EVALUATION OF EQUIPMENT FOR RECOVERING FISH PASSING THROUGH KAPLAN TURBINES

by

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October 1964

FISH-PASSAGE RESEARCH PROGRAM
U. S. Bureau of Commercial Fisheries
Seattle, Washington

INTRODUCTION

Research on mortalities of downstream migrating fingerling salmonids in turbines of low-head dams required the development of a special recovery system. This equipment was attached directly to the draft-tube exit to collect fish that have passed through a turbine. The condition of the recovered fish can provide data on the effect of the turbine on downstream migrants. Before fingerling mortalities can be ascribed specifically to the turbines, however, the effect of the recovery equipment on survival must be determined.

To assess the effect of the recovery equipment, an experiment was conducted at Bonneville Dam downstream from turbine number 9 during the high-water period in the spring of 1964. Groups of fingerling salmonids were released at the draft-tube exits and in the turbine intakes and were captured by the recovery equipment. Subsequent examinations were made to classify injuries caused by the turbines and by the equipment.

In addition, releases of salmonid fingerlings were made at two different depths in the turbine intake to explore the possibility that mortalities might vary in accordance with the depth at which fish enter turbines. These studies also provided a basis for classifying injuries to fish caused by Kaplan turbines. Cramer and Olighter (1960) described injuries occurring to fish that have passed through high-head dams with Francis-type turbine, but no accurate description of injuries inflicted by low-head Kaplan-type turbines has been made. These data are necessary to evaluate properly the total mortality experienced by fingerling salmon migrating downstream past hydroelectric plants on the Columbia River system.

The evaluation of the fish recovery equipment and the result of the exploratory turbine tests described in this report facilitate a detailed analysis of fish passage through turbines. Future experiments can be directed toward determining the relationsship of fish mortality to such factors as depth of travel, area of entrance into the turbine, wicket-gate openings, blade angles, power output of the unit, cavitation, and discharge water conditions in the draft tube.

MATERIALS AND METHODS

Research Area

The Bonneville Dam powerhouse is composed of 10 vertical-shaft Kaplan turbines. Each of the turbines contain five blades that revolve at a rate of 75 revolutions per minute inside of a throat ring 280 inches in diameter. The turbines are capable of passing 13, 000 c. f. s. of water to produce a maximum of 58, 000 Kilowatts.

Each turbine is powered by water obtained from the forebay through three separate intakes designated A, B, and C from the left or Oregon shore (looking downstream). After passing through a turbine the water is discharged downstream through a draft tube which is divided into two main sections. Both sections of the draft tube contain splitters designed to straighten out the flow of water discharged from the unit. When turbine 9 is operated at peak efficiency, the left section (looking downstream) of the draft tube passes more water at higher velocities than does the right section. Velocities from the exits range from 1. 1 to 10. 8 feet per second (Fig. 1).

Two structures of interest to fish-passage studies are the generator cooling-water intake and the draft-tube gatewell. The openings to these structures are both upstream of the recovery equipment and are possible escape routes for fish experimentally passed through the unit.

Equipment

The recovery net and sanctuary barge used to recover fish is shown in Figure 2. The funnel-type net, 32 feet high by 82 feet wide at the mouth and about 230 feet long, narrows to a circular opening 18 inches diameter at the cod end. When the net is in a fishing position and is straining the entire discharge of a single turbine, fish and water flow continuously through the net into the sanctuary. Here the fish are diverted into a holding pen by means of an inclined screen.

Fish-release capsules were used to release fish at specific locations during the experiments. The capsules held about 100 fish 4 or 5 inches in length and were opened by remote control. Before fish were released, each capsule was prechedked to ensure that the release mechanisms were operating properly. Water was circulated continuously through the capsules during transportation by means of a hose, but when theywere submerged in the intake or draft tube, a pump inside the unit supplied the fish with a constant flow of water.

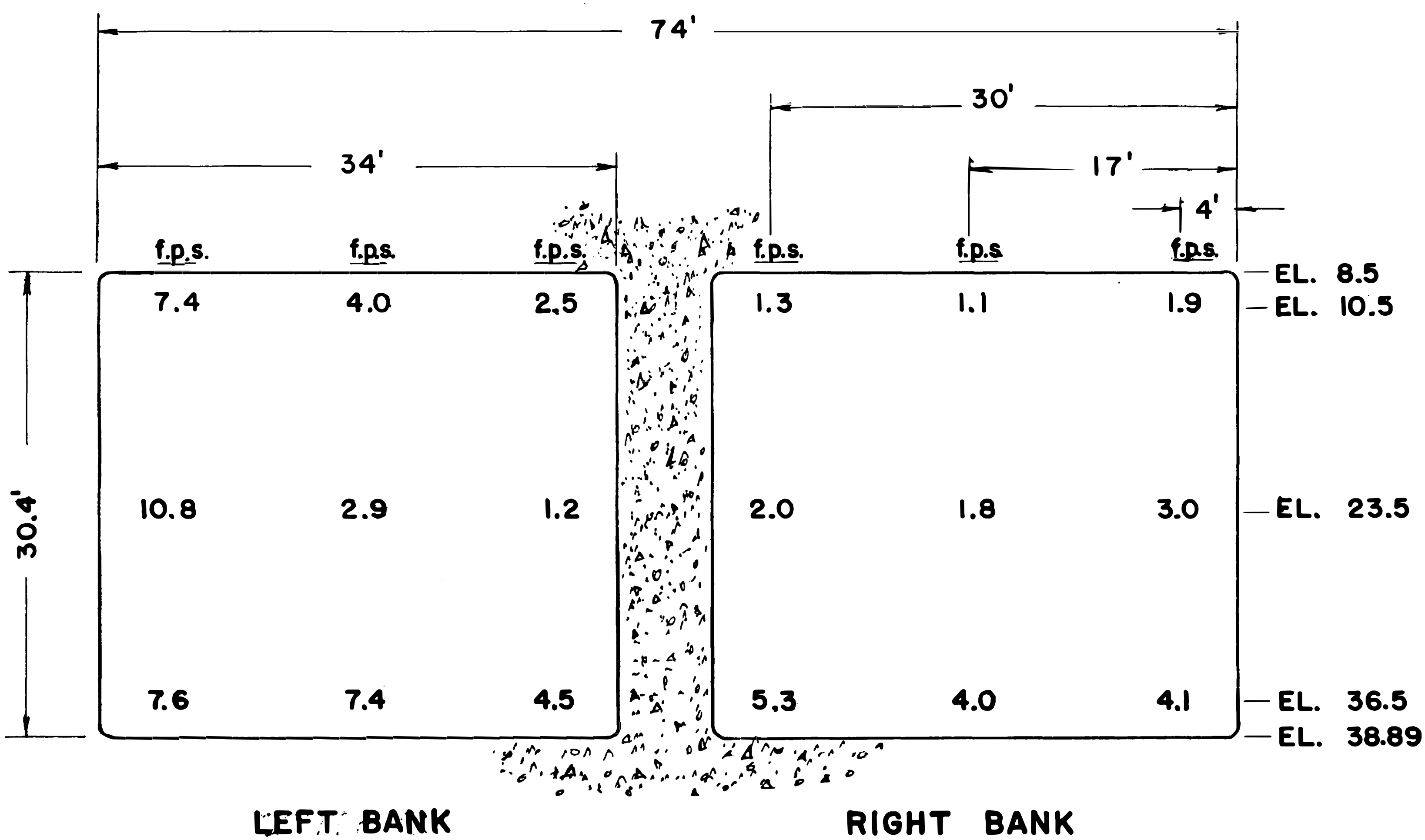

Figure 1.--Water velocities in feet per second at draft tube exits of unit 9, Bonneville Dam, with turbine operating at peak efficiency, about 7,800 c.f.s. (looking downstream).

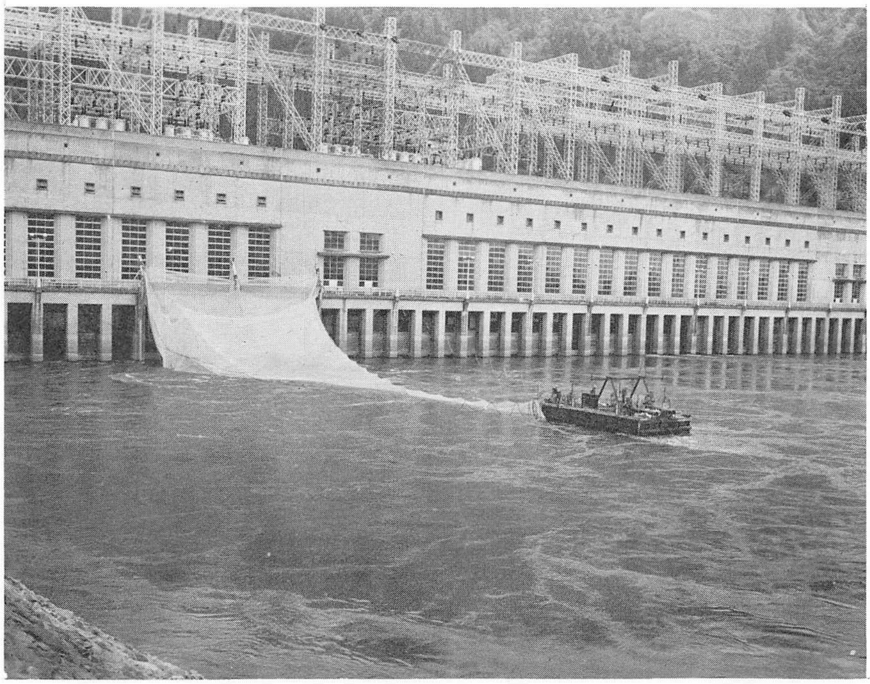

Figure 2.--Recovery net and fish sanctuary used to recover fish at Bonneville Dam.

Procedure

The experiments to evaluate the recovery equipment and to explore the effect on fish taking different passage routes through the turbines were conducted simultaneously with coho salmon (Oncorhynchus kisutch) yearling. These fish were removed from a pond by means of a siphon system and randomized into 18 subgroups in separate holding pens. At this time, one subgroup was set aside as a control and held until completion of a 6-day holding period at the end of the test. The remaining 17 groups were marked by tattooing. At this point, another group was set aside until completion of the test as a control on the marking technique. All marked fish for use in the experiment were held for 3 days to eliminate any initial mortality that might occur due to marking and to permit the fish to recover from any other stresses inposed on them up to this time.

For marking, the fish were anesthetized with Tricaine Methanesulfonate (M. S. 222) and tattooed with fluorescent pigments to identify the position of release. Fish used for evaluating the net were identified by one or two marks located anterior or posterior of the dorsal fin, either dorsally or on the sides of the fish. Fish intended for passage through the turbine were marked so that the anterior and posterior body sections bore the same mark. This provided a means of identifying fish that might be severed or severely lacerated.

Some of the fish released in the turbine intake for passage through the turbine were both tattooed and marked by immersion staining. It was desirable to stain the total body tissues of fish to be passed through turbines because of the possibility of the fish being torn or but into several pieces. Preliminary tests had indicated that Neutral Red and Bismark Brown Y dyes could be used, but after a few initial groups of fish had been stained, it became apparent that the fished dyed with Neutral Red experienced a high mortality. This method was discontinued.

After the 3-day holding period, the fish were transferred into numbered release capsules and transported to the release area. Two spare capsules containing fish served as standby replacements for any units that failed a prelease check; one of these capsules was returned to the hatchery as a capsule control if not used in the test.

During the course of a single test, the turbine was operated at different settings to produce specific flow conditions. The fish-release capsules were positioned at the mouth of the net and in the turbine intake at speed-no-load, an operating condition that produces a minimal discharge of about 1,000 cubic feet per second. No power is produced at this setting. After the capsules were in place, the flows were increased to about 5,000 c. f. s. (power output, 10 megawatts) and the recovery net was lowered into position. When it was determined that the net was functioning properly, the turbine output was increased to peak efficiency (about 7,800 c. f. s.) and the capsules were opened to release the fish. Peak efficiency is an operating conditon wherein the unit produces the most amount of water at any given gross head (the difference between forebay and tailwater levels). Figure 3 shows the peak efficiency operational range for turbine 9.

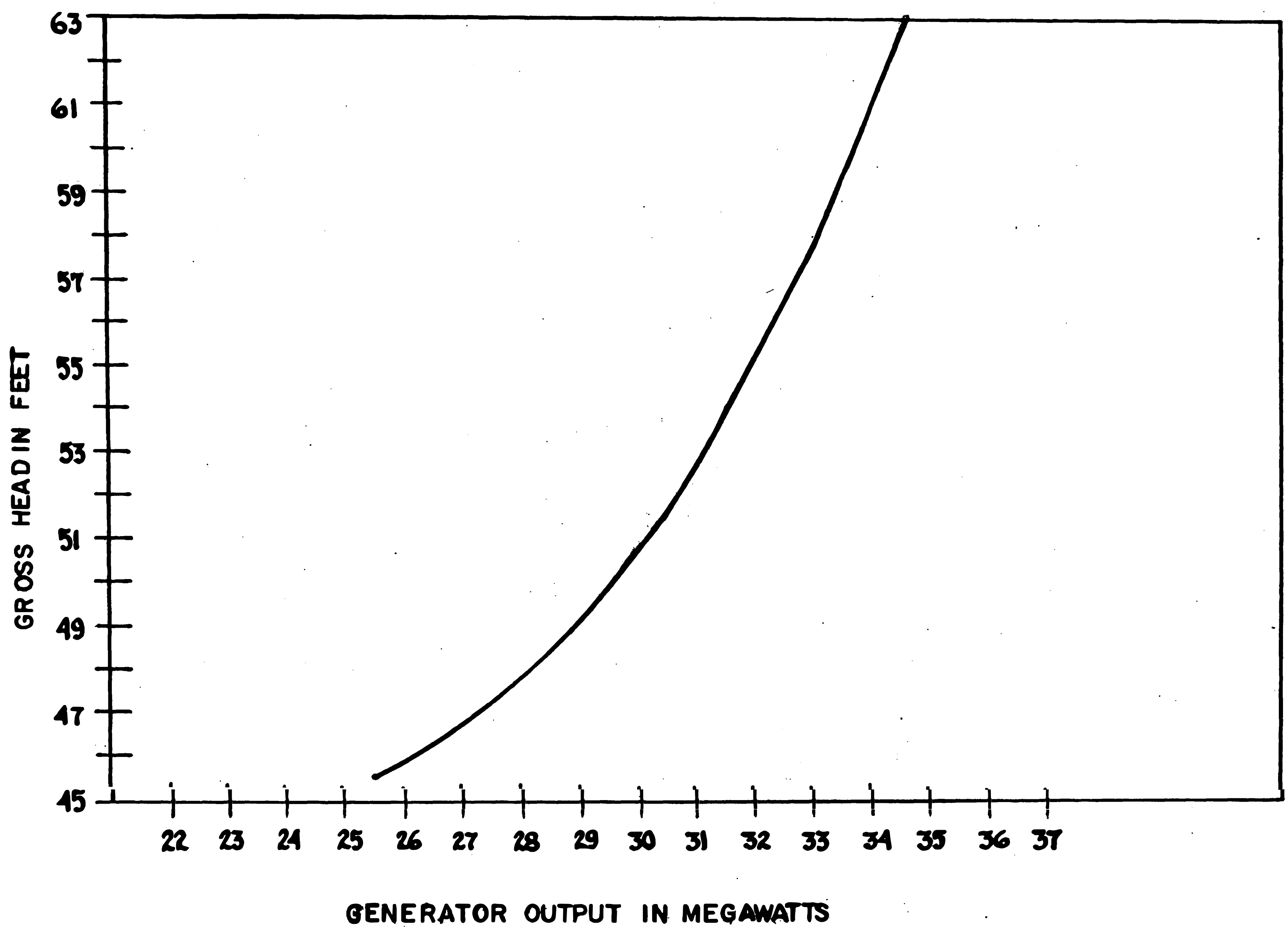

Figure 3.--Peak efficiency curve for turbine 9 at Bonneville Dam (taken from Index Test for turbine 5, 1960).

After the fish were released, the recovery net was operated until no more fish were observed entering the sanctuary barge, usually 60 to 90 minutes. At this time, the net was purged by raising the mouth above water level and increasing turbine discharge to approximately 10, 000 c. f. s. This action raised the remainder of the net toward the water surface and forced fish remaining within the net into the sanctuary.

At the conclusion of each test, all fish were transported to the hatchery and held for 6 days for observation. Mortalities occurring on the day of the experiment were recorded as initial mortality and were normally obtained within 2 to 4 hours after the time of release. During the 6-day holding period following the test, live fish were not disturbed, but all dead fish were removed daily and examined for evidence of injuries. On the sixth, and final, day of holding, all the live fish remaining were anesthetized and examined for marks and injuries to obtain a total count of the fish recovered. A flow diagram (Fig. 4) illustrates the procedure from start to finish.

Injuries that could be determined by macroexamination were classified into various types selected to reveal possible differences between net and turbine-inflicted injuries. The categories selected were:

1. No apparent injury.
   Cause of death not determined.

2. Eyes.
   Hemorrhaged, damaged, or missing.

3. Gills.
   Any injury to gill covers or gills.

4. Fins.
   Broken, torn; base bruised or hemorrhaged.

5. Descaling.
   Abrasion with obvious loss of scales, with or without hemorrhage.

6. Contusion.
   Bruised or crushed with hemorrhage.

7. Laceration.
   Decapitation; flesh torn or cut.

8. Internal organs.
   Organs damaged.

9. Internal hemorrhage.
   Organ or body-wall hemorrhage.

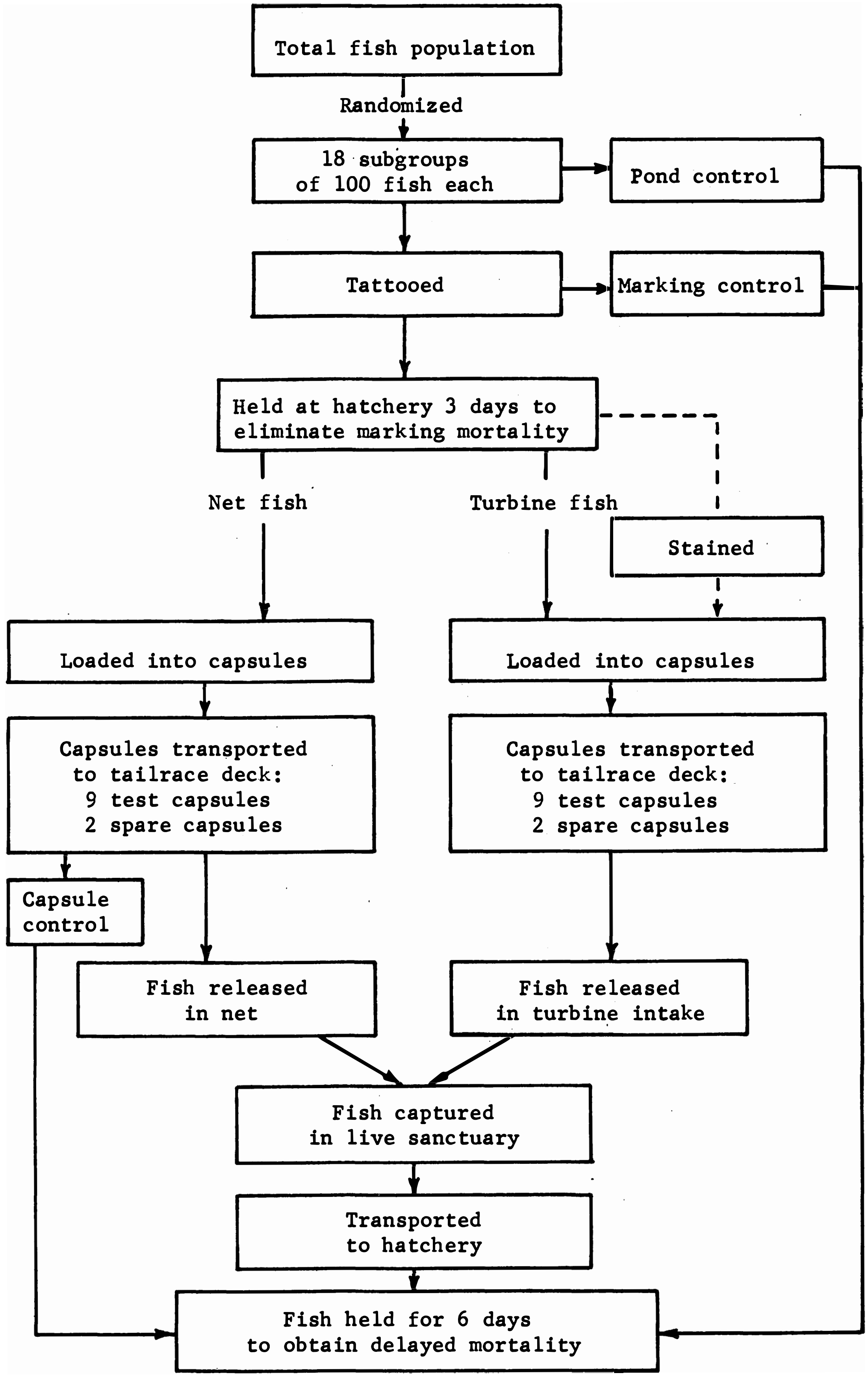

Figure 4.--Flow diagram of fish handling procedures during evaluation tests of fish recovery equipment at Bonneville Dam, 1964.

Analysis of all mortality data was based on th total number of test fish recovered rather than on the total number released in order to obtain a more accurate evaluation of the recovery equipment.

Fish were released at specific positions (Fig. 5) in the net mouth to determine fingerling mortality in relation to the flows at the release point. A single test consisted of the simultaneous release of nine groups of approximately 100 fish each. Three groups were positioned near the left side of the net mouth, three in the middle, and three near the right side. Since a majority of the water is apparently discharged from the left bank section of the draft tube and because higher discharges in this area would probably be associated with higher mortalities, the three middle capsules were positioned to release fish on the left side of the dividing wall of the draft tube.

For the turbine intake releases, the capsules were lowered to the deisred position through the intake gatewell. An inflated bag was used to float the capsules near the intake ceiling, and heavy weights were attached to sink them to the desired depth. The actual depth of each capsule in the turbine intake was determined by measuring the air pressure required to exhaust water from an open-end tube within the capsule. This was accomplished by introducing compressed air into a tube extending from the capsule to the intake deck. The approximate positions of the capsules when fish were released are shown in Figure 6.

Two release capsules were positioned in one of the three intakes for each day's test. One capsule was positioned within 10 feet of the intake ceiling, and the second capsule was submerged to about 15 feet above the intake floor.

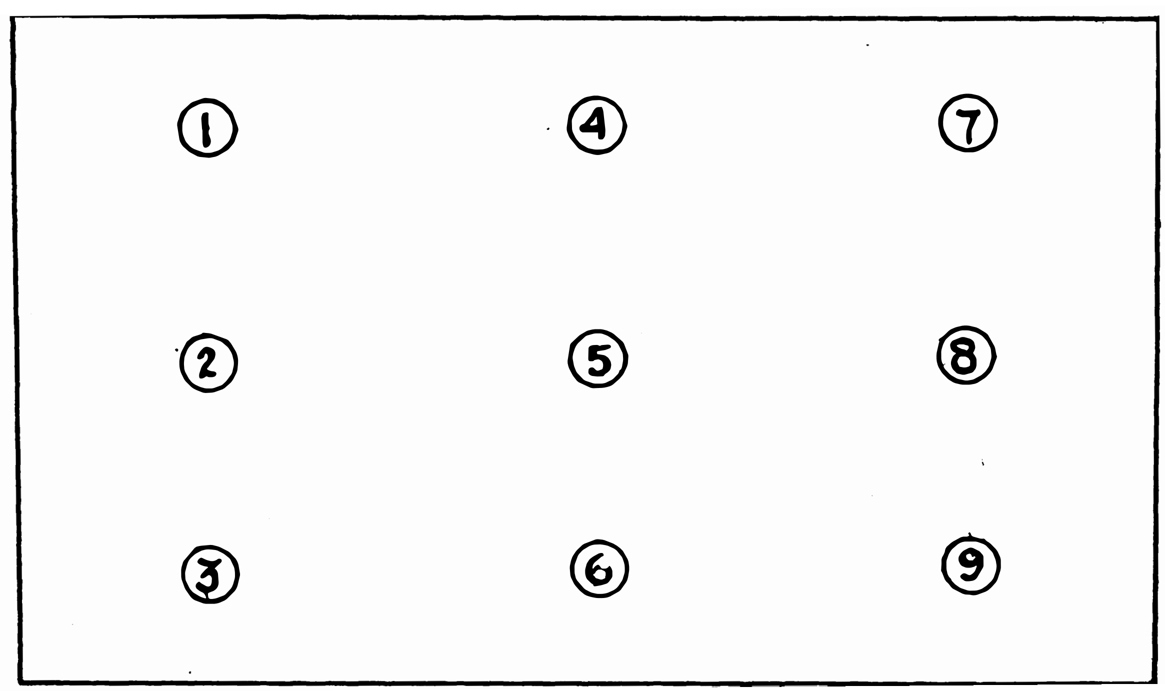

Figure 5.--Fish release positions in mouth of funnel net (looking downstream from Bonneville Dam toward the cod end).

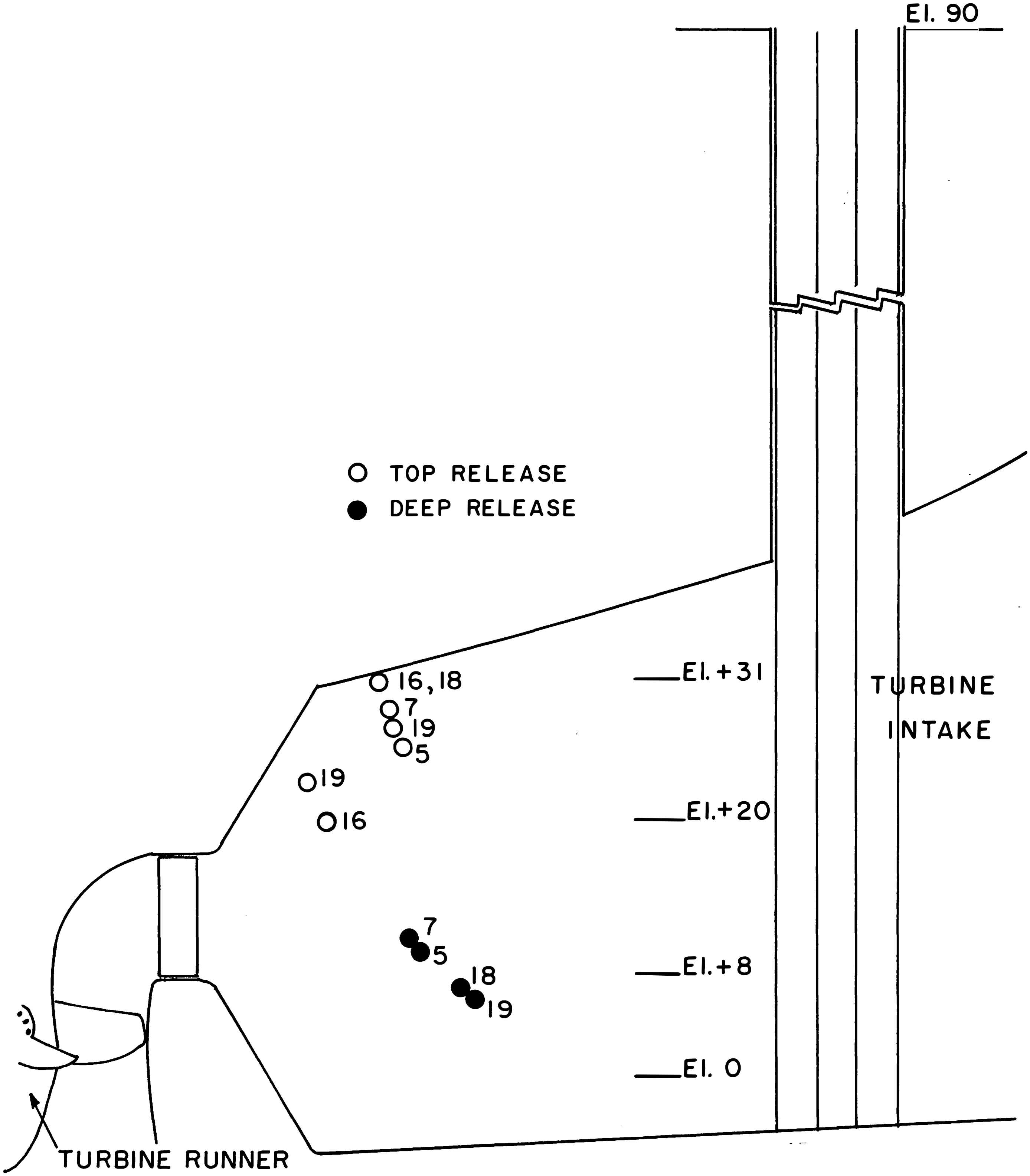

Figure 6.--Fish release positions in intake of turbine 9, Bonneville Dam, in May 1964. Figures indicate date of release.

RESULTS

Recovery of Fish Released in Net Mouth

Recoveries of fish released in each position in the mouth of the net are shown in Table 1. The average recovery for all fish released was 96. 5 percent. Recoveries from individual releases ranged from 78. 2 to 100 percent. The lowest number of recoveries were from fish released in position 1, but examination of the data by an analysis of variance test--converting percentages to arcsin values (Snedecor, 1957)--indicates no significant difference between recovery rates by release position.

The average mortality experienced by fish released in the net mouth was 11. 0 percent. Of this total, 3. 9 percent occurred as initial mortality on the day of the test, and 5. 9 percent occurred in the first 24 hours. The remainder of the mortalities (1. 2 percent) occurred during the subsequent 5 days of the holding period (Table 2). The highest mortality occurred to fish released in positions 1, 2, and 4, where the average mortality percentages were 56. 8, 10. 2, and 10. 1, respectively. These high mortalities appear to be associated with water velocities and proximity of the fish to the net ceiling (Table 3). Discharged water spirals upward toward the side and ceiling in the upper left corner of the net mouth.

The principal injury associated with mortalities of fish was descaling. A majority of these fish exhibited severe descaling for most of the body length on one or both sides. Numerous injuries occurred also to the eyes of the fish, whereas fewer injuries appeared in the gill and fin areas (Table 4).

Recovery of Fish from Turbine Intake Releases

The recovery for all fish passed through turbine 9 was 93. 1 percent (Table 5). This compares favorably with recovery from net-mouth releases and with the recovery of two groups of dead fish (average 93. 5 percent) released in the turbine intake on two separate occasions to determine if differences in recovery existed between active and inactive fish.

The total combined mortality caused by the turbine and the recovery net system to all fish recovered was 14. 9 percent (Table 5). The majority of fatalities, 8. 0 percent, occurred on the day of the tests, and 5. 4 percent took place in the first 24 hours of holding; 1. 5 percent of the mortalities occurred in the next 5 days. This mortality pattern was similar to that obtained from releases in the mouth of the recovery net.

The mortalities of fish released in the turbine intakes (A, B, or C) and recovered downstream varied in relation to the intake and position of release within the intake (Table 6). The highest and lowest mortalities were experienced from

Table 1. --Recoveries of coho almon yearlings in sanctuary barge in relation to number and position of fish released in mouth of funnel net. (looking downstream)

Date	Number Re-leased	Number Re-covered	Percent Re-covered	Number Re-leased	Number Re-covered	Percent Re-covered	Number Re-leased	Number Re-covered	Percent Re-covered
1964	(Position No. 1)			(Position No. 4)			(Position No. 7)		
May 5	82	78	95.1	107	104	97.2	94	94	100
7	96	94	97.9	99	91	91.9	97	97	100
16	--[1]	--[1]	----	89	87	97.8	79	76	96.2
18	76	65	85.5	79	75	95.0	--[1]	--[1]	------[1]
19	101	78	78.2	95	95	100.0	100	94	94.0
Average			89.2			96.4			97.6
	(Position No. 2)			(Position No. 5)			(Position No. 8)		
May 5	--[1]	--[1]	--[1]	94	94	100.0	--[1]	--[1]	------[1]
7	108	104	96.3	97	95	97.9	92	91	98.9
16	94	94	100.0	91	88	96.7	95	89	93.7
18	83	83	100.0	81	81	100.0	--[1]	--[1]	------[1]
19	112	102	91.1	--[1]	--[1]	----[1]	102	99	97.1
Average			96.8			98.6			96.6
	(Position No. 3)			(Position No. 6)			(Position No. 9)		
May 5	102	97	95.1	98	98	100.0	102	102	100.0
7	99	99	100.0	--[1]	--[1]	----[1]	107	107	100.0
16	94	86	91.5	88	80	90.9	96	94	97.9
18	81	77	95.1	78	78	100.0	80	81[2]	100.0
19	100	98	98.0	100	99	99.0	--[1]	--[1]	-----[1]
Average			95.9			97.5			99.5

[1]No fish released.

[2]One fish more was recovered than released.

Table 2. --Percentage mortalities experienced by yearling coho salmon released in mouth of recovery net in relation to release position (looking downstream).

Date 1964	Percentage mortality by release position		
	(Position No. 1)	(Position No. 4)	(Position No. 7)
May 5	60.3	4.8	0.0
7	64.9	8.8	1.0
16	*	10.3	7.9
18	33.8	10.7	*
19	68.4	15.8	4.3
Average	56.8	10.1	3.3
	(Position No. 2)	(Position No. 5)	(Position No. 8)
May 5	*	0.0	*
7	9.6	5.3	0.0
16	5.3	9.1	6.7
18	3.6	1.2	*
19	22.5	*	5.1
Average	10.2	3.9	3.9
	(Position No. 3)	(Position No. 6)	(Position No. 9)
May 5	0.0	1.0	2.9
7	1.0	*	0.9
16	1.2	0.0	2.1
18	2.6	0.0	0.0
19	12.2	11.7	*
Average	3.4	3.2	1.5

*No fish released.

Table 3. --Average mortalities of coho salmon yearlings recovered in sanctuary barge in relation to water velocities at release positions in net mouth (looking downstream).

Left			Center			Right		
Release position	Water velocity (F. p. s.)	Mortality (average percent)	Release position	Water velocity (F p. s.)	Mortality (average percent)	Release position	Water velocity (F. p. s.)	Mortality (average percent)
1	7.4	56.8	4	2.5	10.1	7	1.9	3.3
2	10.8	10.2	5	1.2	3.9	8	3.0	3.9
3	7.6	3.4	6	4.5	3.2	9	4.1	1.5

Table 4. --Frequency and types of injury related to coho salmon yearling mortalities in recovery equipment in relation to positions of release in net mouth.

	Release position in net mouth									
Type of injury	1	2	3	4	5	6	7	8	9	Total
None apparent	8	1	2	3	0	1	0	0	3	18
Eyes	5	2	2	2	2	1	2	1	0	17
Gills	2	0	0	0	1	0	0	3	0	6
Fin	1	1	0	1	2	0	0	0	0	5
Scales	183	39	14	41	12	11	11	11	3	325
Contusion	0	0	1	0	0	0	0	0	0	1
Laceration	0	0	0	0	0	0	0	0	0	0
Internal organs	0	0	0	0	0	0	0	0	1	1
Internal hemorrhage	0	1	1	1	0	0	0	0	0	3
Totals	199	44	20	48	17	13	13	15	7	376

Table 5.--Recoveries and mortalities (turbine-and net-caused) of coho salmon yearlings released in intakes A, B, and C of turbine Number 9 at Bonneville Dam and taken in recovery equipment downstream.

Date	Fish release position	Turbine intake	Number released	Number recovered	Recovery (percent)	Number of Mortalities	Mortality (percent)
May 5	Top	C	92	89	96.7	5	5.6[1]
5	Deep	C	84[2]	82[2]	97.8	--	----
May 7	Top	C	104	97	93.3	7	7.2
7	Deep	C	100	96	96.0	28	29.2
May 16	Top	A	97	89	91.8	8	9.0[1]
16	Deep	A	92	86	93.5	11	12.8
May 18	Top	A	85	80	94.1	12	15.0
18	Deep	A	74	70	94.6	3	4.3
19	Top	B	100	87	87.0	29	33.3
19	Top	B	103	100	97.1	26	26.0
19	Deep	B	92	77	83.7	1	1.3

[1] Fish stained with Bismark Brown Y dye.

[2] High mortality resulted from Neutral Red dye stain. Not used in computing mortality.

Table 6. -- Summary of Combined turbine and net mortalities in percentages of coho salmon yearlings released in top and deep positions of turbine intakes A, B, and C and recovered in sanctuary barge.

Intake A		Intake B		Intake C	
Top release[1]	Deep release[2]	Top release	Deep release	Top release	Deep release
9.0	4.3	33.3	1.3	5.6	29.2
12.8	---	26.0	---	7.2	----
15.0	---	---	---	---	----

[1] Within 10 feet of intake ceiling.

[2] Within 15 feet of intake floor.

intake B releases. Between intakes, the highest mortalities occurred from releases near the top of intake B and from releases at the bottom of intake C. The least mortalities were observed from the bottom releases in intakes A and B.

The most frequent injury observed in the turbine tests was descaling (Table 7). This descaling and other injuries in such areas as the eyes, gills, fins, and internal organs were similar to those occurring in fish released in the net mouth. However, the fish passing through the turbine received contusions and lacerations that did not occur to fish released in the net mouth. Injuries sustained by a few of the turbine-released fish are illustrated in Figures 7 and 8. The top fish in Figure 7 exhibited petechial hemorrhage at the base of the anal and pelvic fins, the fish at the bottom experienced severe hemorrhaging of the right eye, and the fish in the middle was lacerated. The fish in Figure 8 were severely lacerated and decapitated, but this happened to only seven fish of all those passing through the turbine. It appears, therefore, that injuries obviously caused by the turbine were contusions and lacerations.

Table 7.--Frequency and types of injury related to coho salmon yearling mortalities after passing through turbine 9 and through recovery equipment at Bonneville Dam.

Type of injury	Release Location						
	Ceiling			Bottom			Total
	Intake A	Intake B	Intake C	Intake A	Intake B	Intake C	
None apparent	0	0	8	0	0	22[1]	30
Eyes	2	5	1	2	1	3	14
Gills	0	3	0	0	0	0	3
Fin	0	0	0	1	0	5	6
Scales	49	26	3	12	0	79	169
Contusion	1	0	1	2	0	1	5
Laceration	0	0	0	1	1	5	7
Internal organs	0	0	0	1	0	0	1
Internal hemorrhage	0	0	0	1	0	0	1
Total	52	34	13	20	2	115	236

[1] 18 fish stained with Neutral Red dye, determined to be detrimental.

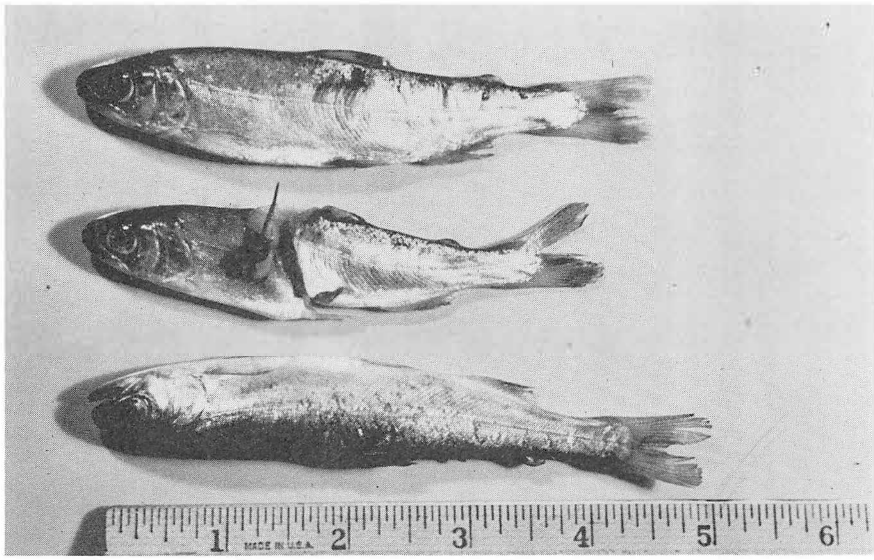

Figure 7.--Fish injured passing through the turbine.

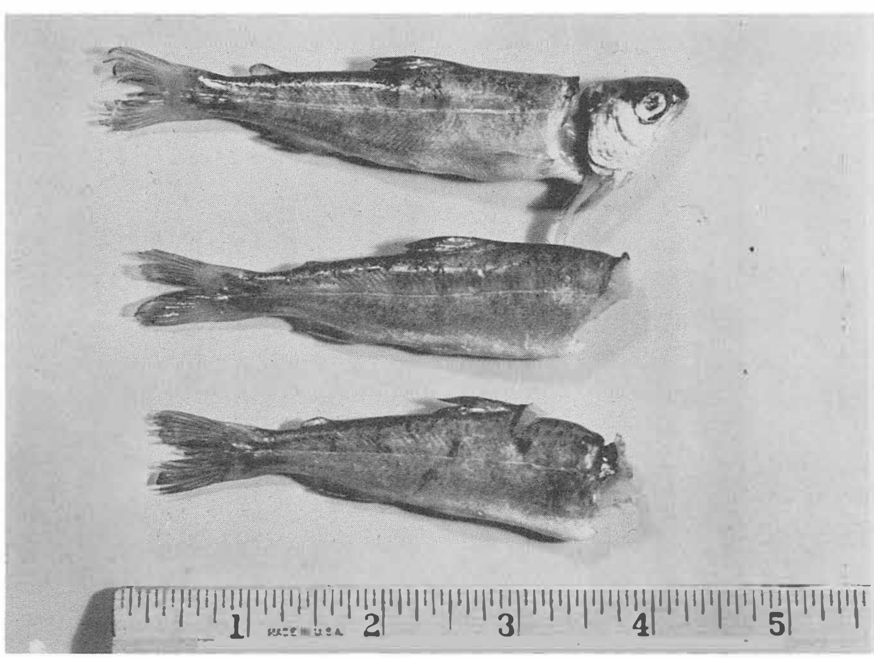

Figure 8.--Fish decapitated during passage through turbine.

DISCUSSION

The funnel net consistently recovered a high percentage of fish released in the net mouth and in the turbine intakes. Mortalities of fish released in the turbine intake and induced by the turbine and the recovery equipment appear to vary in relation to the intake and the release position in the intake. The mortalities of fish released in the net nouth were consistent for each zone of release but varied considerably between zones. Because of the variability in mortality due to the net variabilities, a meaningful assessment of turbine-induced mortalities cannot be made from the fish captured by the recovery equipment. When the recovery equipment has been modified to reduce the variability in mortalities between zones and more data become available on the types of injury occurring within turbines, an assignment of overall turbine mortality can be made.

The differences between mortality rates obtained from releases at different points within the intakes, and the apparent similarity of mortality in relation to the respective release positions, suggest that the fish were passing through the turbine along separate and distinct routes. The mortalities for three groups of fish released at the top in intake A (9. 0, 12. 8, 15. 0 percent), two groups released at the top in intake B (33. 3 and 26. 0 percent), and two groups released at the top of intake C (5. 6 and 7. 2 percent), are similar within the respective intakes although of a different magnitude. Mortality levels appear to be reproducible at these three locations. Some variation of mortality rates between separate releases within intake A may be expected because the fish have a greater distance to traverse and therefore more chance of changing position before entering the turbine. A single deep release in each of the three intakes revealed that while the deep release in intake A (4. 3-percent mortality) was similar in magnitude to the release in intake B (1. 3-percent mortality), these two differed considerably from the deep release in intake C (29. 2-percent mortality). These data imply that the rates of mortality may be defined according to zones of fish passage. If mortality varies with location within the intake, the overall loss of fish may be influenced by manipulating their distribution upstream of turbines.

CONCLUSIONS

1. The recovery system can be successfully used to collect and retain high percentages of fish passing out of draft-tube exits similar to those of turbine number 9 at Bonneville Dam.

2. Modifications to the funnel net are required to reduce the variability in net-caused mortalities so that a meaningful assessment of turbine-induced mortalities can be made.

SUMMARY

Experiments were conducted at Bonneville Dam in the spring of 1964 to evaluate equipment for recovering downstream migrants and to explore the possibilities of safe passage routes for fingerlings through a Kaplan turbine. Coho salmon yearlings 3 to 5 inches long, released in the mouth of the net and in turbine intakes, were recovered in a sanctuary barge after passage through a funnel net which strained the entire flow from one turbine. The fish recovered were observed for mortalities, and the apparent injuries were classified according to type and frequency of occurrence. All tests were conducted with the turbine operating at peak efficiency.

The average recovery rate of fish released in the mouth of the funnel net was 96.5 percent, with a range of 78.2 to 100 percent for individual release. Total mortality was 11 percent, with 9.8 percent occurring within 24 hours after the fish were released. The highest mortalities occurred in the top two sections along the left side and in the top middle section of the net (looking downstream). These mortalities appear to be associated with the water-current patterns and velocities which are greatest at those points.

Recoveries of fish released in the turbine intakes ranged from 83.7 to 97.8 percent and averaged 93.1 percent.

Mortalities from turbine intake releases varied in relation to the intake (A, B, or C) and to the position of release (top or bottom). Highest mortalities occurred from fish released in the top of turbine intake B (33.3 percent), and releases with the least mortalities were from a deep release in intake B (1.3 percent). The mortalities include those incurred in the net. Differences between mortality in relation to release position suggest that fish travel distinct routes through turbines. The mortalities on fish released near the ceiling in intake B (33.3 and 26.0 percent) are of a greater magnitude than mortalities to fish released near the ceiling in either C (5.6 and 7.2 percent) or A intakes (9.0, 12.8 and 15.0 percent). Also, the mortalities from a deep release in intake C (29.2 percent) are of a greater magnitude than from deep releases in intakes A (4.3 percent and B (1.3 percent).

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