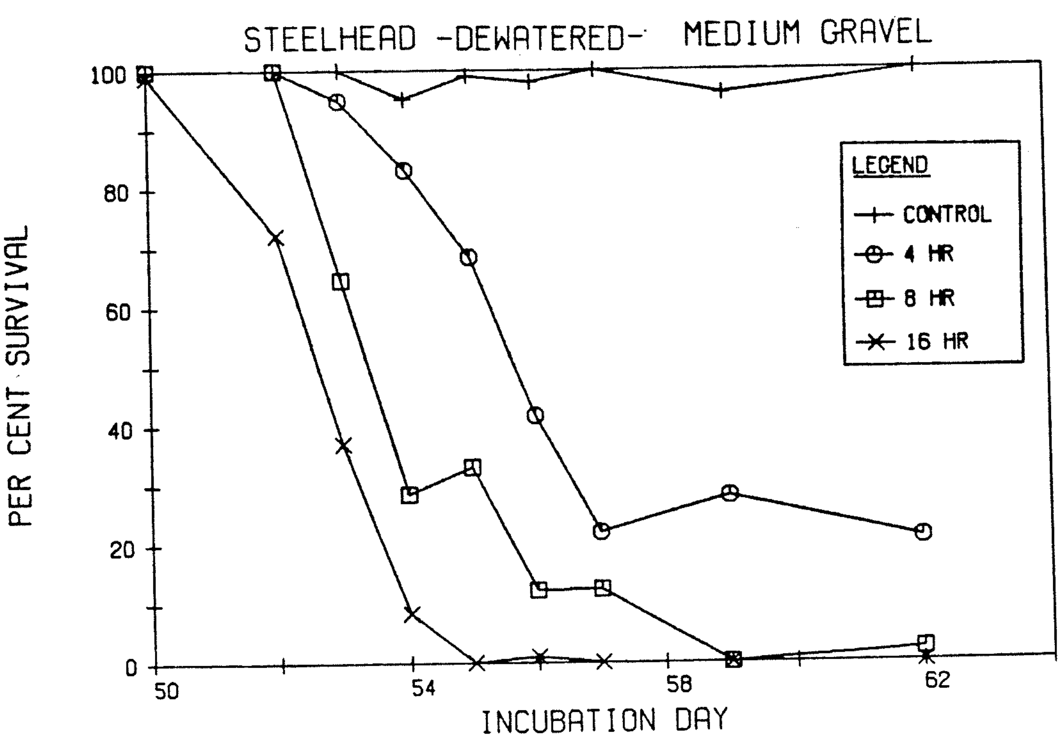

Fig. 66. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

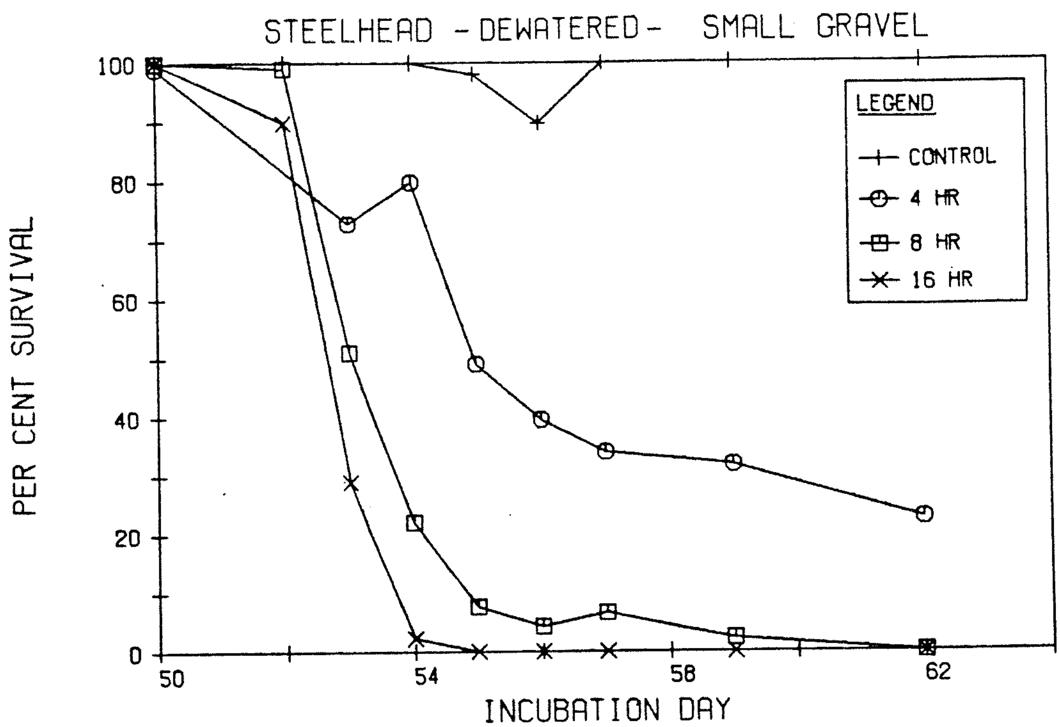

Fig. 67. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

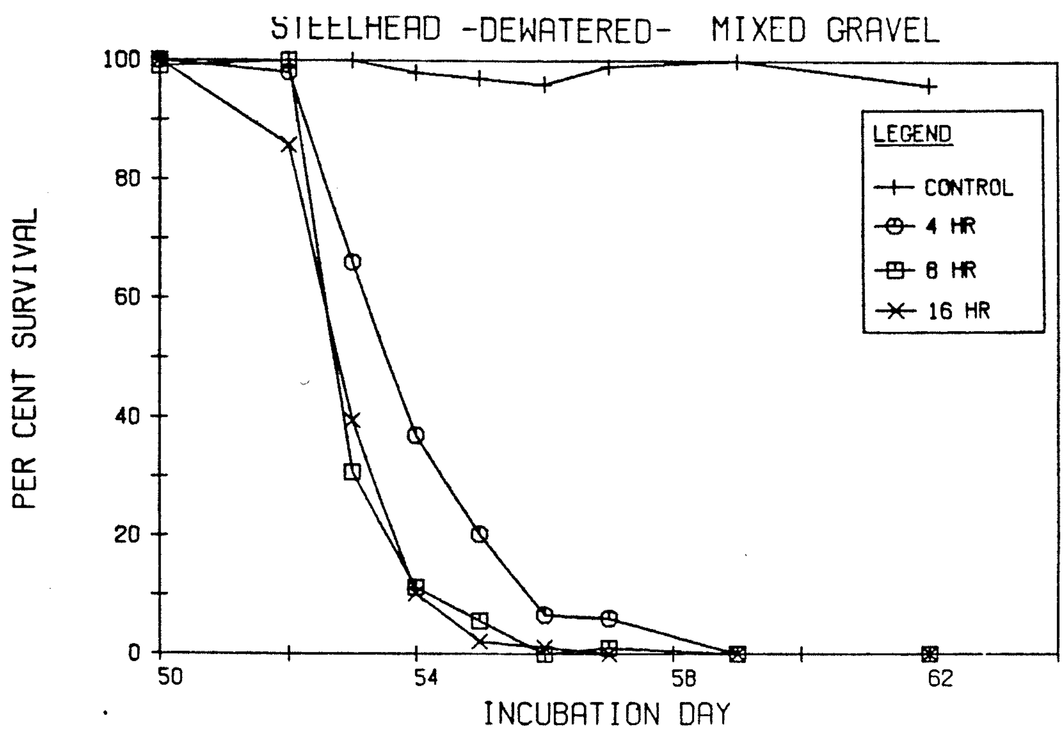

Fig. 68. Percent survival of steelhead trout embryos dewatered for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

STEELHEAD DEWATER

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

Fig. 69. Incubation days to 50 percent mortality for steelhead trout tested under four dewatering regimes and gravel sizes.

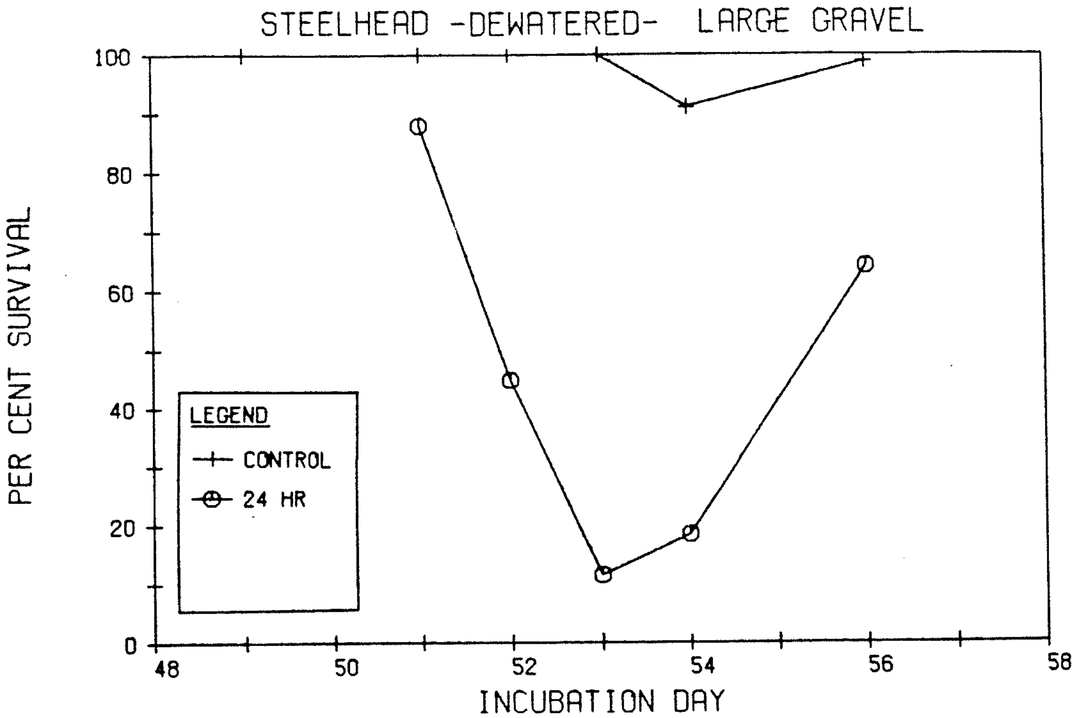

Fig. 70. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in large gravel from eyed through hatching.

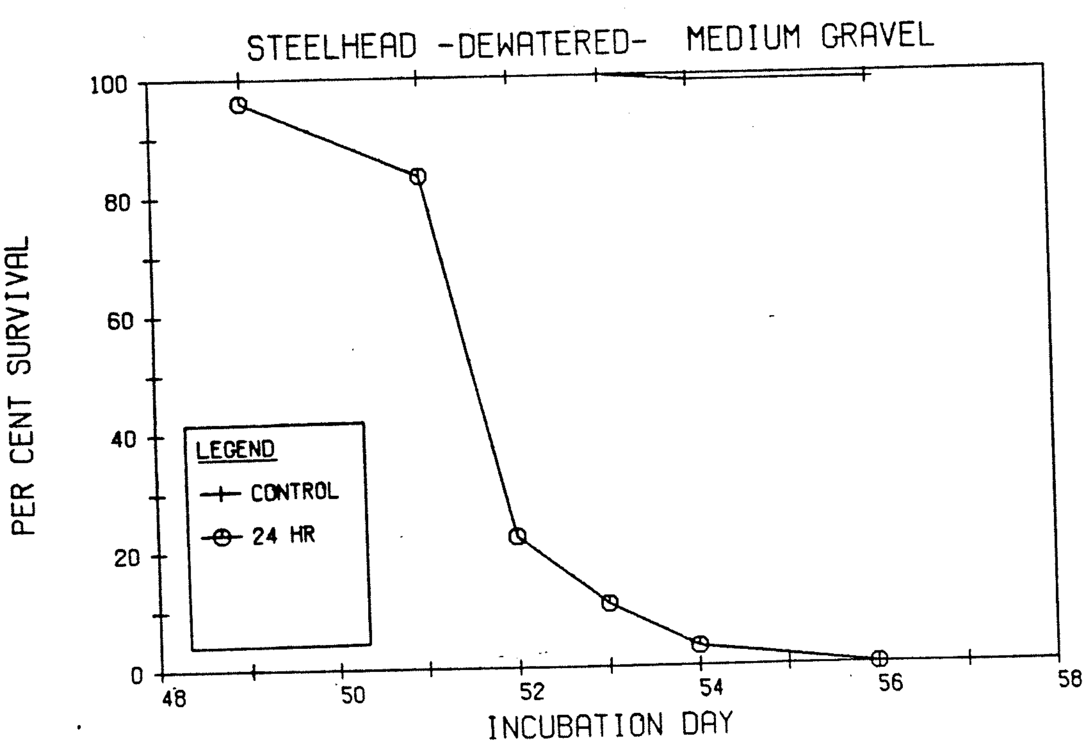

Fig. 71. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in medium gravel from eyed through hatching.

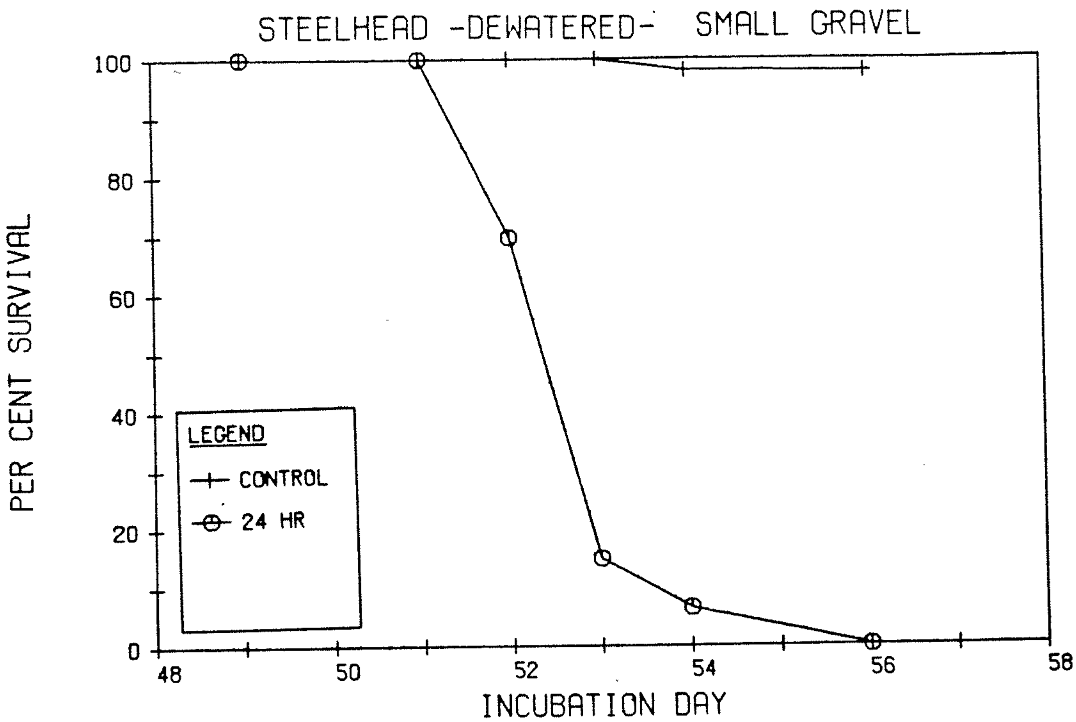

Fig. 72. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in small gravel from eyed through hatching.

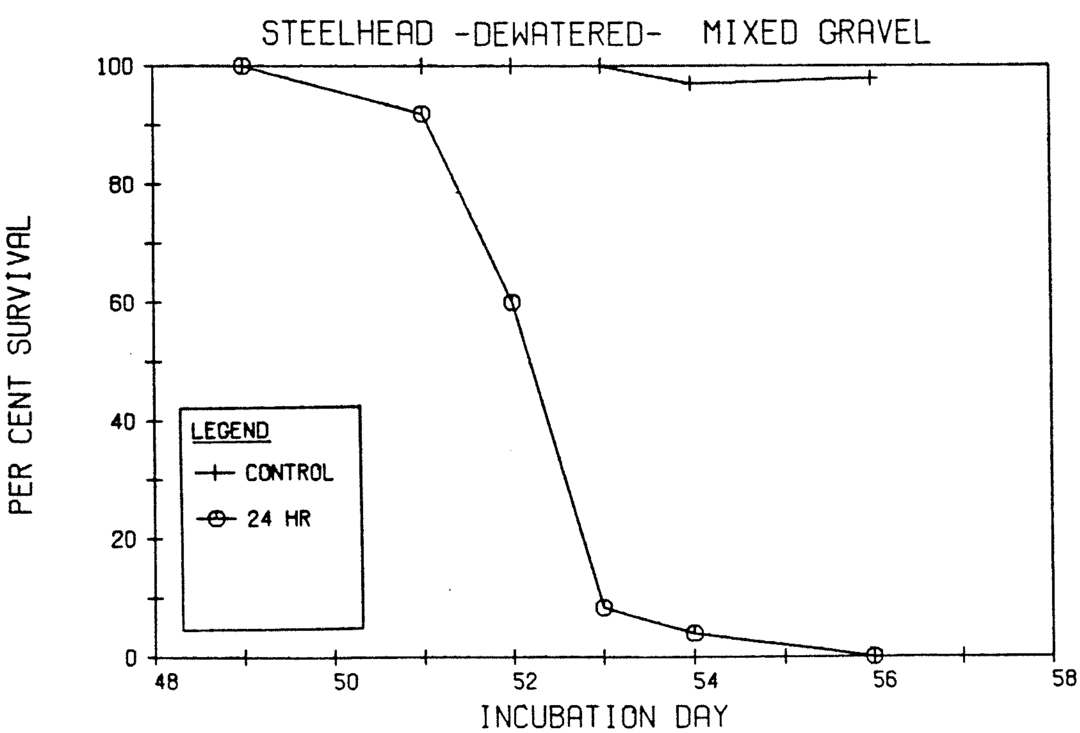

Fig. 73. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in mixed gravel from eyed through hatching.

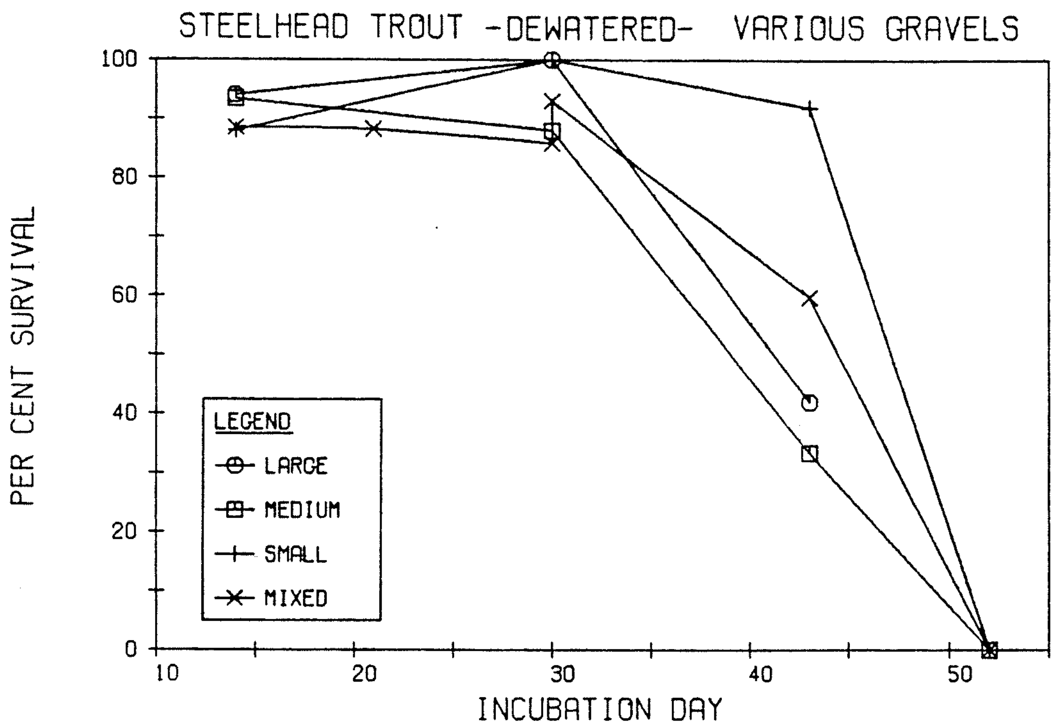

Fig. 74. Percent survival of steelhead trout embryos dewatered for 24 hrs/day in large, medium, small and mixed gravels from fertilization through hatching.

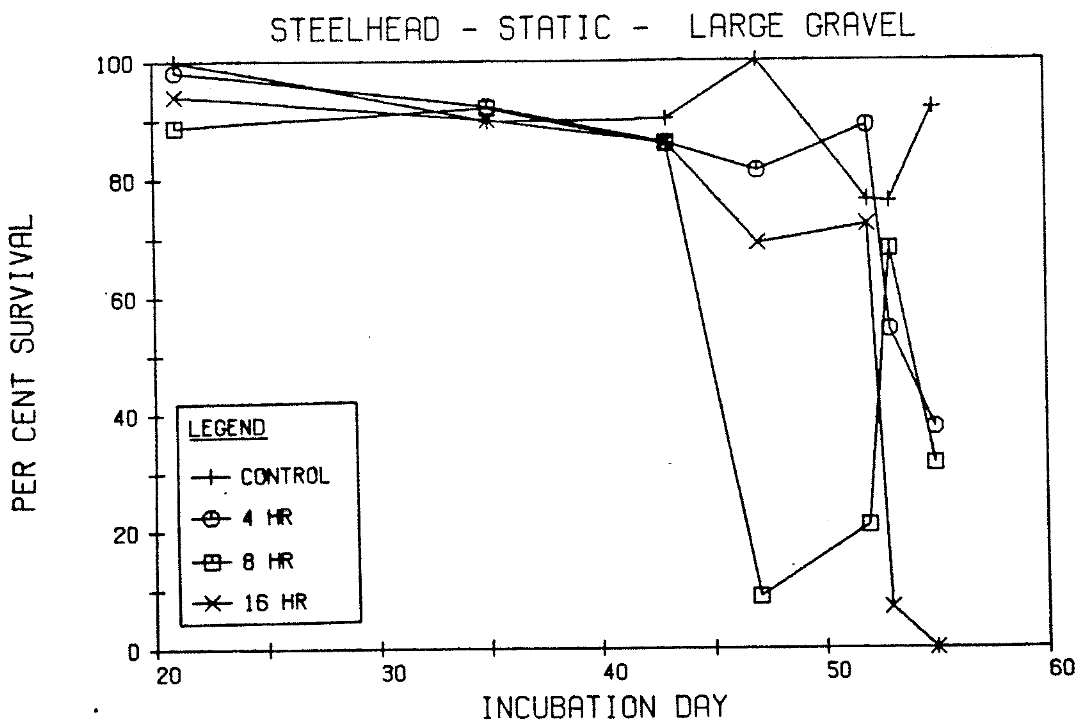

Fig. 75. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in large gravel from fertilization to the eyed stage.

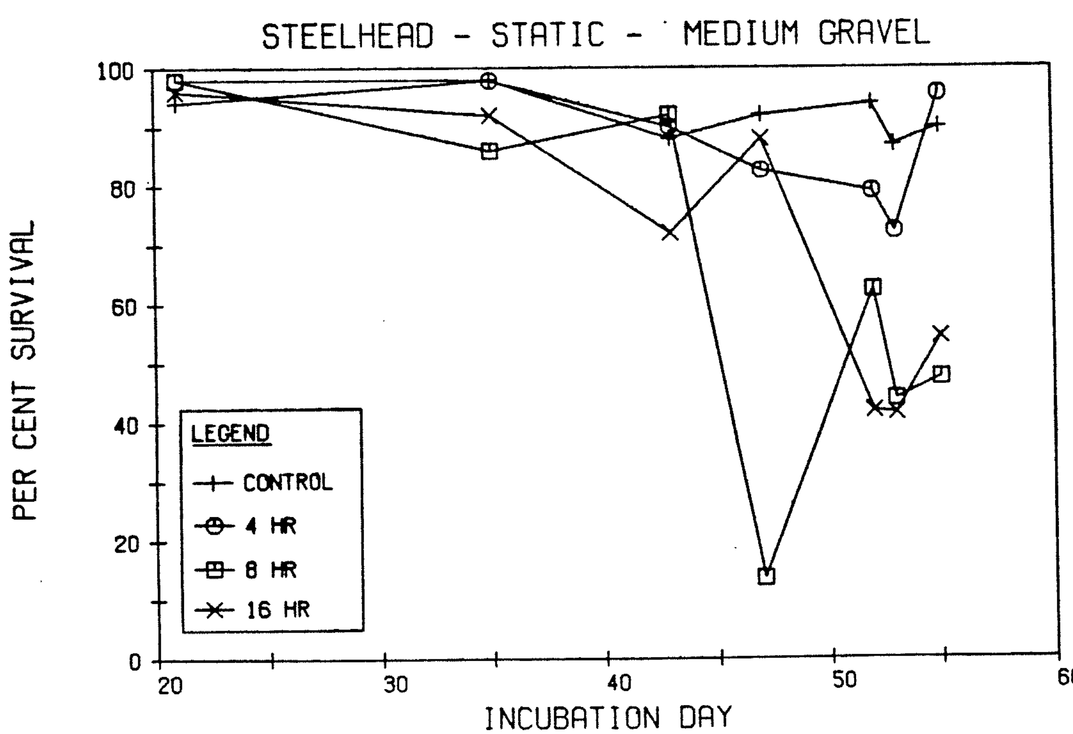

Fig. 76. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in medium gravel from fertilization to the eyed stage.

76, 77 and 78). The 8 hr/day survival decreased drastically on day 47 in all gravel sizes when the eggs were accidentally left in static water for 24 hrs.

Posthatching survival in stage two static tests remained high (Figs. 79, 80, 81 and 82). Survival generally decreased in direct relation to the amount of time in static water. The 8 and 16 hr/day tests generally had similar lower rates of survival while the 4 hr/day test approximated the higher survival of the controls.

Survival in the continuous 24 hr/day static tests varied with the gravel size (Figs. 83, 84, 85 and 86). Generally the higher survival rates were found in the larger gravel. All experiments were performed on the steelhead except for the continuous 24 hr/day static tests on stage one eggs for all gravels.

These studies indicate that the eggs of all four species (chinook, coho, chum and steelhead) have a high rate of survival to hatching under dewatered conditions of as much as 24 hrs/day. Reiser (1981) found similar results in studies of chinook and steelhead eggs on the Snake River, Idaho. He stated that "salmonid eggs are extremely tolerant to long periods of in-situ dewatering (1 to 5 weeks) with no significant effects on hatching survival". Other in-situ observations report similar high prehatching survival in brown trout (*Salmo trutta*) and chinook salmon redds dewatered for 3 to 5 weeks (Hobbs 1937, Hawke 1978).

Our studies indicated a lower prehatching survival in static water tests of 16 and 24 hrs/day than in the static tests of 4 and 8 hrs/day and the dewatering tests. The eggs in the dewatered gravel could obtain sufficient moisture from the surrounding gravel to sustain oxygen transfer across the egg membrane, which probably facilitated the use of atmospheric oxygen. The

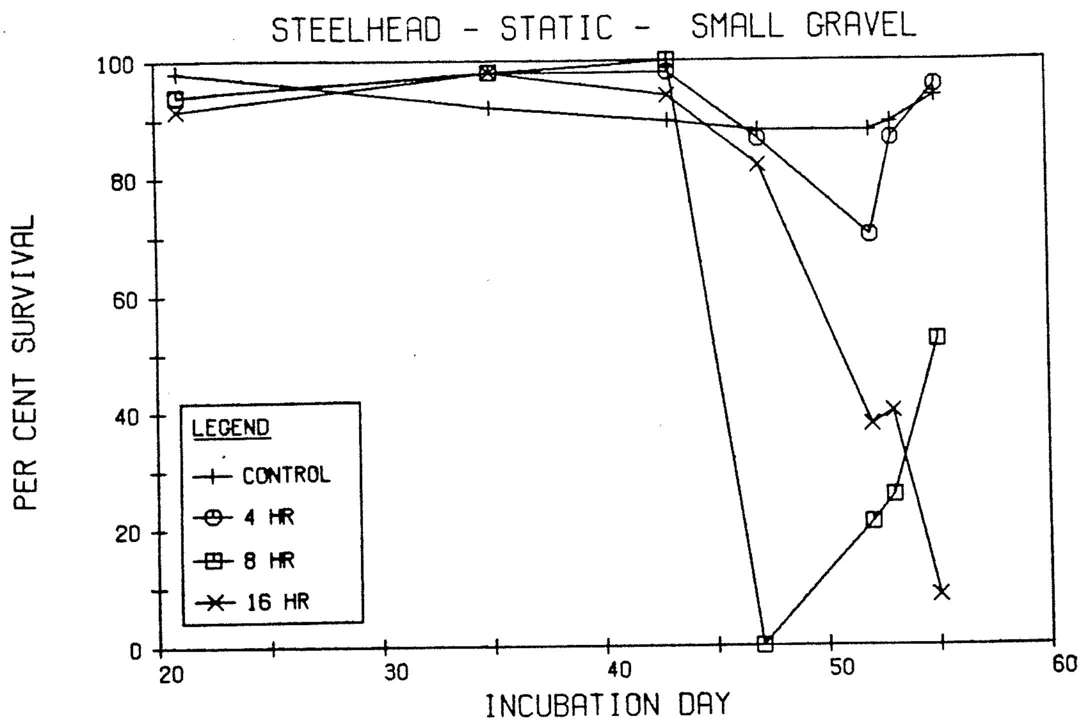

Fig. 77. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in small gravel from fertilization to the eyed stage.

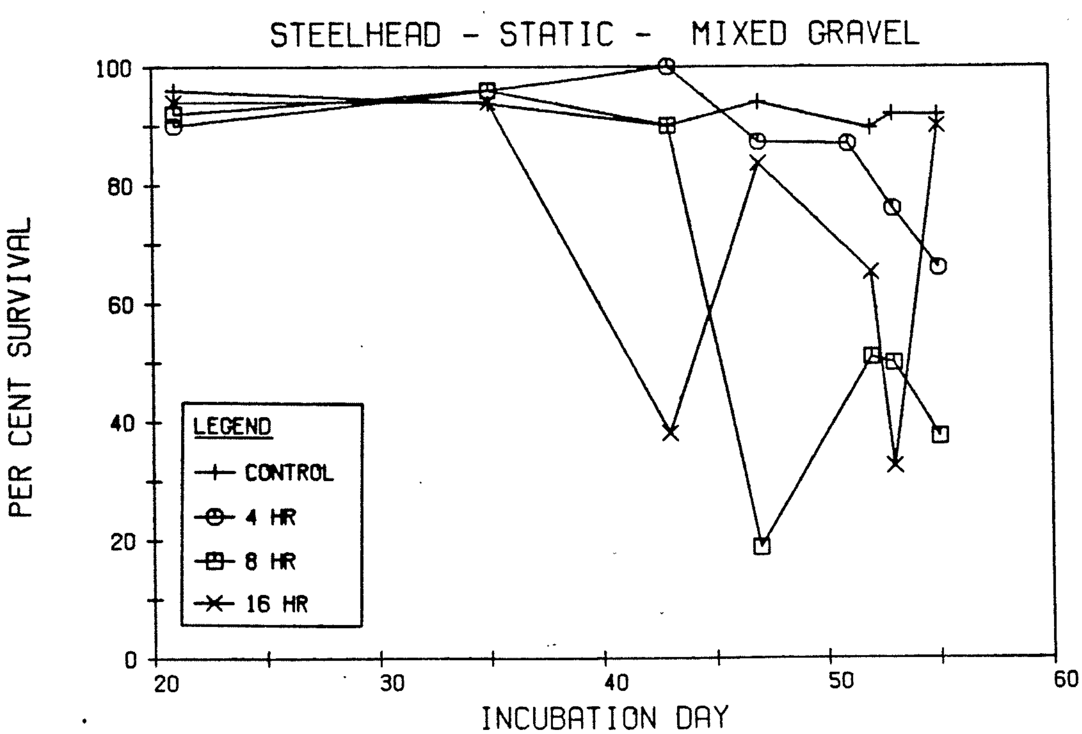

Fig. 78. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from fertilization to the eyed stage.

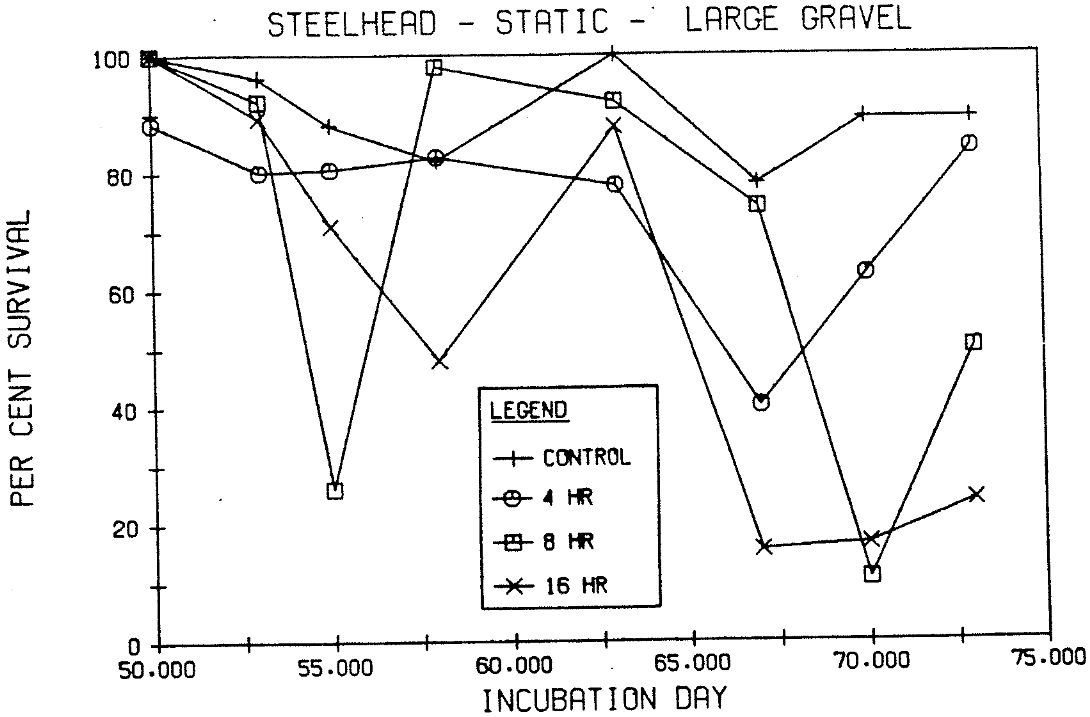

Fig. 79. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in large gravel from eyed through hatching.

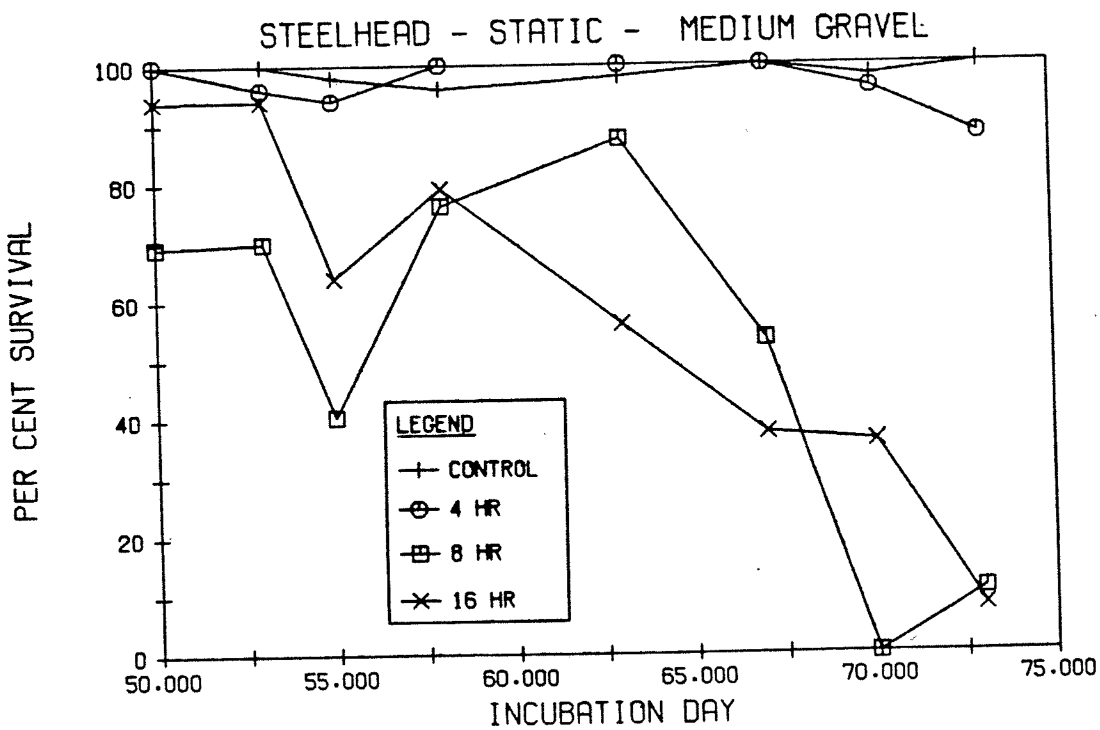

Fig. 80. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in medium gravel from eyed through hatching.

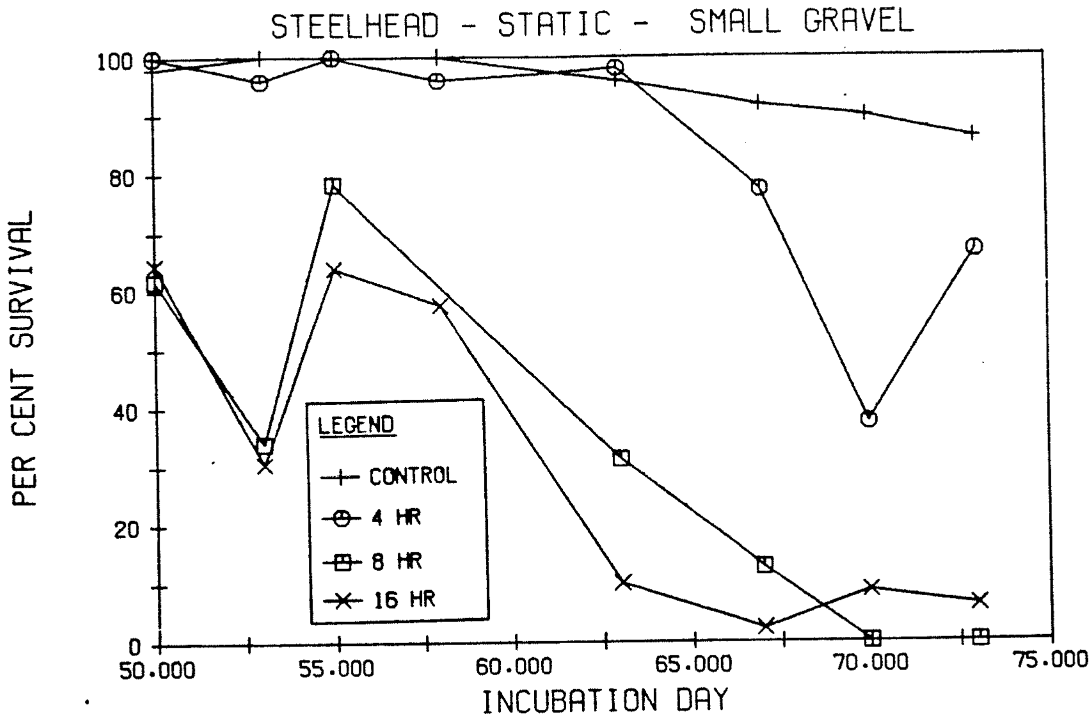

Fig. 81. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in small gravel from eyed through hatching.

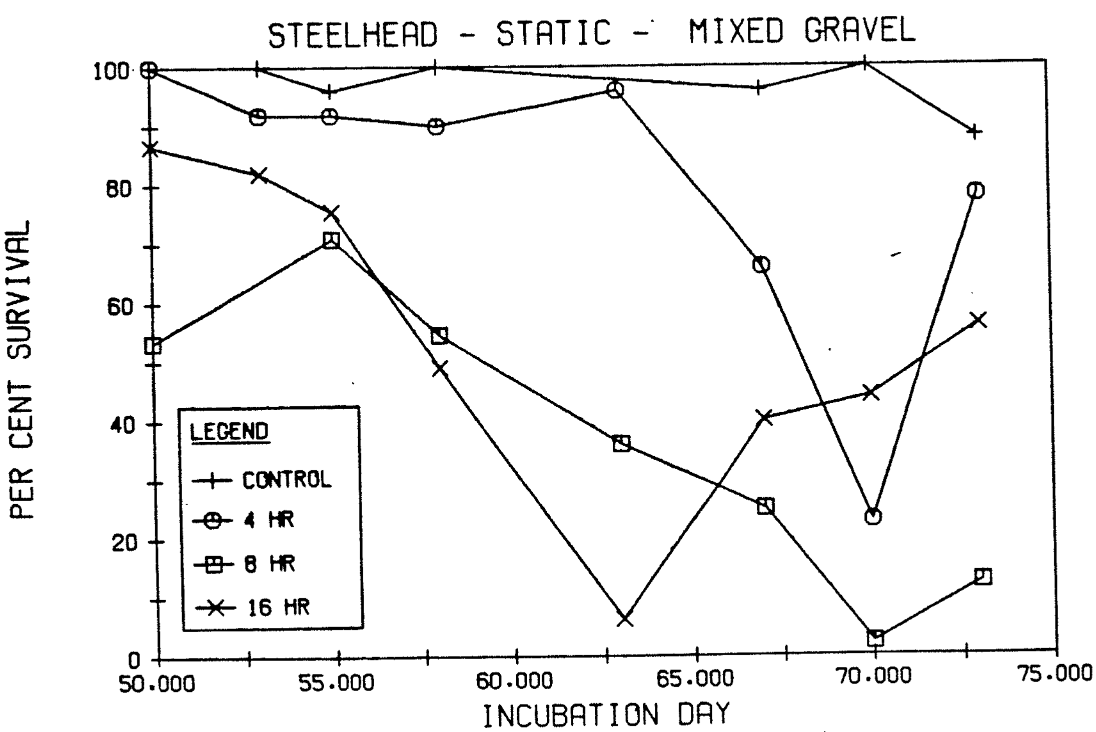

Fig. 82. Percent survival of steelhead trout embryos in static water for 4, 8 and 16 hrs/day in mixed gravel from eyed through hatching.

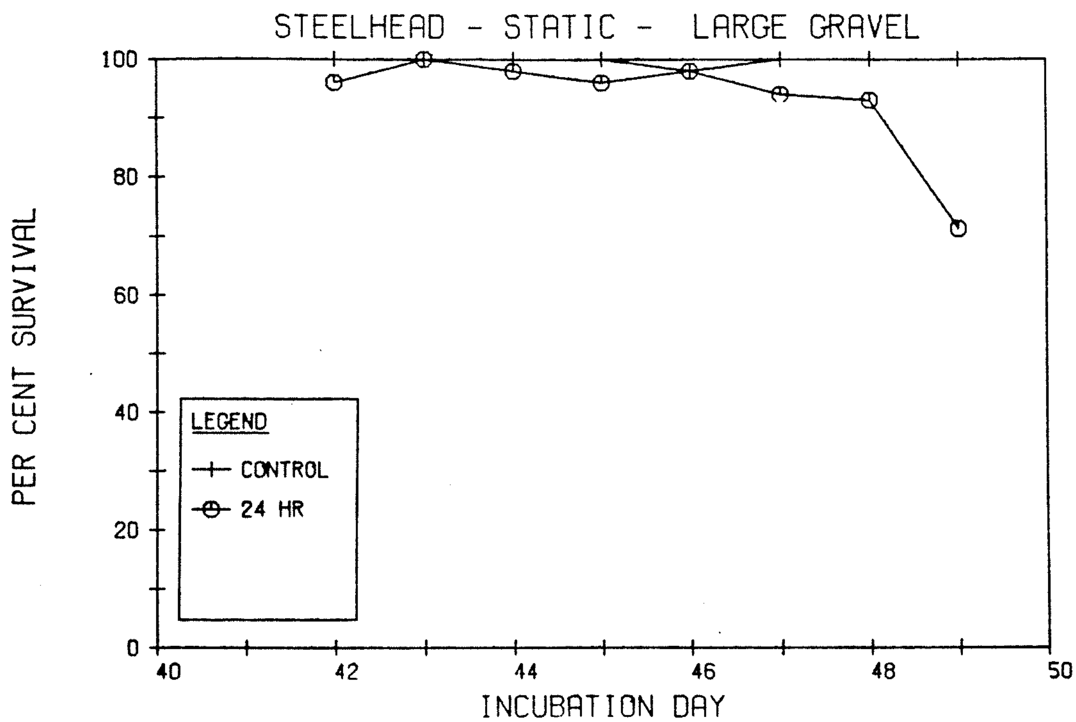

Fig. 83. Percent survival of steelhead trout embryos in static water for 24 hrs/day in large gravel from eyed to hatching.

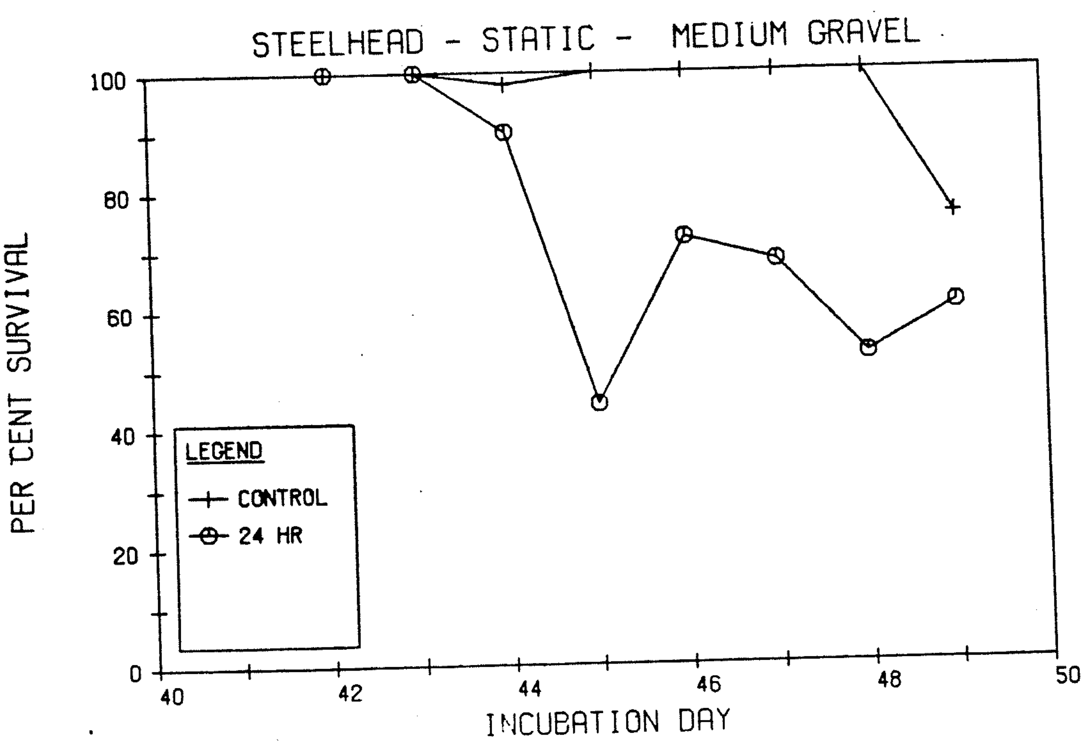

Fig. 84. Percent survival of steelhead trout embryos in static water for 24 hrs/day in medium gravel from eyed to hatching.

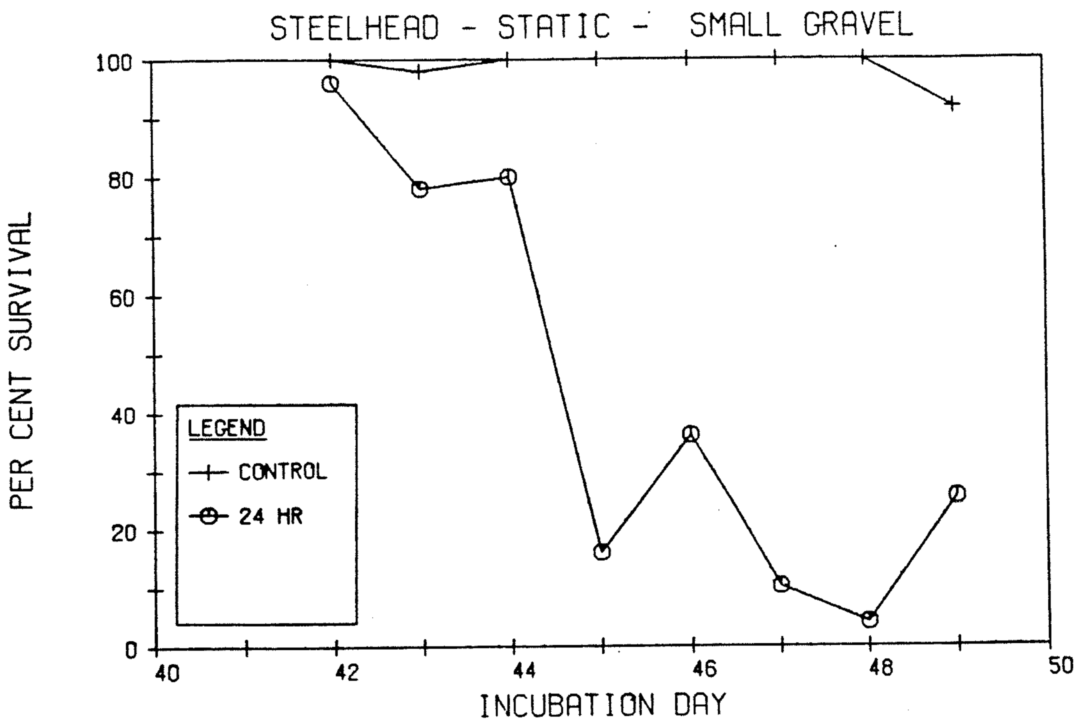

Fig. 85. Percent survival of steelhead trout embryos in static water for 24 hrs/day in small gravel from eyed to hatching.

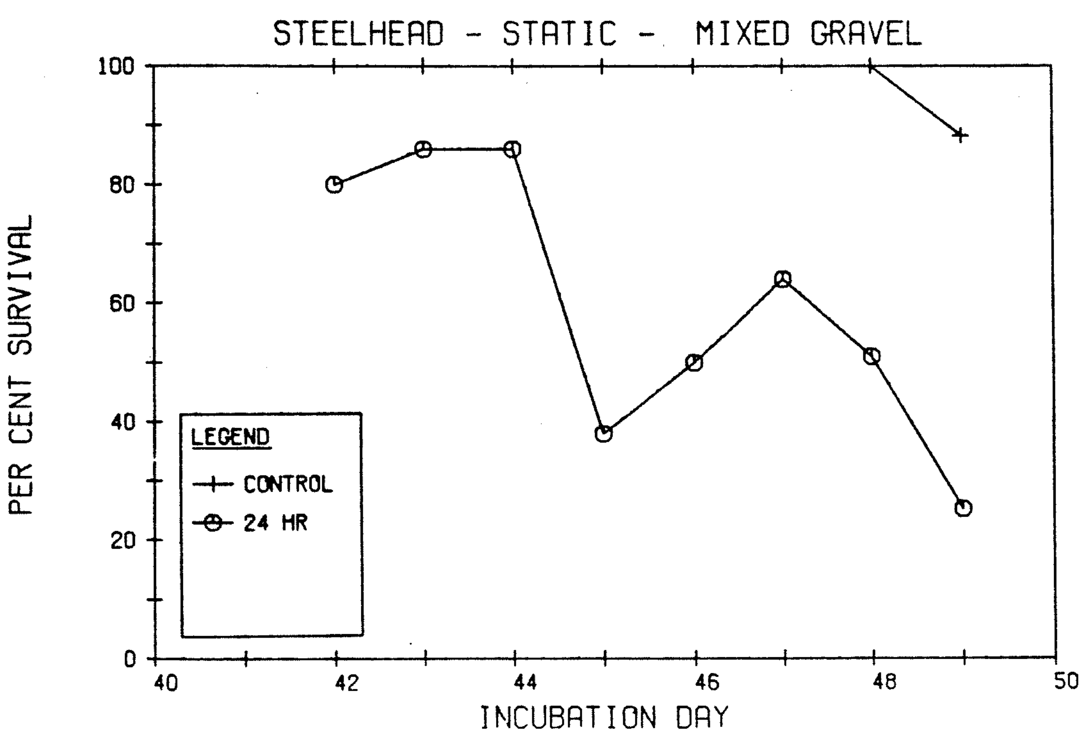

Fig. 86. Percent survival of steelhead trout embryos in static water for 24 hrs/day in mixed gravel from eyed to hatching.

eggs in the long-term static water (16 and 24 hrs/day) probably depleted the dissolved oxygen supply in the aquatic microenvironment adjacent to the membrane. With no water movement replacing the deoxygenated water the dissolved oxygen level probably dropped below the level acceptable for sustaining life in the developing embryos. Thus it is important that gravel permeability allow for sufficient water velocity to continually carry dissolved oxygen to the eggs. The embryos exposed to static water for 4 and 8 hrs/day probably did not utilize a sufficient amount of oxygen from the water to deplete the dissolved oxygen below the critical level during the shorter period of time they were exposed. Alderdice et al. (1958) found the critical level of dissolved oxygen in chum salmon (*O. keta*) to be 3.7 mg/l at the eyed stage and 7.19 mg/l at hatching. The critical level for Atlantic salmon (*Salmo salar*) was 3.1 mg/l at eyed stage and 7.1 mg/l at hatching (Hayes et al. 1951). Hayes also demonstrated that hatched larvae of Atlantic salmon could obtain twice as much oxygen as unhatched eggs in the same water. Thus in static water tests the most critical low oxygen levels occurred just before hatching, resulting in high mortality. Dissolved oxygen levels in our static experiments were 8.4, 6.9 and 4.1 mg/l in 4, 8 and 16 hr/day tests, respectively.

There are possible sublethal effects of low oxygen levels on salmonid embryos. Several studies have shown that chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*) and steelhead trout (*Salmo gairdneri*) embryos subjected to chronic low oxygen concentrations hatched later and were smaller than fry incubated at higher dissolved oxygen concentrations (Silver et al. 1963, Shumway et al. 1964). These authors felt that the smaller and weaker fry produced from the low oxygen concentrations could not be expected to survive. Brannon (1965) observed retarded morphological development but did not find any delay in hatching time in sockeye salmon (O. nerka) embryos incubated at low oxygen concentrations. He reported that these embryos and alevins reared at low oxygen levels emerged later than, but at approximately the same weight as, fry reared at higher oxygen concentrations. Brannon also suggested that alevins which hatched prematurely may be smaller and weaker than alevins hatched at a later developmental stage but that this condition does not necessarily reflect their ability to survive. Mason (1969) in a study of competition among coho fry found that size differences caused by hypoxial stress were increased with time and that the fry reared under the most severe hypoxial conditions were most likely to emigrate from the test stream. These emigrants, when placed in a vacant replicate stream system, became as large as, or larger than, the non-emigrants. Thus size differences due to hypoxial stress are not definite indicators of ability to survive.

Posthatching survival dropped throughout the hatching period in all dewatering experiments. There was a direct relationship between increasing amount of time dewatered and alevin mortality. As the embryos hatched the alevins were no longer capable of diffusion respiration utilizing atmospheric oxygen but relied on branchial respiration. Branchial respiration requires a continual flow of oxygenated water over the gill membranes. Dewatered alevin mortality increased with the length of time they were incapable of pumping water over their gills. High survival in dewatered cylinders occurred only when alevins were capable of moving downward through the gravel and could continue normal branchial respiration in the water retained in the bottom of the cylinder. Posthatching survival did not drop in the static water experiments due to the ability of the alevins to pump water over their gills. Intragravel movement of alevins was possible in the continually watered static situation. This allowed for increased distance between alevins and higher water quality in the microenvironment of each alevin.

6.5.3 Fry 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 are shown in Tables 27-29. 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 30-32). 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.

The chinook and coho alevins were incubated under optimum 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

Table 27. Mean and range of lengths for chinook salmon alevins dewatered 0, 4, 8, 16, and 24 hrs/day as eggs in four gravel sizes.

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

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 29. Mean and range of condition factors for chinook salmon alevins dewatered 0, 4, 8, 16, and 24 hrs, and gravel sizes.

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

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

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 32. 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.

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	--

had higher condition factors than fry from watered embryos. Although no explanation 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.

6.5.4 Intragravel Behavior

6.5.4.1 Chinook salmon

Data collected on intragravel movement of chinook alevins indicated that early stage posthatching alevins could make successful downward movements in the large gravel (Fig. 87) but not in the three smaller gravel sizes, as illustrated in Fig. 88 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. 87). 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 studied. 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. 88). This was attributed to the inability of chinook alevins to move through smaller gravel sizes.

In studies on later-stage, premergent 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.

6.5.4.2 Coho salmon

The post-hatching survival of coho alevins remained high under all dewatered regimes tested in the large gravel (Fig. 89). Survival decreased in the small, medium and mixed gravel with increased time dewatered (Fig. 90,

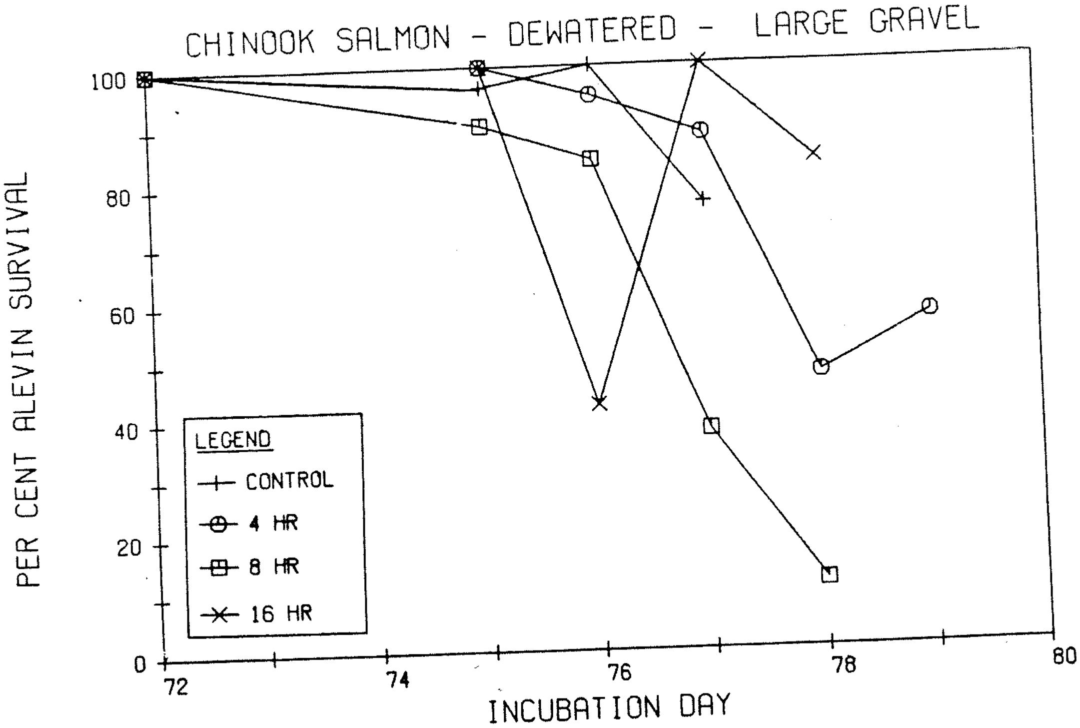

Fig. 87. Percent survival of chinook salmon alevins dewatered for 4, 8 and 16 hrs/day in large gravel through the hatching period.

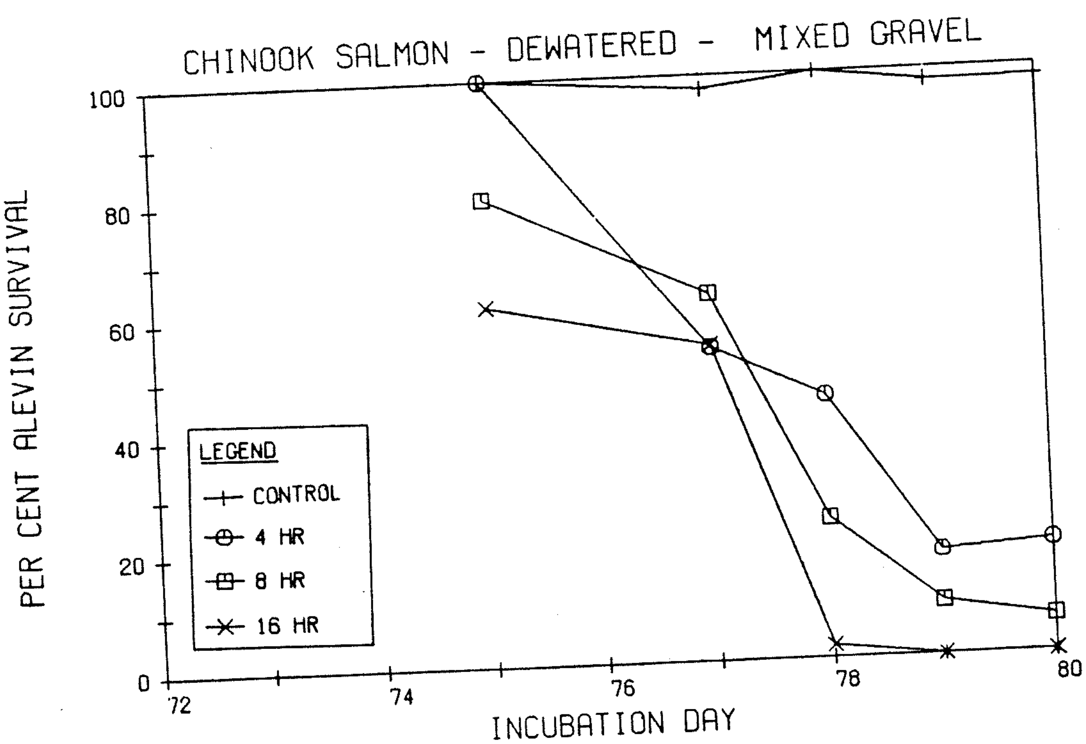

Fig. 88. Percent survival of chinook salmon alevins dewatered for 4, 8 and 16 hrs/day in mixed gravel through the hatching period.

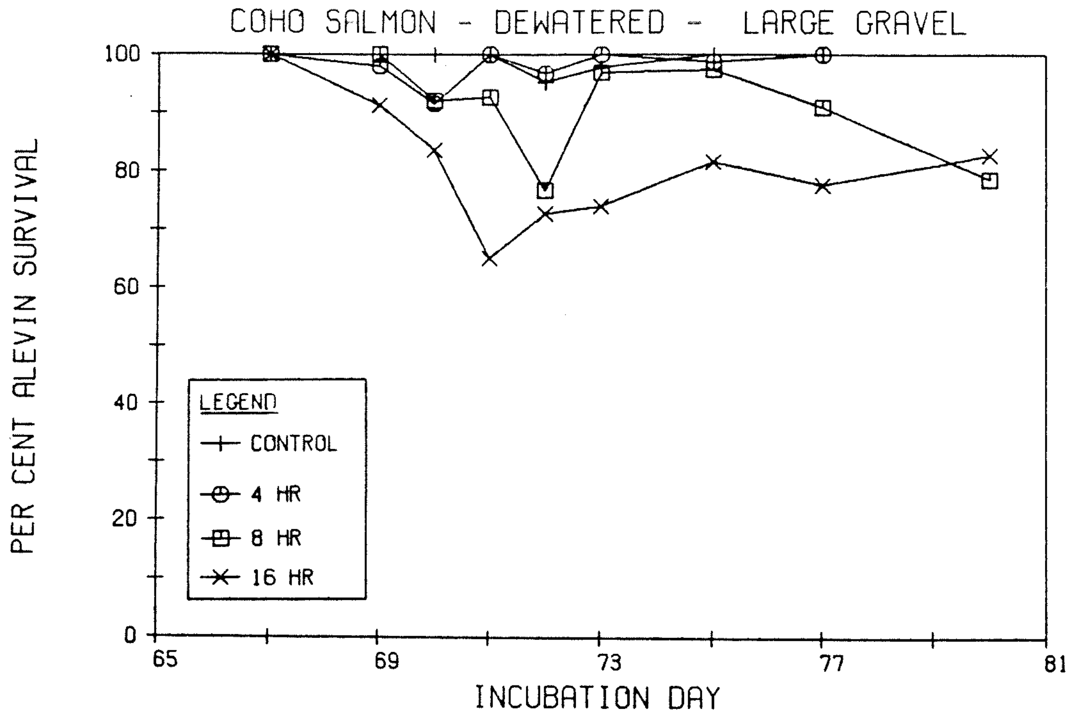

Fig. 89. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in large gravel through the hatching period.

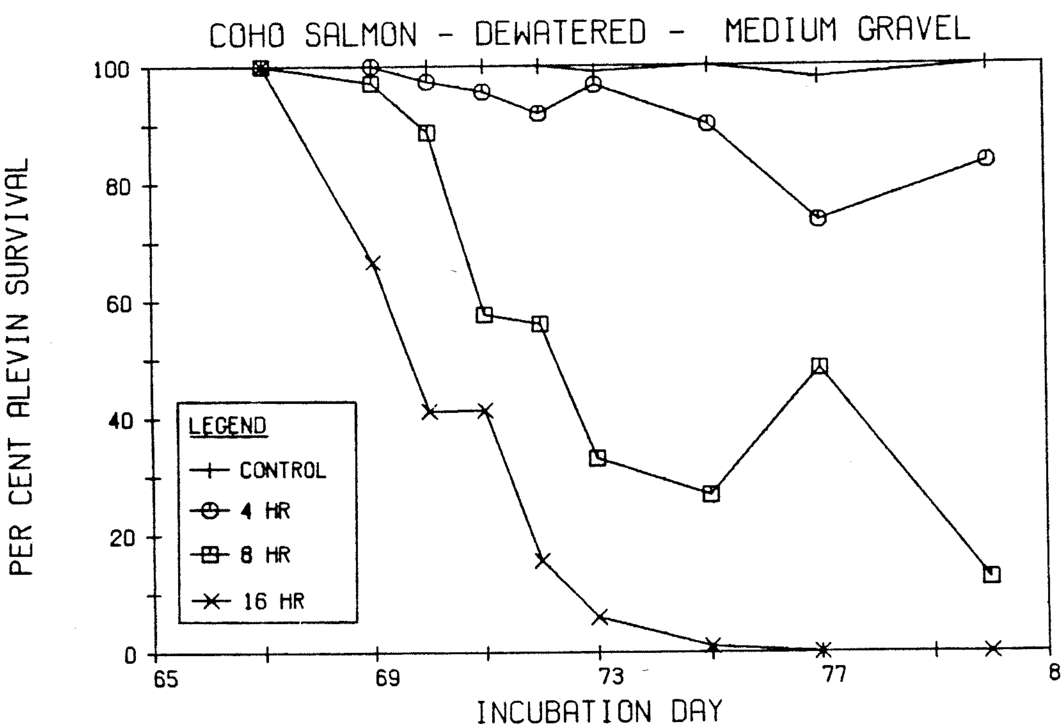

Fig. 90. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in medium gravel through the hatching period.

91 and 92). The decrease in survival in the smaller gravels showed a direct relationship with the amount of time the alevins had been dewatered. There was no posthatching survival in the three smaller-sized gravels dewatered for 16 hr/day and 8 hr/day in the mixed gravel.

Survival of coho through the hatching stage in large gravel (1.35-5.08 cm) is shown graphically in Fig. 89. 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. Posthatching 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. 92). 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 distance 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.

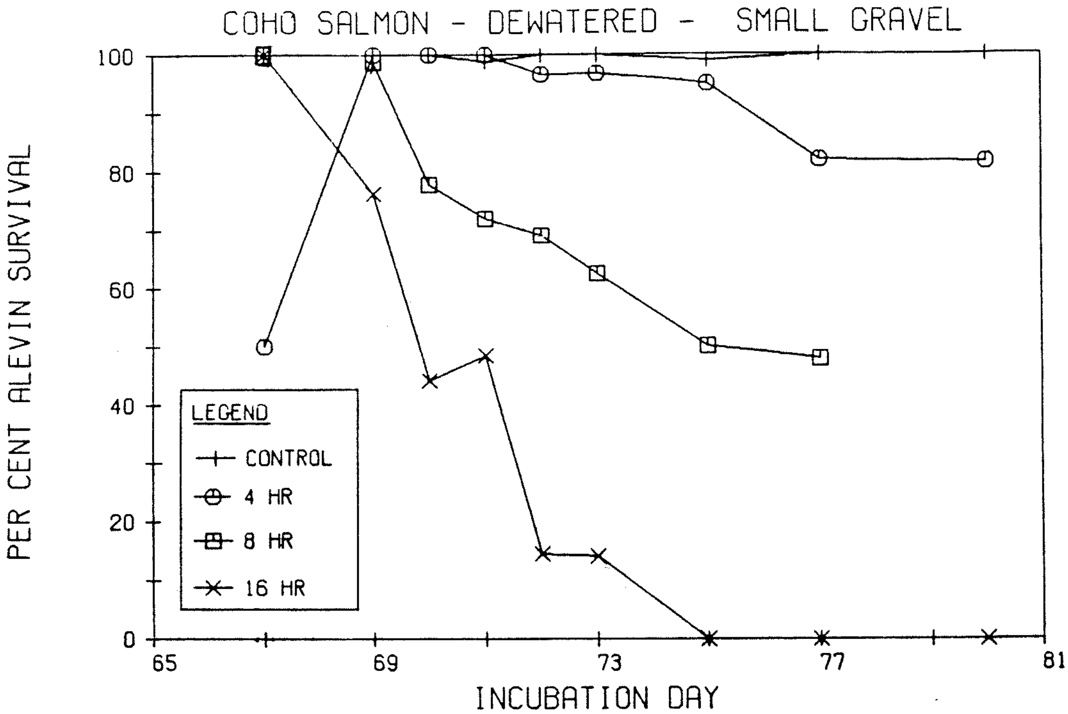

Fig. 91. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in small gravel through the hatching period.

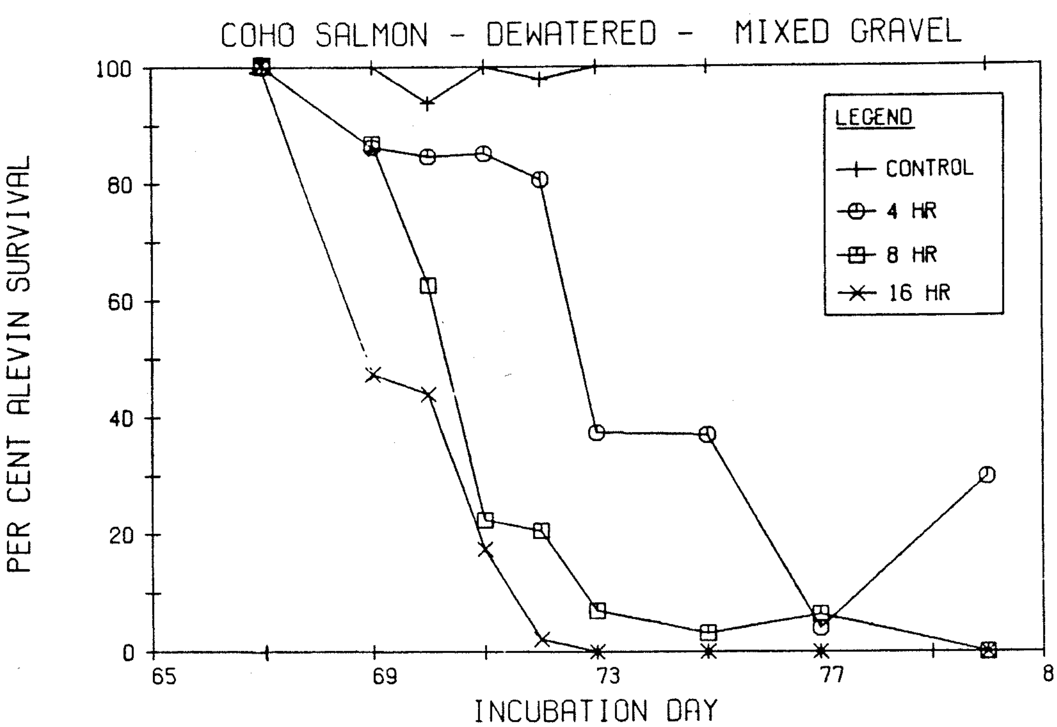

Fig. 92. Percent survival of coho salmon alevins dewatered for 4, 8 and 16 hrs/day in mixed gravel through the hatching period.

6.5.4.3. Steelhead trout

The posthatching tests of steelhead alevins (Figs. 93, 94, 95 and 96) indicated survival occurred in alevins dewatered for 4 hrs/day in large (Fig. 93), medium (Fig. 94), and small (Fig. 95) gravel. Those exposed 8 hrs/day survived only in the large gravel (Fig. 93). The 16 hr/day exposure resulted in complete mortality in all gravel sizes except about 3 percent survival remained in the large gravel (Fig. 93). 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 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 33). 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.

These studies have shown that chinook, coho and steelhead alevins are capable of making rapid downward migrations 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

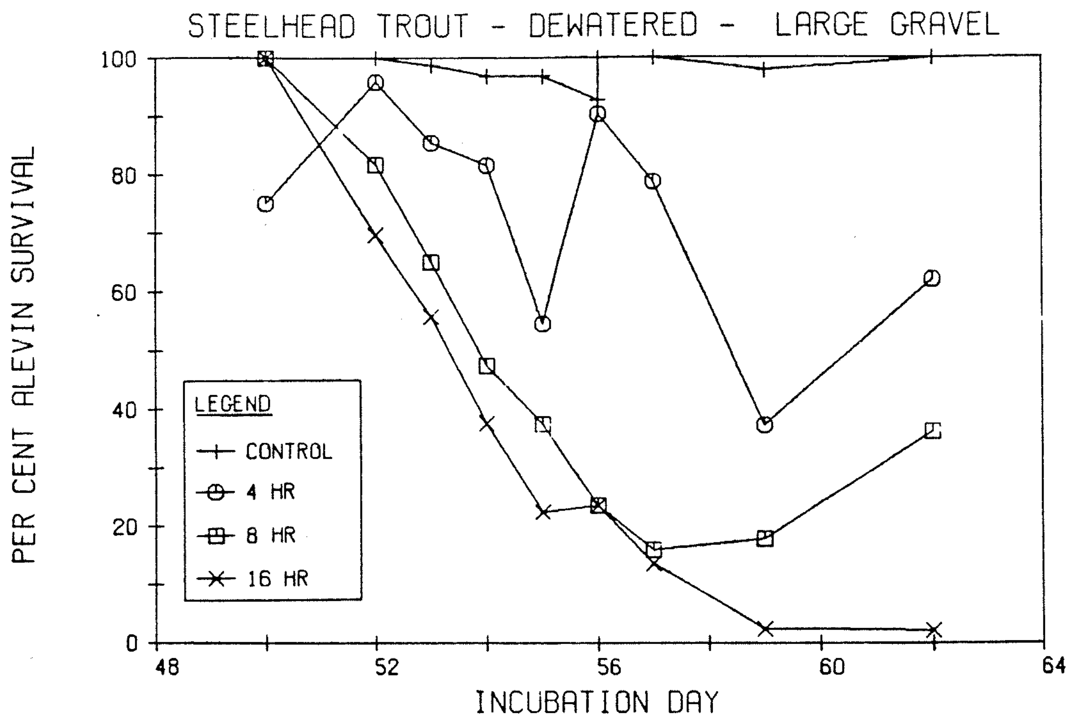

Fig. 93. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in large gravel through the hatching period.

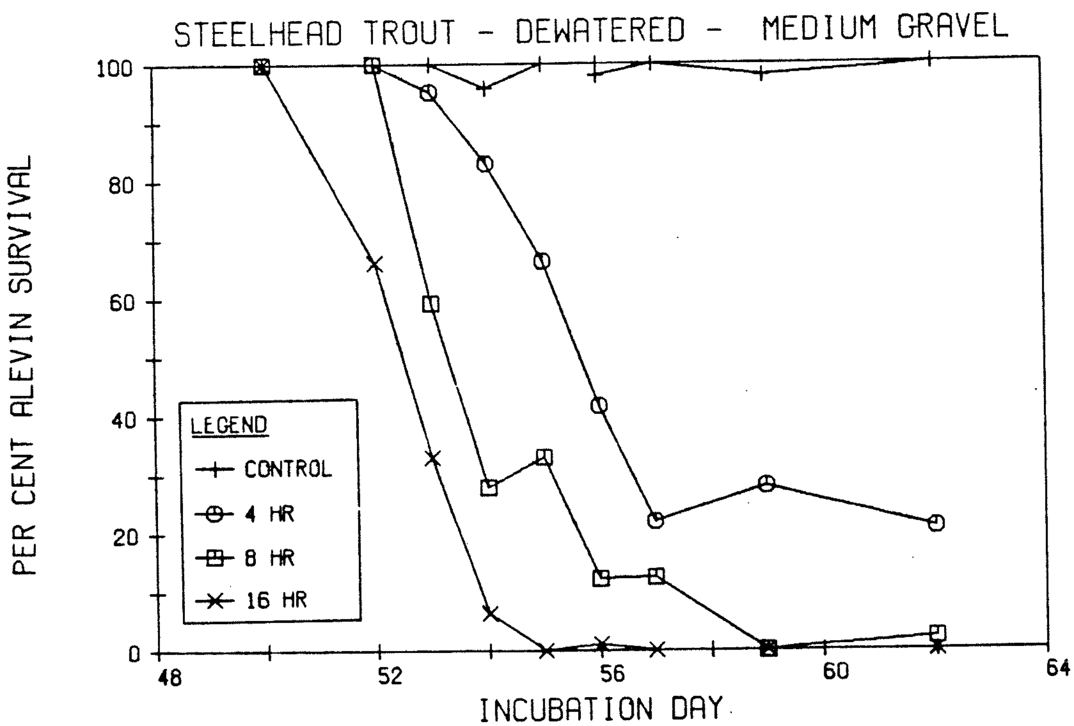

Fig. 94. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in medium gravel through the hatching period.

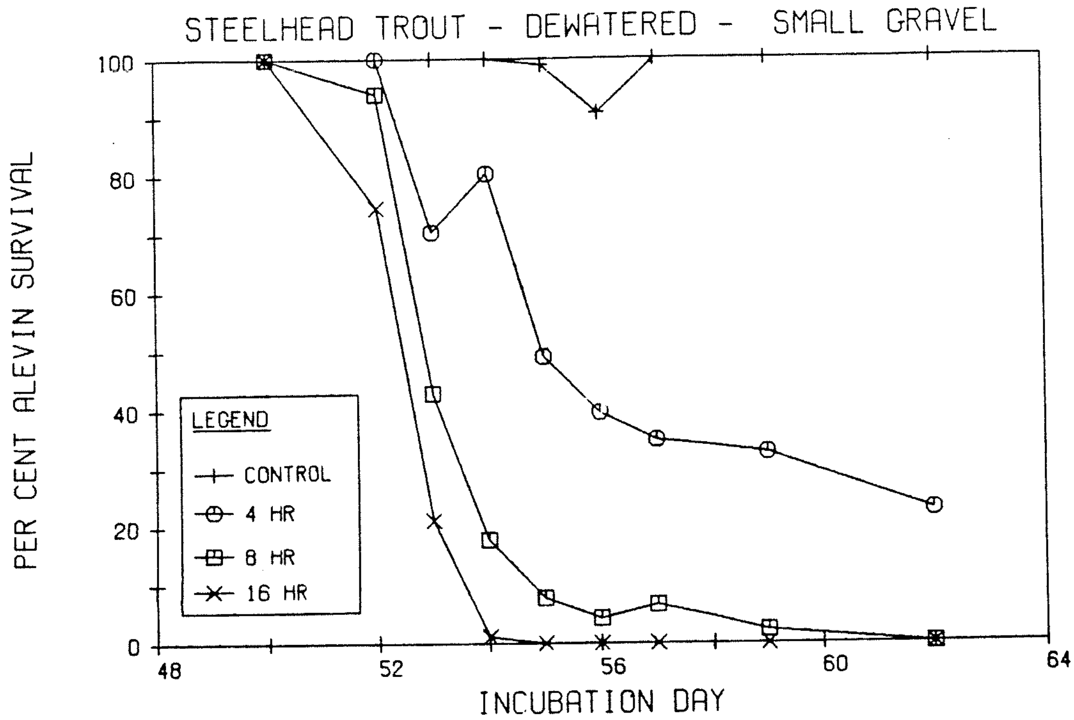

Fig. 95. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in small gravel through the hatching period.

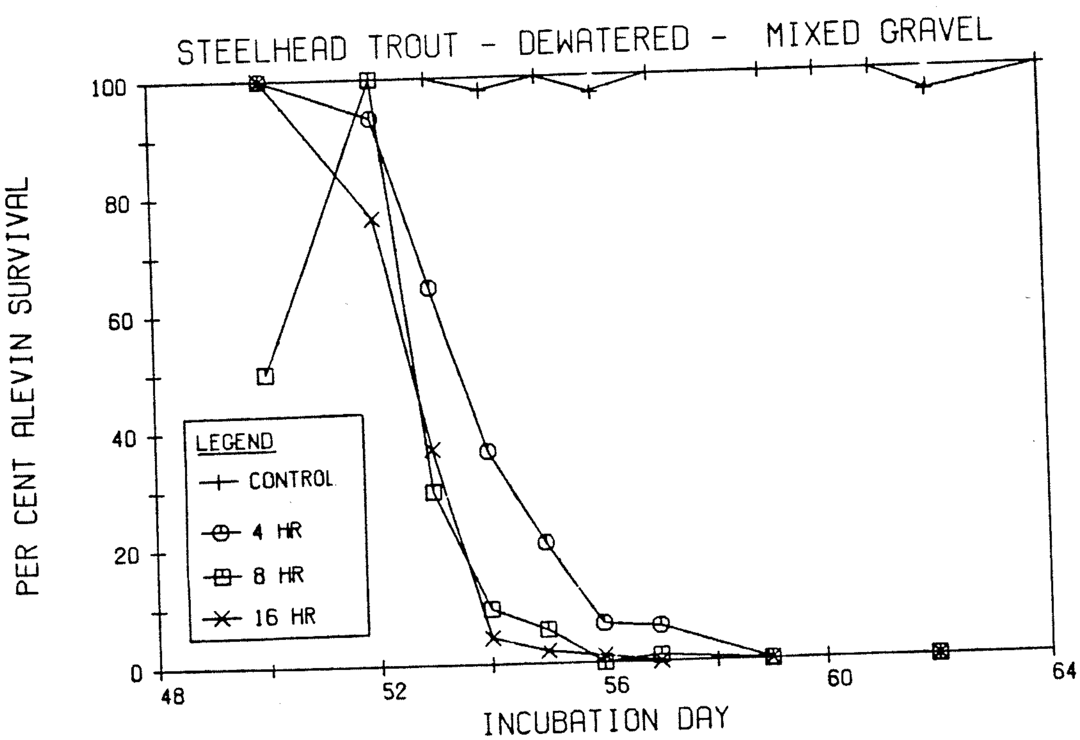

Fig. 96. Percent survival of steelhead trout alevins dewatered for 4, 8 and 16 hrs/day in mixed gravel through the hatching period.

Table 33. 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

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. 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.

Steelhead alevins demonstrated an increased ability to migrate as they progressed toward the emergence stage. 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).

6.6 Fry Stranding

6.6.1 Background

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.

6.6.2 Abundance of Fry

The abundance data and abundance indices for Thornton Creek, Marblemount and Rockport study sites are presented in Tables 34, 35 and 36, respectively. The abundance of fry varied significantly between study sites, study years and dates within sites and years. The Marblemount site consistently had the highest abundance of chinook fry. The Rockport site had the greatest abundance of pink and chum fry. The Thornton Creek site had the greatest abundance of coho fry and generally a slightly greater chinook fry abundance than the Rockport site. These site-specific variances in fry abundance are related to the spawning ground distribution of the adults and the dispersal characteristics of the fry.

Chronological examination of the fry abundance data particularly at the Marblemount site shows an increasing chinook fry population throughout the study period in 1980 and a relatively stable chinook fry population during the 1981 study period. This could be due to the greater length of the 1980 study period, 23 days vs. 8 days in 1981, or earlier emergence and actual greater population stability in 1981.

6.6.3 Stream Flow

The regulated flows which SCL provided for these studies were measured to Newhalem U.S.G.S. (12-1780). The daily maximum, minimum and mean discharge is plotted in Figs. 97 and 98 for March and April 1980 and in Fig. 99 for March 1981. The influence of tributary inflow is illustrated by comparing Figures 97, 98 and 99 with Figures 100, 101 and 102 which give the flows at Marblemount for the same period. The time required to accomplish the downramp, change in flow during the downramp, downramp rate, tributary inflow, and tributary inflow factor are all presented in Table 37.

The regulated flows provided a variety of downramp rates between 360 and 1,588 cfs per hour. During the latest two years of study the tributary inflow

Table 34. Data pertinent to the measurement of chinook fry stranding at the Thornton Creek study site.

Date	Chinook fry Abundance	Abundance factor [1/]	Pink fry Abundance	Chum fry Abundance	Coho fry Abundance	Chinook fry Stranded	Stranding Index	Pink fry Stranded	Chum fry Stranded
3/23/80	11	1.1	1	0	0	16	179	1	0
3/24/80	10	1.0	0	0	0	2	33	1	0
3/30/80	24	2.4	1	0	0	1	9	2	0
3/31/80	44	4.4	0	0	1	2	7	0	0
4/13/80	42	4.2	0	1	3	3	13	0	0
4/14/80	39	3.9	1	1	1	1	10	0	0
3/24/81	44	1.4	-	1	1	2	23	-	0
3/25/81	31	1.0	-	0	0	1	23	-	0
3/26/81	37	1.2	-	0	0	1	18	-	0
3/27/81	59	1.9	-	1	1	3	22	-	0
3/31/81	120	3.9	-	1	6	0	4	-	0

1/ Abundance factor computed independently for each year's data.

Table 35. Data pertinent to the measurement of chinook fry stranding at the Marblemount study site.

Date	Chinook fry Abundance	Abundance factor[1]	Pink fry Abundance	Chum fry Abundance	Coho fry Abundance	Chinook fry Stranded	Stranding Index	Pink fry Stranded	Chum fry Stranded
3/23/80	59	3.1	2	0	0	29	112	0	1
3/24/80	19	1.0	0	0	0	8	98	0	0
3/30/80	156	8.2	2	0	0	18	25	0	0
3/31/80	169	8.9	1	1	0	14	17	0	0
4/13/80	163	8.6	2	2	4	0	2	0	0
4/14/80	287	15.1	1	8	2	0	1	0	0
3/24/81	217	3.1	-	1	0	7	28	-	0
3/25/81	109	1.6	-	0	0	0	7	-	1
3/26/81	69	1.0	-	1	0	26	289	-	0
3/27/81	122	1.8	-	0	0	2	18	-	0
3/31/81	162	2.3	-	0	0	5	40	-	0
3/17/73[2]	291	1.0	-	-	-	16	112	-	-

[1] Abundance factor computed independently for each year's data.

[2] Data from (Phinney, 1974)

Table 36. Data pertinent to the measurement of chinook fry stranding at the Rockport study site.

Date	Chinook fry Abundance	Abundance[1] factor	Pink fry Abundance	Chum fry Abundance	Coho fry Abundance	Chinook fry Stranded	Stranding Index	Pink fry Stranded	Chum fry Stranded
3/23/80	15	2.1	4	0	0	17	99	1	0
3/24/80	7	1.0	0	0	0	18	207	5	0
3/30/80	9	1.3	0	0	0	3	33	2	2
3/31/80	9	1.3	0	1	0	9	77	8	2
4/13/80	13	1.9	17	6	0	3	28	2	5
4/14/80	7	1.0	10	6	0	4	98	2	0
3/24/81	71	4.7	-	7	0	73	170	-	6
3/25/81	28	1.9	-	3	0	20	125	-	1
3/26/81	19	1.3	-	1	0	39	329	-	10
3/27/81	15	1.0	-	1	0	11	128	-	4
3/31/81	63	4.2	-	2	3	5	22	-	1
3/17/73[2]	239	1.0	-	-	-	28	191	-	-

[1] Abundance factor computed independently for each year's data.

[2] Data from (Phinney, 1974).

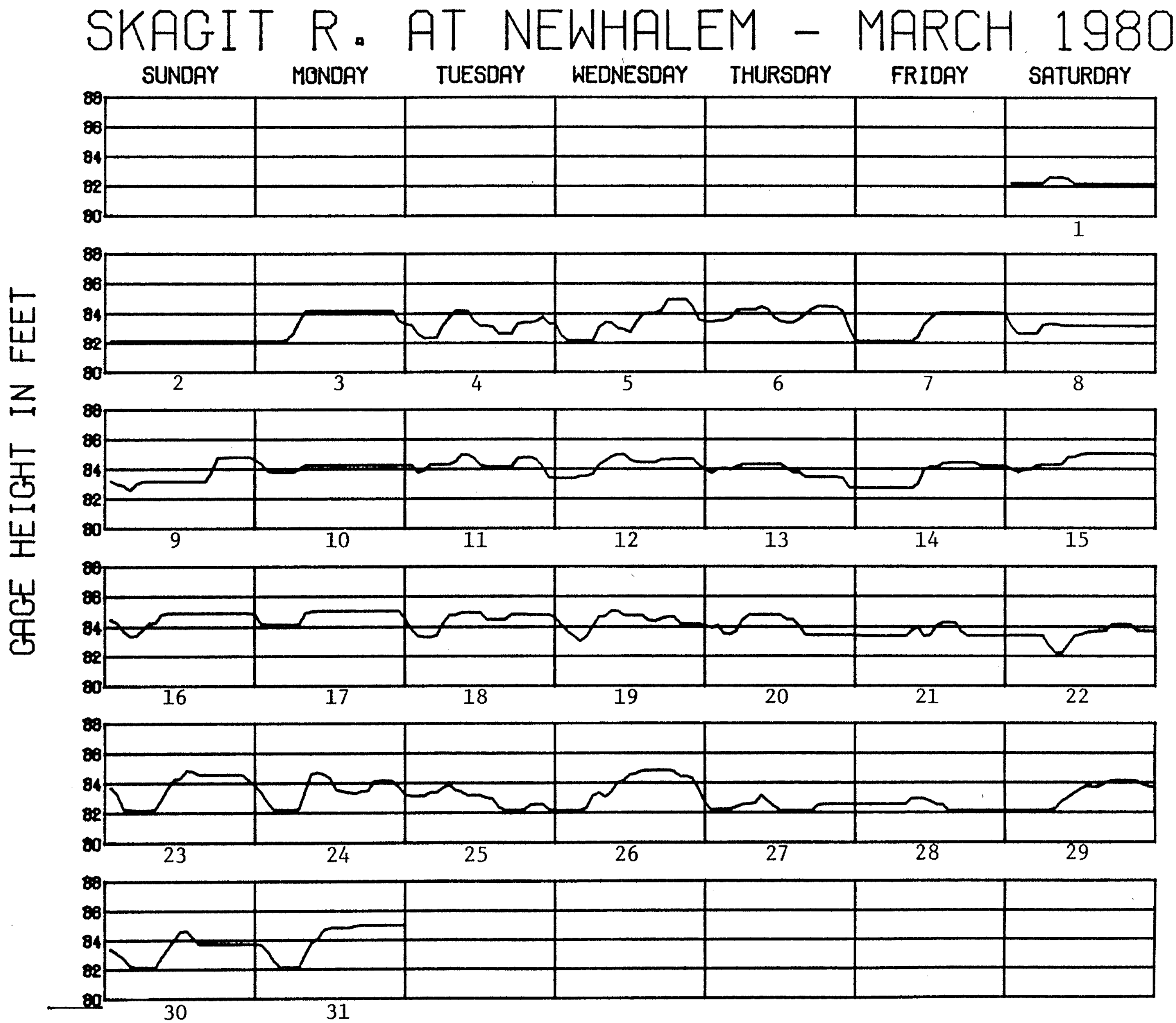

Figure 97. Hourly gage height data for Skagit River at Newhalem (USGS), March 1980.

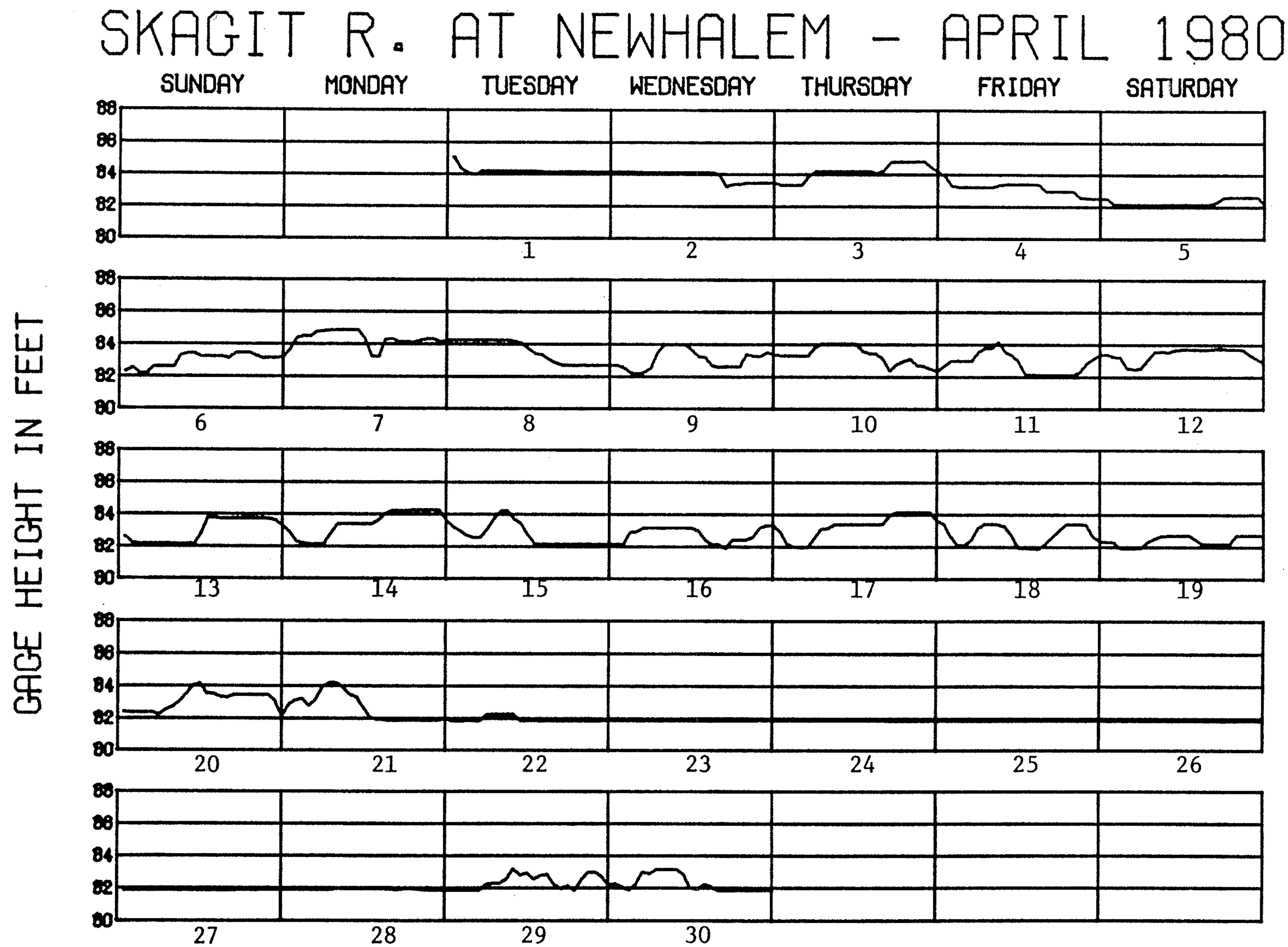

Figure 98. Hourly gage height data for Skagit River at Newhalem (USGS), April 1980.

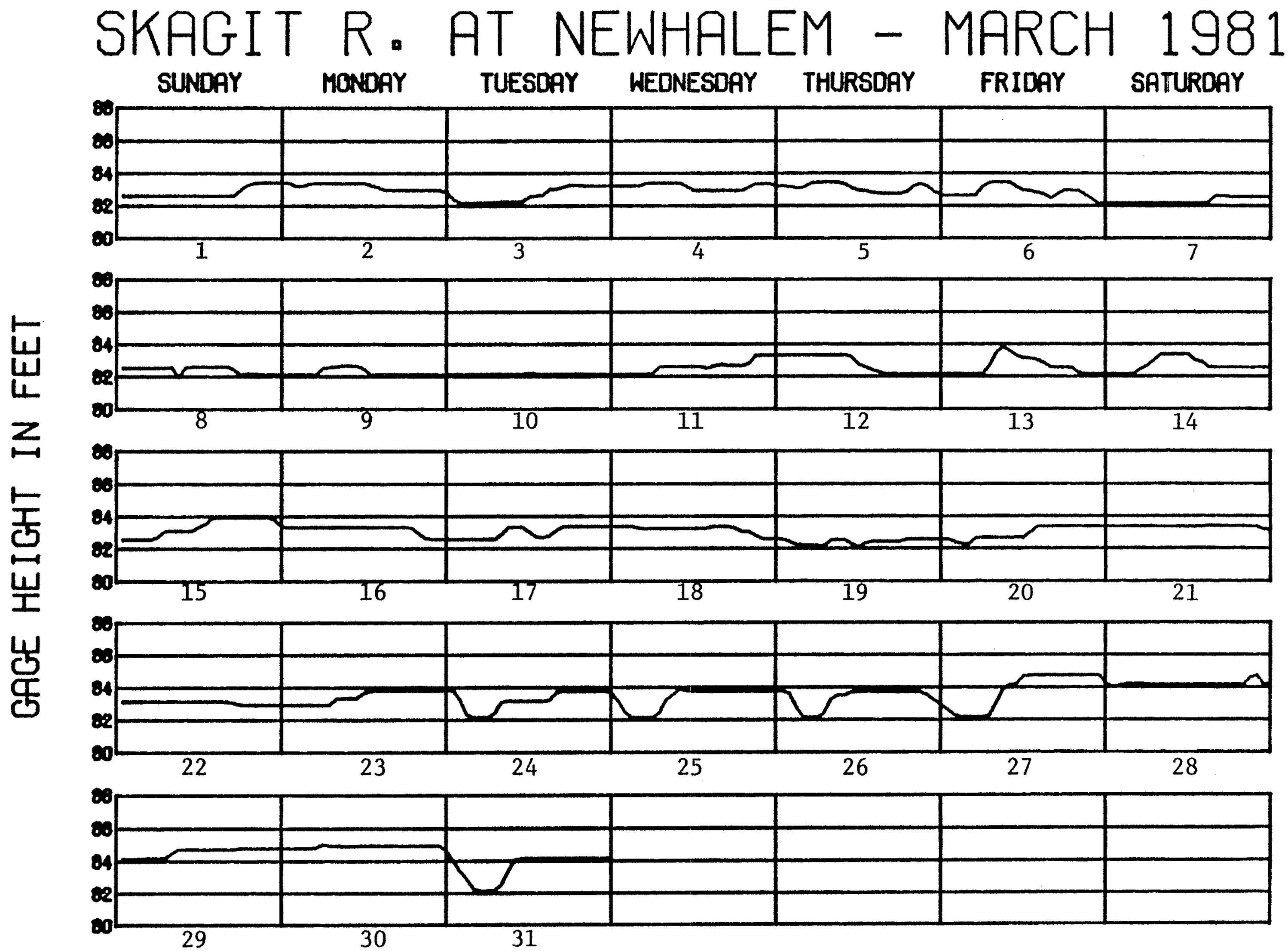

Figure 99. Hourly gage height data for Skagit River at Newhalem (USGS), March 1981.

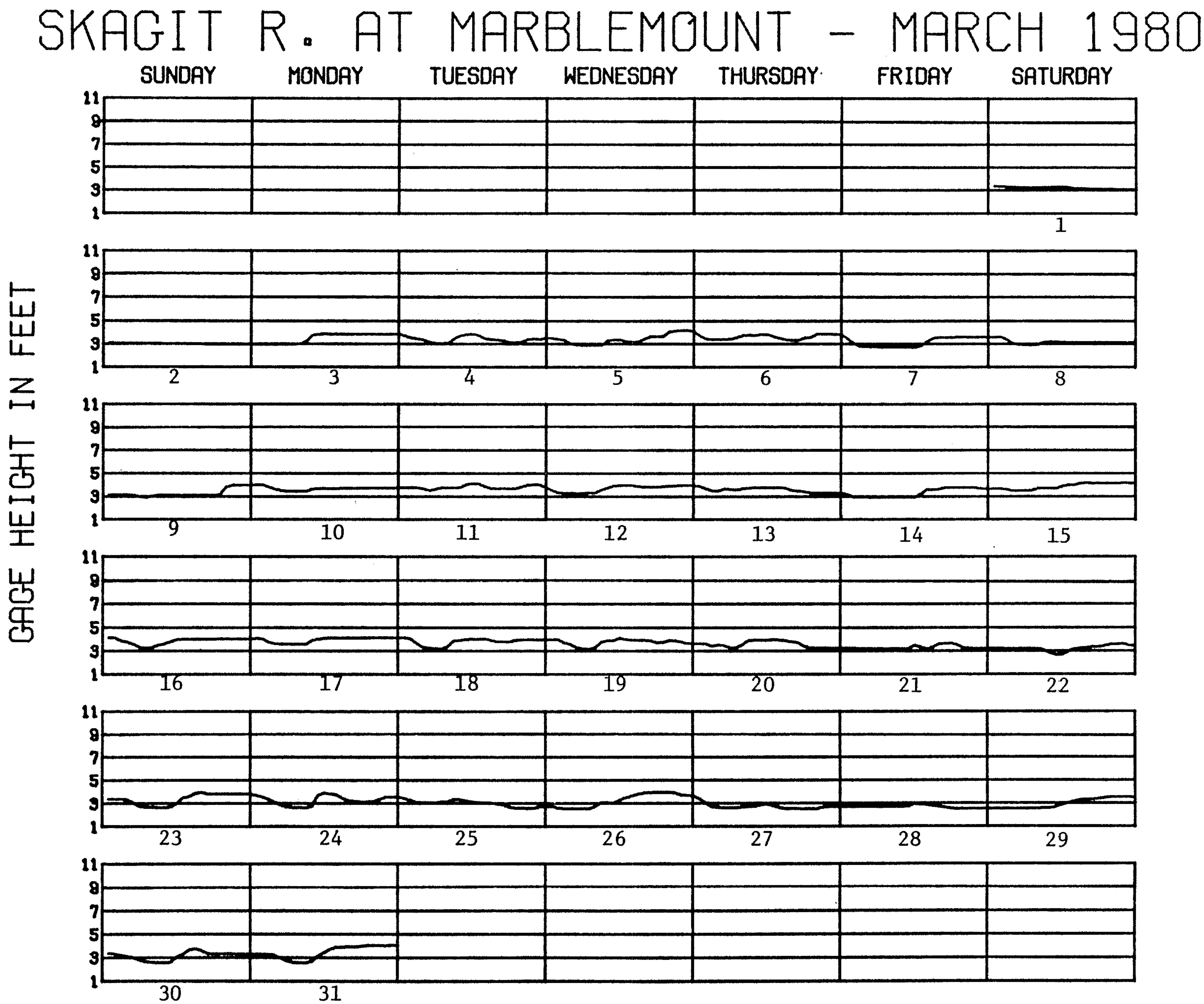

Figure 100. Hourly gage height data for Skagit River at Marblemount (USGS), March 1980.

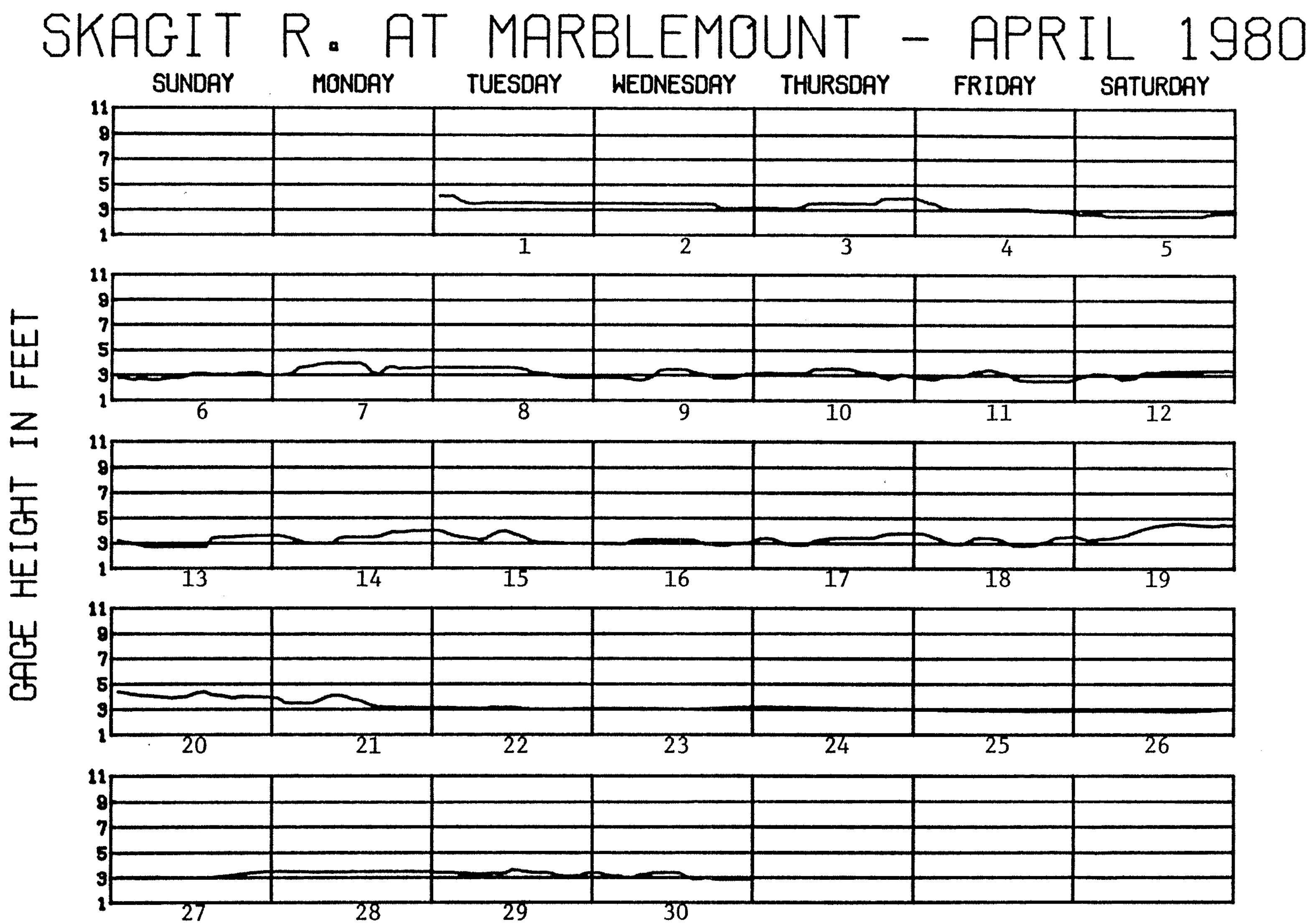

Figure 101. Hourly gage height data for Skagit River at Marblemount (USGS), April 1980.

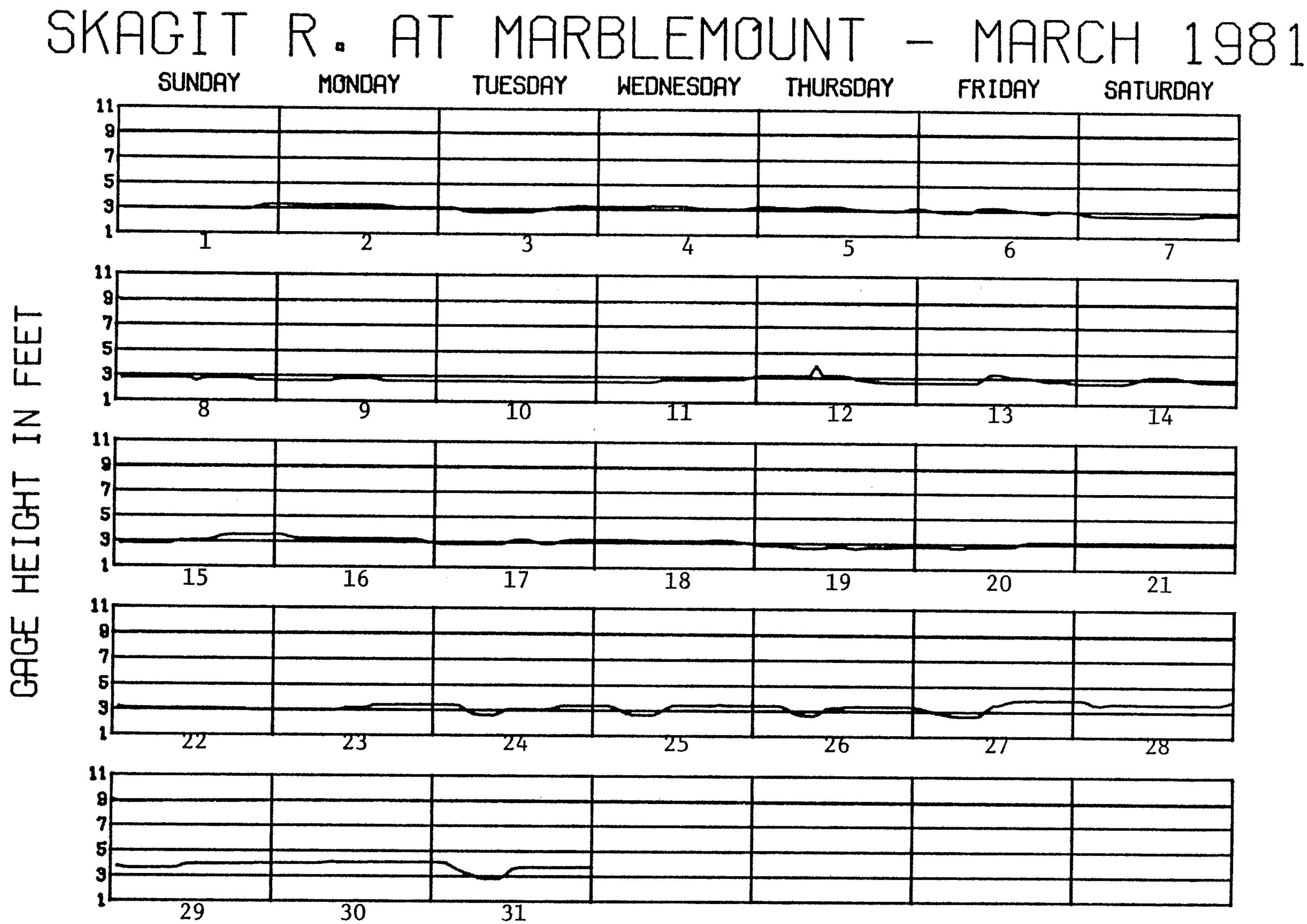

Figure 102. Hourly gage height data for Skagit River at Marblemount (USGS), March 1981.

Table 37. Streamflow data during downramping studies.

Date	Time of downramping (hrs)	Inflow Newhalem to Marblemount (cfs)	Ramp rate (cfs/hr)	Tributary inflow (cfs)	Inflow factor
3/23/80	1.5	2182	1454	1164	1.16
3/24/80	4.3	2613	603	1092	1.09
3/30/80	6.3	2233	357	1066	1.07
3/31/80	2.5	2210	870	997	1.00
4/13/80	5.0	2182	436	1320	1.32
4/14/80	3.1	2199	714	1973	1.97
3/24/81	1.5	2353	1569	1077	1.08
3/25/81	2.5	2090	836	1138	1.14
3/26/81	1.4	2233	1588	1066	1.07
3/27/81	5.2	2172	418	1066	1.07
3/21/81	4.6	4625	Var[1]	1523	1.52
3/17/73[2]	1.6	3120	1950	657	0.66

[1] Variable downramp rate per exhibit C of settlement agreement.

[2] Data from Phinney (1974).

was more highly variable in 1980 than in 1981. During the 1973 test done by Phinney the tributary inflow was about one-half that experienced in 1980 and 1981. This is reflected in the minimum flows reached 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). The 1980 and 1981 flows are the average minimum achieved for all tests each year.

6.6.4 Index of Stranding

The computed stranding indices for the Thornton Creek, Marblemount and Rockport study sites are presented in Tables 34, 35 and 36, respectively. There is considerable variance in stranding indices both within and between sites. The stranding index relates only to chinook fry.

6.6.5 Downramp Rate vs. Stranding

The graphical displays comparing downramp rates and fry stranding indices for the observed and ln transformed data are presented in Figures 103 through 108. The degree of standing at all ramp rates tended to increase from one site to the next moving downstream, i.e. the Thornton Creek site generally had the least stranding and the Rockport site generally had the greatest stranding.

This site-specific trend in stranding is apparently not associated with chinook 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.

At each site there is a general trend of increasing stranding with increasing downramp rate. This relationship was examined utilizing linear regression on the base data and with a log e- log e transformation of the base

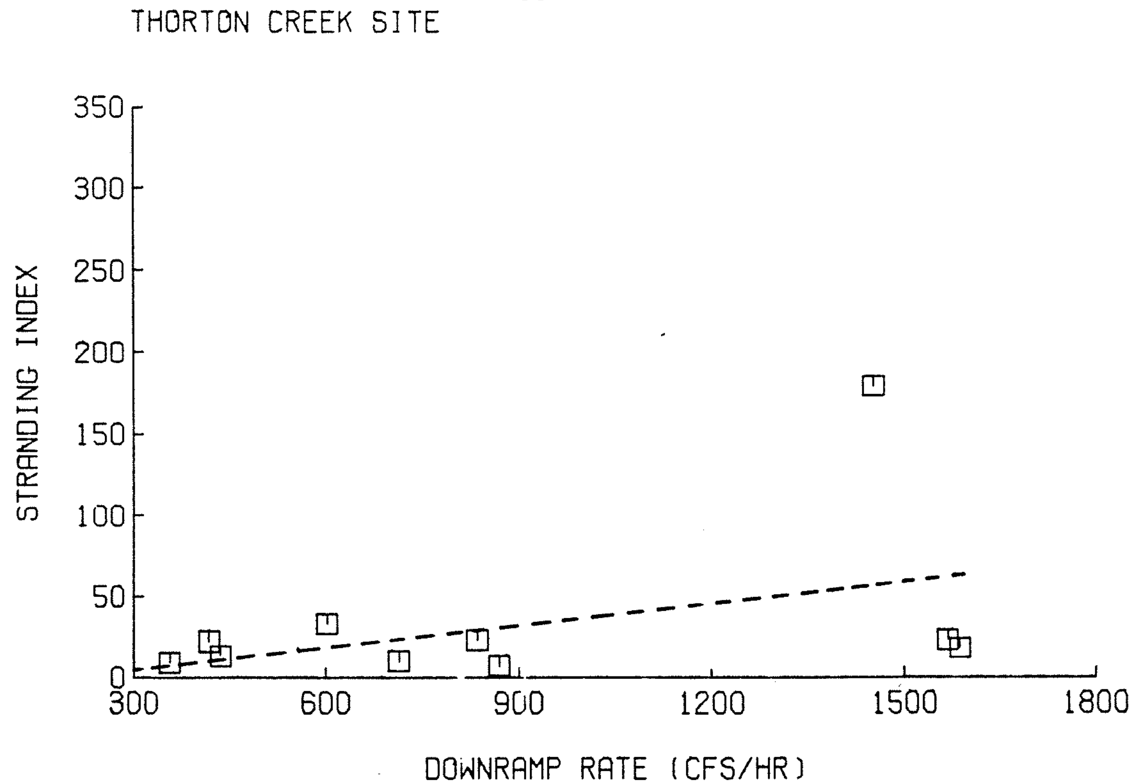

Fig. 103. Downramp rate vs stranding index for the Thornton Creek study site, 1980 and 1981 data combined.

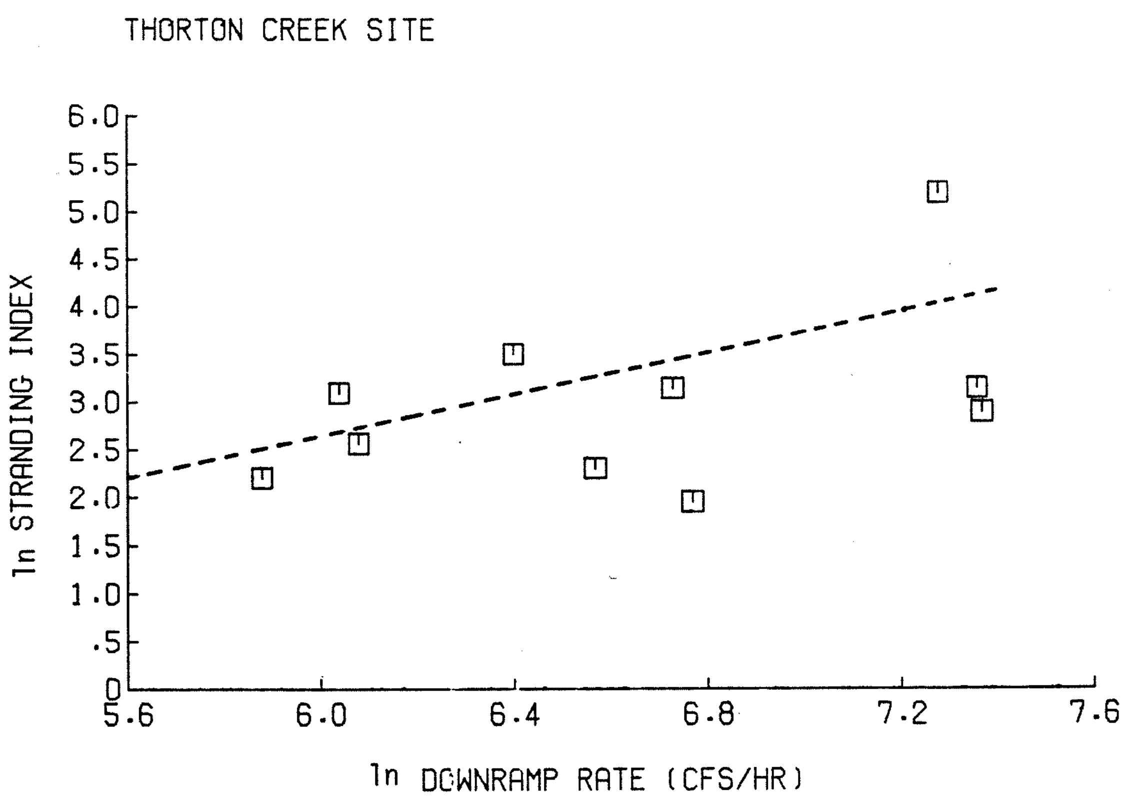

Fig. 104. Downramp rate vs stranding index, transformed data, for the Thornton Creek study site, 1980 and 1981 data combined.

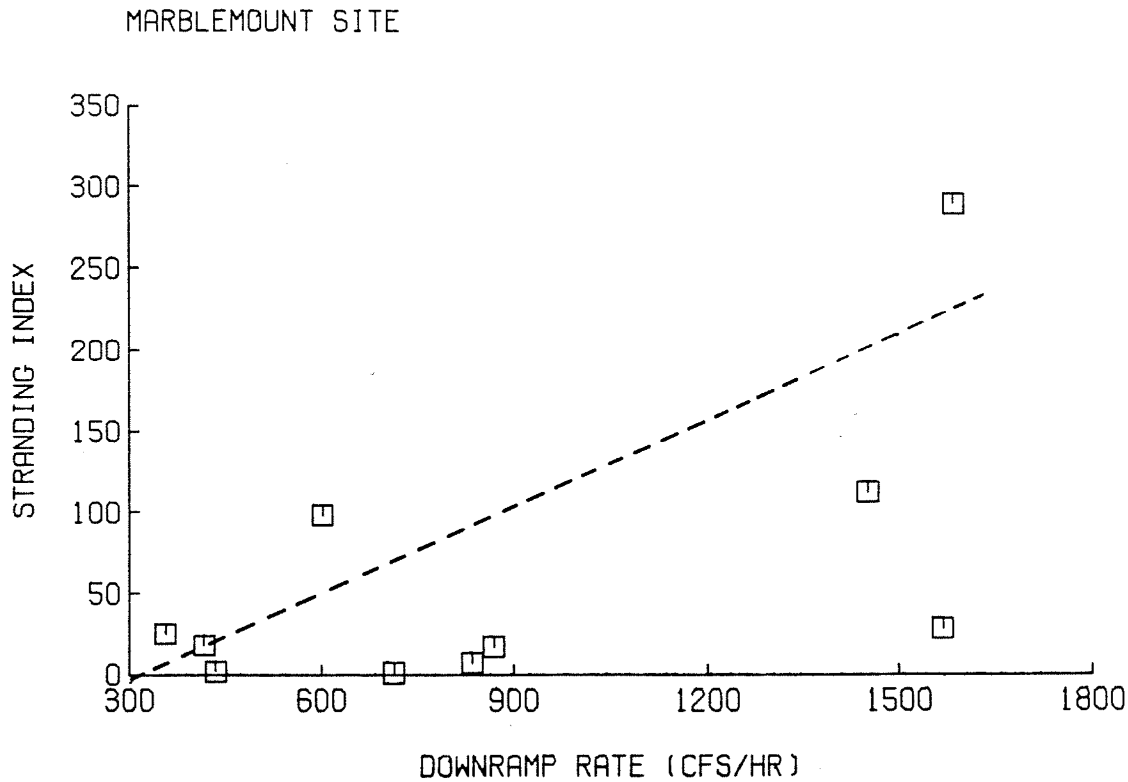

Fig. 105. Downramp rate vs stranding index for the Marblemount study site, 1980 and 1981 data combined.

Fig. 106. Downramp rate vs stranding index, transformed data, for the Marblemount study site, 1980 and 1981 data combined.

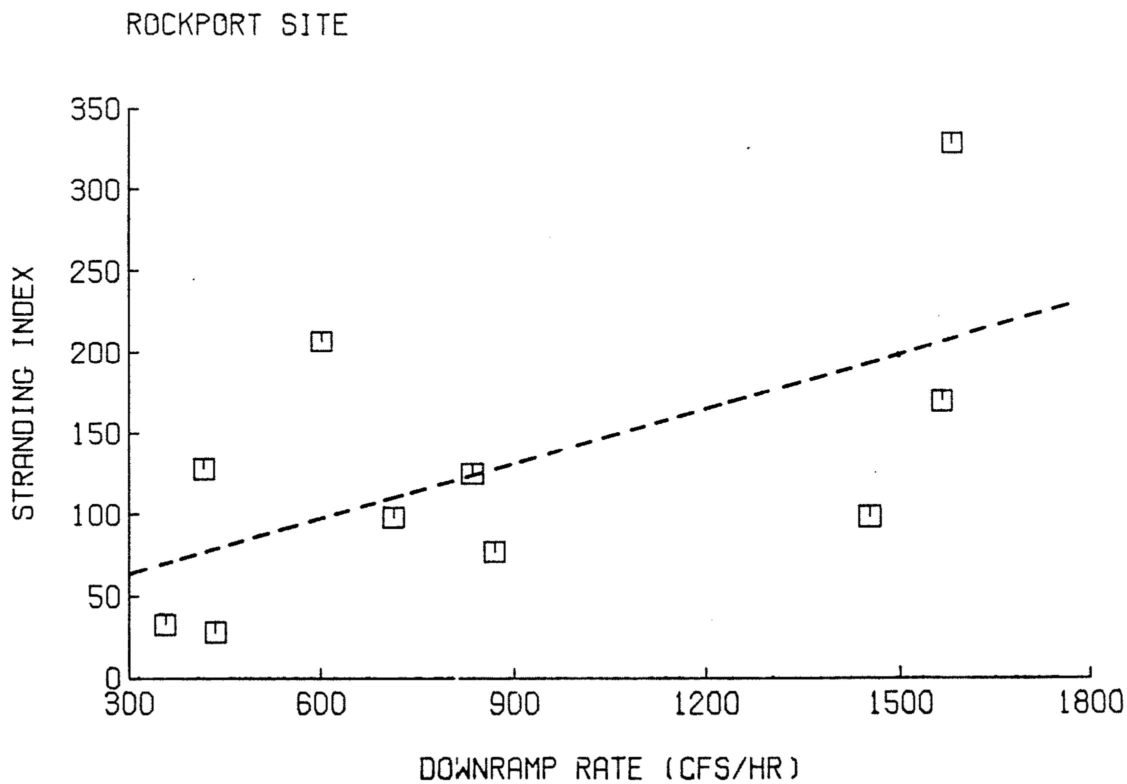

Fig. 107. Downramp rate vs stranding index for the Rockport study site, 1980 and 1981 data combined.

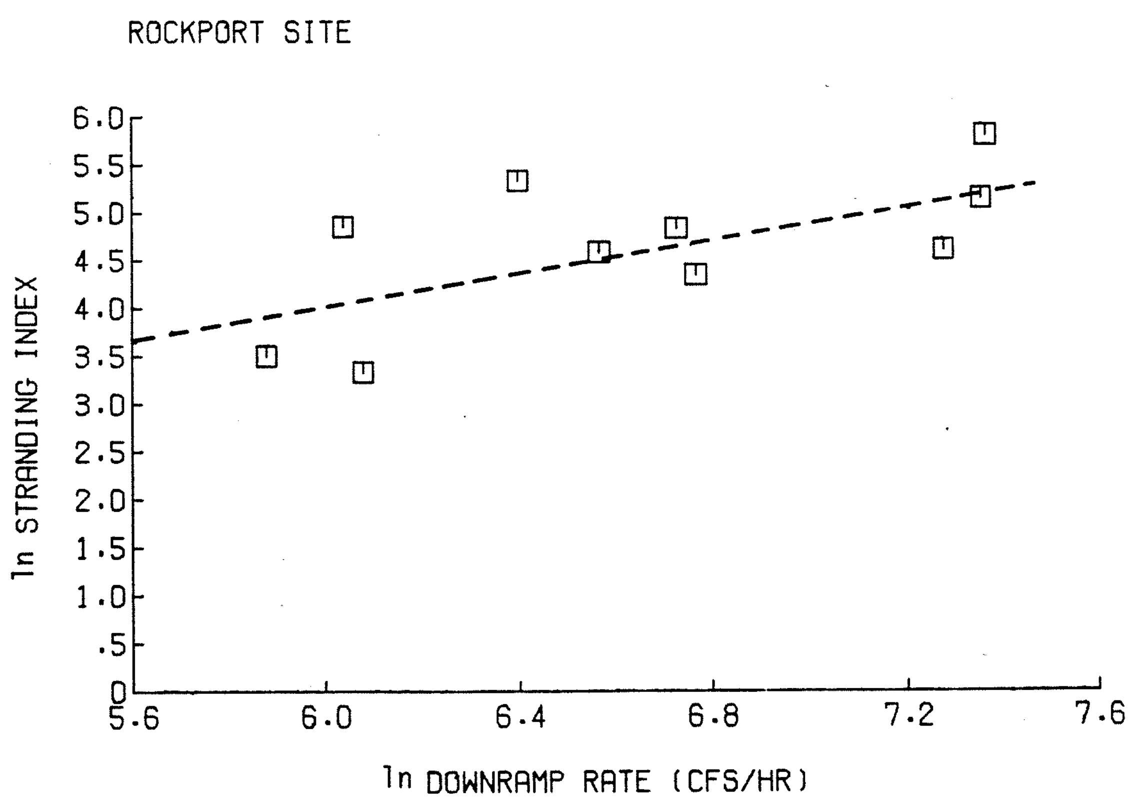

Fig. 108. Downramp rate vs stranding index, transformed data, for the Rockport study site, 1980 and 1981 data combined.

data. The log e - log e transformation was to evaluate whether an exponential model fit the data better than the linear model. The statistics for these regression analyses are presented in Appendix II.

The regression analyses indicate that except for the Marblemount site the exponential model provides a better mathematical description of the relationship between fry stranding and downramp rates. However, as indicated by the R-squared values, neither the linear nor the exponential models indicate that the majority of the variation in stranding rates is accounted for by variation in downramp rates. There are many possible explanations for this poor correlation including faulty assumptions or techniques in calculating stranding indices, coarseness in technique of measuring fry abundance and actual stranding, and the possibility of too narrow a range of observed rates to develop an adequate data base. These factors will be given further consideration when planning next season's field work and when conducting the data analysis for the final report.

7.0 SUMMARY AND CONCLUSIONS

7.1 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 1978-1980 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 1980-1981 spawning periods were the first for which escapement estimates were available, so comparison with previous years was not possible. Escapement for the mainstem Skagit for these years ranged from 913 to 1,897. The section of the Skagit mainstem most heavily spawned extended from the Cascade River to the Sauk River.

7.2 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.

7.3 Steelhead Temperature Unit Requirement

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

7.4 Instream Incubation Tests

Chum salmon eggs enclosed in either freezer container 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.

7.5 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 4 x 4 factorial design was employed with 4 dewatered or static conditions (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. 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.

7.6 Fry Stranding

The relationship between ramping rates ranging from 357 to 1588 cfs/hr and fry stranding mortality was investigated at three sites along the Skagit. A relationship appeared to exist; however, there was significant variance associated with the data. Following regression analysis neither a linear nor an exponential model indicated that the majority of the variation in stranding rates was accounted for by variation in the downramp rate.

8.0 RECOMMENDATIONS

Minimization of the adverse effects of Skagit flow fluctuations on the salmonid resource could be accomplished by the development and use of a habitat model that lessens perturbations on critical habitat requirements for the various freshwater life stages. Such a model would be a function of adult spawning, egg and alevin incubation, and fry rearing for each salmonid species utilizing the river. Modifications or additions to the present data base may be necessary for conceptualization of a quantitative habitat model. The extensive information available needs review, additional analysis, or further interpretation in order to begin model development. Although it may be necessary to develop some additional basic data, emphasis should be placed on synthesis of existing data.

8.1 Adult Spawning

8.1.1 Discharge-to-Stage Relationship by River Section

The relationship between discharge at Gorge Dam and the stage height at points downstream is a function of tributary inflow and channel configuration at each reach: the greater the tributary inflow and the wider the channel, the less the stage will be affected by discharge fluctuations. With tributary inflow and channel configuration factors for five river sections between the major points of inflow, the discharge-stage relationship can be described. These data do not exist and will be needed if a finely tuned habitat model is desired.

8.1.2 Spawning Distribution and Timing for Each Species and River Section

The spawning distribution for each species is required to establish the degree to which the percentage of the spawning population using each river section is affected by flow fluctuations. Timing of spawning is required on a section basis for similar reasons. Boat and aerial surveys by WDF and WDG have provided these data in the past and should continue to do so in the future.

8.1.3 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.

8.2 Egg and Alevin Incubation

8.2.1 Redd Depth Frequency Distribution

The distribution of spawning depths in each section of the river is needed to define the egg and alevin habitat for each species. The depth distributions need to be referenced to a section stage and mean flow during the spawning season for each species. If, for example, the mean discharge during chinook salmon spawning was 4500 cfs, it would correspond to a gage height of $\simeq$ 3.0 ft. If 10 percent of chinook redds were measured at a depth of 1.0 ft or less and the flow decreased below 2200 cfs or gage height of 2.0 ft, one would say 10 percent of the habitat was affected (discounting egg depth within a redd). Redd depth distribution data are available from previous FRI reports but need to be referenced to river section stages.

8.2.2 Hatching and Emergence Timing for Each Species and River Section

The data obtained from 8.1.1, 8.1.2 and 8.2.1 combined with temperature unit data allow estimation of hatching and emergence periods for each species.

8.2.3 Incubation Habitat Loss

As indicated in 8.2.1 the percentage of habitat affected (redds dewatered) for any given flow reduction can be determined. The extent of loss, however, is dependent on the duration of dewatering and the developmental stage of the incubating embryos. These data inputs are currently being developed in laboratory experiments.

8.3 Fry Stranding

A reduction in the variance associated with these studies may be attained by reevaluation of the data and methodology. In the current methodology, two factors that are thought to influence the number of fry stranded at a given downramp, the abundance estimates and tributary inflow, are used in computing stranding indices. Both of these factors, while necessary, may be introducing significant variance into the data. It has been assumed that fry abundance estimates on the day prior to a test are or represent a portion of the population subjected to a downramp the following day. However, data on the variability of these estimates on a daily or hourly basis are lacking. The residency time of individual fish and variability of abundance estimates may be elucidated by an intensive localized mark-recapture and electrofishing effort for the period several days before a given test.

The second factor, tributary inflow, was assumed to be indirectly related to number of fry stranded. For example, if the tributary inflow had doubled from one test to the next with all other factors being equal, the number of stranded fry would be halved. It is unlikely that this is the case. The influence of tributary inflow might better be determined by establishing a stage at each of the sites and record the drop in stage height/unit time during each test. With this procedure, one would be recording what the fish is actually experiencing. For instance, a high ramping during a period of high tributary inflow could effect the same change in stage height as a low ramping rate and low tributary inflow.

It is also recommended that the effects of consecutive-day testing vs a hiatus of 1, 2, or 3 days between tests be examined. Additional observations are needed at downramp rate extremes and with the variable ramp rate to increase the sample size as rapidly as possible.

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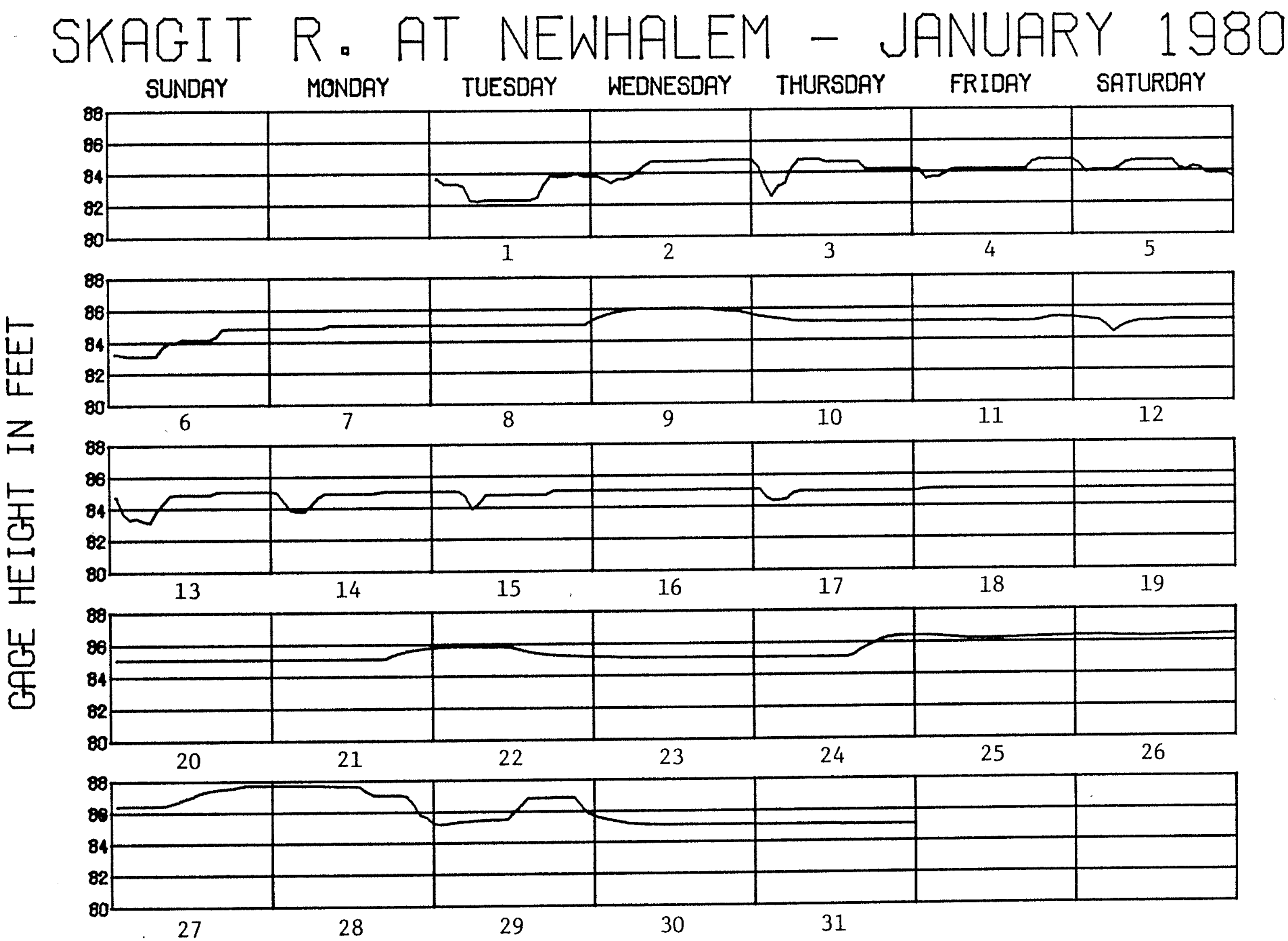
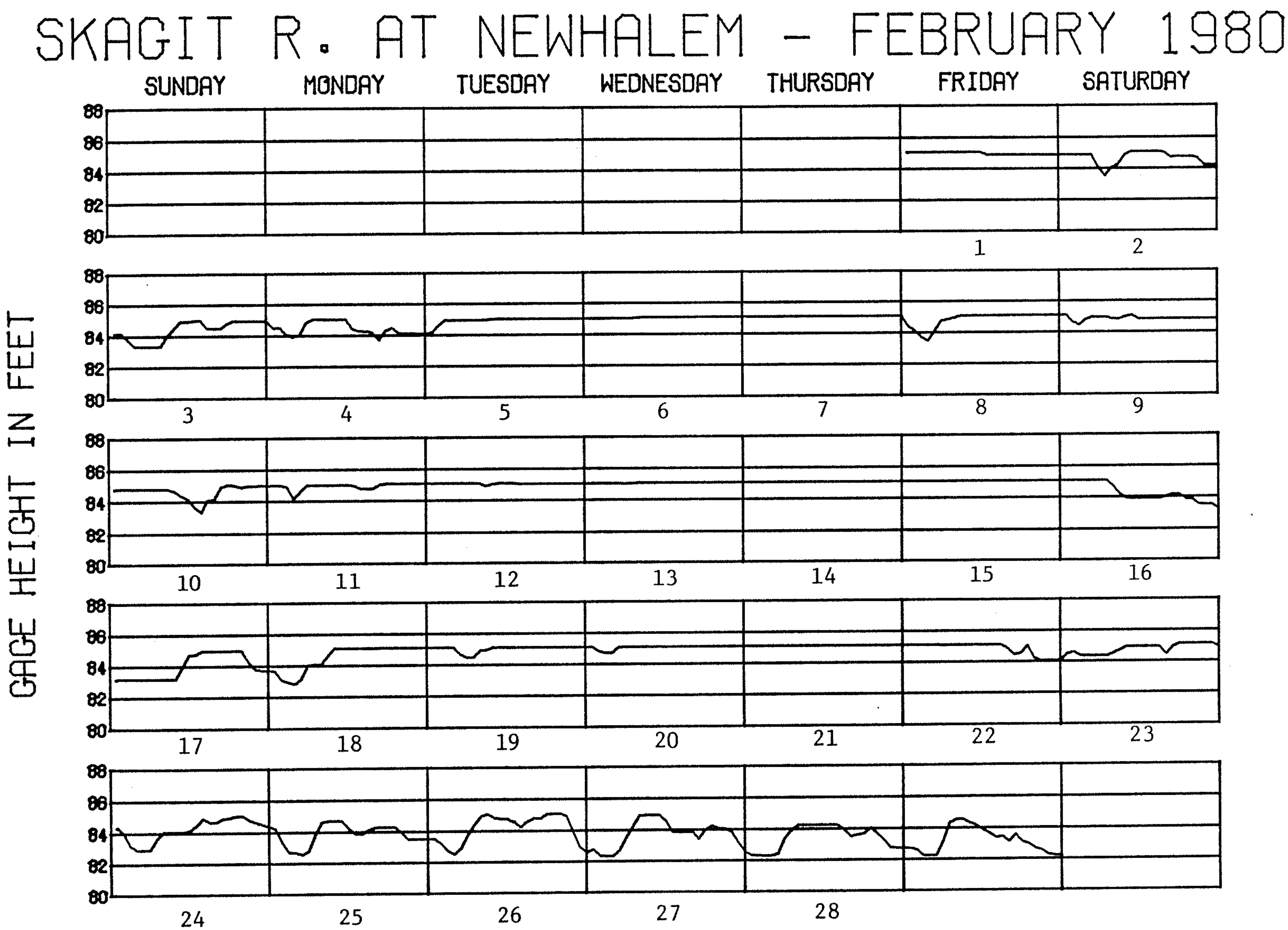
10.0 APPENDICES



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



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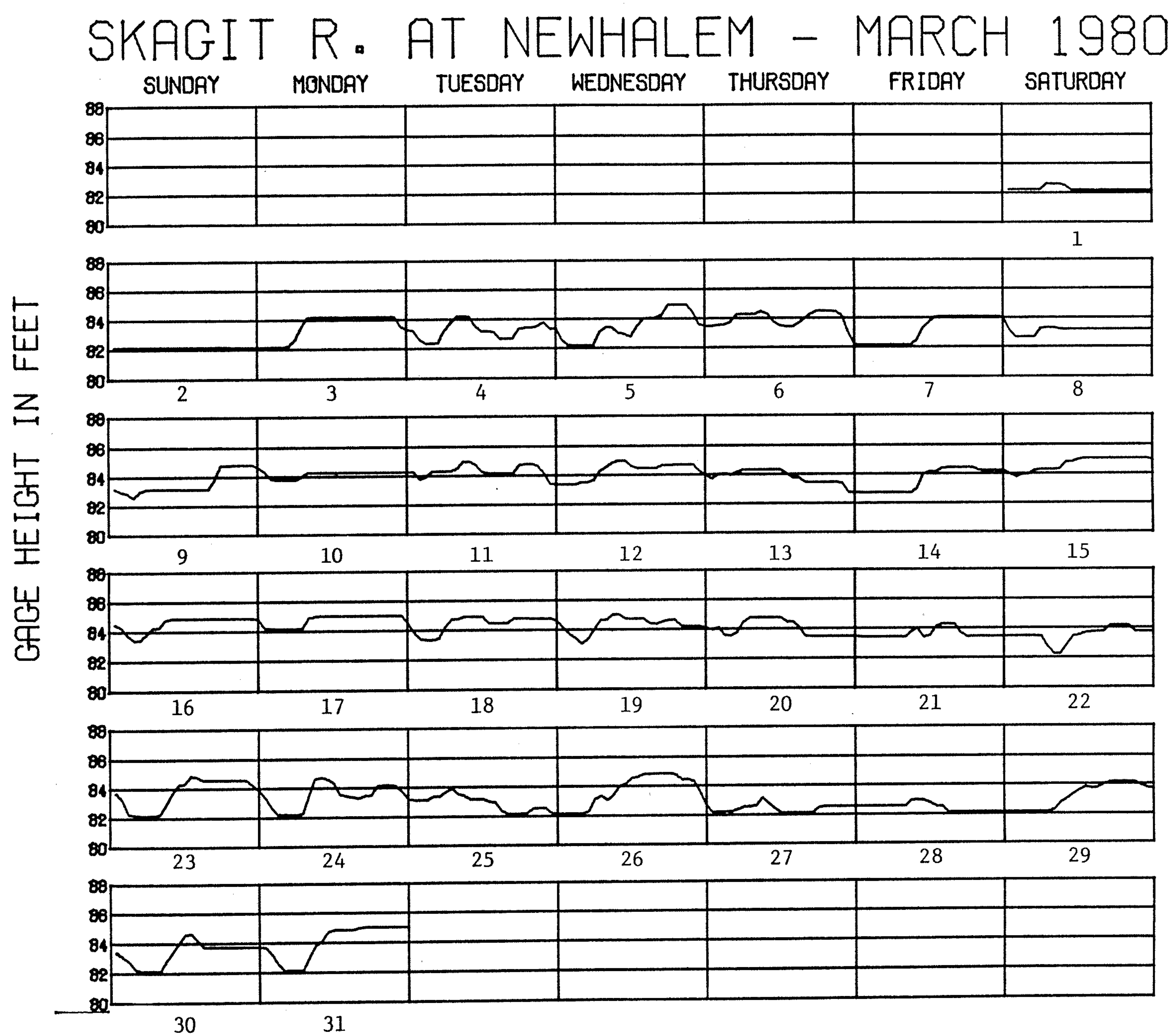

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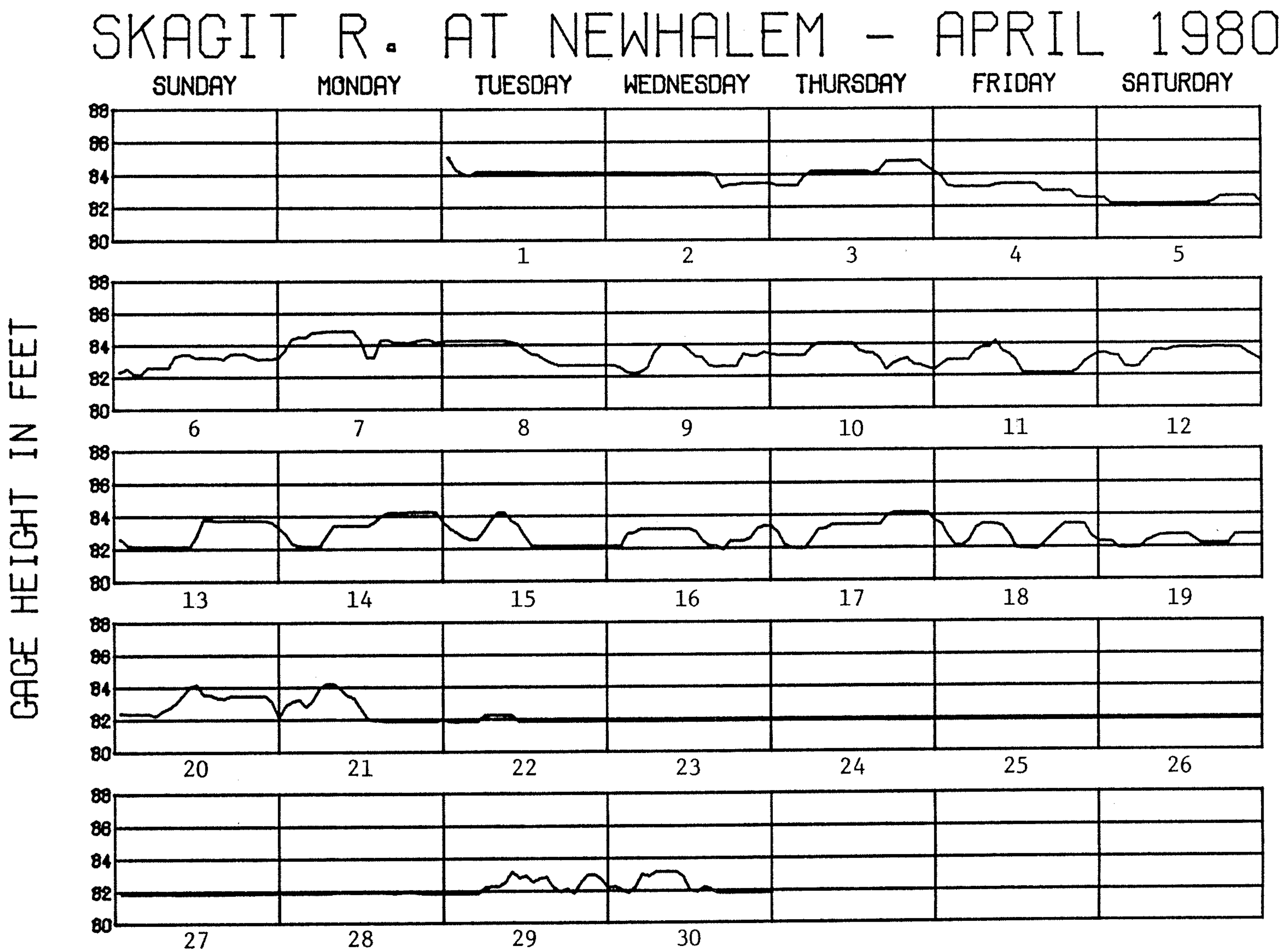

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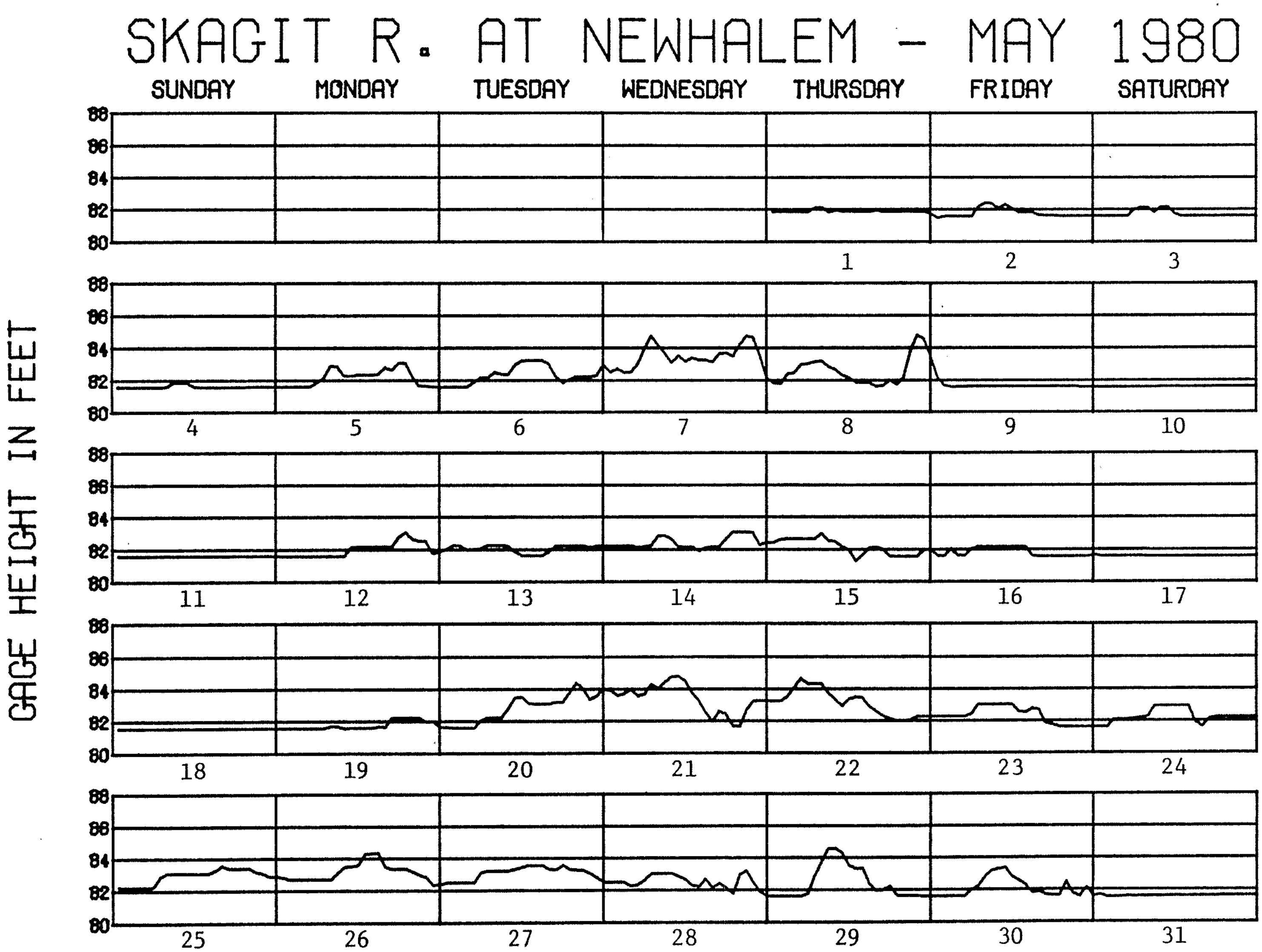

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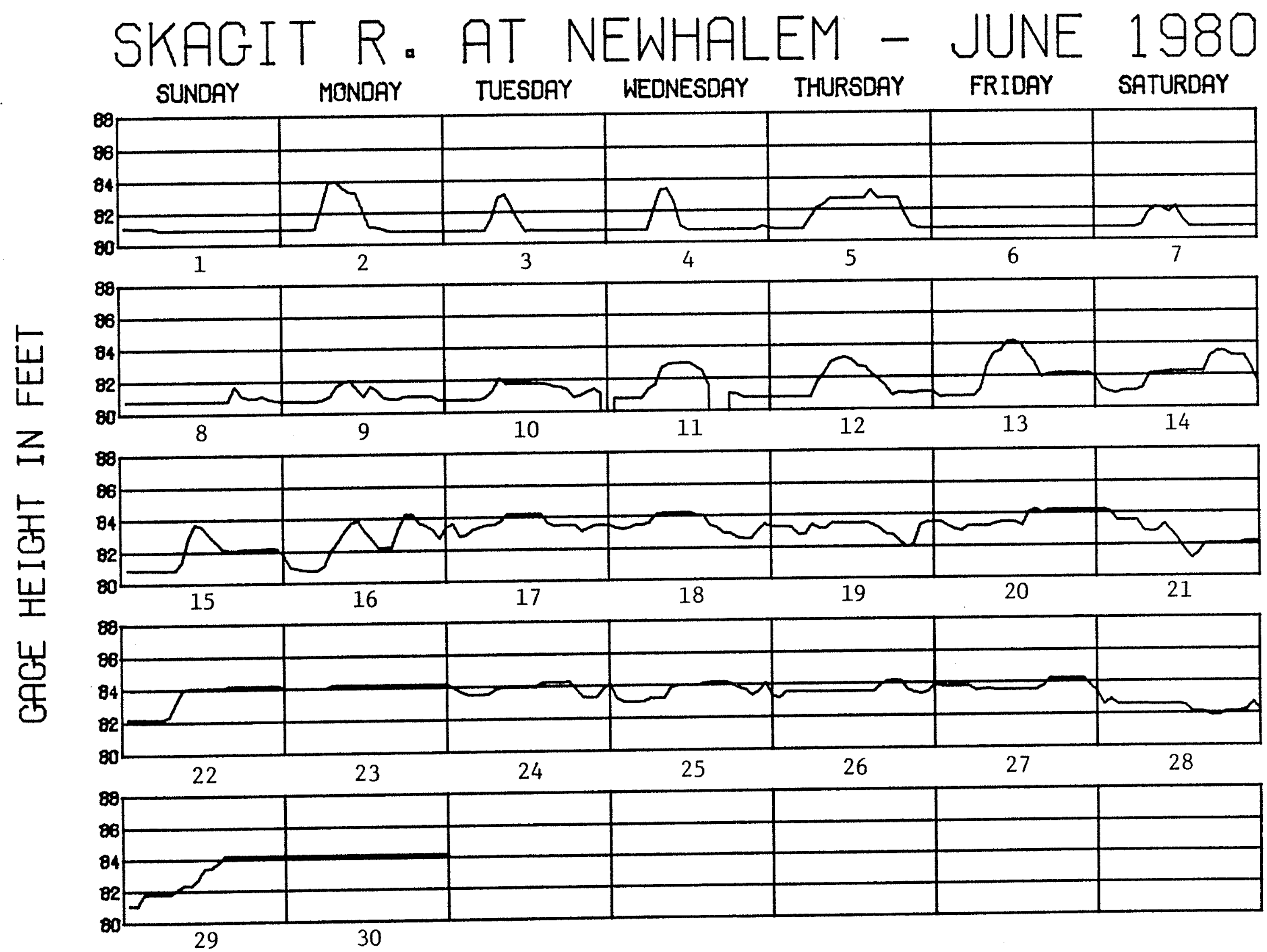

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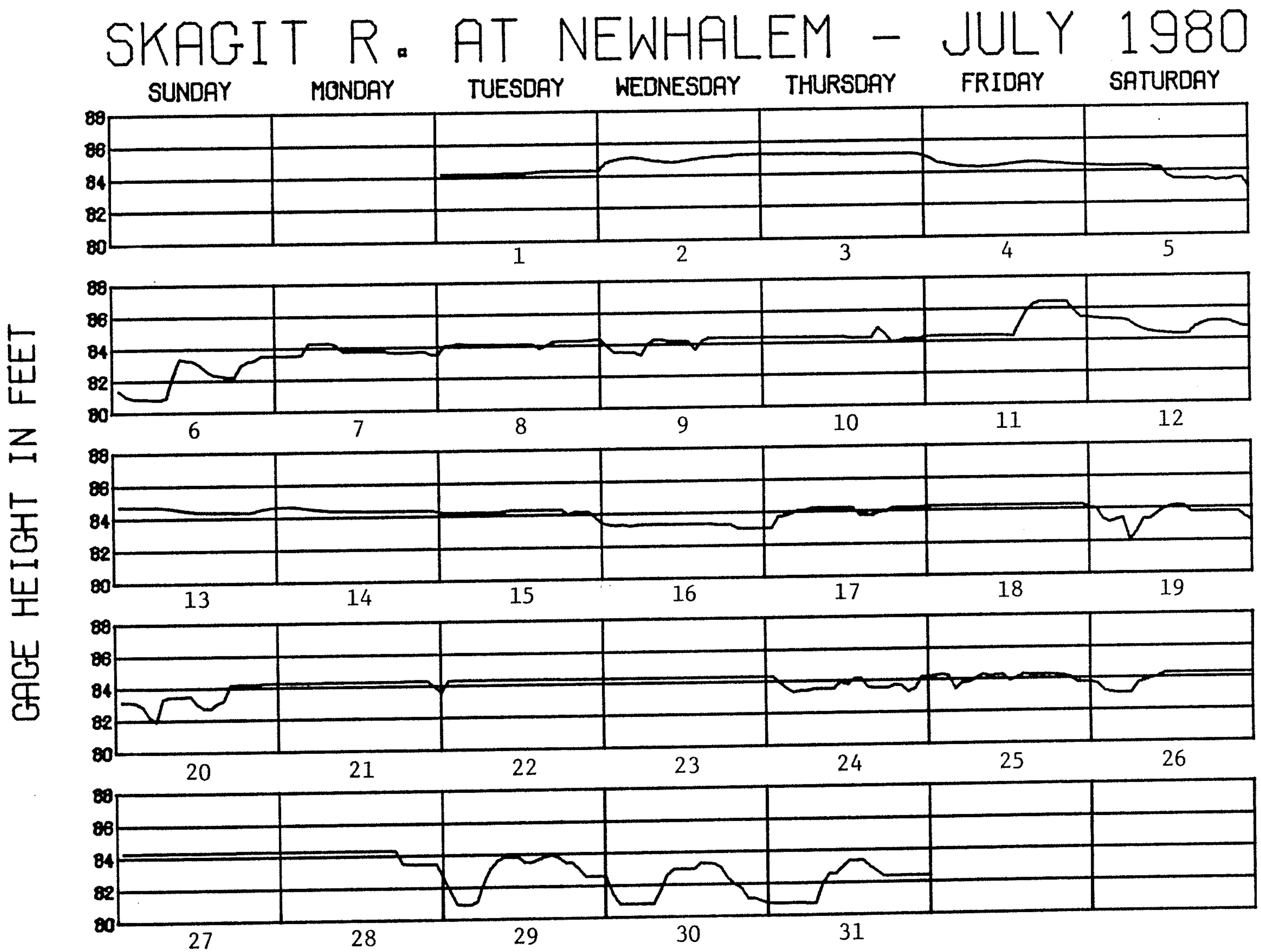

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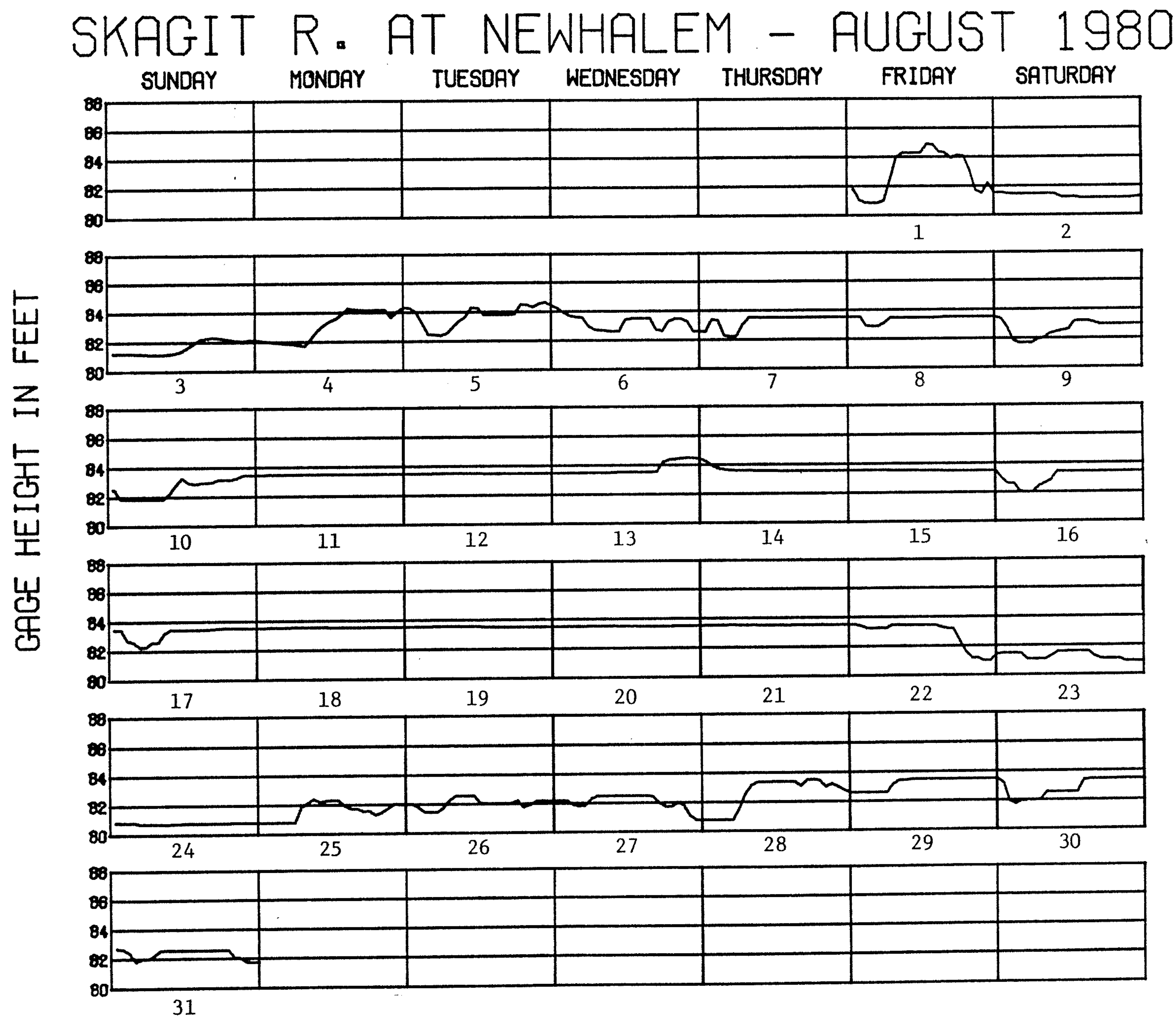

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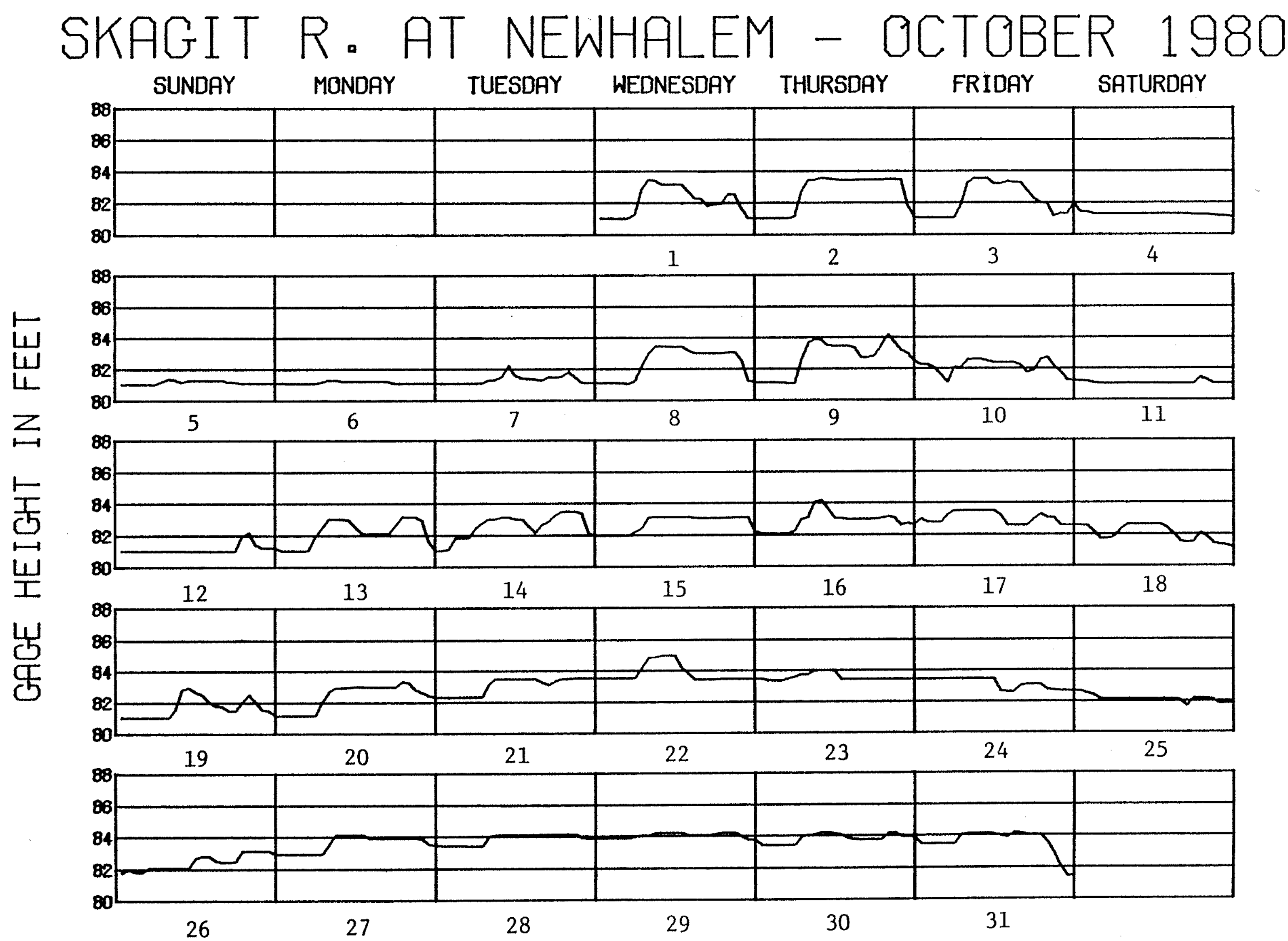

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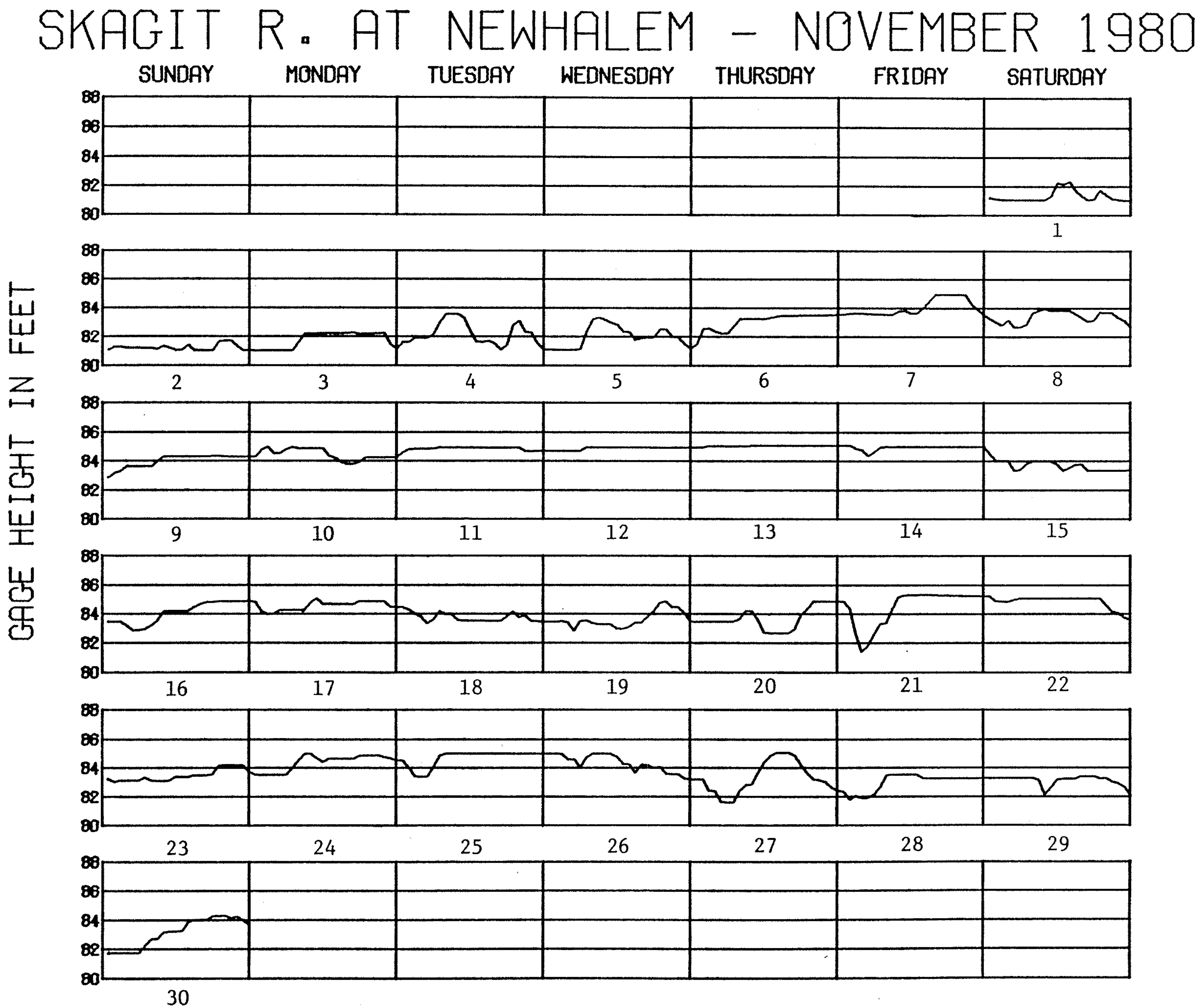

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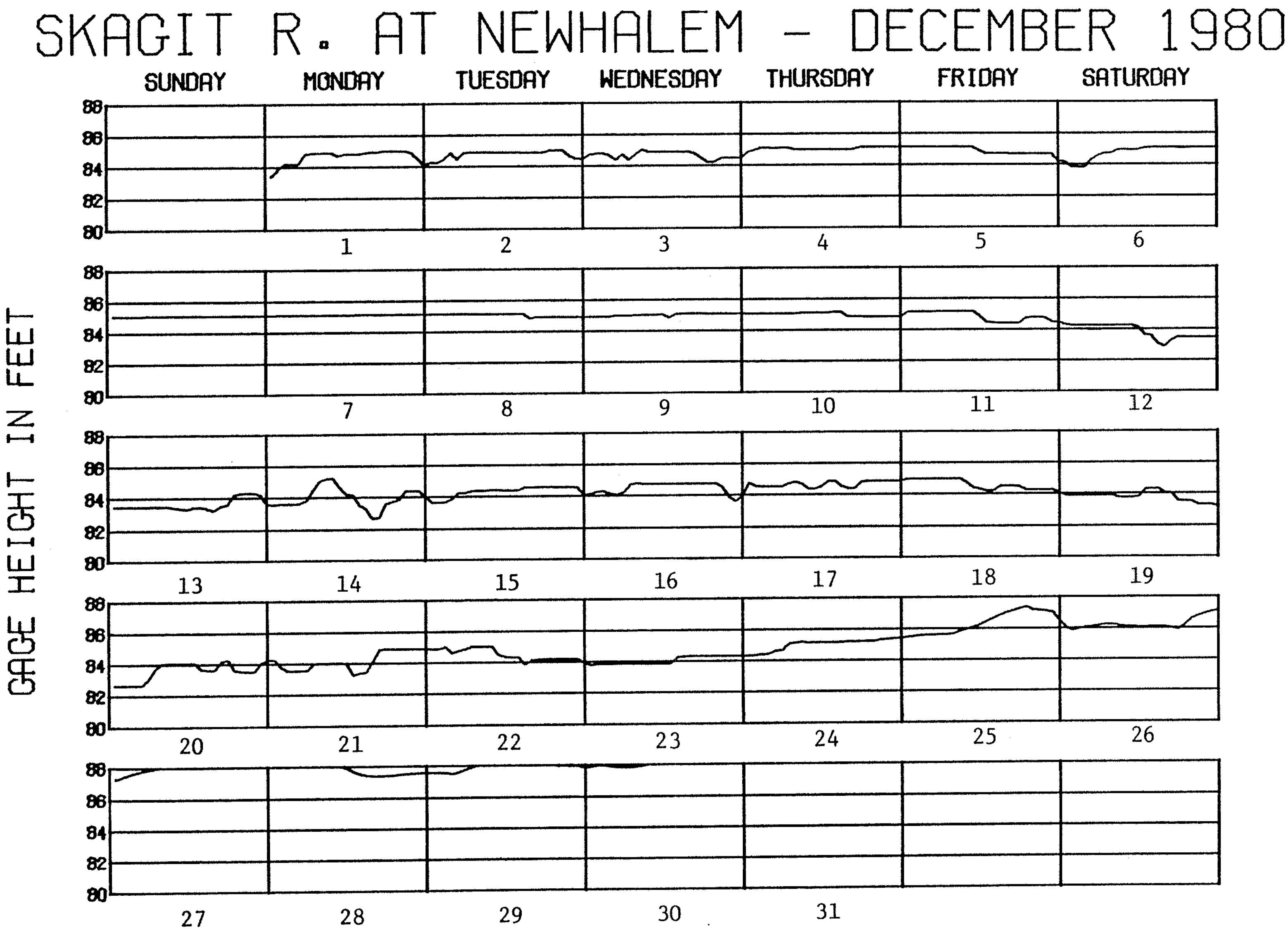

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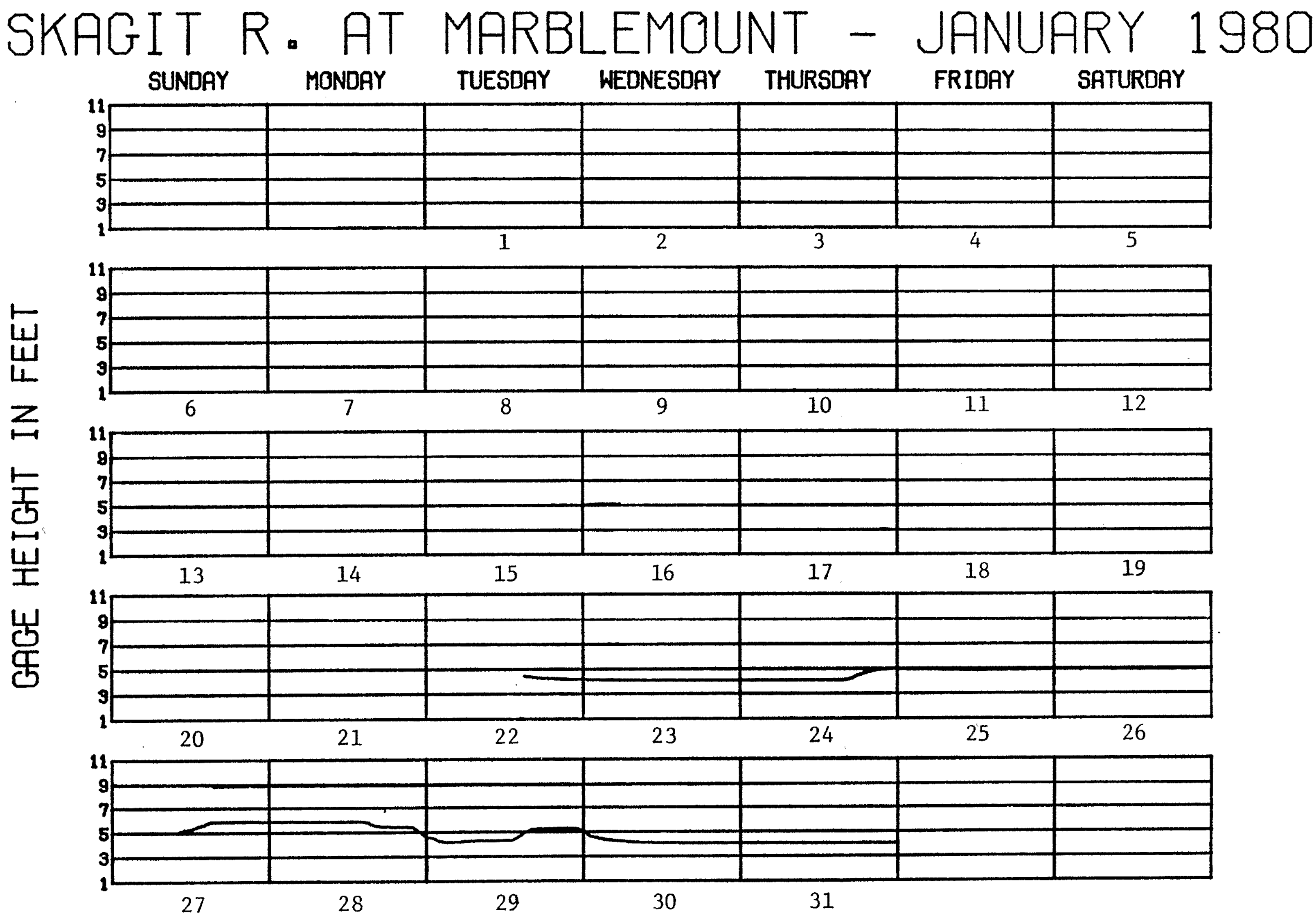
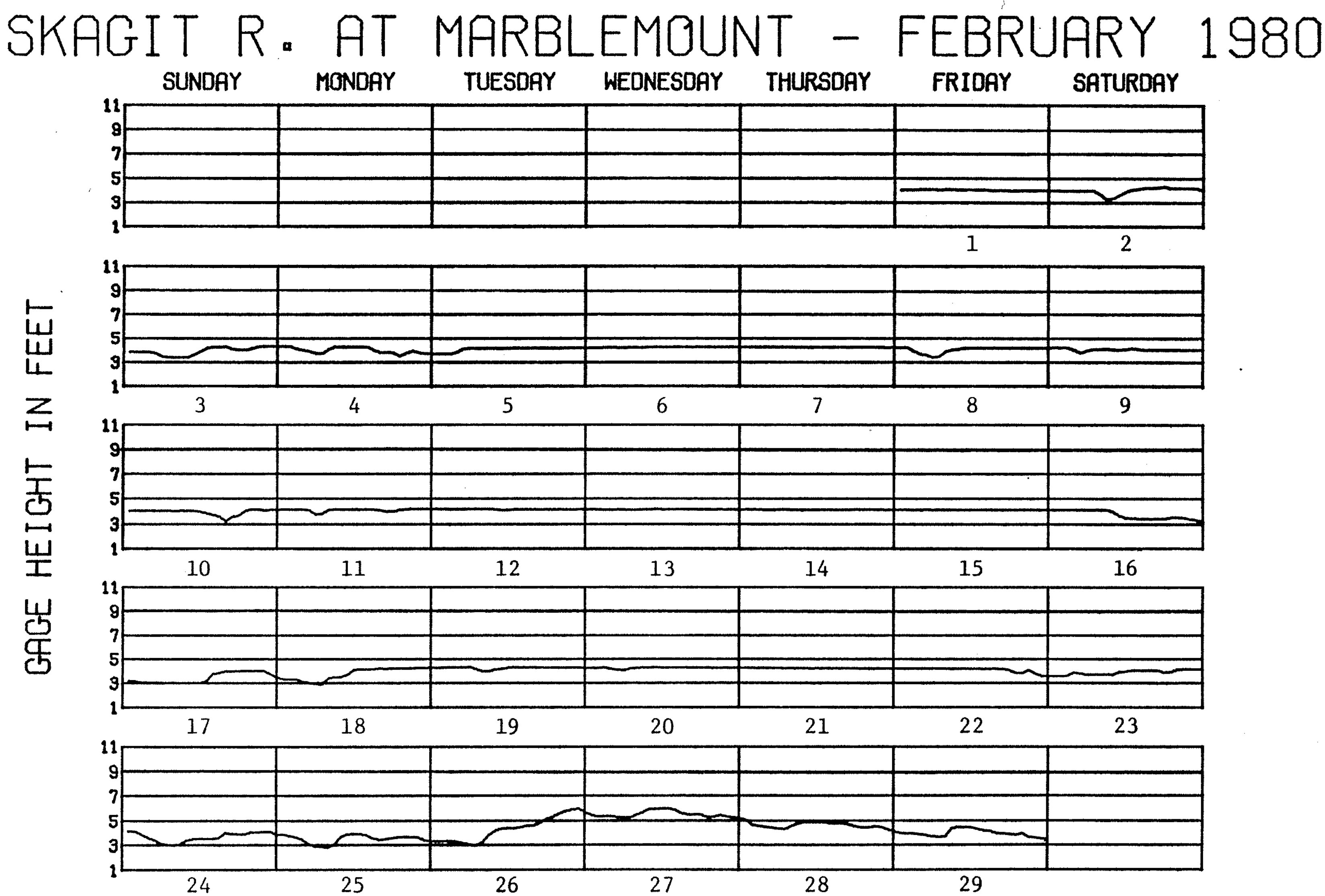


Appendix I, Figure 2. Hourly gage height data for Skagit River at Marblemount (USGS), January-December 1980.



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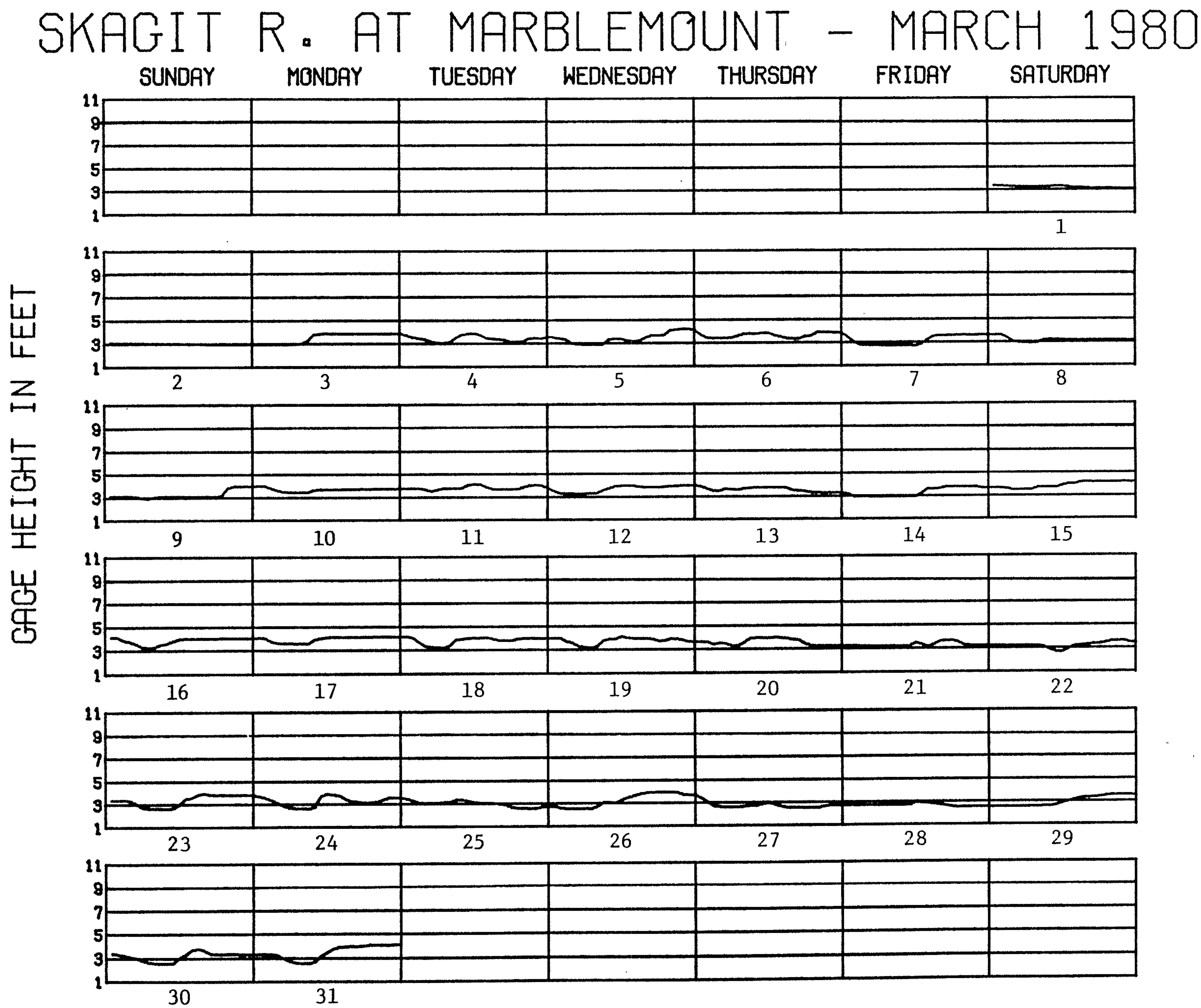

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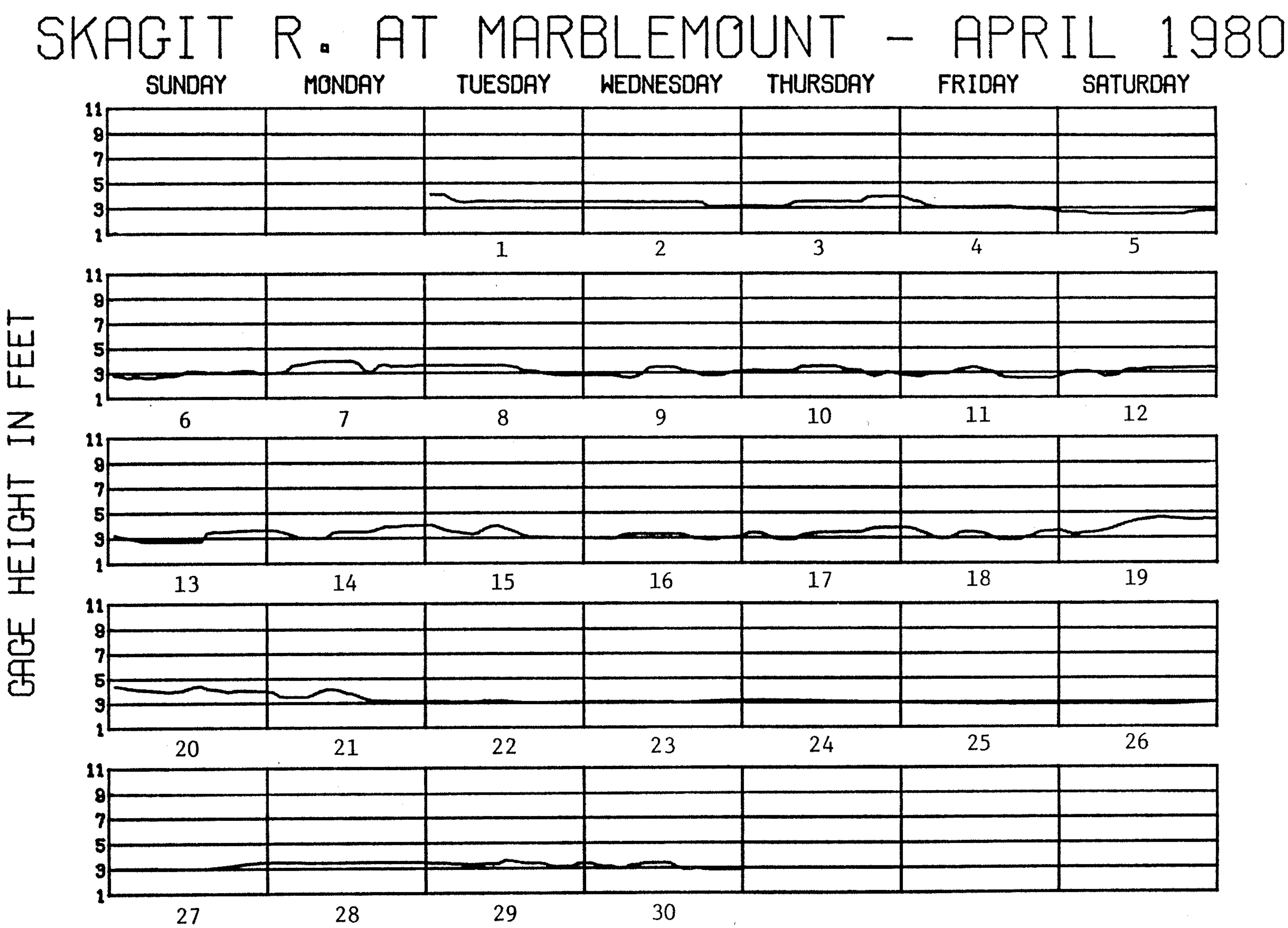

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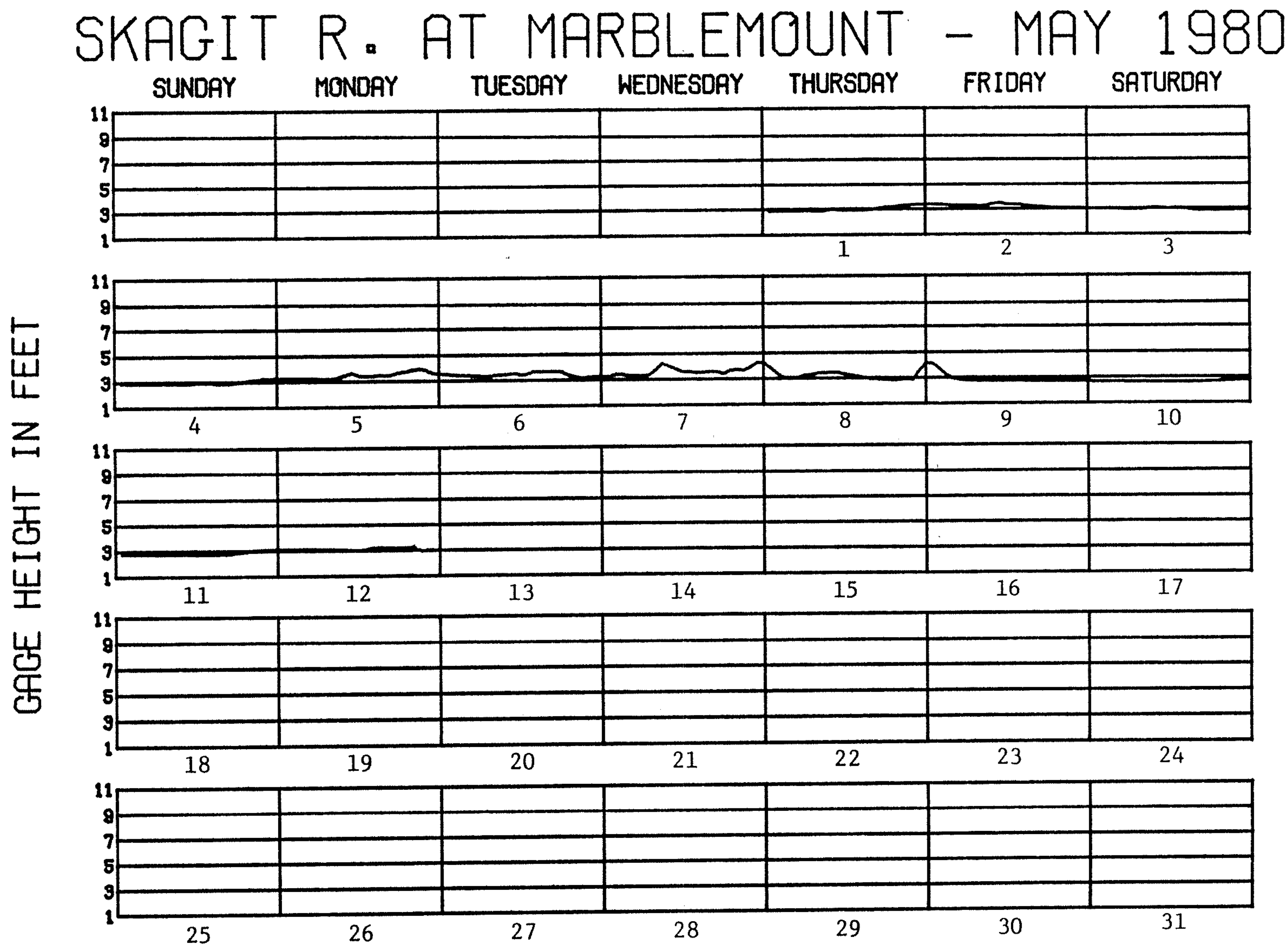

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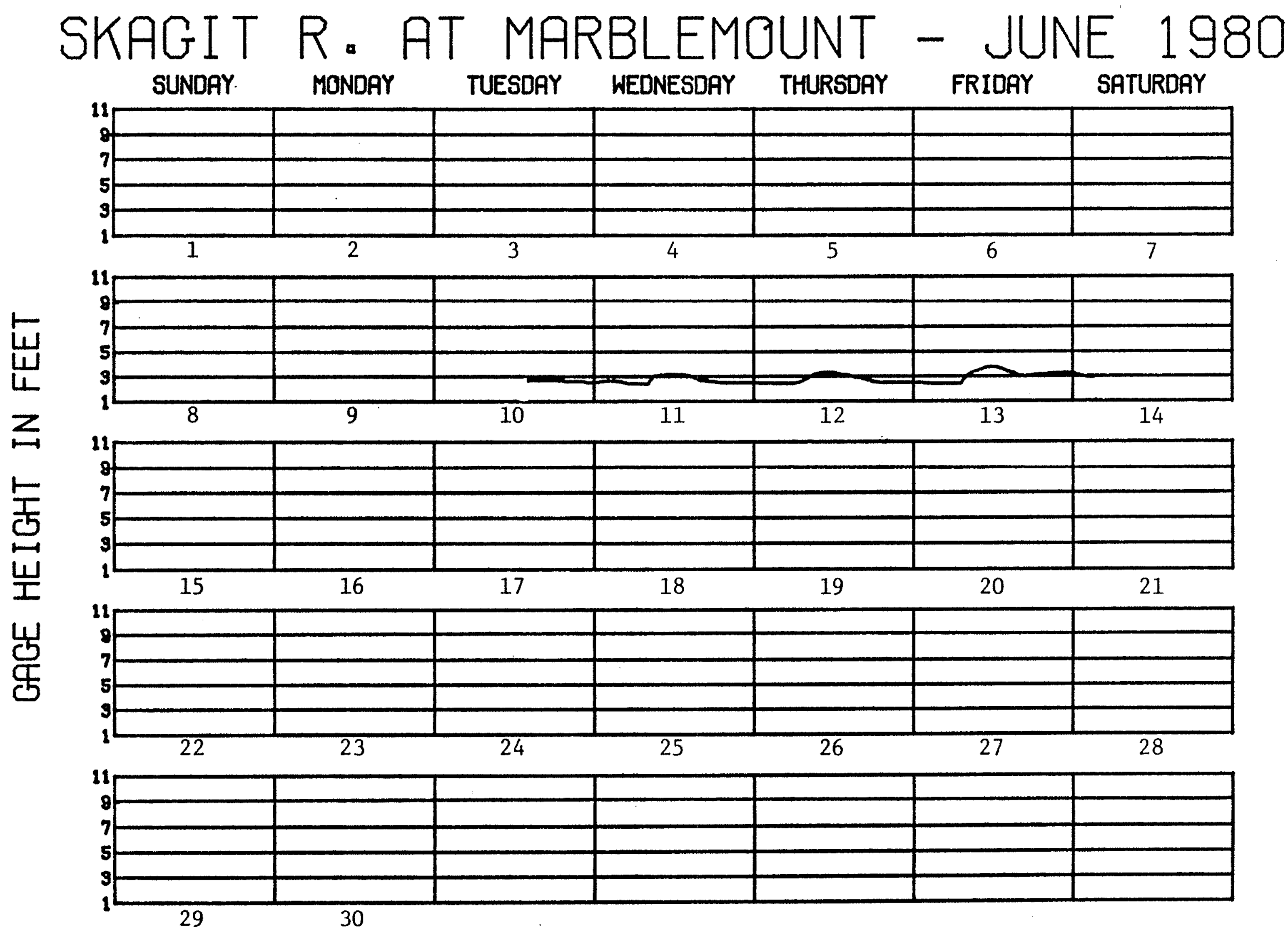

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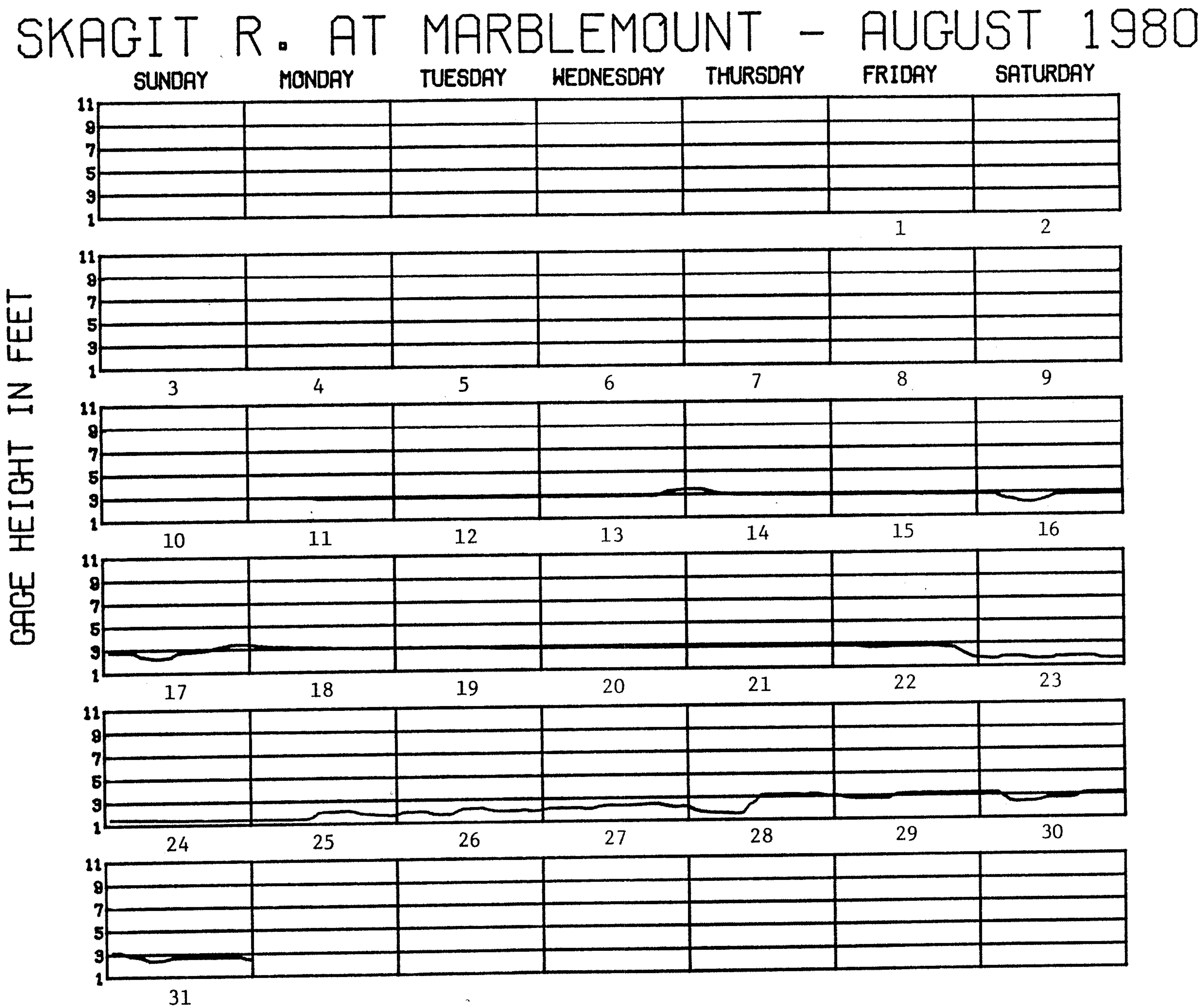

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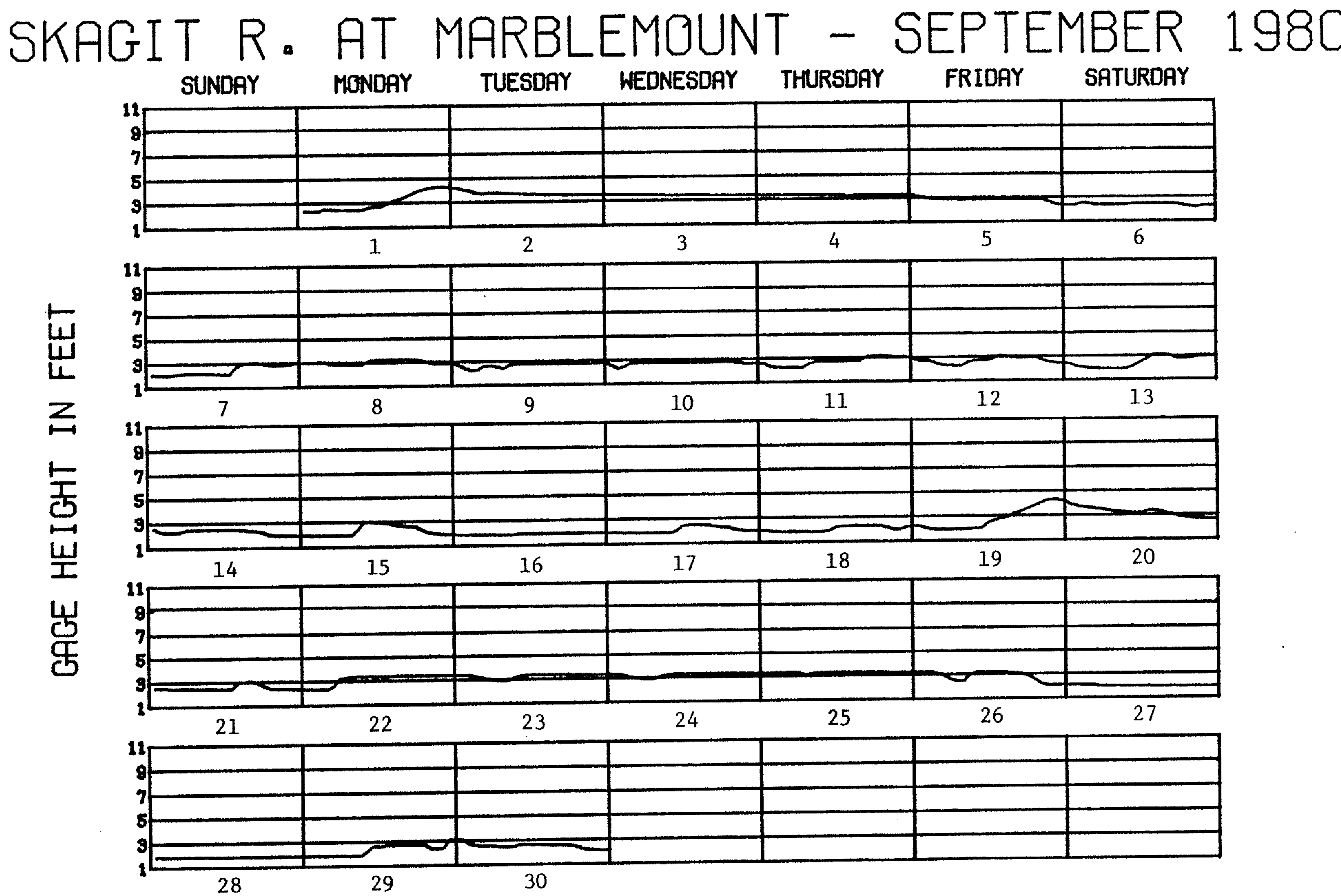

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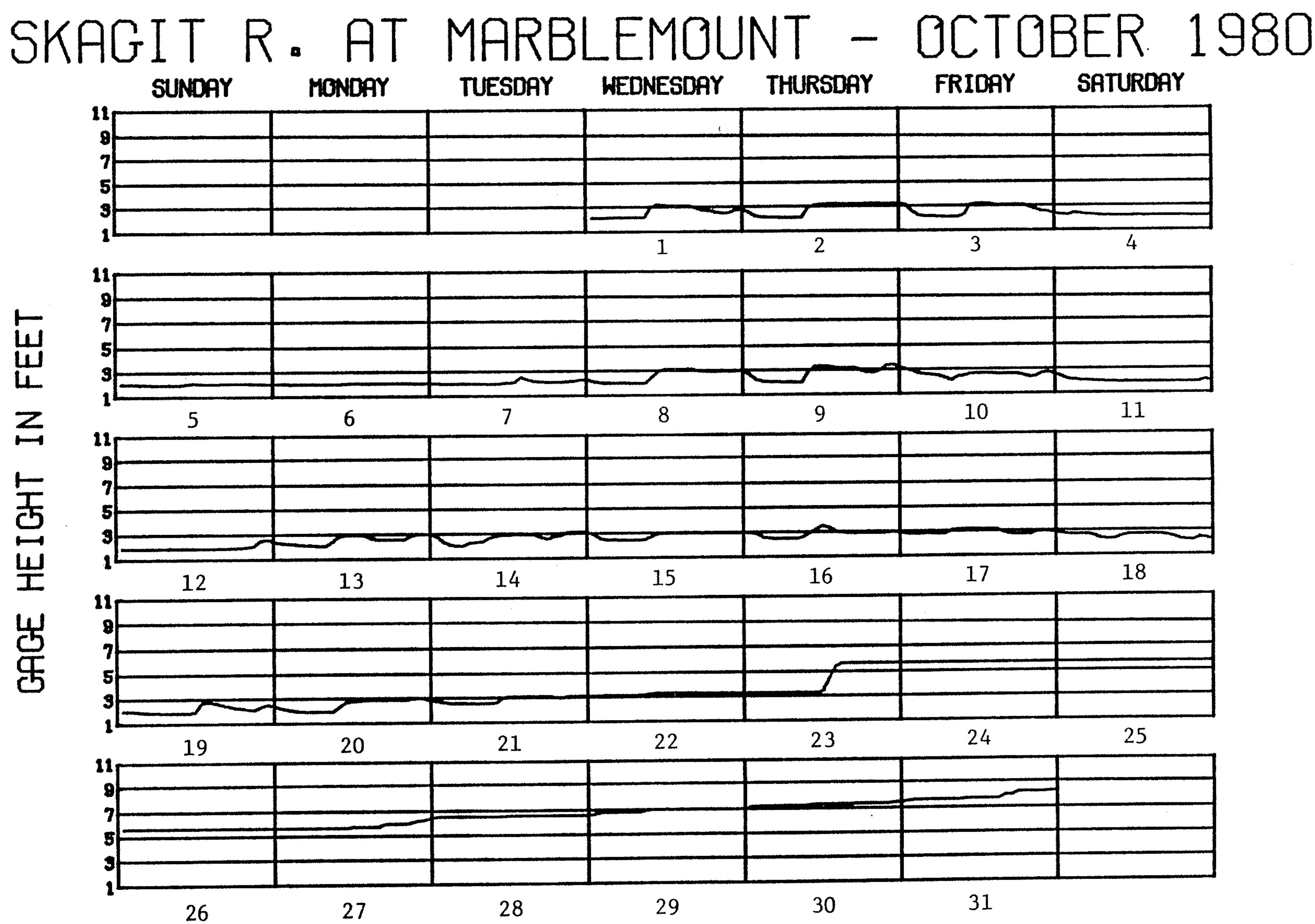

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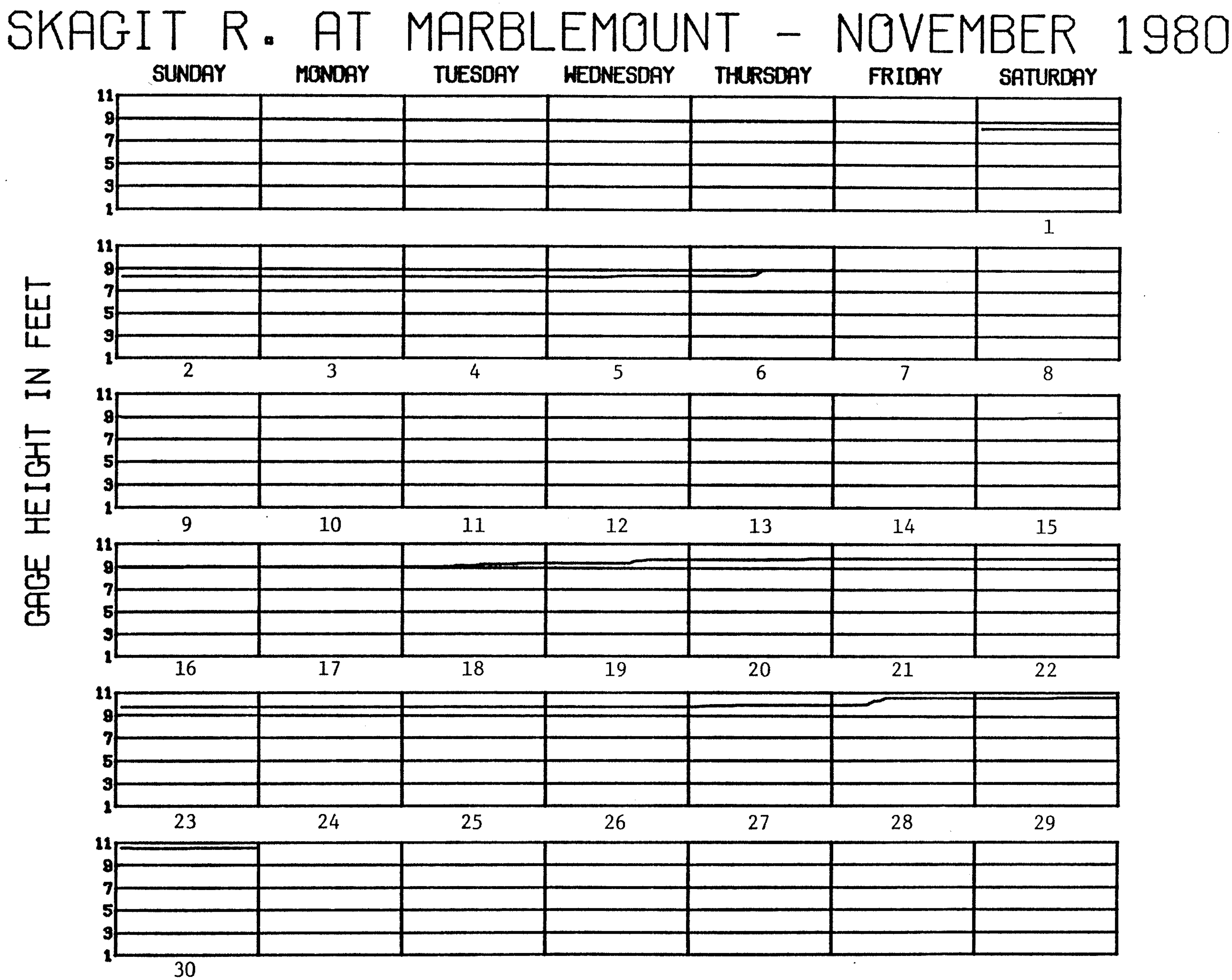

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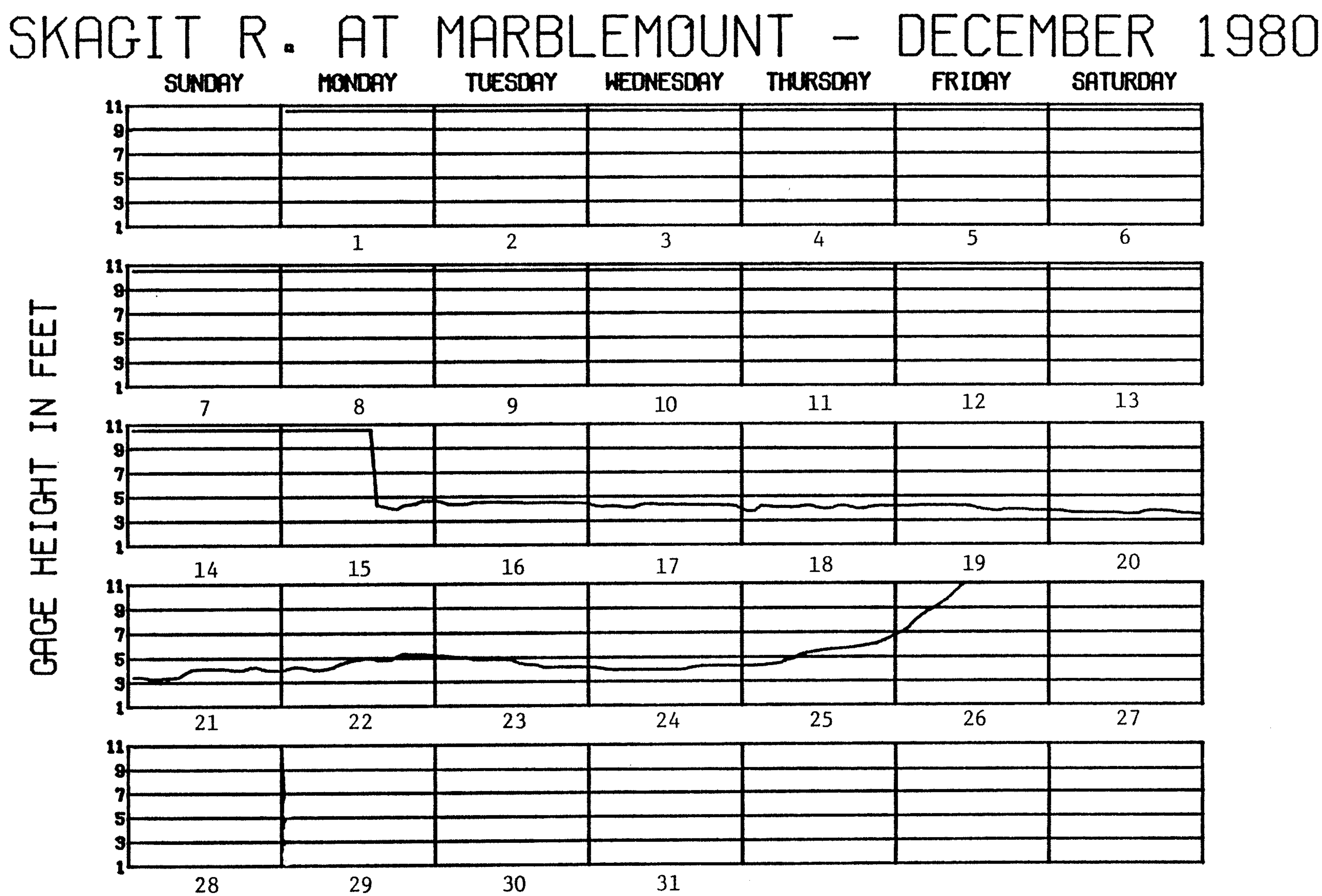

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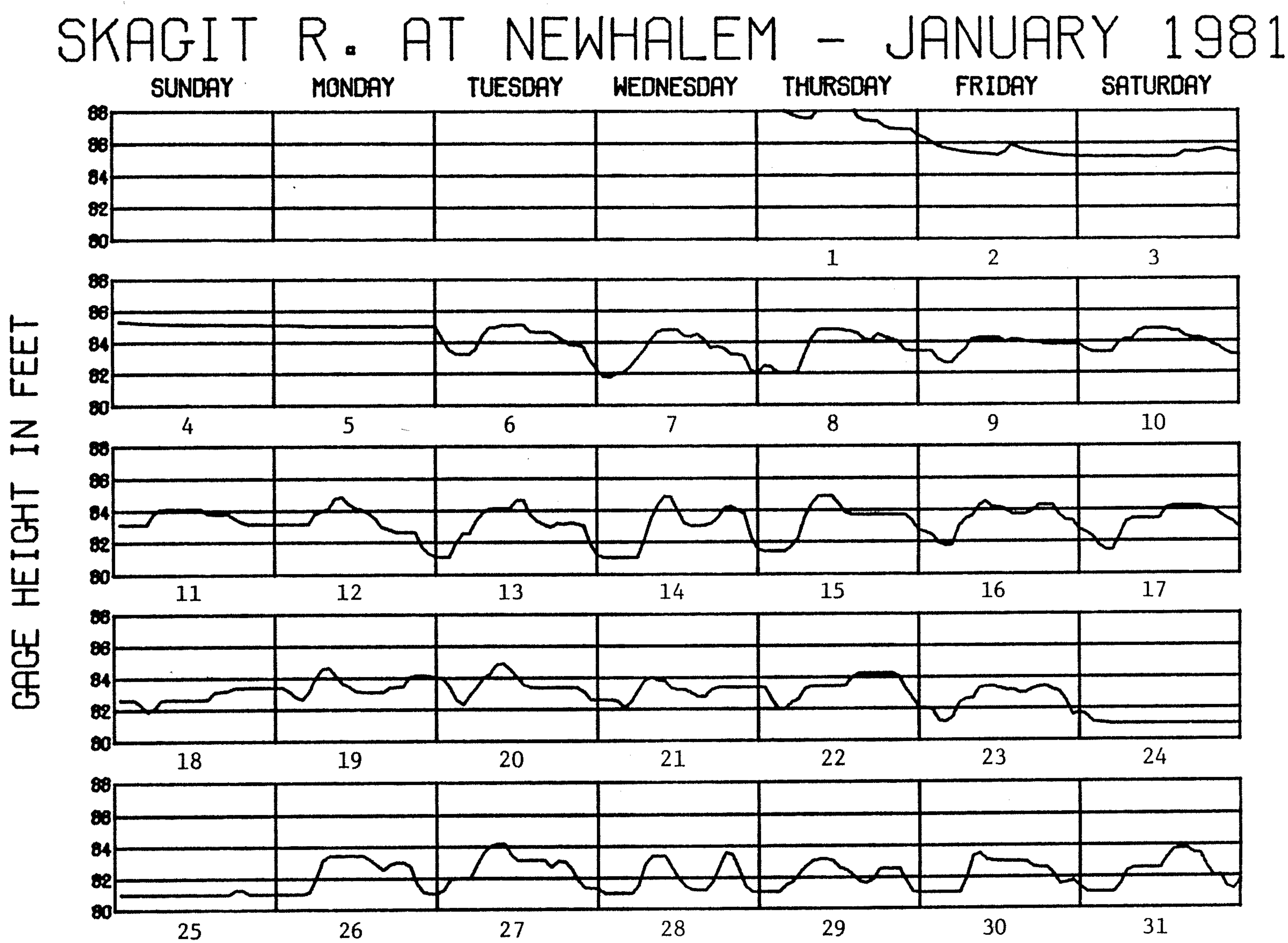

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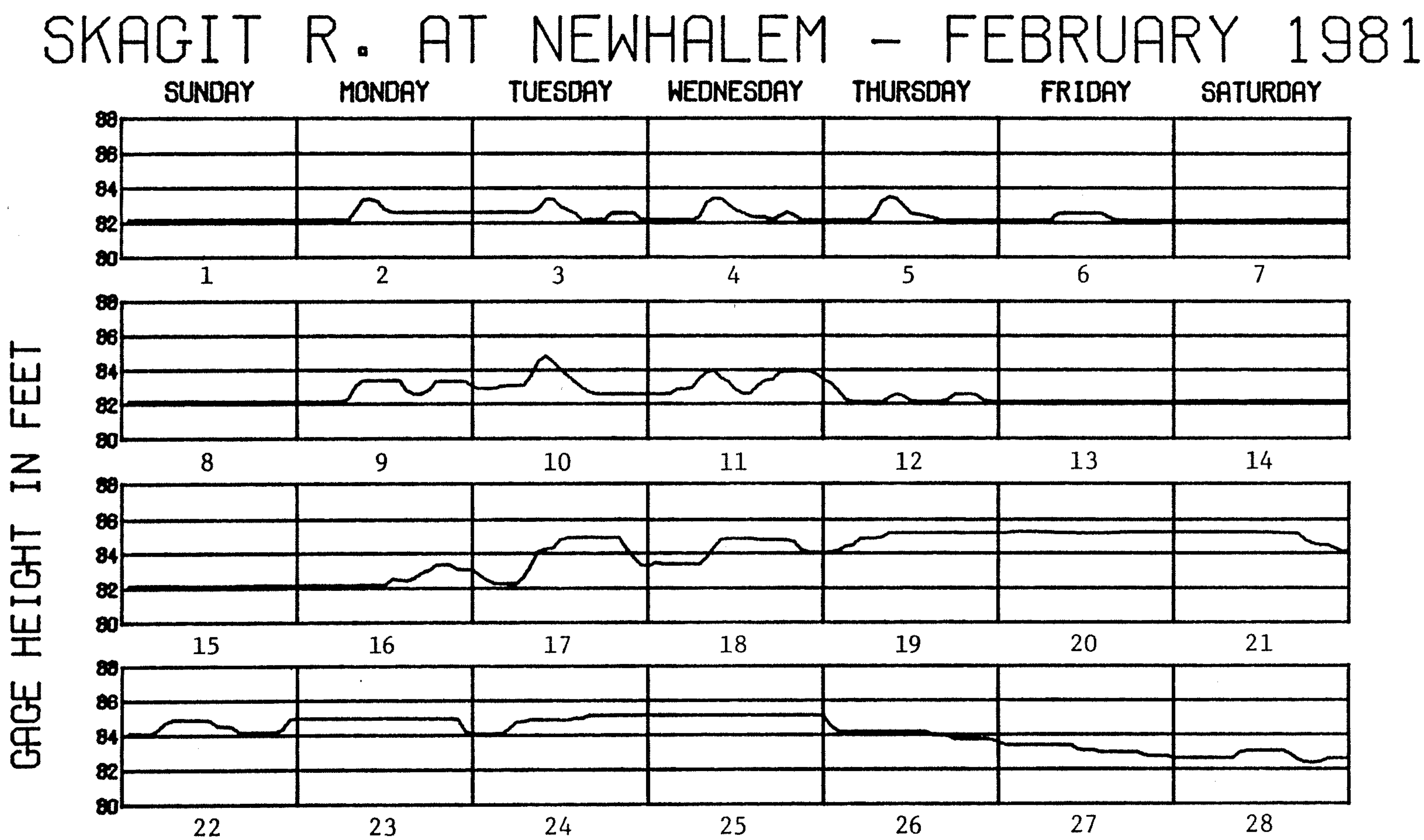

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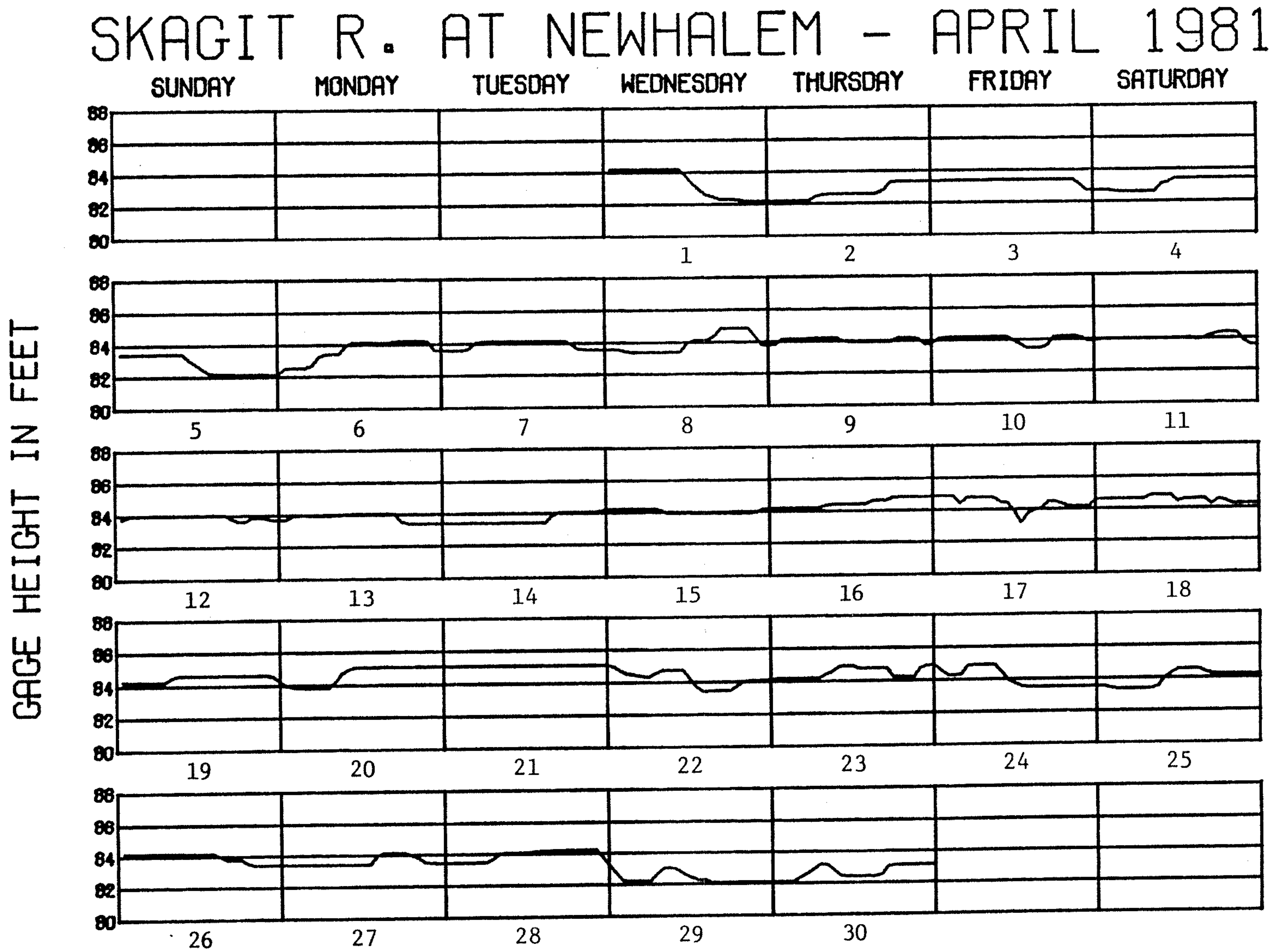

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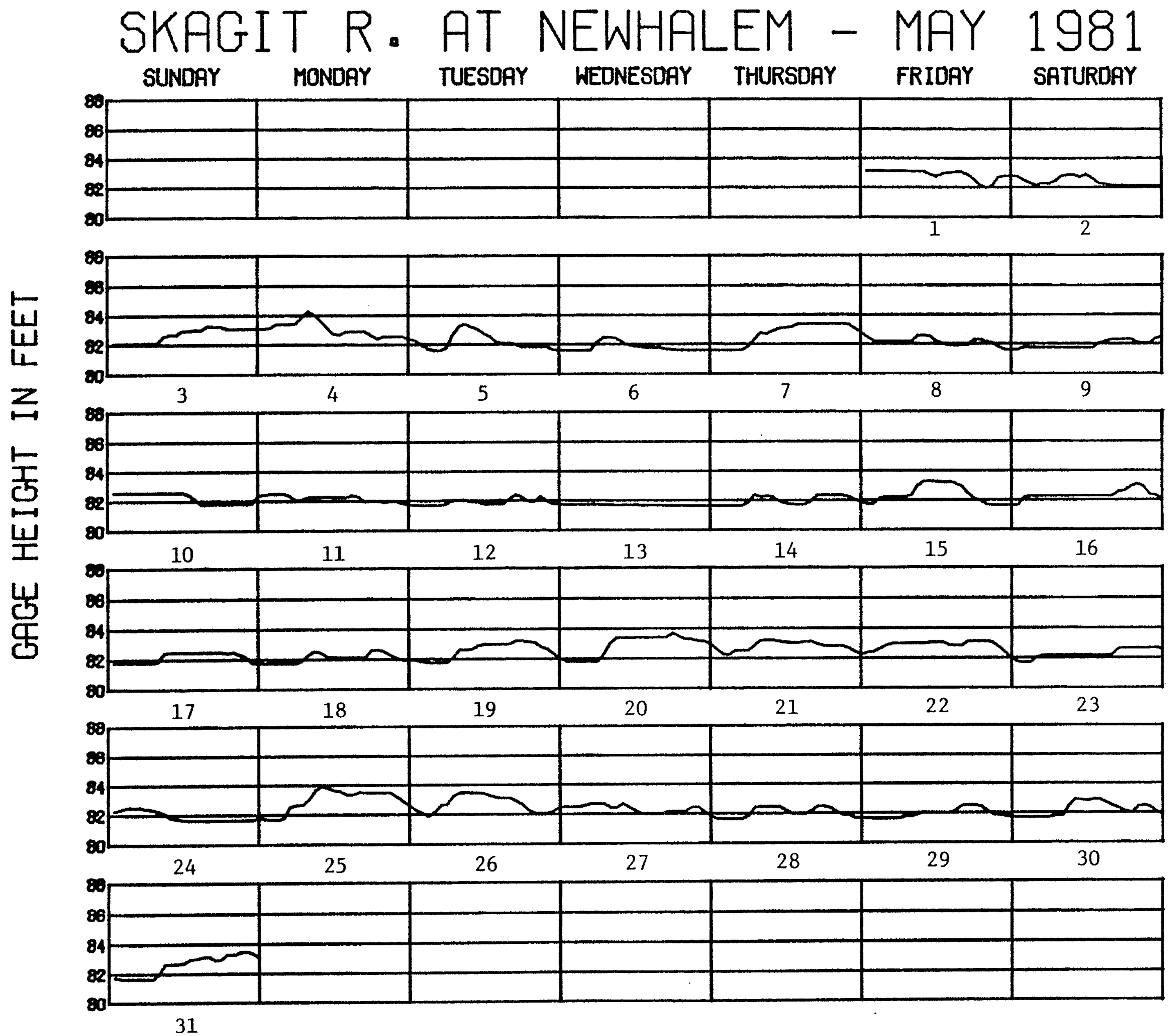

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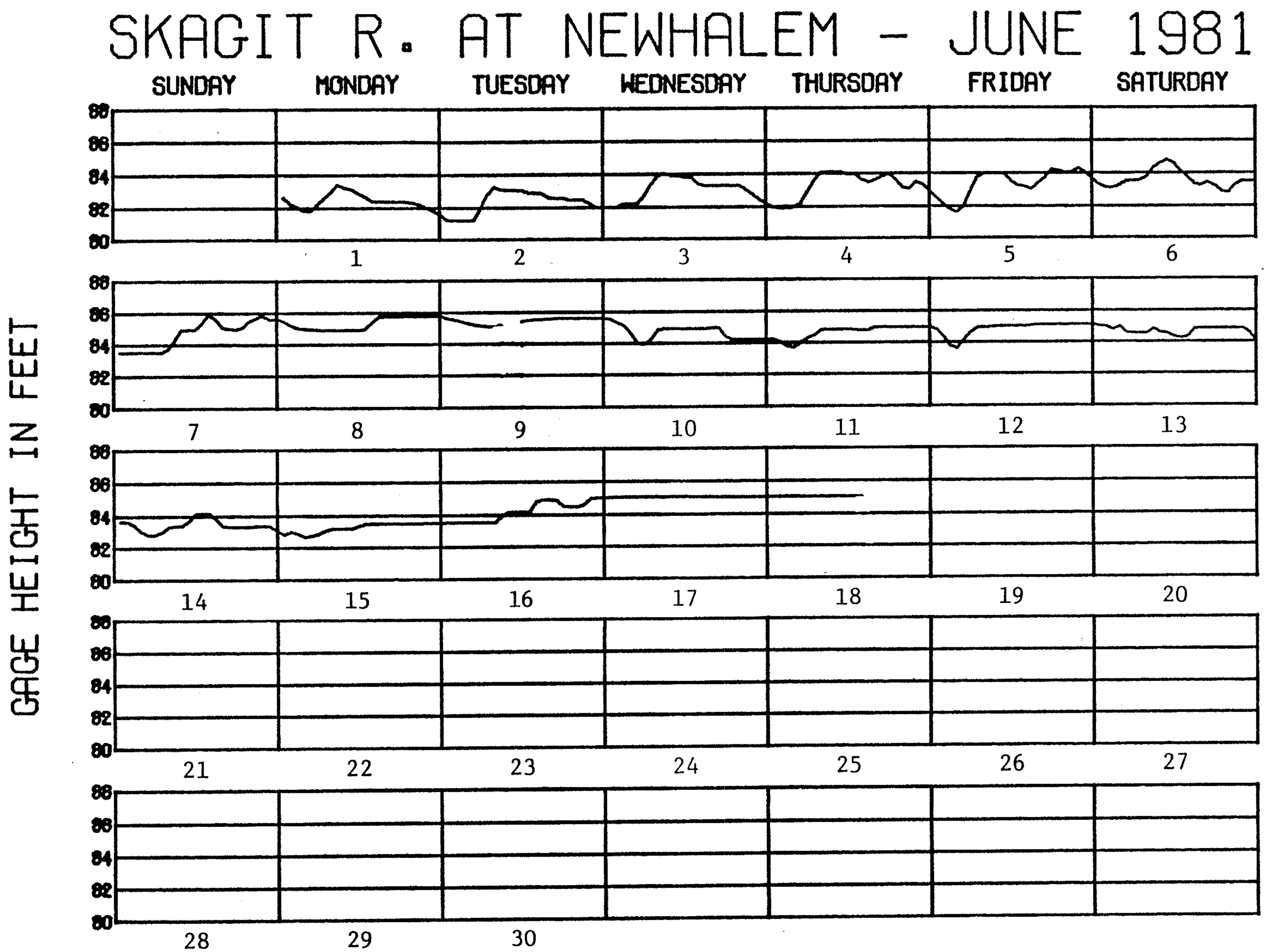

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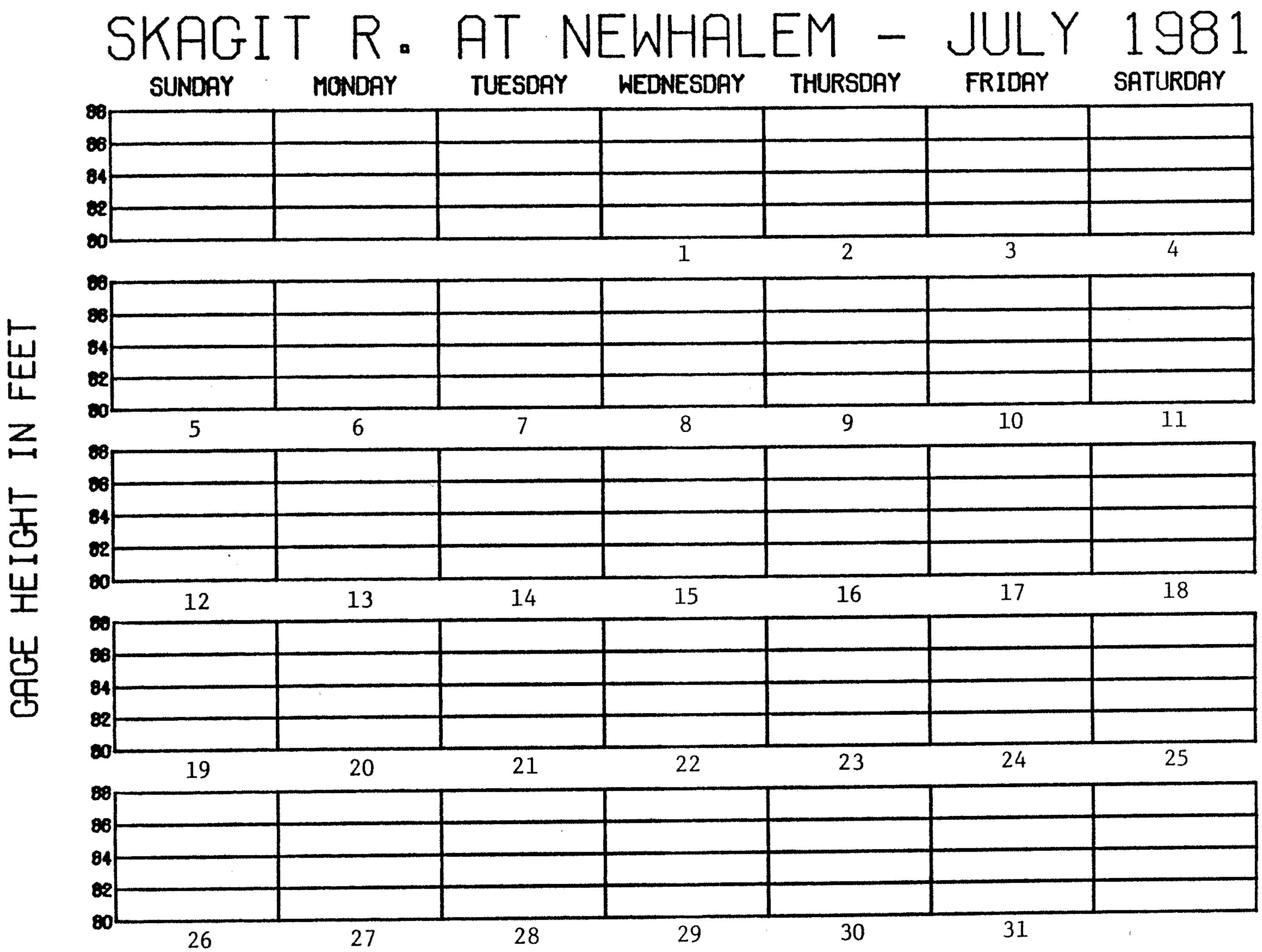

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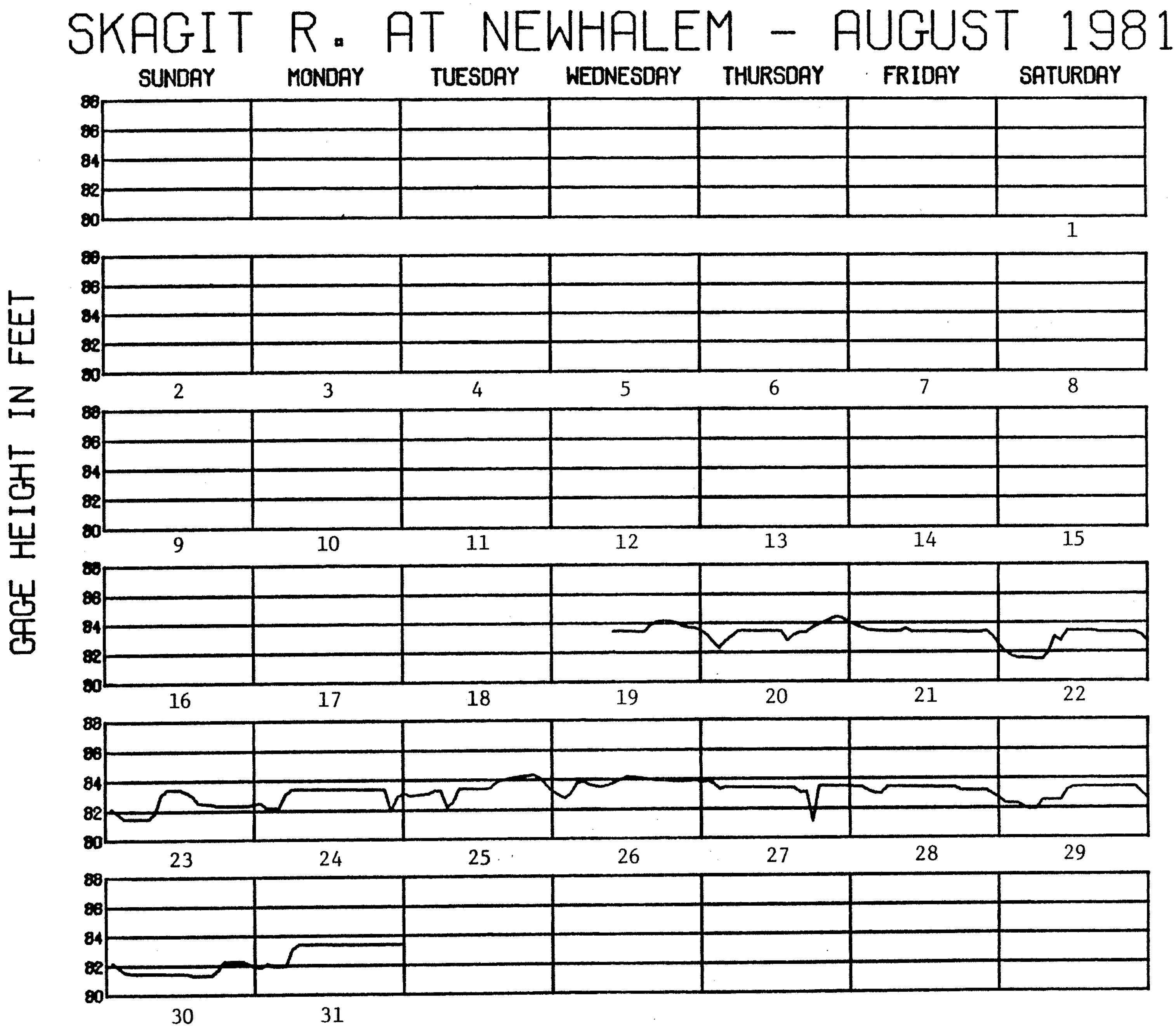

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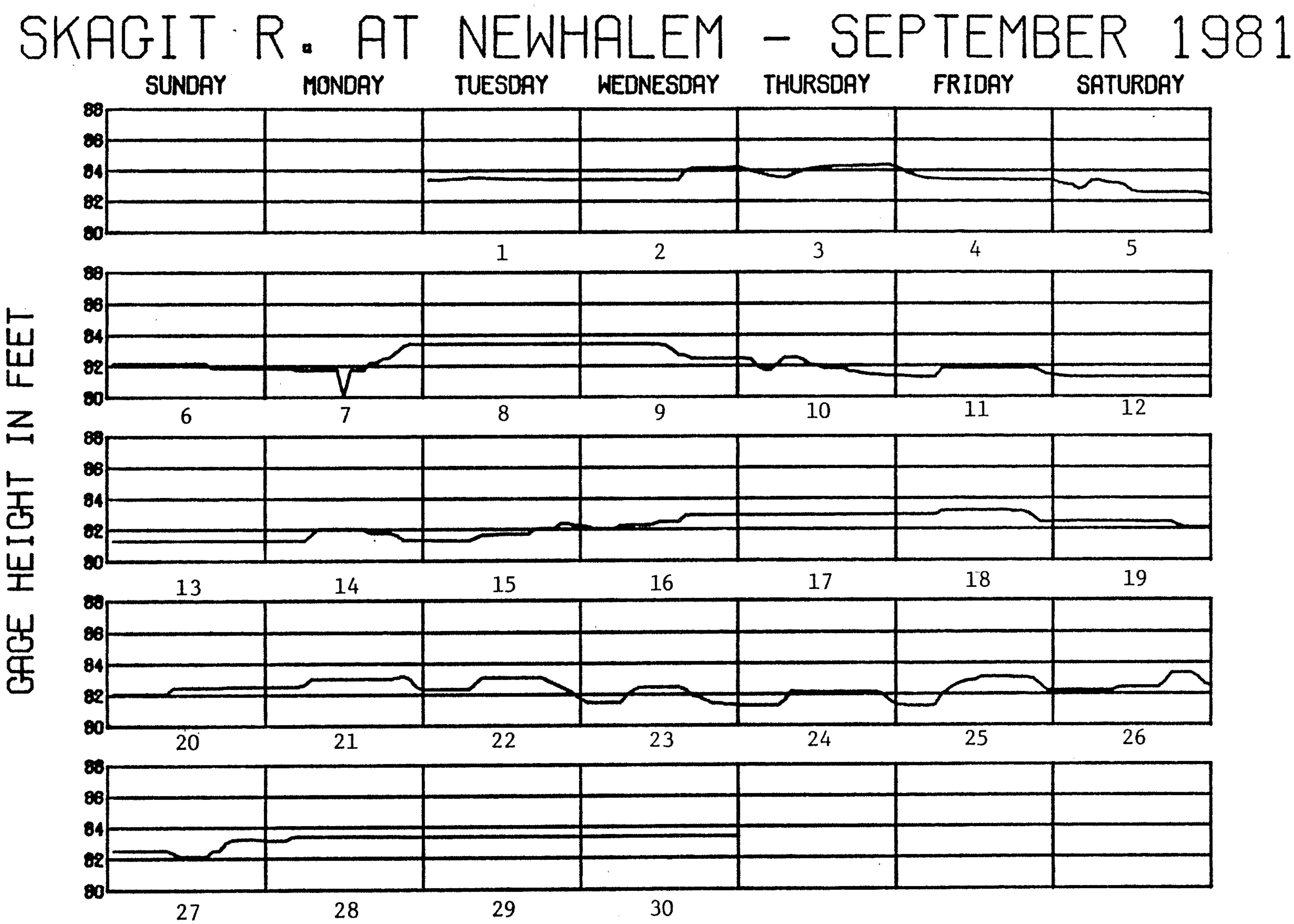

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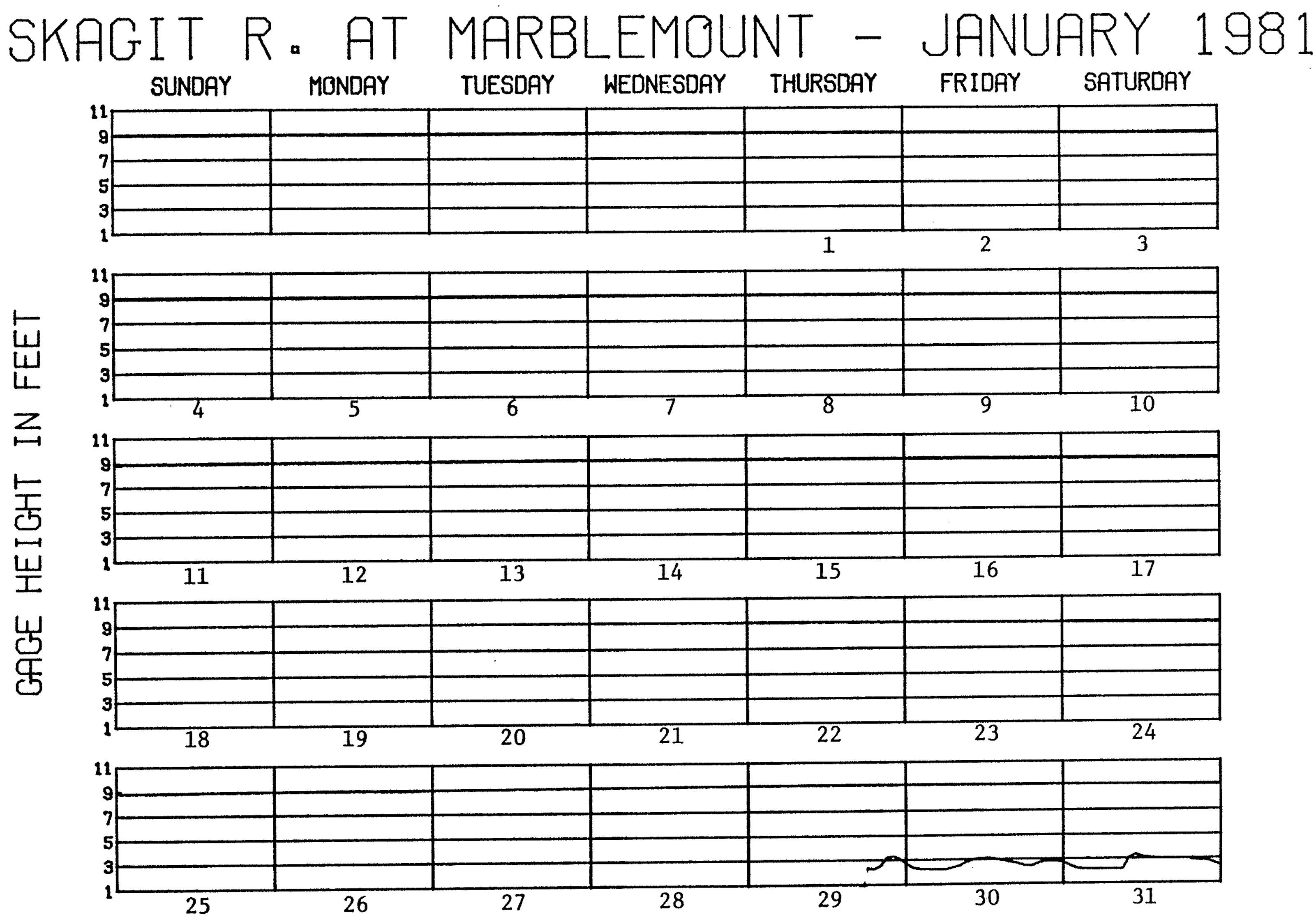

Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981.

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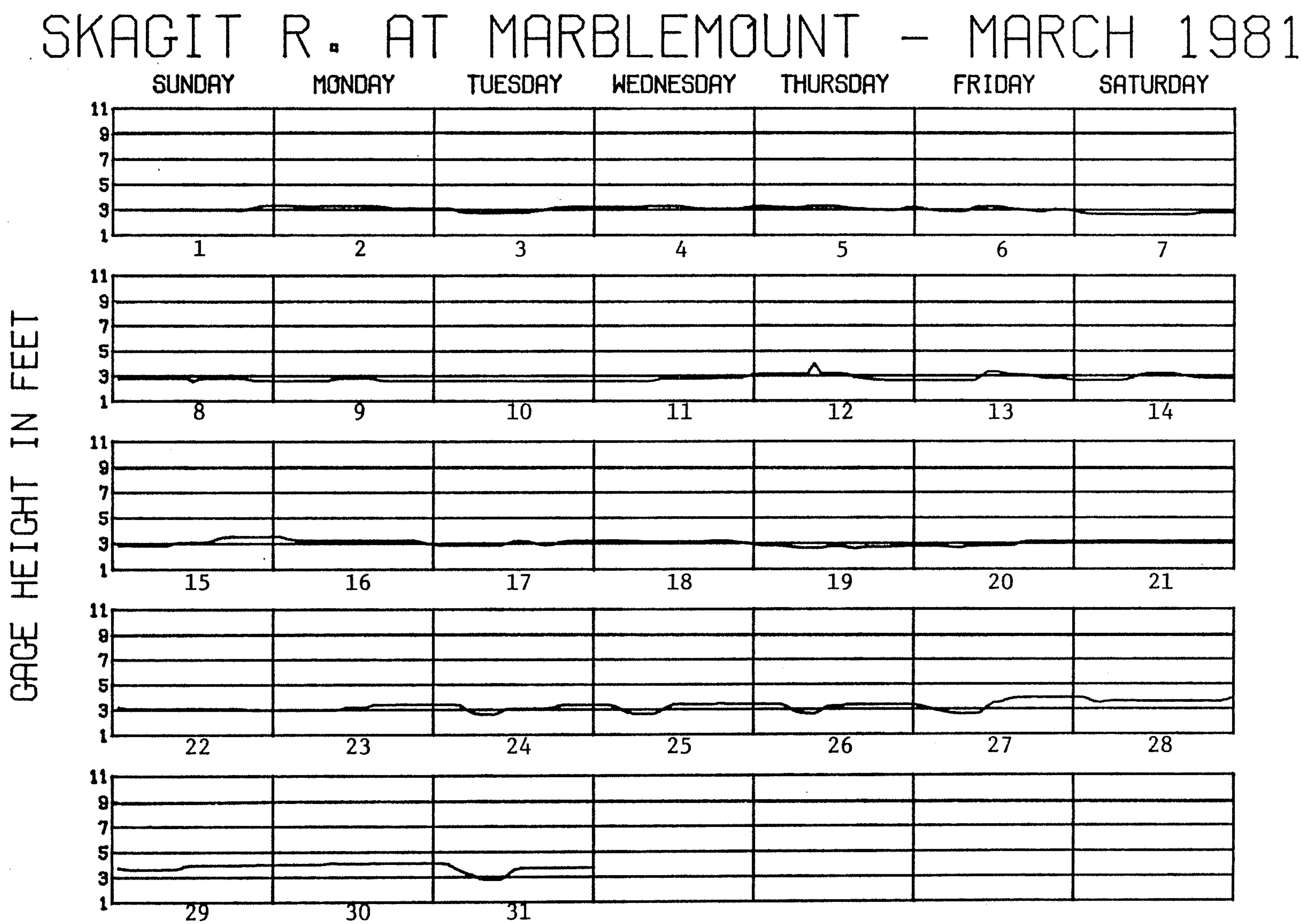

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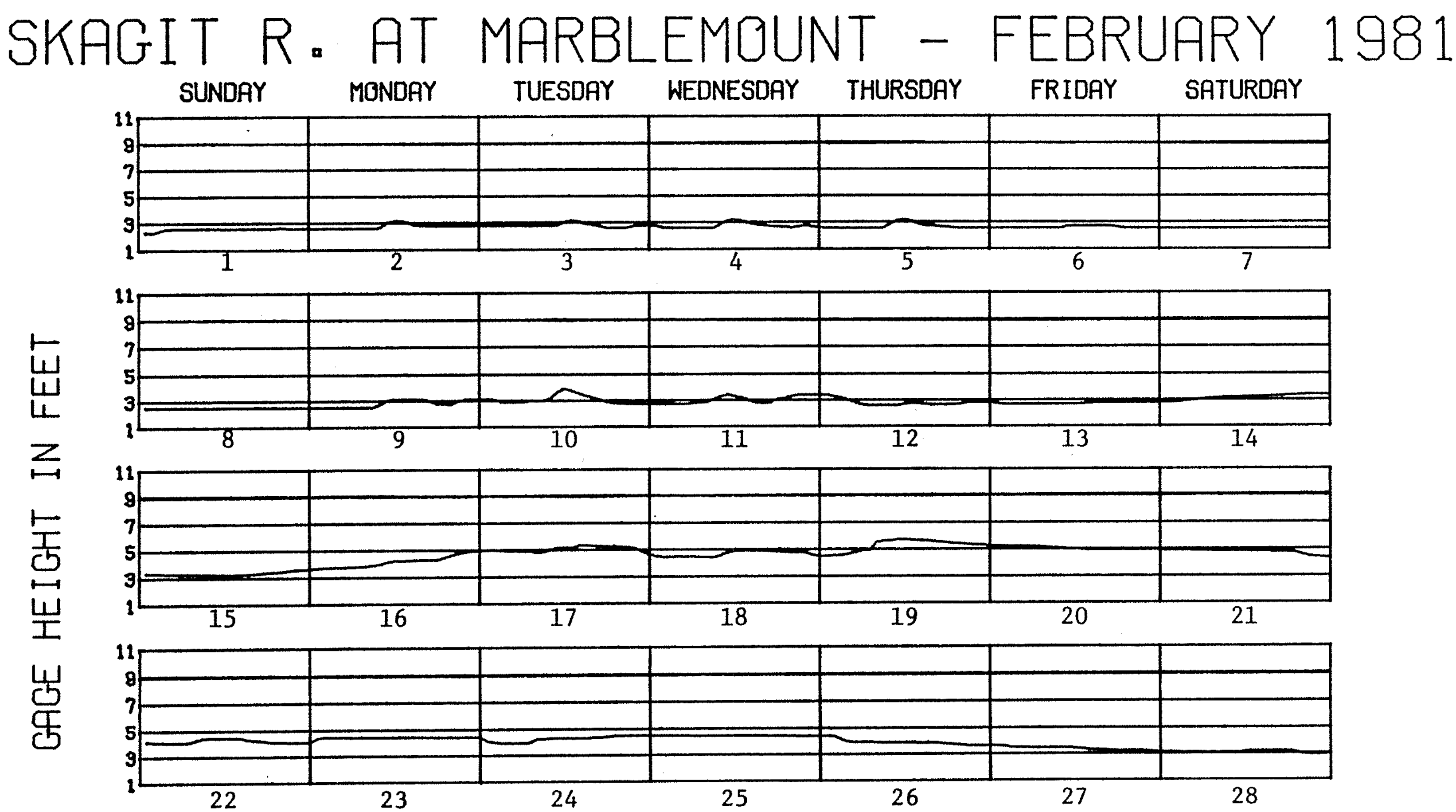

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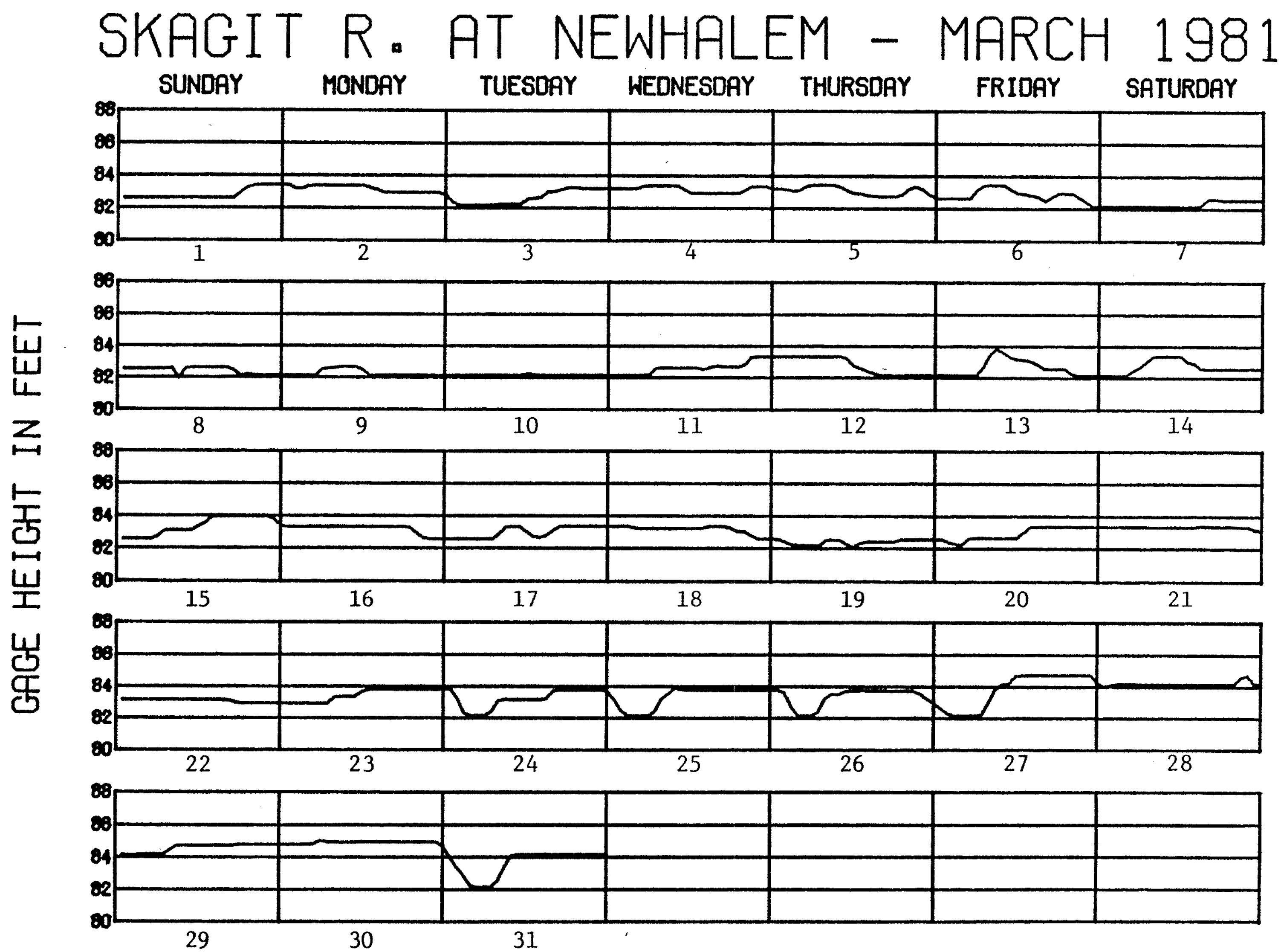
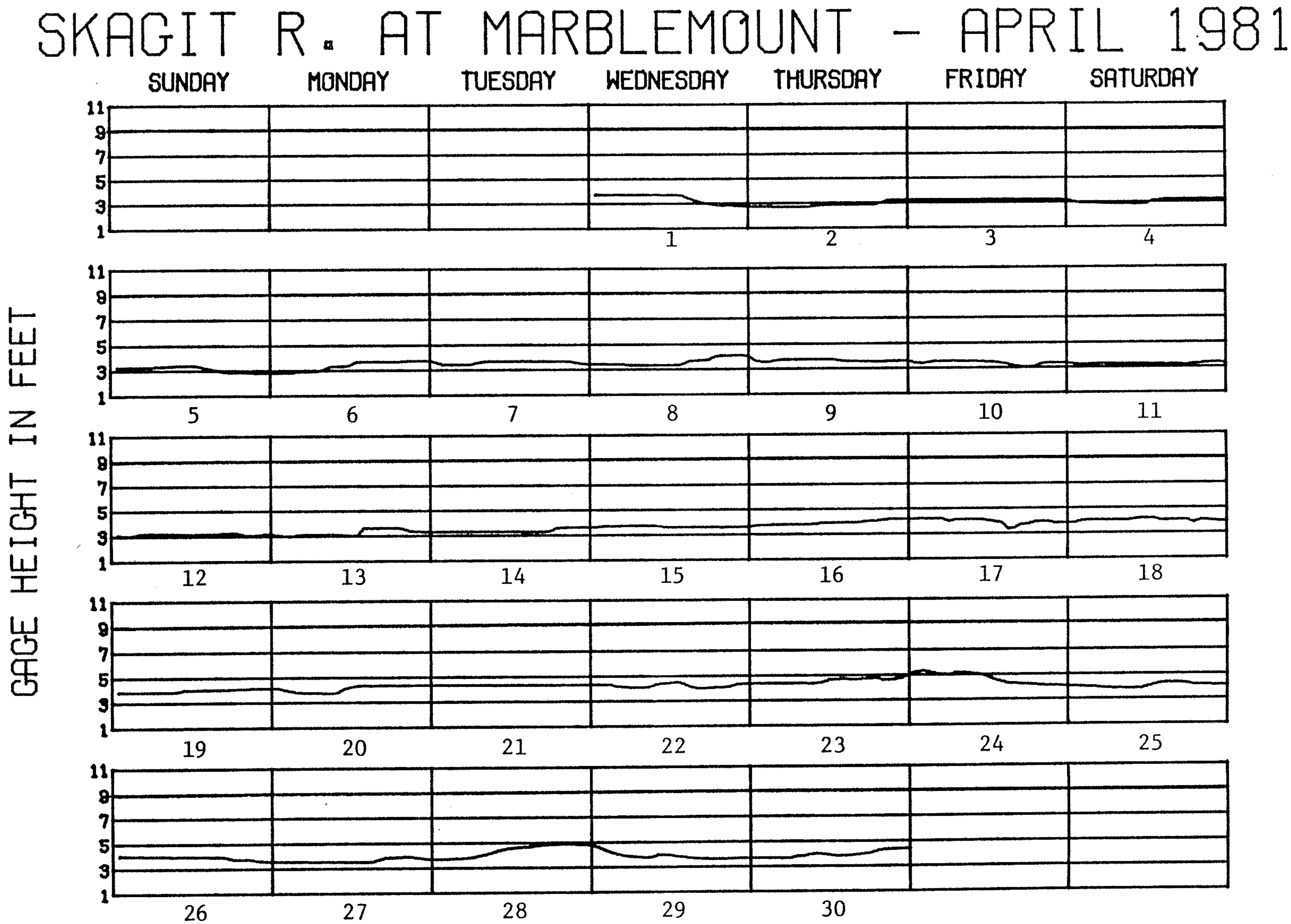
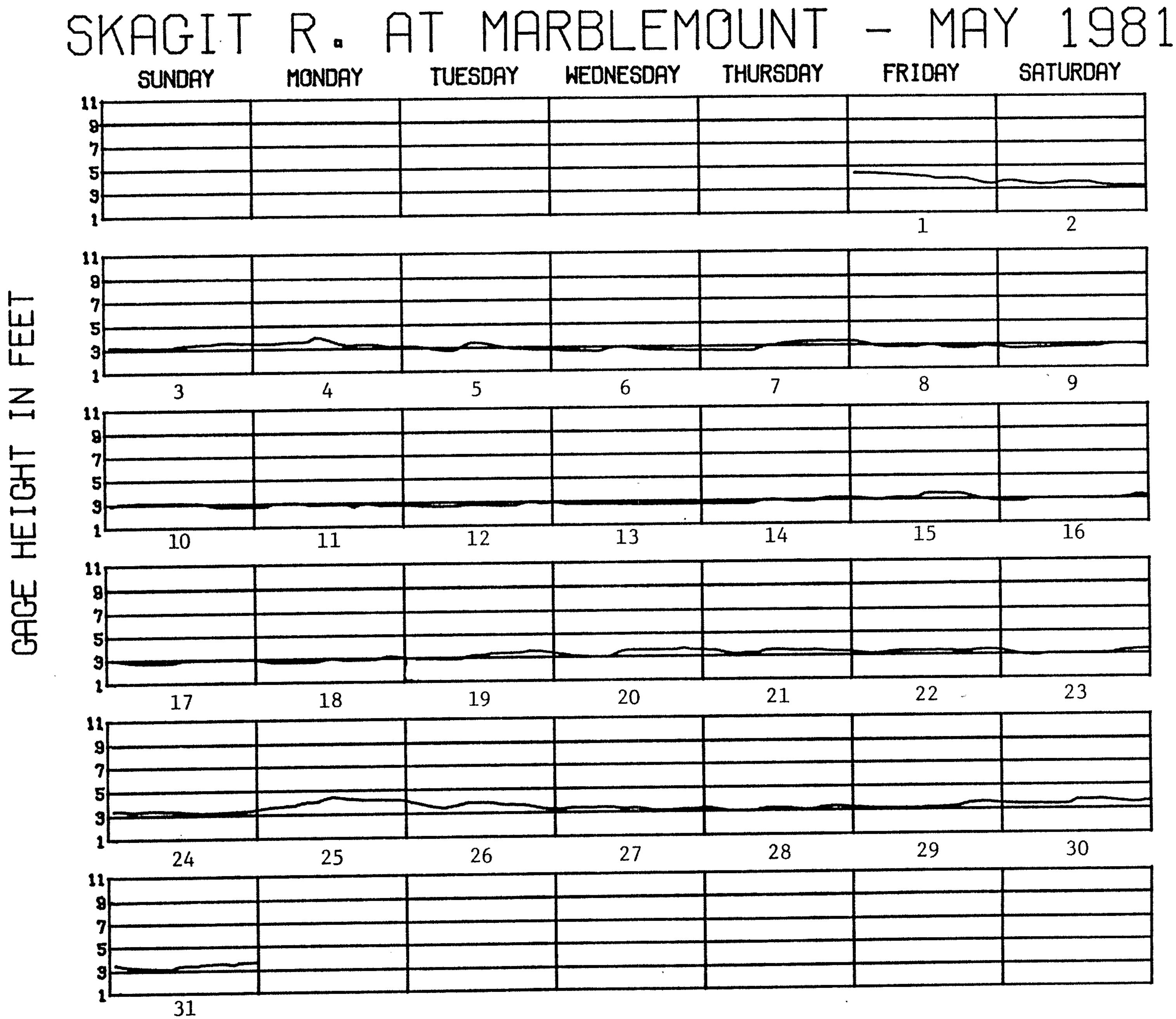


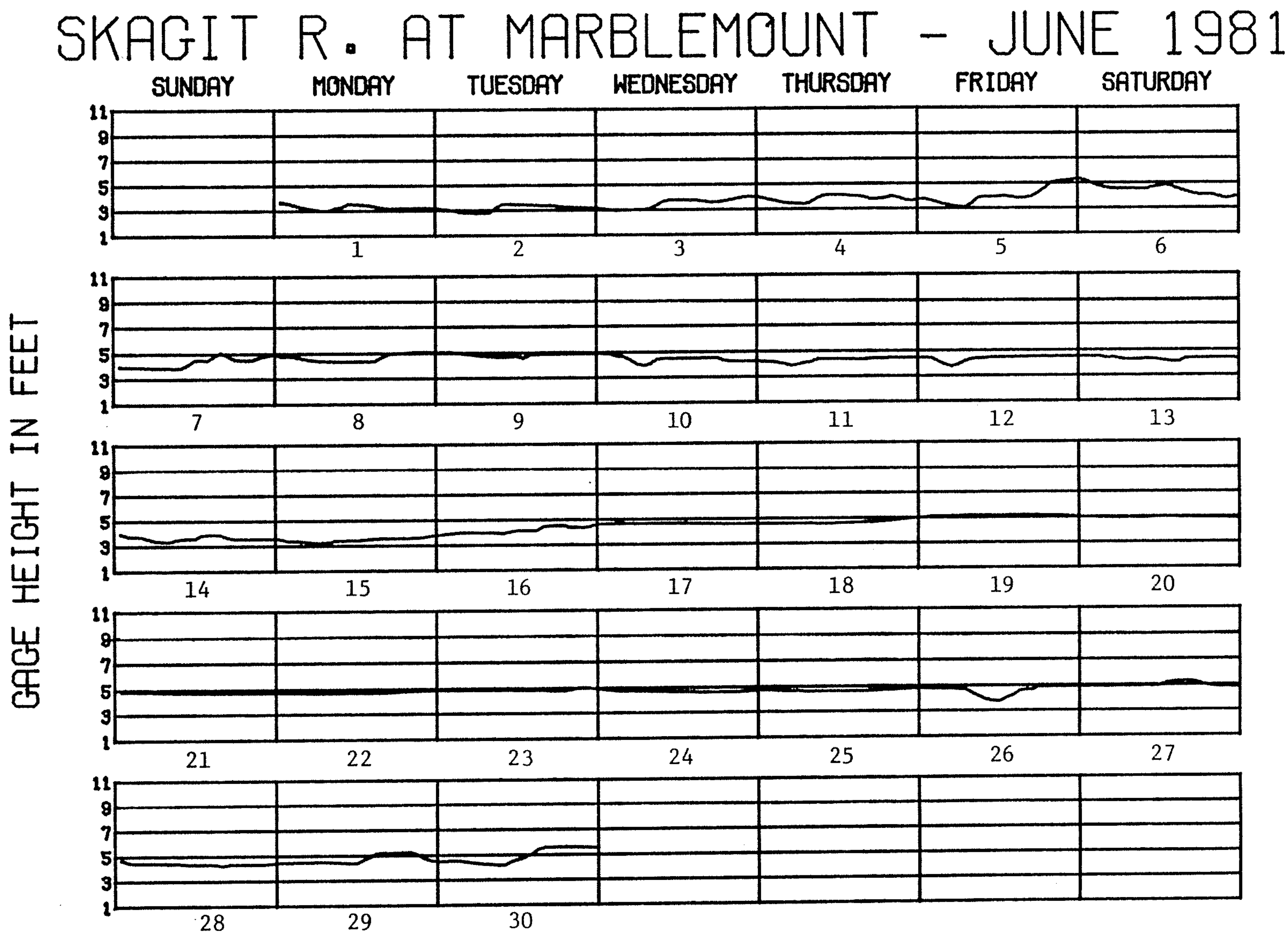
Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



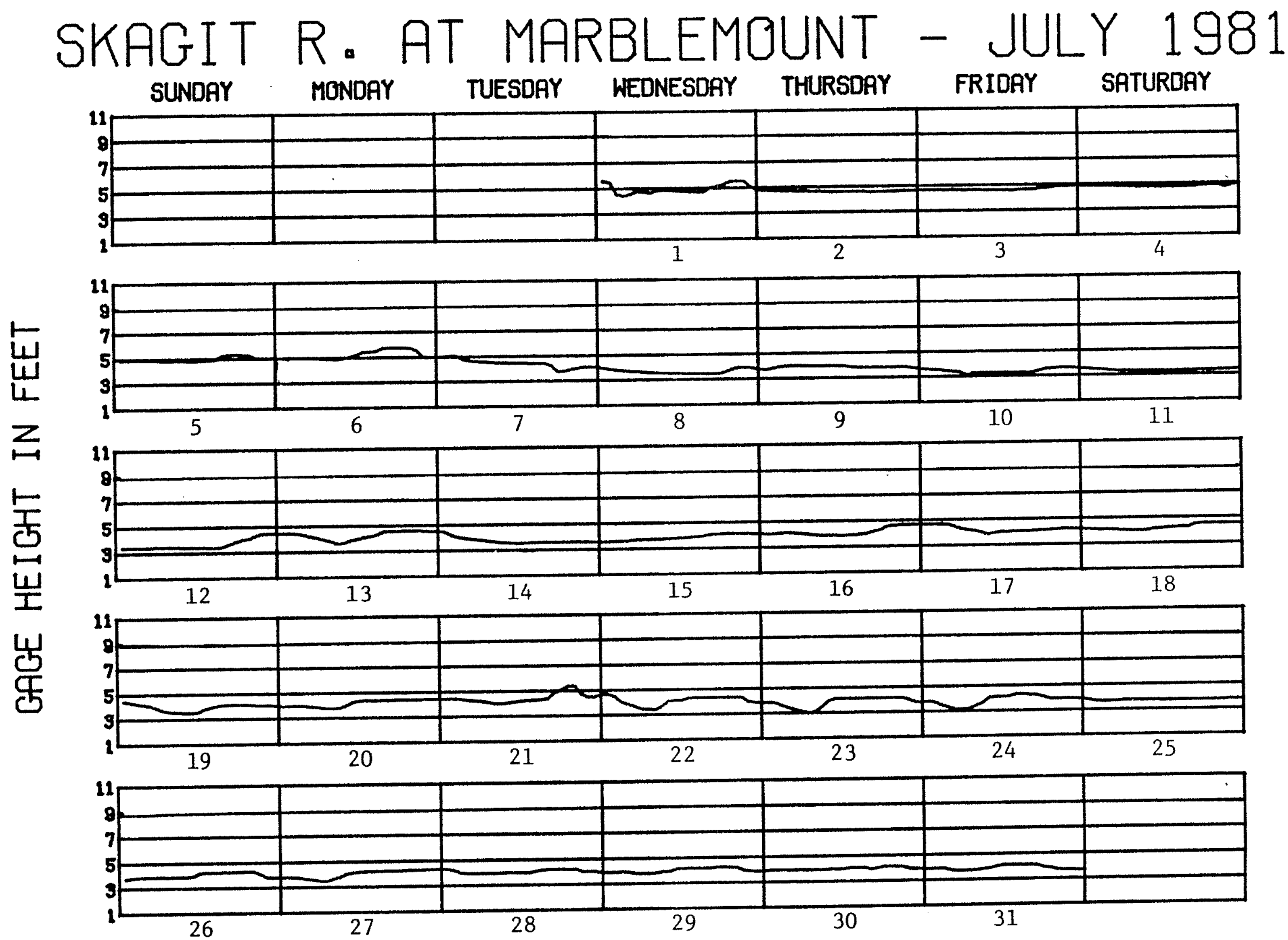
Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



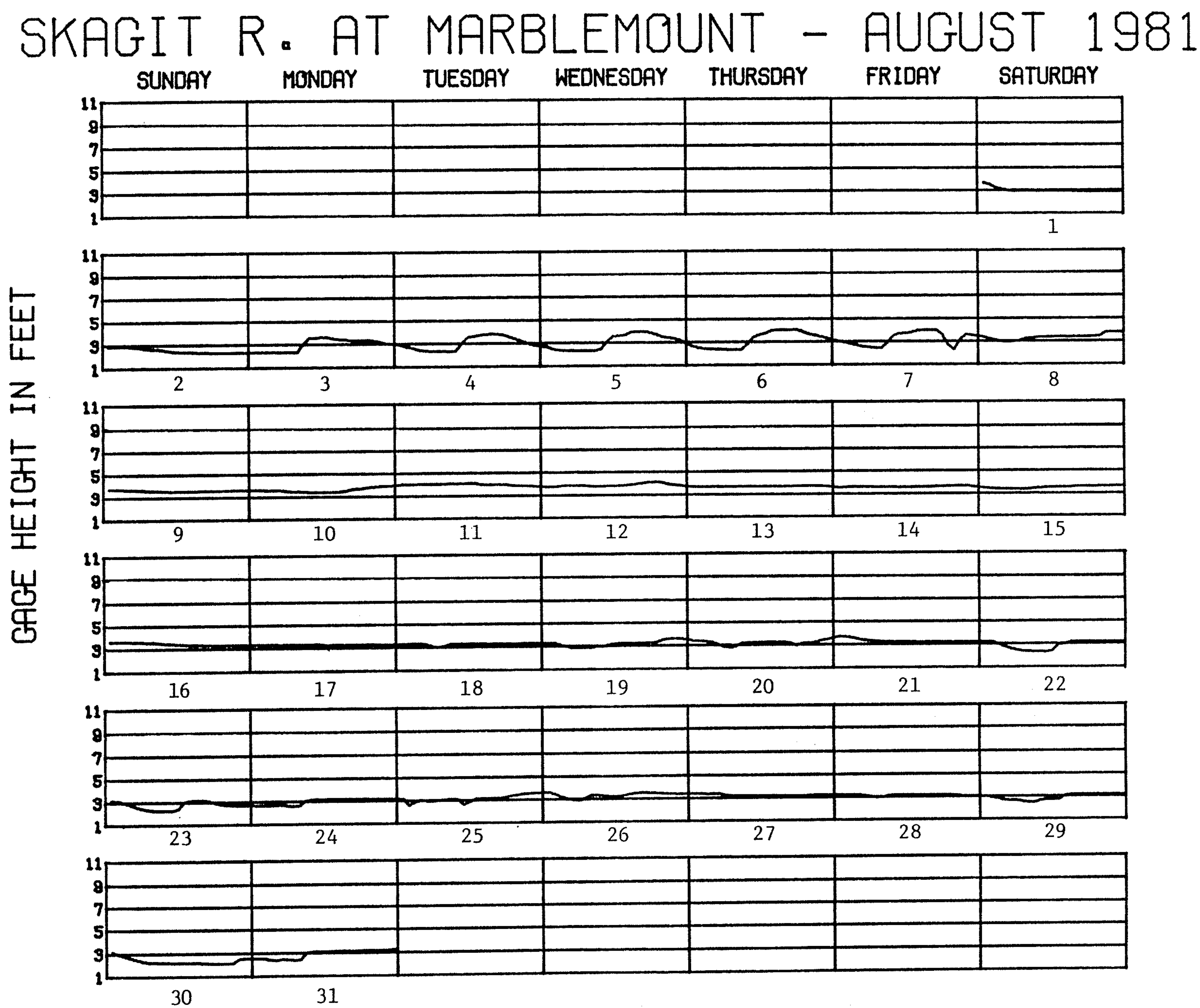
Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



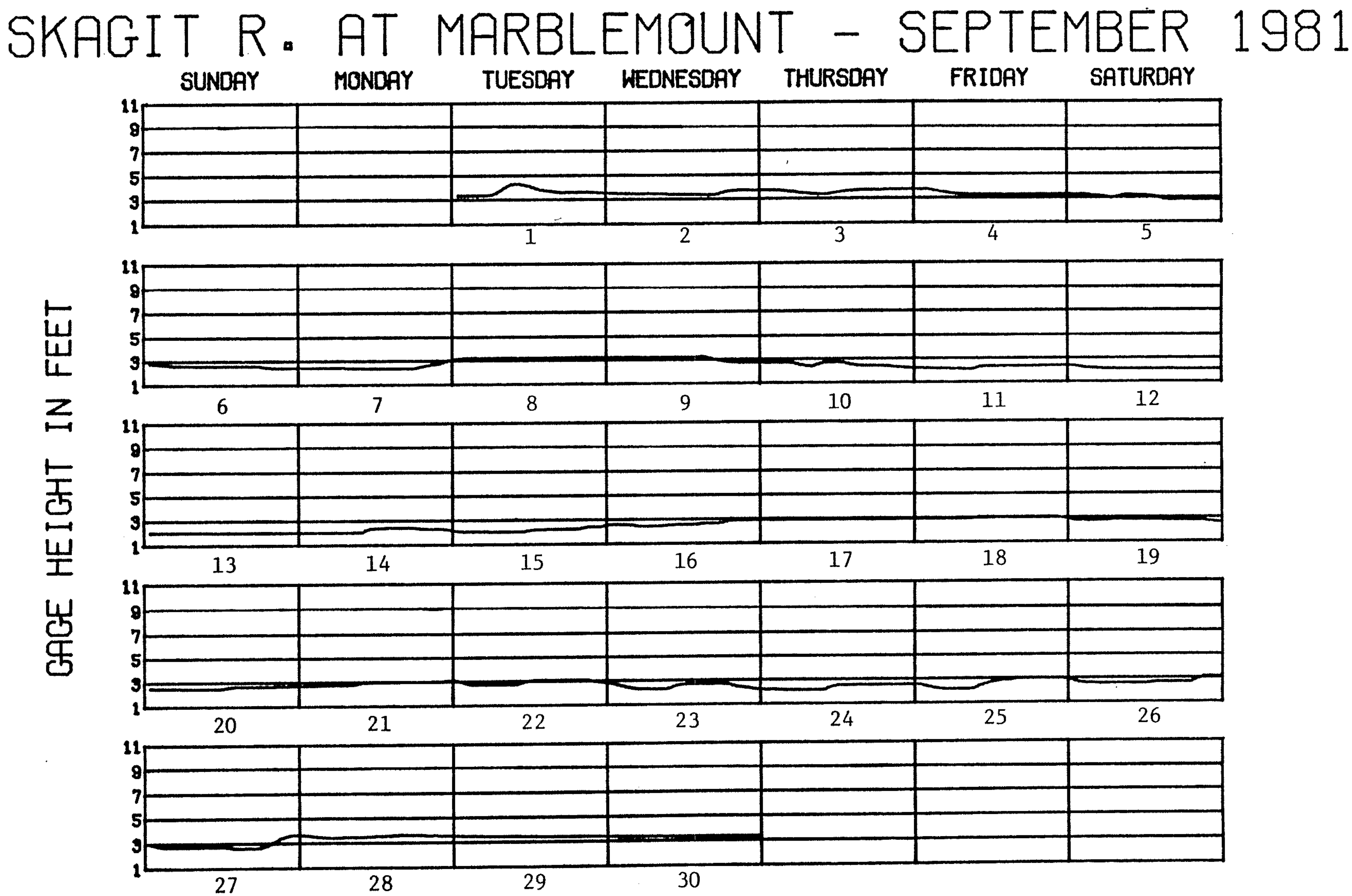
Appendix I, Figure 4. Hourly gage height data for Skagit River at Marblemount (USGS), January - December 1981. (Continued).



Appendix I, Figure 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 II

Appendix II Table 1. Thorton Creek site with base data.

The regression equation is

Y = -7.36 + .046 X 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	--	-7.364	33.98	-0.22
X1	C3	.046	0.03412	1.36

The St. Dev. of Y about regression line is
S = 46.38
with (10- 2) = 8 degrees of freedom

R-squared = 18.8 percent
R-squared = 8.6 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	4517	4517
Residual	8	19521	2440
Total	9	24038	

Appendix II Table 2. Thorton Creek site with transformed data.

The regression equation is

Y= -1.81 + .723 X 1

	Column	Coefficent	St. Dev. of Coef.	T-ratio = Coef/S.D.
	--	-1.809	3.460	-0.52
X1	C5	0.7227	0.5189	1.39

The St. Dev. of Y about regression line is
S = 0.8698
with (10- 2) = 8 degress of freedom

R-squared = 19.5 percent
R-squared = 9.5 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	1.4671	1.4671
Residual	8	6.0520	0.7565
Total	9	7.5191	

Appendix II Table 3. Marblemount site with base data.

The regression equation is

Y = -39.7 + .112 X 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	--	-39.67	51.97	-0.76
X1	C1	0.11234	0.05218	2.15

The St. Dev. of Y about regression line is
S = 75.54
with (10- 2) = 8 degrees of freedom

R-squared = 36.7 percent
R-squared = 28.8 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	26450	26450
Residual	8	45654	5707
Total	9	72104	

Appendix II Table 4. Marblemount site with transformed data.

The regression equation is

Y = -6.95 + 1.50 X 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	--	-6.953	6.585	-1.06
X1	C5	1.4956	0.9876	1.51

The St. Dev. of Y about regression line is
S = 1.655
with (10- 2) = 8 degrees of freedom

R-squared = 22.3 percent
R-squared = 12.6 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	6.284	6.284
Residual	8	21.920	2.740
Total	9	28.205	

Appendix II Table 5. Rockport site with base data.

The regression equation is

Y = 31.3 + .111 X 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	--	31.33	52.17	0.60
X 1	C1	0.11088	0.05238	2.12

The St. Dev. of Y about regression line is
S = 75.83
with (10- 2) = 8 degrees of freedom

R-squared = 35.9 percent
R-squared = 27.9 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	25763	25763
Residual	8	45999	5750
Total	9	71762	

Appendix II Table 6. Rockport site with transformed data.

The regression equation is

Y = -1.21 + .879 X 1

	Column	Coefficient	St. Dev. of Coef.	T-ratio = Coef/S.D.
	--	-1.211	2.470	-0.49
X 1	C5	0.8787	0.3704	2.37

The St. Dev. of Y about regression line is
S = 0.6208
with (10- 2) = 8 degrees of freedom

R-squared = 41.3 percent
R-squared = 34.0 percent, adjusted for D.F.

Analysis of variance

Due to	DF	SS	MS=SS/DF
Regression	1	2.1692	2.1692
Residual	8	3.0830	0.3854
Total	9	5.2522	