FALLBACK OF ADULT CHINOOK SALMON (*Oncorhynchus tshawytscha*) AT ICE HARBOR DAM SPILLWAY--1964

by

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INTRODUCTION

The occurrence of fallback, or upstream migrant fish swept downstream through a spillway dam, has been frequently noted when tagged salmon released above a dam were recovered below it, or were observed reascending its fishways. It is generally assumed that fallback is most likely to occur when adults are passing a dam at which heavy spilling is in progress. When there is a coincidence of large numbers of fish and heavy spilling, the resulting fallback may become a serious problem. How serious has largely been a point of conjecture because there was, until recently, no effective tool for measuring fallback frequency. Development of the sonic fish tag provided such a tool.

An exploratory study of the problem was made in the spring of 1962. At Ice Harbor Dam, 3 out of 30 sonic-tagged salmon tracked individually in the forebay were observed being swept through open spillgates (fig. 1). Although this work was inconclusive because of the small sample size, the frequency of 10 percent fallback still warranted further investigation.

An approach to the problem was conceived by which an adequate number of observations could be made using fixed monitoring equipment in a spillway area. With the cooperation of the U.S. Army Corps of Engineers, a field study was conducted in the spring of 1964.

Objectives

Principal objectives of the study were:

1. To determine whether or not one of the Ice Harbor Dam fishway exit locations contributes to a higher fallback frequency than the other.

South ladder fish enter the Ice Harbor forebay from an exit over 1,100 feet from the nearest spillgate and close to the shoreline (fig. 2), a location which would appear to offer exiting fish ample opportunity to proceed safely upstream. North ladder fish enter the forebay from an exit only 150 feet from the nearest spillgate and several hundred feet from the nearest shoreline (fig. 2). Considering the relative proximities of the two exits to the spillway and to shorelines, it would seem reasonable to assume that a larger proportion of north ladder fish are being exposed to the spillway and that this difference is reflected in the respective fallback frequencies.

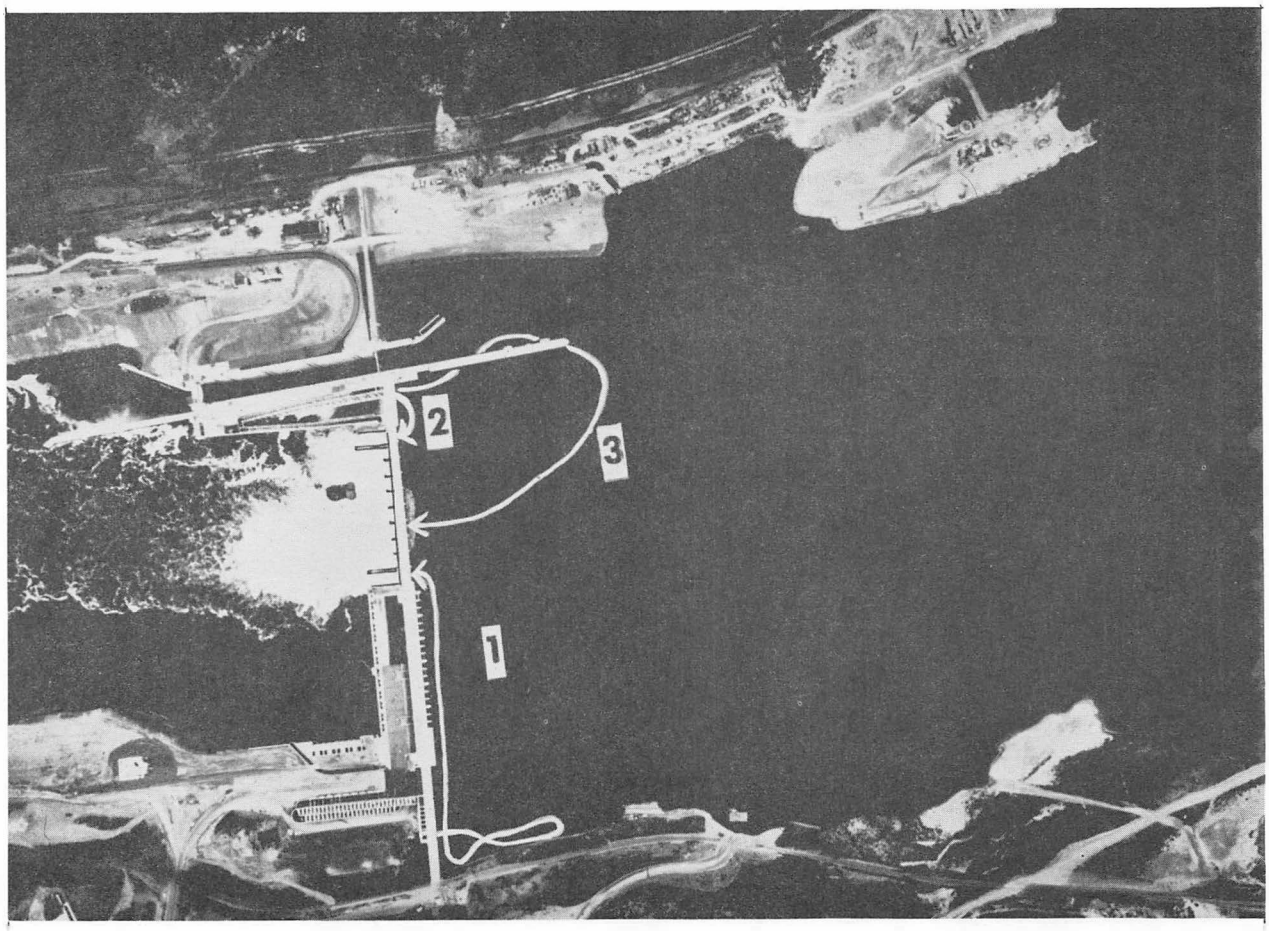

Figure 1.--Aerial view of Ice Harbor Dam. Arrows indicate courses followed by three sonic-tagged salmon swept through spillway. Each fish was tracked individually from fish ladder exit to the point where tag signal disappeared in front of spillway gate. These observations were made during a period of low spilling, May and June 1962.

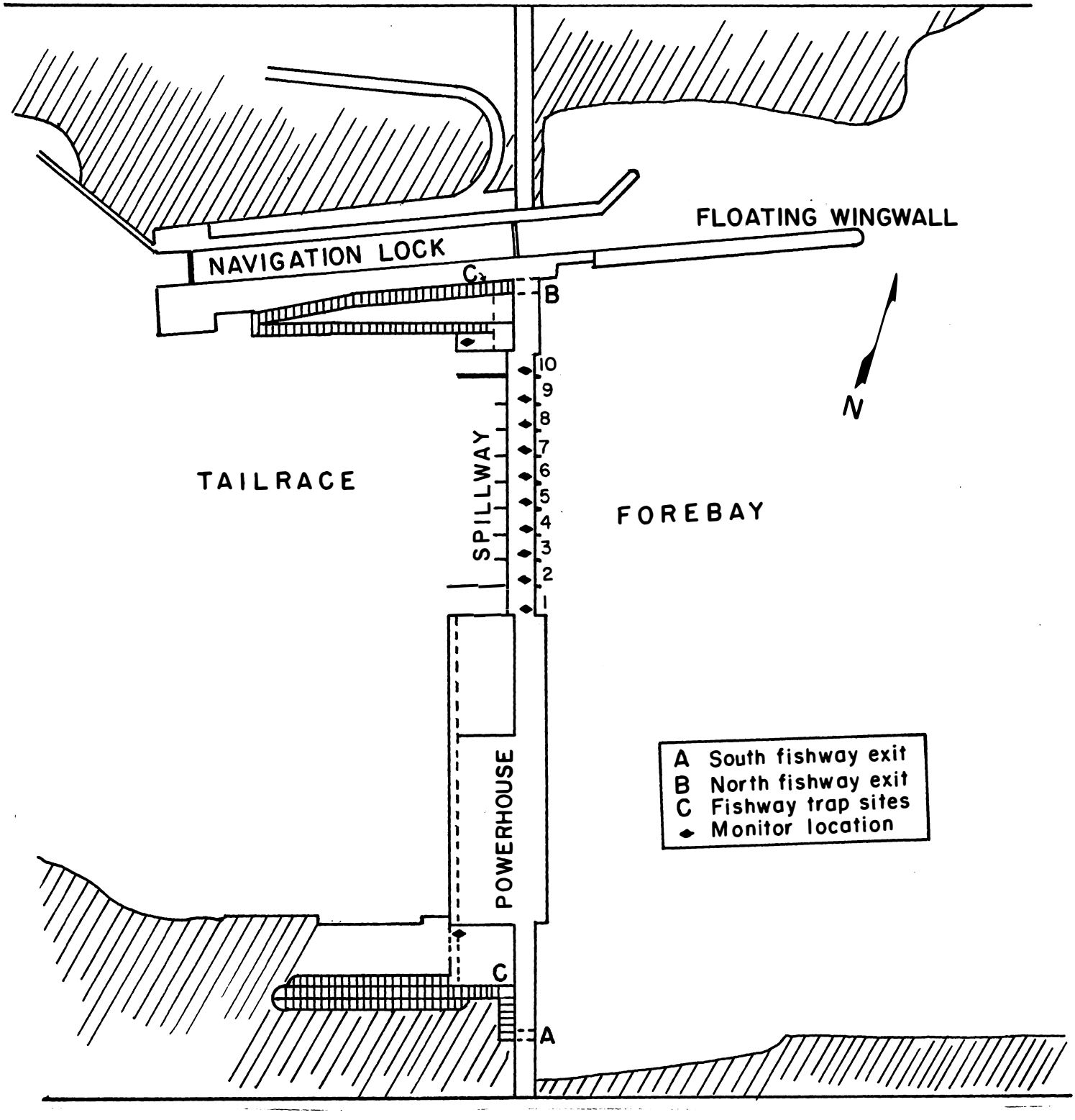

Figure 2.--Ice Harbor Dam fallback research site (plan view).

2. To determine the total frequency of adult chinook fallback through the spillway of Ice Harbor Dam during the spring chinook run.

3. To determine the percentage of survival of fallback fish.

Research Site

Ice Harbor Dam, near the mouth of the Snake River at Pasco, Washington, was selected as the research site for the following reasons: First, it affords the opportunity to compare two fishway exit locations which vary widely in their relation to the same spillway; second, information obtained here is particularly applicable to fishway design for future lower and middle Snake River dams; and third, some knowledge of the behavior patterns of fish entering the Ice Harbor forebay had already been obtained from the sonic tracking work performed there in 1962.

METHODS AND MATERIALS

Spring-run chinook salmon arriving at the upper end of each of the Ice Harbor fish ladders were trapped, tagged with sonic fish tags, and released back in the fishway. On emerging from a ladder exit, each fish either made its way upstream without incident or passed back downstream through the dam. Sonic-tagged fish swept through the spillway were detected by acoustic monitors which identified each fish according to release point and recorded the time of each event and the spillway gate at which it occurred.

Thus, for comparison, fallback frequency was obtained for fish issuing from each fish ladder. The two frequencies combined provided a total percentage of fallback during the period of study. Sonic-tagged fish which survived fallback to make a second fish ladder ascent were noted as they passed through counting stations near the upper end of each ladder.

Trapping

A brail trap built of wood pickets in a steel frame was located in a pool near the upper end of each ladder. Fish passing over the weir section, against which the trap abutted, entered an enclosure 5 feet square by 4½ feet deep (fig. 3). The brail, which formed the bottom of the enclosure, was raised by an electric hoist to position the fish at a depth convenient for

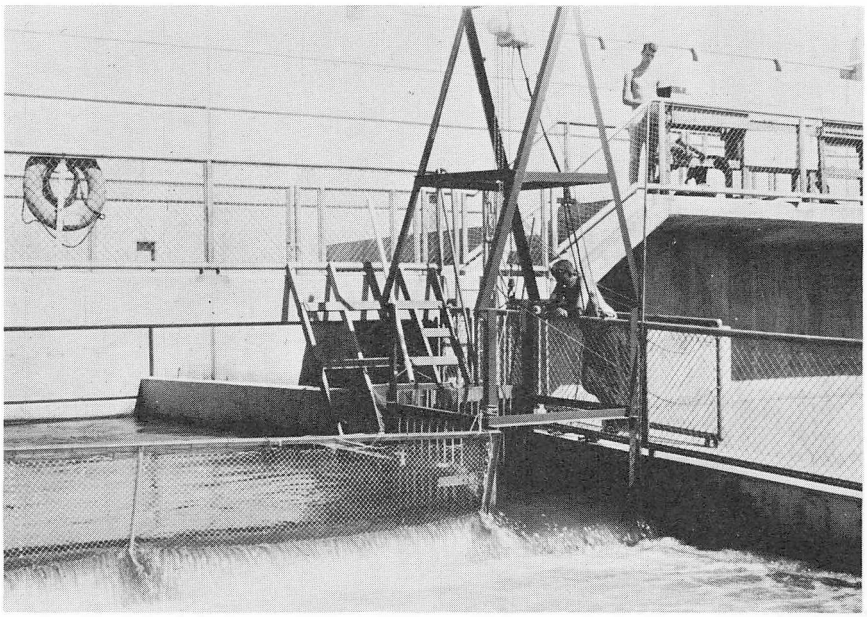

Figure 3.--Fish trap used in south fishway. Fish entered trap by passing over weir crest. Removable barrier net (left foreground) was used to divert fish into trap when small numbers were present in fishway.

dipnetting. Fish were then removed from the trap, one or two at a time, and placed in tagging tanks on the walkway alongside the ladder.

Tagging

The tagging tanks contained anesthetic tricaine methanesulfonate (M.S. 222) in a solution sufficient to produce quiescence in the fish in approximately 2 minutes. Fish were first measured and a scale sample was taken. Fish less than 24 inches fork length were returned to the ladder untagged.

A sonic tag with a double strap fastener was attached to each fish immediately in front of its dorsal fin (fig. 4). Plastic pins, one-eighth inch in diameter, passed with a needle through the skin and muscle tissue of the back, secured the tag to the fish. A supplemental plastic dart tag was also attached to identify fish in the event of loss of the sonic tag. The time taken to apply both tags averaged 90 seconds.

The tagged fish were then carried rapidly in a shallow net bag to an open-ended pen located near the exit of the fishway. The fish required from 1 to 3 minutes to revive from the anesthetic. The time of exit from the pen for each fish was voluntary. Some swam out within a few minutes after reviving, whereas others remained inside over an hour. Distance from release pens to fishway exits leading into the forebay was approximately 40 feet. A fishway counting station was located several yards downstream from the release pen in each ladder. The stations were manned daily from 4 a.m. until 8 p.m. by Corps of Engineers employees. During the intervening 8 hours (8 p.m. to 4 a.m.) and also during 10-minute hourly rest periods taken by the counters, a raised grating prevented movement of salmon past the station in either direction.

Tagged fish that dropped back over the counting board were logged by the Corps counters, as were all tagged fish which swam upstream past the stations. In each case, color combinations on the tags were noted.

Sonic Fish Tag

The sonic tag is a miniature high frequency sound transmitter sealed inside a streamlined plastic capsule 3.5 inches in length and 0.75 inches in diameter. A 5.6 volt mercury cell battery supplies power to the transistorized oscillator circuit, driving a resonating crystal cemented in one end of the

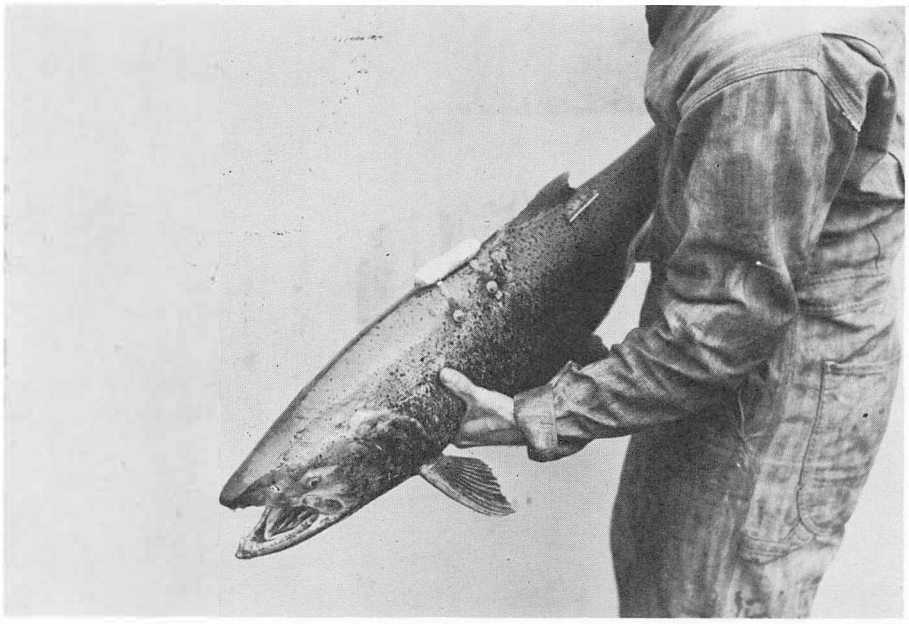

Figure 4.--Sonic-tagged salmon prior to release. Supplemental plastic dart tag is seen near base of dorsal fin.

capsule. A small hand magnet was placed on the capsule's outer wall opposite a magnetic switch to close the oscillator circuit and activate the tag immediately prior to attachment.

The tag used in this study transmitted,omnidirectionally, a continuous wave signal of one of two carrier frequencies: 159 kilocycles for tags placed on north ladder fish and 127 kilocycles for tags placed on south ladder fish. The difference in tag carrier frequency served to identify recorded fallback fish according to the ladder in which they were released. In addition, the tags were color-coded so that in the event of subsequent observation or recovery they could be identified as to ladder origin and the approximate date of their release.

Monitoring Equipment: Location and Description

The Ice Harbor spillway is made up of ten 50-foot-wide spillgates, separated by concrete piers 10 feet thick. The area between two opposing piers is conventionally referred to as a bay. Bays and their corresponding spillgates are numbered, beginning with Number 1 on the south end (left bank side) of the spillway and ending with Number 10 at the north end (right bank side) (fig. 2). Spilling is from underneath the radial-type gates, 40 to 50 feet beneath the surface of the forebay (fig. 5). During this study the spillway was operated normally. Spillway gates 1 and 10 were, with few exceptions, kept at either a 2.0- or 1.4-foot opening, independent of the amount of river flow. To maintain uniform flow conditions across the spillway, gates 2 to 9 were operated as a block, with openings of the eight gates never varying more than 1 foot at any given time. The opening beneath those gates ranged from 1.4 to 12.0 feet, depending on the amount of river flow.

A transducer was mounted in a vertical stoplog slot in the concrete pier wall twelve feet upstream from each spillway gate and 8 to 10 feet beneath the forebay surface. The transducer pattern of sonic tag signal reception is shown in figure 6.

Transducers (fig. 7) were connected by electrical cable to receiver-amplifiers located overhead in the spillway service gallery. Amplified tag signals were automatically recorded on chart paper in two multichannel recorders (fig. 8). This monitoring system provided a record not only of fallback but also of nonfallback sonic-tagged fish which passed within receiving range of the transducers.

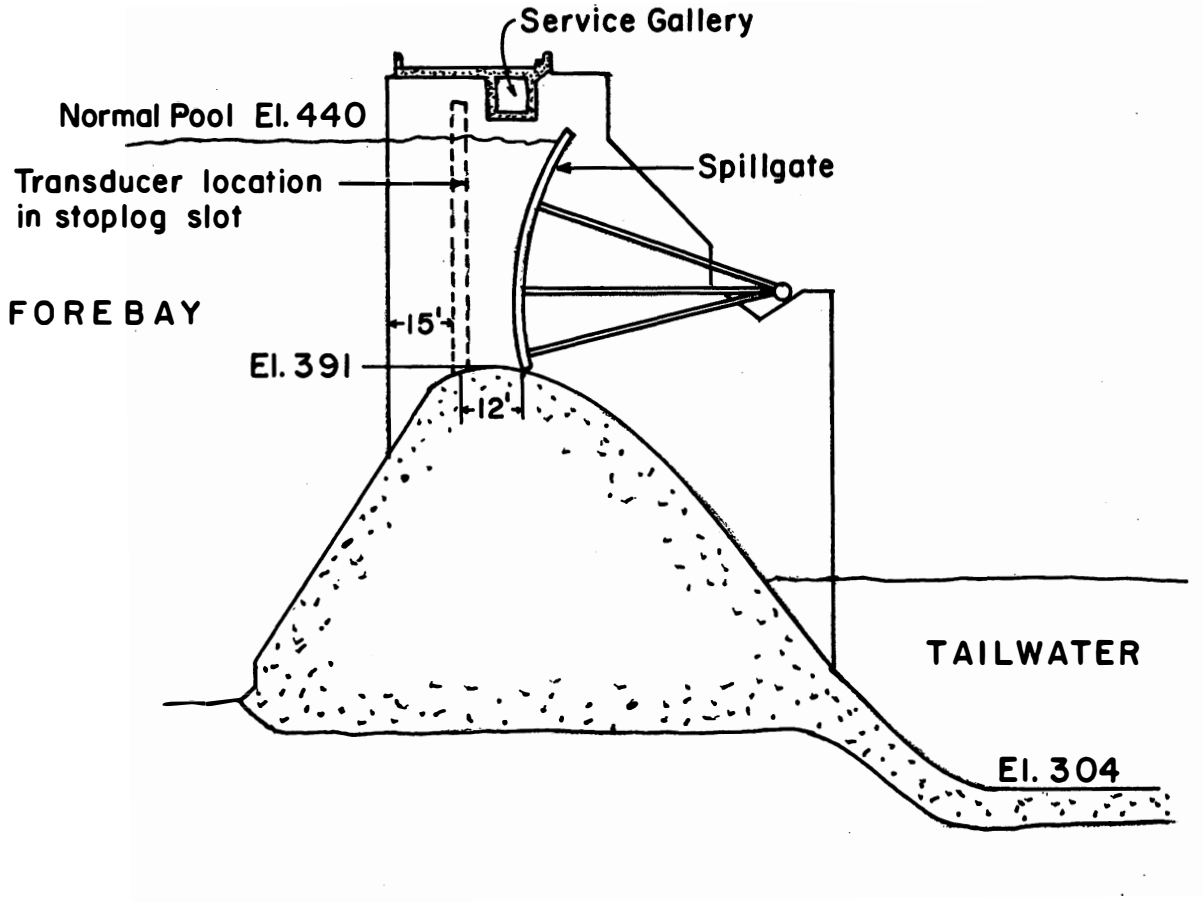

Figure 5.--Ice Harbor Dam spillway (cross section).

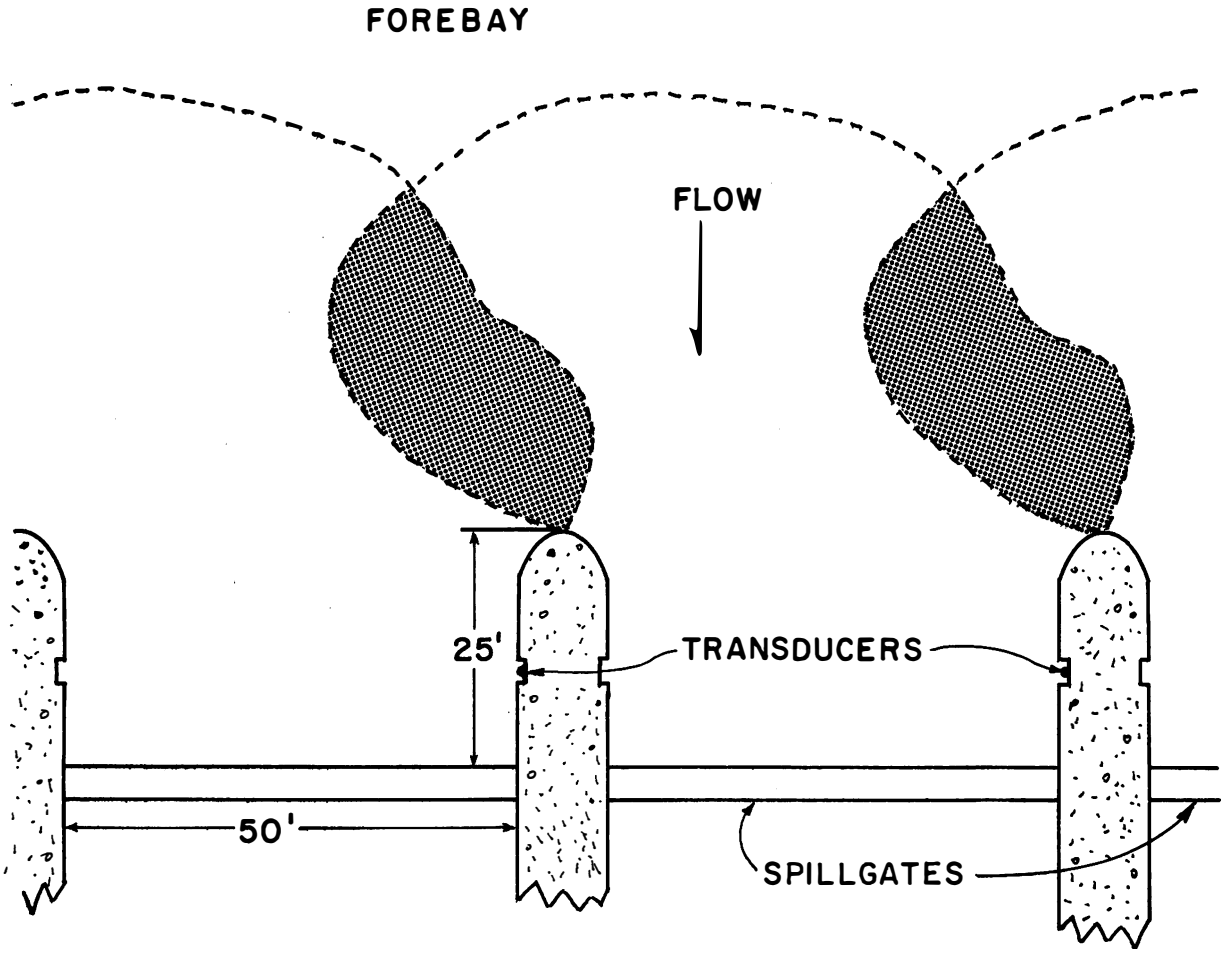

Figure 6.--Pattern of sonic tag signal reception by transducers in each spillway bay. Simultaneous detection by two units occurred in shaded areas from signal reflection of wall and spillgate.

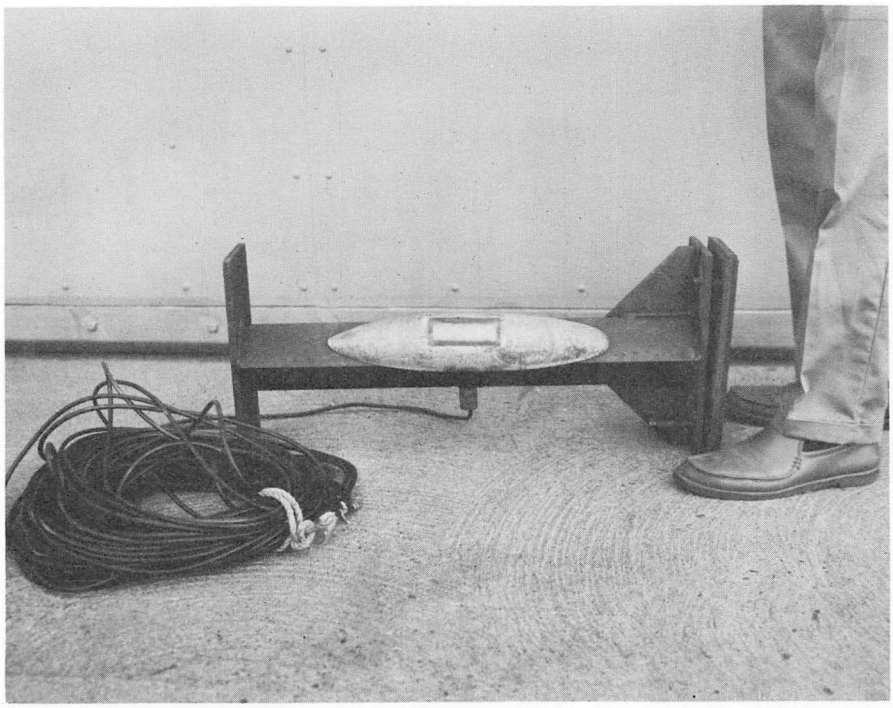

Figure 7.--Transducer and transmission cable before installation in stoplog slot.

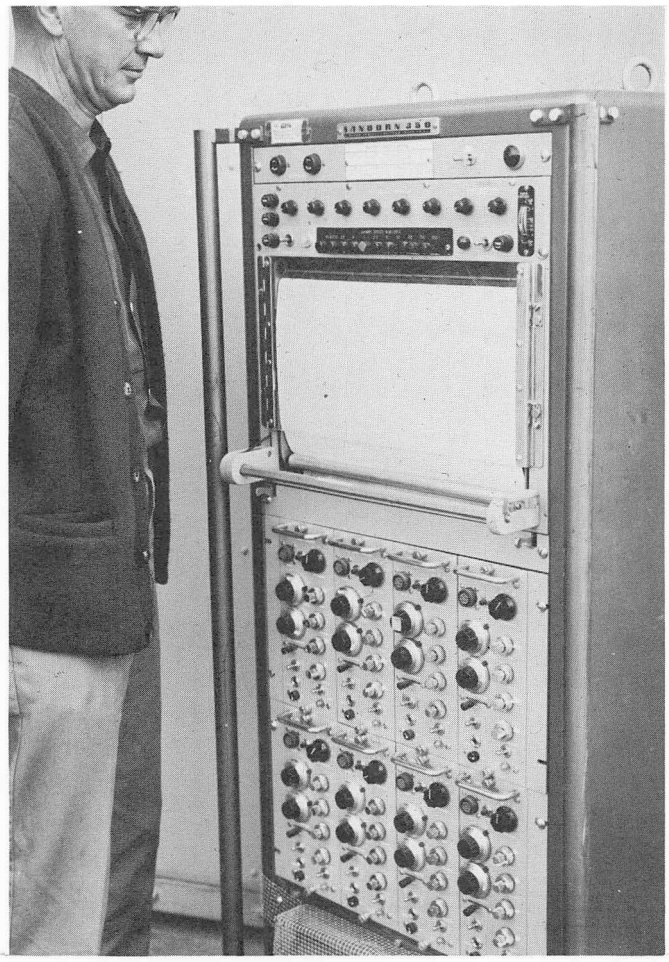

Figure 8.--Multichannel paper strip chart recorder provided permanent record of signals from sonic-tagged fish swimming in front of spillway or falling back beneath spillgate.

Distribution of Fish by Ladder

During the period of this study, 88 percent of the total salmon count at Ice Harbor Dam (excluding jacks, which were not tagged) was in the south fishway. In the first week of the experiment, the number of fish tagged in the south ladder was limited to approximate the number of fish that could be trapped and tagged in the north ladder. By May 15 it was apparent this plan of operation was unworkable since few fish were being obtained in the north ladder. As spillway flows approached their peak (May 22), salmon counts in both ladders declined and the north ladder passed only 13 fish in the 8-day period, May 18-25, inclusive (fig. 9).

Although fish were virtually unobtainable from the north ladder during the high flow period, tagging was continued in the south ladder. This provided a means of comparing the response of fish from this ladder under both low and high flow conditions.

Fallback Determination

Determination of fallback (including time and location) was made by inspection of recorder charts. The photographed chart traces in figure 10 illustrate the principal criterion on which the judgment of fallback or nonfallback was based. The beginning of each trace is at the left, indicating the moment the fish entered the transducer reception area. The uncircled traces build to a peak--which is sustained for the time the fish remains within close range of the transducer--and then diminish and terminate as the fish leaves the reception area. The circled trace builds to a peak, which is briefly maintained, and then terminates abruptly. The circled trace is interpreted as a fallback; the uncircled traces, nonfallbacks.

Extensive testing performed prior to and during the study period substantiated the validity of this interpretation. Sonic tags towed either slowly or swiftly past spillway bays, at various depths and in either direction, invariably produced chart traces showing some diminishment of signal before termination. Traces obtained by dropping sonic tags into the forebay in front of the spillway invariably terminated abruptly, presumably at the instant the tag was swept through the gate opening.

The relatively few questionable traces obtained during the study were designated nonfallbacks. Bias within the results therefore favors nonfallback, and the fallback frequencies obtained may be regarded as minimal.

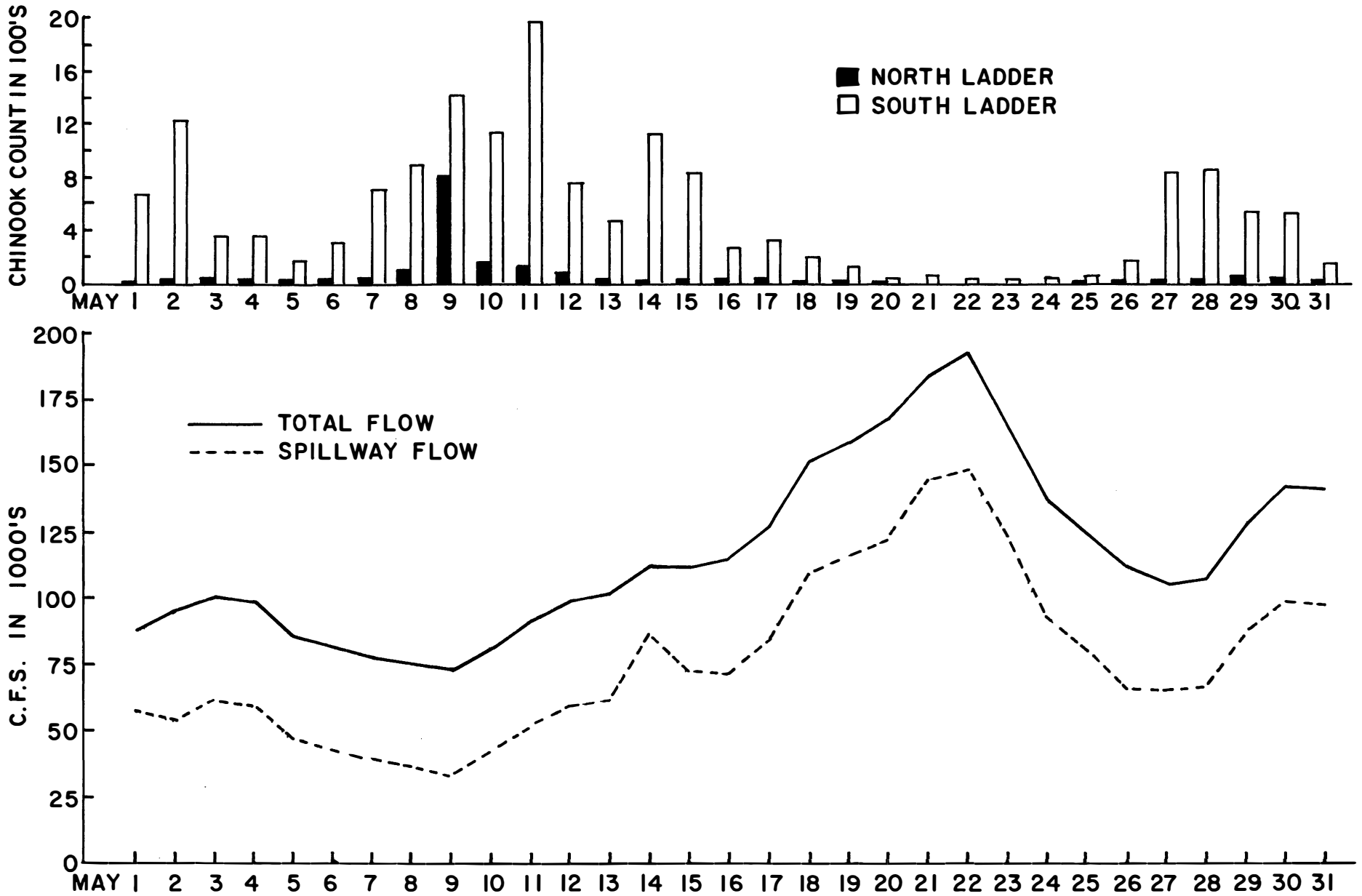

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Figure 9.--Volume of flow and chinook salmon counts (jacks excluded) at Ice Harbor Dam, May 1964. Fallback study began May 8 and terminated May 24, 1964.

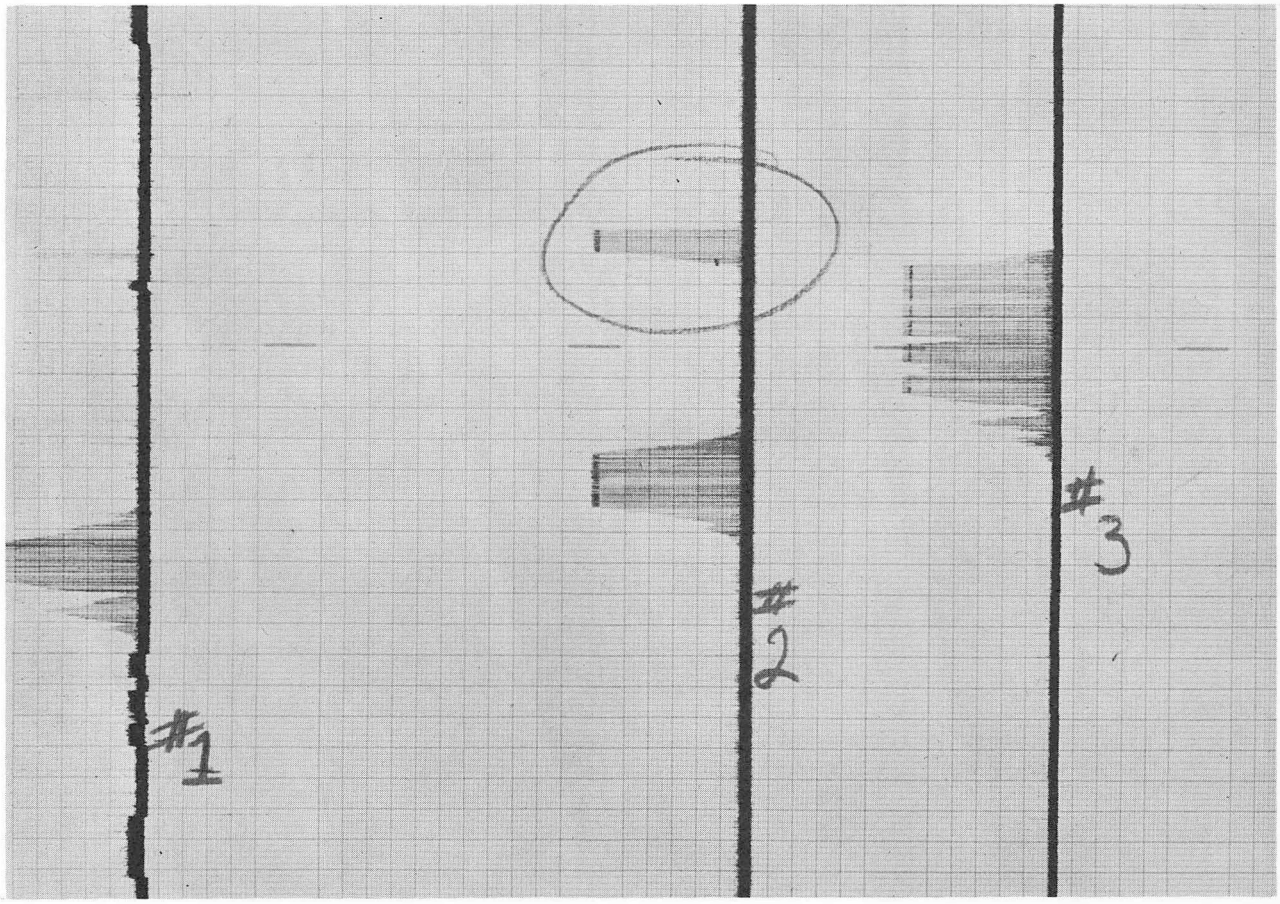

Figure 10.--Example of strip chart recording made during fallback study. Sequence in time is read from bottom to top. Numbers (1, 2, and 3) indicate spillway bay. In these tracings, a single fish is shown passing successively in front of bays 1, 2, and 3 and finally back into bay 2 (circled) where fallback occurred. Fallback is indicated by the abrupt termination of the signal trace.

Nonfallback tracings are characterized by a more gradual decline of signal amplitude as the fish moved from one bay to the next. Sequence took 4 minutes 40 seconds. Note that all traces appear on left of baseline. This indicates the fish was released from the south fishway. If the fish had been released from the north fishway, the tracings would have shown on the right of the baseline.

RESULTS

During a period which began May 8 and ended May 27, a total of 223 salmon were sonic-tagged and released--159 in the south fishway and 64 in the north. Twenty-three fallbacks were recorded, 11 from south ladder fish and 12 from north ladder fish. During the study period, the spillway was approached 42 times by fish from the north ladder and 106 times by fish from the south ladder. Each approach consisted of one or more exposures (individual traces) to individual spillway bays. There were 195 exposures of fish from the north fishway and 522 from the south fishway.

Because of the disproportionate number of fish using the two fishways and because of the wide variation of fish counts in the respective fishways due to fluctuation in river flow, it was necessary to weight the data statistically. The data from each ladder are summarized in table 1.

Fallback Frequency per Fishway

A comparison of observations during the low flow period indicated a fallback of 18.7 percent from the north ladder and 3.5 percent from the south (table 1), a statistically significant difference.

During the high flow period, when no fish were released from the north ladder, fallback frequency from the south ladder was 15.5 percent. High and low flow fallback frequencies cannot be compared statistically because more than 20 percent of the expected values are numerically smaller than 5 (Dixon and Massey, 1957). However, the magnitude of daily fish counts and the rates of fallback at the two flow levels differ enough to warrant separate treatment of low and high flow fallback frequencies in estimating the total percentage of fallback from the south ladder, which was 4.7 percent (table 1).

To obtain a comparable estimate of percentage fallback from the north ladder, the frequency of fallback during the high flow period was assumed to be at least equal to the frequency observed during the low flow period, or 18.7 percent. Most probably it was higher if the trend in the north ladder followed that observed for north ladder fish. Since only 66 fish were counted in the north ladder during the high flow test periods, the projected calculation of fallback during this period (18.7 percent) did not materially affect the combined result for both flow periods.

Table 1.--Summary data during tests of the fallback frequency of adult spring-run chinook salmon through Ice Harbor Dam spillways, showing observed and expected number and percentage of fallback from north and south fishways.

	North ladder			South ladder			
	May 8-15, 26, 27 Low flow	May 16-25 High flow	Total	May 8-15, 26, 27 Low flow	May 16-25 High flow	Total	Combined totals
Fishway count[1]	1,315	66	1,381	9,672	1,136	10,898	12,279
Number tagged	64	0	64	114	45	159	223
Observed fallback	12	0	12	4	7	11	23
Observed percentage fallback	18.7	------	------	3.5	15.5	------	------
Expected number fallback	246	12[2]	258	341	176	517	775
Expected percentage fallback per fishway		$\left(\frac{258}{1,381}\right)$ 18.7			$\left(\frac{517}{10,898}\right)$	4.7	------
Expected percentage fallback per total		$\left(\frac{258}{12,279}\right)$ 2.1			$\left(\frac{517}{12,279}\right)$	4.2	$\left(\frac{775}{12,279}\right) = 6.3$

1/ Jacks excluded.

2/ Fallback frequency during period May 16-25 considered equal to or greater than that in low flow period. Calculation based on frequency of 18.7 percent.

It should be emphasized that these estimated values apply specifically to circumstances existing at Ice Harbor during this period of study. Combined percentage values will change with any variation in the proportion of fish counts by ladder, even if the observed fallback frequencies remain constant.

Estimated Total Fallback

The total expected fallback (775) in relation to total count (12,279) was 6.3 percent--2.1 and 4.2 percent, respectively, from the north and south ladders.

Return of Fallback Fish

A number of tagged fish were observed passing upstream at counting stations in both ladders. Some of these fish had previously passed downstream over the counting board after release near the exit of the ladders. These fish were eliminated from the total count in order to assess the probable return of marked fish that had fallen back through the spillway. After the process of elimination, 11 fish were considered probable returns from those passing through the spill gates. This represents approximately 50 percent of the total (23) observed fallback over the spillway.

One returning fish spent a minimum of 13 days below the dam, another at least 9 days. Other fallbacks reascended within 24 hours after release. Some of the returning fish retained all of the sonic tag, whereas others carried only the strap or the dart tag. Four fish were noted to have crossed over below the dam and ascended the opposite ladder on their second ascent.

Approach Frequency and Number of Exposures Per Approach of Fish Reaching the Spillway

The monitoring system provided a record of every tagged fish which approached within approximately 75 feet of the spillway, whether the fish fell back or not. It was therefore possible to compare the proportions of fish from each ladder that were exposed to the spillway.

The following comparisons were made with the assumption that north and south ladder fish reapproached the spillway with the same frequency. This assumption is necessary because there is no way of determining how many of the 64 north ladder releases are represented in the 42 recorded spillway approaches by north ladder fish; i.e., there is no way to tell

how many times a single fish approached the spillway, left it, and reapproached it. The same would apply to the 106 approaches made by south ladder fish.

There was no significant difference between the frequencies of approach from the two ladders during the low flow period (.65 vs. .48, table 2). A significantly higher proportion of fish from the south ladder approached the spillway during high flows than during low flows.

The number of times a fish was exposed to individual spillway bays, after its initial approach to the dam and before leaving the area, ranged from 1 exposure (38 instances) to 25 exposures (1 instance). Comparing low flow period observations (table 3), no significant difference can be shown in the number of exposures per approach from the two ladders.

A comparison of exposures of fish from the south ladder showed that significantly fewer exposures occurred during high flows than at low flows.

Table 2.--Approach frequency of adult chinook salmon to Ice Harbor Dam spillway, May 1964.

	North Ladder	South Ladder		
Number	Low flow period	Low flow period	High flow period	Combined periods
Approaches	42	65	41	106
Tagged	64	114	45	159
Approaches per fish tagged	.65	.48	.91	.66

Table 3.--Individual exposures of fish to spillway gates, related to number of initial approaches to the spillway area, Ice Harbor Dam, May 1964.

	North Ladder	South Ladder		
Number	Low flow period	Low flow period	High flow period	Combined periods
Exposures	195	381	141	522
Initial approaches	42	65	41	106
Exposures per approach	4.64	5.86	3.43	4.92

Spillway Distribution of Exposure and Fallback of Tagged Fish

Though the behavior of individual fish varied widely, a general pattern of movement was evidenced in the distribution of exposures to the spillway. As expected, the greatest exposure for south ladder fish occurred at bays closest to the south fishway exit--bays 1, 2, and 3 (table 4). Similarly, north ladder fish exposure was highest at bays 10 and 9 on the north end of the spillway.

The low numbers of fallback per exposure at bays 1 and 10 are probably a reflection of the low flows passing through the gate openings regularly maintained in those bays (generally 2.0 or 1.4 feet). Gate openings in the eight remaining bays (2 through 9) ranged from 1 to 12 feet.

Table 4.--Summary of exposures and fallbacks of adult salmon approaching Ice Harbor Dam spillway bays from north and south fishways. Bay numbers are listed sequentially, left to right, beginning with bay nearest the respective fishway exits.

	South ladder fish									
Bay No.	1	2	3	4	5	6	7	8	9	10
Exposures	72	63	55	45	42	52	52	57	46	38
Fallbacks	0	4	3	1	1	1	0	0	1	0

	North ladder fish									
Bay No.	10	9	8	7	6	5	4	3	2	1
Exposures	46	25	18	14	11	16	17	16	15	17
Fallbacks	2	5	1	2	0	0	1	1	0	0

DISCUSSION

The results obtained in this investigation were not unexpected where related to fish from the north shore fishway. It was largely for that reason Ice Harbor was selected as the site for this study. The observed higher fallback frequency of fish from the north ladder and evidence that fallback is much higher during high flow periods generally confirm our previous conceptions of the problem.

Fortunately the seriousness of the situation is reduced considerably due to the fact that only a small proportion of the run uses the north ladder. Applying the observed fallback percentage during the study period to the north ladder count (2,586) for the entire spring run (April, May, and June), an estimate of approximately 500 north ladder fallbacks was obtained.

While there is clearly a problem related to the location of the north ladder exit, the fallback problem at Ice Harbor relates in much higher degree to the south fishway. During the period of study, the south fishway is estimated to have contributed twice as many fallbacks to the spillway as the north ladder--an estimated 1,858 fish fell back (compared to 500 from the north ladder) during the entire spring run. This was not expected, since fish leave the south ladder exit and enter the forebay almost 1/4 mile from the spillway.

Significance of Exposure Rate Similarity Between Ladder Groups

It was expected that a higher rate of fallback would be seen for fish coming from the north ladder, and this was verified. An assumption that this would be true because of a higher rate of spillway exposure by north ladder fish seemed obvious at the outset. However, no difference was shown in the frequency at which north and south ladder fish approached the spillway during the low flow period, raising the following unforeseen question: Since the two groups approached the spillway in the same proportion as they were tagged, how is the difference in fallback frequency to be accounted for?

Once in front of the spillway, some unascribed behavioral difference produced a higher rate of fallback in north ladder fish. With the available data we cannot determine the nature or cause of that difference.

Effect of Flow Conditions on Approach and Exposure Rate of South Ladder Fish

It is interesting to note that for south ladder fish the number of approaches to the spillway per fish tagged almost doubled during the high flow period. Presumably this was a response to change in flow conditions in the forebay, but we are unable to account for it.

At the same time, the number of exposures per approach decreased significantly. This could be expected as more fish fell back during the high flow period, precluding possible

additional exposures. However, the reduction in exposures applied to nonfallbacks as well, indicating that fish were less inclined to stay in front of the spillway during high flow periods than they were during low flow periods.

Significance of Fallback Survival

The observed 50 percent survival merely indicated that those fish were capable and willing to make a second ladder ascent following fallback--some after a delay of more than a week. The extent of observed delay is not regarded as critical for spring-run fish. Considering the stresses placed on fish passing through the turbulent area below the spillway, it is surprising that a considerable number survived. There is no assurance that reascending fallback salmon did not suffer injuries which ultimately prevented them from reaching the spawning grounds, or from spawning successfully after they arrived there.

The observed frequency of survival indicates that half the estimated number of fallbacks during the study period (388 fish) reascended the fishways and were recounted. This implies that the total Ice Harbor salmon count during the period (12,279) was approximately 3 percent high. The slight discrepancy may fall within the normal range of counting error and, therefore, is of little significance. However, if the percentages of fallback and survival vary among dams, this may account for some of the puzzling variation in fish counts at Columbia River dams in past years.

SUMMARY AND CONCLUSIONS

An investigation of the problem of adult salmon fallback over a spillway was made at Ice Harbor Dam in May 1964. Objectives of the study were to determine the respective fallback frequencies of fish groups issuing from the north and south fish ladders, the combined frequency of fallback, and the survival of fallback fish.

Sonic-tagged salmon were released in each ladder near the exit. The north ladder exit is about 150 feet from the spillway and the south ladder exit is 1,100 feet from the nearest spillgate. Tagged fish which approached the spillway were detected by an acoustic monitoring system which recorded the time, the number and sequence of spillgates approached by the fish, and the ladder origin of the fish. Fallbacks were identified by special characteristics of the recorded sonic-tag signal traces.

The results showed that 18.7 percent of north ladder fish fell back through the spillway during a period of low river flow compared to only 3.5 percent of the south ladder fish.

During a period of high river flow, 15.5 percent of the south ladder fish fell back. Few fish ascended the north ladder during high flows. As a result, no fish were tagged in the north ladder during this period, but it was assumed that the frequency of fallback was at least 18.7 percent and probably higher.

Combined estimated fallback frequencies for the entire period of study were a minimum 18.7 percent for north ladder fish and 4.7 percent for south ladder fish.

The estimated percentage of the run which fell back from each ladder during the study period was 2.1 percent for north ladder fish and 4.2 percent for south ladder fish, a total of 6.3 percent from both ladders. Reflected in these figures is the disproportionate use of the ladders by the migrating salmon--88 percent used the south ladder.

Eleven tagged fish, or approximately 50 percent of the recorded number of fallbacks, reascended the fishways and were counted a second time. If half of the estimated number of fallbacks (388) reascended the fishways, the total salmon count (12,279) at Ice Harbor during the test period was high by approximately 3 percent. Duplications in counts may account for some of the unexplained variations in fish counts at various dams in the Columbia River, particularly if fallback and mortality are not constant for all dams.

Fish from the two ladders approached the spillway in equal proportions to the numbers tagged. Thus, the higher percentage of fallback from the north ladder was not the result of a higher percentage of fish approaching the spillway (due to close proximity of that ladder exit to the spillway). It appeared that a difference in behavior of the two groups of fish in front of the spillway accounted for the difference in fallback. There was no apparent explanation for the variation in behavior.

When fallback frequencies observed during the period of study were applied to the total salmon count in the respective fishways during the 1964 spring run (April, May, and June), estimates of total fallback were approximately 500 from the north ladder and 1,858 from the south ladder.

In summary, it would appear that a modification of the north fishway exit (placing it further away from the spill) would result in only a nominal reduction of total fallback at Ice Harbor Dam. Solution of the fallback problem at Ice Harbor Dam or other dams of similar design will require careful consideration of the location of both fishway exits. Before recommendations can be made, it will be necessary to establish the most suitable exit locations for reducing or eliminating fallback.

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