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WASHINGTON Department of FISHERIES

EFFECTS OF PEAKING (STRANDING) OF COLUMBIA RIVER DAMS ON JUVENILE ANADROMOUS FISHES BELOW THE DALLES DAM, 1974 AND 1975

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Technical Report 31

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State of Washington
DEPARTMENT OF FISHERIES

Technical Report No. 31

EFFECTS OF PEAKING (STRANDING) OF COLUMBIA RIVER DAMS ON JUVENILE ANADROMOUS FISHES BELOW THE DALLES DAM, 1974 AND 1975

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ABSTRACT

Investigations on several hydro-developed Western Washington streams have shown that peaking flow fluctuations strand and kill juvenile salmonids. In 1974 and 1975, stranding observations were conducted in the Columbia River downstream of The Dalles Dam to determine the extent of juvenile stranding.

In 1974, an extremely high-water year, observations were limited in scope and confined to the river below Bonneville Dam. Peaking-related stranding was minimal since most potential stranding areas were continually inundated by water, and flow reductions (the cause of stranding) were not frequent. Stranding observations downstream of Vancouver, Washington--the upstream end of the deep-draft navigation channel-- indicated that waves produced by large ships could strand significant numbers of juveniles and warranted further investigation in 1975.

In 1975, a more typical water year, peaking-related stranding observations were conducted regularily in the spring at two sites between The Dalles Dam and Bonneville Dam (the Bonneville Pool) and at four sites in the Bonneville Dam to Vancouver, Washington, reach. Based on the observed sample site mortality, the estimated stranding mortality in Bonneville Pool was 19,349 chinook, 816 coho, and 425 trout from March 2 through May 10, 1975. Stranding in the pool was limited by the number of stranding sites, fish availability, and timing of the spring runoff. Within the Bonneville Dam to Vancouver reach, the estimated mortality was 2,848 chinook, 310 coho, 1,243 chum, and 39 trout from February 2 through May 10, 1975. The relative absence of stranding in this reach was related to the flow reduction rate, the magnitude of the flow reductions, and the minimum discharge at Bonneville Dam.

Ship-wash stranding observations were conducted at five sites along the Columbia River deep-draft navigation channel. Based on these observations, the estimated mortality in the 33-mile reach between the Willamette and Cowlitz Rivers at all identified stranding sites was 145,003 chinook, 1,359 coho, 4,771 chum, and 537 trout from February through July 1975. The ability of a ship to strand fish is a function of the size of wave it produces. Wave size is related to ship velocity, channel depth, draft, and distance from shore.

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INTRODUCTION

The effects of peaking on juvenile anadromous fishes in the Columbia River are largely unknown. Under contract with the Army Corps of Engineers, the Washington Department of Fisheries (WDF) investigated one possible impact: stranding of juvenile anadrmous fishes in the Columbia River from The Dalles Dam, downstream to Vancouver, Washington (Figure 1). The study was funded for 1974 and 1975. This report contains results of both years' field work.

Peaking flow regulation is the hourly, daily, and seasonal manipulation of river flow to generate hydroelectric power during periods of high demand. Peaking causes considerable fluctuations in hourly and daily discharge and river stage. During the reduction phase of a flow fluctuation, beach and shoal areas are dewatered by receding water levels. As the water recedes, some juvenile fishes may be stranded on the exposed shoreline or are trapped in watered depressions (potholes). Since peaking flow regulation does create a situation where flow reductions are common, stranding could be a serious problem in the maintenance of anadromous fish runs in the Columbia River.

The Columbia River presently supports six species of anadromous salmonids and two species of anadromous non-salmonids: chinook (Oncorhynchus tshawytscha), coho (O. kisutch), sockeye (O. nerka), chum (O. keta), steelhead trout (Salmo gairdneri), cutthroat trout (S. clarkii), shad (Alosa sapidissima), and Columbia River smelt (Thaleichthys pacificus). The juveniles of these species, except shad, migrate down the Columbia River throughout the spring and summer. Unlike salmon, juvenile shad out-migrate during the fall and winter months. The juveniles of all species are subjected to stranding conditions.

Recent studies by WDF on hydro-developed streams have demonstrated that significant losses of juvenile salmon can be incurred during flow reductions. Stranding observations on the Skagit River by Thompson (1970) indicated that large numbers of salmon fry can be killed by stranding under certain flow conditions. The study was repeated in 1973 (Phinney, 1974); and during 2 days of test flow reductions, an estimated 272,600 fry were stranded and killed. Observations on the North Fork Lewis River also revealed a serious stranding problem during peaking-related flow reductions (Phinney, 1974).

Another source of juvenile mortality, stranding by the wave action of ships, has been observed by WDF personnel in past years (Wendler, personal communication). The movement of large ships through a confined body of water results in considerable wave action along the shoreline. Fish inhabiting shoreline waters can be

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caught in these waves and stranded on the beach as the water recedes or is absorbed into the sand. Although ship-wash stranding is not directly related to peaking, this problem was also investigated and will be discussed in the report.

STUDY OBJECTIVES

This investigation was designed to identify major stranding areas; isolate the cause(s) of stranding; determine the species, size, and timing of stranded fish; and estimate total fish loss. If stranding was found to be a significant source of mortality, recommendations would be made to minimize fish loss.

PEAKING OPERATION RULES -- THE DALLES AND BONNEVILLE DAMS

Insight as to how these dams are operated will be helpful in understanding further text in the report. The rules of operation at a dam define minimum project discharge and the rate at which discharge can be changed. These limits are set by the U.S. Army Corps of Engineers.

The Dalles Dam (River Mile [RM] 191.5) is operated primarily as a peaking hydroelectric project. The hydraulic capacity of the dam (the amount of water that will pass through the turbines) is approximately 360,000 cubic feet per second (cfs). Discharge at the project can be increased or decreased at a maximum rate of 150,000 cfs per hour throughout the year. A change in discharge of 150,000 cfs will result in a change in tailwater elevation of 4.5 to 6.0 ft, depending upon the initial elevation. From March through November, a minimum discharge of 50,000 cfs is maintained. The minimum discharge is 12,500 cfs for the remainder of the year, a flow seldom reached.

Bonneville Dam (RM 145.5), the lowermost project on the Columbia River and downstream of The Dalles Dam, is governed by a more restrictive set of rules. Presently, the hydraulic capacity of Bonneville Dam is approximately 140,000 cfs. During the summer season, April through September, daily tailwater fluctuations will not exceed 4 ft (60,000 to 80,000 cfs), with a maximum hourly change of 1.5 ft. The 4-ft daily fluctuation can be increased to 5 ft a maximum of 10 days per season. During the winter season, October through March, daily tailwater fluctuations will not exceed 7 ft, with a maximum hourly change of 3 ft. The 7-ft limit can be extended to 10 ft a maximum of 18 days per season.

During both seasons, the minimum instantaneous flow at Bonneville Dam will be 80,000 cfs and the daily average minimum will be 100,000 cfs, except during extremely

low water conditions--125,000 cfs weekly average. If this occurs, 70,000 cfs would become the absolute minimum instantaneous flow and the daily average minimum flow would be 80% of the weekly average flow.

THE 1974 STUDY

Methods

Abnormally high-flow conditions in the Columbia River from March through June 1974 altered the planned investigation. Beach and shoal areas identified as primary stranding sites were rarely exposed by fluctuating water levels, eliminating the possibility of assessing stranding mortality in the desired manner. Therefore, the 1974 investigation was limited to (1) identification of potential flow flucuation stranding sites, (2) general stranding observations during flow reductions, (3) juvenile seining, (4) monitoring river stage levels, and (5) documenting ship-wash stranding and identification of sites. All work accomplished was confined to the reach downstream of Bonneville Dam.

Potential flow fluctuation stranding sites were identified utilizing aerial photographs coupled with field surveys. Aerial photographs, taken in 1973 during minimum flow at Bonneville Dam (80,000 cfs) were examined for extensive beaches and shoals. Generally, these will be the areas where stranding will occur when exposed by a flow reduction. Field surveys were then conducted to determine at what flows significant beach exposure (and stranding) could be expected at the various sites.

In March, April, and May, flow fluctuation stranding observations were conducted from Bonneville Dam to the Cowlitz River. In March, permanent sampling areas were identified and a sampling schedule formulated. However, by April it was apparent that flow conditions would not permit conduct of the study in this manner. Therefore, beginning in April, observations were scheduled to coincide with flow reductions conducted by the Corps of Engineers to reduce nitrogen saturation. During or immediately after the flow reduction, observation crews inspected areas which appeared to have stranding potential for mortality or fish isolated in potholes. No attempts were made to estimate the amount of area examined or total mortality.

The juvenile seining program for 1974, like the stranding work, was limited by high-water conditions. A firm schedule to seine specific sites at designated times could not be adhered to; however, some juvenile seining was accomplished during the early spring and late summer in the Bonneville Dam to Cowlitz River

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reach. Seine sets were made with a 100- x 7-ft beach seine consisting of two 35-ft, untapered, 1/2-inch mesh wings and a 30-ft, 1/8-inch mesh, bobinett center. Seining sites were selected on the day of seining, the length of the set dependent on the site. All salmonids in the catch were identified, counted, and a random sample of each species measured.

Columbia River stage and Bonneville Dam discharge were monitored throughout the spring and summer. The Army Corps of Engineers provided the Hourly Operation Data Report for Bonneville Dam, and Crown Zellerbach Corporation furnished records from the Washougal gauge located in Camas Slough, Camas, Washington.

Ship-wash stranding sites were identified by field surveys along the Columbia River navigation channel, downstream of the Willamette River. Coves, inlets, or moderately sloped beaches which allow waves to travel onshore were examined for dead fish. When possible, the site was inspected immediately after a ship passed the site. At all sites examined, presence of dead juveniles in the drift line formed by the maximum shoreward extension of the waves or fish trapped behind objects on the beach was considered evidence of ship-wash stranding.

Results

Flow fluctuation stranding sites

Potential flow fluctuation stranding sites in the Bonneville Dam to Vancouver, Washington, reach were identified using aerial photographs coupled with field surveys. A total of 12 beaches and shoals was identified where significant juvenile stranding could be expected with a minimum Bonneville Dam discharge of 80,000 cfs. These sites are listed in Table 1. The Reed Island, Sandy River Bar, and McGuire Island sites appeared to have the greatest stranding potential. This assessment was based on the length of the stranding site and the amount of bar that potentially could be exposed by flow fluctuations.

Columbia River flow and stage

An early and near-record spring runoff occurred in the Columbia River in 1974. Discharge at Bonneville Dam in April and May was much higher than normal, eliminating peaking flow regulation during those months. Daily maximum and minimum discharges at the dam are summarized in Tables 2 and 3 for the months March through June and July through September 1974. Corresponding daily changes in Bonneville tailrace elevation and Washougal gauge elevation are shown in Figures 2 and 3.

With the exception of the March through April 1 time period, Bonneville discharge was not less than 250,000 cfs and the tailrace elevation did not fall below 21.8 ft (Table 2, Figure 2). At the Washougal gauge, approximately 23 miles downstream of the dam, minimum gauge elevation was never less than 13.0 ft (Figure 3). This high-flow condition persisted until mid-July, at which time normal peaking flow fluctuations were resumed.

Areas identified as major stranding sites were completely inundated by water throughout most of the April to mid-July time period.

Flow fluctuation stranding observations

In March, frequent stranding observations were conducted at Pierce Island, Sandy River bar, McGuire Island, and Government Island. Stranding was infrequent at all sites except Sandy River bar. Results of all stranding observations in 1974 are summarized in Table 4.

Stranded or isolated fish were observed at the Sandy River bar on 5 of the 6 observation days in March. A total of 75 chinook and 16 coho was found stranded and 23 isolated in potholes. The majority (80) of these fish were found on March 15 in a small dewatered pothole. All mortalities were fry in the 35- to 45-mm size range (fork length).

After March, as river flow increased and flow reductions became uncommon, daily observations were discontinued. Two scheduled flow reductions in April and May provided an opportunity for further surveys, however.

On April 24, discharge from Bonneville Dam was reduced from 326,200 cfs to 261,300 cfs over a 4-hour period. As a result, river stage dropped nearly 3 ft at Bonneville tailrace and 1.7 ft at Washougal. Inspection of several sites between Bonneville Dam and the Lewis River on April 24, 25, and 26 yielded three stranded chinook and one coho.

The next significant flow reduction occurred from May 10 through 14 when Bonneville discharge was reduced from 420,000 cfs to 290,000 cfs. During this 5-day flow reduction, Bonneville tailrace elevation decreased 6.2 ft and the river stage dropped 5.1 ft at Washougal. Inspection of potential problem areas in the Bonneville Dam to Lewis River reach on May 13 produced eight stranded chinook and nine coho.

During the spring of 1974, a total of 86 chinook and 26 coho were found stranded during 16 observation days. Approximately 96% of the mortality was found at the Sandy River bar.

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Juveniles observed trapped in potholes were not counted as mortalities. In most cases, the potholes were quickly reunited with the main river as flows were increased, allowing the fish to escape. Undoubtedly, some bird predation occurred while the juveniles were trapped, but it was not observed.

Since peaking flow fluctuations did not occur with any frequency during the spring migration period, stranding by flow fluctuations was not a significant source of juvenile mortality in 1974. Most stranding areas were continually under water during much of the juvenile migration period.

Ship-wash stranding

Although not directly related to peaking, ship-wash stranding was one possible source of juvenile mortality noted in the study proposal. Ship-wash stranding results when juveniles are caught in ships' waves which, upon hitting the shore, travel a considerable distance up the beach. Juveniles within the waves are then deposited on the beach as the water retreats or is absorbed in the sand. Stranded fish are often concentrated along the high-water line, in and around obstructions or debris which impedes return flow, and along the path of return flow. Ship-wash stranding is generally confined to sand beaches with a low slope angle or coves which constrict the waves and force the water onshore.

In the spring of 1974, ship-wash stranding was observed at three locations downstream of Vancouver. Along an undulating 200-ft sand beach at Bachelor Island, 10 chinook were observed stranded by one ship. At Fishtrap Shoal (Sauvies Island), 527 chinook were found stranded in one small cove. The ship(s) that stranded the fish was not observed; however, the fish were stranded in the pattern characteristic of ship-wash stranding. Stranding was also observed at a cove 1/2 mile downstream from the Lewis River mouth (this site is referred to as the Austin Point site in 1975 discussions). Two ships were observed; the first stranded 81 chinook and the second 16. The fish ranged in size from 38 to 83 mm.

As was the case for flow fluctuation mortality, no attempt was made to estimate losses. The observed losses provided impetus for further investigation in 1975.

Juvenile seining

A juvenile seining program was initiated on March 16 to monitor abundance, timing, and size of fish which could be subjected to stranding. By late April, increased flow forced termination of this phase of the study also. After the

spring runoff, some seining was conducted in August and September. Seining results are summarized in Table 5.

Seine catches indicated a low salmonid population in mid-March when the catch averaged six fish per set. Salmonid catches steadily increased to 158 fish per set by April 26, the last day of spring seining. Chinook, coho, and chum juveniles were captured--chinook represented 94% of the catch.

When seining was resumed in August, the catch ranged from less than one to over six salmonids per set. Nearly all were chinook.

Approximately 26% of the 947 chinook captured by seine were measured. Within the fish measured, three size groups were evident: (1) 30- to 55-mm fish (18.6%); (2) 55- to 95-mm (70.8%); and (3) 95- to 155-mm fish (10.6%). Virtually all coho were yearlings in the 95- to 190-mm size class. The chum fry captured ranged from 39 to 50 mm in length.

THE 1975 STUDY

Methods

Flow conditions in the Columbia River were conducive for the conduct of the stranding study in 1975. Flow projections by the Corps of Engineers predicted an average water year, with minimum flows of 140,000 cfs from Bonneville Dam and typical peaking flow fluctuations at The Dalles project. These conditions provided the opportunity to estimate peaking-related mortality in the Bonneville pool and in the Bonneville Dam to Vancouver reach.

Sample site delineation - flow fluctuations

To determine juvenile mortality attributable to flow fluctuations, six beaches in The Dalles Dam to Vancouver reach were periodically examined for stranded fish. The sites examined had a low angle of slope, often contained depressions (potholes), and would be dewatered by anticipated flow reductions during the spring of 1975. The sites were identified during river surveys in 1974 and February 1975 by methods described earlier.

Sampling transects were established at selected stranding sites. These transects included all or a portion of the stranding area, depending on the size of the site. Parallel transects were spaced 200 ft apart and extended from the high water line, perpendicular to the water's edge, to the extreme low water line. Each transect was permanently marked at 100-ft intervals with a 3-ft wooden stake. At three of the sites, the parallel transects would not provide adequate coverage. Therefore, similarly marked transects radiating from a single point were used. Plates 1 through 5 show the transect locations at five of the six sites.

Sampling techniques - flow fluctuations

Stranding site sampling coincided with periods of flow reduction at The Dalles and Bonneville Dams. On each observation day, sampling began during the pre-dawn hours or at daylight, depending upon the flow situation, and continued until the river stabilized at the lower flow. A measured width along each transect was examined for mortality from the previous day's high water line to the low water line. All mortalities found on transect were collected, recorded, and preserved for identification and measuring. When watered potholes were encountered on transect, the number of fish trapped was estimated. As samplers became familiar with the sites, they could predict whether the potholes would drain and the trapped fish should be counted as mortalities. Predator control bombs were exploded when necessary to keep birds from removing stranded fish.

In addition to marking the area to be sampled, the transects provided a method of calculating the area examined and area within the sample site. When low river stage was reached, the length of beach exposure (high to low water line) was measured on each transect using the marker stakes as reference points. The width of the path inspected along the transects was also measured. The product of the length-width measurements provided area-examined estimates. The high and low water measurements provided a basis to calculate total exposed area within the transected portion of the sample site.

Mortality estimates - flow fluctuations

Juvenile mortality estimates were calculated on a daily, 2-week, and seasonal basis. The methods used to calculate mortality differed for each time unit and are described below.

Daily mortality estimates were calculated for each site for observation days only, and included only the portion of the stranding site transected. The formula used to calculate daily mortality was:

$$\frac{\text{observed mortality}}{\text{area examined}} \quad \text{area exposed} \quad = \text{daily mortality} \qquad (1)$$

The methods used to calculate area exposed per flow reduction are described in Appendix I, Section 1. Using this method, it is assumed that the stranding observed on transect is representative of the entire site.

A mortality estimate for the sampled portion of each stranding site under observation was calculated at 2-week intervals. For each 2-week time period, the mortality was estimated with the following formula:

$$\left(\frac{\Sigma \text{ observed mortality}}{\Sigma \text{ area examined}}\right)\left(\Sigma \text{ area exposed}\right) = \text{2-week mortality} \qquad (2)$$

The method used to estimate total area exposed per 2-week interval and the variance of the mortality estimates is described in Appendix I, Section 2. If the entire stranding area at the site was transected and sampled, Formula (2) provided a total mortality estimate for that site.

When the entire stranding area of a site was not transected and sampled, an alternate method of calculating mortality was necessary. In this situation, mortality was related to beach length using the following formula:

$$\left(\frac{\text{2-week mortality estimate}}{\text{length of sampled beach}}\right)\left(\text{length of unsampled beach}\right) = \text{mortality of unsampled beach} \qquad (3)$$

Mortality was established for entirely unsampled stranding sites using Formula (3). The mortality rate assigned to the unsampled site was that rate calculated for the sampled site which most closely resembled in physical characteristics the unsampled beach. If the unsampled site did not resemble any of the sample sites, the 2-week mortality per linear foot rates of the appropriate sample sites were averaged and applied to the unsampled site.

Beach lengths used in these calculations were determined by field measurements and from aerial photographs using a Hamilton Map Measurer (Model No. 331) and checked with an engineer's scale.

Sample techniques - ship-wash stranding

Observations in 1974 indicated the need for additional ship-wash stranding work in 1975. Based on surveys of the river in 1974 and 1975, several sites were selected as representative sample areas for stranding observations.

Initially, attempts were made to coordinate observation times through the Columbia River Pilots Association, the individuals who pilot the ships in the Columbia River. This procedure was not successful because even the pilots had

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little warning when the ships would arrive or depart. Therefore, it became necessary to schedule observations at 8-hour shifts on the sample beaches. From February to May, observations were generally conducted from 9:00 AM to 5:00 PM. Sites were monitored over a 24-hour period in May and early June. After late June, only night observations (10:00 PM to 6:00 AM) were scheduled.

On a given observation day, the sample site was immediately cleared of any prior mortality. Fish found at this time were not used in calculating mortality. After a ship passed the site, the area was again systematically inspected and all stranded fish counted and preserved for further examination.

Mortality estimate - ship-wash stranding

Since much of the sampling effort was concentrated in the upper one-third of the shipping channel, a mortality estimate for the 33-mile reach between the Willamette and Cowlitz Rivers was derived. As was the case with flow fluctuation stranding, a mortality estimate was developed for individual ship-wash sample sites during observation periods and a total estimate for sampled and unsampled sites. All ship-wash mortality estimates were calculated on a monthly basis.

To estimate the monthly mortality at an individual sample site, the following formula was used:

$$\left(\frac{\text{No. fish observed stranded that month}}{\text{No. ships observed that month}}\right)\left(\begin{matrix}\text{No. ships passing}\\ \text{the site that month}\end{matrix}\right) = \begin{matrix}\text{monthly}\\ \text{mortality}\end{matrix} \qquad (4)$$

The mortality at unsampled stranding sites was estimated using an average mortality rate. The number of fish stranded and the number of ships observed at all sampled sites were summed by month, then an average mortality per ship calculated. The products of this mortality rate, the number of ships, and the number of unsampled stranding sites produced the mortality estimate.

Or,

$$\left(\begin{matrix}\text{mortality at}\\ \text{unsampled sites}\end{matrix}\right) = \left(\frac{\Sigma \text{ fish observed stranded}}{\text{No. of ships observed}}\right)\left(\begin{matrix}\text{No. of ships}\\ \text{that month}\end{matrix}\right)\left(\begin{matrix}\text{No. unsampled}\\ \text{stranding sites}\end{matrix}\right) \qquad (5)$$

To determine the number of sites, other than sample sites, where mortality should be assigned, the reach between the Willamette and Cowlitz Rivers was surveyed at pre-spring runoff levels and during the spring runoff. Additional sites were identified while seining in this reach. An area was classified as a stranding site if stranding was actually observed or evidence (dead fish) of stranding was found.

The number of ships' factor is twice the number of ships which entered the Columbia River that month since each ship passes the stranding site twice.

Juvenile seining

The abundance, species composition, and size range of the near-shore juvenile population were monitored by a beach seining program. Between Bonneville Dam and Longview, Washington, five sites were seined weekly from February through September. All sites were seined on the same day.

The seine employed was a 100- x 7-ft juvenile beach seine consisting of two 35-ft, untapered, 1/2-inch mesh wings and a 30-ft, 1/8-inch mesh, bobinett center. At each site, a 200-ft river section was seined. Sets were made by walking the seine out to a depth of 3-1/2 to 4 ft, then walking downriver the designated distance. All fish in the catch were identified, counted, and a random sample of each salmonid species measured (fork length - mm).

In addition, one site was seined at 2-hour intervals 1 day per month in April, May, and June to determine diel juvenile movement. Sets were made in the manner described above: the first set made at 1400 hours and the last at 1200 hours the following day. Again, all fish were identified and counted, and a random sample of salmonid species measured when possible. After inspection, the fish were placed in a 50-gallon can, transported 1/2 mile downstream, and released in mid-channel.

Flow data

Flow and river stage data were obtained from the Army Corps of Engineers for The Dalles and Bonneville projects. The Corps also provided river stage data from the Vancouver, Washington and Rainier, Oregon gauges. The Crown Zellerbach Corporation supplied records from the Washougal gauge located in the Camas Slough, Camas, Washington.

Ship traffic data

The U.S. Department of Customs, Portland District, provided information on the movement of ships and their draft while in the Columbia River. Additional data were obtained from the Merchants Exchange, Portland, Oregon.

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Results

Peaking flow fluctuation stranding - Bonneville Pool

In the Bonneville Pool, five areas were identified where juvenile stranding would occur: (1) an extensive left-bank sand beach (RM 183, Oregon shore) downstream of Squally Point; (2) the accreted sand shoal at the Klickitat River mouth (RM 179); (3) the left-bank sand bar near the town of Mosier, Oregon (RM 173.5); (4) the large sand shoal (RM 166.5) downstream of Hood River, Oregon; and (5) the sand and gravel bar adjacent to the Knappton Towboat Company's log storage yard in the Wind River. Figure 1 shows the approximate locations of the sites. All sites were inundated and exposed by fluctuating water levels in the Bonneville Pool during the spring of 1975. Figure 4 shows the daily The Dalles Dam tailrace fluctuations for the period February 24 through May 18, 1975.

To determine juvenile mortality rates in the Bonneville Pool, the Klickitat and Mosier sites were transected and regularly inspected for mortality. These sites were selected for sampling because they were easily accessible by foot.

Stranding observations began at both sites on March 2 and continued through May 10, 1975. Observations were temporarily terminated after May 10 because of high flows, but were resumed in July at the Klickitat site and continued until August 10, 1975.

Klickitat Shoal. Juvenile stranding was observed at the Klickitat site (Plate 1) throughout the March to mid-May period. A total of 186 chinook, 16 coho, and 6 trout was collected on transect during 32 observations (Table 6). Tailrace fluctuations on observations days ranged from 1 to 7.5 ft, with most of the observations occurring during 4- to 6-ft tailrace fluctuations. Calculated bar exposure ranged from 0.25 million to 0.75 million square feet (sq ft). Observed daily mortality counts ranged from 0 to 27 fish, the highest counts occurring in April and May. The calculated mortality for individual observation days ranged from 0 to 93 fish (Table 6).

The estimated total mortality at the Klickitat sample area, for the spring sampling period, was 1,968 chinook, 164 coho, and 72 steelhead trout. This estimate is based on a calculated area of nearly 57 million sq ft exposed at the site during 254 reductions in gauge elevation of 0.5 ft or greater (Table 7). The critical gauge elevation for this site--the elevation at which bar exposure will occur if the water level falls below that point--is 82.0 ft measured at The Dalles Dam tailrace.

A length-frequency analysis of the fish stranded at this site showed that 16.7% of the chinook, 57.9% of the coho, and 100% of the steelhead trout were yearling size (greater than 100 mm). This is the only site where yearlings were frequently stranded.

The fish observed trapped in potholes were not counted as mortalities. In most instances, the daily flow increases liberated the isolated fish before the pothole could drain. On several occasions, potholes with fish were monitored and loss to predation was not observed.

Mosier site. Observed stranding at the Mosier site was confined to chinook fry in the 30- to 45-mm size range. During 25 observations, a total of 73 fry was collected on transect (Table 8). Daily observation counts ranged from 0 to 24 fry, with most of the stranding occurring from mid-March through early April. On observation days, The Dalles Dam tailrace fluctuations ranged from 1.5 to 8.2 ft. The calculated area exposed per fluctuation ranged from 18,300 sq ft to 140,000 sq ft. The calculated mortality for individual days was from 0 to 55 fish (Table 8).

The estimated total mortality at the Mosier site was 750 chinook. This estimate is based on a calculated bar exposure of 6.65 million square feet during 254 reductions in gauge elevation of 0.5 ft or greater (Table 9). The critical gauge elevation for this site is 81.5 ft, measured at The Dalles Dam tailrace.

As at the Klickitat site, fish observed in potholes were not counted as mortalities.

Total mortality estimate

The above estimates indicated mortalities for the sample bars. To develop a mortality estimate for the unsampled areas it was necessary to convert the 2-week mortality estimate to mortality per linear foot (M/LF) of bar exposed. Unlike the mortality per square foot rate, this mortality rate can be applied to all stranding sites where bar length can be measured. The M/LF rates were calculated for the necessary sites and are shown in Table 10.

The Klickitat M/LF rates were applied to the unsampled shoal on the east bank of the Klickitat River mouth and the Wind River site. Both areas are very similar to the sample site. The coho M/LF was not applied to the Wind River bar since hatchery coho are not released from Carson Hatchery and little coho spawning occurs in the Wind River. To calculate mortality for the Squalley Point

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beach and the Hood River site, the mortality rates of the sample bars were average and applied to the sites.

Based on these calculations, the total mortality in the Bonneville Pool was estimated to be 19,349 chinook, 816 coho, and 425 trout for a total of 20,590 fish for the period March 2 through May 10, 1975. Highest mortalities were incurred during the March 30 to April 12 time period, when 39% of the total estimate was killed (Table 11).

Mortality was not calculated for July and August because stranding was found to be infrequent.

Peaking flow fluctuation stranding - Bonneville Dam to Vancouver

In the Bonneville Dam to Vancouver reach, five areas were identified where stranding would occur during the projected 1975 spring flow regime: (1) the east end of Ives Island (RM 143); (2) the north and south sides of Pierce Island (RM 142); (3) the Sandy River bar (RM 122); (4) the east end of McGuire Island (RM 118); and (5) the south beach between Government and Lemon Islands (RM 113). Sampling areas were established on all but Ives Island. Figure 1 shows the location of the stranding sites.

Daily changes in river elevation measured at the Bonneville tailrace and Washougal gauge are graphically depicted in Figure 5 for the period February 2 through May 10, 1975.

Pierce Island. A total of 17 stranding observations was conducted at the Pierce Island site (Plate 2) from February 27 through May 10, 1975. Only eight chinook and one coho were observed stranded on transect during the observations (Table 12). Bonneville Dam tailrace fluctuations ranged from 0.9 ft to 5.5 ft on observation days. The calculated area exposed within the sample site varied from 20,237 sq ft to 234,703 sq ft. The calculated mortality for individual observation days ranged from zero to eight fish (Table 12).

The total mortality estimate for the sampled portion of Pierce Island was 198 chinook and 12 coho. The estimate is based on a calculated exposed area of 8.7 million sq ft resulting from 88 flow reductions of 0.5 ft or greater measured at the Bonneville Dam tailrace (Table 13).

Exposed area was calculated only when the tailrace elevation dropped below 24.9 ft, the critical elevation for that site.

Sandy River bar. Spring stranding observations at Sandy River bar (Plate 3) began on February 6 and were terminated May 3, 1975. During 17 observations, a total of 35 chinook, 1 coho, 14 chum, and 1 trout was collected on transect (Table 14). River stage fluctuations, measured at the Washougal gauge, ranged from 0.1 ft to 3.4 ft on observation days. The calculated area exposed by those fluctuations ranged from 11,802 sq ft to 654,894 sq ft. The calculated mortality for individual observation days ranged from 0 to 84 fish (Table 14).

The calculated mortality within the sampled portion of the site during the spring period is 249 chinook, 48 coho, 104 chum, and 6 trout, totaling 406 fish. The amount of area exposed within the sample site was over 17 million square feet resulting from 95 flow reductions which registered greater than 0.25 ft at the Washougal gauge (Table 15).

The critical gauge elevation at this site was 11.0 ft measured at the Washougal gauge.

McGuire Island. Stranding observations were conducted at McGuire Island (Plate 4) from February 23 through May 11, 1975. A total of 22 observations was logged at this site with 28 chinook, 1 coho, and 46 chum found stranded on transect (Table 16). River stage fluctuations, measured at the Washougal gauge, ranged from 0.1 ft to 3.4 ft on observation days. The calculated area exposed by these fluctuations ranged from 42,227 sq ft to over 1.2 million square feet. Daily mortality estimates varied from 0 to 169 fish (Table 16).

The calculated mortality at McGuire Island for the period March 2 through May 10 is 328 chinook, 11 coho, 747 chum, and 12 trout, totaling 1,093 fish. A calculated area of over 24.1 million square feet was exposed by 65 flow reductions greater than 0.25 ft (Table 17).

The McGuire Island site had two critical river elevation levels: 13.2 ft for the sample area delineated by parallel transects, and 12.0 ft for the area denoted by radial transects.

Government Island. A total of 16 stranding observations was conducted at the Government Island site (Plate 5) from March 12 through May 5, 1975. Only four chinook and three chum were found stranded on transect during the observations (Table 16). River stage fluctuations ranged from 0.3 ft to 2.4 ft on observation days exposing a maximum of 278,000 sq ft at the site. Daily mortality estimates ranged from zero to seven fish (Table 18).

During the March 2 through May 10 time period, a total of 65 flow reductions (0.25 ft or greater) exposed an estimated 8.14 million square feet of beach and stranded 32 chinook and 28 chum (Table 19).

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The critical river level elevation at this site was 13.0 ft, measured at the Washougal gauge.

Total mortality estimate. Additional stranding mortality was calculated for Ives Island, the unsampled portion of Pierce Island, and the unsampled portion of the Sandy River bar stranding site. Again, the 2-week mortality estimates were converted to mortality per linear feet (M/LF) of bar exposed and applied to the length of unsampled beach.

The M/LF factor calculated for Pierce Island was used to estimate mortality on 4,200 ft of shoreline on Ives Island and 2,900 ft of unsampled shoreline on Pierce Island. Similarly, the M/LF factor calculated for Sandy River bar was used to estimate mortality on 5,600 ft of unsampled shoreline at this site (Table 10).

The combined estimated mortality for sampled and unsampled stranding sites in the Bonneville Dam to Vancouver reach is 2,848 chinook, 310 coho, 1,243 chum, and 39 trout, totaling 4,440 salmonids for the February 2 through May 10, 1975, time period (Table 20). Like the Bonneville Pool estimate, the highest mortalities occurred from March 30 to April 12.

Stranding by species

Chinook juveniles were the dominant species stranded in both reaches of the Columbia River under investigation. In the Bonneville Pool, chinook comprised 94.0% of the estimated mortality and 64.1% below Bonneville. Coho were 4% of the mortality in the pool and 7% below the dam. Chum, although not observed stranded in the pool, comprised 28% of the mortality below Bonneville Dam. Trout constituted 2.0% of the pool mortality and 0.9% below the dam.

Size distribution of stranded fish

Peaking fluctuations stranded juveniles of all sizes. However, nearly 86% of all fish collected on and off transect were within the 30- to 50-mm size range. The majority of these fish were chinook (78%), with chum (20%) and coho (2%) the remaining fry mortality (Figure 6).

Chinook, coho, and trout yearlings were observed stranded, nearly all at the Klickitat site in Bonneville Pool.

Flow reduction rates and size of flow reduction

The rate at which flows were reduced at The Dalles and Bonneville projects varied significantly. As can be seen in Table 21, the average rate of gauge elevation drop at The Dalles ranged from 0.699 to 0.592 ft/hour, at nearly twice the Bonneville drop rate for most 2-week periods. When compared to Washougal drop rates, The Dalles was about 5 times faster in most cases. When expressed in terms of flow, the average reduction rate at The Dalles ranged from 20,000 to 16,900 cfs/hour, nearly 3 times greater than the Bonneville flow reduction rates.

The average size of the flow reductions at the three gauging points was also calculated for each 2-week interval. At The Dalles, the average tailrace elevation drop per flow reduction ranged from 2.31 ft/reduction (approximately 66,000 cfs/reduction) to 1.79 ft/reduction (approximately 51,100 cfs/reduction). At the Bonneville tailrace, the average tailrace elevation drop per flow reduction ranged from 2.69 ft/reduction (47,100 cfs/reduction) to 1.57 cfs/reduction (27,500 cfs/reduction). The average gauge elevation drop at Washougal ranged from 1.39 to 0.82 ft/reduction (Table 22).

Additional observations

In March and April, several stranding observations were conducted on the extensive, flat, sand shoal at Hunter Point, Sandy Island (RM 76). Here, flow fluctuations result from Bonneville discharge, tidal fluctuations, and Willamette River flow. The observations, conducted on the outgoing tide phase, produced no stranding and therefore were discontinued.

In July and August, after the spring runoff, additional surveys were made at the Klickitat, Pierce Island, Sandy River bar, and McGuire Island sample sites. The only salmonid stranding observed was at the Klickitat site, where three trout and one whitefish were found stranded (Table 6).

The shoals adjacent to Reed Island and the beach at Rooster Rock State Park (Figure 1) were inspected in late July and August, when Bonneville discharge dropped below 140,000 cfs and exposed these shoals. Juvenile salmonid stranding was not observed on any occasion.

Ship-wash stranding

Ship-wash stranding, resulting from the wave action of large ships coursing the Columbia River, was a constant source of juvenile mortality through the spring and early summer. Observations were conducted at five sites from Vancouver to Stella, Washington, from February through August 1975. A total of 216 ships

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was observed passing the sites stranding 2,297 chinook, 25 coho, 66 chum, and 9 trout. In February, March, and April, stranding observations were conducted during daylight hours. From May through late June, sites were monitored for 24 hours. Beginning in mid-June, very little stranding was observed during daylight hours; therefore, starting June 26 and continuing through August, all observations were scheduled at night.

Fishtrap Shoal (Sauvies Island). Observations at Fishtrap Shoal (RM 91) were conducted from early February through mid-May, when the stranding area was inundated. At this site, three coves were inspected for mortality. The slopes or gradients at these coves ranged from 1.5% to 5.4%.

A total of 36 ships was observed passing the site stranding 147 chinook, 6 chum, and 1 trout. On specific observation days, the mortality per ship ranged from 0 to 28 fish. Mortality rates for the months of February, March, April, and May 1-15 were 6.0, 5.3, 1.7, and 1.5 fish/ship, respectively (Table 23).

The estimated total stranding mortality at the Fishtrap Shoal site during months of actual observation is 3,800 chinook, 154 chum, and 14 trout (Table 24).

Marshall Beach (Sauvies Island). The Marshall Beach site (RM 97) was selected for sampling after high water flooded Fishtrap Shoal. At this site, two inlets were inspected for mortality during the months of May, June, July, and August 1975. The gradients at this beach were not measured.

A total of 34 ships was observed at this site stranding 235 chinook and 1 trout. On individual observation days, the mortality per ship ranged from 0 to 30 fish. The monthly mortality rates for May, June, July, and August were 14.0, 1.6, 0.0, and 0.0 fish per ship, respectively (Table 25).

The estimated total mortality at this site during the observation period is 2,465 chinook and 10 trout (Table 24).

Austin Point. The Austin Point site (RM 86.5), located 1/2 mile downstream of the Lewis River mouth, consisted of a single inlet. Observations were conducted from March through August 1975. Observations were not made from mid-May through late June because the site was under water. The gradient at this inlet ranged from 3.4% to 4.1%.

From March through August, a total of 1,002 chinook, 20 coho, 54 chum, and 5 trout was observed stranded by 64 ships. During this time period, daily

mortality-per-ship rates ranged from 0 to 117 fish. The monthly rates for March, April, May, June, July, and August were 5.7, 32.9, 23.0, 4.7, 1.7, and 0.0 fish per ship, respectively (Table 26).

The estimated total mortality at the Austin Point site during the months of observation is 14,662 chinook, 229 coho, 916 chum, and 97 trout (Table 24).

Woodland Bar. The Woodland Bar site (RM 81.5), another single inlet site, is located at the upstream entrance of Burke Slough. Stranding observations were conducted at this site in April and May, and again in July and August. Like the Austin Point site, Woodland Bar was inundated by water from mid-May through June.

During the observation period, a total of 446 chinook, 5 coho, and 3 chum was observed stranded by 30 ships. Daily mortality-per-ship rates ranged from 0.0 to 42.0 fish. Monthly mortality rates for April, May, July, and August were 21.8, 13.1, 0.0, and 0.5 fish per ship, respectively (Table 24). The gradient at this inlet was approximately 0.5%.

Hoagy's Bar. Stranding observations began at Hoagy's Bar in April and continued through August 1975. Unlike the other sites, Hoagy's is a low, sloped beach with no defined inlets. The sample area is located at RM 57, about 3/4 mile upstream of the Coal Creek Slough entrance. Approximately 1/4 mile of beach was inspected for mortality. The gradient on this beach ranged from 5.75% to 7.25%. Plate 6 is a pictorial sequence showing the wave action created by a ship passing the site.

During the entire observation period, a total of 467 chinook, 3 chum, and 2 trout was observed stranded by 52 ships. Daily mortality-per-ship rates ranged from 0 to 39 fish. Mortality rates for April, May, June, July, and August were 5.9, 9.8, 10.9, 0.0, and 0.0 fish per ship, respectively (Table 28).

The estimated total mortality during the above months at this site totaled 8,149 chinook, 130 chum, and 34 trout (Table 24).

Unsampled stranding sites

In April prior to the spring runoff, 10 unsampled sites were identified in the Willamette to Cowlitz River reach. At this time, Columbia River stage (Rainier, Oregon [RM 66.1]) ranged from 3 to 7 ft, with Bonneville Dam discharge averaging 216,000 cfs and Willamette inflow 28,300 cfs. During the spring runoff, only four unsampled sites were found. For the period May 15 through June 15, Columbia River stage at Rainier ranged from 7 to 9+ ft, with Bonneville discharge averaging 346,000 cfs and Willamette inflow 25,500 cfs.

Ships in the Columbia River

The number of ships entering the Columbia River, according to the Merchants Exchange tabulations, was 140, 143, 162, 138, 171, and 166 for the months of February, March, April, May, June, and July 1975, respectively. By doubling the monthly totals, the number-of-ships-passing-the-site factor is obtained. As can be seen in Table 24, this factor has been adjusted according to the number of days or time of day a site has stranding potential.

Presently, ships in the Columbia River operate under no speed restrictions.

Total mortality estimate - Willamette River to Cowlitz River

A mortality estimate based on the number of stranding sites identified in the Willamette to Cowlitz River reach, the average monthly mortality rates (Table 29), and the number of ships passing the sites was developed for the period February through July. The combined mortality estimate at sampled and unsampled ship-wash stranding sites for this reach is 145,003 chinook, 1,359 coho, 4,771 chum, and 537 trout, totaling 151,670 juvenile salmonids. The greatest mortality occurred in April when an estimated 68,674 fish were killed in this 33-mile reach (Table 30).

Stranding by species

Chinook, coho, chum, and trout juveniles were observed stranded by ship-wash; approximately 95.8% of the observed mortality was chinook. Chum comprised 2.8% of the mortality, coho 1.9%, and trout 0.3%.

Size of stranded fish

The size distribution of fish stranded by ship-wash is graphically represented in Figure 7. As can be seen, juveniles in the 30- to 45-mm size range were severely impacted. A high percentage of these fish was stranded in March and April, the period when only daytime observations were made. As observations were extended over a 24-hour period in May and June, the majority of the stranded fish were in the 50- to 100-mm size class. The only 100+ mm fish observed were yearling coho.

Over the entire observation period, 53% of the fish stranded were within the 30- to 45-mm size range and 47% were greater than 45 mm.

Further observations

All Columbia River boat traffic did not strand fish. Stranding was not observed when pleasure craft or tug boats passed the site. Of the large ships observed, only 48% stranded fish. The vessels that did not strand fish generally produced relatively small waves, and the wave uprush, the distance the wave traveled onto the beach above the still-water edge, was minor.

Of the 216 ships observed, the draft of 68 vessels was determined for the time of observation. A plot of draft versus mortality shows that most fish are stranded by ships with a draft of 25 ft or greater. The mortality rate of the 31 ships with a draft greater than 25 ft was 19 fish per ship. Conversely, the mortality rate of the 37 ships with a draft less than 25 ft was three fish per ship.

The time of day a ship travels the Columbia River appears to be important only during the summer. In May, when 24-hour observations were conducted at four of the five sites, the mortality rates of day versus night traffic were very similar. Ships observed during daylight hours averaged 16.5 fish per ship and night traffic 13.8 fish per ship. After mid-June, all observed stranding occurred at night as previously explained.

Juvenile abundance and size distribution

The near-shore juvenile population was monitored by a seining program conducted from February 12 through September 25, 1975. Sets were made weekly at Sandy Island (RM 131), Government Island (RM 115), Sauvies Island (RM 97), and Sandy Island (RM 76). A fifth site at Lord Island (RM 63) was added on March 26, 1975.

Chinook. Juvenile chinook were present in the catch throughout the seining period. Peak catches occurred from early April to late May. Mid-May and early June combined catches are artificially low because high water prevented seining at two of the sites on occasion (Table 31). After the first week of July, the combined weekly catch at all sites did not exceed 27 chinook (Figure 8).

During the 8-month seining period, 89.6% of all salmonids captured were chinook.

Chinook captured by beach seine ranged from 30 to 215 mm in length. Within the size range, three distinct size groups were present: (1) 30- to 60-mm fish representing natural production (2) 61- to 100-mm fish which are predominantly

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hatchery fall chinook; and (3) 100+ mm fish which are natural and hatchery production spring chinook (Figure 9). The percentage each group represents in the catch is 35.5%, 57.3%, and 7.2%, respectively.

Coho. Juvenile coho were present in the catch from early March through late May, peaking in early May. Coho were abundant only during the last week of April and the first 2 weeks of May, however (Figure 8).

Over the entire seining period, coho constituted 9.1% of the salmonid catch.

Nearly all coho captured were yearlings, ranging in size from 100 to 170 mm (Figure 9). Approximately 98% of the coho were within this size group.

Chum. Chum juveniles entered the catch in late March and were present through early May. Peak abundance occurred throughout the month of April at a relatively low level (Figure 8).

The chum juveniles, which made up 1.3% of the salmonid catch, were within the 30- to 45-mm size class (Figure 9).

Supplemental seining

In addition to the weekly seining, the Government Island site was seined over a 24-hour period in April, May, and June 1975. Sets were made every 2 hours, beginning at 1400 hours and ending at 1200 hours the next day. The data provided insight as to when juveniles are abundant in near-shore waters and most susceptible to stranding.

On April 24 and 25, overall juvenile abundance was highest from 2200 hours to 0400 hours. Excluding the initial catch at 1400 hours, chinook abundance peaked in the evening (1800-2000 hours) with catches generally decreasing throughout the night and morning. The major onshore movement of coho took place between 2200 and 0400 hours (Figure 10).

The May catches displayed a more defined time of onshore movement. Excluding the initial catch, both coho and chinook peaked in abundance at 2000 hours and again at 0800 hours (Figure 11).

When seining was repeated in June, only chinook were captured. As can be seen in Figure 12, very few juveniles were present in this river section. A slight peak did occur at 2000 hours, however, similar to the April and May trends.

DISCUSSIONS AND CONCLUSIONS

Observations conducted in 1974 indicated that with high Columbia River flows--greater than 250,00 cfs--peaking activity is limited at Bonneville Dam. Therefore, most potential stranding areas below Bonneville Dam are continually inundated and juvenile stranding is minimal.

In 1975, a more typical water year, the investigation demonstrated that chinook, coho, chum, and trout juveniles are stranded by peaking flow fluctuations in the Bonneville Pool and in the Bonneville Dam to Vancouver reach. In the pool, stranding was found to occur when The Dalles tailrace elevation fell below 82.0 ft. Between Bonneville Dam and Vancouver, stranding was observed when Bonneville Dam discharge fluctuated from 250,000 cfs down to 140,000 cfs. Downstream of Vancouver most stranding was caused by ship-wash.

An estimated total of 20,590 salmon and steelhead trout was killed by peaking fluctuations in the Bonneville Pool from March 2 through May 10, 1975 (Table 11). In the Bonneville Dam to Vancouver reach, the estimated peaking mortality was 4,440 salmonid juveniles from February 2 through May 10, 1975 (Table 20). Stranding was found to be minimal in July and August; therefore, a mortality estimate was not calculated.

The estimated ship-wash stranding mortality from the Willamette to Cowlitz Rivers was 151,670 salmonids for the period February through July 1975 (Table 30).

Since the mode of operation at The Dalles and Bonneville Dams is quite different, stranding related to each project will be discussed separately. However, the timing of the spring runoff and the timing of the juvenile out-migration may be reviewed first because they apply to both projects.

The timing and magnitude of the spring runoff determine, to a great extent, if stranding will be a problem in the lower Columbia River. If, as was the case in 1974, the spring runoff begins early and continues through June, peaking flow fluctuations are not common during the juvenile migration (Figures 2 and 3; Tables 2 and 3), and stranding is not a significant source of mortality. In 1975, however, the spring runoff did not begin until May 13, with typical peaking fluctuations and stranding occurring until that time (Figures 4 and 5). Fluctuations which could cause stranding were not resumed until July 1, 1975.

Most salmonid juveniles in the Columbia River are migrating seaward. The timing of this migration has an important bearing on fish available to be stranded. The juvenile seining program demonstrated that salmonid juveniles were abundant in near-shore waters from late March through June (Figure 8). Chinook, the predominant species stranded, were abundant throughout this period. Chum juveniles, not present in the pool, but frequently stranded below Bonneville, were abundant in April. Coho, observed stranded in both reaches in small numbers, were abundant from late April through mid-May. Steelhead trout, the species most infrequently stranded, did not enter the seine catches in significant numbers. The timing of the steelhead migration is very similar to coho, however.

Bonneville Pool

In the Bonneville Pool, stranding is a result of peaking flow fluctuations at The Dalles Dam. Under present operating conditions, mortality is limited by the number of stranding sites, the availability of the fish, and the timing of the spring runoff.

The rate (Table 21), frequency (Figure 4; Tables 7 and 9), and magnitude (Table 22) of the flow reductions at The Dalles project provide ideal stranding conditions. Stranding sites are dewatered rapidly, with a major flow reduction occurring at least once daily exposing most of the potential stranding area. Fortunately, only five sites were identified which were inundated and exposed by the fluctuating water levels.

Completion of the second Bonneville powerhouse will change that situation, however. By raising the maximum operating elevation at Bonneville Dam, additional stranding areas in the pool will be subjected to daily water level fluctuations. Many of the additional sites will be in the lower reaches of pool tributaries, similar to the Klickitat site. Observations at this site demonstrated that significant juvenile stranding does occur in such areas (Table 6). The mortality rates (Table 10) calculated for the Klickitat site are an excellent indicator of the stranding that will occur at the new sites.

Bonneville Dam to Vancouver Reach

Juvenile stranding was not a serious source of juvenile mortality between Bonneville Dam and Vancouver in 1974 or 1975. The lack of stranding in this reach can be attributed to several factors which are discussed below.

As stated previously, high Columbia River flows and relatively few flow reductions protected juvenile migrants in the spring of 1974. In 1975, the minimum flow experienced from Bonneville Dam was approximately 140,000 cfs. With a minimum flow of 140,000 cfs from Bonneville Dam, however, only 5 of the 12 potential stranding sites in this reach were exposed by the fluctuations, the rest

remained adequately watered. For example, the extensive sand shoal around Reed Island, an area with very high stranding potential, was not dewatered to the extent that stranding would occur. By keeping the minimum flow above the critical level of these sites, mortality was held down.

The rate at which flows were reduced (Table 21) and the magnitude of the flow reductions (Table 22) did much to diminish stranding at sites which were exposed. The relatively slow flow reduction rates experienced at Bonneville Dam and Washougal (compared to The Dalles) evidently provide most juveniles with enough time to reach the safety of deep water. In comparison to The Dalles, the average size of a flow reduction at Bonneville Dam was smaller, which generally means less stranding area will be exposed per flow reduction.

Below Bonneville Dam, river stage is affected by tides and Willamette River inflow as well as Bonneville discharge. During low water periods, tidal influence is recorded on the Washougal gauge (Figure 5, February). Depending upon the tide phase, a flow fluctuation may be accentuated or moderated. High Willamette River inflow can create a backwater curve which will also dampen the effects of a Bonneville flow reduction.

Although peaking fluctuation stranding was not a significant problem below Bonneville Dam during an average or high-water year, it could become a major problem during a low-water year. All major stranding areas are watered at 200,000 cfs and extensively exposed at 80,000 cfs. Frequent fluctuations within this range, especially from 140,000 to 80,000 cfs, will undoubtedly cause severe stranding mortality.

The composition of most Columbia River bars and shoals may be a factor which helps reduce stranding. Personal stranding observations on the Cowlitz River indicate that juveniles will often attempt to seek refuge in the gravel as a river bar is dewatered. This reaction, of course, usually leads to death. Juveniles in the Columbia do not have this option because most shoals and beaches are composed of sand or very fine gravel. Therefore, more time may be spent looking for and finding an escape route.

The rapid loss of water in pools and depressions (potholes) on gravel bars in the Skagit and Lewis Rivers was reported as a major cause of stranding during a flow reduction. On the Columbia River, the sand bars are apparently less permeable; therefore, they retain water for longer periods of time. In many cases, potholes remained well watered until increasing flows liberated trapped fish.

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Ship-Wash Stranding

Ship-wash stranding is the most serious form of juvenile stranding that occurs on the lower Columbia River at this time. As pointed out, ship-wash stranding is related to vessel size, the size of the wave it generates, vessel draft, and time of day and year.

The wave size generated by vessels traveling in the Columbia River is a major consideration in ship-wash stranding. Small boats, such as pleasure craft and tugboats (with or without tow), did not strand fish. These boats produced relatively small waves and the wave uprush was negligible.

The large ships, on the other hand, often produced tremendous waves and an extensive uprush which usually resulted in juvenile stranding. Although the size of the waves was not measured during our investigation, some work has been done in that field. Laboratory tests to determine the maximum wave height (H_{max}) produced by several ship types in water of uniform depth were carried out by Hay (1969). These tests show that H_{max} increased as ship velocity increased, water depth decreased, and distance from sailing line (distance from ship to shore) decreased. The tests also show there are speeds which produce relatively small waves, regardless of depth or distance from shore. For example, the predicted H_{max} is less than 2 ft at velocities less than 13.5 knots for a marine class cargo ship (length -556 ft; draft - 24 ft) moving through water ranging in depth from 33 ft to 72 ft and traveling 283 ft from shore (the distance nearest to shore tested). The predicted H_{max} for the same ship under the same conditions ranges from 4 ft to 10 ft when velocities range from 14.5 knots to 22.25 knots.

As stated, the above tests were for ships traveling through water of uniform depth. Johnson (1969), using similar laboratory techniques, predicted maximum wave height in shoaling waters, similar to conditions present in the Columbia River. He found at slower velocities, the predicted H_{max} is less on shoals than in water of uniform depth. However, at high speeds (above 18 knots), H_{max} is as great or greater on the sloping beaches as in water of uniform depth.

The results of the aforementioned tests are likely one reason that only 48% of the large ocean vessels observed stranded fish. In many instances, the ship was probably traveling at speeds which did not generate waves large enough to strand fish.

The ship's draft is another variable which appears to be a determining factor in juvenile stranding. The mortality rate of ships with a draft greater than 25 ft was 6 times greater than ships with a lesser draft. Studies by Johnson (1958) may offer partial explanation. He found that when the channel

depth to ship's draft ratio fell below 8, the wave heights produced by ships increased rapidly as the ratio approached 1. Since the Columbia River navigation channel is maintained at a 40-ft depth, the depth-to-draft ratio will be substantially less than 8; therefore, most ships will be producing waves of near maximum size for a given speed. The significance of the 25-ft draft depth remains unclear, however.

The time of year ships travel the Columbia River has obvious implications. Juvenile abundance is seasonal, thus when the juvenile population is low, ship-wash stranding will be of minor consequence. The time of day appears important from mid-June through July. During this time period, stranding was observed only at night. Although present, juveniles apparently do not inhabit the near-shore waters during daylight hours. The shift in habitat preference may be related to near-shore water temperatures, light intensity, predation pressures, or feeding habits.

Ship-wash stranding in the Columbia River is a significant source of juvenile mortality. Unless protective measures are taken, stranding mortality will greatly increase in the years ahead. A recent study for the public ports of Washington and Portland (The Aerospace Corporation, 1975) predicts that foreign trade in this region will increase more than 2-1/2 times by the year 2000. Domestic shipments are expected to increase by 60%. To accommodate this increase in trade, more, larger, and faster ships will be plying the waters of the Columbia River creating additional hazards to the migrating juveniles.

RECOMMENDATIONS

In the Bonneville Pool, under existing conditions, juvenile stranding is not a serious source of mortality. With the completion of the second Bonneville powerhouse, additional stranding is expected, the extent depending on the number of new stranding areas which will be within the new pool fluctuation range. Immediately following completion of the powerhouse, further stranding observations and mortality estimates should be made to determine the magnitude of the stranding problem created by the new flow regime.

Between Bonneville Dam and Vancouver, juvenile stranding was found to be insignificant when Bonneville discharge was 140,000 cfs or above. The present rules which govern Bonneville Dam operation are a major reason, therefore should be retained and adhered to strictly. To further protect the juvenile migrants,

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the 4-ft daily tailrace limit should not be violated during the months of April, May, and June. If low-flow conditions (140,000 cfs weekly average) are expected during the above months, peaking fluctuations at Bonneville Dam should be discontinued and a near-constant flow be maintained.

Ship-wash stranding was found to be a significant source of juvenile mortality. The most practical solution is the imposition and enforcement of a speed limit for all ships traveling the Columbia River from March through June. Based on the studies cited, ship speeds in the Columbia River should not exceed 14 knots. If this is not possible, discharge at Bonneville Dam should be regulated to maintain a river stage of 7 to 9 ft at Rainier, Oregon. By doing so, most of the stranding areas will be inundated and juvenile mortality significantly reduced.

Many of the beaches where ship-wash stranding occurred are Corps of Engineers' dredge disposal sites. To help prevent creation of further stranding areas, the river-facing slopes of dredge disposal beaches should be contoured to a 9% minimum gradient immediately after use.

SUMMARY

1974 Study

1. Nearly all major stranding areas identified in the Bonneville Dam to Vancouver reach were continually inundated by water from April to mid-July 1974.
2. Minimum discharge from Bonneville Dam was 250,000 cfs during that time period.
3. Peaking flow fluctuations at Bonneville Dam were not common during the spring of 1974.
4. Juvenile salmonid stranding mortality was not estimated in 1974; however observations indicated minimal mortality during the spring.
5. Ship-wash stranding appeared to be a significant source of juvenile mortality in the Columlbia River downstream of Vancouver, Washington.

1975 Study

1. Stranding observations were conducted in the Bonneville Pool and downstream of Bonneville Dam from mid-February through August.
2. Peaking flow fluctuations occurred at The Dalles and Bonneville Dams until May 12, when the spring runoff began, and were resumed in early July.
3. Minimum discharge experienced at The Dalles was approximately 56,000 cfs and 140,000 cfs at Bonneville during the spring.

4. The estimated stranding mortality in the Bonneville Pool from March 2 through May 10 was 19,349 chinook, 816 coho, and 425 steelhead trout.
5. Stranding in the Bonneville Pool was limited by the number of areas where fish could be stranded.
6. The estimated stranding mortality in the Bonneville Dam to Vancouver reach from February 2 through May 10 was 2,848 chinook, 310 coho, 1,243 chum, and 39 steelhead trout.
7. The lack of stranding in the Bonneville Dam to Vancouver reach was attributed to the restrictive flow fluctuation rules which govern Bonneville Dam operation and the 140,000 cfs minimum flow experienced at Bonneville Dam.
8. Approximately 86% of the fish stranded by peaking fluctuations were fry in the 30- to 50-mm size range.
9. Peaking-related juvenile stranding was not calculated for July and August because stranding was infrequent.
10. Ship-wash stranding observations were conducted on the Columbia River downstream of the Willamette River confluence from February through August.
11. The estimated ship-wash stranding mortality in the Willamette River to Cowlitz River reach was 145,003 chinook, 1,359 coho, 4,771 chum, and 537 steelhead trout from February through July 1975.
12. Of the fish stranded by ship-wash, 53% were from 30 to 45 mm and 47% in the 45- to 135-mm size range.
13. Ship-wash stranding was related to the size of the waves generated by the ship; wave size is a function of ship speed, channel depth, distance from shore, and vessel draft.
14. Seining data show that salmonid juveniles are abundant near-shore from late March through June. Peak abundance occurred in early May.

Recommendations

1. Further stranding investigations in the Bonneville Pool after completion of the second Bonneville powerhouse.
2. Rules which presently govern Bonneville Dam operation be maintained with the following exceptions: (a) the 4-ft daily tailrace fluctuation limit not be exceeded during the months of April, May, and June; and (b) if the

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average weekly discharge at Bonneville Dam is 140,000 cfs or less during the above months, peaking fluctuations be terminated and a near-constant flow maintained.

3. A speed limit of 14 knots be imposed on all ships in the Columbia River from March through June.

4. If a speed limit is not possible, discharge from Bonneville Dam be regulated in such a manner that the river stage at Rainier, Oregon, is maintained at a 7- to 9-ft level from March through June.

5. The river-facing slopes of dredge disposal berms along the deep-draft navigation should be sloped at a 9% minimum gradient immediately after use.

ACKNOWLEDGMENTS

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A P P E N D I X I

Mathematic and Statistical Computations

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APPENDIX I

Mathematical and Statistical Computations

The mathematical and statistical parts of this study can conveniently be broken into two sections. In the first section, an algorithm is devised to convert transect measurements of high and low water into areas of exposure. In the second section, relationships are derived which allow expansion of sampled mortalities to total mortalities.

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SECTION I

The area of exposure between two transects can be estimated by a quadrilateral drawn between high and low water marks. Such a quadrilateral is shown on the top of Figure 1. This quadrilateral is bordered by points a'b'ba. The area of an arbitrary quadrilateral is given by the formula

$$A = \frac{1}{2} D_1 D_2 \sin \gamma$$

where D_1 and D_2 are the lengths of the diagnals and γ is the angle between them. Therefore, an algorithm is needed to compute these three quantities.

The method of analysis which was chosen was to use the base point of the left most transect as the origin, and choose T_1 to be the Y axis. The coordinates of a and b are then computed with respect to this origin. It seemed easiest to compute the coordinates of a and b as polar coordinates, then change them to rectangular coordinates to complete the analysis. Note that the analysis must take into account that a and b can be negative. For the interested individual, the following describes the sequence of calculations. All quantities refer to Figure 1.

First, the coordinates of a and b with respect to the origin 0 must be found.

$$r_a = \sqrt{200^2 + a^2 - 2(200)\, a \cos \emptyset} \qquad \text{(see note below)}$$

$$a^2 = r_a^{\,2} + 200^2 - 2(200)\, r_a \cos \alpha'$$

$$\alpha' = \cos^{-1}\left[\frac{a^2 - (r_a^{\,2} + 200^2)}{-2(200)\, r_a}\right]$$

$$\alpha = \theta - \alpha'$$

Similarly,

$$r_b = \sqrt{200^2 + b^2 - 2(200)\, b \cos \emptyset}$$

NOTE: for "a" negative

$$r_a = \sqrt{200^2 + a^2 + 2(200)\, a \cos \emptyset'}$$

$$\alpha' = \cos^{-1}\left[\frac{a^2 - (r_a^{\,2} + 200^2)}{-2(200)\, r_a}\right]$$

$$\alpha = \alpha' + \theta$$

Similarly for "b" negative.

$$\beta' = \cos^{-1}\left[\frac{b^2 - (r_b^{\,2} + 200^2)}{-2(200)\, r_b}\right]$$

$$\beta = \theta - \beta'$$

With respect to the rectangular coordinate system with origin at 0 and Y axis along transect T_1, the coordinates are as follows.

Point	Polar coordinates	Rectangular coordinates
a	(r_a , α)	$(X' , Y') = (r_a \sin \alpha , r_a \cos \alpha)$
b	(r_b , β)	$(X'' , Y'') = (r_b \sin \beta , r_b \cos \beta)$
a'	(a' , o)	(o, a')
b'	(b' , o)	(o, b')

The rest of the analysis will now be in terms of rectangular coordinates measured from 0. The equations for lines ℓ_1 and ℓ_2 are

$$\ell_1: \quad Y = a' + \left(\frac{a' - y''}{-x''}\right) X$$

$$\text{and } \ell_2: \quad Y = b' + \left(\frac{b' - y'}{-x'}\right) X .$$

Their intersection 0" is then given by the point where

$$a' + \left(\frac{a' - y''}{-x''}\right) X = b' + \left(\frac{b' - y'}{-x'}\right) X .$$

The coordinates of this point are

$$X_{o''} = \frac{(a' - b')}{\left(\frac{b' - y'}{-x'}\right) - \left(\frac{a' - y''}{-x''}\right)}$$

$$\text{and } Y_{o''} = a' + \left(\frac{a' - y''}{-x''}\right) X_{o''}$$

$$0'' = (X_{o''} , Y_{o''}) .$$

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Let d_1 be the distance between O" and b, and d_2 the distance between O" and a. Then

$$d_1 = \sqrt{(X_{O''} - x'')^2 + (Y_{O''} - Y'')^2} \quad ,$$

$$d_2 = \sqrt{(X_{O''} - X')^2 + (Y_{O''} - Y')^2} \quad ,$$

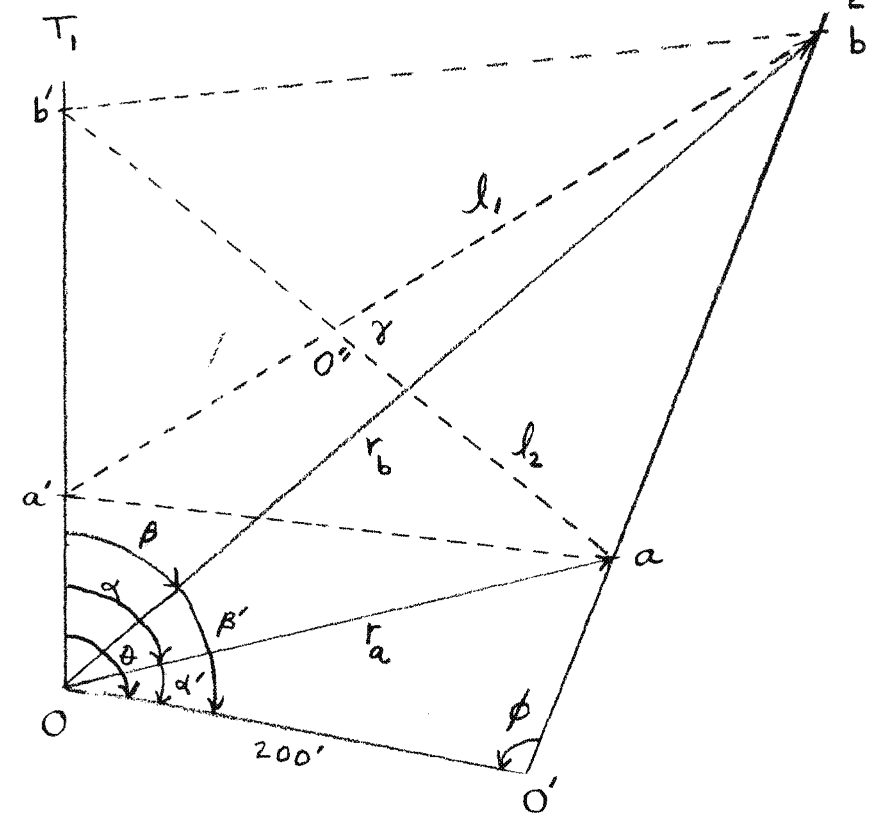
$$\text{and} \quad \gamma = \cos^{-1}\left[\frac{(b-a)^2 - (d_1{}^2 + d_2{}^2)}{-2\, d_1 d_2}\right] \quad .$$

If D_1 is the distance from a' to b and D_2 is the distance from b' to a, then

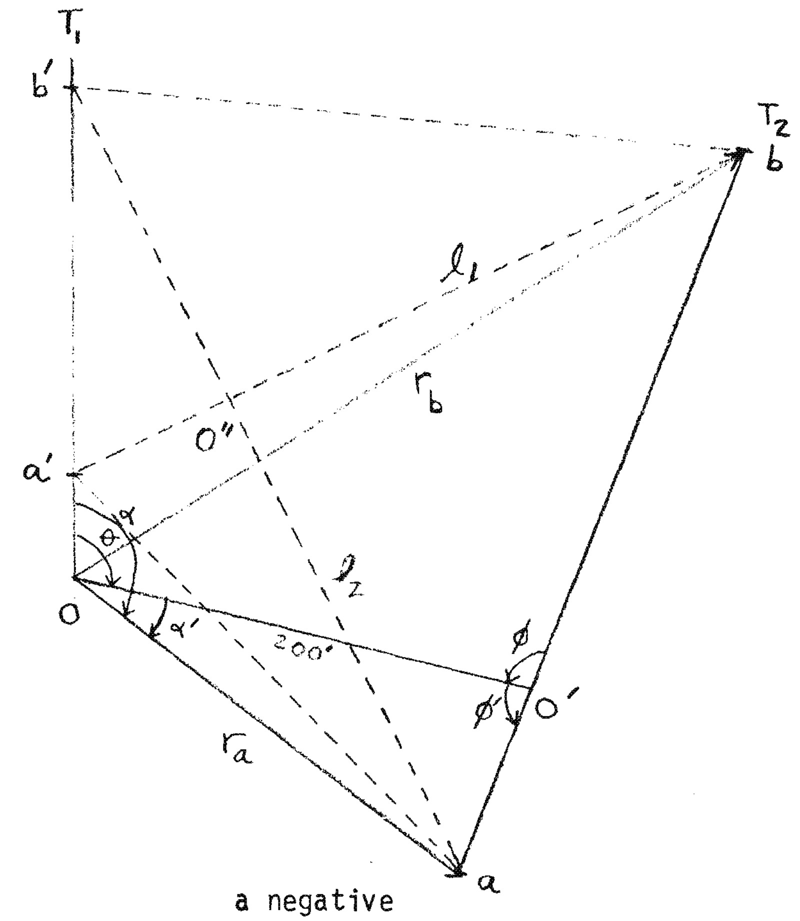
$$D_1 = \sqrt{X''^2 + (Y'' - a')^2} \quad ,$$

$$D_2 = \sqrt{X'^2 + (Y' - b')^2} \quad ,$$

$$\text{and} \quad A = \frac{1}{2} D_1 D_2 \sin\gamma .$$



a positive



a negative

Figure 1.

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SECTION 2

Total mortality estimates at each of the seven sites were made in the following three steps:

1. A linear relationship was derived relating the drop in gauge readings to the area of exposure.
2. Estimates of the total area exposed for a specific site were then made by a computer program scanning a time series of gauge readings.
3. Total mortality estimates were then made by stratifying the data into 2-week time periods. Total area exposed estimates and mortality density estimates were made for each time period, and the product taken for a total mortality estimate. The total mortalty estimates for each period were then summed for a grand total mortality over all time periods.

Table 1 shows the data used in deriving the regression equations relating the drop in gauge readings to the area of exposure. When necessary, gauge readings were adjusted to a maximum critical height above which there is known to be little or no area exposed. This critical height varied for each site. Table 2 contains the estimated regression coefficients and supplemental statistics for each of the seven sites.

The computer program which scanned the time series of gauge readings operated in a very simple manner. First, the program selected only those drops exceeding a threshold value. The drops which exceeded this threshold were then adjusted for the critical height value and the area exposed estimated from the linear regression equation. Total mortality estimates were then calculated as described in (3) above.

The following is a mathematical description of this procedure. The subscript i refers to a 2-week period.

$\hat{Y}_i$ is the estimated exposure for period i

X_i is the total of the drops in gauge readings for period i

N_i is the number of drops during period i

$\hat{y}_{ik} = \hat{a} + \hat{b}\, x_{ik}$ is the estimated relationship between gauge drop x_{ik} and the area of exposure $\hat{y}_{ik}$.

$$\hat{D}_i = \frac{\text{Total mortality for period i}}{\text{Sampled area for period i}} = \frac{M_i}{A_i}$$

Therefore

$$\hat{Y}_i = \sum_k y_{ik} = N_i\, \hat{a} + \hat{b} \sum_k x_{ik}$$

$$= N_i\, \hat{a} + \hat{b}\, X_i$$

and

$\hat{M} = \Sigma\, \hat{D}_i\, \hat{Y}_i$ is the total estimated mortality for the site.

A variance estimate of $\hat{M}$ can be derived using the delta method (Rao, 1973) and statistics derived during the estimation of $\hat{a}$ and $\hat{b}$. Assuming there are n time periods for which there are non zero estimates of $\hat{Y}_i$ and $\hat{D}$, $\hat{M} = \sum_{i=1}^{n} \hat{D}_i\, \hat{Y}_i$.

To apply the delta method, it is necessary to have estimates of the partial derivatives

$$\frac{\partial M}{\partial Y_i} = D_i \; (\approx \hat{D}_i)$$

$$\frac{\partial M}{\partial D_i} = Y_i \; (\approx \hat{Y}_i) \qquad \text{and}$$

the covariance matrix of

$$\hat{\theta} = \begin{pmatrix} \hat{Y}_1 \\ \vdots \\ \hat{Y}_n \\ \hat{D}_1 \\ \vdots \\ \hat{D}_n \end{pmatrix}$$

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At this point, caution must be exercised since we wish to take into account the variance of estimating individual Y_i values and not just the variance of the estimating line. It then follows that

$$\text{var}\ (\hat{Y}_i) = N_i^2\ \text{var}\ \hat{a} + X_i^2\ \text{var}\ \hat{b} + 2N_i\ X_i\ \text{cov}\ (\hat{a}\ ,\ \hat{b}) + N_i\ \sigma^2_{y|x}$$

$$\text{cov}\ (\hat{Y}_i\ ,\ \hat{Y}_j) = N_i\ N_j\ \text{var}\ \hat{a} + X_i\ X_j\ \text{var}\ \hat{b} + (N_i\ X_j + N_j\ X_i)\ \text{cov}\ (\hat{a}\ ,\ \hat{b})$$

and $\text{var}\ \hat{D}_i = \text{var}\ \frac{M_i}{A_i}\ (\approx \frac{\hat{D}_i^2}{M_i})$ assuming M_i is distributed with a Poisson distribution.

also $\text{cov}\ (\hat{Y}_i\ ,\ \hat{D}_j) = 0$ for all $i\ ,\ j$

and $\text{cov}\ (\hat{D}_i\ ,\ \hat{D}_j) = 0$ for $I \neq j$.

Since all of the unknown elements allow estimates from Table 2, the covariance matrix of $\hat{\theta}$, say Σ_θ, is now easily estimated and the application of the delta method states that

$$\text{var}\ (\hat{M}) = \text{var} \sum_{i=1}^{n} \hat{D}_i\ \hat{Y}_i$$

$$\approx (\hat{D}_1 \ldots \hat{D}_n\ ,\ \hat{Y}_1 \ldots \hat{Y}_n)\ \Sigma_\theta \begin{pmatrix} \hat{D}_1 \\ \vdots \\ \hat{D}_n \\ \hat{Y}_1 \\ \vdots \\ \hat{Y}_n \end{pmatrix}$$

and for each i, $\hat{M}_i = \hat{D}_i\ \hat{Y}_i$, and $\text{var}\ \hat{M}_i = \text{var}\ \hat{D}_i\ \hat{Y}_i \approx \hat{D}_i^2\ \text{var}\ \hat{Y}_i + \hat{Y}_i^2\ \text{var}\ \hat{D}_i$.

Appendix Table 1.

Site	Adjusted gauge elevation (ft)	Minimum gauge elevation (ft)	Adjusted drop (ft)	Area exposed (sq ft)
Klickitat	81.50	78.00	3.50	442,846
	82.00	75.20	6.80	776,229
	81.20	76.70	4.50	379,209
	82.00	76.80	5.20	482,420
	81.40	74.50	6.90	767,898
	82.00	78.70	3.30	310,451
	80.50	75.40	5.10	629,957
	81.50	78.40	3.10	297,358
	79.90	74.70	5.20	637,481
	81.70	75.40	6.30	626,747
	80.20	74.60	5.60	651,456
	81.10	75.60	5.50	666,490
	80.40	75.80	4.60	546,895
	78.30	77.40	.90	259,546
	81.60	76.00	5.60	715,891
	81.00	76.10	4.90	487,893
	82.00	77.10	4.90	378,804
	81.40	75.70	5.70	659,269
	81.70	78.50	3.20	162,464
	81.30	76.80	4.50	493,545
	81.10	76.50	4.60	513,892
Mosier	80.60	77.00	3.60	44,161
	81.50	76.00	5.50	57,537
	81.40	78.00	3.40	48,149
	81.50	75.20	6.30	113,383
	79.50	76.30	3.20	52,848
	79.30	76.50	2.80	54,367
	81.50	74.10	7.40	139,774
	80.30	75.20	5.10	123,579
	79.30	75.80	3.50	65,509
	81.00	76.10	4.90	53,756
	78.60	75.90	2.70	57,916
	80.80	77.60	3.20	26,553
Pierce Island	22.40	16.50	5.90	196,250
	20.60	19.50	1.10	136,977
	22.20	19.80	2.40	83,581
	21.50	17.40	4.10	151,521
	19.70	16.80	2.90	234,703
	20.50	18.70	1.80	107,988
	16.90	14.80	2.10	91,750
	20.50	17.30	3.20	128,609
	23.10	21.20	1.90	67,841
	22.50	21.30	1.20	38,351
	22.40	20.10	2.30	46,522
	21.80	19.50	2.30	47,518

(Continued)

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Appendix Table 1.

Site	Adjusted gauge elevation (ft)	Minimum gauge elevation (ft)	Adjusted drop (ft)	Area exposed (sq ft)
Sandy River bar	10.00	8.00	2.00	552,685
	11.00	9.10	1.90	478,209
	11.00	10.00	1.00	323,925
	11.00	9.90	1.10	245,526
	11.00	10.10	.90	225,054
	11.00	8.70	2.30	458,964
	10.00	7.40	2.60	654,894
	10.20	8.50	1.70	526,232
	8.30	7.20	1.10	313,030
	10.10	8.50	1.60	365,828
	8.50	8.00	.50	168,127
	11.00	10.90	.10	77,142
	11.00	10.50	.50	49,877
	11.00	11.30	.00	11,802
McGuire Island (transects)	12.50	9.10	3.40	519,848
	12.50	10.20	2.30	376,610
	12.00	9.90	2.10	410,884
	12.20	11.20	1.00	120,064
	13.20	12.00	1.20	115,327
	13.20	12.50	.70	75,324
	13.20	12.30	.90	148,650
	10.60	8.80	1.80	641,203
	9.00	7.40	1.60	94,467
	10.30	8.90	1.40	309,682
	10.20	9.00	1.20	290,271
	11.40	10.80	.60	59,069
	10.10	9.00	1.10	359,011
	9.00	8.20	.80	175,463
	10.60	9.80	.80	263,851
	13.00	12.80	.20	55,732
McGuire Island (radials)	12.00	9.10	2.90	626,531
	12.00	10.20	1.80	225,274
	12.00	9.90	2.10	311,813
	12.00	11.20	.80	13,180
	10.60	8.80	1.80	559,725
	9.00	7.40	1.60	271,793
	10.30	8.90	1.40	355,138
	10.20	9.00	1.20	275,930
	11.40	10.80	.60	31,054
	10.10	9.00	1.10	444,336
	10.60	9.80	.80	172,713
	9.00	8.20	.80	113,523

(Continued)

Appendix Table 1.

Site	Adjusted gauge elevation (ft)	Minimum gauge elevation (ft)	Adjusted drop (ft)	Area exposed (sq ft)
Government Island	12.00	9.90	2.10	278,094
	11.80	11.10	.70	83,858
	13.00	11.00	2.00	277,565
	12.10	10.10	2.00	272,328
	10.00	9.00	1.00	111,494
	11.10	9.70	1.40	184,549
	11.90	10.90	1.00	94,195

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Appendix Table 2. Linear regression coefficients relating drop in gauge readings to area exposed.

Site	n	$\hat{a}$	$\hat{b}$	R^2	Var $(\hat{a})$	Var $(\hat{b})$	Cov $(\hat{a},\hat{b})$	S_{y1x}
Klickitat	21	4,767.9	107,974.1	.748	5,046,448,683	206,286,225	-981,333,042	89,108.1
Mosier	12	-10,684.1	18,715.9	.641	403,605,373	19,600,423	- 84,281,818	22,233.4
Pierce Island	12	38,778.2	27,765.1	.359	1,152,901,044	137,632,437	-357,844,335	51,672.7
Sandy River bar	14	24,880.8	237,165.6	.917	908,017,554	425,870,880	-526,254,730	60,067.0
McGuire Island (transects)	16	33,706.8	164,746.3	.541	3,812,491,972	1,644,644,690	-2,168,875,185	123,436.6
McGuire Island (radials)	12	-31,050.1	223,290.6	.606	7,772,798,171	3,244,298,367	-4,569,053,534	126,714.5
Government Island	7	-39,599.8	154,831.5	.982	206,292,357	85,649,258	-124,803,205	13,078.8

APPENDIX II

(Tables 1 through 31)
(Pages 46 through 72)

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Table 1. Potential stranding sites in Bonneville Dam to Vancouver, Washington reach.

	Location	River mile	Length of beach (ft)	Bed material
(1)	Ives Island, east end and south side	143	3,400	Rubble and gravel
(2)	Pierce Island, south side	141.5	2,250	Rubble and gravel
(3)	Sandy Island, west end	135	1,750	Sand
(4)	Sand Island, north side	131	5,000	Sand
(5)	Rooster Rock State Park	129	3,250	Sand
(6)	Reed Island, east end	127.5	3,125	Sand
(7)	Reed Island Slough	126.5-127.5	5,375	Sand
(8)	Flag and Gary Islands	124-125	6,875	Sand
(9)	Sandy River Bar	120.5-123	13,750	Fine gravel and sand
(10)	McGuire Island, east end	118	4,500	Fine gravel and sand
(11)	Sand Island, east end	118	3,000	Sand
(12)	Government/Lemon Island Beach, south side	113	3,500	Sand

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Table 2. Daily maximum and minimum discharge (cfs) measured at Bonneville Dam, March through June, 1974.

Day	March		April		May		June	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1	269,500	141,500	294,200	225,800	404,600	391,100	356,500	343,600
2	272,300	223,500	334,800	271,500	415,500	391,100	358,500	343,100
3	257,500	195,000	326,400	302,500	414,000	400,900	363,200	349,700
4	285,400	218,500	324,700	294,000	407,700	401,400	385,500	350,300
5	279,900	197,400	317,000	264,900	410,300	396,700	412,700	395,700
6	291,200	142,100	276,700	252,000	417,700	405,200	406,600	395,100
7	276,900	207,200	289,000	250,600	425,700	408,900	412,000	398,200
8	251,300	212,600	313,600	270,400	424,700	415,700	408,000	395,800
9	250,700	214,500	293,200	268,000	432,100	414,700	402,100	397,000
10	251,500	144,400	295,700	270,900	420,400	384,900	403,200	390,300
11	233,000	145,300	303,600	290,500	385,800	369,700	404,100	367,300
12	253,400	218,300	305,600	282,800	370,900	317,000	404,400	390,600
13	255,200	173,100	312,300	308,500	325,700	305,500	424,200	403,600
14	254,000	230,600	312,500	282,800	313,900	289,400	445,100	420,100
15	256,300	251,600	287,200	265,100	314,700	296,100	474,200	441,000
16	255,500	188,200	308,200	264,900	314,000	289,100	491,000	472,800
17	237,500	166,300	329,400	305,100	324,900	277,000	540,700	488,600
18	279,600	216,100	318,800	305,000	338,700	318,600	549,400	528,900
19	290,600	215,000	323,000	312,600	324,300	315,900	560,900	538,700
20	289,800	170,800	329,500	315,600	324,000	298,700	570,900	550,800
21	272,700	238,100	318,200	292,100	314,100	303,300	570,100	556,600
22	249,500	209,300	310,500	292,600	309,400	299,600	570,400	566,500
23	251,400	248,300	323,400	291,400	303,500	300,200	568,800	563,800
24	251,200	165,500	326,200	261,300	323,800	293,600	578,500	555,800
25	279,200	177,100	290,900	261,000	327,000	319,100	561,300	553,700
26	277,800	175,400	370,900	288,000	325,600	311,800	562,900	556,300
27	277,900	231,000	385,800	363,600	360,700	312,400	559,800	543,500
28	313,900	231,200	407,300	371,400	377,300	355,800	553,300	531,900
29	313,100	142,800	397,500	380,400	388,200	355,400	533,100	496,800
30	312,200	281,100	406,900	339,300	411,300	379,100		
31	280,700	235,500			377,000	358,400		

Table 3. Daily maximum and minimum discharge (cfs) measured at Bonneville Dam, July through September, 1974.

Day	July		August		September	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1	486,000	467,000	287,400	193,000	135,100	87,100
2	467,900	460,000	249,200	150,300	135,500	110,000
3	464,900	459,700	226,300	156,200	179,100	133,700
4	465,900	446,600	211,800	143,000	171,700	143,100
5	452,700	438,200	256,000	167,500	177,000	139,300
6	438,800	401,700	236,200	152,000	171,900	131,900
7	403,900	378,000	236,900	156,700	157,200	113,200
8	383,000	370,000	229,900	161,100	133,900	82,800
9	370,400	316,800	229,000	176,800	160,700	121,800
10	318,900	306,300	211,200	168,800	143,200	136,800
11	317,700	293,900	211,300	162,200	170,600	135,800
12	318,000	270,800	237,600	163,500	219,200	139,000
13	280,500	260,800	233,200	189,300	201,200	169,600
14	268,600	198,100	190,300	153,300	188,500	126,600
15	271,500	217,600	229,800	141,100	122,300	91,900
16	227,500	214,600	204,100	164,400	141,400	91,800
17	223,200	213,300	172,400	128,800	140,700	98,800
18	251,700	216,900	139,800	102,500	169,500	123,000
19	250,500	237,300	194,200	135,400	198,400	137,800
20	275,800	234,600	194,100	143,700	176,300	143,000
21	270,400	252,400	171,400	126,800	143,200	99,800
22	268,100	218,300	182,500	120,900	126,800	96,400
23	258,500	224,800	170,400	137,900	143,000	134,600
24	304,100	257,200	144,000	108,000	149,900	137,500
25	303,500	248,700	135,100	83,700	167,400	136,800
26	272,500	241,200	171,500	121,800	184,200	144,000
27	250,900	162,800	188,000	134,900	169,200	144,400
28	214,500	155,500	233,000	140,900	159,200	108,400
29	237,400	147,900	236,200	143,900	138,200	99,900
30	240,500	201,300	157,900	127,800	163,000	138,600
31	247,500	148,900	137,400	109,600		

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Table 4. Summary of observations at stranding sites on Columbia River below Bonneville Dam, 1974.

Site	Date	Observed mortality Chinook	Observed mortality Coho	Observed isolated in watered pothole
Pierce Island	22 Mar	0	0	0
	25 Mar	0	0	11
	26 Mar	0	0	0
	28 Mar	0	0	0
	31 Mar	0	0	0
	1 Apr	0	0	0
	24 Apr	0	1	0
Totals		0	1	11
Sandy River bar	14 Mar	0	0	12
	15 Mar	68	12	0
	16 Mar	1	0	0
	23 Mar	0	0	11
	25 Mar	6	4	0
	29 Mar	0	0	0
	13 May	7	9	0
Totals		82	25	23
McGuire Island	17 Mar	0	0	0
	25 Mar	0	0	0
	26 Mar	0	0	0
	29 Mar	0	0	0
	1 Apr	0	0	0
	24 Apr	3	0	0
	13 May	1	0	13
Totals		4	0	13
Government Island	17 Mar	0	0	0
	27 Mar	0	0	0
	29 Mar	0	0	0
Totals		0	0	0
Bachelor Island	14 May	0	0	4
Mouth of Lewis River	26 Apr	0	0	300 1/
	14 May	0	0	100 1/
Totals		0	0	400

1/ Estimated totals, fish were likely isolated by ship-wash.

Table 5. Juvenile salmonids captured by beach seine in the Bonneville Dam to Lewis River reach of the Columbia River, 1974.

Date	Number sets	Catch Chinook	Catch Coho	Catch Chum	Catch per set
16 March	4	24	1	0	6.25
24 March	5	103	2	13	23.6
30 March	4	153	0	2	38.77
26 April	4	595	37	0	158.00
9 August	7	5	0	0	0.71
15 August	6	38	0	0	6.33
13 August	6	29	1	0	5.00
Total	36	947	41	51	--

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Table 6. Summary of observations at the Klickitat site, (RM 180), including calculated exposed area and mortality estimates for observation days only, 1975.

Date	Drop in gauge elevation (ft)	Area sampled (sq. ft)	Observed mortality Chinook	Observed mortality Coho	Observed mortality Trout	Calculated sq. ft exposed	Calculated mortality Chinook	Calculated mortality Coho	Calculated mortality Trout	Comments
3/2/75	1.5	61,650	3	0	0	326,894	16	0	0	No fish in potholes; little scavenger activity.
3/8/75	4.3	134,846	0	0	0	453,741	0	0	0	One salmonid in pothole; bird activity on east side.
3/9/75	7.6	193,471	4	0	1	707,339	15	0	4	No fish in potholes; coon tracks on site.
3/12/75	7.4	142,183	0	0	0	584,230	0	0	0	No fish in potholes; coon tracks on site.
3/15/75	3.8	136,908	0	0	0	442,846	0	0	0	No fish in potholes; no scavenger activity.
3/16/75	7.1	202,255	1	1	1	776,229	4	4	4	One catfish in pothole; coon tracks.
3/19/75	3.9	125,478	13	1	0	379,209	39	3	0	No fish in potholes; all fish found were yearlings.
3/21/75	7.7	141,42[illegible]	3	0	0	482,420	10	0	0	No fish in potholes; coon tracks.
3/22/75	7.0	198,23[illegible]	0	0	0	767,898	0	0	0	Three salmonids in potholes; heron and coon tracks.
3/28/75	4.2	116,23[illegible]	0	0	0	310,451	0	0	0	No fish in potholes; heron tracks.
3/30/75	5.3	177,423	6	1	0	629,957	21	4	0	No fish in potholes; heron, seagull activity.
4/2/75	4.8	83,240	2	0	0	297,358	7	0	0	No fish in potholes.
4/4/75	5.6	170,341	3	0	0	650,017	11	0	0	No fish in potholes; coon tracks.
4/5/75	5.6	174,240	0	1	0	637,481	0	3	0	No fish in potholes; coon tracks.
4/9/75	7.5	175,456	8	0	0	640,148	29	0	0	Eight fish in potholes; heron tracks.
4/10/75	6.3	172,001	10	1	0	626,747	36	4	0	Three fish in potholes; no scavenging.
4/11/75	5.8	119,750	17	1	0	523,320	74	4	0	No fish in potholes; coon tracks.
4/12/75	5.8	141,649	6	0	0	651,456	28	0	0	16 fish in potholes; heron tracks.
4/17/75	5.8	185,011	22	3	1	666,490	79	10	4	One fish in potholes; no scavenging.
4/18/75	4.9	144,098	3	0	0	546,895	11	0	0	Two fish in potholes; crows present.
4/19/75	1.0	96,545	2	0	1	259,546	5	0	3	No fish in potholes; no scavenging.
4/23/75	5.8	194,987	2	1	0	715,891	7	4	0	No fish in potholes; no scavenging.
4/24/75	4.9	157,489	4	0	0	487,893	12	0	0	One fish in potholes; muskrat on site.
4/26/75	5.5	127,286	5	0	0	378,804	15	0	0	No fish in potholes; no scavenging.
4/30/75	7.1	182,038	18	2	0	726,369	72	8	0	No fish in potholes; cow, coon, and muskrat tracks.
5/1/75	5.9	185,856	8	1	0	659,269	28	4	0	Three fish in potholes; heron tracks.
5/2/76	4.7	124,658	27	0	0	397,675	86	0	0	No fish in potholes; no scavenging.
5/3/76	5.4	109,566	0	0	0	312,285	0	0	0	15 fish in potholes; no scavenging.
5/7/75	4.4	71,650	0	0	0	162,464	0	0	0	One fish in potholes; no scavenging.
5/8/76	6.6	175,898	13	2	2	493,545	36	6	6	11 fish in potholes; bird tracks.
5/9/75	4.8	147,840	3	0	0	513,892	10	0	0	33 fish in potholes; coon tracks.
5/10/75	5.2	157,670	3	1	0	543,052	10	3	0	One fish in potholes; coon tracks.
7/19/75	–	313,030	0	0	3	871,835	0	0	8	Three whitefish and two trout in potholes.
7/20/75	–	206,640	0	0	0	597,053	0	0	0	One fish in pothole; heron tracks.
7/26/75	–	227,233	0	0	0	732,013	0	0	0	One whitefish and four bass juveniles stranded.
8/1/75	–	97,900	0	0	0	no est.	0	0	0	Two juvenile bass stranded.
8/20/75	–	92,930	0	0	0	no est.	0	0	0	
Totals			186	16	9		661	57	29	

Table 7. Estimated area exposed and mortality during indicated time period and within the transected portion of the Klickitat sample site, 1975.

Time period	Number of flow reductions	Estimated sq. ft exposed	Estimated mortality Chinook	Estimated mortality Coho	Estimated mortality Chum	Estimated mortality Trout	Estimated mortality Totals	Standard deviation
3/2-3/15/75	56	13,407,452	140	0		20	160	64
3/16-3/29/75	53	11,946,295	259	30		15	304	92
3/30-4/12/75	50	12,623,026	541	42		0	583	125
4/13-4/26/75	44	8,599,376	380	38		19	437	127
4/27-5/10/75	51	10,403,527	648	54		18	720	187
Totals	254	56,979,676	1,968	164		72	2,204	479

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Table 8. Summary of observations at the Mosier site, (RM 175), including calculated exposed area and mortality estimates for observation days only, 1975.

Date	Drop in gauge elevation (ft)	Area sampled (sq. ft)	Observed mortality			Calculated sq. ft exposed	Calculated mortality			Comments
			Chinook	Coho	Trout		Chinook	Coho	Trout	
3/2/75	1.5	1/	3	0	0	1/	0	0	0	Transects removed by vandals.
3/12/75	7.6	24,696	0	0	0	44,161	0	0	0	No fish in potholes; muskrat tracks.
3/13/75	6.4	31,536	0	0	0	57,537	0	0	0	No fish in potholes; no scavenging.
3/15/75	3.8	31,737	2	0	0	48,194	3	0	0	No fish in potholes; coon tracks.
3/16/75	7.1	52,324	2	0	0	113,383	4	0	0	No fish in potholes; no scavenging.
3/19/75	3.9	12,561	7	0	0	18,378	10	0	0	No fish in potholes; no scavenging.
3/21/75	7.7	24,350	1	0	0	42,963	2	0	0	Two fish in potholes; no scavenging.
3/23/75	3.4	31,179	0	0	0	52,848	0	0	0	No fish in potholes; no scavenging.
3/26/75	4.1	29,778	7	0	0	46,492	11	0	0	One fish in potholes; no scavenging.
3/29/75	2.8	30,053	3	0	0	54,367	5	0	0	No fish in potholes; no scavenging.
4/3/75	8.2	60,652	24	0	0	139,744	55	0	0	No fish in potholes; no scavenging.
4/6/75	2.9	49,082	15	0	0	123,597	38	0	0	No fish in potholes; no scavenging.
4/10/75	6.3	20,548	0	0	0	38,657	0	0	0	No fish in potholes; no scavenging.
4/13/75	1.6	12,565	0	0	0	65,246	0	0	0	No fish in potholes; no scavenging.
4/17/75	5.8	34,908	1	0	0	76,157	2	0	0	One fish in potholes; coon tracks.
4/18/75	4.9	33,618	2	0	0	65,509	4	0	0	Two fish in potholes; no scavenging.
4/20/75	1.5	13,886	0	0	0	21,237	0	0	0	No fish in potholes; no scavenging.
4/23/75	5.8	25,470	0	0	0	53,756	0	0	0	One fish in potholes; bird tracks.
4/24/75	4.9	28,038	0	0	0	50,659	0	0	0	No fish in potholes; bird tracks.
4/30/75	7.1	15,271	0	0	0	57,916	0	0	0	No fish in potholes; bird and animal tracks.
5/1/75	5.9	28,284	2	0	0	67,581	5	0	0	No fish in potholes; bird and animal tracks.
5/2/75	4.7	17,190	2	0	0	37,313	4	0	0	No fish in potholes; animal tracks.
5/8/75	6.6	20,172	1	0	0	33,368	2	0	0	Three fish in potholes; animal tracks.
5/9/75	4.8	22,980	0	0	0	41,757	0	0	0	12 fish in potholes; animal tracks.
5/11/75	3.4	14,876	1	0	0	26,553	2	0	0	Two fish in potholes; no scavenging.
Totals			73	0	0		147	0	0	

1/ Area could not be calculated because marker stakes were removed.

Table 9. Estimated area exposed and mortality during indicated time period and within the transected portion of the Mosier sample site, 1975.

Time period	Number of flow reductions	Estimated sq. ft exposed	Estimated mortality					Standard deviation
			Chinook	Coho	Chum	Trout	Totals	
3/2-3/15/75	56	1,617,654	37	0		0	37	30
3/16-3/29/75	53	1,400,785	155	0		0	155	81
3/30-4/12/75	50	1,585,762	475	0		0	475	188
4/13-4/26/75	44	941,079	19	0		0	19	16
4/27-5/10/75	51	1,107,726	64	0		0	64	47
Totals	254	6,653,006	750	0		0	750	319

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Table 10. Mortality per linear foot of sampled beaches used to calculate mortality at unsampled stranding beaches, 1975.

Site	Time period	Beach length (ft)	Mortality per linear foot of beach			
			Chinook	Coho	Trout	Chum
Klickitat	3/2-3/15/75	1,066	0.1313	0.0000	0.0188	0.0000
	3/16-3/29/75	1,066	0.2430	0.0281	0.0141	0.0000
	3/30-4/12/75	1,066	0.5075	0.0394	0.0000	0.0000
	4/13-4/26/75	1,066	0.3565	0.0356	0.0178	0.0000
	4/27-5/10/75	1,066	0.6079	0.0507	0.0169	0.0000
Mosier	3/2-3/15/75	322	0.1149	0.0000	0.0000	0.0000
	3/16-3/29/75	322	0.4814	0.0000	0.0000	0.0000
	3/30-4/12/75	322	1.4752	0.0000	0.0000	0.0000
	4/13-4/26/75	322	0.0590	0.0000	0.0000	0.0000
	4/27-5/10/75	322	0.1988	0.0000	0.0000	0.0000
Pierce Island	3/2-3/15/75	1,200	0.0483	0.0000	0.0000	0.0000
	3/16-3/29/75	1,200	0.0758	0.0000	0.0000	0.0000
	3/30-4/12/75	1,200	0.0208	0.0000	0.0000	0.0000
	4/13-4/26/75	1,200	0.0000	0.0000	0.0000	0.0000
	4/27-5/10/75	1,200	0.0200	0.0100	0.0000	0.0000
Sandy River	2/2-2/15/75	1,600	0.0000	0.0300	0.0000	0.0000
	2/16-3/1/75	1,600	0.0000	0.0000	0.0000	0.0000
	3/2-3/15/75	1,600	0.0106	0.0000	0.0000	0.0000
	3/16-3/29/75	1,600	0.0000	0.0000	0.0000	0.0000
	3/30-4/12/75	1,600	0.0756	0.0000	0.0000	0.0381
	4/13-4/26/75	1,600	0.0694	0.0000	0.0038	0.0269
	4/27-5/10/75	1,600	0.0000	0.0000	0.0000	0.0000

Table 11. Estimated total juvenile mortality in the Bonneville Pool for the period March 2 through May 10, 1975.

Time period	Estimated mortality				Standard deviation
	Chinook	Coho	Trout	Total	
March 2-March 15	1,213	0	116	1,329	354
March 16-March 29	3,120	149	89	3,358	552
March 30-April 12	8,050	209	0	8,259	887
April 13-April 26	2,444	189	113	2,746	679
April 27-May 10	4,522	269	107	4,898	1,008
Totals	19,349	816	425	20,590	2,743

Table 12. Summary of observations at the Pierce Island site, (RM 142), including calculated exposed area and mortality estimates for observation days only, 1975.

Date	Drop in gauge elevation (ft)	Area sampled (sq. ft)	Observed mortality			Calculated sq. ft exposed	Calculated mortality			Comments
			Chinook	Coho	Chum		Chinook	Coho	Chum	
2/27/75	5.5	1/	0	0	0	1/	0	0	0	12 fish trapped in 3.5 ft deep pothole; could not determine high water line.
3/11/75	5.8	47,840	1	0	0	196,250	4	0	0	No fish in potholes; no scavenging.
3/14/75	1.1	29,640	1	0	0	136,977	5	0	0	No fish in potholes; no scavenging.
3/22/75	5.2	1/	0	0	0	1/	0	0	0	Could not determine high water line; no fish in potholes.
3/29/75	2.6	19,880	1	0	0	83,581	4	0	0	No fish in potholes; coon tracks.
4/3/75	4.2	37,120	2	0	0	151,521	8	0	0	No fish in potholes; no scavenging.
4/5/75	2.8	78,240	0	0	0	234,703	0	0	0	One fish in pothole; no scavenging.
4/10/75	1.8	31,080	0	0	0	107,988	0	0	0	No fish in potholes; no scavenging.
4/13/75	2.1	46,560	0	0	0	91,750	0	0	0	Approx. 110 fish in potholes off transects, 60% of which were yearling-size fish. Water level held constant for 23 hours, which would allow the shallow potholes to drain and kill 86 of these fish.
4/17/75	3.2	58,880	0	0	0	128,609	0	0	0	No fish in potholes; no scavenging.
4/18/75	2.5	126,320	1	0	0	1/	0	0	0	Could not determine high water level. No fish in potholes.
4/27/75	0.9	51,040	0	0	0	1/	0	0	0	Could not determine high water level.
5/2/75	1.9	12,500	1	0	0	20,233	2	0	0	Low water occurred prior to site inspection. 11 fish trapped in potholes.
5/4/75	2.0	36,240	0	1	0	67,841	0	2	0	No fish in potholes.
5/8/75	1.7	18,560	1	0	0	38,951	2	0	0	No fish in potholes.
5/9/75	2.3	28,560	0	0	0	46,522	0	0	0	Two fish in potholes.
5/10/75	2.3	22,720	0	0	0	47,518	0	0	0	One fish in potholes.
Totals			8	1	0		25	2	0	

1/ Area estimates not calculated because samplers could not determine high-water line.

Table 13. Estimated area exposed and mortality during indicated time period and within the transected portion of the Pierce Island sample site, 1975.

Time period	Number of flow reductions	Estimated sq. ft exposed	Estimated mortality Chinook	Coho	Chum	Trout	Totals	Standard deviation
3/2-3/15/75	20	2,238,787	58	0		0	58	42
3/16-3/29/75	16	1,817,129	91	0		0	91	93
3/30-4/12/75	20	1,855,628	25	0		0	25	19
4/13-4/26/75	15	1,397,968	0	0		0	0	0
4/27-5/10/75	17	1,400,559	24	12		0	36	23
Totals	88	8,710,071	198	12		0	210	109

Table 14. Summary of observations at the Sandy River Bar site, (RM 122), including calculated exposed area and mortality estimates for observation days only, 1975.

Date	Drop in gauge elevation (ft)	Area sampled (sq. ft)	Observed mortality Chinook	Coho	Chum	Calculated sq. ft exposed	Calculated mortality Chinook	Coho	Chum	Comments
2/6/75	2.1	92,460	0	1	0	552,685	0	6	0	No fish in potholes; no scavenging.
2/23/75	3.4	51,300	0	0	0	478,209	0	0	0	No fish in potholes; no scavenging.
2/28/75	0.3	31,400	0	0	0	[1]	0	0	0	No fish in potholes; no scavenging.
3/11/75	2.5	59,470	0	0	0	323,925	0	0	0	No fish in potholes; no scavenging.
3/12/75	2.2	52,720	1	0	0	245,526	5	0	0	Nine fish trapped in potholes; no scavenging.
3/30/75	2.2	59,694	0	0	0	225,054	0	0	0	No fish in potholes; no scavenging.
4/4/75	1.9	97,600	0	0	0	458,949	0	0	0	Two fish in potholes; 12 chinook, 1 chum, and 1 trout fry found dead off transect.
4/6/75	1.6	140,960	11	0	7	654,894	51	0	33	Approx. 130 fish trapped in well-watered potholes; no scavenging.
4/12/75	1.7	166,800	3	0	0	526,232	10	0	0	Entire exposed are inspected yielding total mortality of 8 chinook and 11 chums. Crow and coon tracks on site.
4/13/75	1.3	167,300	3	0	2	313,030	6	0	4	Nine fish in potholes; scanvenging by crows occurred prior to sampling.
4/18/75	1.1	154,880	4	0	1	365,828	10	0	2	11 fish in potholes; no scavenging.
4/19/75	0.9	71,569	11	0	4	168,127	24		9	Approx. 90 fish trapped in large potholes; no scavenging.
4/24/75	1.0	77,142	1	0	0	77,142	2	0	0	Entire area inspected; no scavenging.
5/1/75	[2]	24,320	0	0	0	0	0	0	0	No fish in potholes; no scanvenging. Site nearly covered at these flows.
5/3/75	0.4	5,200	0	0	0	11,802	0	0	0	No fish in potholes; no stranding potential at these flows.
Totals			35	1	14		108	6	48	

1/ Area estimate not calculated because samplers could not determine high-water line.

2/ Washougal gauge malfunction.

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Table 15. Estimated area exposed and mortality during indicated time period and within the transected portion of the Sandy River Bar sample site, 1975.

Time period	Number of flow reductions	Estimated sq. ft exposed	Estimated mortality: Chinook	Coho	Chum	Trout	Totals	Standard deviation
2/2-2/15/75	16	4,333,876	0	48	0	0	48	48
2/16-3/1/75	14	3,405,438	0	0	0	0	0	0
3/2-3/15/75	15	1,834,324	17	0	0	0	17	17
3/16-3/29/75	9	595,242	0	0	0	0	0	0
3/30-4/12/75	16	3,952,083	121	0	61	0	182	42
4/13-4/26/75	13	2,526,761	111	0	43	6	160	36
4/27-5/10/75	12	548,973	0	0	0	0	0	0
Totals	95	17,196,717	249	48	104	6	406	77

Table 16. Summary of observations at the McGuire Island site, (RM 118), including calculated exposed area and mortality estimates for observation days only, 1975.

Date	Drop in gauge elevation (ft)	Area sampled (sq. ft)	Observed mortality: Chinook	Coho	Chum	Calculated sq. ft exposed	Calculated mortality: Chinook	Coho	Chum	Comments
2/23/75	3.4	101,040	0	0	0	1,146,379	0	0	0	No fish in potholes; no scavenging.
2/28/75	[1]	51,300	0	0	0	279,985	0	0	0	No fish in potholes; no scavenging.
3/11/75	2.5	207,609	0	0	0	601,884	0	0	0	No fish in potholes; no scavenging.
3/12/75	2.2	187,441	0	0	0	722,697	0	0	0	No fish in potholes; no scavenging.
3/13/75	1.0	64,148	0	0	0	133,172	0	0	0	No fish in potholes; heron tracks on site.
3/19/75	1.2	29,877	0	0	9	115,327	0	0	35	No fish in potholes; no scavenging.
3/21/75	1.5	18,602	0	0	0	75,324	0	0	0	No fish in potholes; no scavenging.
3/26/75	0.1	6,158	0	0	0	23,967	0	0	0	No fish in potholes; very little stranding area exposed.
3/29/75	2.0	38,651	0	0	0	148,650	0	0	0	Dead, spawned-out smelt abundant on beach; no salmonids in potholes.
4/2/75	0.4	10,965	0	0	0	42,227	0	0	0	Gulls resting on site at arrival; no fish in potholes.
4/4/75	1.9	271,069	0	0	0	1,236,928	0	0	0	No fish in potholes; gulls on site at arrival.
4/6/75	1.6	63,289	10	0	20	336,260	53	0	116	No fish in potholes; gulls on island at arrival.
4/9/75	1.4	167,548	16	0	11	664,820	65	0	44	No fish in potholes; very little gull activity.
4/12/75	1.2	95,526	0	0	1	566,201	0	0	6	Three fish in potholes; heron and gull tracks.
4/16/75	0.6	29,123	0	0	0	90,123	0	0	0	No fish in potholes; no scavenging.
4/18/75	1.1	158,729	0	0	0	803,347	0	0	0	No fish in potholes; no scavenging.
4/19/75	0.7	70,420	1	0	5	288,986	4	0	21	Six fish in potholes; no scavenging.
4/23/75	0.8	116,000	0	0	0	436,564	0	0	0	One fish in potholes; no scavenging.
5/1/75	[1]	125,559	1	1	0	299,371	2	2	0	No fish in potholes; heron tracks on site.
5/4/75	0.4	28,610	0	0	0	55,735	0	0	0	No fish in potholes; small stranding potential.
5/10/75	0.6	73,317	0	0	0	87,331	0	0	0	No fish in potholes; heron and coon tracks on site.
5/11/75	0.5	31,773	0	0	0	39,370	0	0	0	No fish in potholes; little stranding potential.
Totals			28	1	46		124	2	222	

[1] Washougal gauge malfunction.

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Table 17. Estimated area exposed and mortality during indicated time period and within the transected portion of the McGuire Island sample site, 1975.

Time period	Number of flow reductions	Estimated sq. ft exposed	Estimated mortality					Standard deviation
			Chinook	Coho	Chum	Trout	Totals	
3/2-3/15/75	15	6,934,400	0	0	0	0	0	0
3/16-3/29/75	9	3,219,190	0	0	311	0	311	98
3/30-4/12/75	16	6,677,816	304	0	373	12	689	122
4/13-4/26/75	13	4,686,902	13	0	63	0	76	26
4/27-5/10/75	12	2,616,388	11	11	0	0	18	14
Totals	65	24,134,696	328	11	747	12	1,098	184

Table 18. Summary of observations at the Government Island site, (RM 113), including calculated exposed area and mortality estimates for observation days only, 1975.

Date	Drop in gauge elevation (ft)	Area sampled (sq. ft)	Observed mortality			Calculated sq. ft exposed	Calculated mortality			Comments
			Chinook	Coho	Chum		Chinook	Coho	Chum	
3/12/75	2.2	65,998	0	0	0	278,094	0	0	0	No potholes formed; heron tracks along beach.
3/14/75	0.7	20,007	0	0	0	83,850	0	0	0	No potholes formed; crow at site on arrival.
3/20/75	1.0	10,585	0	0	0	44,975	0	0	0	No potholes formed; no scavenging.
3/22/75	2.4	64,327	0	0	0	277,565	0	0	0	One stranded catfish; no scavenging.
3/30/75	1.9	61,993	0	0	0	248,993	0	0	0	Dead smelt (spawned-out) abundant; gulls present at arrival.
4/3/75	1.9	71,499	2	0	2	272,328	7	0	7	Dead smelt present; no potholes formed.
4/5/75	1.1	25,659	0	0	0	111,494	0	0	0	Four fish observed in large pothole off transect area.
4/10/75	0.3	51,356	0	0	0	51,356	0	0	0	Inspected all of site. Pothole off transect area containing approximately 200 trapped chinook and chum fry.
4/13/75	0.8	92,008	0	0	0	92,008	0	0	0	All of site inspected; pothole noted on 4/19/75 inspected and only two dead chum remained.
4/17/75	1.4	42,455	0	0	0	184,549	0	0	0	No pothole formed; heron tracks.
4/20/75	0.6	127,914	0	0	1	127,914	0	0	1	No pothole formed; geese on island when arrived. Entire site inspected.
4/24/75	1.0	94,195	0	0	0	94,195	0	0	0	Entire site inspected; no scavenging.
4/26/75	0.4	34,110	1	0	0	34,110	2	0	0	Entire site inspected; no scavenging.
5/2/75	1/	61,600	0	0	0	0	0	0	0	No pothole formed; no scavenging.
5/4/75	0.4	69,294	1	0	0	69,294	1	0	0	Entire site inspected; no scavenging.
5/8/75	0.8	196,843	0	0	0	196,843	0	0	0	Entire site inspected; crow and gull tracks.
Totals			4	0	3		10	0	9	

1/ Washougal gauge malfunction.

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Table 19. Estimated area exposed and mortality during indicated time period and within the transected portion of the Government Island sample site, 1975.

Time period	Number of flow reductions	Estimated sq. ft exposed	Estimated mortality: Chinook	Coho	Chum	Trout	Totals	Standard deviation
3/2-3/15/75	15	2,502,633	0	0	0	0	0	0
3/16-3/29/75	9	1,315,782	0	0	0	0	0	0
3/30-4/12/75	16	2,060,471	22	0	22	0	44	22
4/13-4/26/75	13	1,405,113	6	0	6	0	12	8
4/27-5/10/75	12	856,353	4	0	0	0	4	4
Totals	65	8,140,352	32	0	28	0	60	24

Table 20. Estimated total juvenile mortality from Bonneville Dam to Vancouver, Washington, February 2 through May 10, 1975.

Time period	Estimated mortality: Chinook	Coho	Chum	Trout	Total	Standard deviation
February 2-February 15	0	216	0	0	216	219
February 16-March 1	0	0	0	0	0	0
March 2-March 15	477	0	0	0	477	299
March 16-March 29	629	0	311	0	940	649
March 30-April 12	1,042	0	669	12	1,723	261
April 13-April 26	519	0	263	27	809	164
April 27-May 10	181	94	0	0	275	159
Totals	2,848	310	1,243	39	4,440	848

Table 21. Average rate of drop in gauge elevation (ft/hr) and equivalent water volume (cfs/hr) calculated at 2-week intervals at The Dalles Dam tailrace (RM 192), Bonneville Dam tailrace (RM 145), and Washougal gauge (RM 122.9) from March 2 through May 10, 1975.

Time period	The Dalles1/ ft/hr	The Dalles1/ Approx. cfs/hr	Bonneville1/ ft/hr	Bonneville1/ Approx. cfs/hr	Washougal2/ ft/hr	Washougal2/ Approx. cfs/hr
3/2-3/15/75	0.699	20,000	0.439	7,700	0.156	-
3/16-3/29/75	0.681	19,500	0.375	6,600	0.144	-
3/30-4/12/75	0.689	19,700	0.381	6,700	0.131	-
4/13-4/26/75	0.592	16,900	0.373	6,500	0.125	-
4/27-5/10/75	0.619	17,700	0.303	5,300	0.100	-

1/ Rates computed for all drops of 0.5 ft or greater.
2/ Rates computed for all drops of 0.25 ft or greater, rating rable for flow not available.

Table 22. Average size of flow reductions expressed as drop in gauge elevation (ft/drop) and water volume (cfs/drop) calculated at 2-week intervals at The Dalles tailres, Bonneville tailrace, and Washougal gauge from March 2 through May 10, 1975.

Time period	The Dalles1/ ft/drop	The Dalles1/ Approx. cfs/drop	Bonneville1/ ft/drop	Bonneville1/ Approx. cfs/drop	Washougal2/ ft/drop	Washougal2/ Approx. cfs/drop
3/2-3/15/75	2.20	62,900	2.64	46,200	1.39	-
3/16-3/29/75	2.11	60,300	2.69	47,100	15.9	-
3/30-4/12/75	2.31	66,000	1.95	34,100	1.09	-
4/13-4/26/75	1.79	51,100	1.81	31,700	0.97	-
4/27-5/10/75	2.00	57,100	1.57	27,500	0.82	-

1/ Calculated for all drops of 0.5 ft or greater.
2/ Calculated for all drops of 0.25 ft or greater; rating table for discharge not available.

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Table 23. Summary of ship-wash stranding observations at Fishtrap Shoal (RM 92), Sauvies Island, 1975.

Date	Number of ships	Observed mortality					Mortality per ship
		Chinook	Coho	Chum	Trout	Total	
February 9	1	17	0	0	0	17	17.0
February 20	3	7	0	0	0	7	2.3
Totals	4	24	0	0	0	24	Av. 6.0
March 7	3	0	0	0	0	0	0.0
March 8	6	2	0	0	0	2	0.3
March 15	2	0	0	0	0	0	0.0
March 19	2	21	0	0	0	21	10.5
March 22	2	4	0	0	0	4	2.0
March 27	3	2	0	0	0	2	0.7
March 29	3	78	0	4	1	83	27.7
Totals	21	107	0	4	1	112	Av. 5.3
April 2	4	7	0	0	0	7	1.8
April 12	3	3	0	2	0	5	1.7
Totals	7	10	0	2	0	12	Av. 1.7
May 15	4	6	0	0	0	6	1.5
Grand totals	36	147	0	6	1	154	

Table 24. Calculated ship-wash stranding mortality at observation sites during sample periods only, 1975.

Site	Month	Mortality rate (fish/ship)				Number of ships passing site	Calculated mortality				
		Chinook	Coho	Chum	Trout		Chinook	Coho	Chum	Trout	Total
Fishtrap Shoal	February	6.0	0.0	0.0	0.0	280	1,680	0	0	0	1,680
	March	5.1	0.0	0.2	0.05	286	1,459	0	57	14	1,530
	April	1.4	0.0	0.3	0.0	324	454	0	97	0	551
	May (1-15)	1.5	0.0	0.0	0.0	138	207	0	0	0	207
	Totals					1,028	3,800	0	154	14	3,968
Marshall Beach	May (16-31)	13.9	0.0	0.0	0.07	138	1,918	0	0	10	1,928
	June	1.6	0.0	0.0	0.0	342 1/	547	0	0	0	547
	July	0.0	0.0	0.0	0.0	110	0	0	0	0	0
	Totals					590	2,465	0	0	10	2,475
Austin Point	March	5.4	0.3	0.0	0.0	286	1,544	86	0	0	1,630
	April	29.8	0.06	2.7	0.3	324	9,655	19	875	97	10,646
	May 1-15)	21.8	0.9	0.3	0.0	138	3,008	124	41	0	3,173
	June (25-30)	4.7	0.0	0.0	0.0	57 1/	268	0	0	0	268
	July	1.7	0.0	0.0	0.0	110	187	0	0	0	187
	Totals					915	14,662	229	916	97	15,904
Woodland Bar	April	21.5	0.0	0.3	0.0	324	6,966	0	97	0	7,063
	May (1-15)	12.8	0.3	0.0	0.0	138	1,766	41	0	0	1,807
	Totals					462	8,732	41	97	0	8,870
Hoagy's	April	5.4	0.0	0.4	0.0	324	1,750	0	130	0	1,880
	May	9.8	0.0	0.0	0.0	276	2,705	0	0	0	2,705
	June	10.8	0.0	0.0	0.1	342	3,694	0	0	34	3,728
	July	0.0	0.0	0.0	0.0	110	0	0	0	0	0
	Totals					1,052	8,149	0	130	34	8,313

1/ Ship numbers adjusted since stranding occurred at night only.

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Table 25. Summary of ship-wash stranding observations at Marshall Beach (RM 97), Sauvies Island, 1975.

Date	Number of ships	Observed mortality					Mortality per ship
		Chinook	Coho	Chum	Trout	Total	
May 23	6	177	0	0	1	178	29.7
May 31	9	32	0	0	0	32	8.6
Totals	15	209	0	0	1	210	Av. 14.0
June 5	7	13	0	0	0	13	1.9
June 12	9	13	0	0	0	13	1.4
Totals	16	26	0	0	0	26	Av. 1.6
July 30	3	0	0	0	0	0	0.0
Grand totals	34	235	0	0	1	236	

Table 26. Summary of ship-wash stranding observations at Austin Point (RM 86), 1975.

Date	Number of ships	Observed mortality					Mortality per ship
		Chinook	Coho	Chum	Trout	Total	
March 7	3	1	0	0	0	1	0.3
March 8	4	11	0	0	0	11	2.8
March 13	4	31	3	0	0	34	8.5
March 15	3	62	2	0	0	64	21.3
March 20	2	3	0	0	0	3	1.5
March 23	4	4	0	0	0	4	1.0
March 26	2	7	1	0	0	8	4.0
Totals	22	119	6	0	0	125	Av. 5.7
April 5	2	48	0	0	0	48	24.0
April 6	2	231	0	4	0	235	117.5
April 7	1	95	0	8	1	104	104.0
April 10	4	90	1	11	2	104	52.0
April 16	5	11	0	0	1	12	2.4
April 17	2	2	0	0	1	3	1.5
April 26	2	60	0	26	0	86	43.0
Totals	18	537	1	49	5	592	Av. 32.9
May 1	10	268	8	5	0	281	28.1
May 8	5	59	5	0	0	64	12.8
Totals	15	327	13	5	0	345	Av. 23.0
June 26	3	14	0	0	0	14	4.7
July 10	3	5	0	0	0	5	1.7
August 14	3	0	0	0	0	0	0.0
Grand totals	64	1,002	20	54	5	1,081	

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Table 27. Summary of ship-wash stranding observations at Woodland Bar (RM 82), 1975.

Date	Number of ships	Observed mortality					Mortality per ship
		Chinook	Coho	Chum	Trout	Total	
April 10,13[1/]	0	202	0	0	0	202	0.0
April 16[2/]	5	210	0	1	0	211	42.2
April 17	2	5	0	2	0	7	2.5
April 26	3	0	0	0	0	0	0.0
Totals	10	215	0	3	0	218	Av. 21.8
May 7	10	226	5	0	0	231	23.1
May 14	8	4	0	0	0	4	0.5
Totals	18	230	5	0	0	235	Av. 13.1
July 7[1/]	0	38	0	0	0	38	0.0
August 15	2	1	0	0	0	1	0.5
Grand totals	30	446	5	3	0	454	

1/ Spot check at site, mortality result of unobserved ships and are not included in totals.

2/ Includes estimated 200 juveniles trapped in shallow depression which dewatered after leaving site.

Table 28. Summary of ship-wash stranding observations at Hoagy's Bar (RM 57), 1975.

Date	Number of ships	Observed mortality					Mortality per ship
		Chinook	Coho	Chum	Trout	Total	
April 3	1	36	0	3	0	39	39.0
April 9	2	2	0	0	0	2	1.0
April 13	1	0	0	0	0	0	0.0
April 30	3	0	0	0	0	0	0.0
Totals	7	38	0	3	0	41	Av. 5.9
May 24	8	96	0	0	0	96	12.0
May 28	6	41	0	0	0	41	6.8
Totals	14	137	0	0	0	137	Av. 9.8
June 5	11	78	0	0	2	80	7.3
June 12	12	192	0	0	0	192	16.0
June 26	2	21	0	0	0	21	10.5
June 27	2	1	0	0	0	1	0.5
Totals	27	292	0	0	2	294	Av. 10.9
July 6	2	0	0	0	0	0	0.0
July 10	2	0	0	0	0	0	0.0
Totals	4	0	0	0	0	0	Av. 0.0
August 16	0[1/]	0	0	0	0	0	0.0
Grand totals	52	467	0	3	2	472	

1/ No ships passed the site.

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Table 29. Averaged ship-wash stranding mortality rates used to calculate mortality in Willamette River to Cowlitz River reach, 1975.

Month	Average mortality rate (fish/ship)			
	Chinook	Coho	Chum	Trout
February	6.00	0.00	0.00	0.00
March	5.25	0.15	0.10	0.03
April	14.53	0.02	0.93	0.08
May 1-15	12.03	0.40	0.20	0.00
May 16-31	11.85	0.00	0.00	0.04
June	5.70	0.00	0.00	0.03
July	0.07	0.00	0.00	0.00

Table 30. Ship-wash stranding mortality estimates for all sites on the Willamette River to Cowlitz River reach, February through July, 1975.

Month	Estimated mortality				
	Chinook	Coho	Chum	Trout	Total
February	21,840	0	0	0	21,840
March	19,520	558	372	108	20,558
April	64,152	84	4,082	356	68,674
May 1-15	21,582	717	317	0	22,616
May 16-31	8,459	0	0	32	8,491
June	8,631	0	0	41	8,672
July	819	0	0	0	819
Totals	145,003	1,359	4,771	537	151,670

[illegible]

Site	Sand Island (R.M. 131)			Government Island (R.M. 115)			Sauvies Island (R.M. 97)			Sandy Island (R.M. 76)			Lord Island (R.M. 63)			Water temperature
Date	Chin.	Coho	Chum	Chin.	Coho	Chum	Chin.	Coho	Chum	Chin.	Coho	Chum	Chin.	Coho	Chum	(°F)
February 13	1	0	0	3	0	0	9	0	0	5	0	0				41-44
19	2	0	0	4	0	0	3	0	1	4	0	0				39-43
26	1	0	0	4	0	0	10	0	1	3	0	0				39-44
March 5	0	0	0	0	0	0	7	0	0	2	0	0				42-44
13	3	0	0	0	0	0	7	1	0	4	0	0				42-46
19	1	0	0	6	0	0	9	0	0	2	0	1				41-44
26	14	1	1	3	0	2	6	0	0	5	0	0	26	0	0	44-46
April 2	22	0	4	37	0	1	2	0	0	4	0	4	63	1	6	43-46
9	245	0	12	62	0	0	47	0	4	104	0	1	287	0	4	43-51
16	57	1	4	70	0	3	170	0	3	37	0	1	96	0	7	43-49
23	26	0	4	23	3	0	77	0	9	35	0	0	136	0	1	47-54
30	6	1	0	48	2	1	240	17	4	469	6	0	281	20	0	49-54
May 7	46	1	0	56	83	0	99	44	0	70	40	0	269	167	0	49-53
14				32	106	0	57	10	0	35	14	0	205	0	0	54-59
21				161	3	0	186	14	0	54	0	0	69	2	0	57-64
28	9	3	0	116	0	0	215	1	0	26	0	0	187	0	0	54-63
June 4				33	0	0	34	0	0	15	2	0				57-62
11				33	0	0	13	0	0	24	0	0				61-66
19	25	0	0	13	0	0	16	0	0	16	0	0	50	0	0	58-62
25	20	0	0	10	0	0	12	0	0	28	0	0	27	0	0	58-62
July 3	8	1	0	7	0	0	30	0	0	50	0	0	84	0	0	58-63
9	6	1	0	0	0	0	2	0	0	12	0	0	5	0	0	64-69
16	0	0	0	1	0	0	4	0	0	6	0	0	10	0	0	64-68
23	0	0	0	1	0	0	0	0	0	1	0	0	23	0	0	63-74
30	0	0	0	0	0	0	3	0	0	2	0	0	4	0	0	63-69
August 6	0	0	0	2	0	0	2	0	0	3	0	0	2	0	0	60-73
13	0	0	0	3	0	0	0	0	0	0	0	0	5	0	0	70-74
21	1	0	0	3	0	0	1	0	0	0	0	0	7	0	0	67-68
28	0	0	0	1	0	0	2	0	0	3	0	0	5	0	0	
September 4	0	0	0	2	0	0	0	0	0	3	0	0	7	0	0	64-68
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67-70
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	61-66

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APPENDIX III

(Figures 1 through 12)
(Pages 74 through 108)

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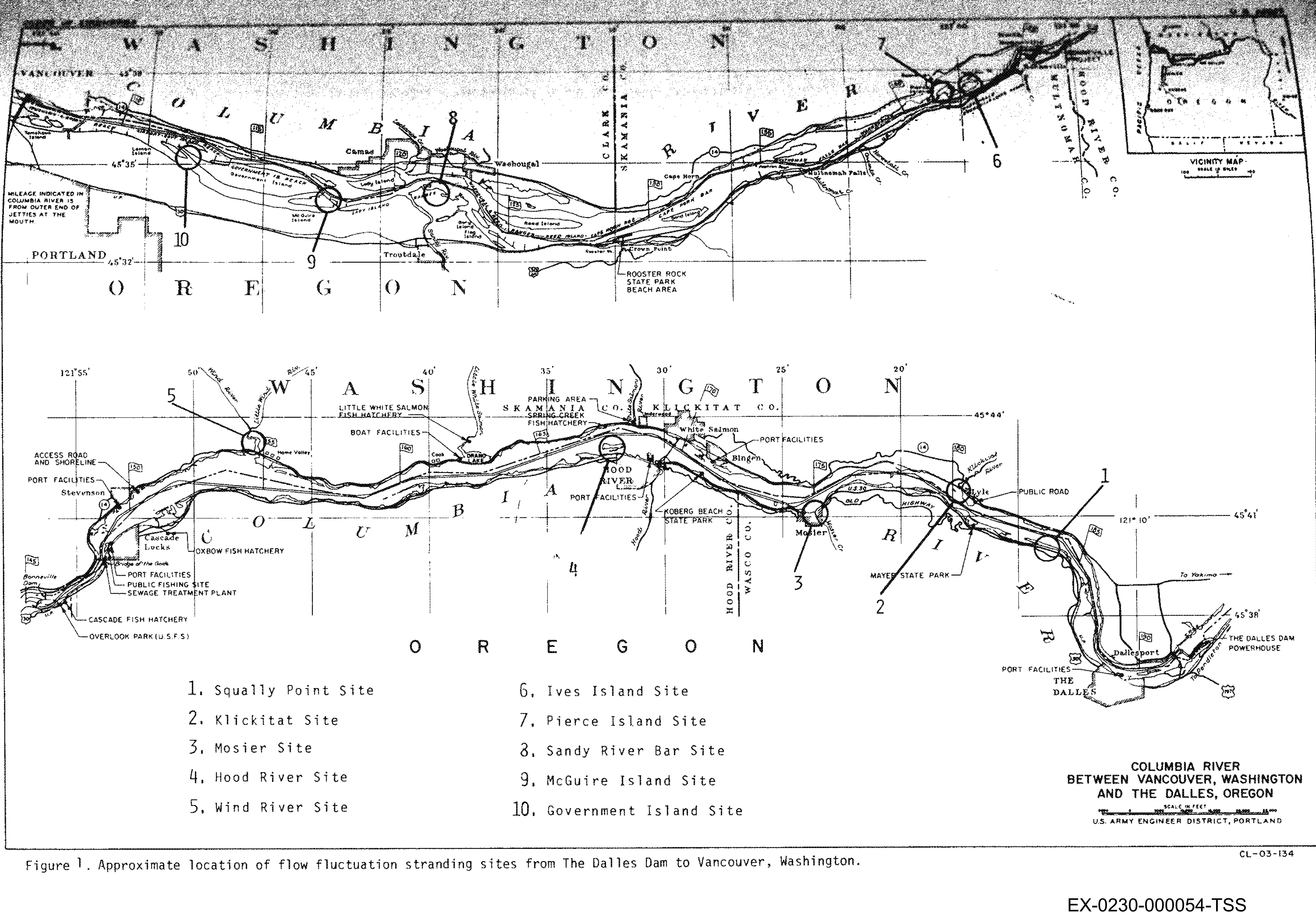


Figure 1. Approximate location of flow fluctuation stranding sites from The Dalles Dam to Vancouver, Washington.

EX-0230-000054-TSS

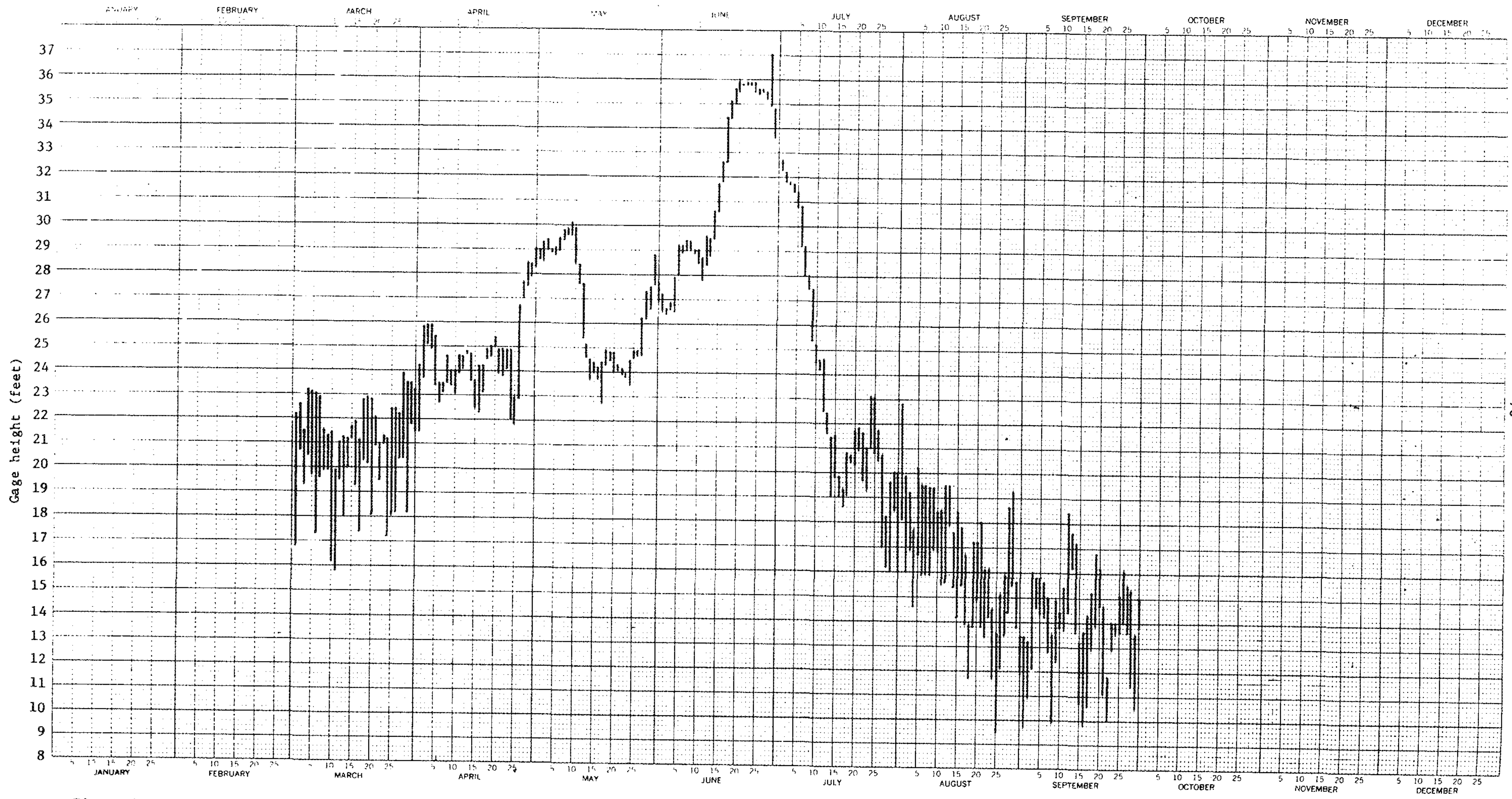


Figure 2. Daily flow fluctuations in the Columbia River measured in the Bonneville Dam tailrace (RM 145.5), March through September 1974.

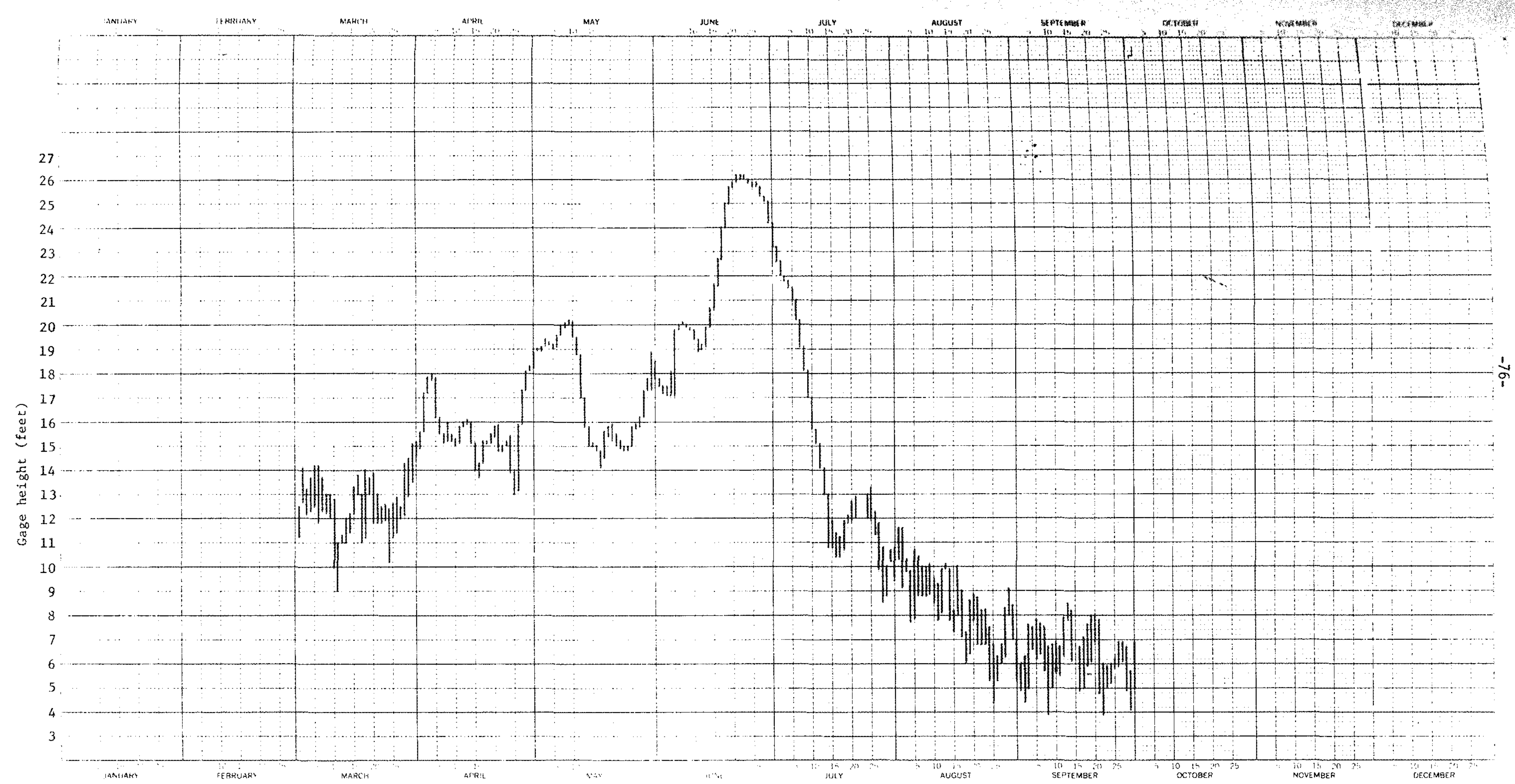


Figure 3. Daily flow fluctuations in the Columbia River as measured at the Washougal gauge (RM 122), March through September 1974.

EX-0230-000055-TSS

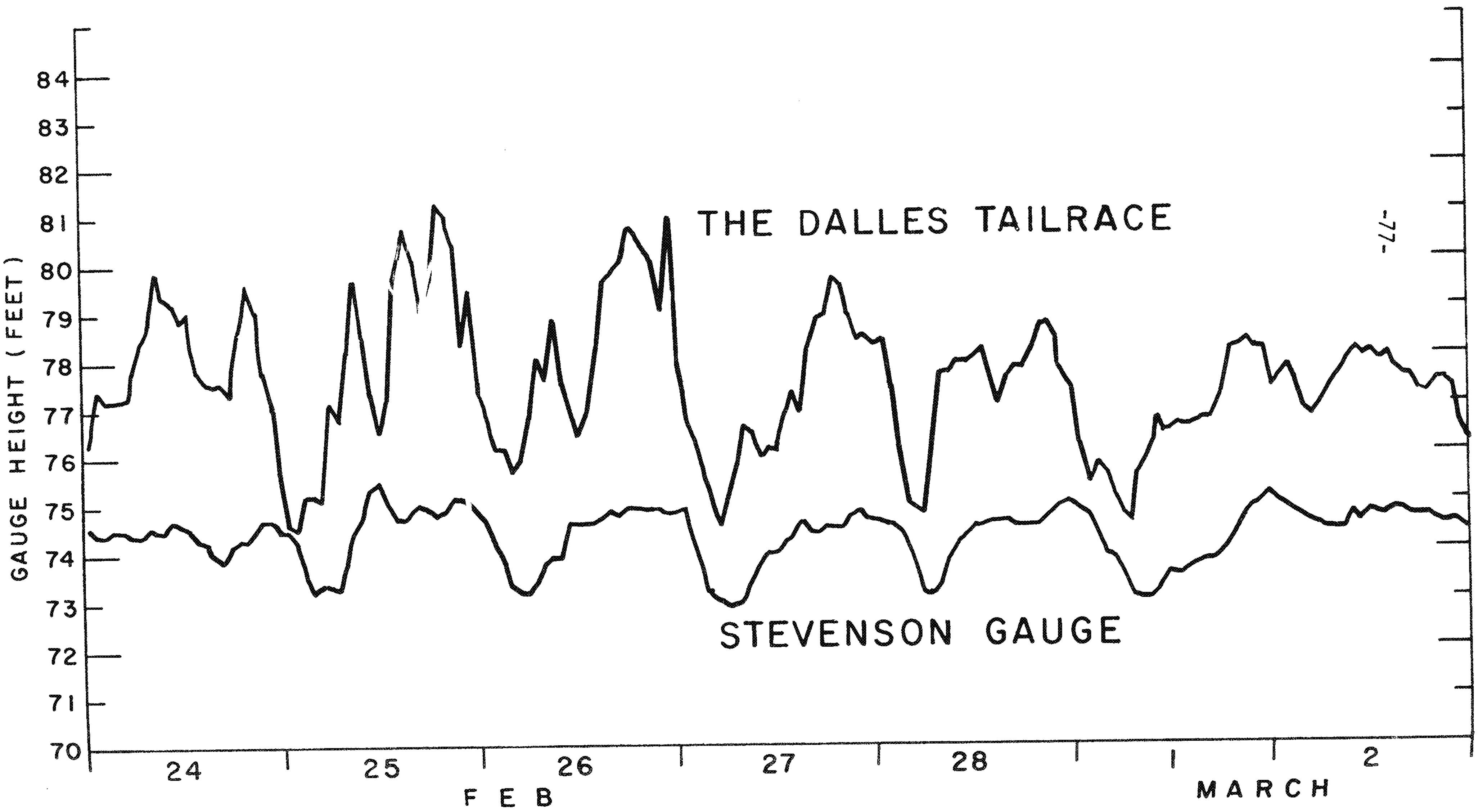


Figure 4. Daily changes in Bonneville Pool elevation measured at The Dalles Dam tailrace and Stevenson, Washington, for the period February 24 through May 18, 1975.

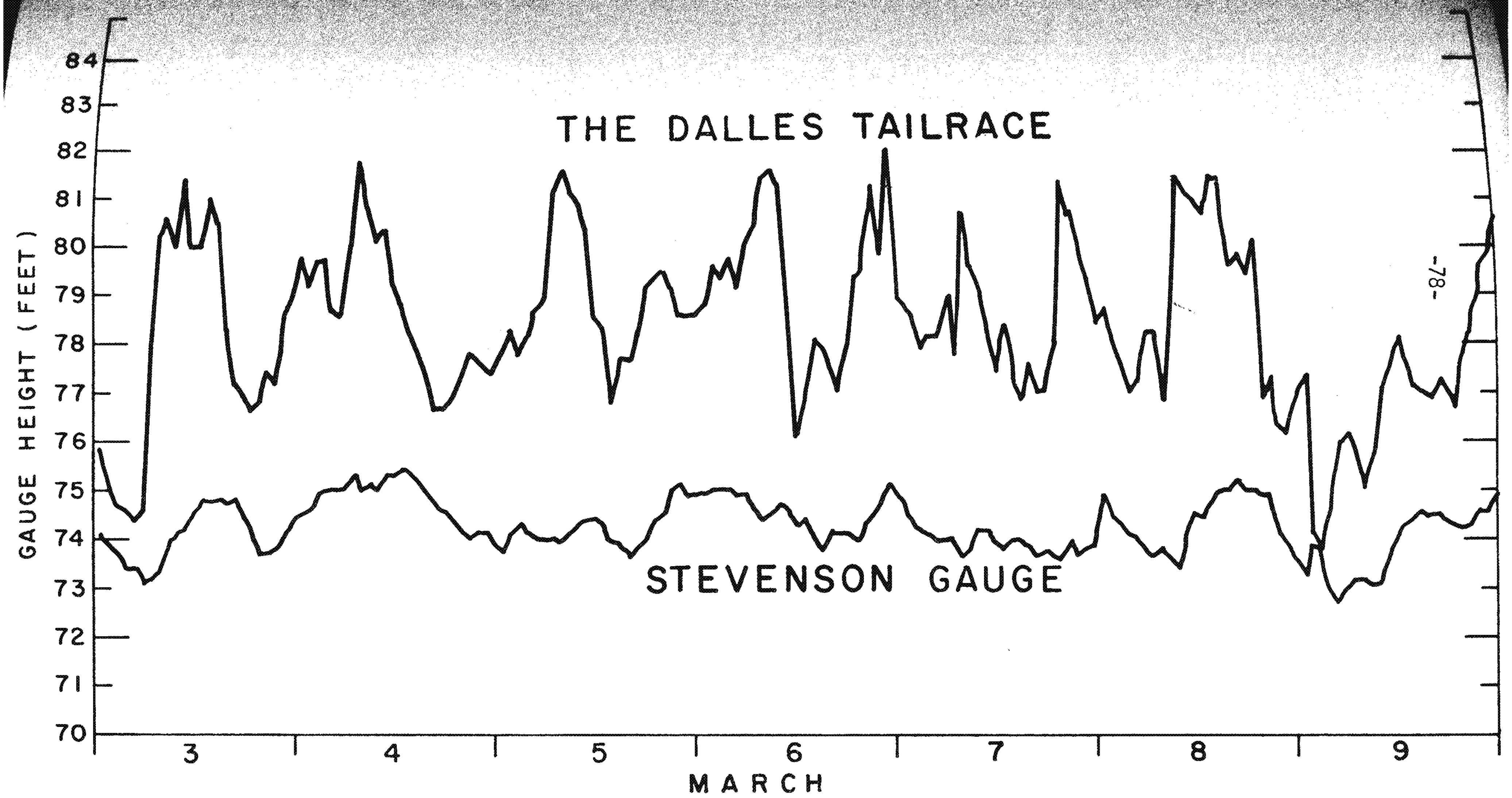
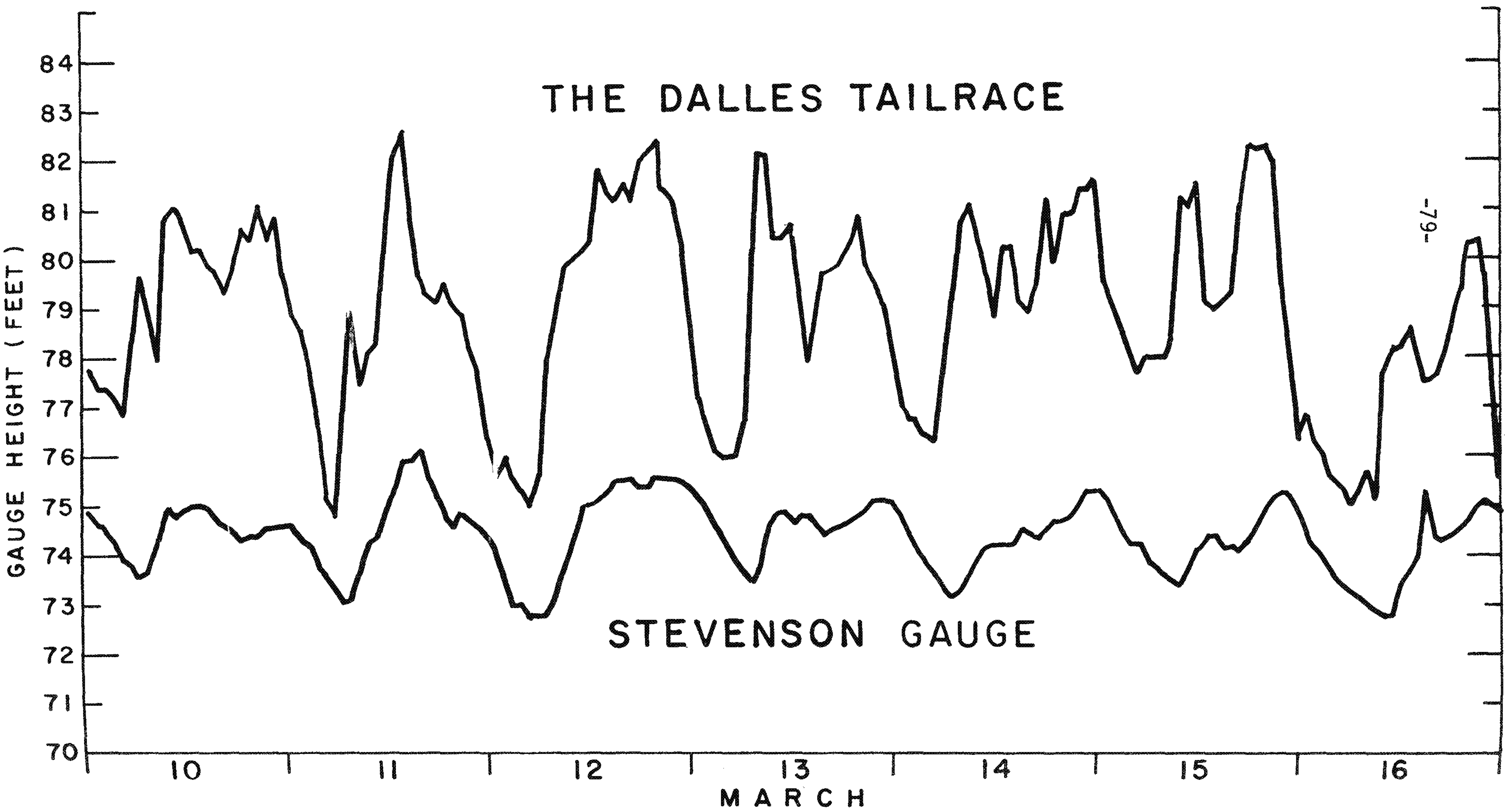


Figure 4. (Continued)

EX-0230-000056-TSS



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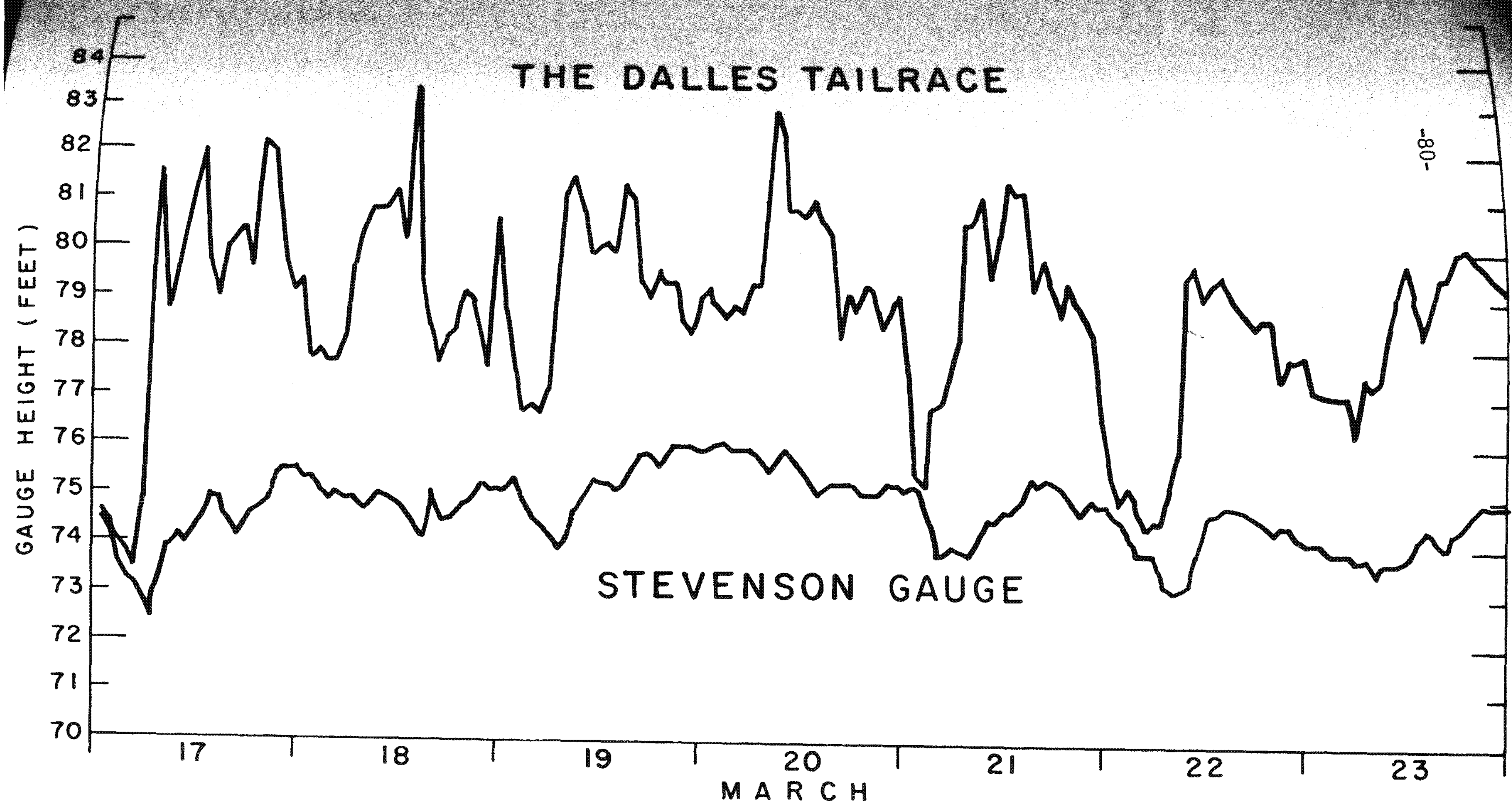

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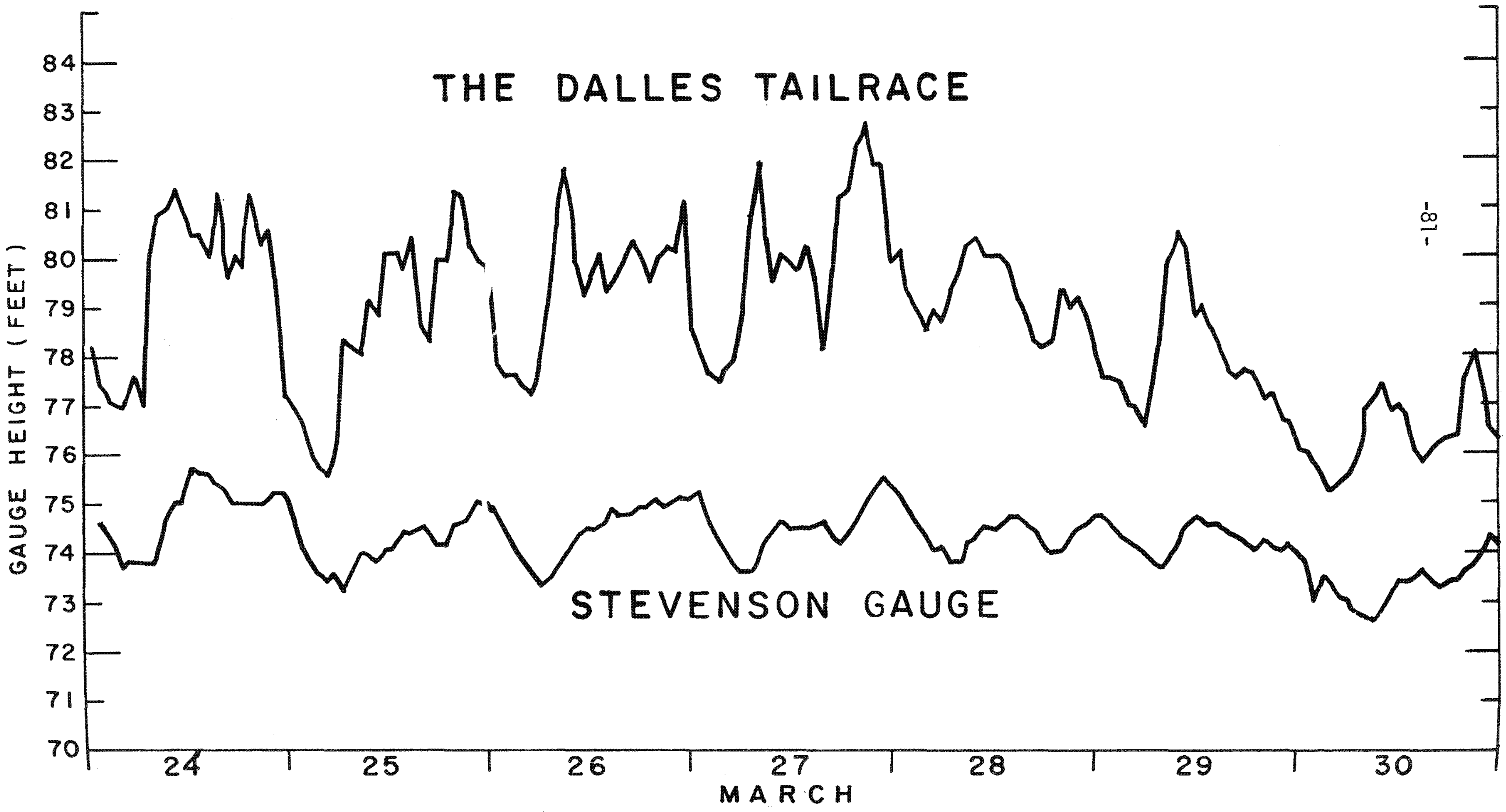
EX-0230-000057-TSS



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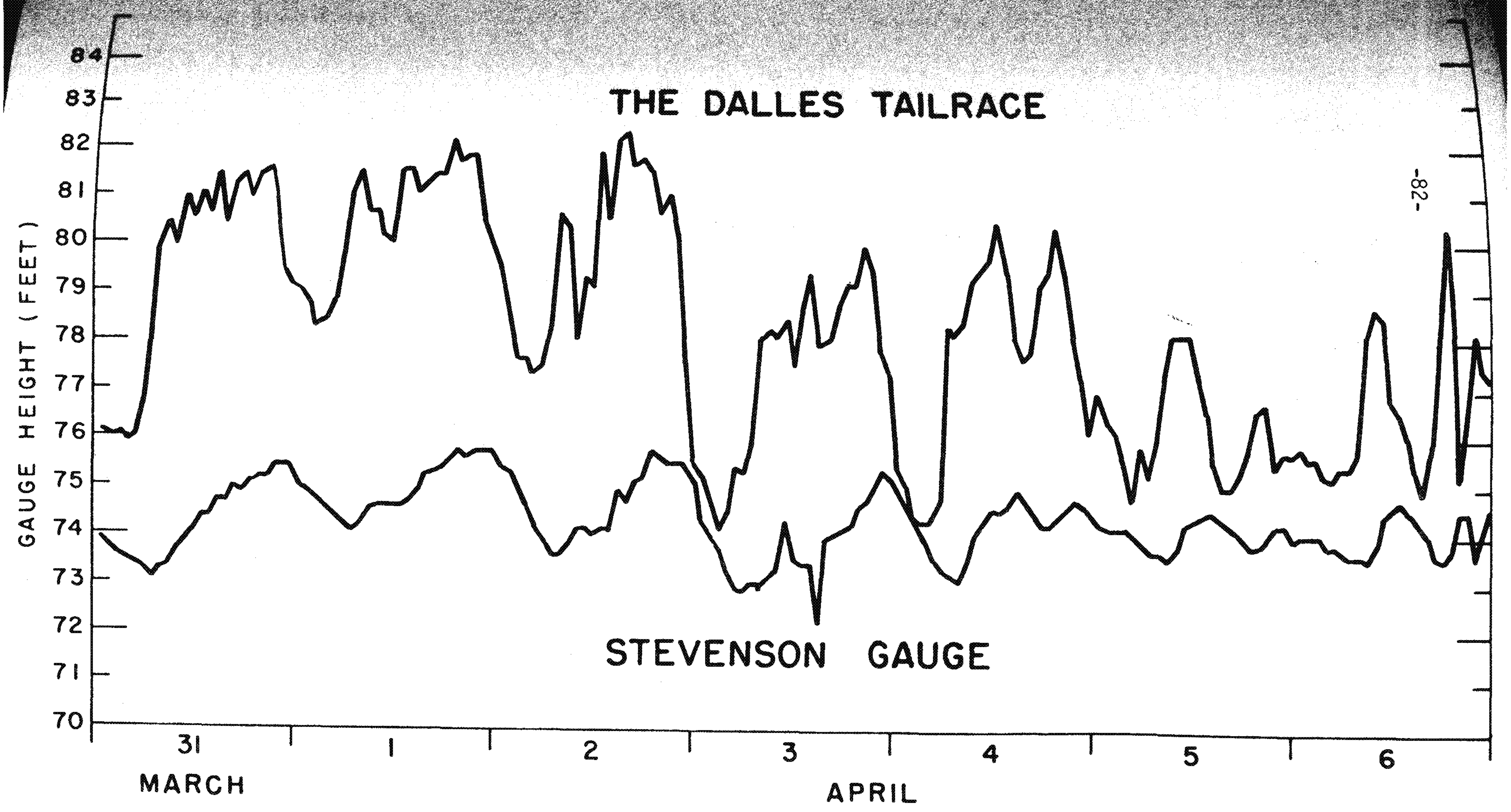

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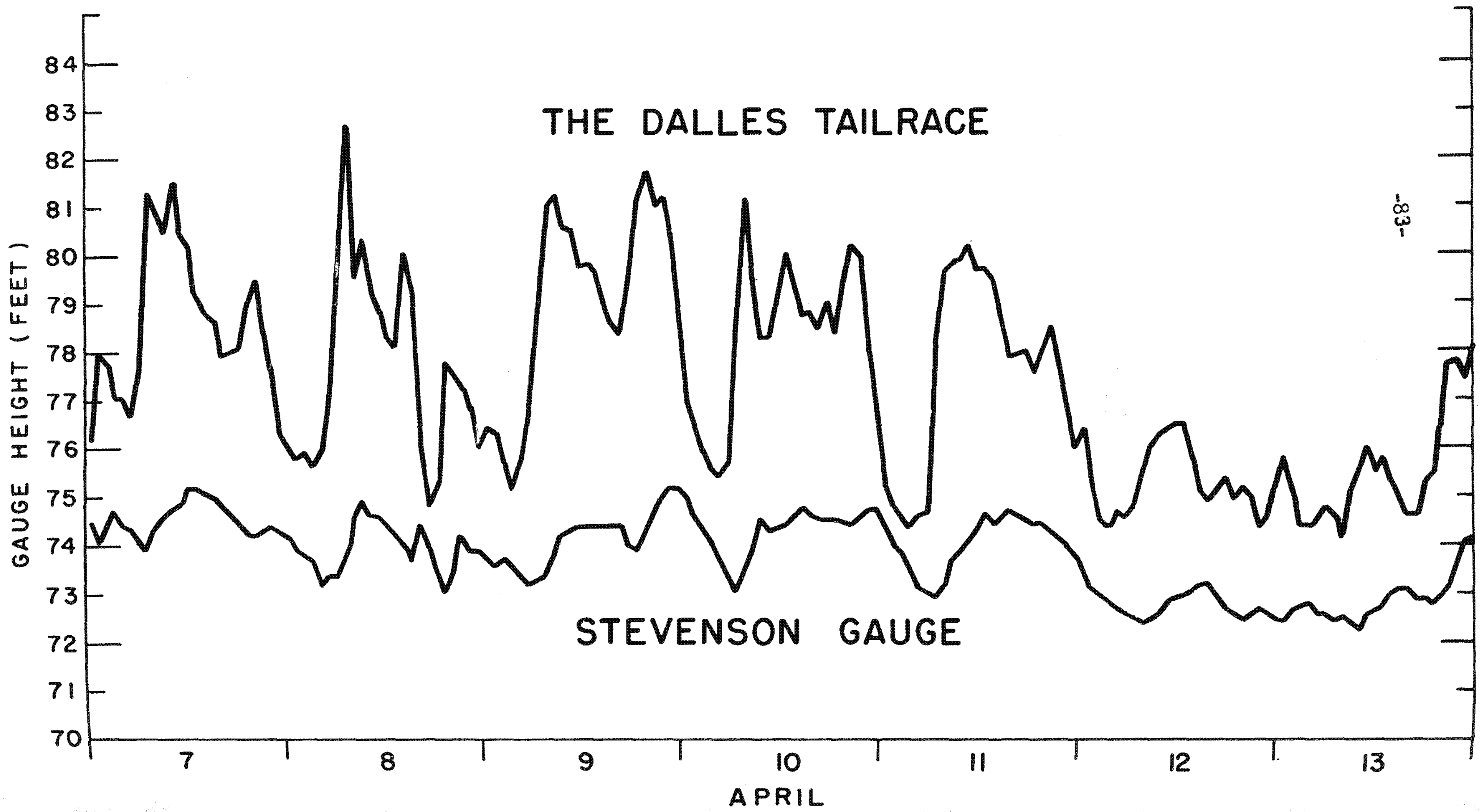

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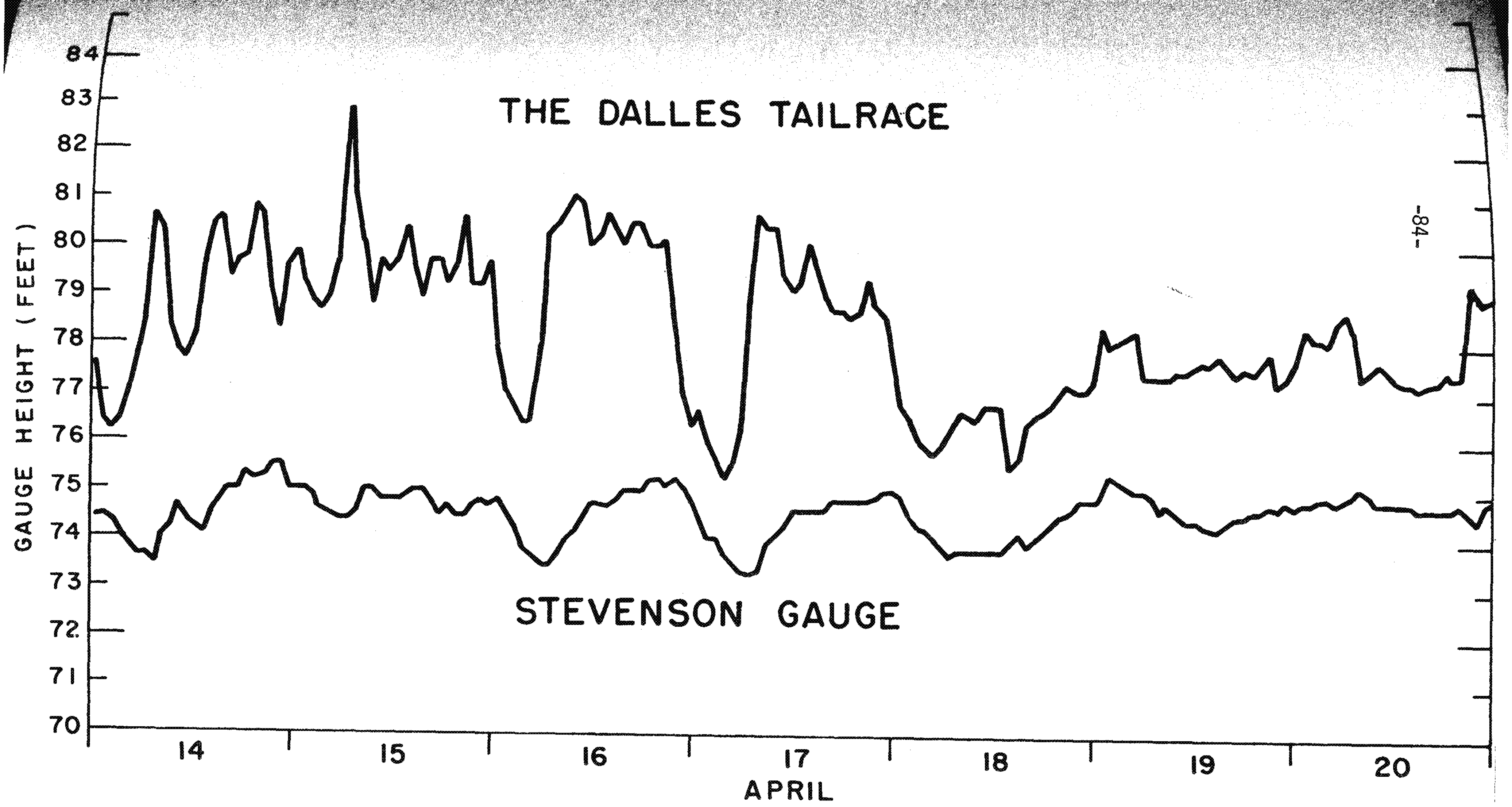

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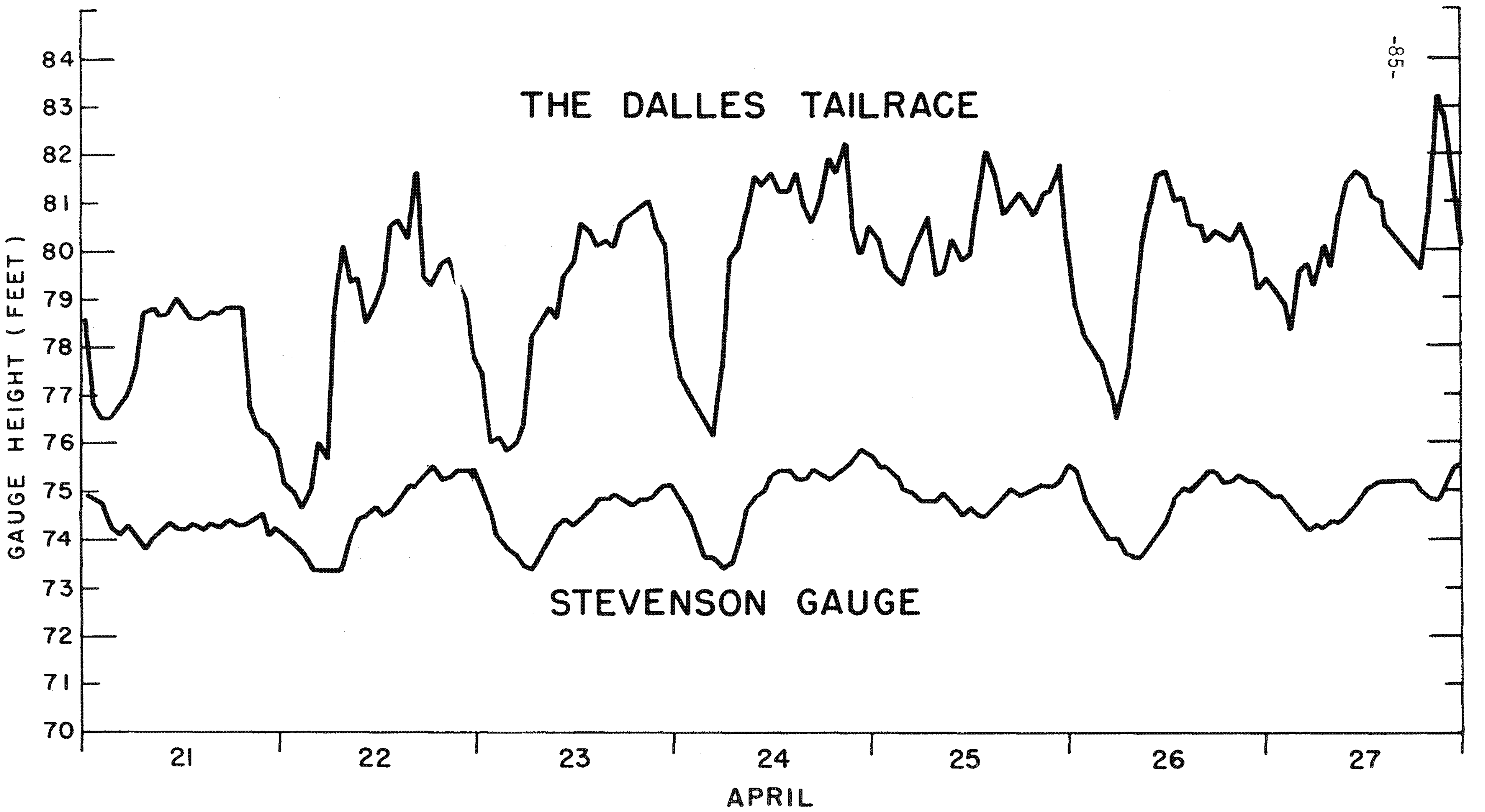

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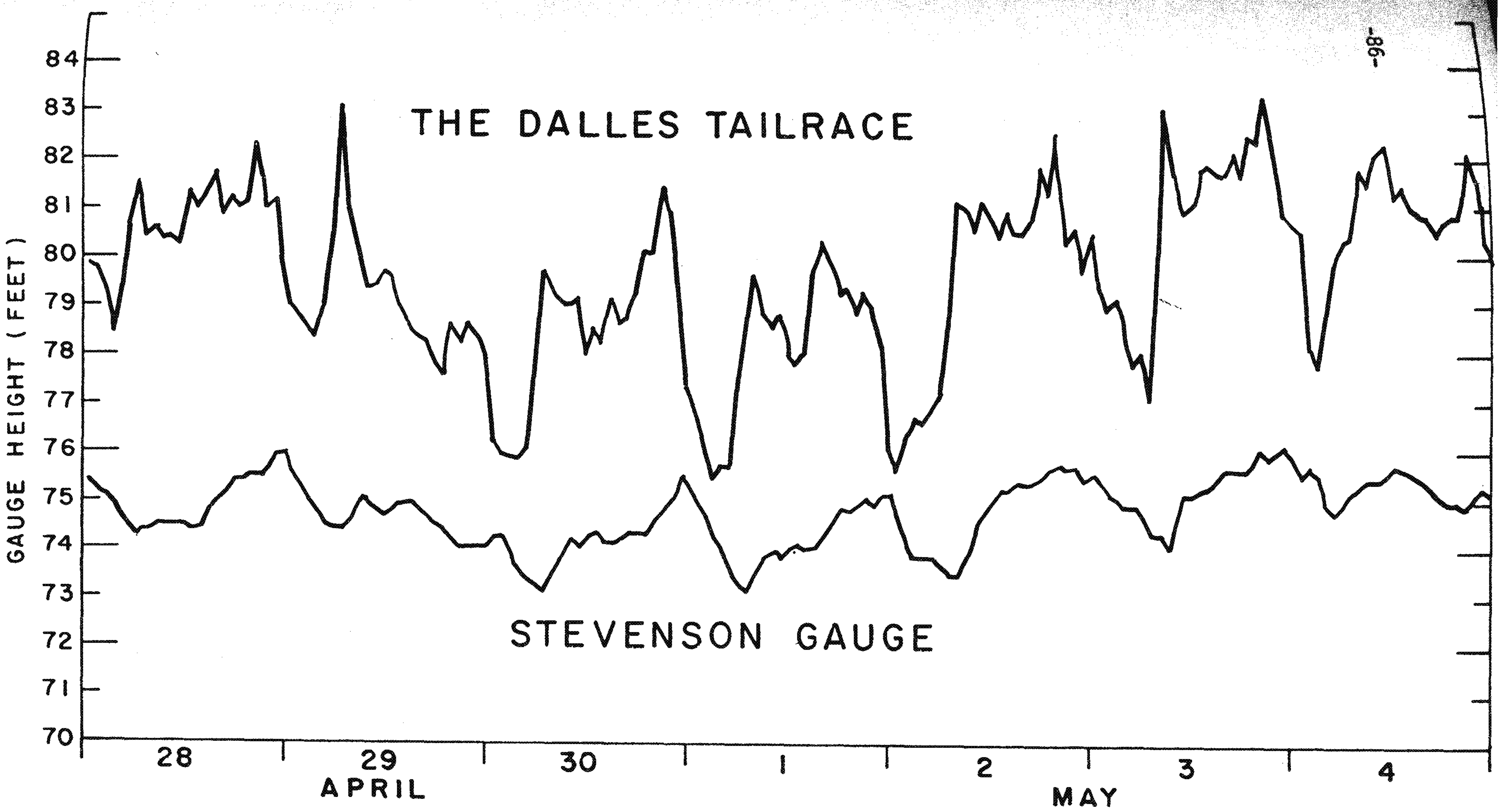

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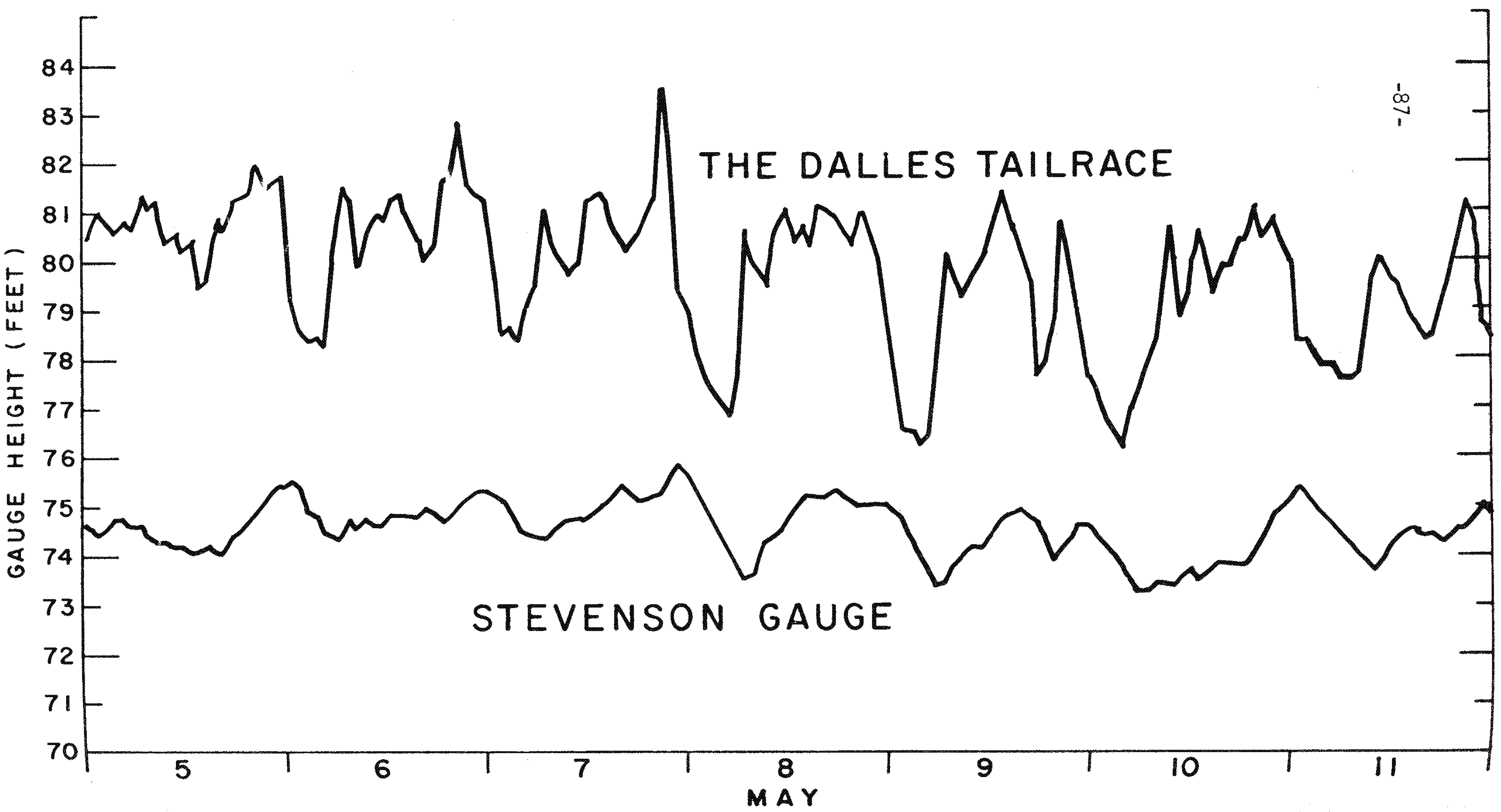
EX-0230-000060-TSS



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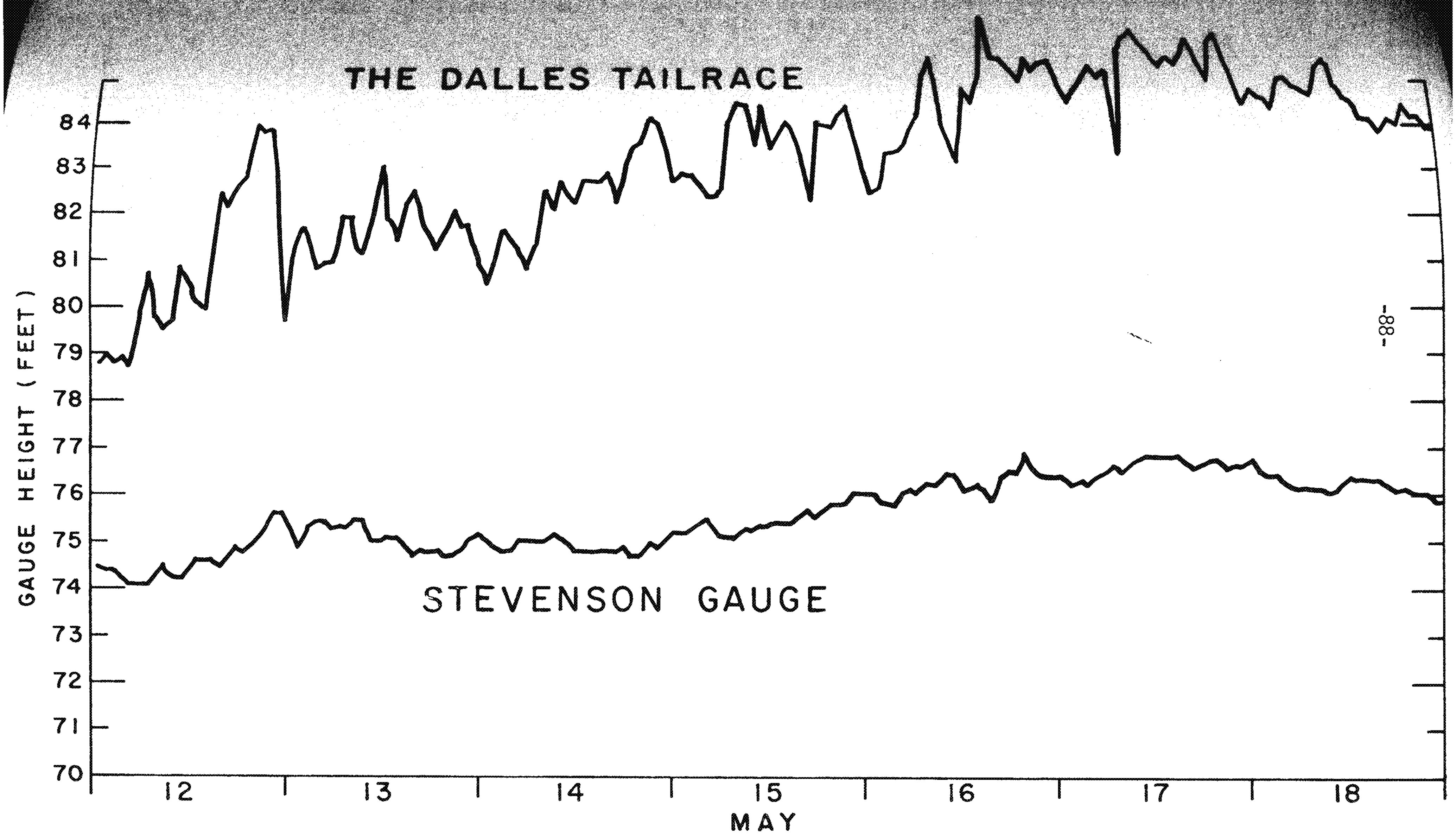

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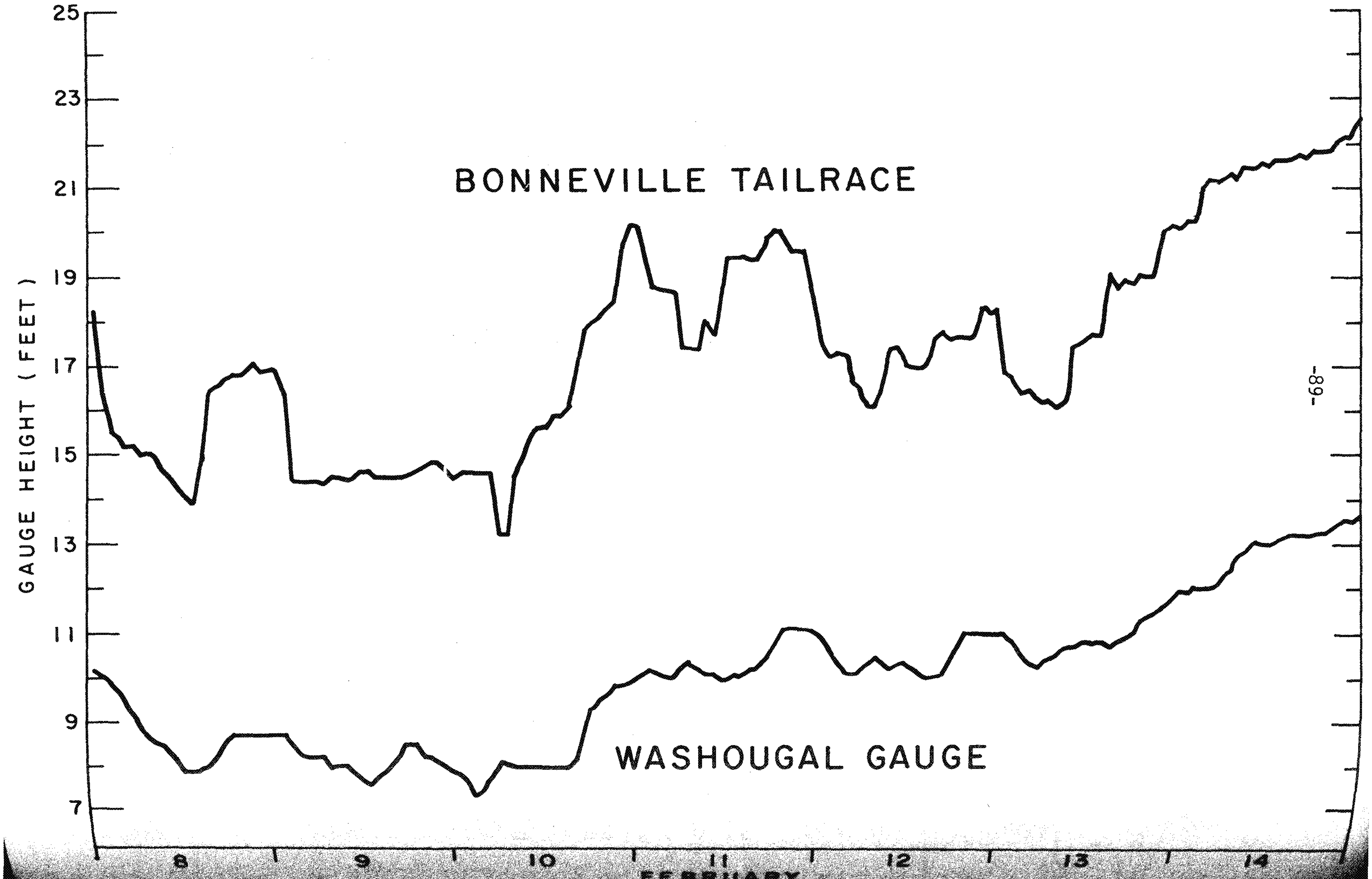

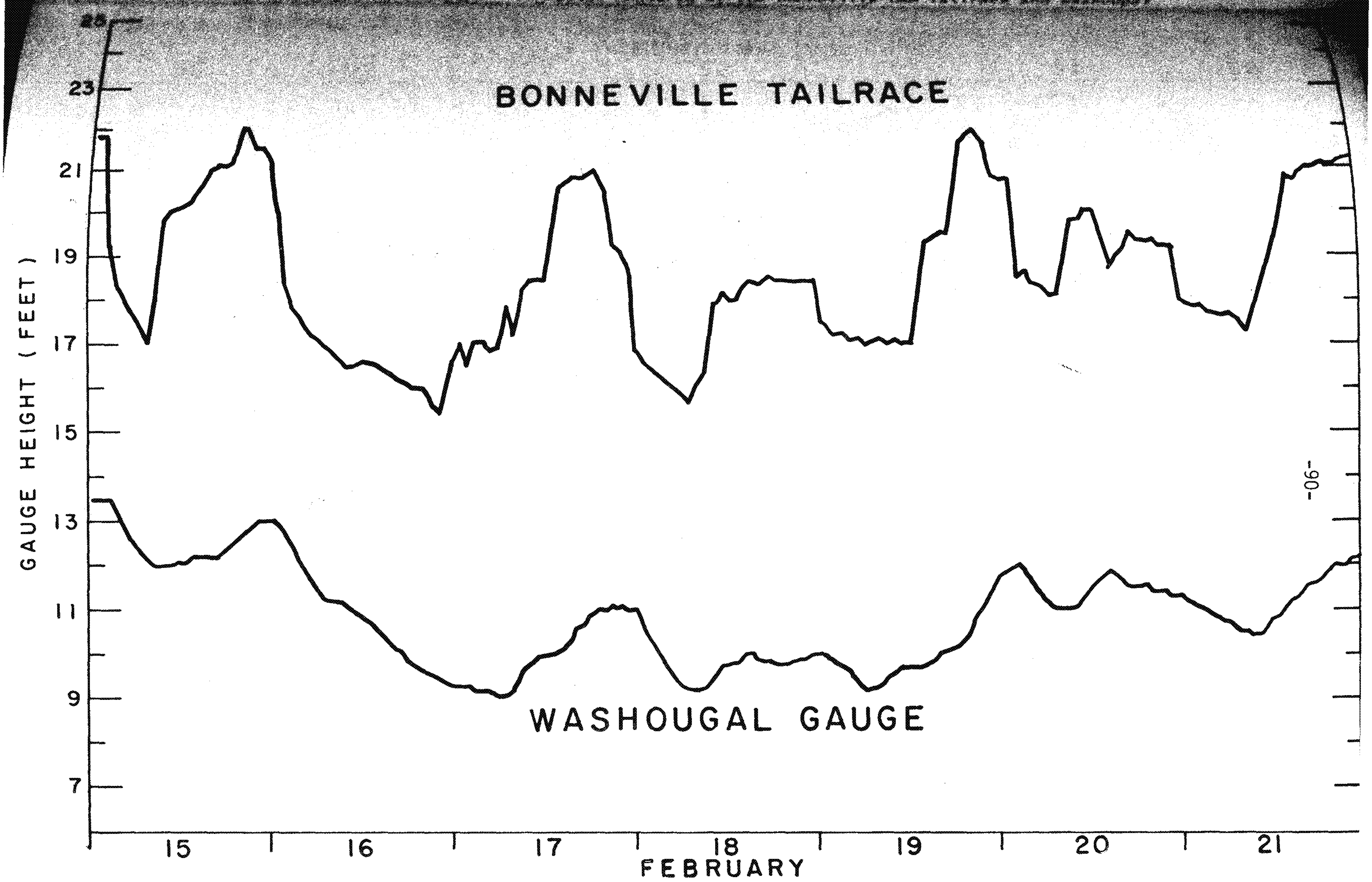

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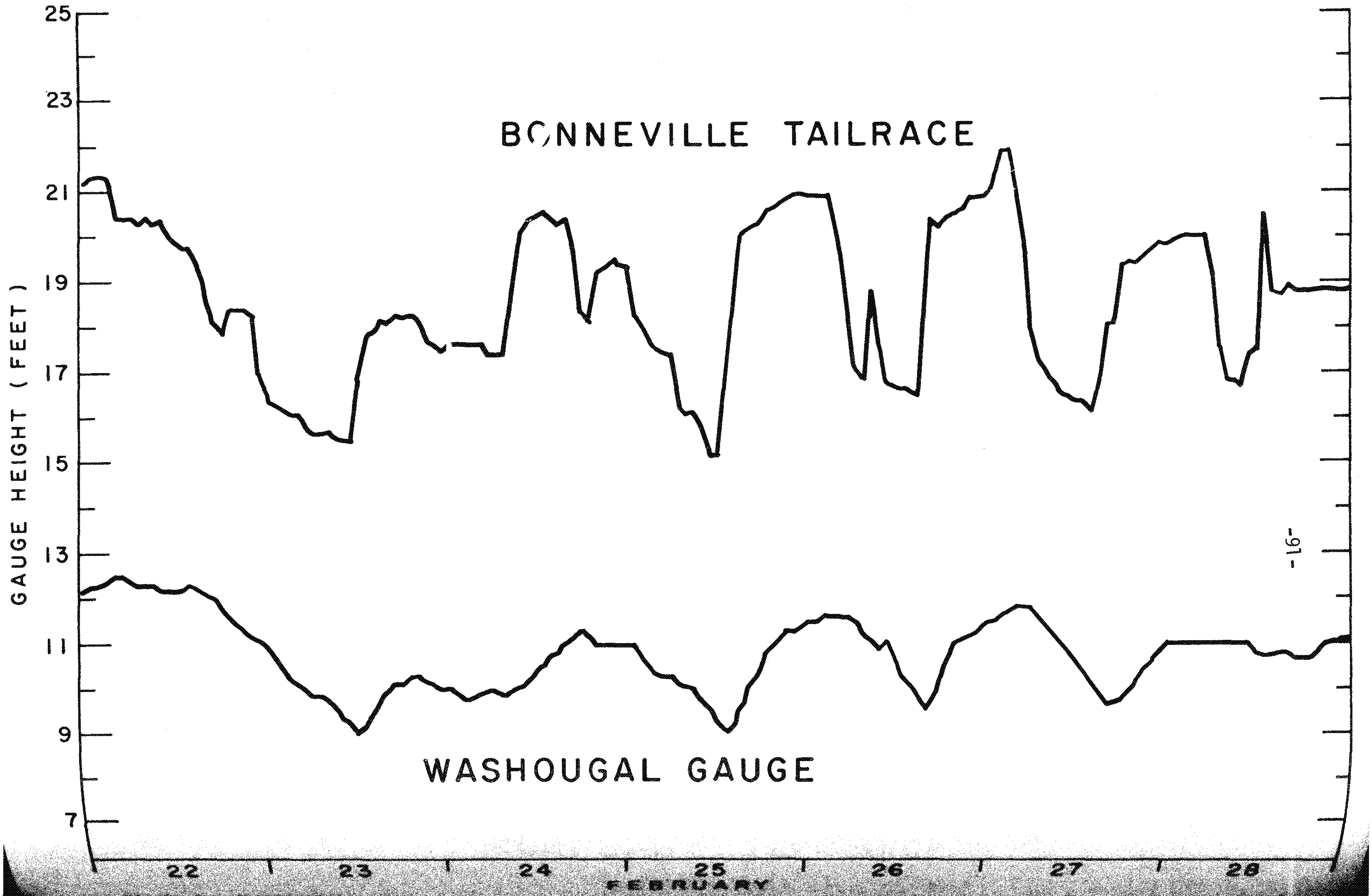

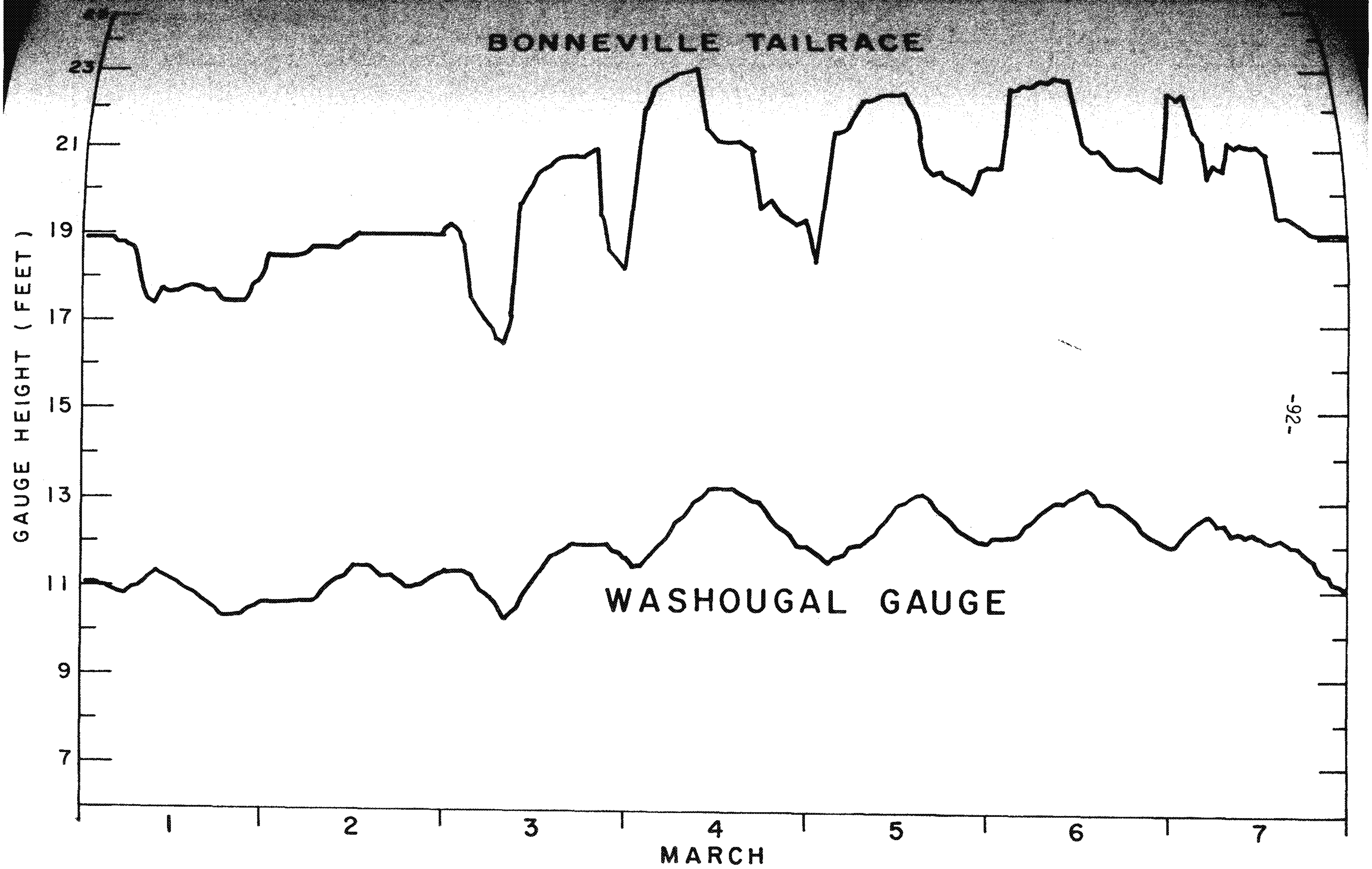

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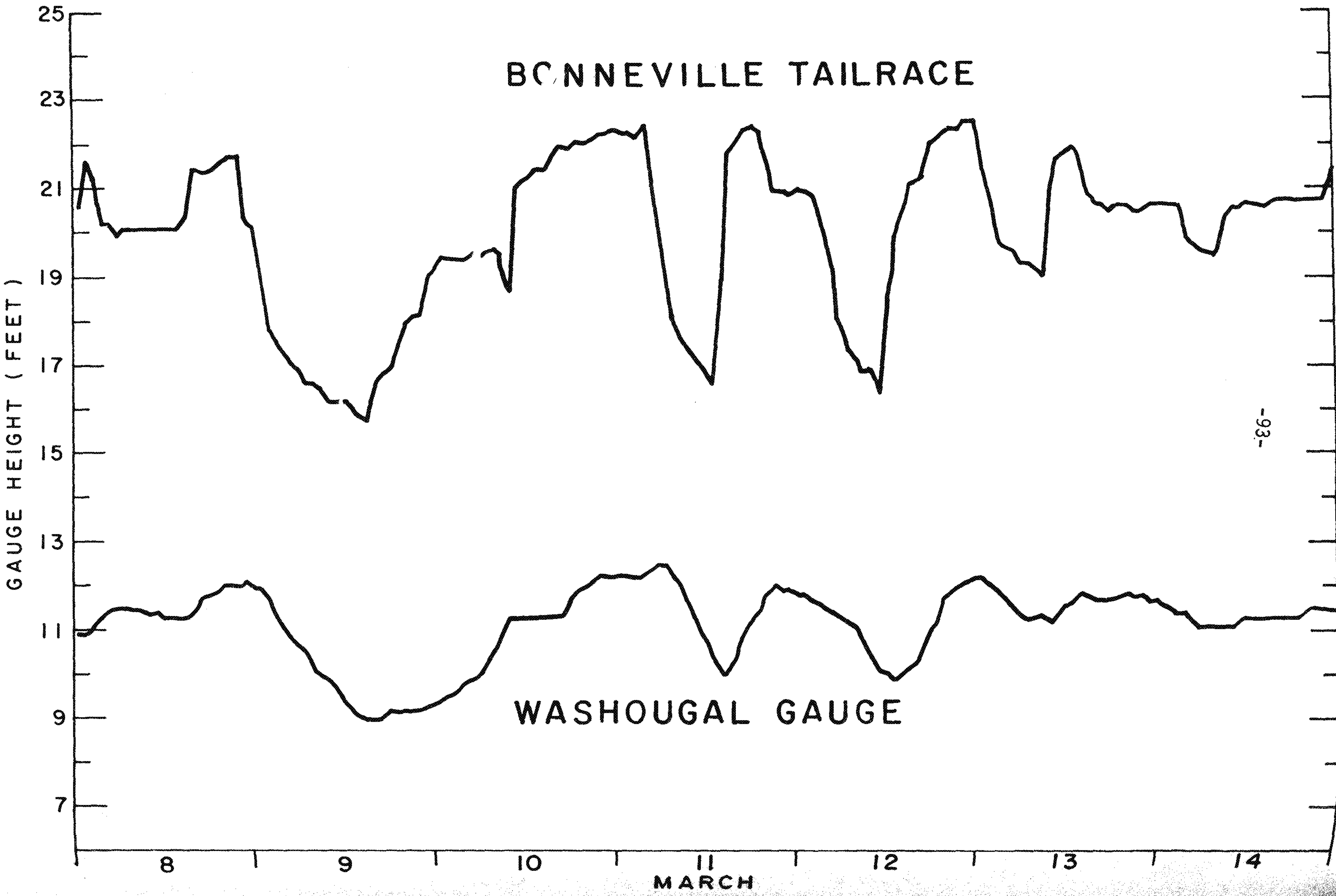

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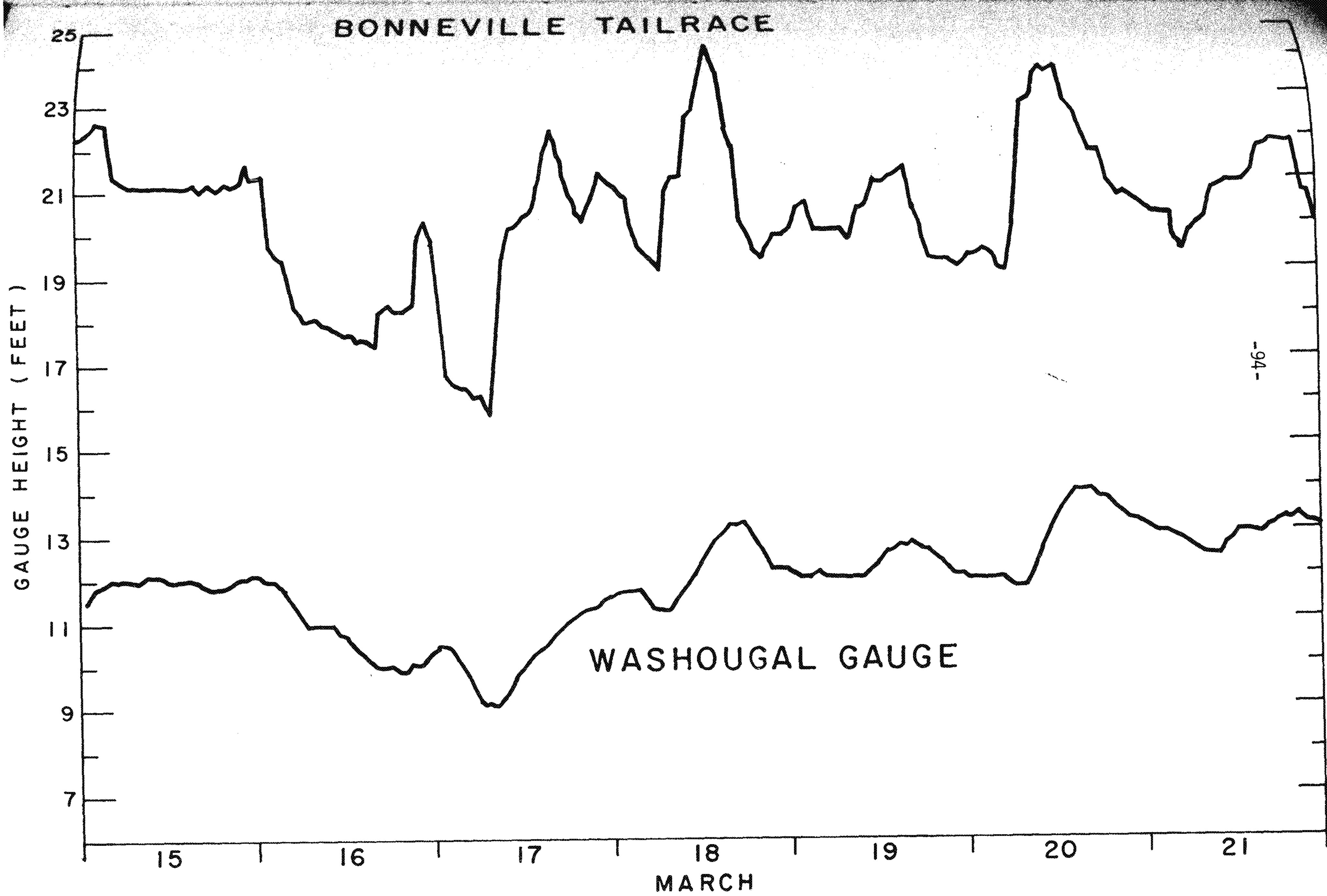

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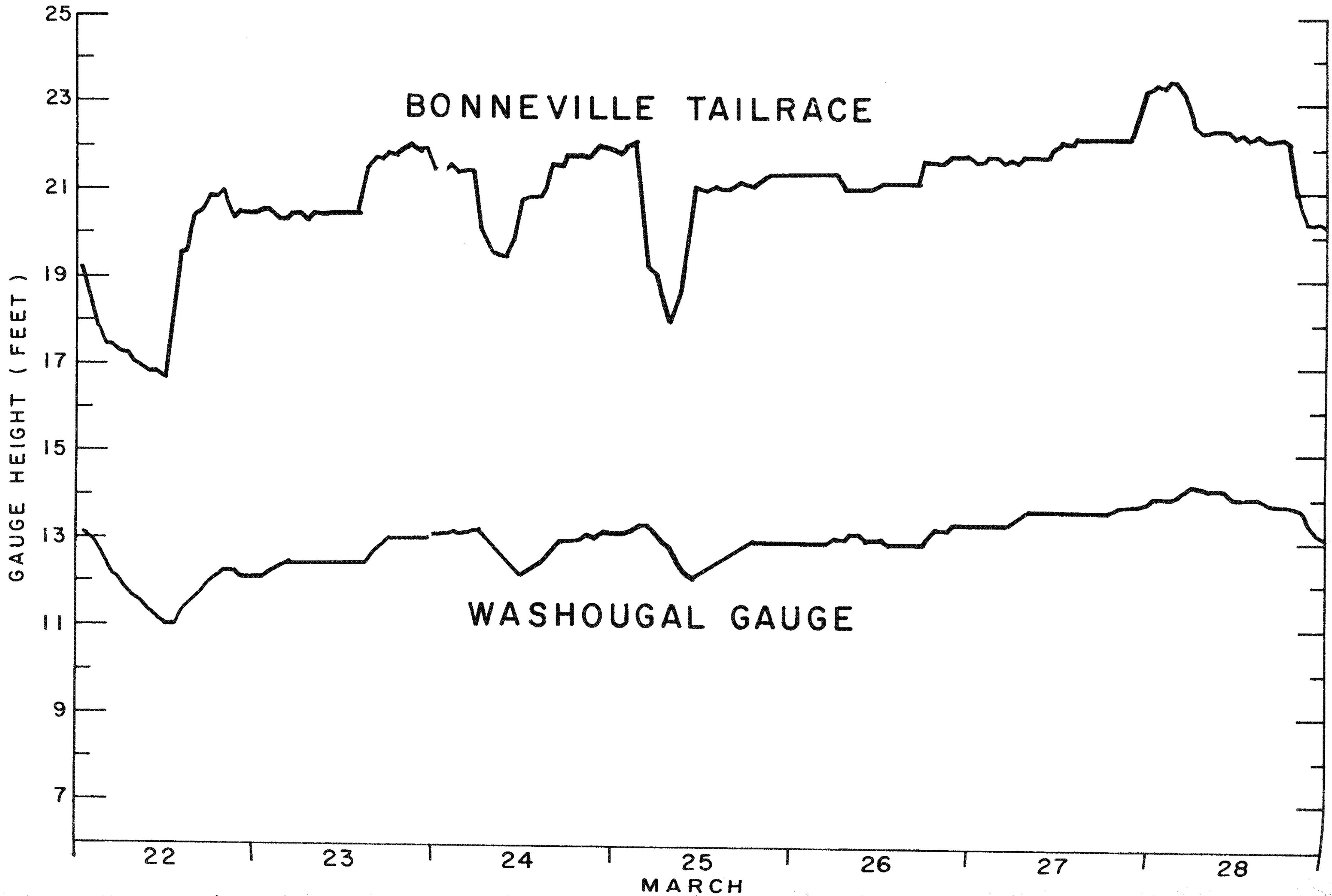

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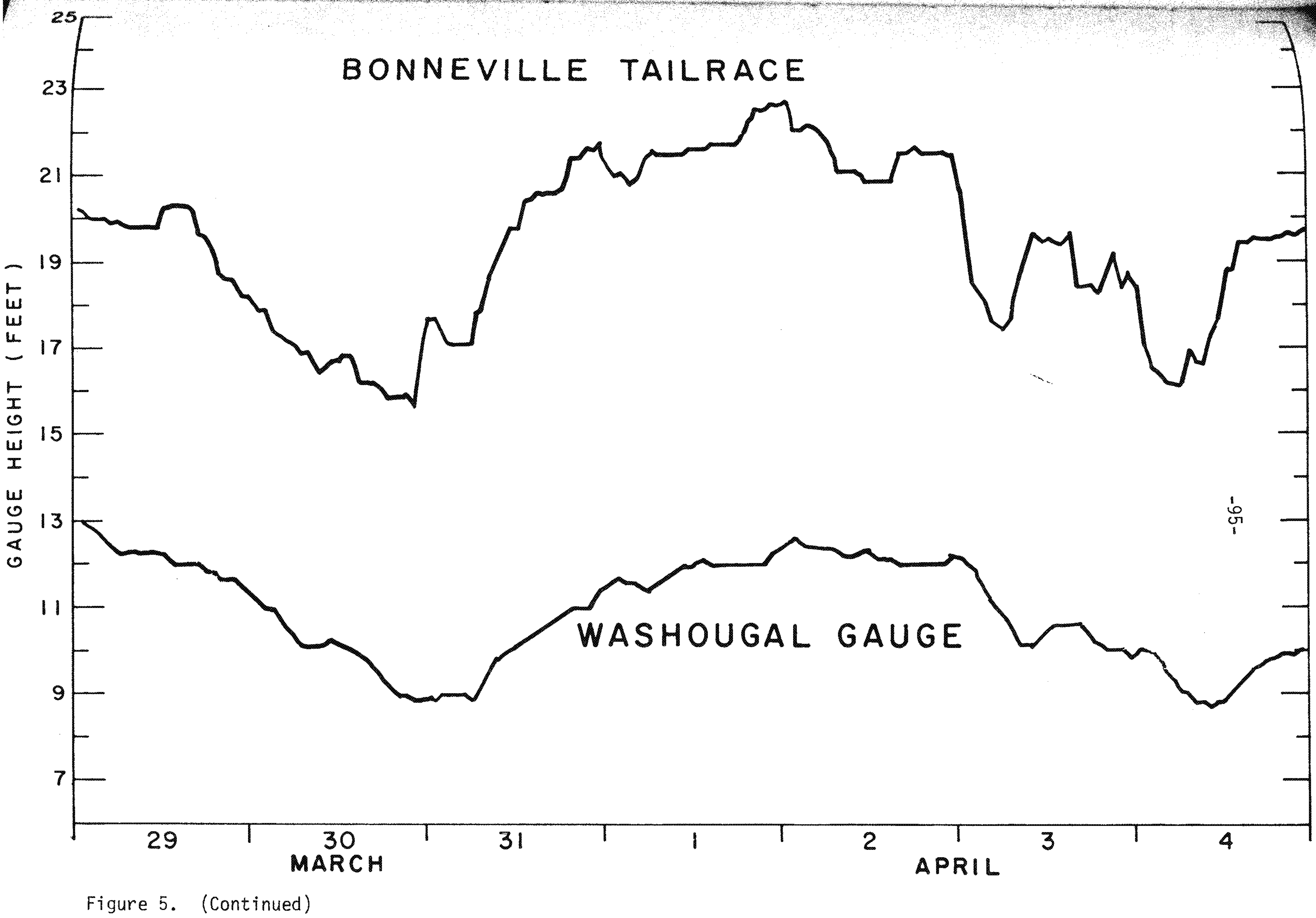

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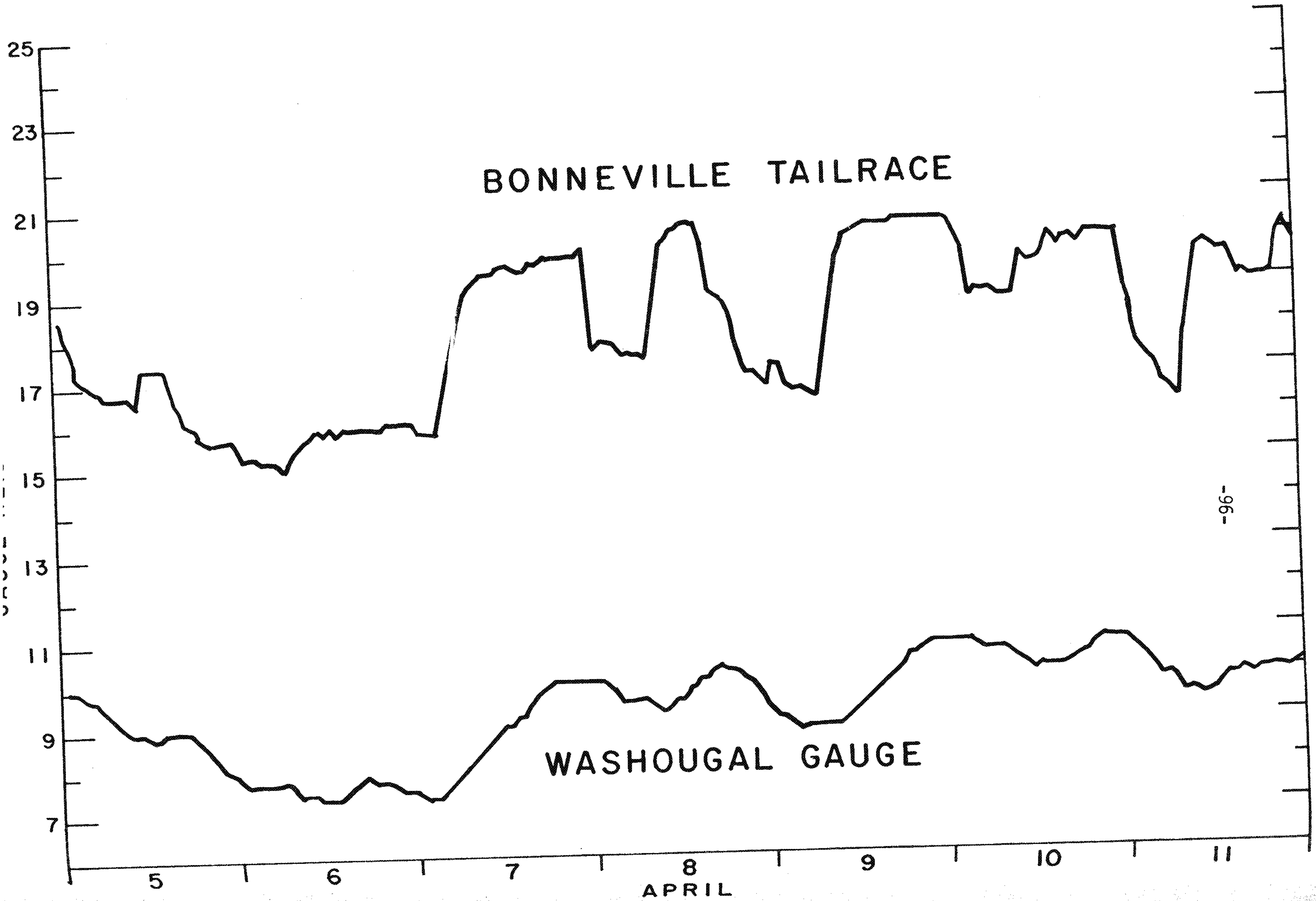

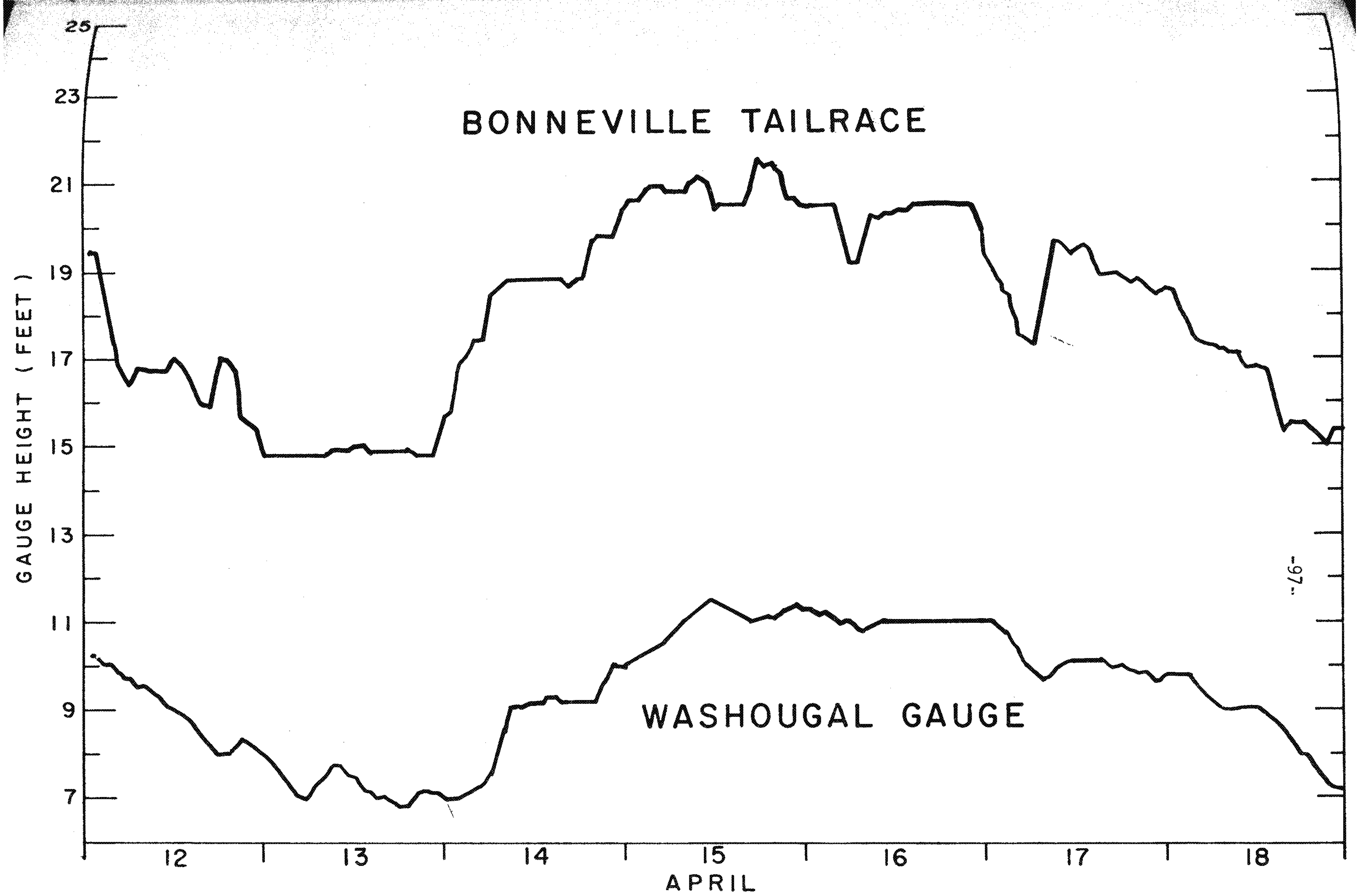

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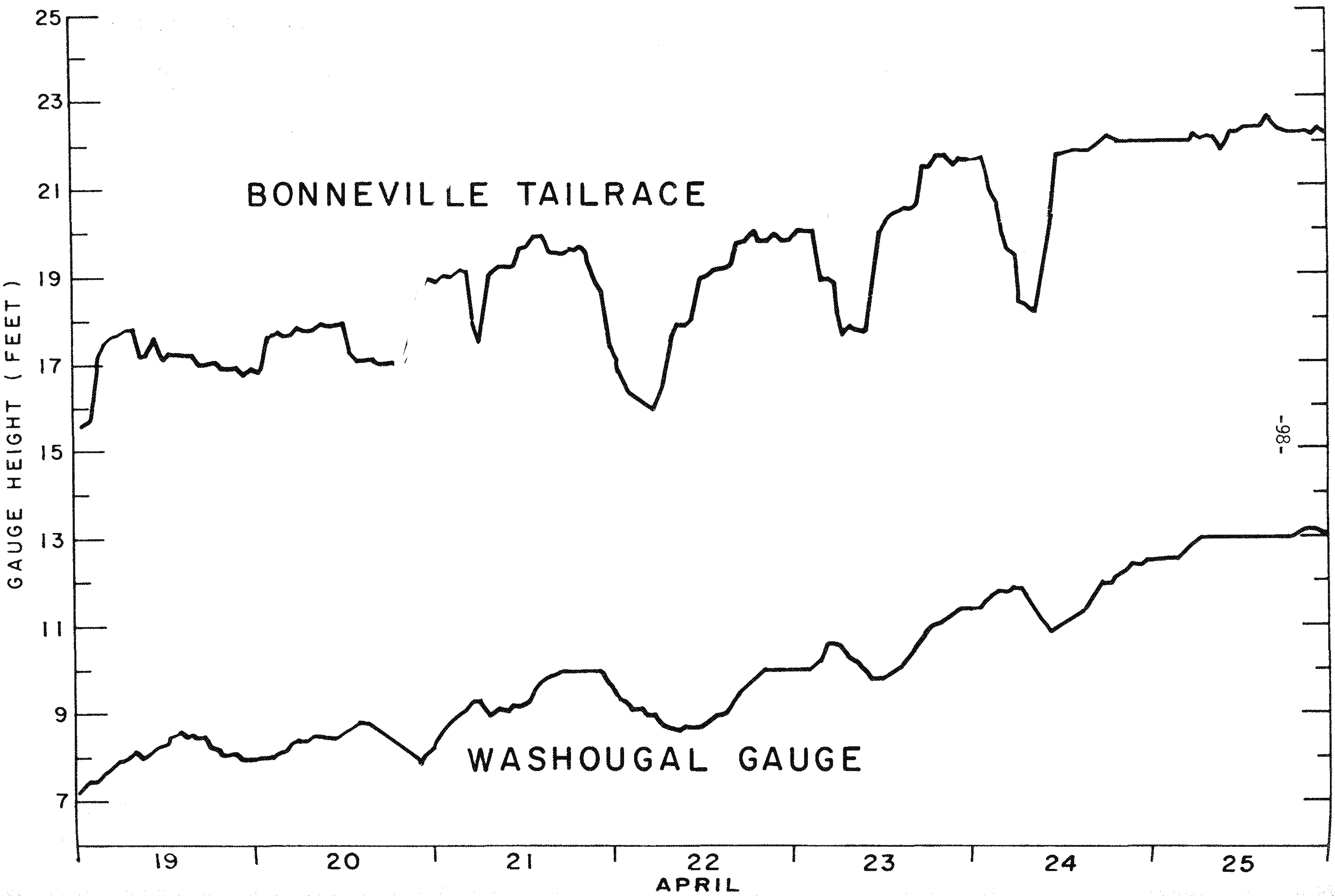
EX-0230-000066-TSS



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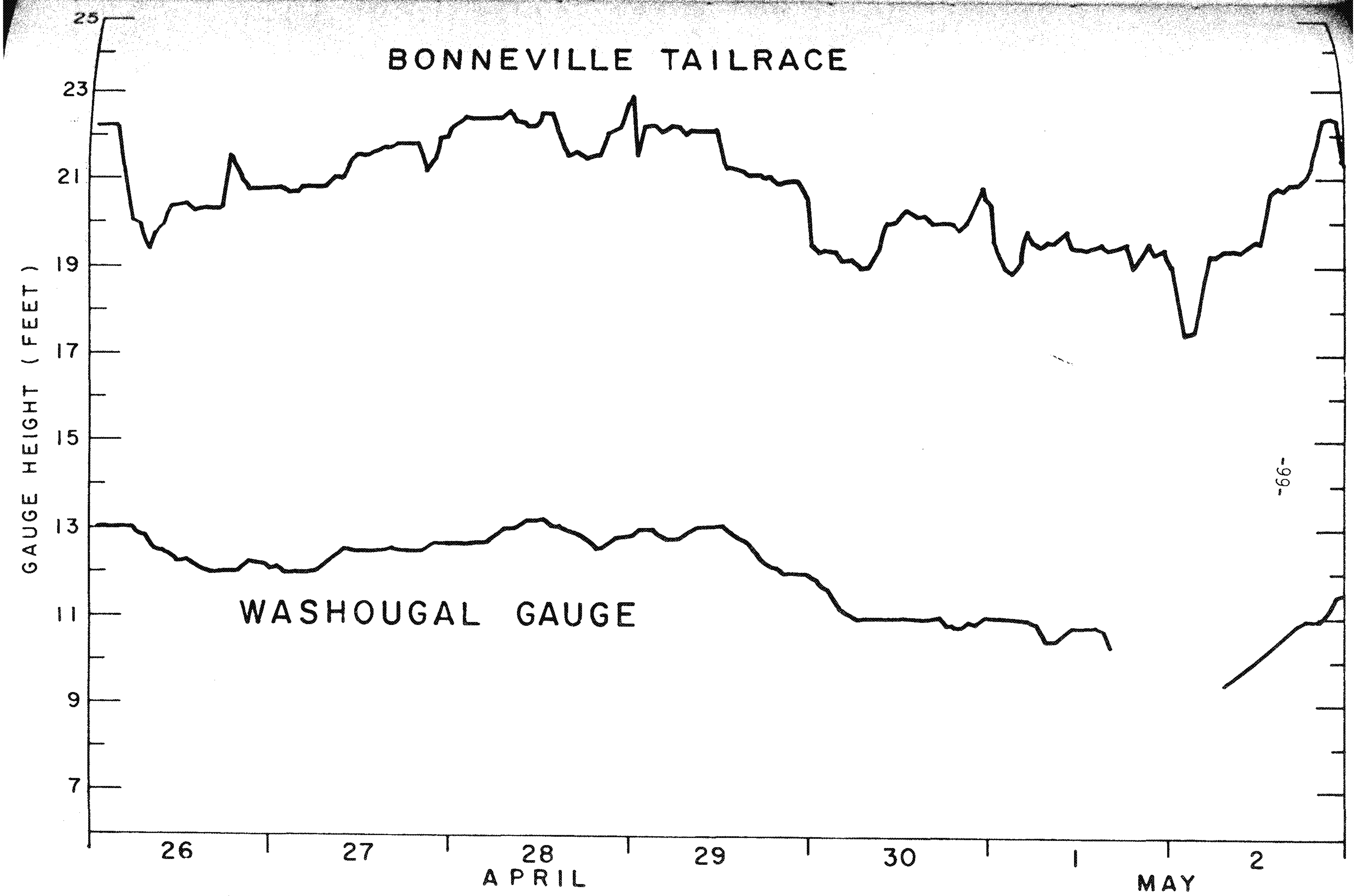

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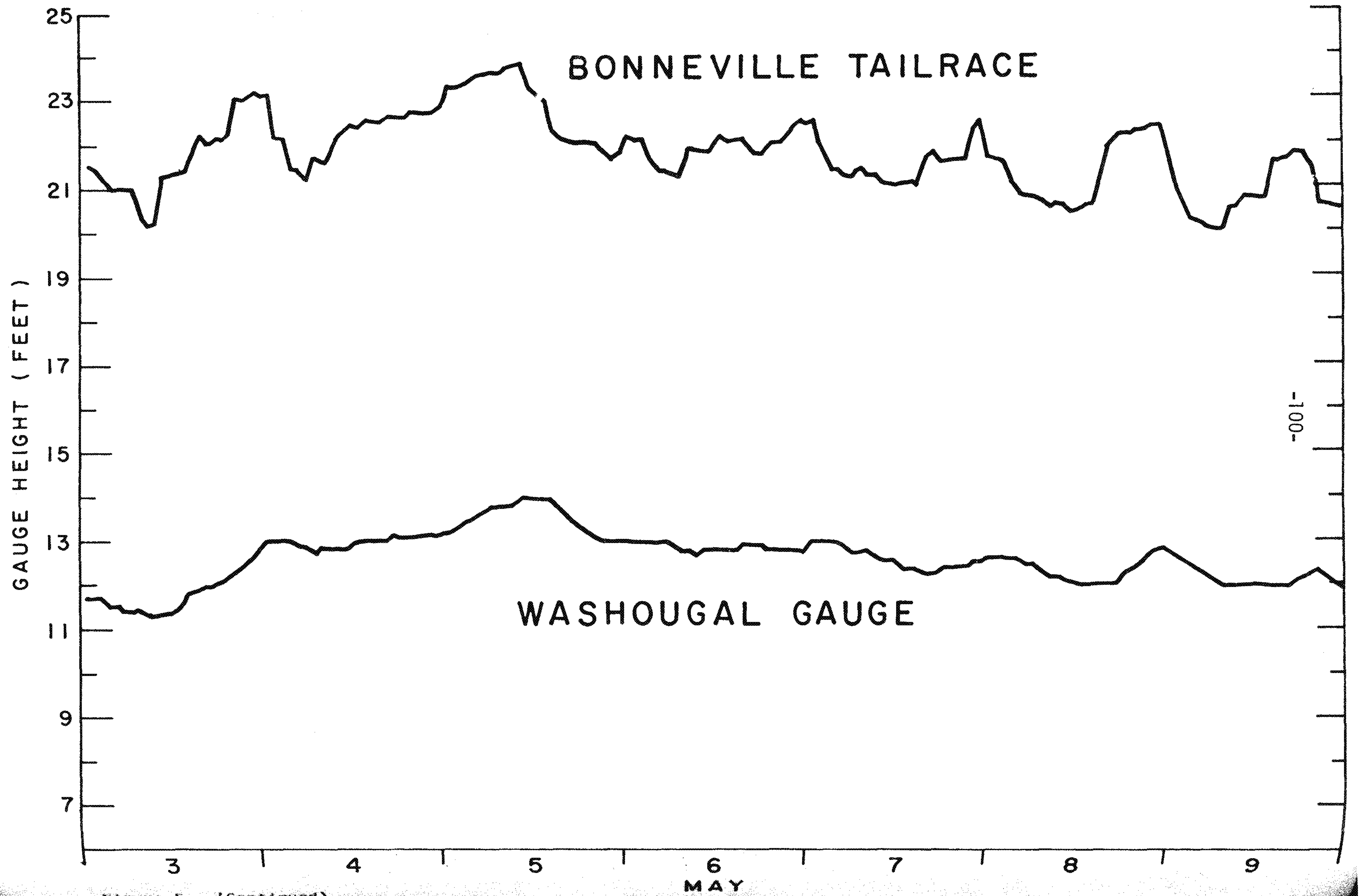

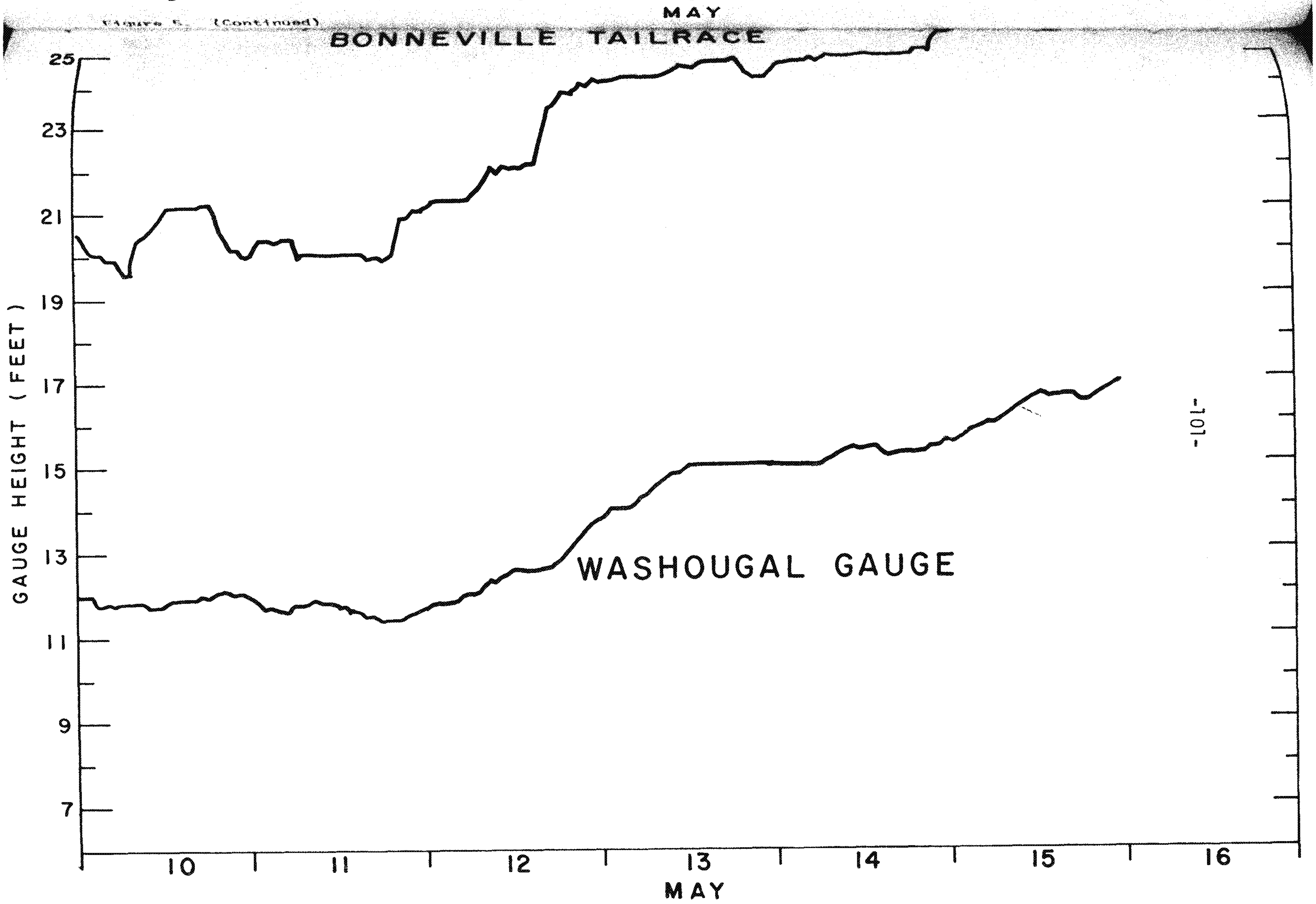

Figure 5. (Continued)

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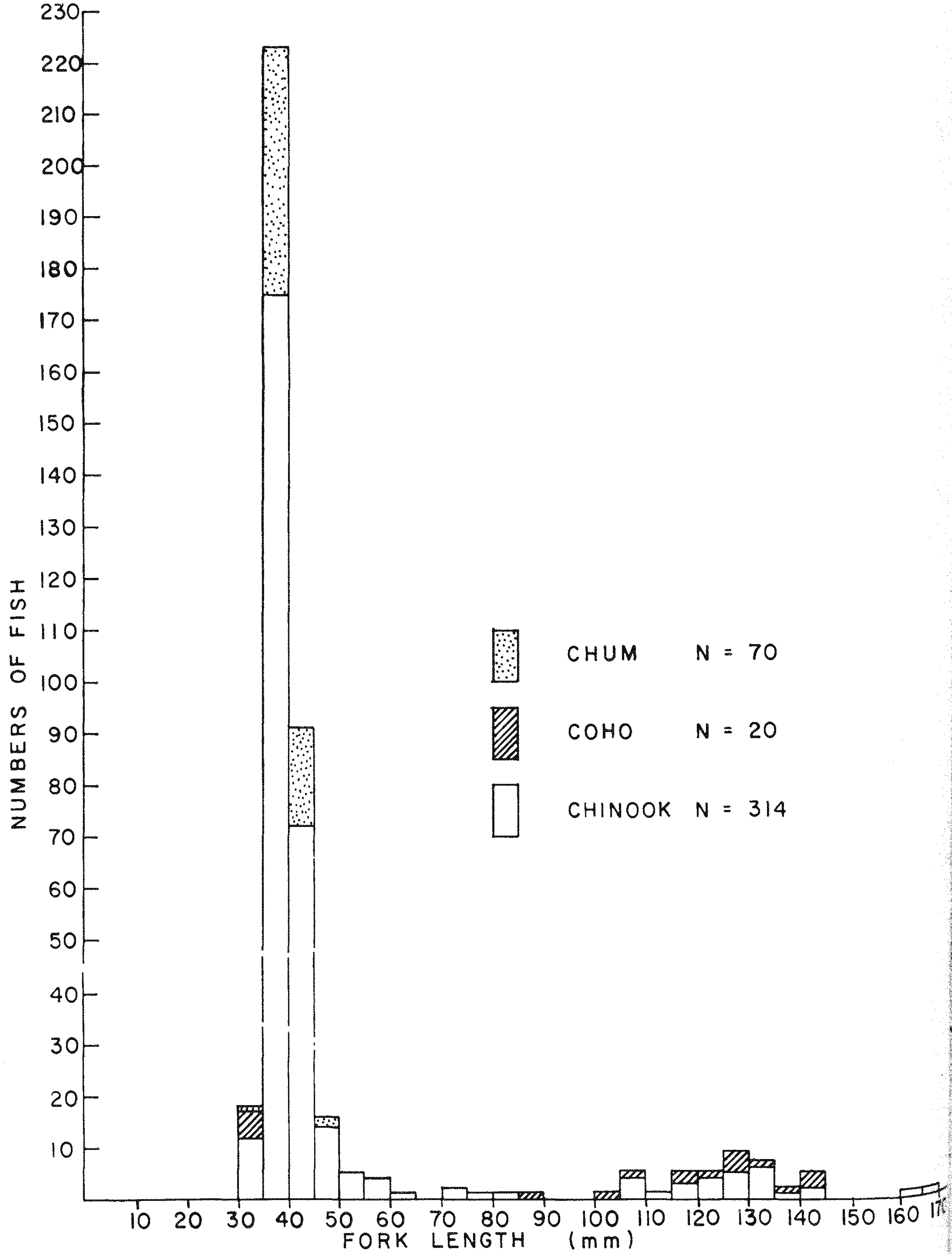


Figure 6. Size distribution of chinook, coho, and chum juveniles stranded by flow fluctuations, March through May, 1975.

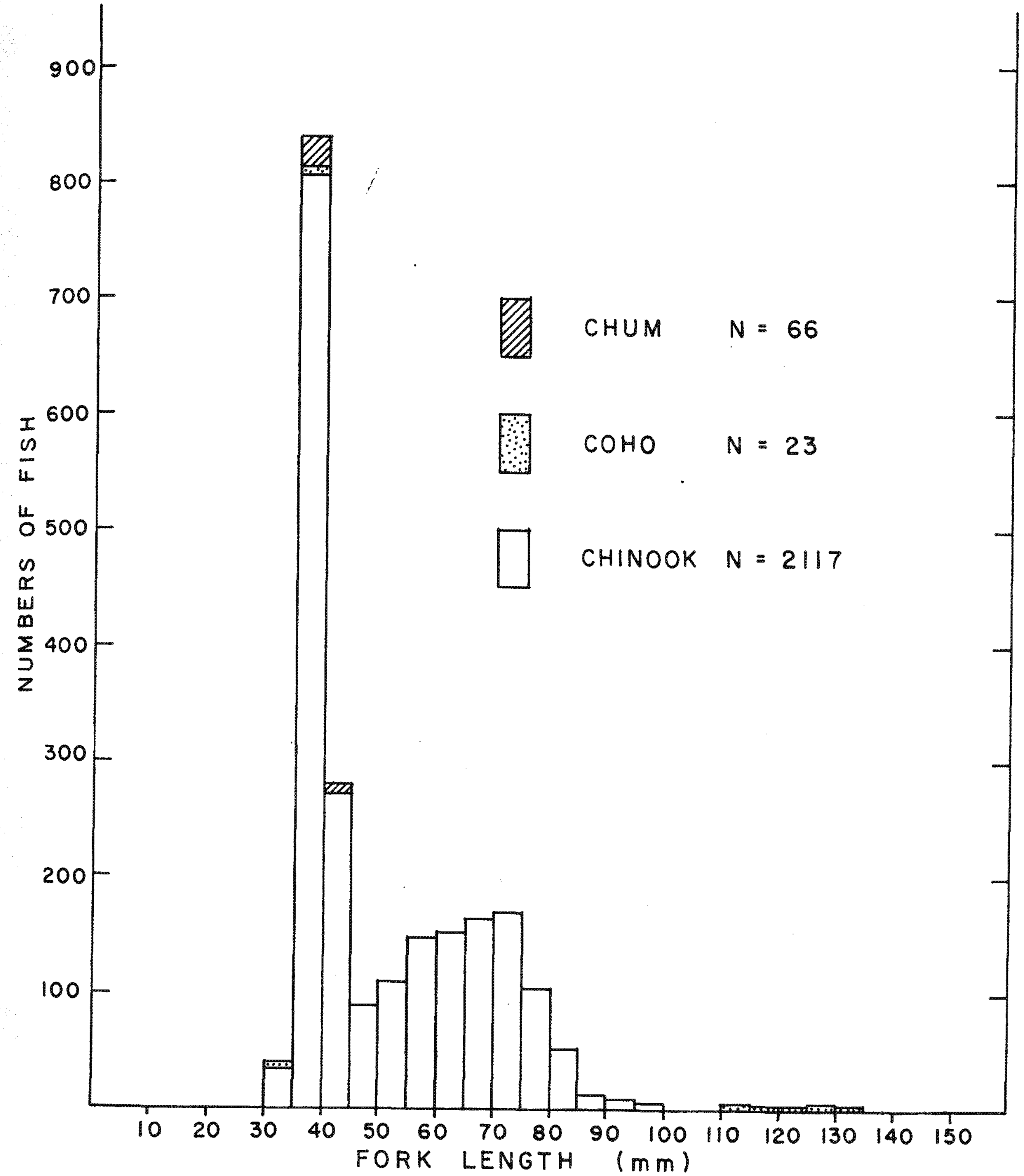


Figure 7. Size distribution of chinook, coho, and chum juveniles stranded by ship - wash in the lower Columbia River from February through July, 1975.

EX-0230-000069-TSS

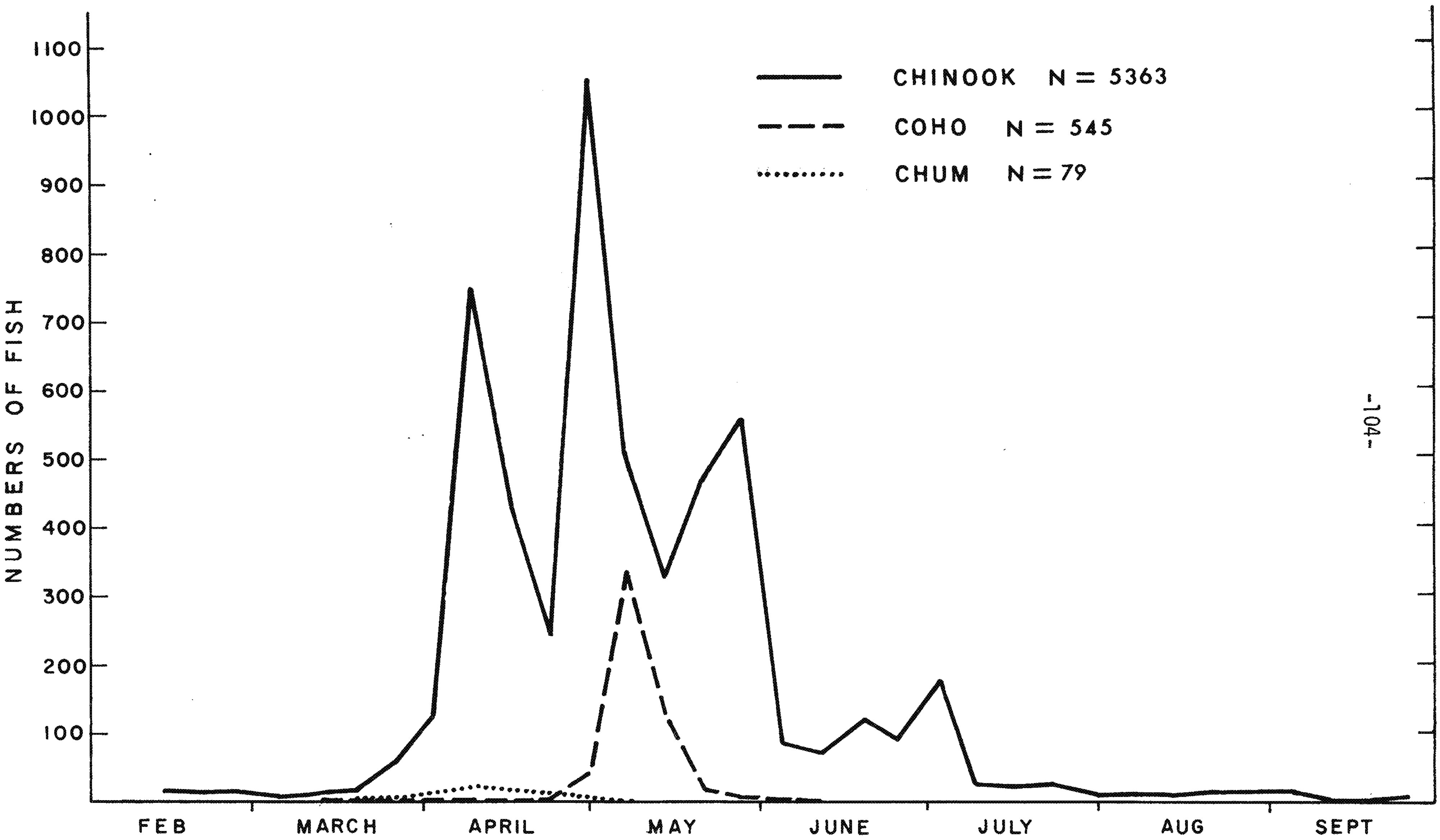


Figure 8. Combined weekly beach seine catch of juvenile chinook, coho, and chum at five sites on the Columbia River, February through September, 1975.

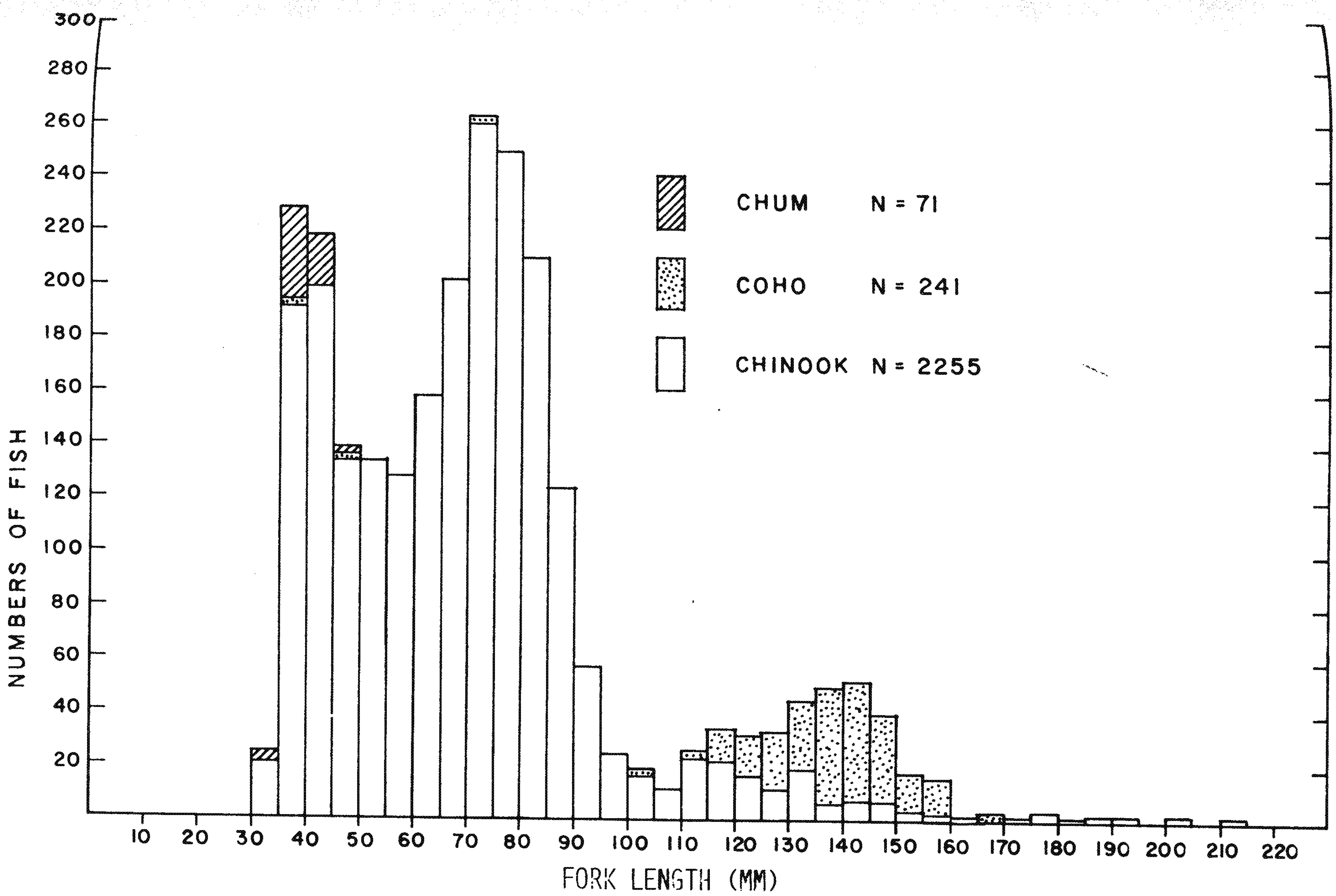


Figure 9. Size distribution of a random sample of chinook, coho, and chum juveniles captured by beach seine in the Columbia River, March through September, 1975.

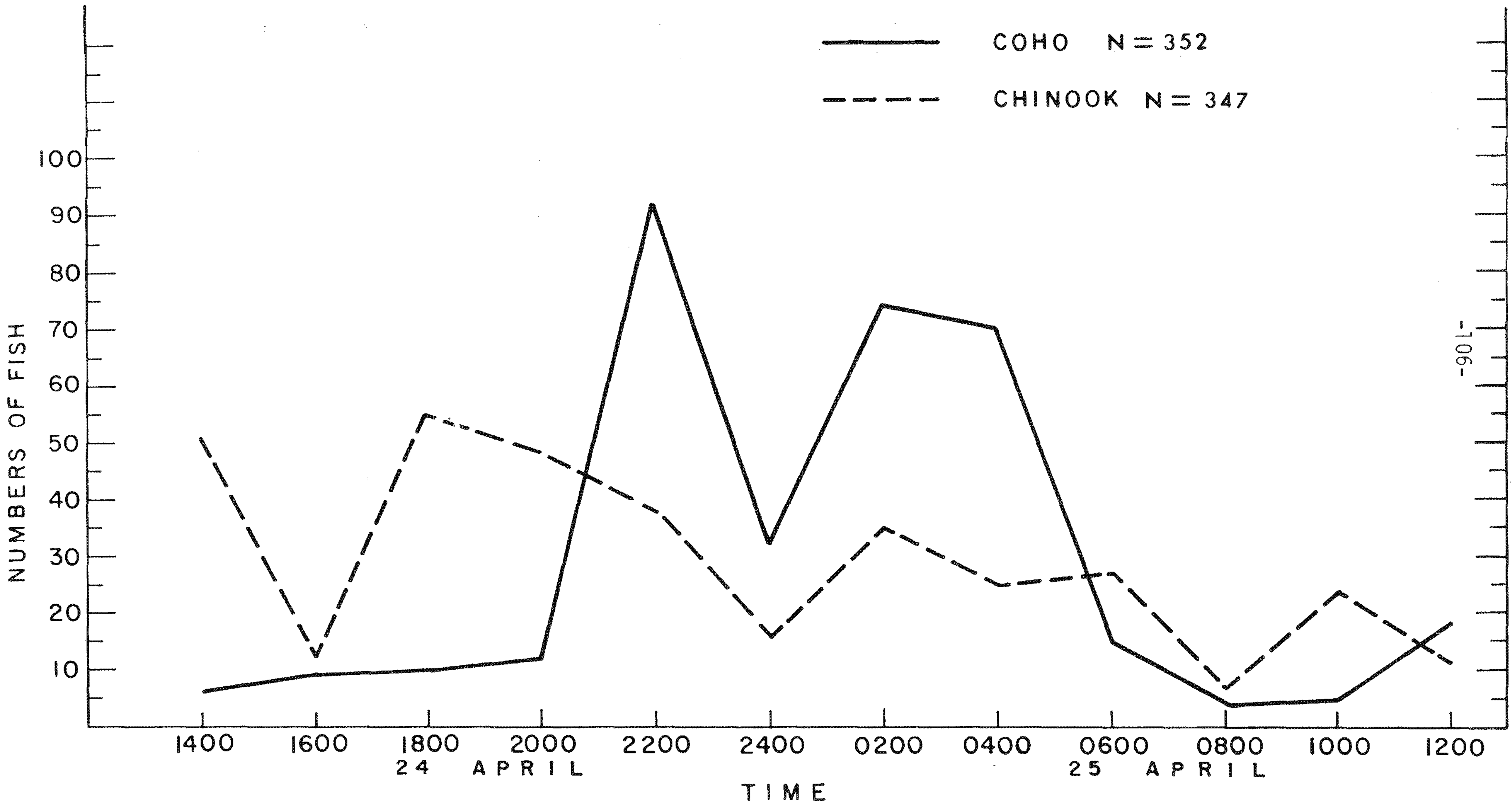


Figure 10. Numbers of chinook and coho captured by seining at two hour intervals at Government Island, April 24 and 25, 1975.

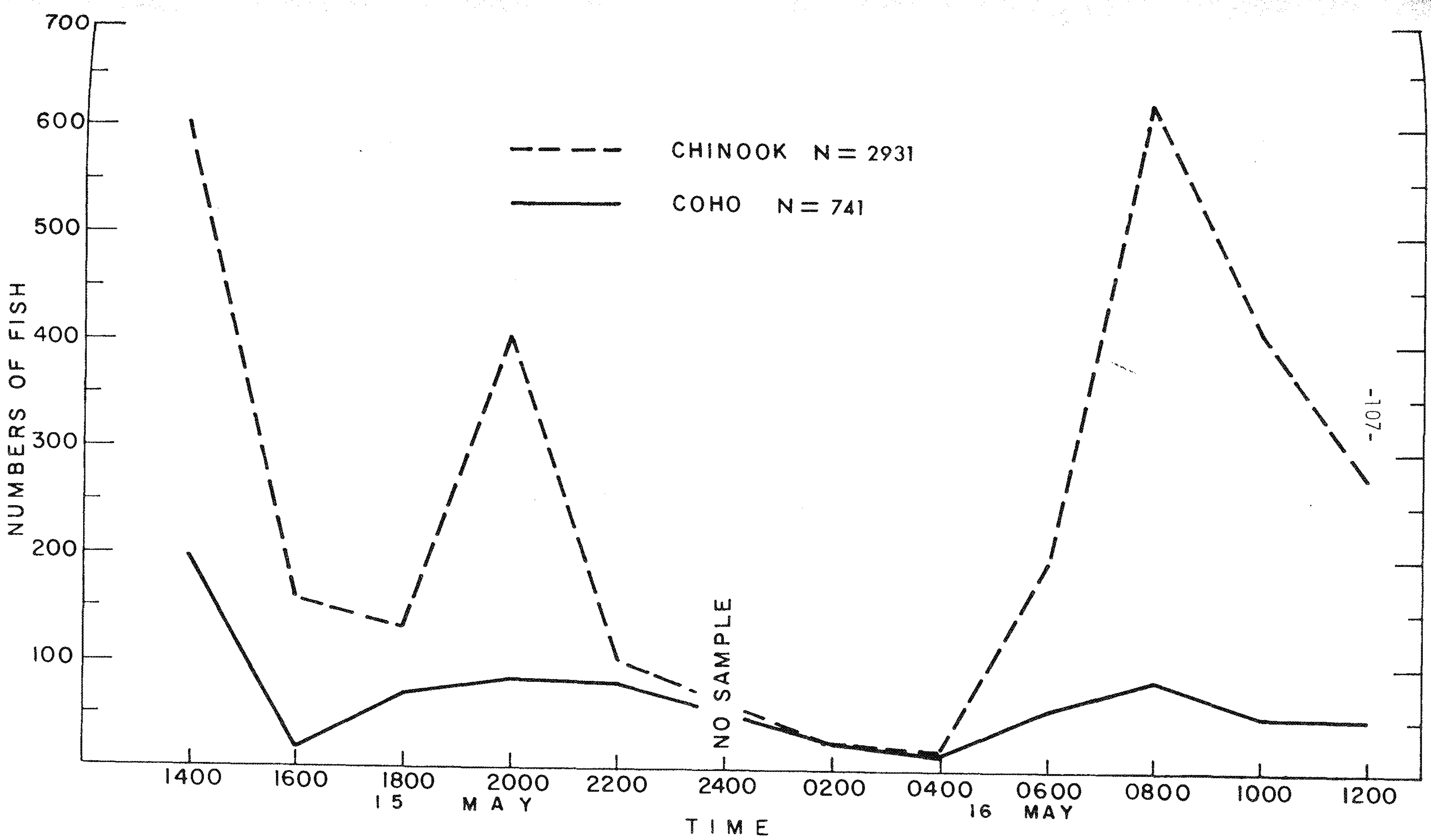


Figure 11. Numbers of chinook and coho captured by seining at two hour intervals at Government Island, May 15 and 16, 1975.

EX-0230-000071-TSS

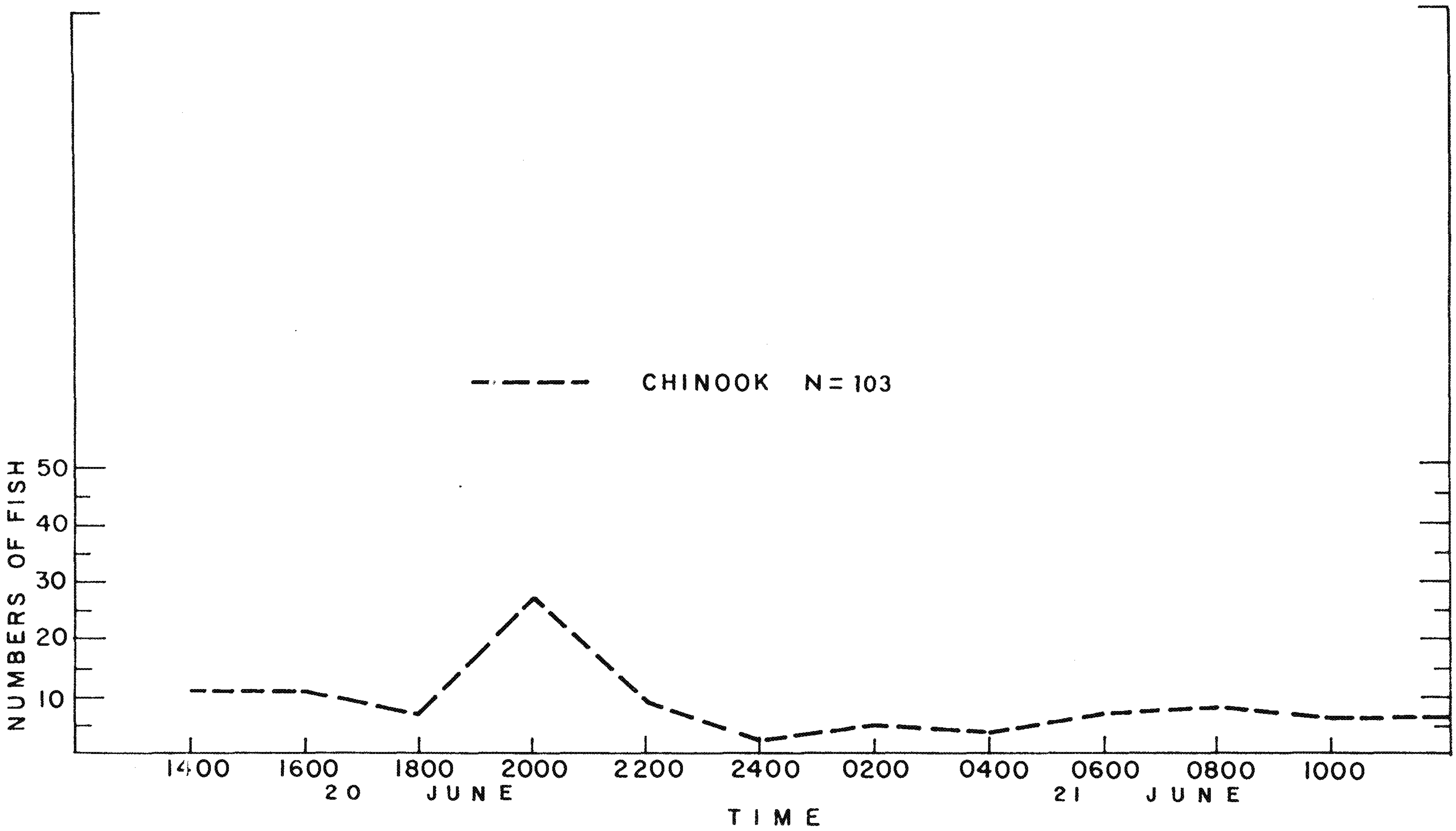


Figure 12. Numbers of chinook and coho captured by seining at two hour intervals at Government Island, June 20 and 21, 1975.

APPENDIX IV.

(Plates 1 through 6)
(Pages 110 through 117)

EX-0230-000072-TSS

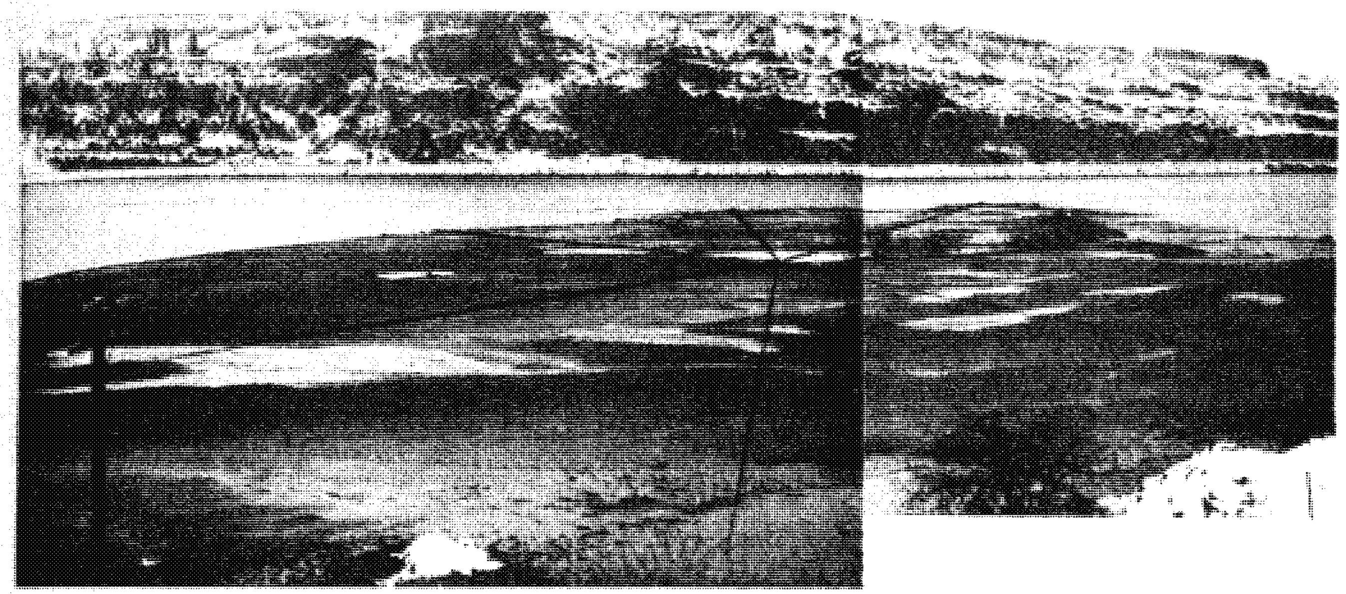


Plate 1. Sample site at the mouth of the Klickitat River, Bonneville Pool; lines showing approximate location fo sampling transects. The Dalles Dam discharge is approximately 100,000 cfs.

EX-0230-000073-TSS

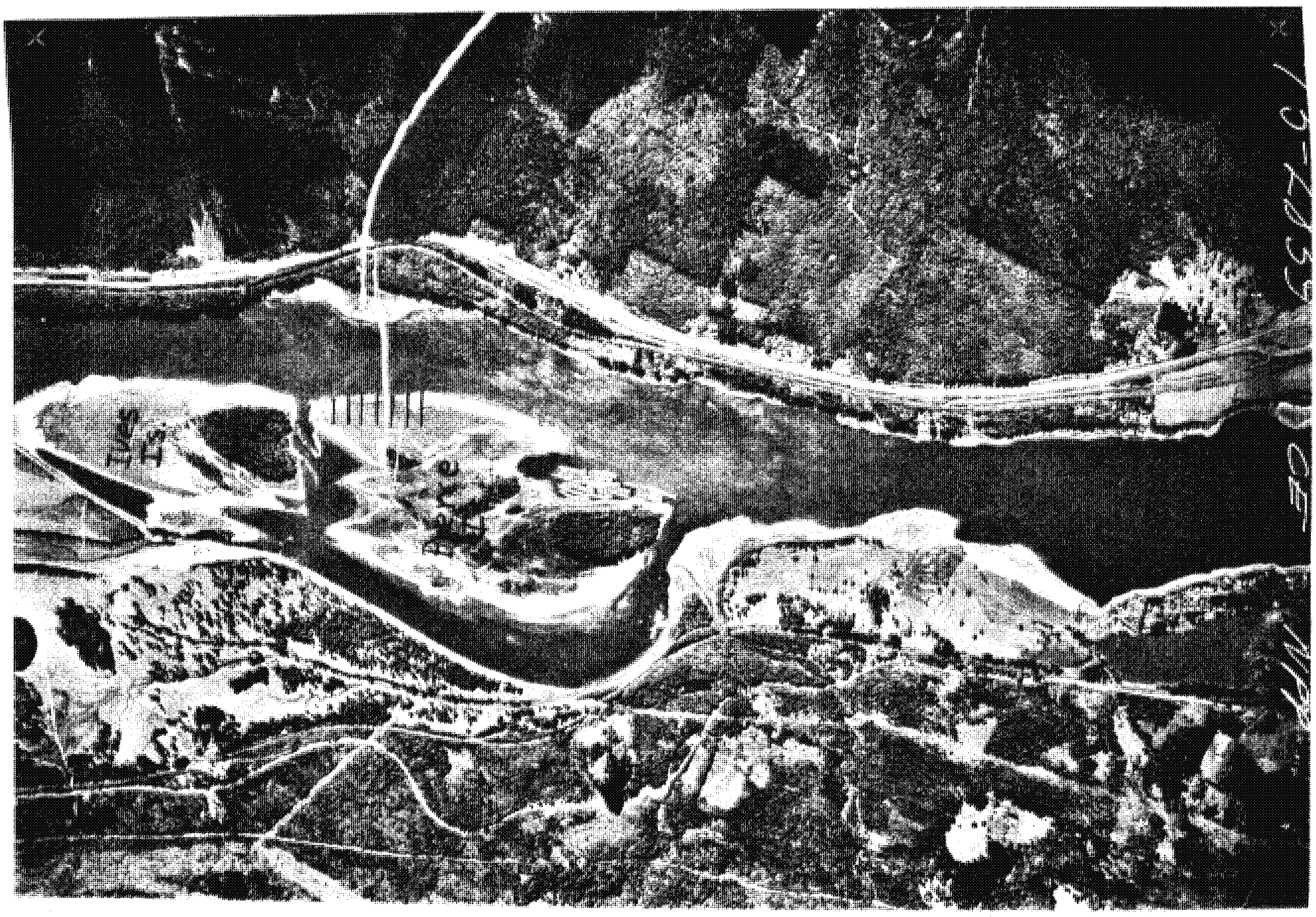


Plate 2. Stranding area at Pierce Island, lines showing approximate location of sampling transects. Columbia River flow is approximately 80,000 cfs.

Plate 3. Stranding area at Sandy River bar, lines showing approximate location of sampling transects. Columbia River is approximately 80,000 cfs.

EX-0230-000074-TSS

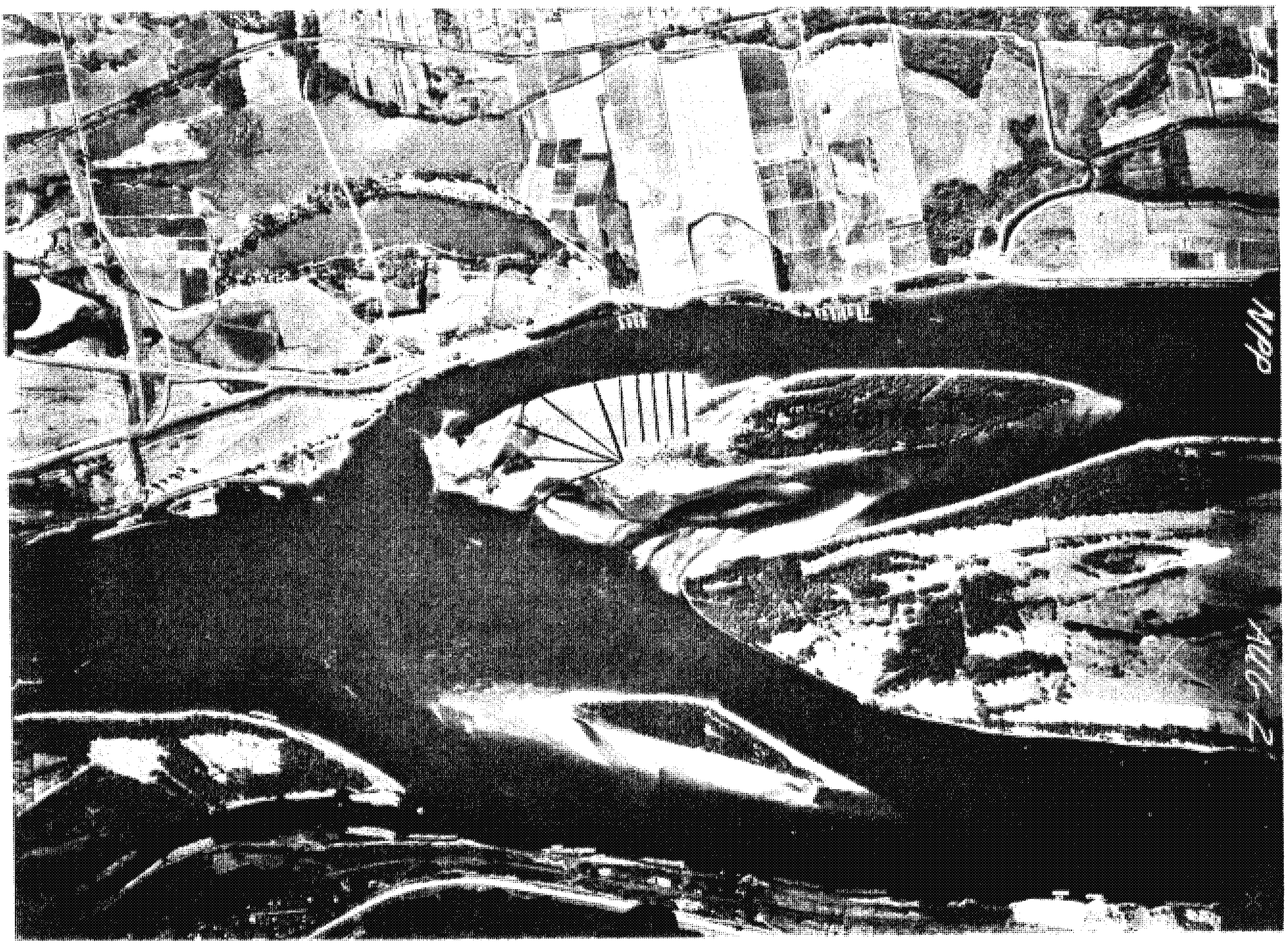


Plate 4. Stranding area at McGuire Island, lines showing approximate location of sampling transects. Columbia River flow is approximately 80,000 cfs.

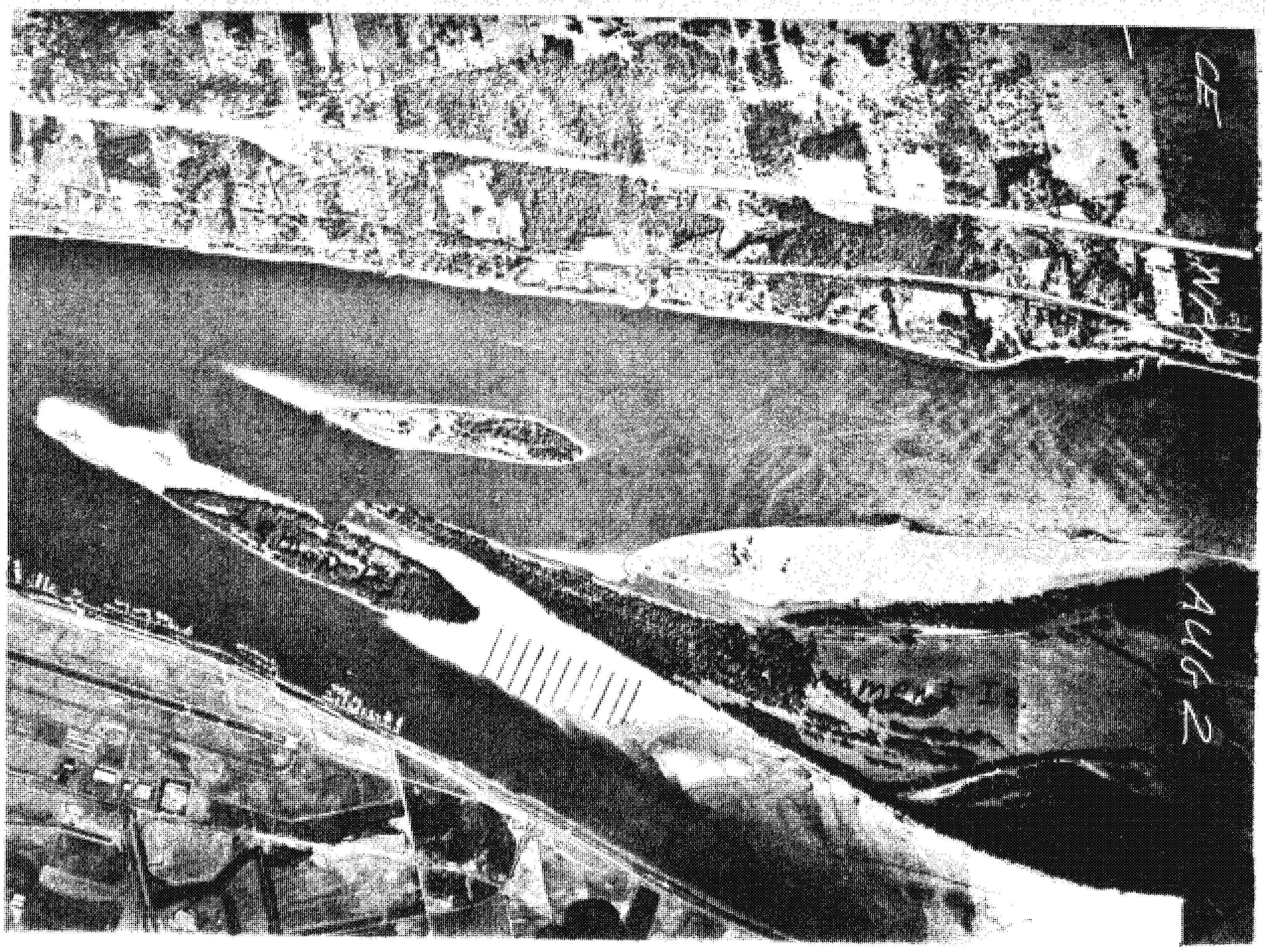
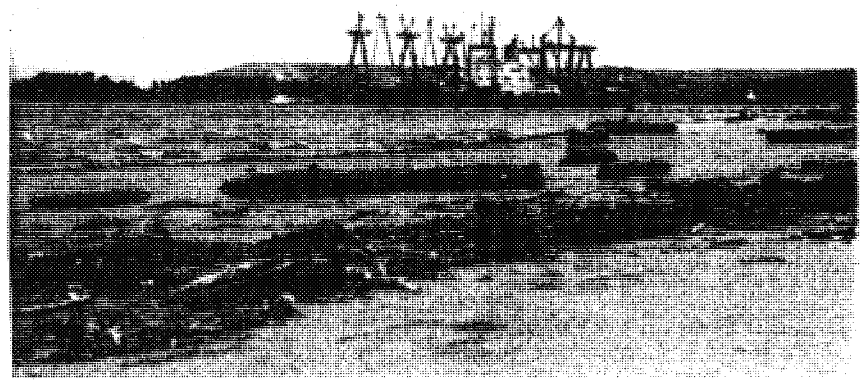
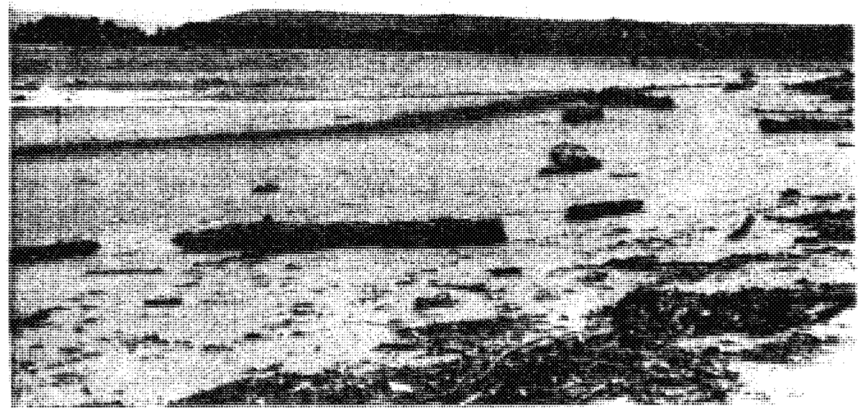


Plate 5. Stranding area at Government Island, lines showing approximate location of sampling transects. Columbia River flow is approximately 80,000 cfs.

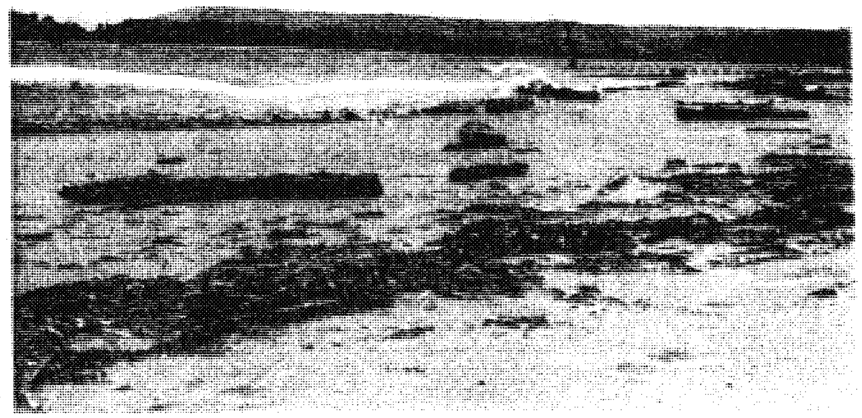
EX-0230-000075-TSS



No. 1 - Ship approaching site traveling upstream.



No. 2 - After ship passes, initial water reaction is to be drawn away from shore. Fish are often momentarily stranded on exposed beach during this phase.



No. 3 - Initial surge of water after being drawn out. The uprush from this wave usually produces maximum onshore extension.

Plate 6. Pictorial sequence of a ship passing Hoagy's bar showing resulting wave action and stranding on June 5, 1975.

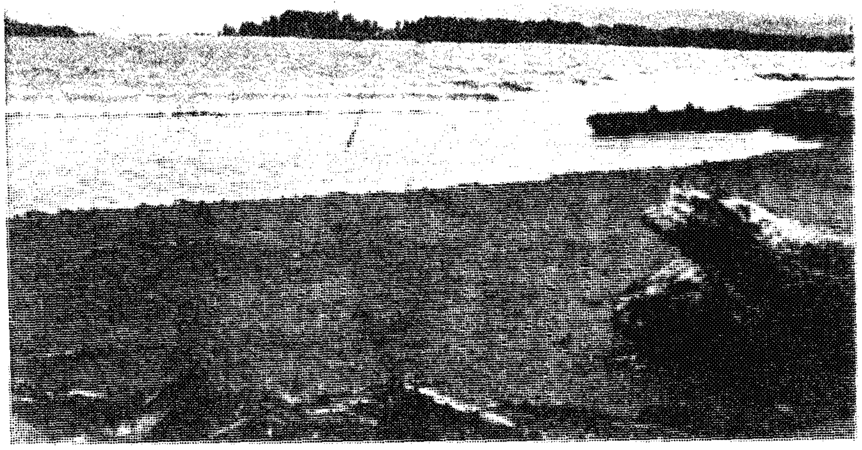
No. 4 - Maximum onshore extension of initial wave.

No. 5 - Initial wave receding. Much of the stranding will occur in the drift line at the wet-dry sand interface and behind logs, etc.

No. 6 - Initial wave fully receded. Second series of waves cresting on shore.

Plate 6. (Continued)

EX-0230-000076-TSS



No. 7 - Maximum uprush of second wave series. Genera fewer fish are stranded by the second wave series, and the maximum wave uprush is less.

No. 8 - Stranding which resulted from ship passing site. A total of 51 fish was collected at the site after the waves subsided.

EX-0230-000077-TSS