FURTHER STUDIES ON FISHWAY SLOPE AND ITS EFFECT ON RATE OF PASSAGE OF SALMONIDS

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ABSTRACT

The rates of passage of chinook (*Oncorhynchus tshawytscha*) and sockeye (*O. nerka*) salmon and steelhead trout (*Salmo gairdneri*) were studied in 1:16- and 1:8-slope, pool-and-overfall fishways. In general, the passage of salmonids through the 1:8-slope fishway with a 1.0-foot rise between pools was as fast as, or faster than, in the 1:16-slope fishway with a 1.0-foot rise. When the rise between pools was increased to 1.5 feet in the 1:8-slope fishway, chinook and sockeye were slower. The "Dalles-type" weir crests in a 1:16-slope fishway appeared to accelerate chinook passage. Chinook and sockeye displayed seasonal differences in times within the species.

The effect of fishway slope [1] on the passage of fish is an important factor in fishway design. Of equal importance is the potential saving in construction costs which will accrue if it can be demonstrated that fishways with steeper slopes pass fish equally as well as the presently accepted standard designs.

Years of water resource development on the Columbia River for irrigation, power, and flood control have produced a multitude of problems relating to the passage of anadromous fishes.

Fish passage requirements and criteria constitute a continuing problem in fishway construction. Varying physical and biological conditions require constant research to meet the demands in each specific instance. Intensive efforts to provide an economical solution to our fish passage problems at dams bring into focus the need for basic information on the reaction of upstream migrant salmon to various physical characteristics of fishways. Until recently little research has been done on fish passage requirements.

Slopes of 1:20, 1:16, and 1:10 are found in existing fishways on the Columbia River. The 1:16 slope has come to be the accepted standard for the larger fishways. If a steeper slope shows equal fish-passing ability, fishway construction costs can be reduced. Scientists at the fisheries-engineering research project, located at Bonneville Dam on the Columbia River, are studying the reaction of migrating salmon to different fishway slopes and other factors that may influence the passage of salmon at dams.[2]

This paper presents a continuation of research, reported by Gauley (1960) on the effect of fishway slope and other factors on the rate of passage of salmonids. The results of this research provide basic information for the solution of fishway problems.

EXPERIMENTAL EQUIPMENT

LABORATORY

The research facilities are adjacent to the Washington shore fishways (figs. 1 and 2). Collins and Elling (1960) present a detailed descrip-

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[1] Fishway slope is defined as the ratio of the rise or vertical distance to the run or horizontal distance.

[2] This project was financed by the U.S. Army Corps of Engineers as part of a broad program of fisheries-engineering research for the purpose of providing design criteria for more economical and more efficient fish-passage facilities at Corps projects on the Columbia River.

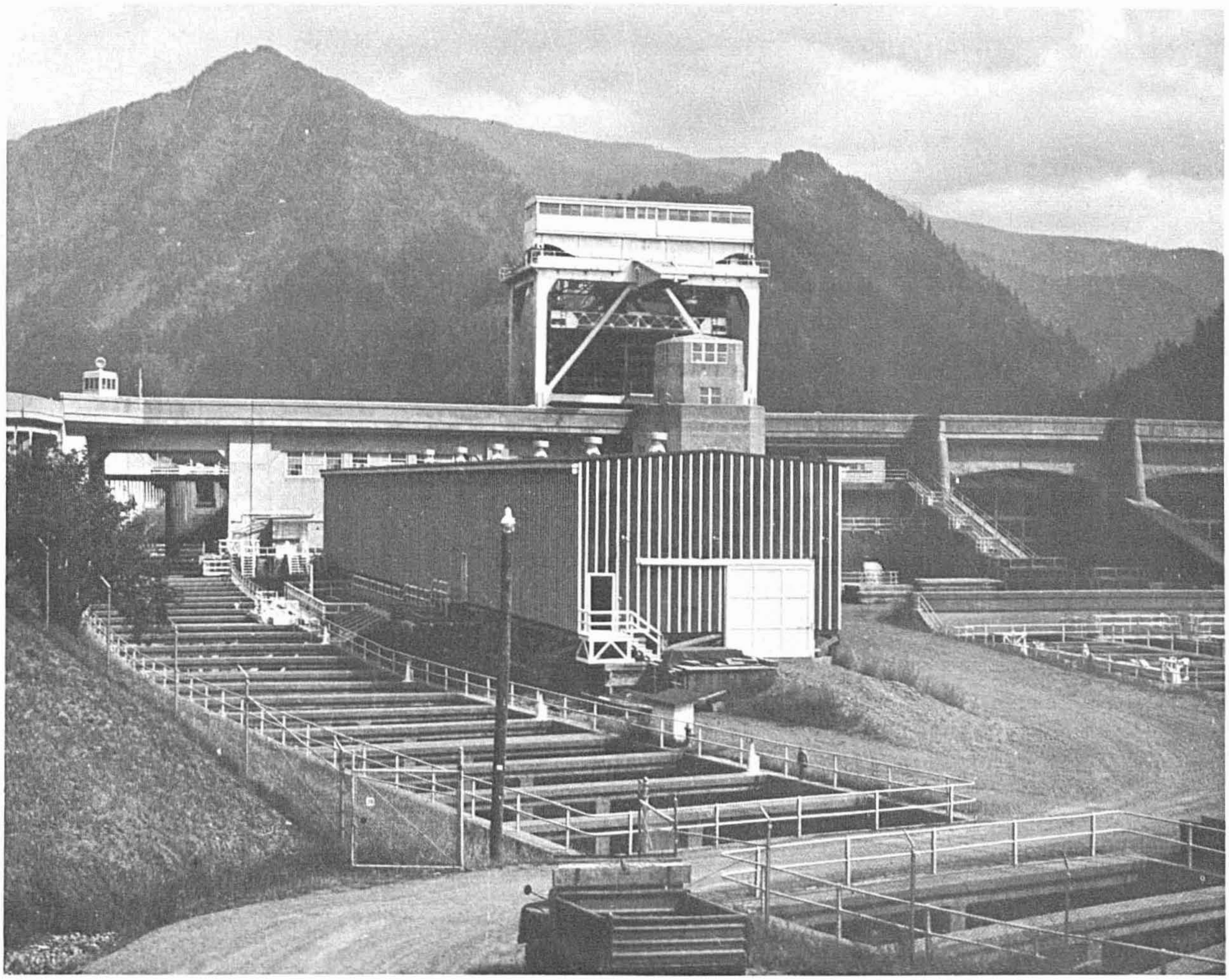

FIGURE 1—Research facilities at Bonneville Dam. The north end of the main dam is shown in the background and part of the Washington shore fishway in the foreground.

tion of the laboratory. In brief, the key features for operation of the facility are (1) the procurement of fish and (2) the introduction and control of water.

A removable picketed lead blocks a small portion of the Washington shore fishway, thus diverting fish into a short entrance fishway leading to a collecting pool in the laboratory. Test fish leave the laboratory through a short exit fishway which returns them to the main fishway.

The water is supplied by two sources and controlled by a system of pipes and valves. Most of the water is supplied from the forebay through a large conduit to the flow introduction pool in the laboratory. The maximum flow is about 200 cubic feet per second (c.f.s.). Water from the main fishway (about 20 c.f.s.) supplies the exit fishway. A series of valves control the inflow of water, and drain valves control the outflow so that hydraulic conditions in the test and control fishway can be accurately controlled.

FISHWAYS

Fish passage was studied in two pool-and-overfall fishways without submerged orifices. The total gain in elevation was the same for both fish-ways, although physical characteristics of each could be altered independently.

Slopes

The experimental fishways were constructed of prefabricated frames and heavy plywood panels. By erecting a center wall, the test area was divided into two passageways 11.5 feet wide. The slopes in both passageways could be made identical, or

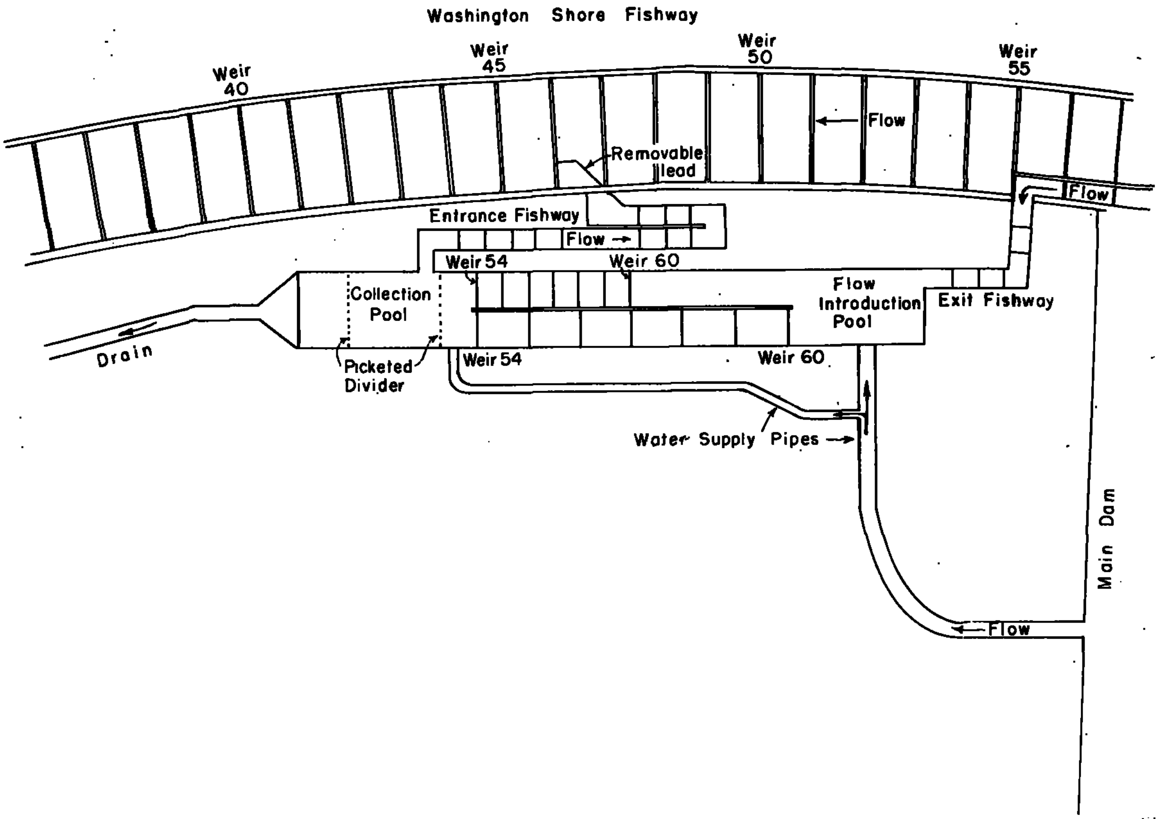

FIGURE 2—General plan of the laboratory, bypass, and associated experimental components. Weir designations indicate elevation in feet above mean sea level.

one could be altered independently without disturbing the other by installing the fishway floors in previously constructed sections to give the desired slope (figs. 3 and 4).

The fishway weirs which were transferable were constructed with concrete bases to reduce buoyancy. By the addition or removal of weirs, rise between pools could be changed. Such changes were made only in the test fishway.

The course of studies utilized two fishway slopes—1:16 (control) and 1:8 (test). The control fishway remained unchanged throughout the season except during a brief period of altered fishway width and weir crests. During the season 1.0-foot and 1.5-foot rises between pools were tested in the 1:8-slope fishway.

Table 1 and figure 5 give the dimensions of fishways used during the 1957 experiments. Hereafter, in the interest of brevity, fishway type numbers will be used to identify the various fishway dimensions and slopes.

TABLE 1.—*Dimensions of fishways used in the slope studies during 1957*

Fishway type	Slope	Number of pools	Pool length	Pool width	Mean pool depth	Rise between pools	Elevation gained
			Feet	*Feet*	*Feet*	*Feet*	*Feet*
1	1:16	6	16.0	11.5	6.30	1.0	6
1 B [1]	1:16	6	16.0	4.0	6.30	1.0	6
2	1:8	6	8.0	11.5	6.30	1.0	6
3	1:8	4	12.0	11.5	6.05	1.5	6

[1] The Dalles-type weir crest (fig. 12) used in this fishway.

Lighting

Controlled light conditions were provided by a battery of 1,000-watt mercury-vapor lamps (fig. 6) which could be adjusted vertically above the water surface, so that identical light intensities prevailed in both fishways. The lamps were suspended vertically 6 feet above the water surface where they produced an average incident light intensity of 700 foot-candles. The range was 300 to 1,000 foot-candles. Light measurements directly beneath the reflectors were highest, whereas the

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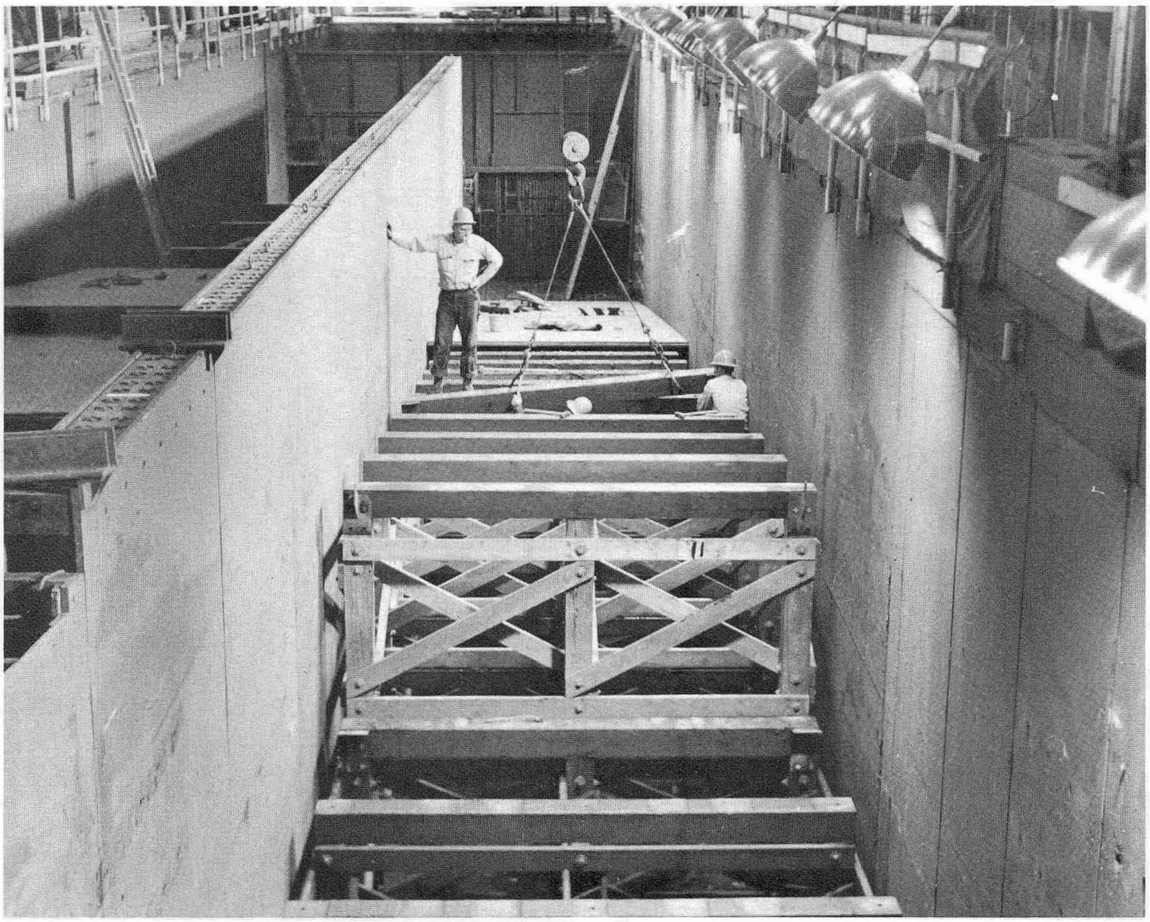

FIGURE 3—Installation of floor frames for the 1:8-slope fishway. A section of floor is in place at the lower end of the fishway.

lower readings were recorded along the walls. These light conditions were comparable to lighting in the main Bonneville fishway during a bright cloudy day.

Hydraulic Conditions

Waterflow through the test area was maintained by regulating the flow of water into the flow introduction pool. Keeping a constant head on the uppermost weir crest permitted maintenance of the water flowing over the fishway weirs at a head of 0.8 foot measured 4 feet upstream from the weir crest. This was the maximum depth at which the desired plunging flow over the weir crests could be stabilized. More water caused a streaming flow in the fishways, which had been demonstrated to temporarily interrupt fish passage (Elling and Raymond, 1959).

METHODS

Release and timing of fish

To evaluate properly the effects of fishway slope on salmonids, the performance of each species both as an individual and in groups, as well as the composite performance of all species must be considered. With this in mind we employed the following three types of releases: (1) an individual fish ascending the fishway alone, (2) groups in which 21 fish of the same species were timed as a group, and (3) mass releases representing all species available.

Individuals

Fish were released into both fishways through the picketed divider at the upstream end of the collection pool. Figure 7 is a side view looking down on the release compartment. The collection

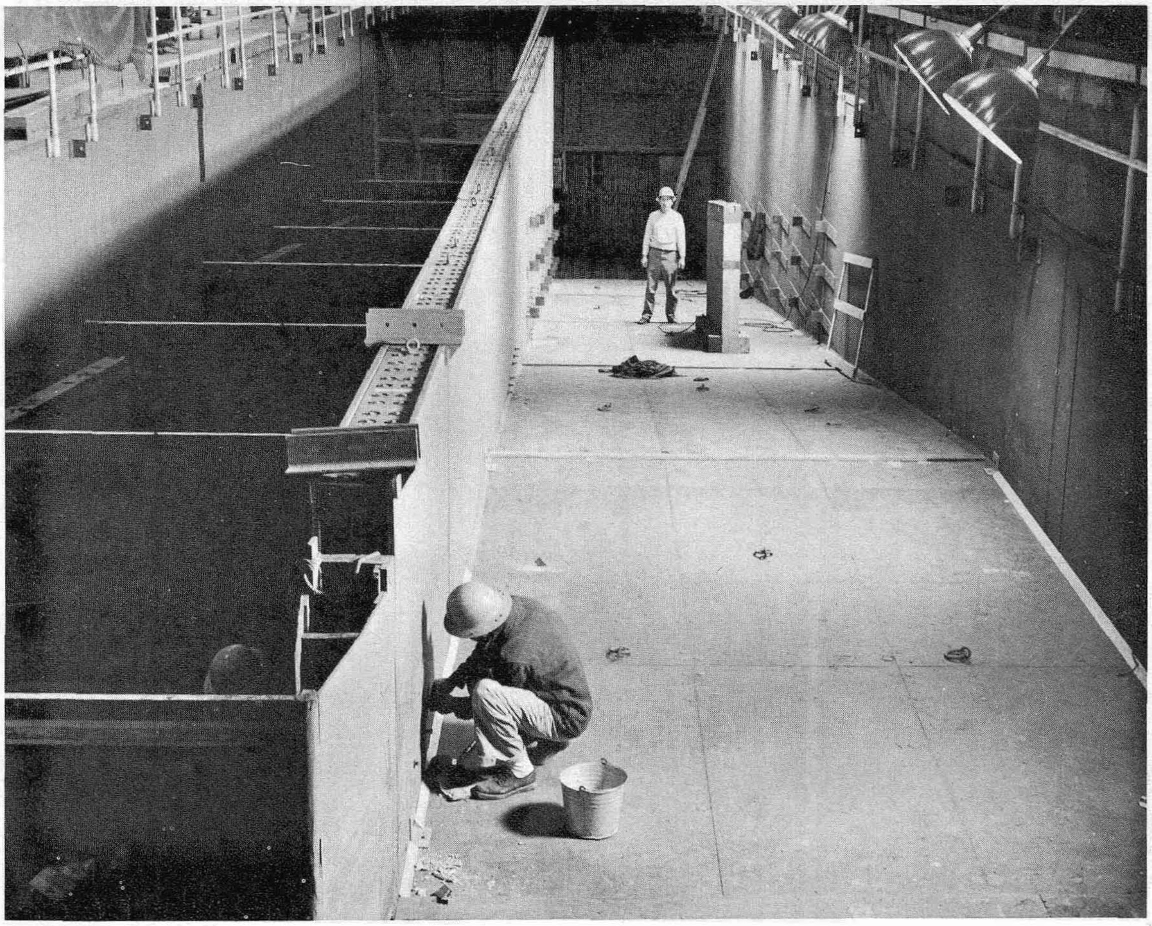

FIGURE 4—The 1:8-slope fishway floor. Wall brackets mark the locations for weirs.

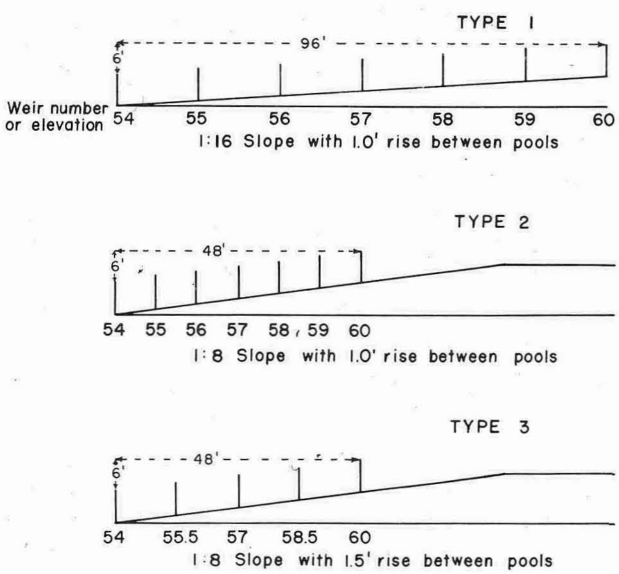

FIGURE 5.—Diagrammatic drawing showing weir placement for the two fishway slopes.

pool is visible at the left margin behind the divider.

The operator at the left has raised the entrance gate to the release compartment to admit a fish from the collection pool, while the operator on the right is preparing to raise the exit gate to the introductory area leading to the test fishway. The second exit gate leads to the control fishway. As each fishway was vacated, another fish was released into the vacant fishway.

During the brief passage through the release compartment each fish was identified by species, and its length was estimated.

The time spent in each pool (pool time) and the total time required to ascend the fishway were kept on separate stop watches. Pool times were obtained by an observer starting one watch and stopping a second one simultaneously as the fish crossed each weir. A second observer timed

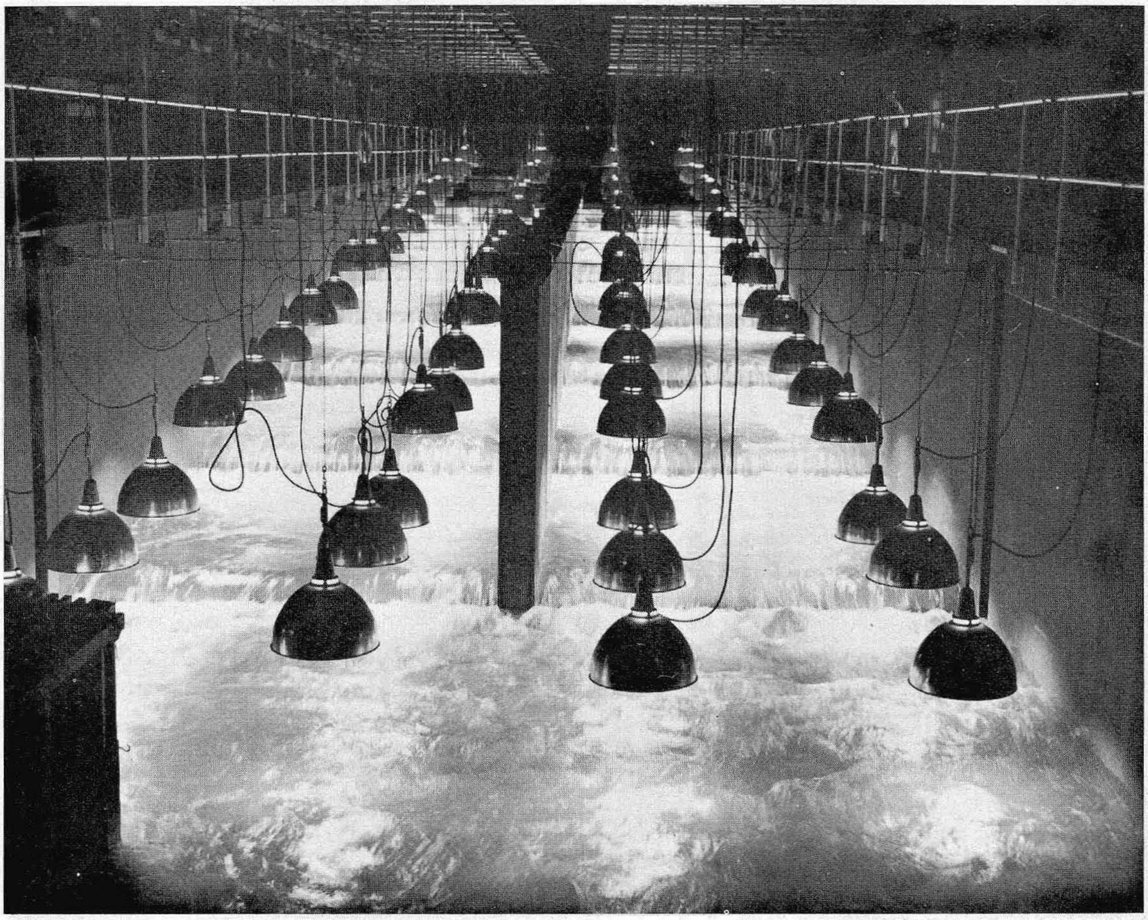

FIGURE 6.—Identical type-1 fishways with 1,000-watt mercury-vapor lights in place. Each light was 6 feet from the water surface.

the fish as it entered and left the fishway, thus obtaining total time spent in the fishway, which could be checked against the sum of the pool times. This method for timing individuals was used by Gauley (1960) for fishway slope experiments at Bonneville.

Groups

Rapid releases of individuals of the same species were made until 21-fish groups were introduced into each fishway. The releasing procedure was similar to that used for individual releases. Fish were released alternately into the test and control fishway until a total of 21 fish had been introduced into each fishway. Lengths were again noted for all fish that entered.

Passage time for group releases was recorded by a 20-pen recorder (fig. 8). The electrically operated recorder was used to tally on a chart all fish entering and leaving each fishway. When contact buttons were pressed at the counting station, a mark was made on the chart. A button at each counting station activated a different pen on the chart. Passage time of the fish was then determined from recorded chart times.

Two observers were stationed at the downstream and upstream ends of each fishway. At the lower end (weir 54) one counter tallied successful passages, while the second counter tallied fish that dropped back out of the test area.

Mass Releases

For these tests, fish were admitted to the introductory pool by raising a section of the picketed divider below each fishway. Thus a number could enter the control and test fishways simultaneously.

To control the number of fish entering, two sizes of release gates were used: A 10-inch wide

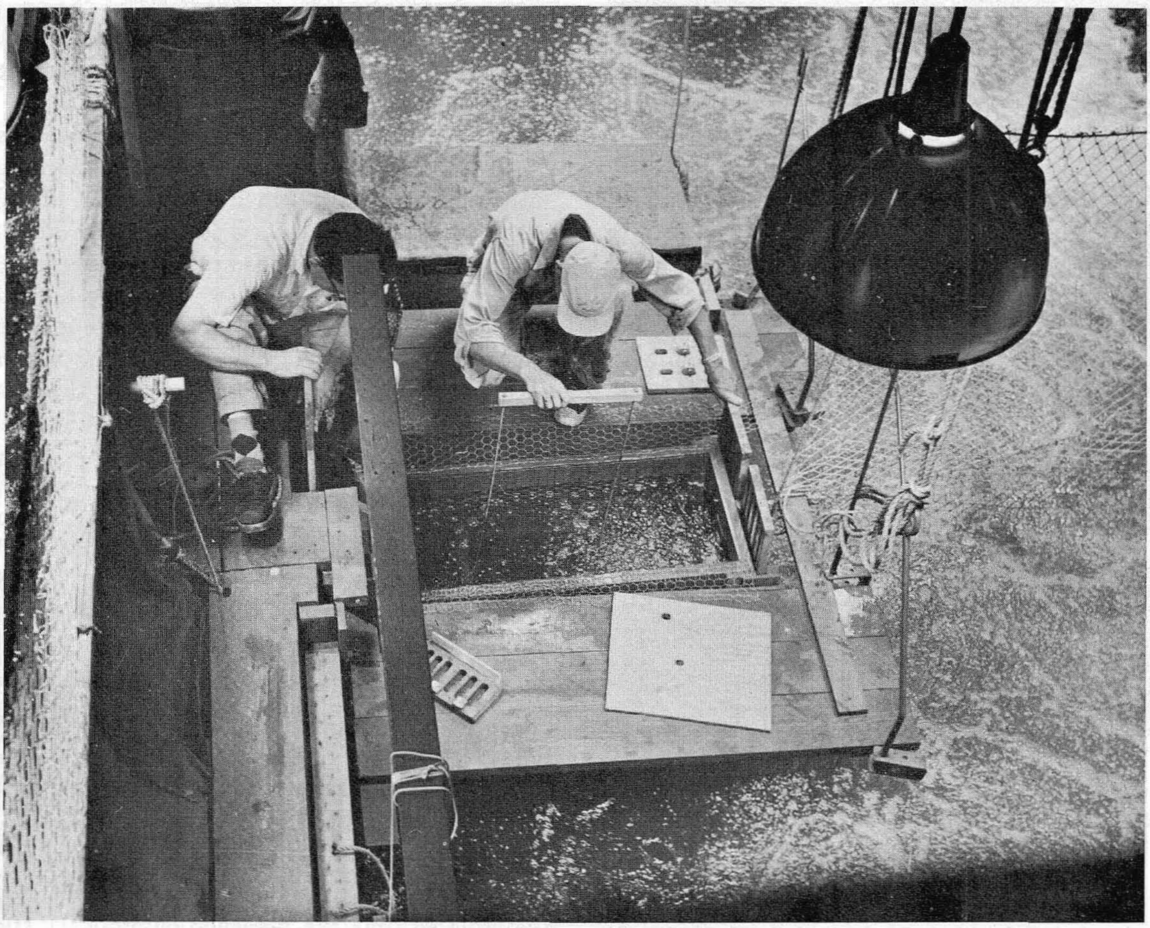

FIGURE 7.—The release compartment. The two exit gates are below the lamp reflector.

opening when fish were in ample supply and a 5-foot opening when fish were less plentiful.

The mass release timing procedure was essentially the same as that used for group releases. Because mass releases were composed of mixed species, it was necessary to identify each fish as it left the fishway at weir 60.

ANALYSIS OF PASSAGE TIMES

Passage time was used as a measure of performance of salmonids in the different fishways tested. The statistic employed and method of analysis varied among individuals, groups, and mass releases, depending on the adaptability of the data to statistical treatment.

Individuals

Median passage times of individuals were compared, and differences between fishways were determined by using 95 percent confidence intervals for the median (Dixon and Massey, 1951). Median passage times with the upper and lower limits are shown in table 2. The median was used in preference to the mean because of the high variance which generally occurred within the passage times in each fishway.

Groups

Both the median elapsed and the mean times were used to evaluate group (21 fish) passage times.

The median elapsed time is defined as the time differences between the median fish entering the fishway and the median fish existing at weir 60. This was determined simply by subtracting the time of the median fish over weir 54 from the time of the median fish over weir 60.

The application of median elapsed time to group releases occasionally appeared to be of limited value as a measure of passage time, because of aberrant values resulting when entry times into

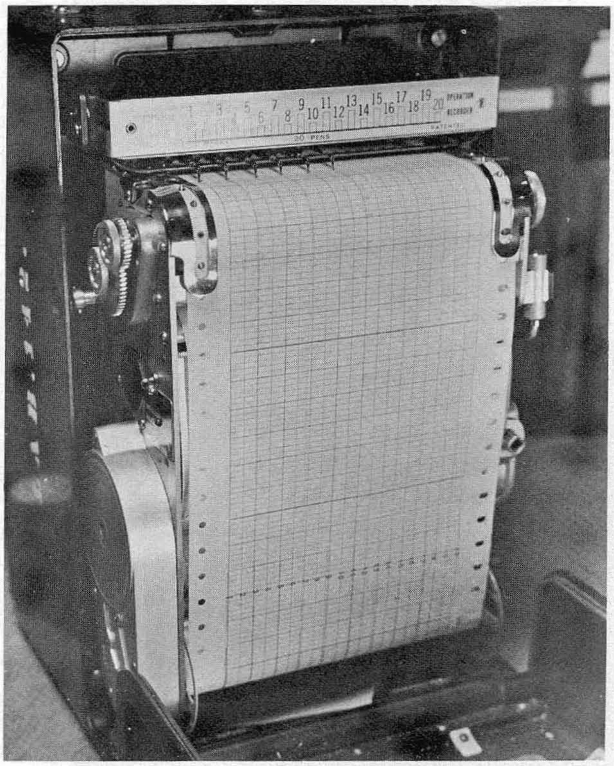

FIGURE 8.—The 20-pen operation recorder used to record passage times during group and mass releases. Six pens are in operation.

the release compartment were prolonged. This situation occurred only when fish were scarce or were reluctant to enter and pass through the release compartment. Consequently, the analysis of median elapsed time of group releases was limited to releases in which the introductory time was less than 1 hour.

The mean passage time is the difference between the mean time of the group over weir 54 and the mean time of the group over weir 60. In some instances it was necessary to assign an arbitrary exit time for individuals that did not cross weir 60.

If a fish had not passed weir 60 one hour after the last fish had gone over weir 54, one more hour was added and the resulting exit time was used in the determination of the mean exit time for all fish. Differences between passage times in the two fishways were tested by a t test on the means or medians at the 95 percent level.

Mass Releases

Mass releases were evaluated by comparing median elapsed times only. Again t tests were applied to determine if differences existed between the passage times of the test and control fishways. Here, t tests were applied to means of the median elapsed times.

The analysis of passage time for each mass release was accepted as being applicable to the dominant species of salmon. As pointed out earlier, however, mass releases included all species available so that the presence of minority species may have influenced the passage times during

TABLE 2.—*Median passage times with lower and upper limits of the 95 percent confidence intervals for chinook, sockeye, and steelhead individuals*

[Table A-25 Dixon and Massey, 1951]

Species	Date	Fishway type [1]	No. in sample	Passage time (minutes)		
				Lower limit	Median	Upper limit
Chinook:						
North	April 16–25	1	38	12.53	17.22	29.46
South		1	52	8.58	14.18	18.30
Test	May 15–16	[2] 1	13	3.47	6.23	24.73
Control		1	10	8.15	12.68	70.08
Test	April 29–May 7	[2] 1 B	69	4.65	6.22	9.02
Control		1	39	7.82	12.97	17.75
Test	May 31–June 7	2	74	7.33	9.88	12.03
Control		1	56	10.50	13.80	16.88
Test	June 12–July 9	3	46	9.73	15.10	31.37
Control		1	68	6.90	10.26	12.37
Sockeye:						
Test	July 12–18	2	111	1.20	1.40	1.90
Control		1	72	11.45	14.66	16.43
Test	June 13–July 9	3	65	7.85	12.30	15.42
Control		1	82	7.53	9.28	9.83
Steelhead:						
Test	April 29–May 7	[2] 1 B	10	5.90	11.26	15.08
Control		1	15	5.35	11.88	18.55
Test	May 31–June 6	2	8	4.12	9.98	28.97
Control		1	6	2.42	10.04	15.17
Test	June 12–July 9	3	33	2.95	6.68	11.22
Control		1	29	2.38	6.48	8.87

[1] See table 1.

[2] The Dalles-type weir crests installed.

these releases. This factor was not present during individual and group releases.

RESULTS

1:16-SLOPE, 1.0-FOOT RISE

Before attempting to determine the effect of slope on the rate of passage of salmonids, we designed an experiment to determine whether passage times were the same in both channels of the experimental flume. If passage times were equal, then any difference found after slope had been altered could be attributed to factors resulting from the difference in slope. Two conventional 1:16-slope fishways with a 1.0-foot rise between pools were installed, one in each channel (fig. 9), and a series of tests, using individuals, groups, and mass releases, were conducted. Results are based mainly on chinook (*Oncorhynchus tshawytscha*), the dominant species in the fish run at the time the tests were conducted.

Thirty-eight individual chinook were tested in the north fishway and 52 in the south fishway. The median passage time was 17.22 minutes in the north fishway and 14.18 minutes in the south. Although the median time was slightly less in the south fishway, it was not significantly so.

Five groups of 21 chinook were timed in their passage through each fishway. The median elapsed passage times are given in table 3. A *t* test on the mean of the median elapsed times indicated there was no significant difference between the passage times in the two fishways.

The results of two mass releases comprised mainly of chinook (table 4) were similar to the individual and group tests which indicated that no difference existed between passage times in the two fishways.

FIGURE. 9—Identical type-1 fishways used to test for equal passage times in the north (on the left) and south channels. The mercury-vapor lamps were removed to provide an unobstructed view of the fishways.

TABLE 3.—*Median elapsed passage times of 5 groups of 21 chinook in two type-1 fishways, Apr. 23–26, 1957*

Date	North fishway	South fishway
	Minutes	*Minutes*
Apr. 23	17.80	18.17
Apr. 24	13.02	24.78
Apr. 25	18.68	12.92
Do	15.43	16.75
Apr. 26	26.11	23.41
Mean	18.21	19.22

t .617
P >.05

TABLE 4.—*Median elapsed passage times and species composition [1] of two mass releases in two type-1 fishways, Apr. 19 and 26, 1957*

Date	North fishway			South fishway		
	Species composition		Median elapsed time	Species composition		Median elapsed time
	Chinook	Steelhead		Chinook	Steelhead	
	Number	*Number*	*Minutes*	*Number*	*Number*	*Minutes*
Apr. 19	61	18	29.53	68	6	33.87
Apr. 26	111	10	34.55	132	10	29.51
Mean			32.04			31.69

[1] Species identification was made as fish left the fishway at weir 60.

1:8-SLOPE 1.0-FOOT RISE

Since the two sides (north and south) must be considered uniform on the basis of the tests, the 1:16-slope fishway in the north channel was removed and a 1:8-slope fishway with a 1.0-foot rise between pools (type 2) was installed (fig. 10). The south fishway was left unchanged to be used as the control fishway. Table 1 gives comparisons of the physical characteristics of the two fishways.

Chinook

Seventy-four individual chinook were timed in the test fishway and 56 in the control fishway from May 31 to June 7. The median passage times were 9.88 and 14.00 minutes, respectively. A table of confidence intervals for the median indicates that the passage time was significantly less in the test fishway.

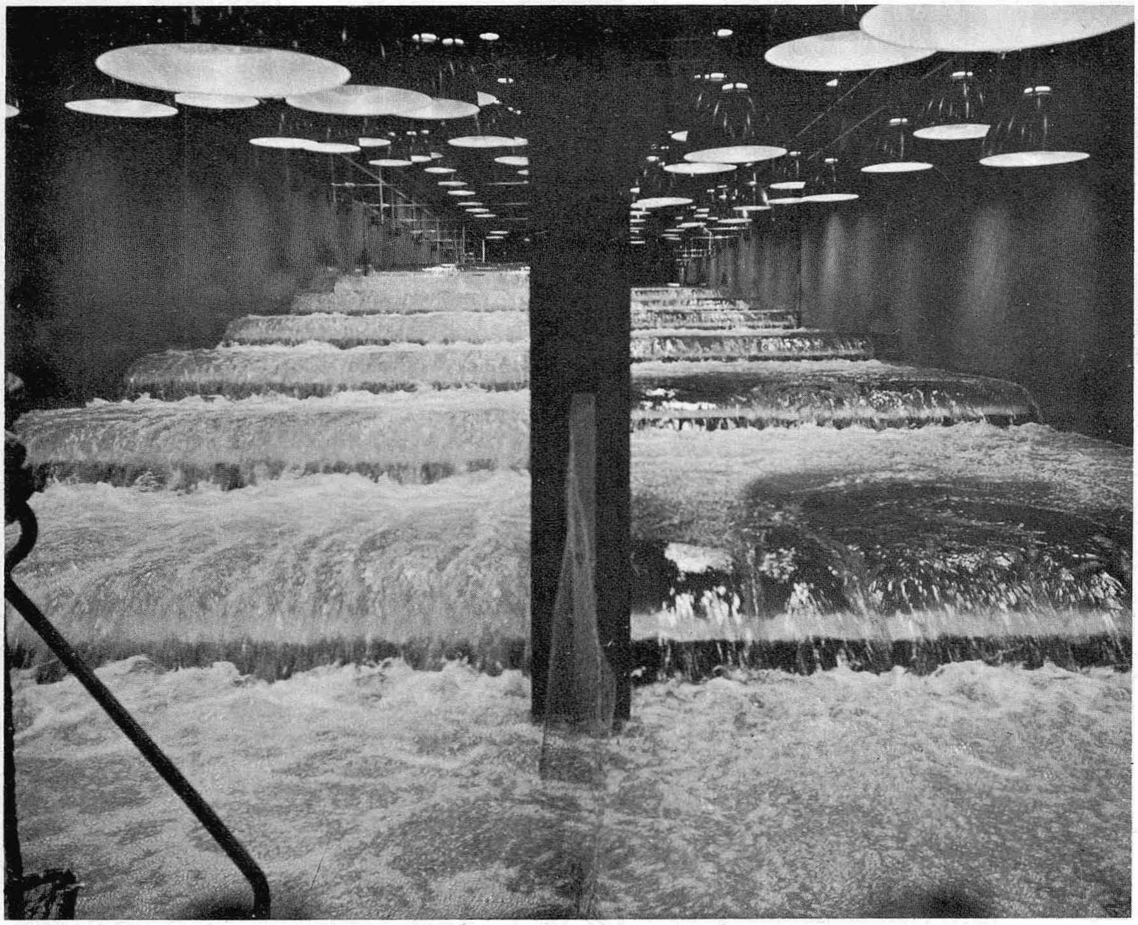

FIGURE 10.—A type-2 fishway on the left and a type-1 on the right. Note the greater turbulence in the type-2 fishway.

TABLE 5.—*Median elapsed and mean passage times of 4 groups of 21 chinook timed in type 2 and type-1 fishways, May 29 and June 5, 1957*

Date	Median elapsed time		Mean time	
	Test type-2 fishway	Control type-1 fishway	Test type-2 fishway	Control type-1 fishway
	Minutes	*Minutes*	*Minutes*	*Minutes*
May 29	11.37	12.33	8.28	18.70
Do	15.08	14.60	20.20	19.05
Do	19.57	19.19	17.73	15.27
June 5[1]			17.79	13.05
Mean	15.34	15.37	16.00	16.52
t	.001		.299	
P	>.05		>.05	

[1] Median elapsed times were not used because entry period exceeded 1 hour.

A comparison of the median elapsed and mean passage times of four groups of 21 chinook timed through the test and control fishways is given in table 5. A t test on the means of the median elapsed times indicated there was no significant difference between passage times in the two fishways. Likewise, an analysis on the means of the mean passage times gave similar results.

A comparison of the median elapsed passage times of six mass releases comprised chiefly of chinook salmon timed through the test and control fishways is given in table 6. Species composition

TABLE 6.—*Median elapsed times of six mass releases tested in type 2 and type-1 fishways, May 29 to June 7, 1957*

Date	Test type-2 fishway	Control type-1 fishway
	Minutes	*Minutes*
May 29	12.76	11.18
June 3	15.79	10.89
June 5	23.42	18.67
June 6	21.00	22.48
Do	21.47	17.13
June 7	13.64	12.52
Mean	18.01	15.48
t	.952	
P	>.05	

of these releases is given in table 7. A t test on the means of the median times indicated there was no significant difference between the passage times in the test and control fishways.

At the present time, we cannot offer an explanation for the difference between results obtained from individual chinook passage times and chinook released as a group and those released en masse. Individual passage times were significantly less in the test fishway than in the control fishway, but group and mass releases indicated no significant difference between passage times in the two fishways.

TABLE 7.—*Species composition* [1] *of mass releases tested in type 2 and type-1 fishways, May 29 to June 7, 1957*

Date	Test type-2 fishway			Control type-1 fishway		
	Chinook	Steelhead	Other [2]	Chinook	Steelhead	Other [2]
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
May 29	65	3		36	2	1
June 3	35	1	16	39	4	7
June 5	13	2	8	37	1	2
June 6	40	1	2	48	3	2
Do	67	1		88	4	1
June 7	33		1	29	2	1

[1] Species identification was made as fish left the fishway at weir 60.
[2] Mostly suckers (*Catostomus sp.*) and squawfish (*Ptychocheilus sp.*).

Sockeye

Tests were conducted on individual sockeye (Columbia River blueback) from July 12 through July 18. A scarcity of this species at this time precluded the use of group or mass releases for comparative purposes. Seventy-two sockeye were timed in the control fishway and 111 in the test fishway. The median times were 14.66 minutes and 1.40 minutes, respectively. Based on the confidence intervals about the medians, a significantly faster ascent was achieved in the test fishway than in the control. Note the striking differences in passage times between the two fishways. This difference was also apparent in the mean passage times (5.98 minutes in the test compared to 16.06 minutes in the control).

This rapid passage time in the test fishway gives rise to several questions. Would these fish react the same way in a longer fishway surmounting a dam? Could they continue at the same rate in a longer fishway, and if so, would this impair their ability to reach the upriver areas and spawn? Examination of these questions will be undertaken in future experiments.

Steelhead

Only 14 individuals were tested during May 31 to June 6, eight in the test fishway and six in the control fishway. The median times based on these small samples are 9.98 and 10.04 minutes respectively, indicating no difference between passage times.

Four mass releases were made in which steelhead comprised the principal species passed (table 8).

The median elapsed times in the test and control fishways are given in table 9. A t test on the

TABLE 8.—*Species composition* [1] *of four mass releases timed through type-2 and type-1 fishways, July 15–18, 1957*

Date	Test type-2 fishway				Control type-1 fishway			
	Chinook	Steelhead	Sockeye	Other [2]	Chinook	Steelhead	Sockeye	Other [2]
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
July 15	111	173	9	16	39	115	6	4
July 16	38	114	10	3	24	80	7	2
July 17	42	85	7	-------	12	77	8	3
July 18	25	111	12	6	9	67	3	2

[1] Species identification was made as fish left the fishway at weir 60.
[2] Carp (*Cyprinus* sp.), squawfish (*Ptychocheilus* sp.), and suckers (*Catostomus* sp.).

TABLE 9.—*Median elapsed times of four mass releases timed through type-2 and type-1 fishways, July 15–18, 1957*

Date	Test, type-2 fishway	Control, type-1 fishway
	Minutes	*Minutes*
July 15	8.98	16.02
July 16	9.22	11.59
July 17	7.75	12.23
July 18	6.50	13.75
Mean	8.11	13.35
t	4.492	
P	<.05	

means of the median elapsed times for the two fishways indicated that the passage time through the test fishway was significantly less. This agrees with the conclusion drawn from research in 1956 (Gauley, 1960); groups of 20 steelhead ascended a similar test fishway in less time than they did the control fishway.

1:8-SLOPE, 1.5-FOOT RISE

In the following series of experiments the 1:8-slope fishway was modified to the condition employing 12-foot pools with a 1.5-foot rise between pools (type 3). It should be noted that an increase in rise between pools changes the flow over the weirs; water velocity increases, and water depth decreases. The control fishway remained unchanged (type 1). The two fishways are illustrated in figure 11.

Chinook

Individual passage times for two periods (June 12–20 and June 28 to July 9) were combined to provide a larger sample. This combination allows comparison of 46 individuals in the test fishway and 68 in the control fishway. The median time of chinook in the test fishway trials (15.10 minutes) was 5 minutes greater than the median time of the controls (10.26 minutes). Although there was approximately a 5-minute difference in passage times, this was not statistically significant.

TABLE 10.—*Median elapsed and mean passage times (minutes) of seven groups of 21 chinook tested in type-3 and type-1 fishways, June 13–19, 1957*

Date	Median elapsed time		Mean time	
	Test, type-3 fishway	Control, type-1 fishway	Test, type-3 fishway	Control, type-1 fishway
June 13	18.65	10.58	24.16	15.03
June 13 [1]			29.96	9.74
June 14	20.19	10.18	48.47	21.21
June 18	20.91	10.80	33.38	10.76
Do	17.40	13.25	37.23	10.02
June 19	18.28	16.05	17.79	14.76
Do	15.65	12.96	17.81	19.26
Mean	18.51	12.30	29.83	14.40
t	5.065		3.405	
P	<.05		<.05	

[1] Median elapsed times were not used because entry period exceeded 1 hour.

The means of the median elapsed and the mean passage times for seven groups of 21 chinook are given in table 10. A t test on the means of the median elapsed times indicated that passage in the test fishway was significantly slower than in the control fishway. A similar analysis on the means of the mean passage times gave the same results.

Four mass releases, containing a preponderance of chinook, were made in the test and control fishways. Species composition for these releases are presented in table 11. Table 12 gives the

TABLE 11.—*Species composition* [1] *of four mass releases passing through type-3 and type-1 fishways, June 12 to July 1, 1957*

Date	Test type-3 fishway			Control type-1 fishway		
	Chinook	Steelhead	Sockeye	Chinook	Steelhead	Sockeye
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
June 12	44	3	---------	49	5	---------
June 13	22	---------	---------	31	4	---------
June 19	79	3	3	116	18	12
July 1	24	8	9	42	14	14

[1] Species identification was made as fish left the fishway at weir 60.

TABLE 12.—*Median elapsed times (minutes) of four mass releases tested in type-3 and type-1 fishways, June 12 to July 1, 1957*

Date	Test type-3 fishway	Control type-1 fishway
June 12	23.85	20.72
June 13	18.46	17.36
June 19	25.75	11.05
July 1	27.97	23.01
Mean	24.01	18.04
t	1.798	
P	>.05	

FIGURE 11.—A type-3 fishway (left) and a type-1 fishway (right).

median elapsed times for four releases in the test and control fishways. In each of the four releases the passage time was greater in the test fishway but a *t* test on the means of the median elapsed times indicated no significant difference between passage times in the two fishways. Here, as was also the case with individual chinook, passage times in the test fishway (type 3) were greater than in the control fishway (type 1) but not significantly so.

Sockeye

Passage times of individual sockeye for the two periods June 13–20 and June 28 to July 9 were combined into a single sample as was done for chinook. The median passage time of 66 sockeye in the test fishway was 12.30 minutes while in the control fishway the median time of 82 sockeye was 9.28 minutes. Although the median time in the test fishway was greater by 3 minutes, there was no significant difference between the passage times in the two fishways.

The median and mean passage times of five groups of sockeye are presented in table 13. Although the passage time was consistently greater in the test fishway, a *t* test on the means of the median elapsed times indicated there was no significant difference between passage times in the two fishways. A similar analysis on the means of the mean passage time gave the same results.

Steelhead

These tests comprised only the passages of individual fish. No group or mass releases were made. The passage time for the two periods June 12–20 and June 28 to July 9 were combined. The median passage times of 33 individuals in the test fishway and 29 in the control fishway were 6.68 minutes and 6.48 minutes, respectively. A comparison of these times indicated there was no

TABLE 13.—*Median elapsed and mean passage times (minutes) of five groups of 21 sockeye tested in type-3 and type-1 fishways, July 3–10, 1957*

Date	Median elapsed time		Mean time	
	Test type-3 fishway	Control type-1 fishway	Test type-3 fishway	Control type-1 fishway
July 3	17.19	15.20	25.99	9.64
July 5	25.50	9.09	17.75	16.02
July 8	15.25	16.19	25.39	18.05
July 9	16.72	12.56	14.27	12.12
July 10	37.10	25.78	34.88	25.80
Mean	22.35	15.76	23.66	16.33
t	1.330		1.615	
P	>.05		>.05	

significant difference in the passage time of steelhead in the test (type 3) fishway and the control (type 1) fishway. Previous experiments by Gauley (1960) yielded similar results.

Other Fish

At certain times during the summer fairly large numbers of carp, squawfish, and suckers ascend the Bonneville fishways. It is desirable to know how these species respond to different fishway conditions.

A mass release of June 18 contained a large percentage of squawfish and suckers. A total of 269 fish entered the control fishway, and approximately the same number passed through the fishway. These were identified as they passed out of the fishway at weir 60. Of the 269 fish, 159 (59 percent) were nonsalmonids. In the test fishway, of 196 entering, only 57 went out at weir 60. Of the 57 fish, seven (12 percent) were nonsalmonids. Assuming that equal proportions of nonsalmonids entered both fishways the suggestion is that the 1:8-slope fishway with a 1.5-foot rise between pools inhibits the passage of squawfish and suckers.

Other factors affecting passage time

Throughout the course of experiments and during the analysis of data on fishway passage times, it became apparent that factors other than fishway slope might have affected the passage time of salmonids through a given fishway. The supplementary nature of data concerning these factors preclude a thorough analysis. Numerous factors were considered, but to date only three—(1) the Dalles-type weir crest, (2) seasonal variation, and (3) rise between pools—have yielded enough information for a brief discussion.

The Dalles-Type Weir Crests

The Dalles-type weir crests (fig. 12) were installed in the south fishway in conjunction with other studies. This installation made possible the comparison of the fish-passing ability of this type of weir crest with the conventional square weir crests in the north fishway.[2] Chinook and steel-

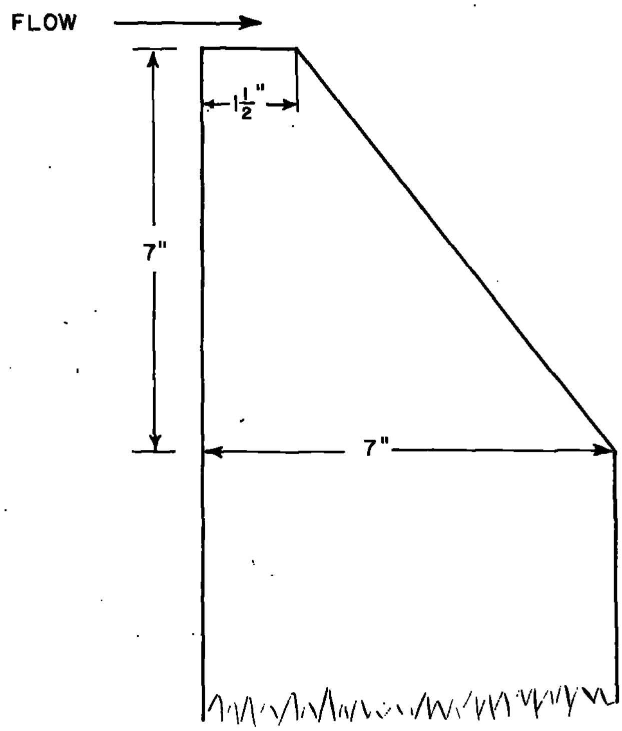

FIGURE 12.—Cross section view of the Dalles-type weir crest.

head individuals were timed through type-1 and type-1, *B* (fig. 13), fishways. (See table 1 for fishway dimensions.)

Three comparisons between the two weir crests and two fishway types, given in table 14, indicate the following with respect to chinook passage: Case 1—chinook moved faster in a 11.5-foot-wide fishway having Dalles-type weir crests than in a similar fishway having square weir crests; Case 2—chinook moved faster in a 4-foot-wide fishway having Dalles-type weir crests than in a fishway 11.5 feet wide having square weir crests; Case 3—there was no difference between chinook passage times in the wide and narrow fishways with the Dalles-type weir crest. Thus, in case 2, the ac-

[2] Here, the Dalles-type weir crest is a sharp crested weir and the square weir crest is considered a broad crested weir. With equal heads on both weir types, the flow over the sharp crested weir will be approximately 10 percent greater.

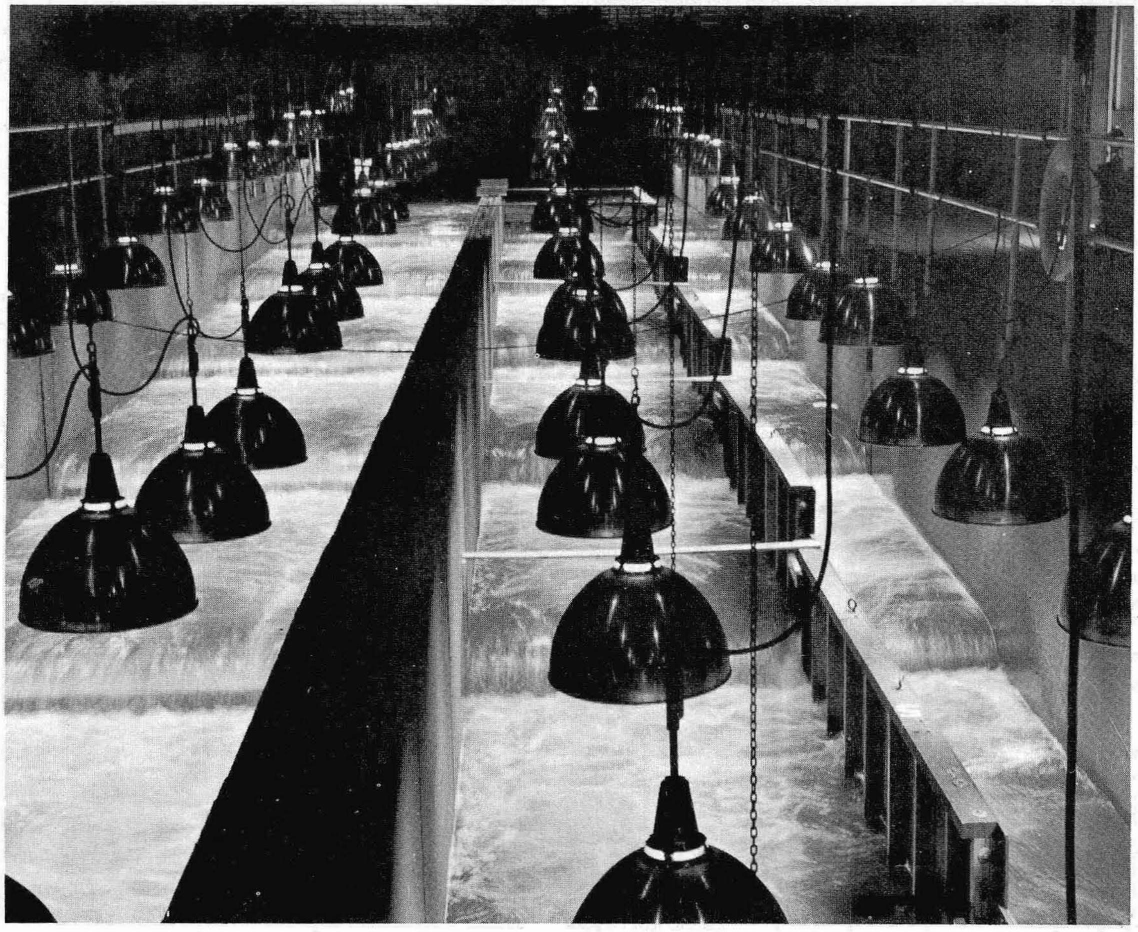

FIGURE 13.—The type-1, *B*-fishway (extreme right), created by installing a partition wall in a type-1 fishway.

TABLE 14.—*Comparisons between the Dalles-type and square type weir crests using individual chinook passage times in type-1 and type-1 B fishways, Apr. 29 to May 16, 1957*

Case	Fishway type	Sample size	Lower limit	Median	Upper limit
		Number of fish	*Minutes*	*Minutes*	*Minutes*
1	Type 1, square crests	10	8.15	12.68	70.08
	Type 1, Dalles crests	13	3.47	6.23	24.73
2	Type 1, square crests	39	7.82	12.97	17.75
	Type 1 B, Dalles crests	69	4.65	6.22	9.02
3	Type 1, Dalles crests	13	3.47	6.23	24.73
	Type 1 B, Dalles crests	69	4.65	6.22	9.02

celerated passage of chinook in the type-1, B fishway appears to have been a function of the Dalles-type weir crests rather than fishway width.

By contrast, a comparison between the passage times of 10 steelhead in a type-1, B fishway having Dalles-type weir crests and 15 steelhead in a type-1 fishway having square crests, showed no difference between the median passage times in the two fishways.

The Dalles-type weir crest appeared to be more advantageous for chinook passage than the square-type crest. Perhaps this is due to the greater flow of water over the sharp-crested weir, the oblique plane of the weir crest, or a combination of factors. The fact that steelhead were not accelerated by the Dalles-type crest suggests that some difference in species or size may affect an individual's ability to negotiate weir crests of different designs.

Seasonal Variation

Previous experiments in 1956 (Gauley, 1960) indicated there was a seasonal variation in passage time of steelhead through the control fishway. In the recent experiments, chinook and sockeye were examined to determine if this were also true for these species. Only passage times in the type-1 (control) fishway were used as this fishway was not altered and provided for passage time comparisons during most of the season.

Individual passage times were used to compare three periods of chinook migration, April 16 to May 7, May 31 to June 7, and June 12 to July 9, corresponding roughly to the spring run, an intermediate peak, and the summer run (fig. 14). The

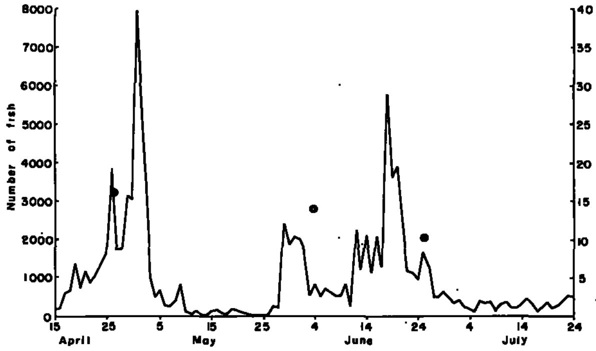

FIGURE 14.—The variation in median passage times (round dots) of chinook individuals during three segments of the run passing Bonneville Dam. The run (solid line) is represented by the daily counts in the Washington shore ladder, 1957. (Daily chinook count obtained from Corps of Engineers.)

median passage times presented in table 15 indicate that individual chinook in the summer period (June 12 to July 9) moved significantly faster than during the other two periods.

TABLE 15.—*Median passage times of chinook tested in a type-1 fishway during three periods, Apr. 16 to July 9, 1957*

Date	Sample size	Lower limit	Median	Upper limit
	Number of fish	*Minutes*	*Minutes*	*Minutes*
Apr. 16–May 7	129	11.60	15.90	17.75
May 31–June 7	56	10.50	13.80	16.88
June 12–July 9	68	6.90	10.26	12.37

Group releases of chinook revealed basically the same result. An analysis of variance on the means of the median elapsed times (table 16) showed a significant difference between the means of the three periods.

Passage times of individual sockeye in a type-1 fishway are available for comparison throughout most of the run. For analysis, the passage times were divided into two groups: June 13 to July 5 and July 8–18, representing the first and last half of the sockeye run (fig. 15). A comparison of the median passage times presented in table 17 indicates that fish in the first part of the run were

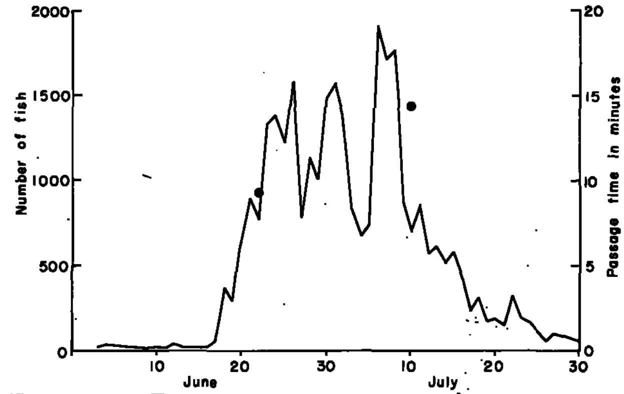

FIGURE 15.—The variation between median passage times (round dots) of sockeye individuals in the first half and the last half of the run passing Bonneville Dam. The run (solid line) is represented by the daily counts in the Washington shore ladder, 1957. (Daily sockeye count obtained from Corps of Engineers.)

TABLE 16.—*Median elapsed times (minutes) of groups of chinook tested in a type-1 fishway during three periods, Apr. 23 to June 19, 1957*

	April 23–26	May 29–June 7	June 13–19
	18.17	12.33	10.58
	24.78	14.60	17.61
	12.92	19.19	10.18
	16.75	12.90	10.80
	23.41		13.25
			16.05
			12.96
Mean	19.22	14.76	13.06

TABLE 17.—*Median passage times of two groups of sockeye tested in a type-1 fishway during June 13–July 18, 1957*

Date	Sample size	Lower limit	Median	Upper limit
	Number of fish	*Minutes*	*Minutes*	*Minutes*
June 13–July 5	73	6.00	9.22	11.58
July 8–18	80	11.28	14.30	16.28

significantly faster than those in the last part of the run.

Rise Between Pools

Research on a 1:8-slope fishway by Gauley (1960) indicated a direct relationship between magnitude of rise between pools and passage time. Recent supporting evidence was found by comparing passage times of chinook and sockeye in the 1:8-slope fishway with 1.0- and 1.5-foot rises, respectively.

The median passage times of sockeye individuals timed through type-2 and type-3 fishways are given in table 18. A comparison of these times showed that the passage time was significantly

TABLE 18.—*Median passage times of sockeye and chinook individuals ascending 1:8-slope fishways with a 1.5-foot rise (type-3 fishway) and a 1-foot rise (type-2 fishway) between pools*

[Passage times in the respective control fishways are included]

Species	Date	Test 1:8-slope					Control 1:16-slope				
		Rise	Sample size	Lower limit	Median	Upper limit	Rise	Sample size	Lower limit	Median	Upper limit
		Feet	*Number of fish*	*Minutes*	*Minutes*	*Minutes*	*Feet*	*Number of fish*	*Minutes*	*Minutes*	*Minutes*
Sockeye	June 17–July 9	1.5	65	7.85	12.30	15.42	1.0	82	7.53	9.28	9.83
	July 12–18	1.0	111	1.20	1.40	1.90	1.0	72	11.45	14.66	16.43
Chinook	June 12–July 9	1.5	46	9.73	15.10	31.37	1.0	68	6.90	10.26	12.37
	May 31–June 7	1.0	74	7.33	9.88	12.03	1.0	56	10.50	13.80	16.88

less in a fishway having a 1.0-foot rise than in a fishway having a 1.5-foot rise. Comparative times given for passage through the control fishway suggest that the differences due to rise would have been even more pronounced, if seasonal variation had been taken into account.

The median passage times of chinook individuals in type-2 and type-3 fishways are also presented in table 18. Chinook ascending the type-2 fishway were faster than those ascending the type-3 fishway but not significantly so. Again comparing passage times in the control fishway, the difference would have been more pronounced if seasonal variation had been considered.

SUMMARY

The effects of fishway slope on the rate of passage of chinook, sockeye, and steelhead were studied at the Fisheries-Engineering Research Laboratory at Bonneville Dam, by comparing passage times of salmonids through two fishways with different slopes—a 1:8-slope test fishway and a 1:16-slope control fishway. Both fishways were pool-and-overfall type without submerged orifices, attaining a total gain in elevation of 6 feet. Passage times of individuals, groups, and mass releases were used to compare fishway slopes and incidental factors.

A comparison of passage times between the 1:8-slope test fishway with a 1.0-foot rise between pools and the 1:16-slope control fishway with a 1.0-foot rise between pools demonstrates that chinook, sockeye, and steelhead ascended the test fishway at a faster rate than the control fishway. The passage times, however, were not always significantly faster.

When the rise between pools in the test fishway was increased to 1.5 feet, there was a corresponding increase in passage time. Most of the chinook, sockeye, and steelhead ascended the test fishway at a slower rate than the control fishway but only chinook groups were significantly slower.

Three incidental factors affected passage time: (1) weir crest design, (2) seasonal variation, and (3) rise between pools. Tests in the 1:16-slope fishway with Dalles-type weir crests and square weir crests showed chinook ascended the Dalles crest faster while steelhead ascents were about the same for both weir crest designs. A significant seasonal variation in passage times through fishways occurred within the respective chinook and sockeye salmon migrations. Chinook in the summer run were significantly faster than individuals in the spring run while the first half of the sockeye run was significantly faster than the last half. The median passage time of chinook and sockeye in a 1:8-slope fishway having a 1.0 foot rise between pools was significantly less than in the same fishway having a 1.5-foot rise between pools.

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LITERATURE CITED

Collins, Gerald B., and Carl H. Elling
1960. Fishway research at the Fisheries-Engineering Research Laboratory. U.S. Fish and Wildlife Service, Circular No. 98, 17 pp.

Dixon, Wilfrid J., and Frank J. Massey, Jr.
1951. Introduction to statistical analysis. First edition. McGraw-Hill Book Company, New York, 370 pp.

Elling, Carl H., and Howard L. Raymond
1959. Fishway capacity experiments, 1956. U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 299, 26 pp.

Gauley, Joseph R.
1960. Effect of fishway slope on rate of passage of salmonids. U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 350, 23 pp.