THE EFFECT OF WATER FLOW REGULATION AT GORGE DAM ON STRANDING OF SALMON FRY IN THE SKAGIT RIVER 1969-1970

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INTRODUCTION

There have been numerous reports in past years of salmon fry, primarily chinook salmon, becoming stranded by rapidly receding water levels in the Skagit River from Newhalem downstream to Hamilton, Washington, a distance of about 57 miles (Figure 1). Large numbers of salmon fry were reportedly stranded and died in the Marblemount-Rockport area during February and March of 1966 and 1967, but none were observed in 1968. The rapid fluctuation of the river level between Newhalem and Concrete, Washington is caused by the regulation of flow releases from Gorge Dam.

Salmon fry, newly emerged from the gravel, tend to seek the quieter waters near the river banks. During periods of high flow, the river bars are submerged, but waterflow manipulation at dams can expose the river bars and strand salmon fry before they can swim to the deeper sections of the river. Once the stranded fish are exposed, they are helpless and subsequently die.

Seattle City Light, hydroelectric developers of the Skagit River, and the Washington Department of Fisheries entered into a cooperative study as part of the license requirements of the Federal Power Commission. The resulting study conducted during March 1969 and 1970 was designed to learn if water flow regulation at Gorge Dam was responsible for fry stranding and, if so, what operating procedures were necessary to alleviate the problem.

AVAILABILITY OF SALMON FRY

The study area in the Skagit River from Marblemount to Concrete, Washington, contains excellent salmon spawning area and is used intensely by chinook, pink, and chum salmon for spawning. Coho salmon use the river for rearing, but most of the spawning occurs in the tributaries.

The low flow tests were timed to occur when large numbers of salmon fry were in the upper Skagit River. This was determined by electro-fishing on the gravel bars. During March of both years, large numbers of chinook fry were available.

TESTING METHODS

Two methods were used for making biological observations of salmon fry stranding. The first year, three sampling areas were established and most of the observations were restricted to these areas. The following year, general observations were made between Marblemount and Rockport by floating the river.

The three areas picked for biological observations of salmon fry stranding in 1969 were Marblemount, Rockport, and Ovenell bars. The uppermost area, Marblemount Bar, was located 18 miles below Gorge Dam. The bar extends from above the Marblemount Bridge downstream for approximately 1/2 mile (Figure 2). The second sampling area was established at Rockport Bar, approximately 9 miles downstream from Marblemount (Figure 3). Another sampling area at Ovenell Bar, near Concrete, was about 11 miles below Rockport (38 miles below Gorge Dam). All three sampling areas were reportedly areas where dead salmon fry were observed in 1966 and 1967.

Reference survey lines were established at right angles to the river bank in each study area. A reference stake was set immediately above high water and the distance from the stake to the water edge was measured. River stage stakes were placed on the reference line for measurement of the relative water elevation. The two measurements were made at 15-minute intervals during the tests and commenced prior to the effect of a flow reduction at the sample site and continued until the end of the test.

Observations were made in 1970 by drifting the river and on foot from Marblemount downstream to the mouth of the Sauk River, 1/2-mile downstream from Rockport. One boat was launched at daybreak from Marblemount and another boat at Washington Eddy Bar (about 7 miles downstream). A third survey party examined some bars on foot.

Bird predation, primarily by crows and robins, was quite intense on the stranded fry; consequently, the observations began as soon after daybreak as possible. This was a serious sampling problem on the Sultan River below Culmback Dam (FPC Project No. 2157) during the tests made there in 1967.

Permission was received from the U.S.G.S. to monitor their gaging station during the low flow tests. The eight recording gages listed below were examined:

Skagit River near Newhalem, Washington
Skagit River above Alma Creek near Marblemount, Washington
Skagit River Marblemount, Washington
Cascade River at Marblemount, Washington
Sauk River near Sauk, Washington
Skagit River near Rockport, Washington
Skagit River near Concrete, Washington
Baker River at Concrete, Washington

The gages were read at 15-minute intervals except for the U.S.G.S. gage on the Skagit River near Concrete, Washington which prints each 1/2 hour. Seattle City Light hourly readings of the Newhalem gage were used in preference to reading the Newhalem gage directly. In 1970, only the first five gages were used.

The Department of Fisheries provided Seattle City Light with a proposed plan for water flow releases at Gorge Dam prior to commencing each test series. The City arranged their power loading schedule to accommodate the tests and made the initial power reductions at midnight because, generally, the timing of reduced power loads occurs about this time. It was desired to have the tests duplicate as near normal procedures as possible.

The initial study of salmon fry mortalities caused by stranding occurred from March 12-14, 1969, and required a controlled flow for a period of 46 hours. Figure 4 depicts the flow release schedule at Gorge Dam that was required during the test period. All flow adjustments were made as rapidly as possible, and the flow increases on the second test day were made in 2-hour increments.

The second test series occurred from 1800 hours on March 27 to 2200 hours on March 30, 1969 (Figure 5). All increases and decreases in water flows during the test were made as rapidly as possible and the increment increases were extended to 4-hours duration.

The third and fourth test series were made in 1970. The third series occurred on March 7 and 8 when 1,300 and 1,100 cfs, respectively, were released during the low flow period (Figure 6). The fourth series consisted of three tests on March 12, 13, and 14. The low flow release from Gorge Dam on March 12 was 2300 cfs, and on March 13 was 1,100 cfs. On March 14, the flow was reduced abruptly at midnight down to 2,500 cfs, remained stable for 1 hour, then reduced gradually to 1,300 cfs over a 6-hour period (Figure 7).

A high-water condition was created before each flow reduction from Gorge Dam. During the 1969 tests, a flow of 5,000 cfs was released from Gorge Dam for 6 hours before reducing the flow. In 1970, flows of 5,000 cfs or greater were released for a period of 4 hours prior to commencing a test.

RESULTS

The river below Gorge Dam was examined during low flow water releases at Gorge Dam from flows of 2,500 cfs to 1,100 cfs during the 2 years of testing (Table 1). Five tests (two test series) were made in 1969 and 6 tests (three test series) in 1970.

1969 Test Results

The tests were designed to observe the fry stranding problem during various flows at Marblemount, Rockport, and Ovenell Bars in relation to river stage and the exposed width of the gravel bars.

2,500 cfs water release at Gorge Dam (March 13)

The first regulated flow reduction occurred at midnight when flow was reduced from 5,000 cfs to 2,500 cfs on March 13 (Table 1, Figure 4). The weather conditions were cold with snow covering the ground and tributary inflow below Gorge Dam was low because of the freezing weather.

Marblemount Bar. Observations were limited to within 300 feet of Reference Line No. 1 located about 1/3-mile downstream from the bridge where dead salmon fry had been reportedly seen in 1966 (Figure 2). Stranding was not observed and only a few fish were seen along the perimeter of the river. A pothole containing large numbers of fry behind the bar did not drain, therefore, no mortality occurred here. Reference Line No. 1 measurements indicated little change in the exposed bar width because of the low flow.

The U.S.G.S. gage, Skagit River at Marblemount, is located about 1/2-mile above Marblemount Bar. No tributaries enter the Skagit River between these two points. Unfortunately, a water flow rating table is not available for the Marblemount River stage gage, therefore, the flow passing Marblemount was calculated by the following method:

1. The water flow of 2,500 cfs at Newhalem (Gorge Dam) can be measured quite accurately. The water flow release is given in rounded figures, but the actual flow was quite close to the recorded water release.
2. The tributary inflow from U.S.G.S. gage, Skagit River at Newhalem, Washington, to the recording gage, Skagit River above Alma Creek near Marblemount, Washington, has a drainage area of 100 square miles. The inflow was calculated at 168 cfs by subtracting the flow at the Newhalem gage (2,500 cfs) from the total low flow (2,668 cfs) recorded at the Alma Creek gage.
3. Likewise, the tributary inflow from the U.S.G.S. gage at Alma Creek to the U.S.G.S. gage, Skagit River at Marblemount, Washington, drains from a 100 square mile area. Consequently, it was assumed the tributary inflow will be roughly the same (168 cfs) although it is realized other factors may influence flows between the two drainage areas.

The flow at Marblemount as calculated by the above method was 2,836 cfs on this first test day when 2,500 cfs was released from Gorge Dam (Table 1).

Rockport Bar. Two chinook were stranded in the sample area on the Rockport Bar located 9 miles downstream from Marblemount (Figure 3). No attempt was made to calculate the river flow at Rockport.

Ovenell Bar. At Ovenell Bar, six chinook fry were stranded on a large flat near the upstream end of the bar. Most of the bar area consists of relatively cleaner and smaller gravel (under 4 inches in diameter) than the upper two sampling areas, except for the flat area. No stranding was observed on that part of the bar containing the cleaner gravel.

It was hoped that the flows at Ovenell Bar could be calculated, however, the U.S.G.S. gage, Skagit River near Concrete, Washington, was difficult to interpret because of the large variation in flows from the Baker River hydroelectric plant.

1,400 cfs water release at Gorge Dam (March 14)

At midnight, March 14, the flow was abruptly dropped from 5,000 cfs to 1,400 cfs at Gorge Dam (Table 1, Figure 4). The weather conditions remained clear and cold resulting in little tributary inflow into the Skagit River.

Marblemount Bar. Stranded salmon fry were not observed in the immediate area of the reference line; however, at daybreak, the river bar was examined for 1/3-mile upstream to the Marblemount Bridge and large numbers of dead fry were observed. Reference Line No. 2 and a new sampling area within the area of fry stranding was established at this time (Figure 2).

A 750 Sq ft plot (15' x 50') was closely examined, and 25 fry - 1 fry per 30 sq ft - were found. The top layer of rocks was removed from the bar surface in some sampling plots, but no additional fry were found. A minimal estimate of 2,500 fry were killed by stranding on Marblemount Bar based on 1 fry per 30 sq ft of bar area, but scavenging by crows and robins markedly affected the concentration. Past studies have demonstrated the scavenging by birds can very rapidly obliterate evidence of stranded fish.

A fairly even distribution of fry was seen over the bar area with a few more near the side next to the river and on the back side of the bar. Depressions in the gravel bars had the largest numbers of dead fry. The bar surface, where fry stranding occurred, was covered with a thin layer of brown silt.

The gravel in the area of the original reference line was clean and the bar contour indicated a greater slope to the river. This may have guided fry into the running river more efficiently or the fry may have been able to readily penetrate the gravel.

The estimated flow at Marblemount was 1,752 cfs based on the previously described method of calculating the flow (Table 1). The inflow from Gorge Dam to the Alma Creek gage indicated 176 cfs and an estimated flow of 176 cfs occurred from Alma Creek gage to the Marblemount staff gage.

Approximately 87 ft of bar area was exposed in the newly established sampling area about 600 ft below the Marblemount Bridge where large numbers of fry were killed (Figure 8).

Rockport Bar. The flow reduction to 1,400 cfs at Gorge Dam likewise caused stranding problems at Rockport Bar. When the first visual observations at daylight were made, many fry were alive but confined in potholes immediately behind the gravel bar. These fish became stranded as the water level receded.

A sampling area 150 ft long and extending from 47 to 100 ft wide (11,100 sq ft), was carefully examine (Figure 3). The dead chinook fry count was 105 with 2% of these stranded on top of the bar, 8% on the side nearest the river, and the remaining 90% trapped in the pothole area. Two 10 x 10 ft plots were closely inspected by moving the top layer of boulders, but no fry were observed that penetrated below the surface of the area examined. It is my opinion that this would occur very seldom, especially in the pothole area where siltation was heavier. No estimate was made for fry mortalities over the entire area of Rockport Bar that was exposed by the low water. The fry mortality in the pothole area was not caused so much by stranding fish on the bar, but trapping fish within the potholes that eventually went dry.

The reference line at Rockport was exposed for a distance of 77 ft (Figure 9).

Ovenell Bar. Six fry were stranded on the flat area of the bar covered with a thin layer of silt. Fry could be seen along the beach near the river but the steeper slope of the bar probably guided them into deeper water. Few were stranded in contrast to the large numbers stranded at Marblemount and Rockport Bars.

The reference line located on the clean gravel beach indicated the water receded about 46 feet horizontally during the low flow test of 1,400 cfs (Figure 10). An exposed reference line would have been considerably longer if it had been located on the large flat area of the bar where limited stranding was observed.

2,500 cfs water release at Gorge Dam (March 28)

The second series of tests between March 28-30 commenced with a flow reduction of 2,500 cfs from 5,000 cfs at the Gorge Dam powerhouse (Figure 5, Table 1). Examination was limited to Rockport and Marblemount Bars. Warmer weather caused the tributaries to greatly increase in flow over the previous test series. General observation indicated more salmon fry were in the area than during the previous test series.

Marblemount Bar. Eight salmon fry were found stranded in a 3,000 sq ft area in the Marblemount Bar study area resulting from the rapid drop to 2,500 cfs, measured at Newhalem (Gorge Dam). The area of large kill observed on March 14 (1,400 cfs release) was completely covered with water. Live fry were readily visible in a pothole and slough area behind Marblemount Bar, and large numbers were observed along the perimeter of the bar area. The river remained nearly "bank full' during the test with only 17 ft of the gravel bar on the reference line exposed (Figure 8). The calculated flow at Marblemount was 3,686 cfs (Table 1).

Rockport Bar. The flow reduction to 2,500 cfs at Newhalem resulted in 13 fry stranding in the pothole area and trapping about 75 fry within the confines of the pothole area that were not killed. Very little bar area was uncovered by this low test (Figure 9).

1,800 cfs water release at Gorge Dam (March 29)

The following day, the water release at Gorge Dam was reduced from 5,000 to 1,800 cfs, 700 cfs less than the previous day.

Marblemount Bar. The upper part of the bar was exposed and shallow depressions still contained water. A total of 11 fry were stranded in an area roughly 4,000 sq ft. About 47 ft of the reference line was exposed at low flow (Figure 8). The calculated flow at Marblemount was 2,990 cfs (Table 1). An additional drop in river stage of 0.5 ft would have exposed an extremely large area of the bar.

Rockport Bar. Eight chinook, two chum fry, and one trout were stranded in the sampling area. All those killed were held captive in a pothole that eventually went dry.

1,400 cfs water release at Gorge Dam (March 30)

The third flow reduction of this test series was from 5,000 cfs to 1,400 cfs released from Gorge Dam and duplicated the flow release made during the earlier test that was so destructive to the chinook salmon fry, however, tributary inflow had markedly increased.

Marblemount Bar. The area examined was approximately 4,500 to 5,000 sq ft and three fry were found, but the river stage was considerably higher at Marblemount than the previous 1,400 cfs test on March 14 (Figure 8). The flow at Marblemount was calculated at 2,820 cfs, about 1,000 cfs greater than the earlier test.

Rockport Bar. Seventeen chinook and 1 chum fry became stranded during this test. The area exposed was considerably less than the area exposed in the 1,400 cfs release in the first test series and the fry were stranded in the higher potholes or debris near the perimeter of the potholes. Thirty-two ft of the reference line was exposed during the test because of higher tributary inflow (Figure 9).

1970 Test Results

The 1970 salmon fry mortality tests were performed to confirm the findings from the 1969 tests and to determine what flow would significantly reduce fry mortalities.

The area from Marblemount downstream to the mouth of the Sauk River, 1/2-mile downstream from Rockport, was examined by floating the river and on foot to determine the area of fry stranding at various river flows.

1,300 cfs water release at Gorge Dam (March 7)

At midnight, the water flow released from Gorge Dam was reduced to 1,300 cfs from a flow exceeding 5,000 cfs. This flow release was regulated to produce a flow of about 1,700 cfs at Marblemount that would duplicate the 1969 test when large numbers of chinook salmon fry were stranded: however, unpredicted torrential rains raised all the creeks during the night with 1.4 inches of rain falling in 24 hours.

Marblemount Bar. A total of 850 sq ft in three sample areas was examined for dead salmon fry. Seventeen stranded fish were found or a total of 1 fish per 50 sq ft, but this statistic cannot be applied to the entire gravel bar area because most of the fish were confined in a shallow depression between the river bank and bar. Other fish were contained in depressions outside of the sample area, but the sample area did contain a larger percentage of the fry. A large pothole near the downstream end of the bar, containing over 1,000 fry, did not drain during the test period.

Marblemount Bar was exposed for 48 ft and can be compared to the 1969 observations (Figure 8). Based on the Marblemount River stage gage and the Alma Creek gage, it would suggest flows of about 2,800 cfs occurred during the low flow, about 1,100 cfs greater than anticipated (Table 1).

Rockport Bar. Stranded fry were not seen at the Rockport Bar during the test. The reference line was exposed to a distance of 37 ft that can be compared to observations made in 1969 (Figure 9).

Washington Eddy Bar. This sample area located about 7 miles downstream from Marblemount was examined for fry mortalities, but none were observed.

Large numbers of fry were in the three sampling areas during the test, but the high tributary inflow provided flows in the Skagit River that prevented large numbers of fry from stranding.

The remainder of the test day was cancelled because of high water.

1,100 cfs water release at Gorge Dam (March 8)

The study at individual sampling stations was discontinued because of the heavy rains, but the river bars between Marblemount and Rockport were examined to observe areas where stranding problems exist.

Marblemount Bar. About 70 ft of bar area was exposed at the reference line and the flow was calculated at 2,152 cfs.

The float trip on the 10 miles of river indicated that nearly all river bars presented some problem. Although the bars were exposed enough to produce some stranding, few fry were actually found. Since large numbers of crows were in evidence all along the river, it was believed many of the stranded fish were eaten. Additional sampling areas were picked for use in the next test series, and it was determined that river bar inspections should commence at daybreak.

A second series of tests commenced on March 12, 1970 with three crews examining the river by boat and on foot commencing at dawn.

2,300 cfs water release at Gorge Dam (March 12)

Five river bars were closely examined. The uppermost, Marblemount Bar, revealed no dead fry in 9,000 sq ft. No stranding occurred in a high water slough above Illabot Creek. Likewise, the pothole area on Hooper Bar remained full of water. A high-water channel near Rockport upstream from the bridge is covered with potholes of varying size and elevations and the higher potholes that did drain, contained several fry. A river bar across from the Sauk River mouth showed one stranded fry, but a slightly lower flow would have caused 10 additional fry to be stranded in an adjacent pothole.

Additional bars were examined and only low numbers of fry were seen. Many of these were examined 1 to 2 hours after daylight and after bird predation could have removed some of the fry, but fry stranding was low. If the water flows remained the same over several hours, some potholes may have drained causing more stranding.

The flow at the Marblemount stage gage was estimated to be 3,000 cfs (Table 1). About 45 to 50 ft of river bar were exposed on the reference line.

1,100 cfs water release at Gorge Dam (March 13)

The river bars observed the previous day were again examined to observe the effects of a flow known to cause excessive stranding.

Large numbers of chinook fry were stranded. At Marblemount Bar, three 100 sq ft sample areas indicated 17 fry and 2 trout. Potholes were already dry at the upper end of the bar, and it is believed that bird activity disposed of a large number of stranded fish. Based on a statistic of one fry per 20 sq ft, at least 1,000 fry were killed on the Marblemount Bar alone (Plates 1 and 2). The Marblemount reference line revealed that 73 ft of the bar were exposed at low flows. The estimated flow at Marblemount was 2,100 cfs.

Hooper Bar revealed 52 dead fry in 7,500 sq ft. Some areas were examined earlier and showed several potholes contained from 5 to 50 fish. When examined later, they were completely drained with few fish in evidence. In one pothole, 25 fry were in the process of being stranded in the receding water (Plates 3 and 4).

A 6,000 sq ft area was examined near the upper end of Illabot slough. The area consists of large boulders (and smaller gravels) that prevented observation of all stranded fish; however, 30 fry and 1 trout were counted (Plate 5). Calculated on the area affected (more than 100,000 sq ft), there would be a minimal mortality of 500 to 600 fry, but very likely greater numbers were stranded. Bird activity was in evidence prior to the investigation, but predation cannot be estimated.

In the Rockport high-water channel, 32 fry were stranded in the early morning but bird predation had been in evidence. One and one-half hours later, two additional potholes that dried up stranded an additional five fish. In 2 hours, 15 potholes had drained that contained water earlier. Generally, if water levels remained low over an extended period, the stranding was compounded by the continuous draining of potholes. It is difficult to determine fry mortalities in the potholes in this area because the gravel in many potholes may be readily penetrated by fry and their survival is unknown. Some potholes trap fish at nearly the highest generating flow, however, the overall number of fish is low. The total number of stranded fry in this area is difficult to determine because of predation and gradual receding of water in potholes.

Variable water release from Gorge Dam (March 14)

The flow at Gorge Dam was abruptly dropped from 5,000 cfs to 2,500 cfs at midnight. Commencing at 0100 hours, the flow was lowered in stages as follows: 0100 hours - 2,525 cfs; 0200 hours - 2,370 cfs: 0300 hours - 2,205 cfs; 0400 hours - 2,029 cfs; 0500 hours - 1,870 cfs; 0600 hours - 1,680 cfs; 0700 hours - 1,531 cfs. The tributary inflow remained relatively high creating an estimated low flow at Marblemount of about 2,700 cfs (Table 1). The flow at Marblemount was difficult to interpret and perhaps this flow was as low as 2,500 cfs.

Incidental numbers of fry were stranded at Hooper Bar, but very few fry mortalities were observed in the other areas. There did not appear to be as many fry stranded in potholed areas; however, rain hampered the observations.

1,100 cfs water release at Gorge Dam (April 14)

Flows at Gorge Dam were reduced to 1,100 cfs on April 14 and observations were made on river bars along the Skagit River. Stranded fish were not seen on Marblemount Bar, but large numbers were seen in potholes containing water. Very few stranded fry were observed on river bars downstream. The reference line at Marblemount Bar was exposed for 55 ft and the flow at Marblemount estimated at 2,570 cfs (Table 1). The high tributary inflow prevented the fry stranding problem from producing serious consequences. The flow reductions were made during the daylight hours; that may influence the movement of fry from the potholes and tops of the bars.

Timing of fry

Electro-fishing indicated that chinook fry were emerging from the gravel in March and, consequently, were available during the tests. After the studies were terminated in 1970, electro-fishing was continued into May.

A 150-ft sampling section near Rocky Creek and a 100-ft sampling section at Rockport were established. The results of the electro-fishing are listed on Table 2. The species composition of the entire section of the river is closely reflected by the sampling. The numbers counted should not be construed to be the population of the sampling area because the shocking equipment is not efficient enough for this purpose. It is our opinion that the concentration of salmon fry was greater on April 24 than at any time during the low flow studies conducted during March, and more species were involved. Although significant numbers of fry were observed through May 21, chinook and chum densities were reduced. No pink salmon fry were in evidence after the May 4 sampling.

River Stage Measurements

The water flow reductions at Gorge Dam were made at midnight and the resulting river water stages measured at the three sampling stations in 1969. The increment increases in the water flows were incorporated into the study to determine what flows would cover the areas of greatest stranding, but proved difficult to use when related to stranding.

Marblemount Bar

A time lag of approximately 2 hours and 30 minutes was required for the first effect of the flow reduction to be measured at Marblemount Bar (Figures 11 and 14). About 3 hours were required for first influence of increased flows. The river stage during the very destructive flow reduction on March 14 reduced about 1.4 ft in 2 hours and 45 minutes, and the most rapid decline in water elevation was about .6 ft per hour over a 2-hour period. Nearly the same rate of drop was observed on March 29, 1969, but the river stage change was not as great.

Rockport Bar

The lag time for the first effect of the flow reduction at Rockport was about 4 hours based on the 4 days of observation in 1969 (Figures 15 and 18). The flows were increased at Gorge Dam at 0600 hours and the first noticeable effect at the Rockport study area was about 5 hours. The 2-hour flow increase steps used in the first test series were not discernible, but the 4-hour increment steps used in the following series were readily measured.

The largest tributary entering the Skagit between Marblemount and Rockport is the Cascade River. During the March 14, 1969 test, the river was flowing about 227 cfs as measured at the U.S.G.S. gage, Cascade River at Marblemount, Washington. On March 28, the flow had increased to 715 cfs and to 800 cfs on March 30, 1969.

Based on the above flows, it is presumed that the flow at the Rockport study area was about 2,100 cfs on March 14, 1969, the day a highly significant fry kill was observed. On March 30, 1969, the flow was estimated at 3,900 cfs, or that 2,500 cfs were entering the Skagit as tributary inflow between Newhalem and Rockport.

Ovenell Bar

The lag time for the first effect of the flow reduction at Ovenell Bar was about 5-1/2 hours on March 14, 1969 (Figure 19). The first effect of flow increased was about 8-1/2 hours based on the 1-day test. The rate of decline in river stage was roughly 0.3 to 0.4 ft per hour during most of the period involved, and occurred during daylight hours.

River Cross Sections

Cross sectional measurements of the Skagit River were made on March 28, 1969, at the Marblemount and Rockport reference lines. At Marblemount, the broad bar area, where the majority of the salmon fry stranding occurred, is on the right bank (Figure 20). The left bank is considerably steeper, and based upon bird activity, minimum stranding probably occurred.

Likewise, the cross section at the Rockport reference line indicates the problem area on the right bank with most of the problem created by draining potholes containing fish (Figure 21).

DISCUSSION AND CONCLUSIONS

Many people intimately acquainted with the Skagit River have mentioned occurrences of fry stranding on the river bars and have related it to the method of operation of the Seattle City Light dams. The area of greatest concern was downstream from Gorge Dam at Newhalem to Concrete, Washington, a distance of about 38 miles; however, fry stranding has been reported by fishermen downstream to Hamilton, Washington.

The salmon fry mortality studies performed under a cooperative agreement with the Seattle City Light and Washington Department of Fisheries were designed to learn what flow releases at Gorge Dam were required to prevent stranding of excessive numbers of salmon fry on river bars.

The tests indicated that several interrelated factors are important regarding the intensity of the salmon fry stranding problem. These are the species, seasonal availability of fry in the area, the tributary inflow, time of day the flow reduction occurs, the peaking flow followed by a low flow release from Gorge Dam, the duration of the low flow, and the topography of the river channel. These specific items are discussed separately as follows:

1. Species and seasonal availability - The tests indicate that chinook salmon fry were easily stranded. Chinook fry begin to emerge from the gravel in February and remain in the area until about May 15. Some chum salmon fry were also stranded during the tests, but sampling indicated that larger numbers were not available until after the tests had been completed. Chum fry have been reportedly stranded in large numbers in the past. Pink salmon fry emerge from the gravel in February and early March, but were not stranded in the tests, possibly because they remained in the deeper waters of the Skagit River and moved rapidly from the area. Coho fry did not appear in large numbers until May and stranding was not observed.
2. Tributary inflow - Several streams enter the Skagit River downstream from Gorge Dam. Some of the major tributaries are Goodell Creek, Damnation Creek, Cooper Creek, Bacon Creek, and Diobsud Creek. If these streams and other tributaries are high because of snow melt or rain, less flow is needed from Gorge Dam to prevent stranding in most of the area above the confluence of the Sauk River.
3. Time of day - The effect of day or night flow reduction on salmon fry stranding suggests that stranding is less if the rapid decreases in water volume are made during the daylight hours. Most of the tests were designed to evaluate near normal power plant operations where the power needs are reduced at night.
4. Peaking flow - A high flow release prior to a reduction in flow at Gorge Dam is necessary to produce a fry stranding potential. The tests were preceded by flow releases of 5,000 cfs or greater that forced the salmon fry to seek the perimeter of the river for more favorable conditions. Often the flow will be bordering the grassy banks behind the gravel bars. The high flows occur during the peak power demand.
5. Low flow - A rapid flow reduction following the high flow from Gorge Dam causes the stranding problems. The lower the flow, the greater the stranding problem. The low flows evaluated for the effect on fry stranding were between 2,500 and 1,100 cfs measured at Gorge Dam.
6. Duration of the low flow - Potholes or depressions containing fish take varying lengths of time to drain. Some potholes receded as fast as the river dropped while others were delayed over a period of time up to 3 or 4 hours. Potholes that do not drain completely sometimes confine the fish in a small area, and the fish are more susceptible to predation.

Briefly, the most severe salmon fry stranding conditions were noted when large numbers of salmon fry were present, the tributary inflow was low, a high flow release was followed by a low flow release from Gorge Dam, and the reduction occurred at night. A combination of all these factors produced serious fry stranding results to chinook salmon fry on the gravel bars in the area.

The studies indicated that about 2,800 cfs at Marblemount Bar were required after a peaking flow to prevent fry from stranding in the section of river downstream to Rockport. If the flow declined to 1,700 cfs at Marblemount Bar following a peaking flow, the damage was extraordinarily severe.

In February, March, and early April, there are days when the tributary inflows to the Skagit River are reduced because of low rainfall or freezing weather. The fry stranding can be severe when these conditions are coupled with low flow releases from Gorge Dam. As the spring season progresses, the tributary inflows to the Skagit generally increases with fewer intermittent low flows occurring. Possibly for this reason, there have been fewer reports of salmon fry stranding during May and June than during the months of March and April.

Accordingly, a single fixed minimum flow from Gorge Dam is not essential, but a flow of approximately 2,800 cfs measured at Marblemount will markedly reduce the stranding problem. This includes tributary inflow between Gorge Dam and Marblemount. For example, one test required a release of 1,400 cfs at Gorge Dam and resulted in about 1,700 cfs (including tributary inflow) passing Marblemount, whereas another test, 15 days later, had the same water release (1,400 cfs) at Gorge Dam and the flow was about 2,800 cfs at Marblemount because of tributary inflow.

Salmon fry stranding was demonstrated to occur downstream to the mouth of the Sauk River; however, no serious damage was observed below this point during the tests. Given proper conditions, it is believed that stranding could occur further downstream. In the past, stranded fish were reported downstream from Concrete, Washington, but this could be in some way affected by water releases at Baker Dam on the Baker River where flows will vary down to a minimum flow of about 100 cfs.

The City of Seattle is presently required to maintain a minimum flow of 1,000 cfs measured at the U.S.G.S. gage, Skagit River at Newhalem, Washington. A temporary agreement between Seattle City Light and Washington Department of Fisheries provided for a minimum flow of 2,300 cfs for release at Gorge Dam from February 1 to April 15, 1970.

RECOMMENDATIONS

Stranding of salmon fry can be materially reduced in the Skagit River by maintaining a minimum flow of 2,800 cfs at Marblemount from February 1 to May 15. This flow would include the Gorge Dam flow release and tributary flows into the Skagit River downstream to Marblemount Bridge. Much of the time, the tributary inflow is high, especially during April and May; consequently, minimum flows at Gorge Dam can be adjusted by utilizing the tributary inflow. Possibly the inflow could be calculated if an automatic recording river stage gaging station was established on a typical tributary between Newhalem and Marblemount.

The following flow release schedule is suggested if Seattle City Light would find it more advantageous to assign minimum flows from Gorge Dam during certain portions of the season:

February 1 to April 15 - 2,300 cfs
April 15 to May 1 - 2,000 cfs
May 1 to May 15 - 1,700 cfs

The scope of this study limits flow regulation recommendations to the months fry stranding is likely to occur. The effect of flow regulation on spawning adult salmon and on salmon incubation must be examined if flow regulation recommendations are to be made for the remainder of the year.

ACKNOWLEDGMENTS

The cooperation and interest of Mr. C. L. Bradeen and by the many Seattle City Light personnel at Gorge Dam and Seattle is gratefully acknowledged.

The valuable recommendations and assistance by William H. Rees, Lloyd O. Rothfus, Russel Orrell, and Jack Olds is greatly appreciated.

A P P E N D I X I

Tables 1 through 2

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Table 1. Minimum water releases at Gorge Dam and estimated flow at Marblemount during low flow.

Date	Gorge Dam Minimum flow releases	Tributary inflow - to Alma Creek gage station	Tributary inflow below Alma Creek gage station	Est. total Skagit River Flow at Marblemount	Stage gage at Marblemount	Marblemount Bar (exposed area)	Cascade River Flow	Cascade River Stage
				1969				
March 13	2,500	168	168	2,836	2.60		230	1.67
March 14	1,400	176	176	1,752	2.08	87 ft	230	1.67
March 28	2,500	593	593	3,686	2.95	16 ft	700	2.95
March 29	1,800	595	595	2,990	2.70	47 ft	715	2.95
March 30	1,400	710	710	2,820	2.63	48 ft	855	3.22
				1970				
March 7	1,300	756	756	2,812	2.55	48 ft	700	2.95
March 8	1,100	526	526	2,152	2.22	70 ft	550	2.65
March 12	2,300	352	352	3,004	2.66	45 ft	380	2.19
March 13	1,100	500	500	2,100	2.19	73 ft	435	2.33
March 14	1,500 1/	598 2/	598	2,696 3/	2.43 3/	-		
April 14	1,100	735	735	2,570	2.50	55 ft	600	2.72

1/ Variable flow reduction - flow 2,500 down to 1,500 cfs from midnight to 0700 hours March 14.

2/ Estimated tributary inflow from Newhalem to the Alma Creek gage station.

3/ Approximate lowest flow.

Table 2. Skagit River electro-fishing samples, 1970.

Date	Location	Chinook	Coho		Chum	Pink	Trout
			0's	1's			
April 24	Rocky Creek	209	28	1/	8	16	-
May 4	Rocky Creek	104	11	25	2	3	10
	Rockport Bar	20	25	1	41	9	2
May 14	Rocky Creek	33	92	23	2	0	7
	Rockport Bar	7	37	9	50	0	11
May 21	Rocky Creek	17	66	8	0	0	1
	Rockport Bar	5	83	1	27	0	2

1/ Large numbers believed to be hatchery planted.

A P P E N D I X II

Figures 1 through 21

Pages 22 through 42

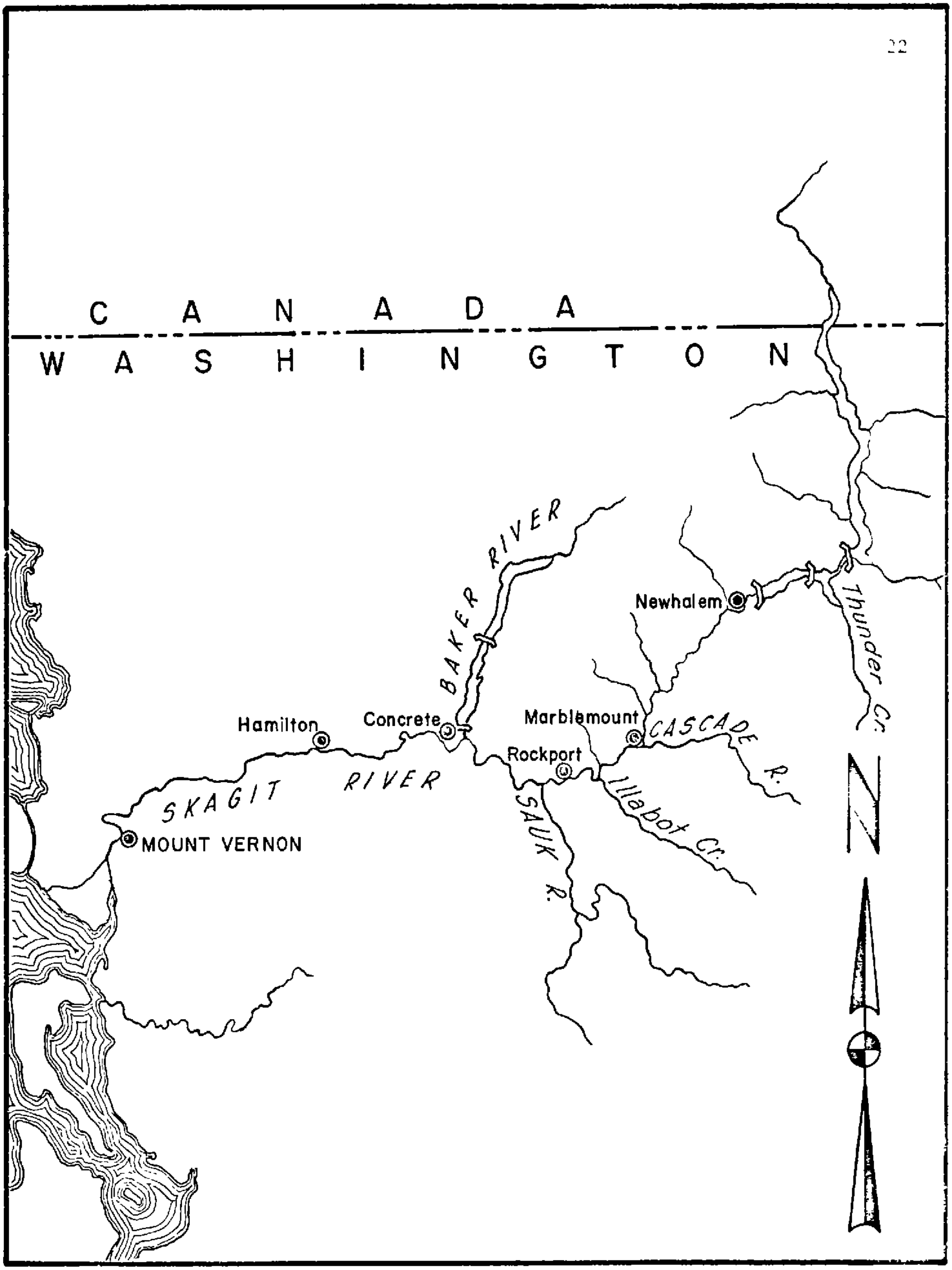

Figure 1. Map of the Skagit River.

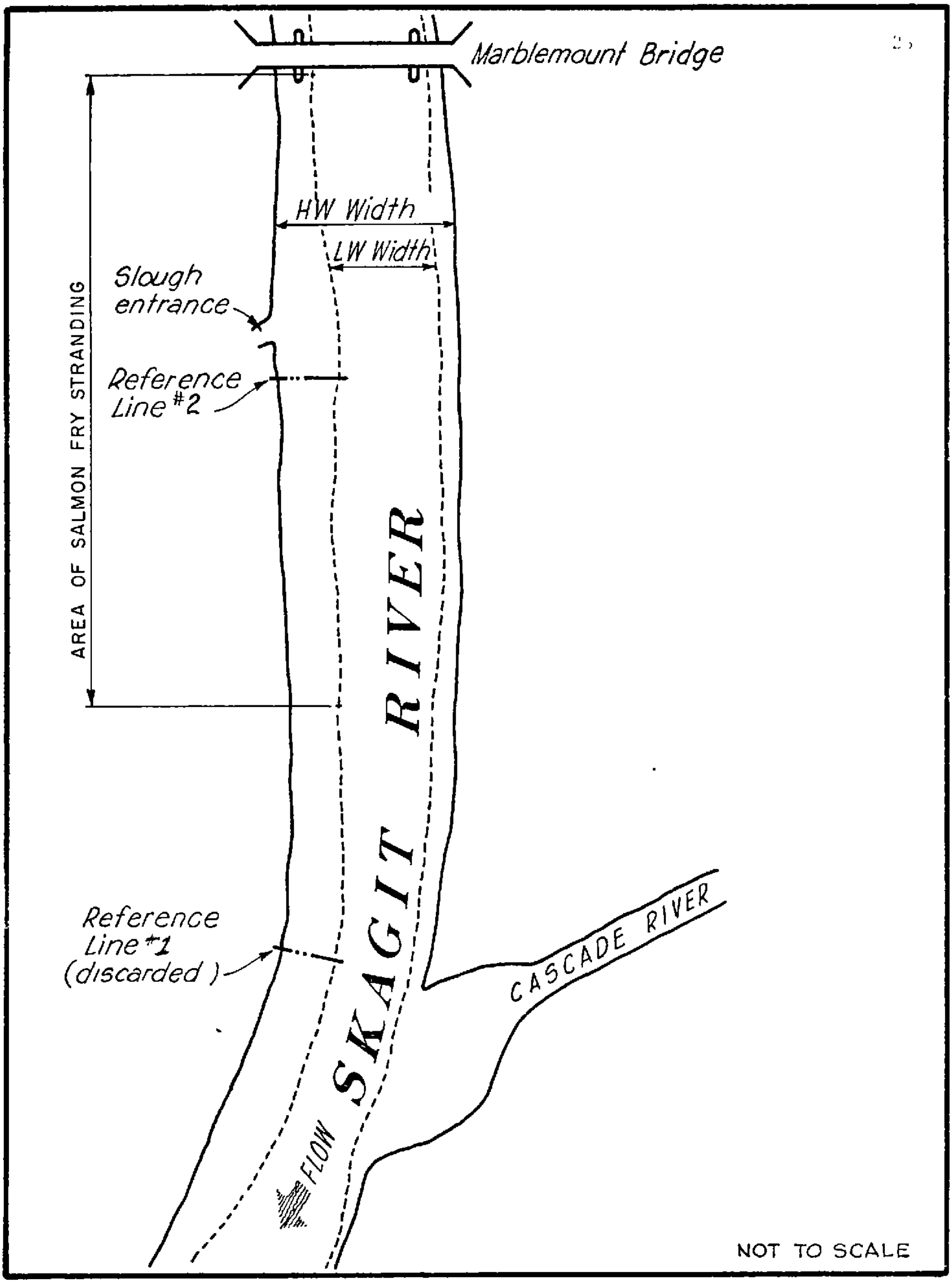

Figure 2. Diagram of Marblemount Bar study area.

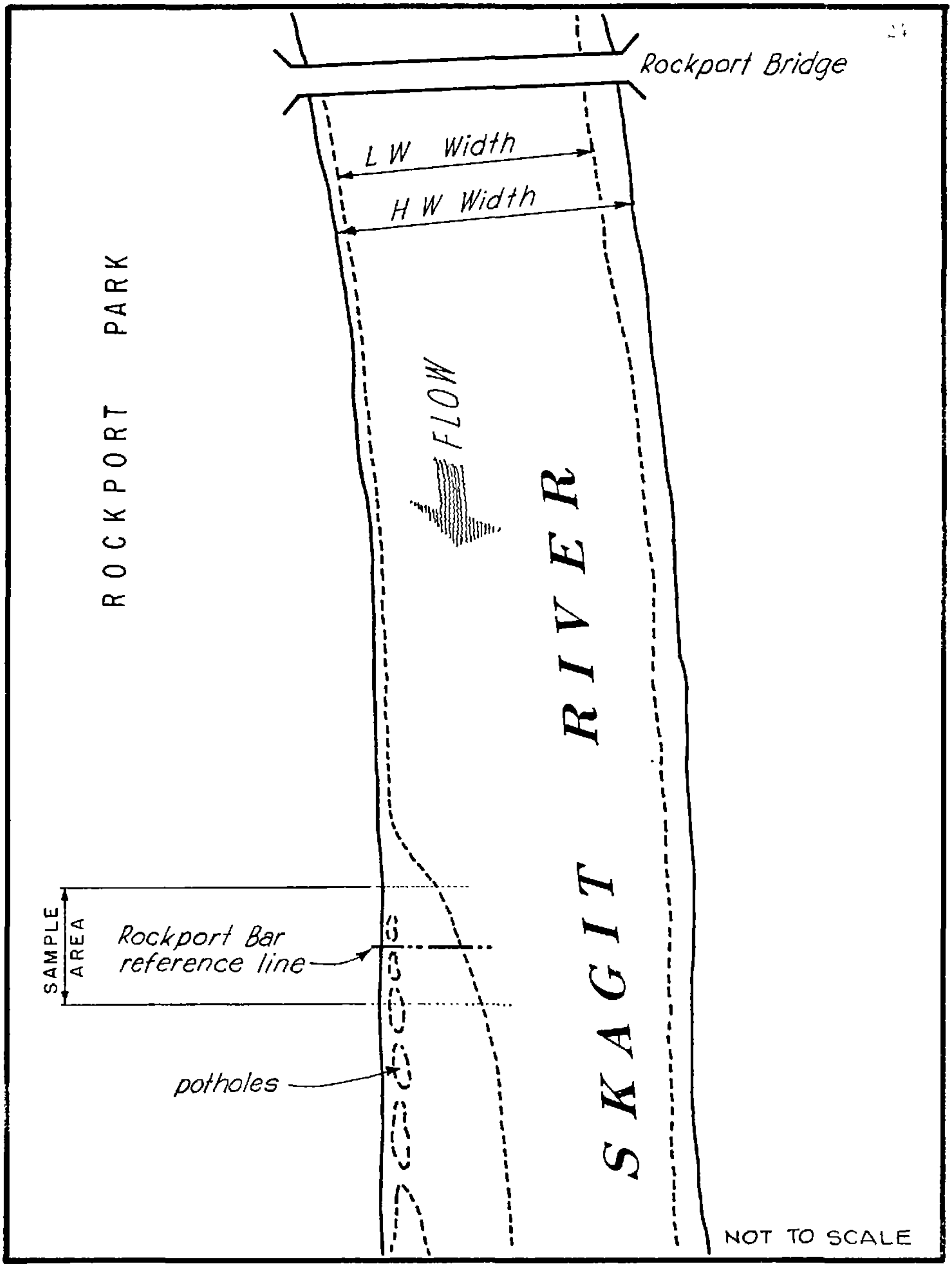

Figure 3. Diagram of Rockport Bar study area.

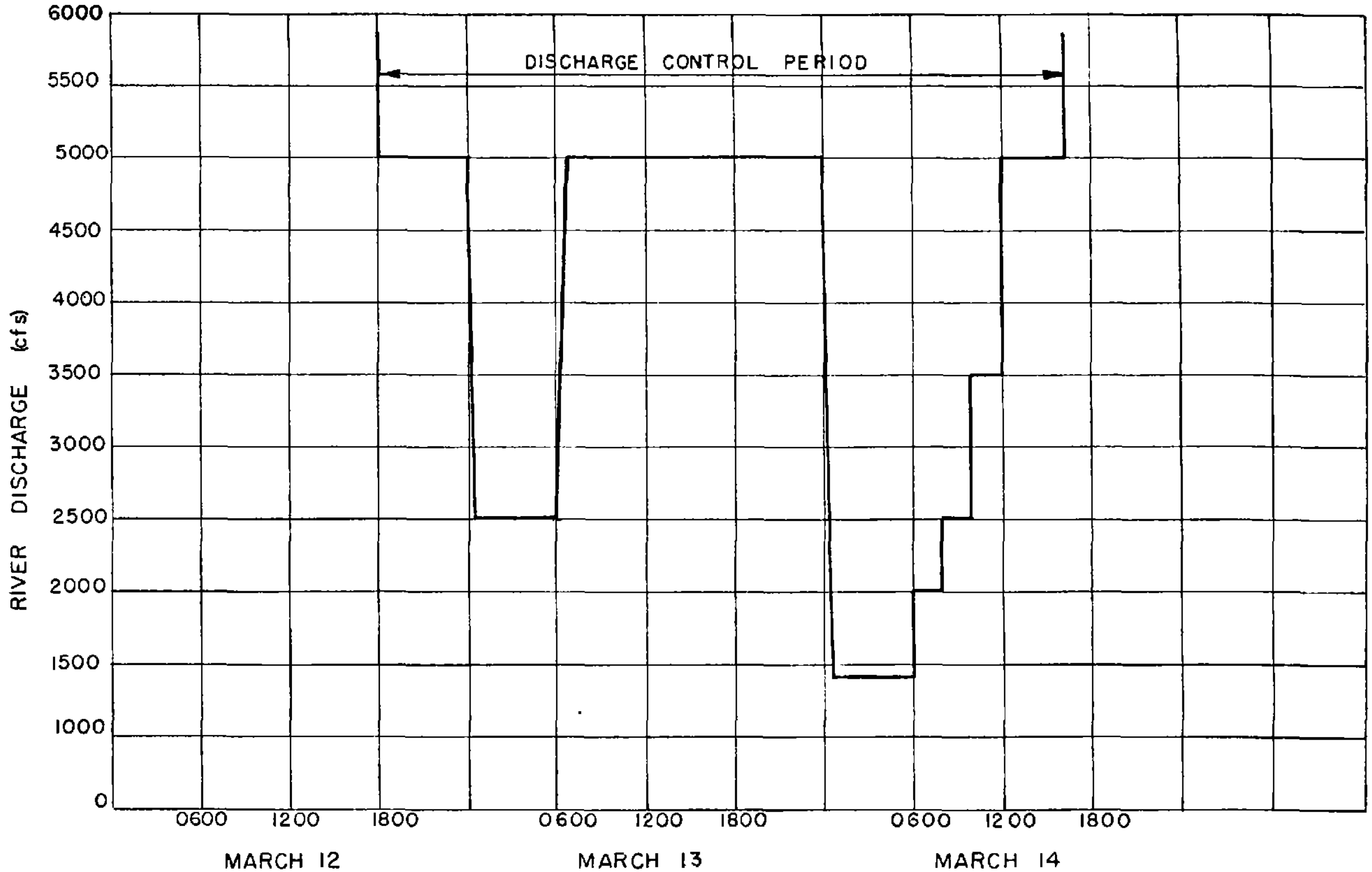

Figure 4. Water flow release schedule from Gorge Dam, March 12 - 14, 1969.

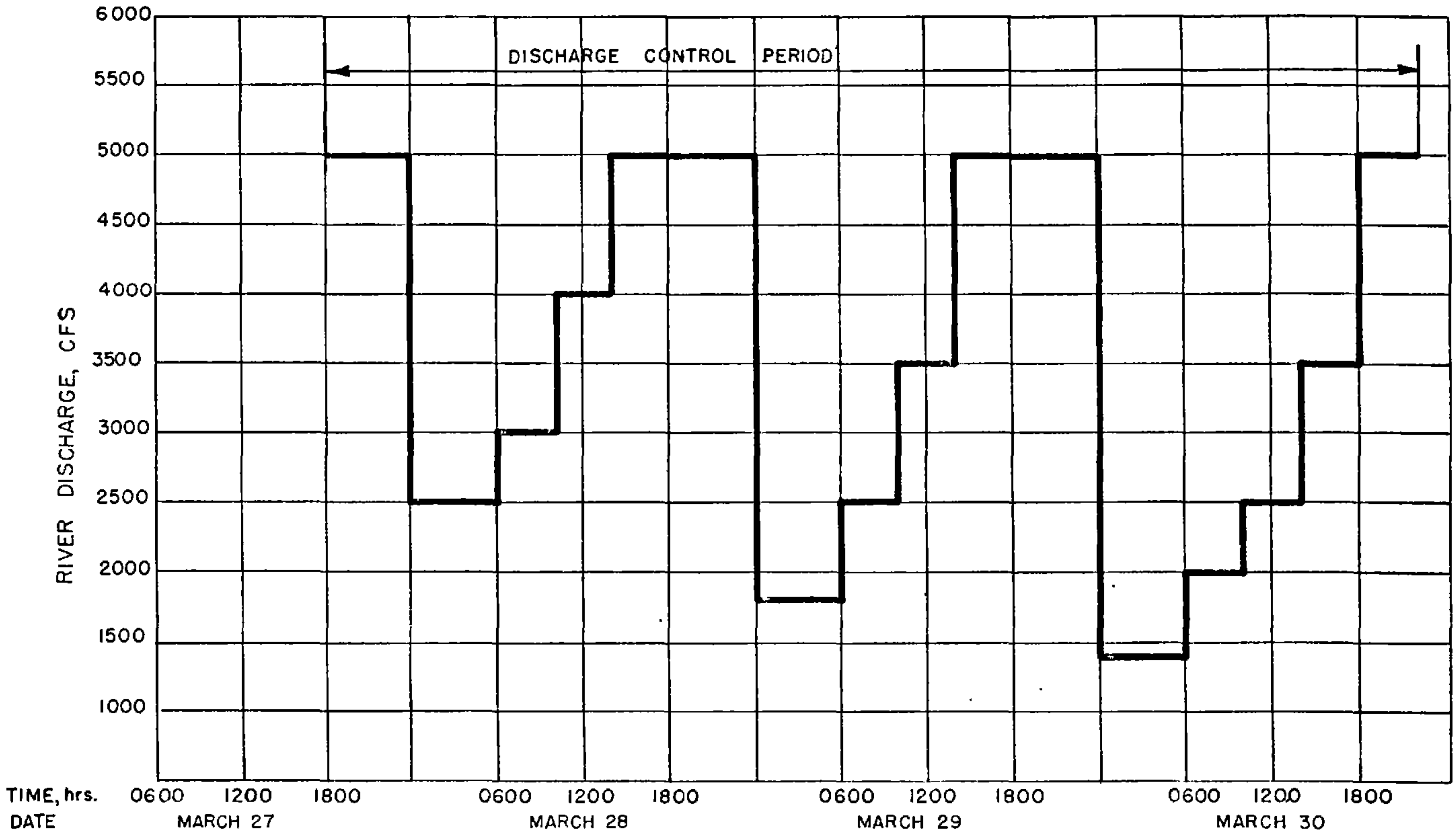

Figure 5. Water flow release schedule from Gorge Dam, March 27 - 30, 1969.

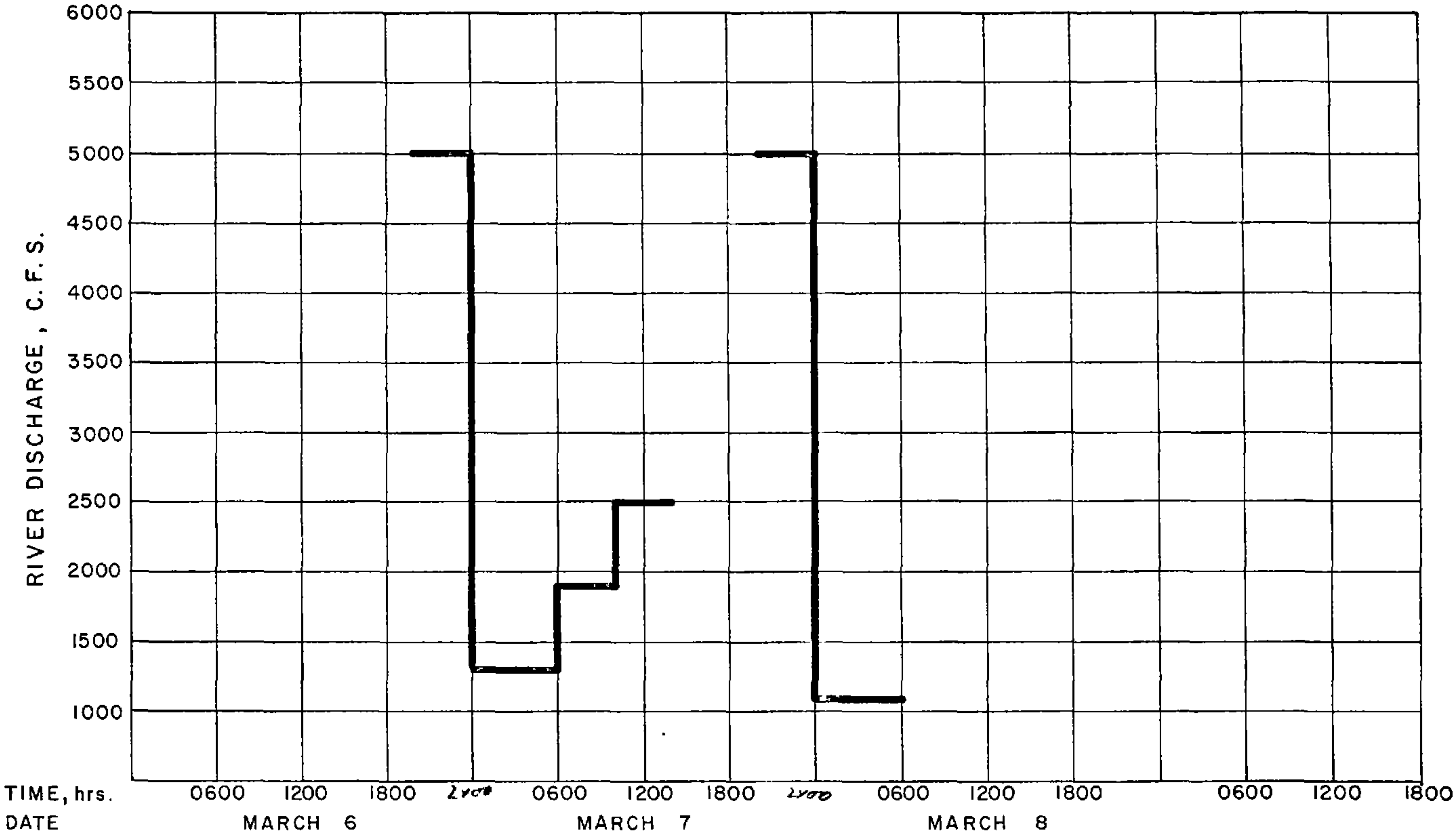

Figure 6. Water flow release schedule from Gorge Dam, March 6 - 8, 1970.

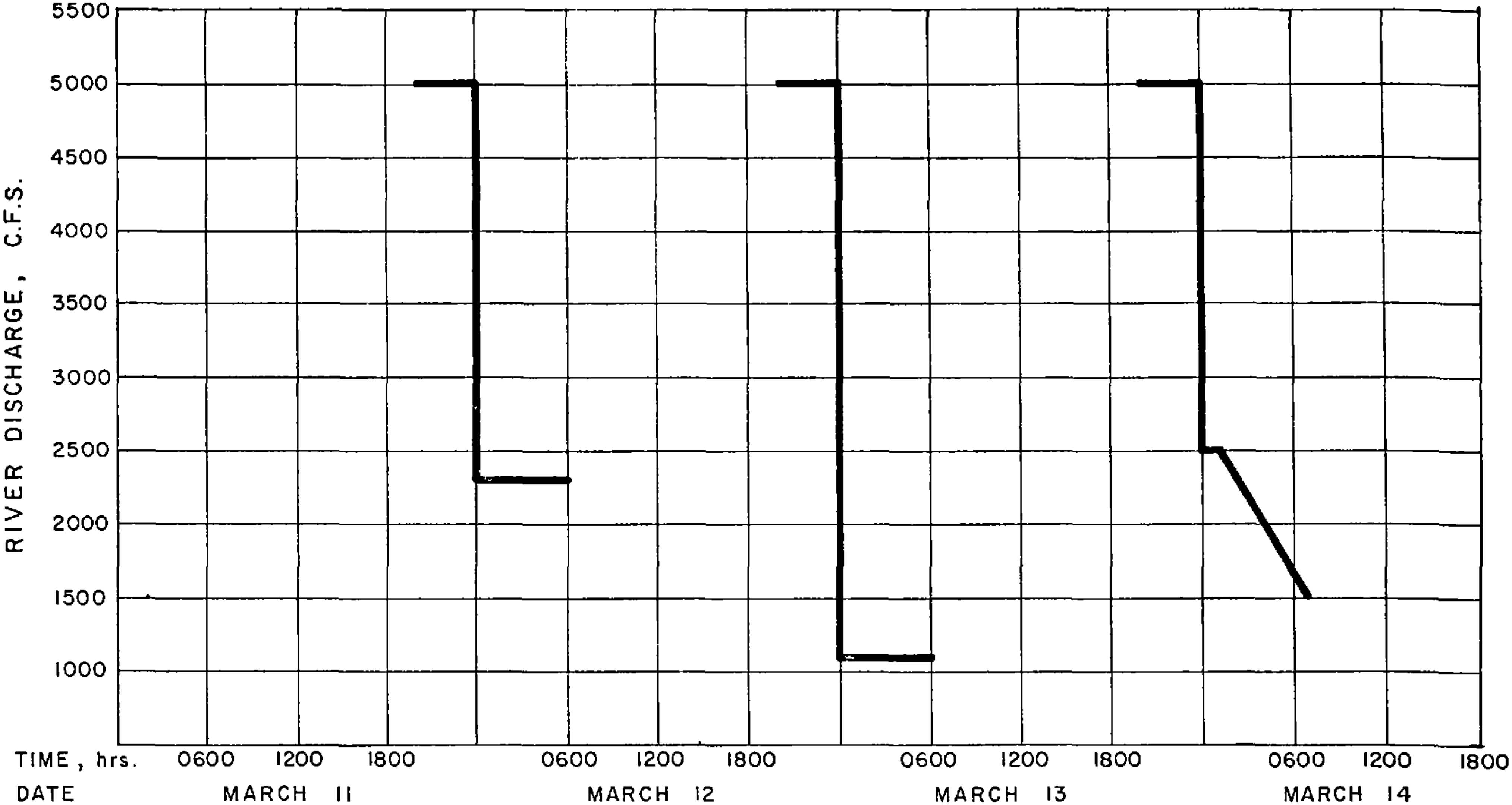

Figure 7. Water flow release schedule from Gorge Dam, March 11 - 14, 1970.

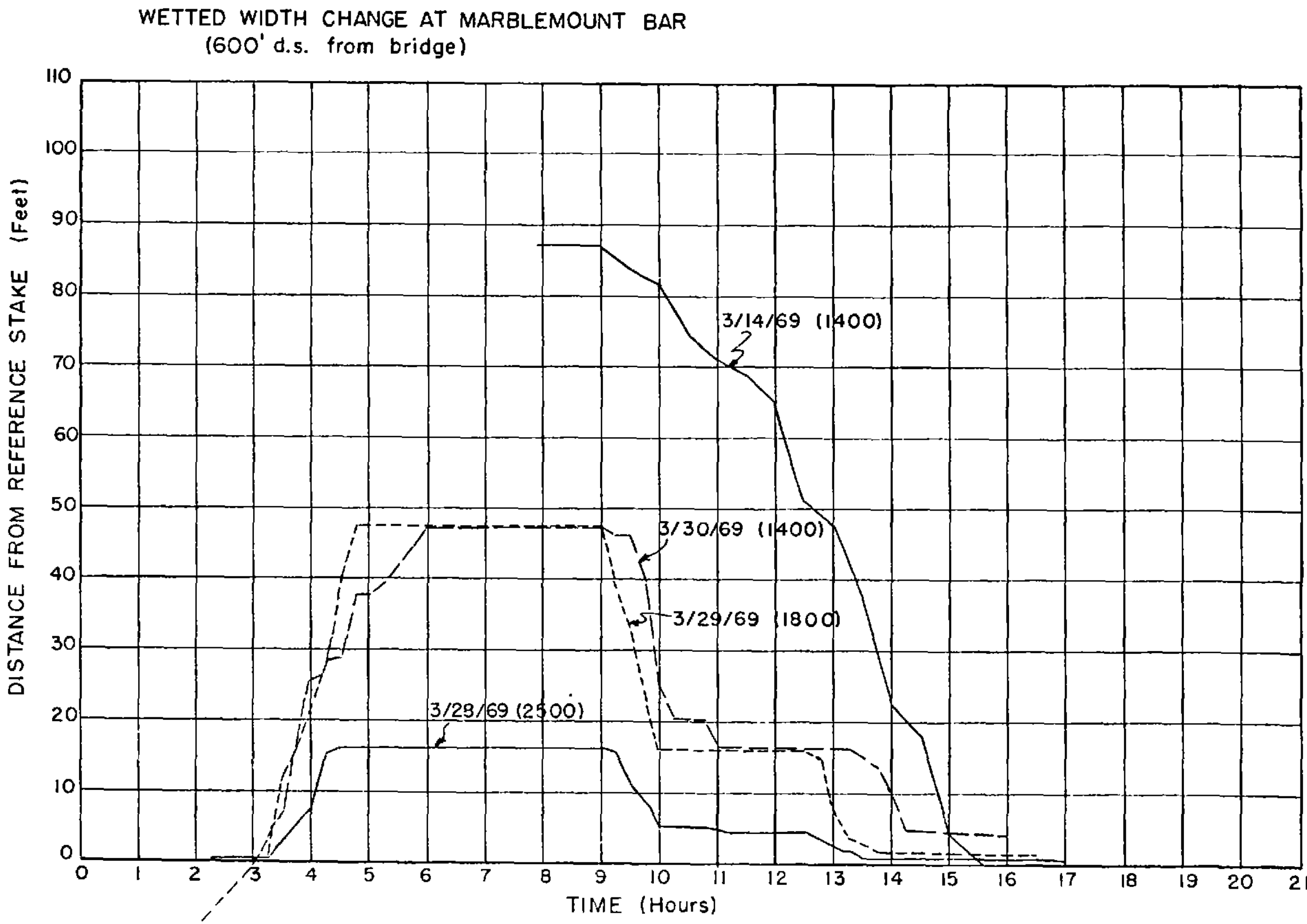

Figure 8. Wetted width change at Marblemount Bar Reference Line #2 during low flow test, 1969. Low water release in cfs at Gorge Dam is in parentheses.

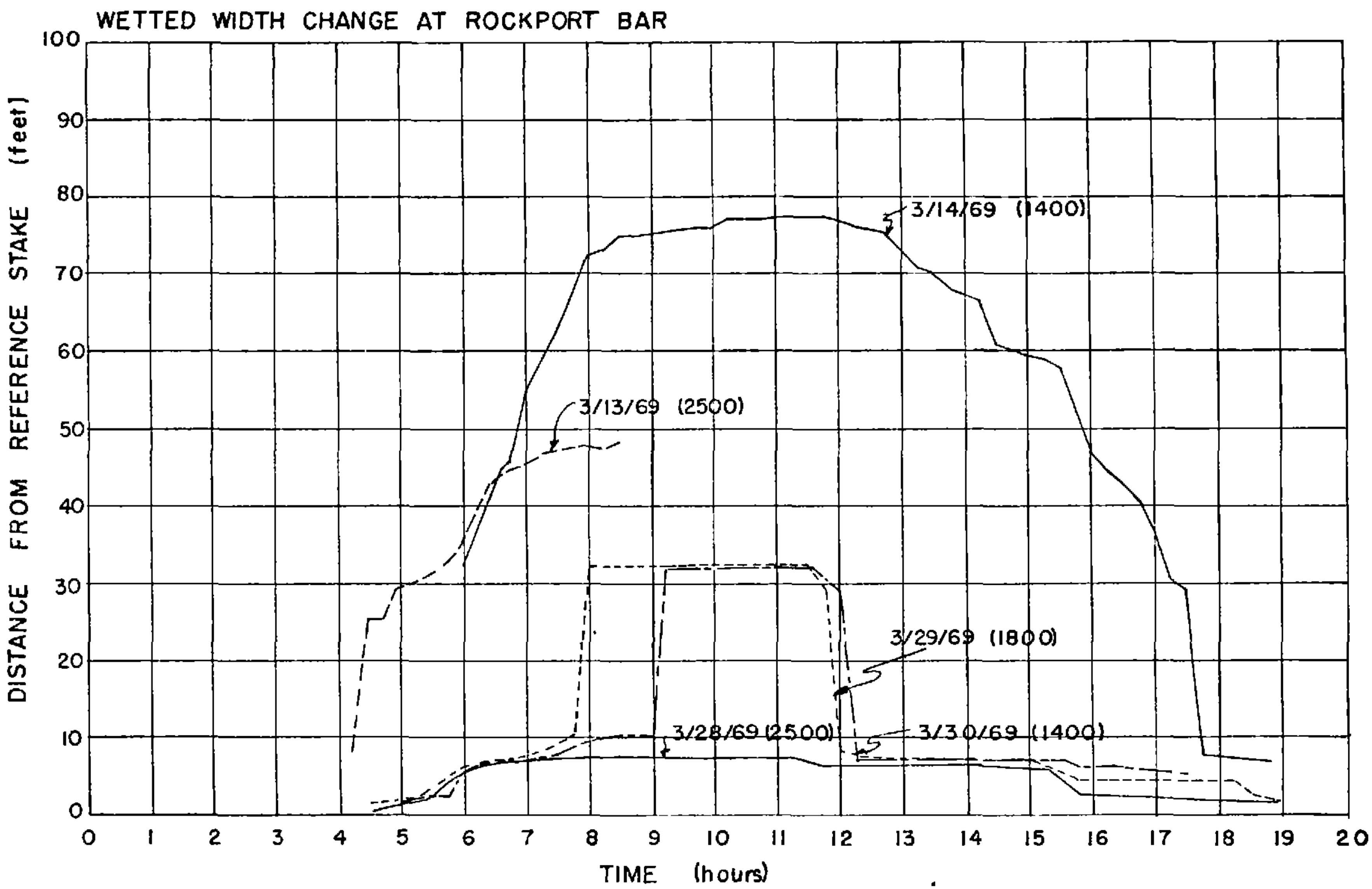

Figure 9. Wetted width change at Rockport Bar Reference Line during low flow tests, 1969.

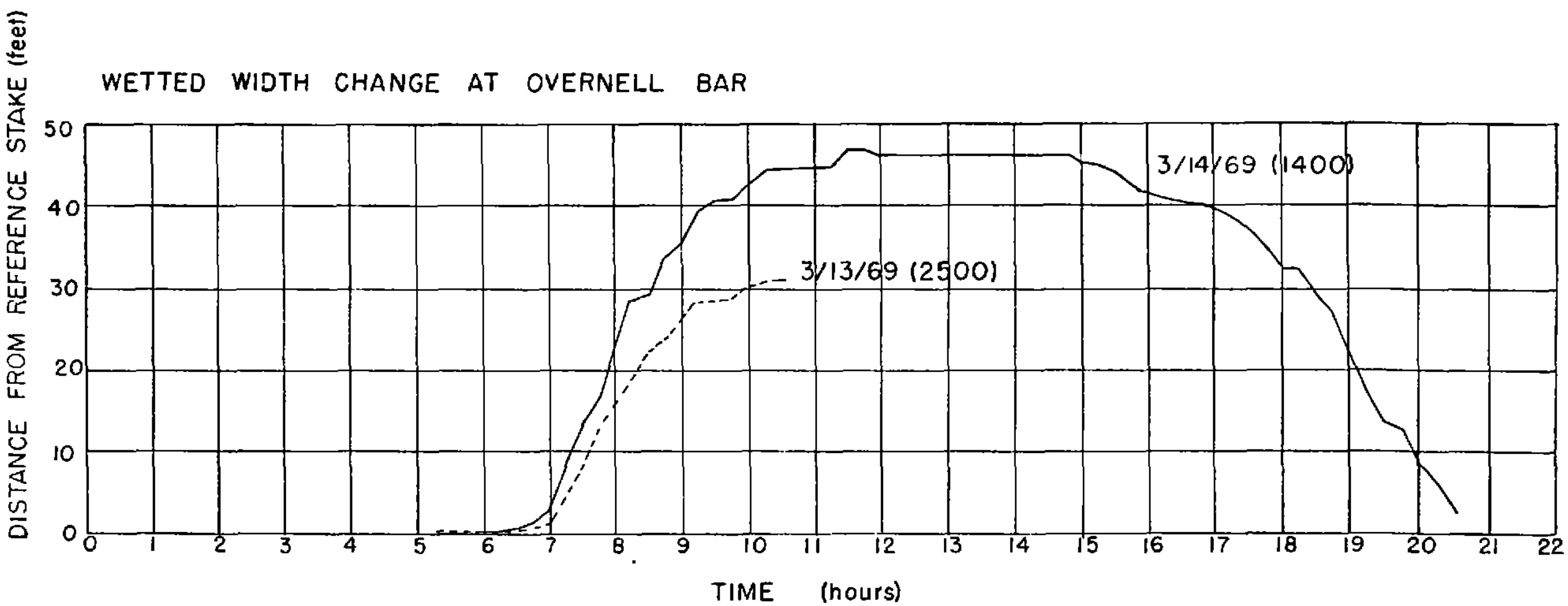

Figure 10. Wetted width change at Ovenell Bar Reference Line during low flow tests, 1969.

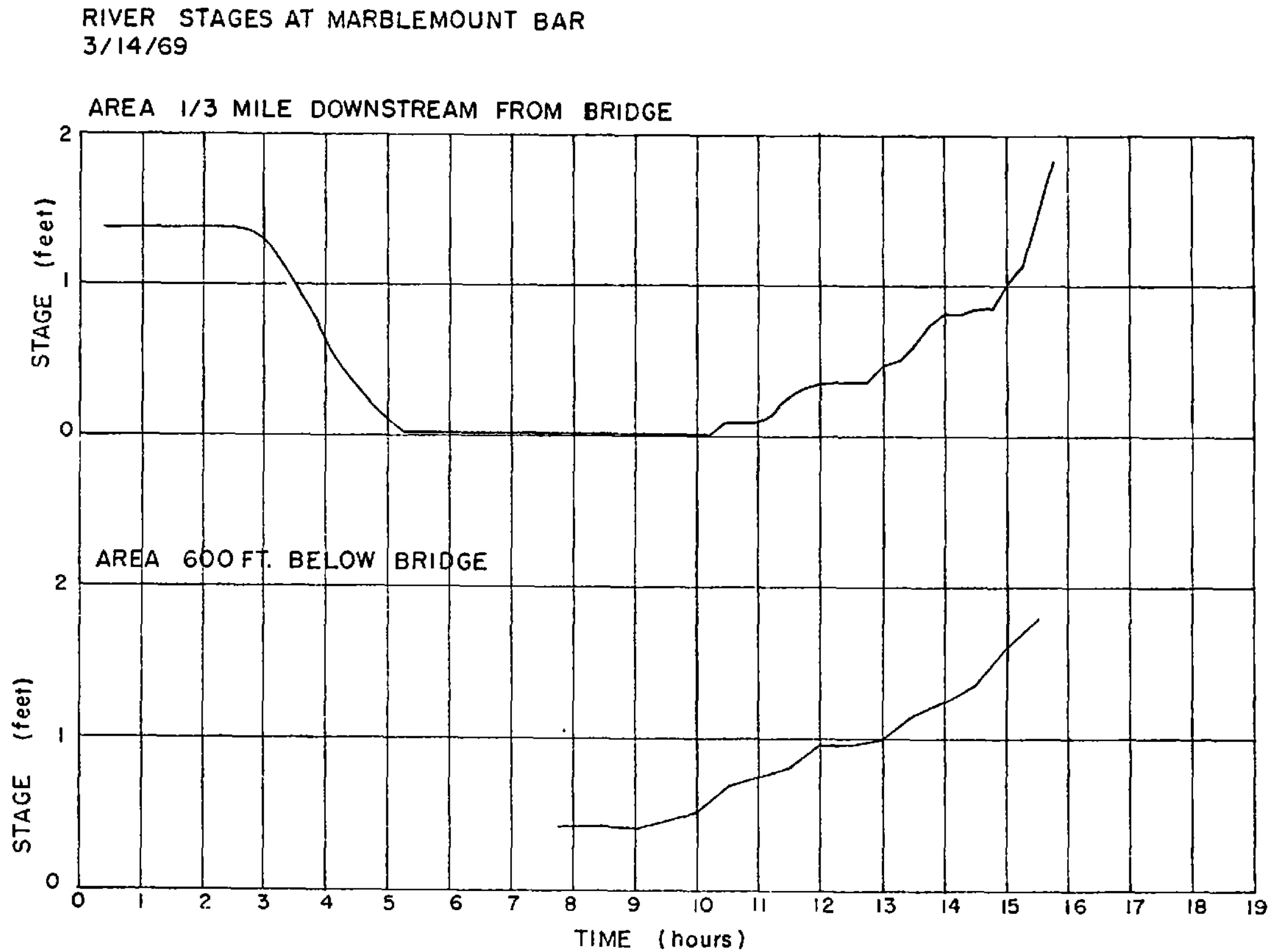

Figure 11. River stage as measured on both reference lines at Marblemount Bar, March 14, 1969.

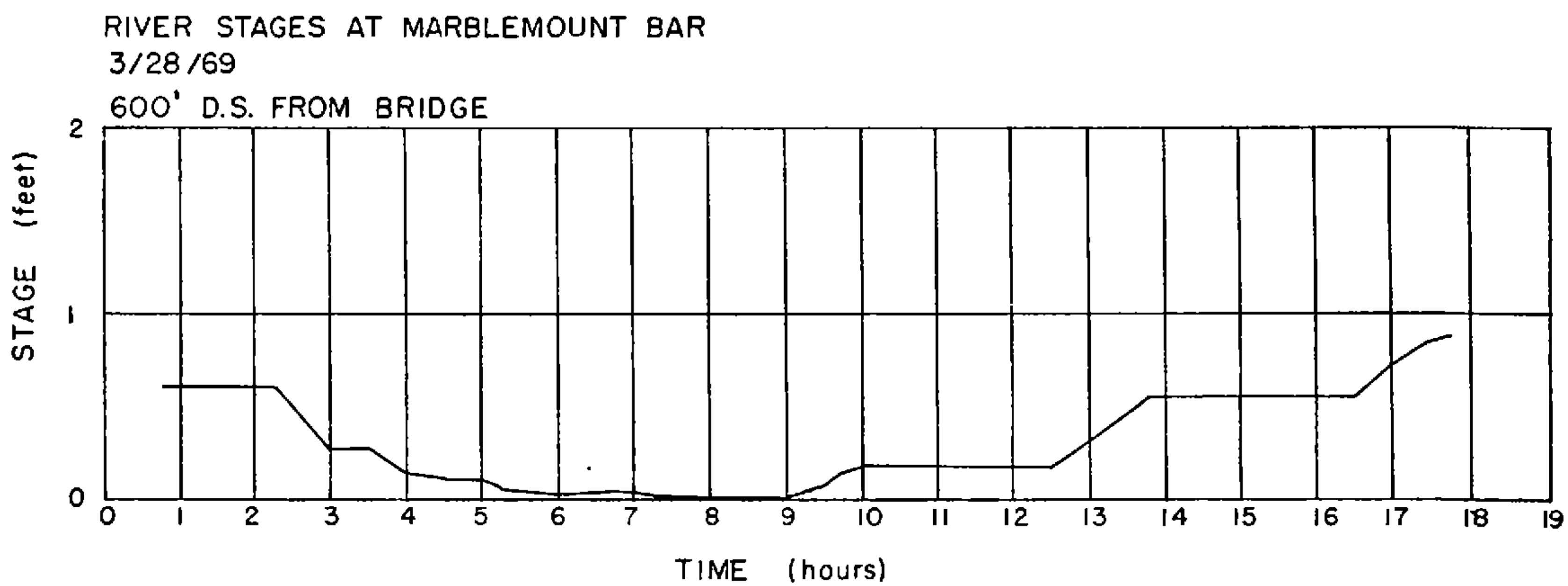

Figure 12. River stage as measured on Marblemount Reference Line #2, March 28, 1969.

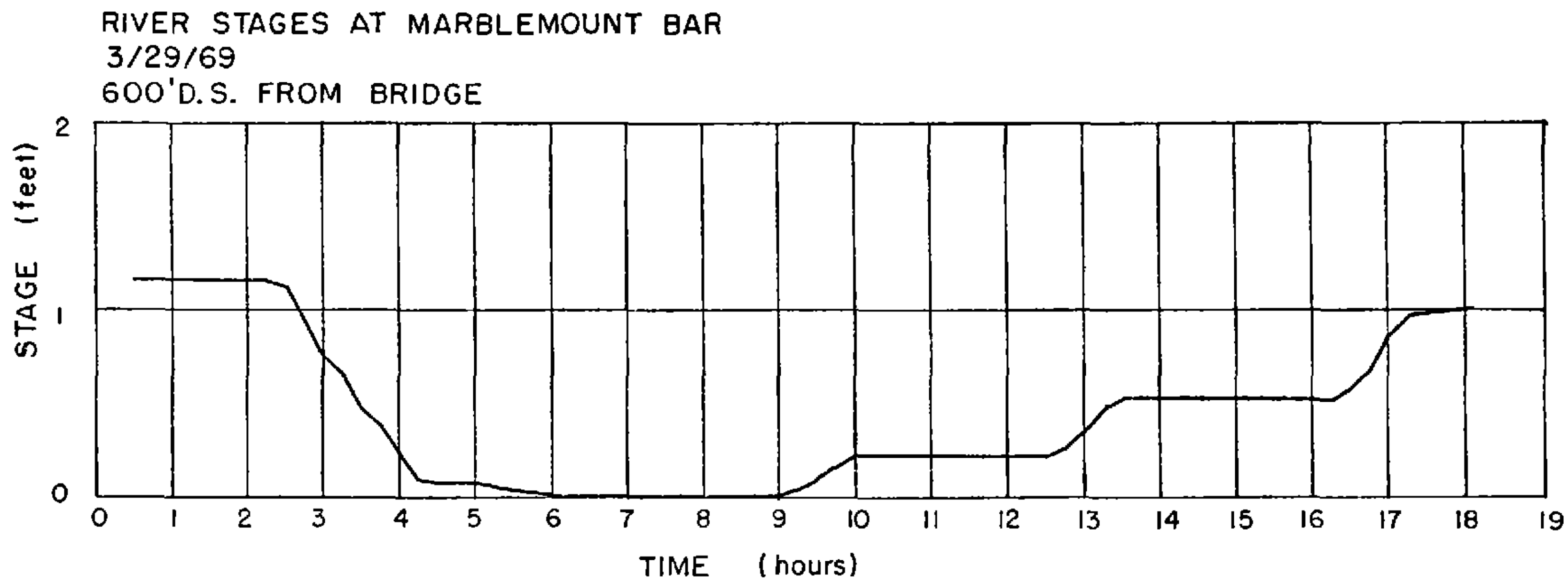

Figure 13. River stage as measured on Marblemount Reference Line #2, March 29, 1969.

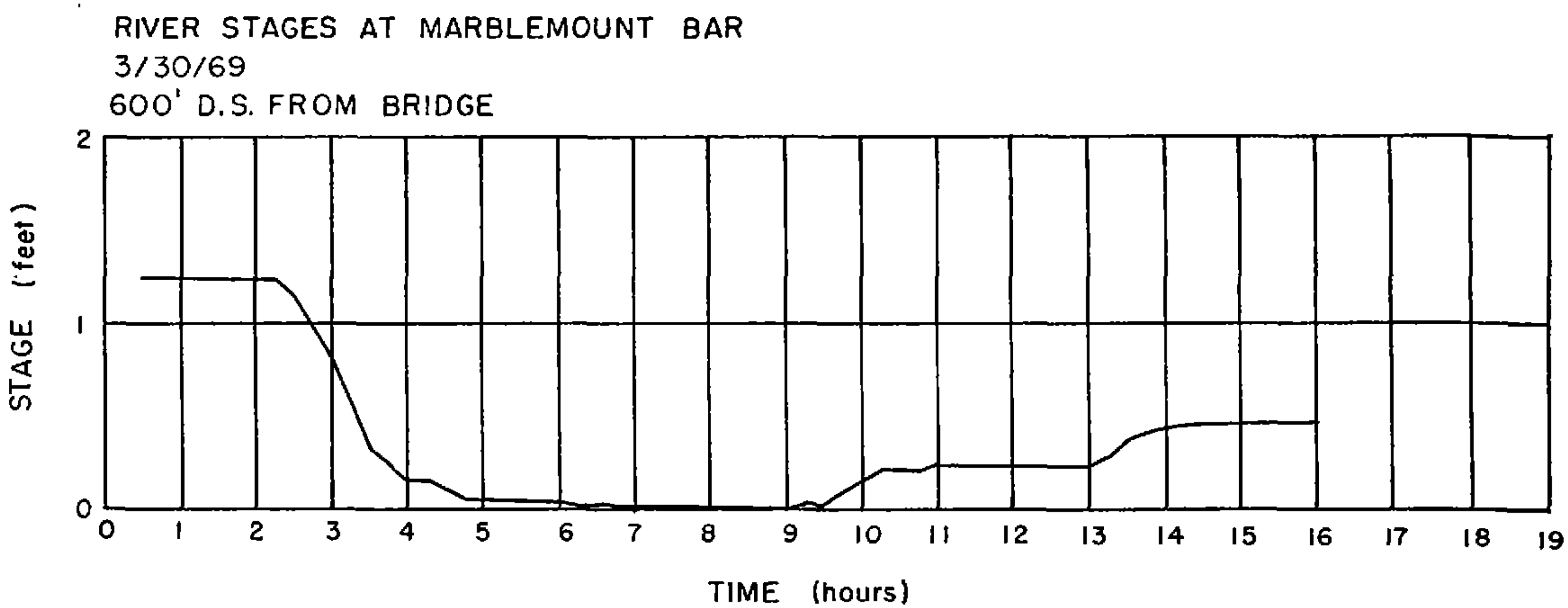

Figure 14. River stage as measured on Marblemount Reference Line #2, March 30, 1969.

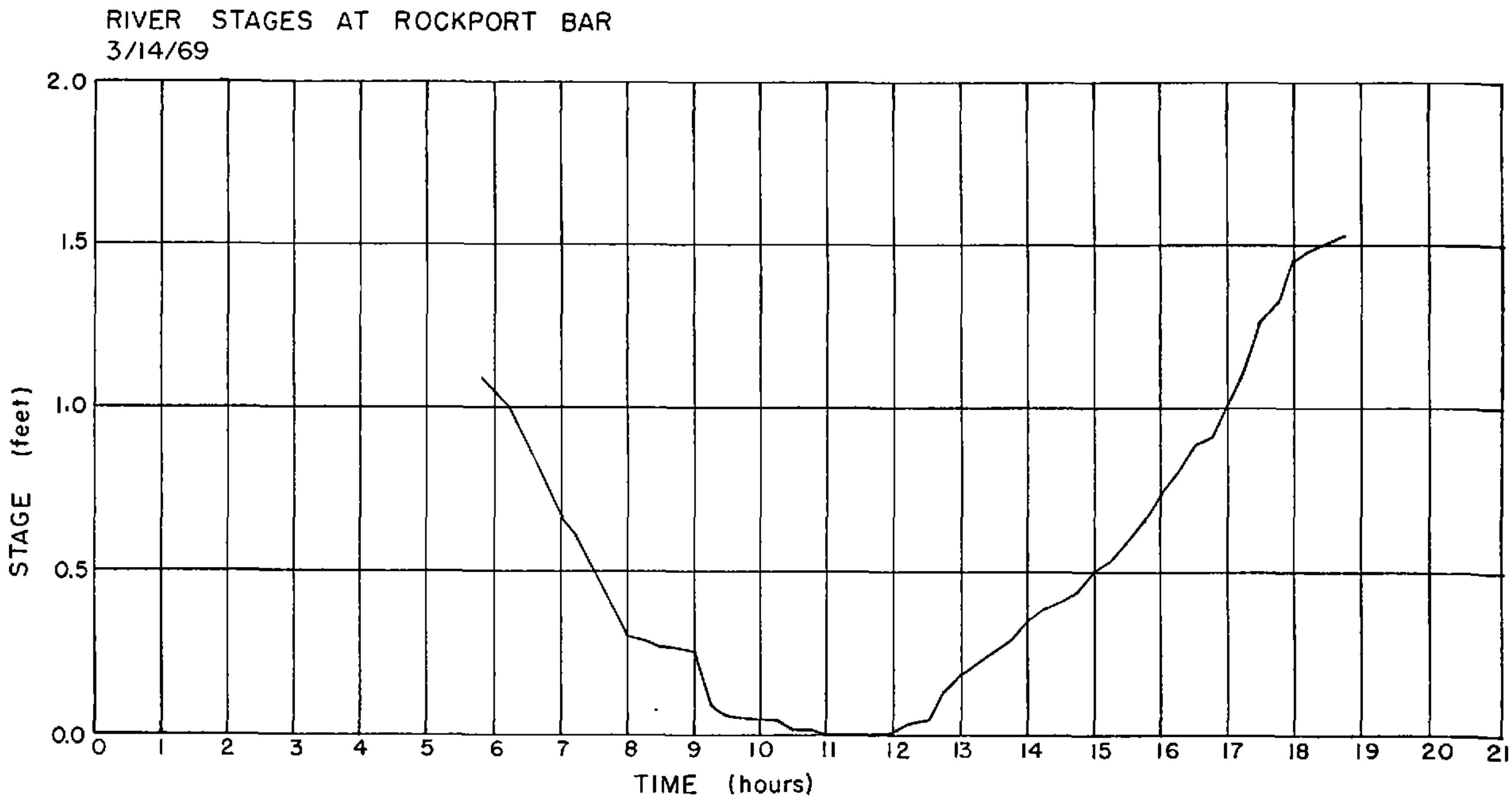

Figure 15. River stage at Rockport Bar, March 14, 1969.

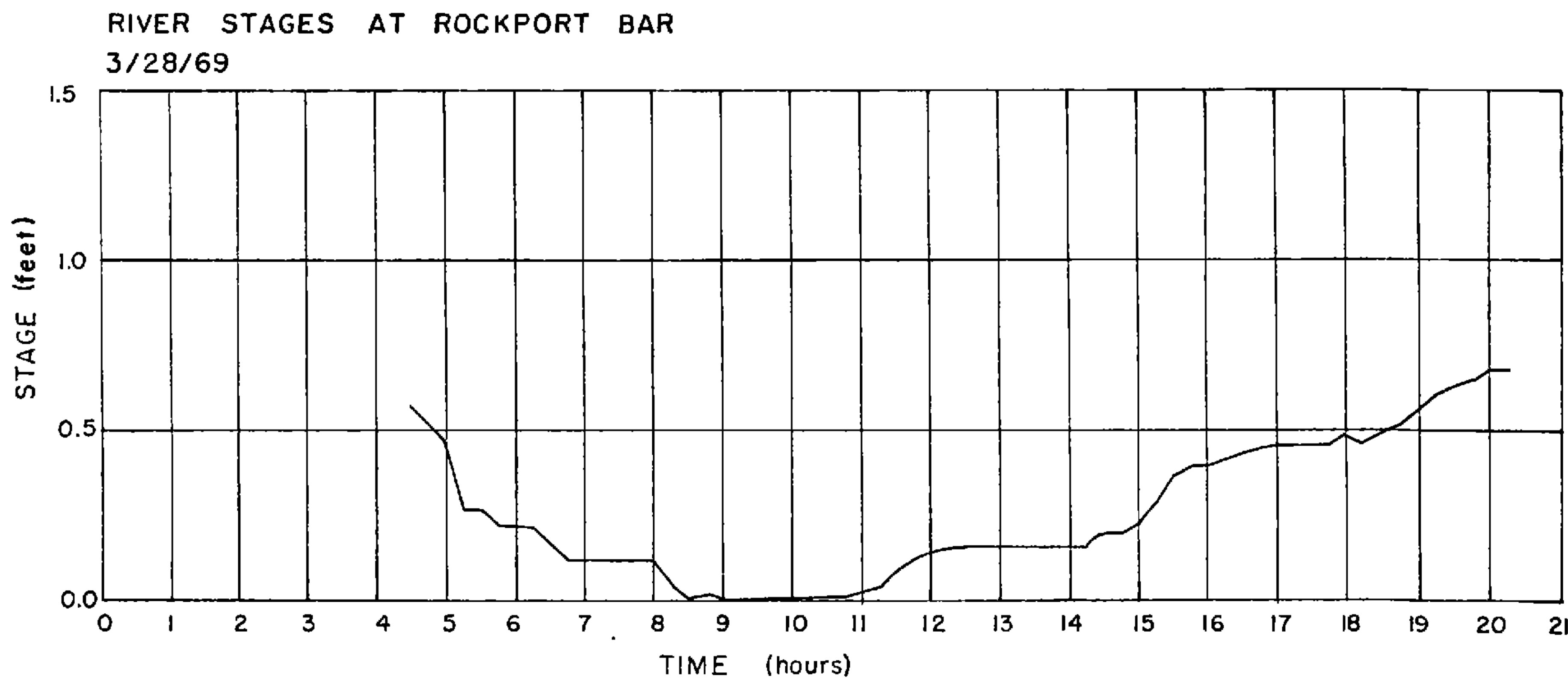

Figure 16. River stage at Rockport Bar, March 28, 1969.

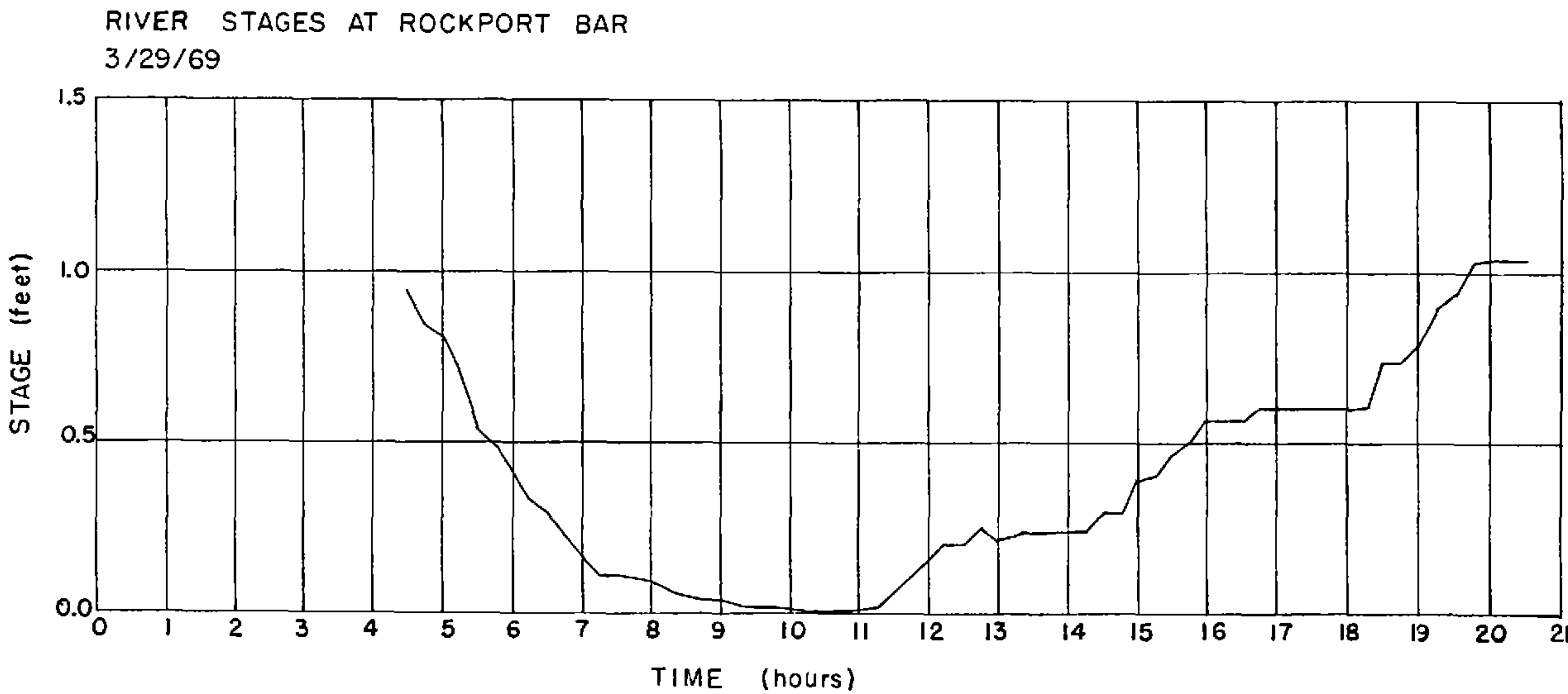

Figure 17. River stage at Rockport Bar, March 29, 1969.

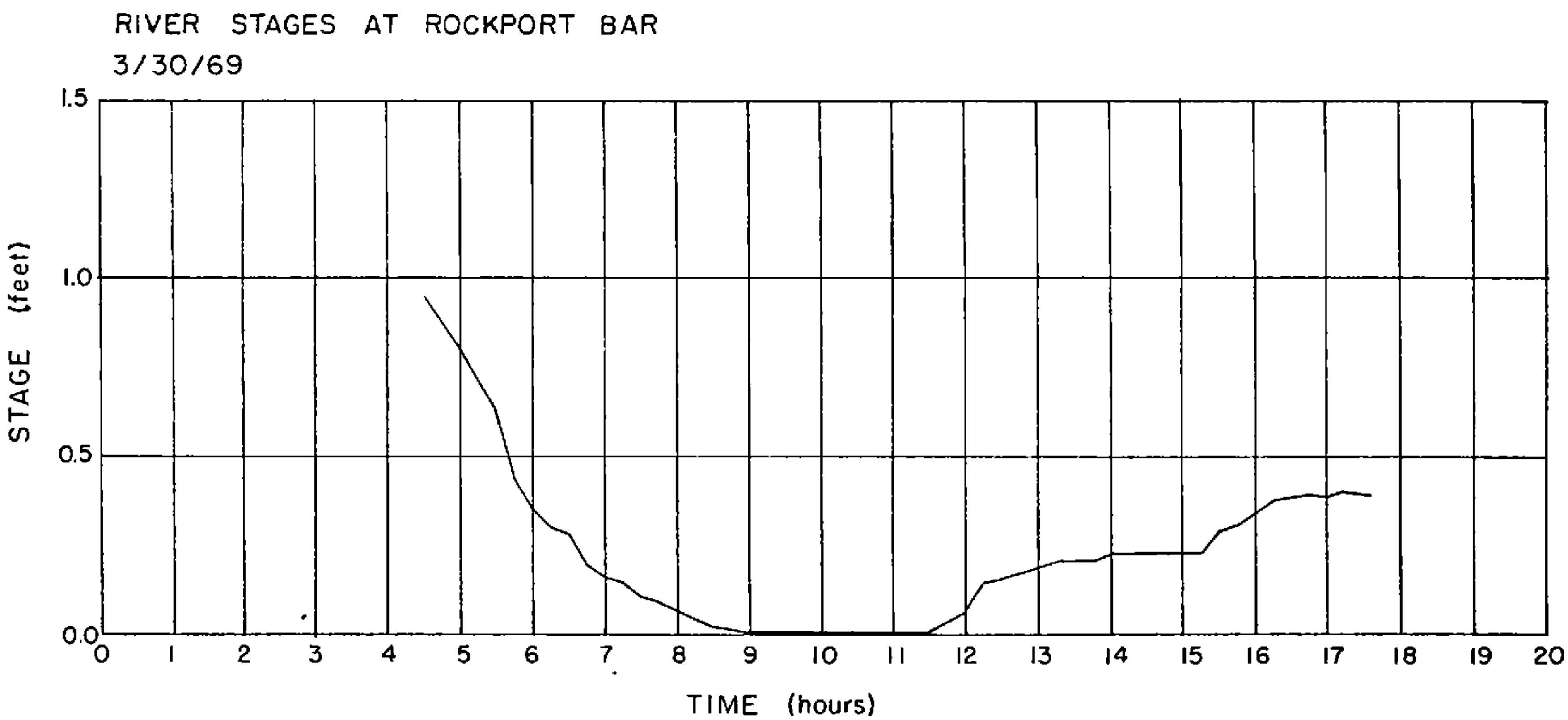

Figure 18. River stage at Rockport Bar, March 30, 1969.

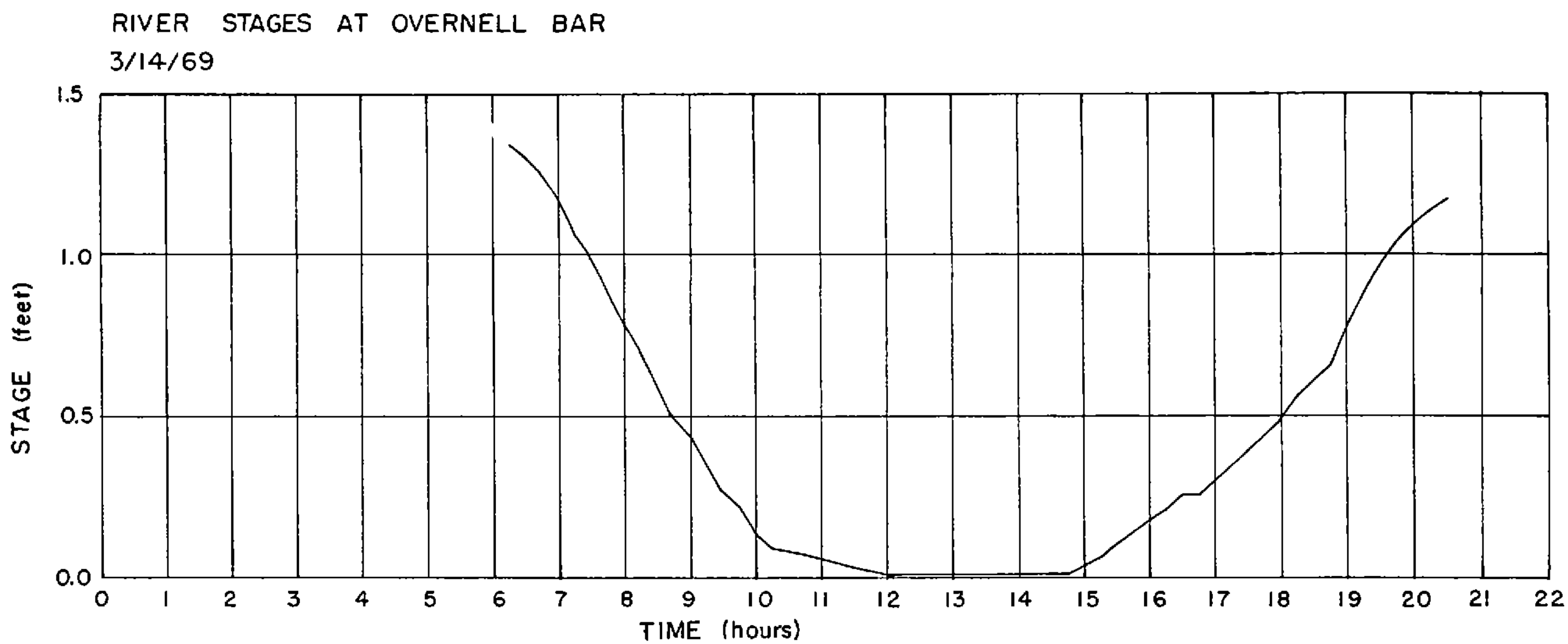

Figure 19. River stage at Ovenell Bar, March 14, 1969.

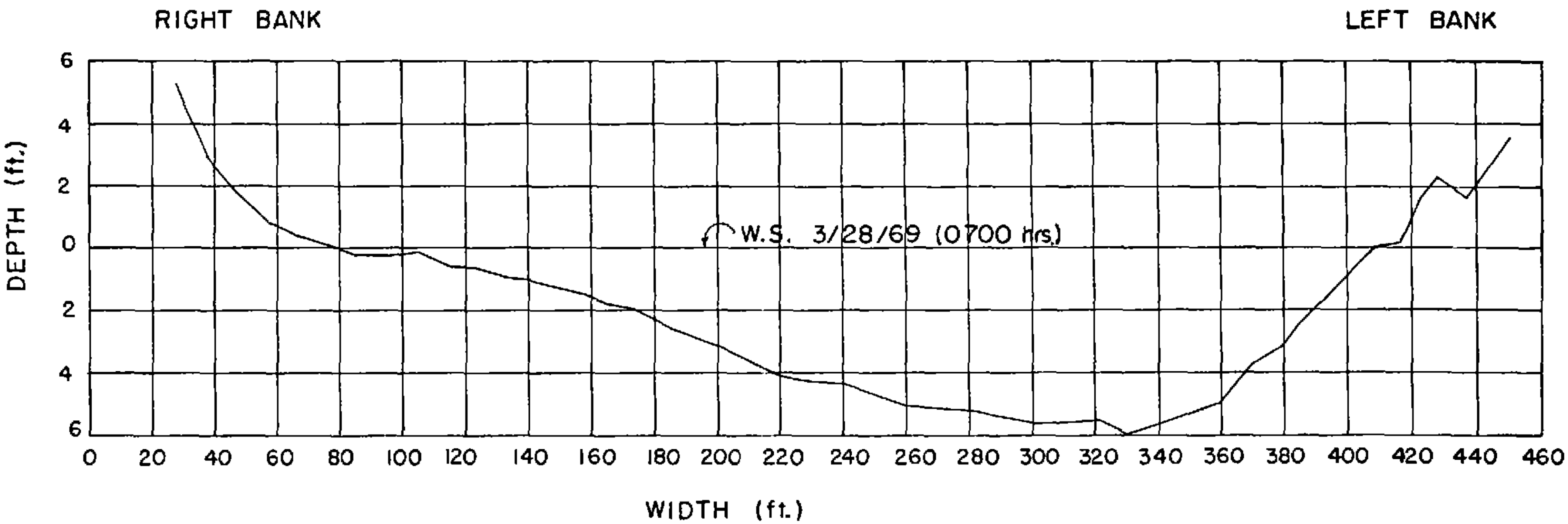

Figure 20. River cross-section at Marblemount Bar Reference Line #2, March 28, 1969.

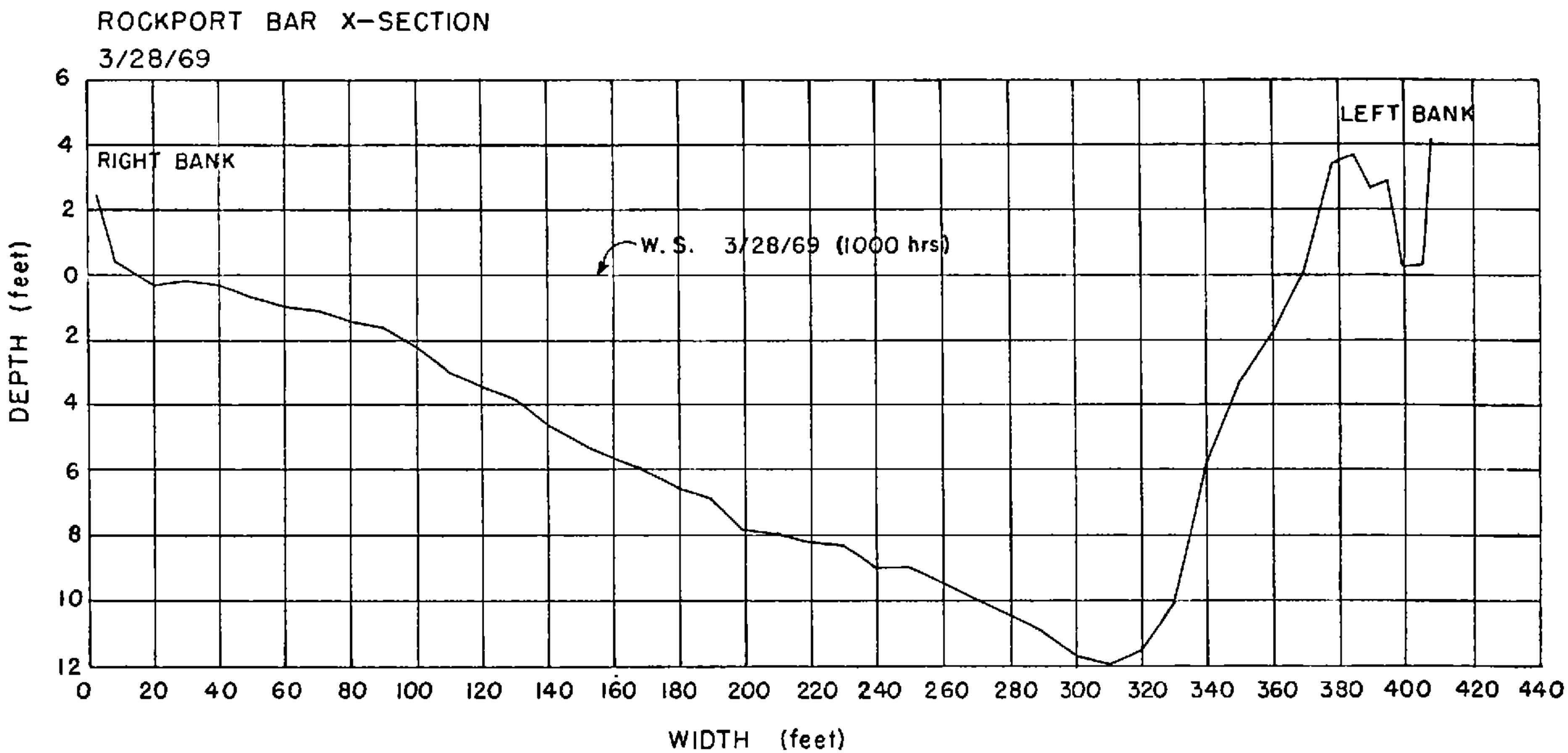

Figure 21. River cross-section of Rockport Bar reference line, March 28, 1969.

A P P E N D I X III

Plates 1 through 6

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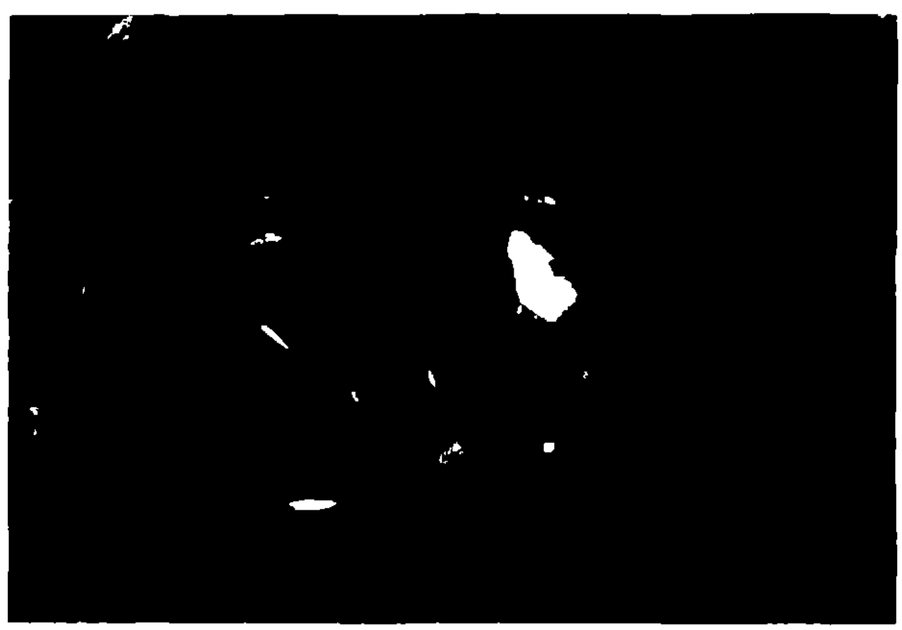

Plates 1 & 2. Chinook salmon fry stranded in shallow depressions by the receding water. The silt covered gravel surface is typical of much of the river area where stranding occurs.

Plate 3. Stranded chinook fry in a shallow depression. The receding river trapped the fry in a pothole that eventually drained completely.

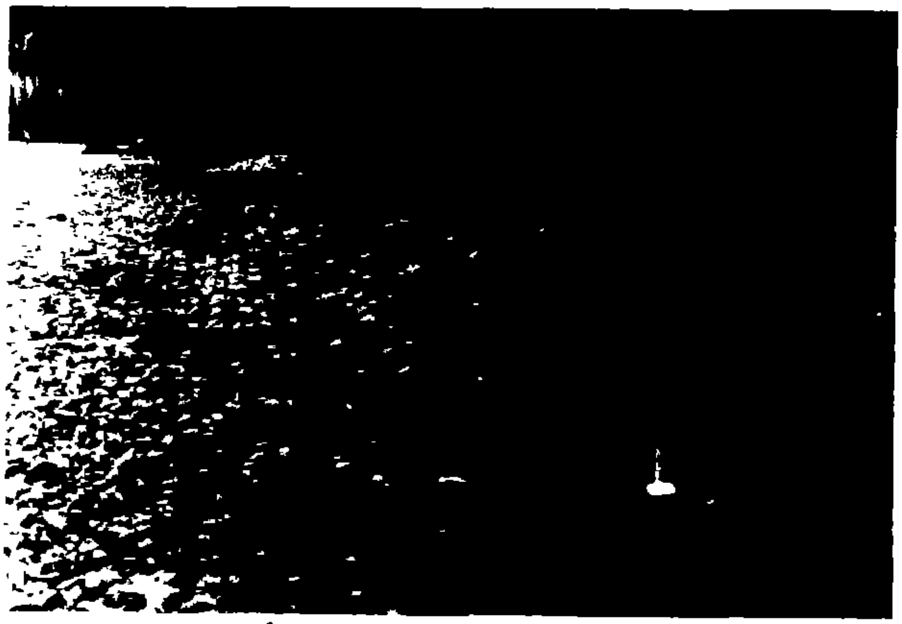

Plate 4. Many salmon fry were confined in the shallow depressions and became stranded or disappeared into the gravel when the water drained completely.

Plate 5. Stranded fry and 1 trout obtained from a sample area near Illabot Creek.

Plate 6. Small depression containing chinook salmon fry trapped by receding water. The fry became stranded less than 1 hour later.