RESPONSE OF MIGRATING ADULT SALMONIDS TO VERTICAL AND HORIZONTAL RECTANGULAR ORIFICES AT TWO DEPTHS

by

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INTRODUCTION

An important part of fish facility complexes at hydroelectric plants on the Columbia River and its tributaries is the powerhouse fish collection system, a long channel with multiple entrances, extending across the face of the powerhouse. This channel is one of several accesses to the main fishways. While large discharges from fishway entrances attract migrants to the main fishladders, migrating adult salmonids approaching the powerhouse discharge must locate entrance ports to enter the collection channel which leads to the main fish ladders.

Fish collection systems have been studied to determine the design criteria that would provide optimum entry conditions for upstream migrants. Research to date indicates salmonids enter the powerhouse collection system at Bonneville Dam through submerged orifices more readily than over an overfall weir entrance (U. S. Army Corps of Engineers Annual Report, 1948). Studies conducted in 1952 and 1954 (Corps of Engineers Progress Report, 1960)[1] indicated that salmonids preferred shallow orifices for entry into the collection system. Continued research in 1960 indicated a slight preference for vertical orifices over horizontal (Corps of Engineers Annual Report 1960), but results were not conclusive.

The objective of this study was to determine if migrating adult salmonids prefer vertical or horizontal submerged orifices and if orifice depth has any effect on preference. Following is the report of this research, conducted at the Fisheries-Engineering Research Laboratory at Bonneville Dam from August 24 to September 20, 1962.

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[1] First reported in Bonneville and Mc Nary Dam annual fish passage reports, 1952 and 1954.

MATERIALS AND METHODS

Laboratory

A detailed description of the laboratory is given by Collins and Elling (1960); therefore, a brief description here should suffice to acquaint the reader with its salient features and current modifications. Water for the experimental area was provided by a water supply and discharge system capable of delivering and discharging up to 200 cubic feet per second (c. f. s.). Flows were regulated by various intake valves and a large drain valve.

A uniform light condition was provided by a battery of 1,000-watt mercury-vapor lights spaced at 6-foot intervals 6 feet above the water surface. The average light intensity of 700 foot-candles was comparable to light conditions in the main Bonneville fishway during a bright cloudy day.

Fish entered the laboratory from the Washington shore fishway, passed through the test area, and returned to the main fishway. From a small entrance fishway, test individuals were released into the orifice choice area to choose a passage through one of two rectangular orifices aligned horizontally or vertically at one of two depths, each orifice providing access to independent transportation channels (hereinafter called "north" and "south" channels). Fish left the test area over an exit weir at the upstream end of each channel.

Orifices. --A pair of 2-by 5-foot rectangular orifices was installed at the junction of the orifice choice area and the two transportation channels (Figs. 1 and 2). The orifice panels were fit into guides and could be removed (Fig. 3), turned 90 degrees, and replaced to change the orifice setting from a vertical to a horizontal position (Fig. 4) or vice versa. Similarly constructed solid panels filled the space above and below the orifice panels.

During all tests, orifices were positioned horizontally or vertically at deep and shallow settings. In the deep position, the centerline of the orifice was 9 feet below the water surface (elevation 49.75 feet)[2] and at the shallow position 3 feet below the water surface (elevation 55.75) (Fig. 5). Water depth in the area immediately downstream of the orifices was 19 feet.

Hydraulics. --Constant hydraulic conditions were obtained in the laboratory by maintaining the water elevations shown in Figure 1. Water levels in the orifice choice area and the transportation channels were kept at elevations 59 and 60 respectively to maintain a 1-foot head on the orifices. This produced a calculated flow of 49 c. f. s. through each orifice. Sixteen and one-half c. f. s. passed over the exit weir while the remaining flow requirement was supplied by an orifice

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[2] All elevations are designated as feet above mean sea level.

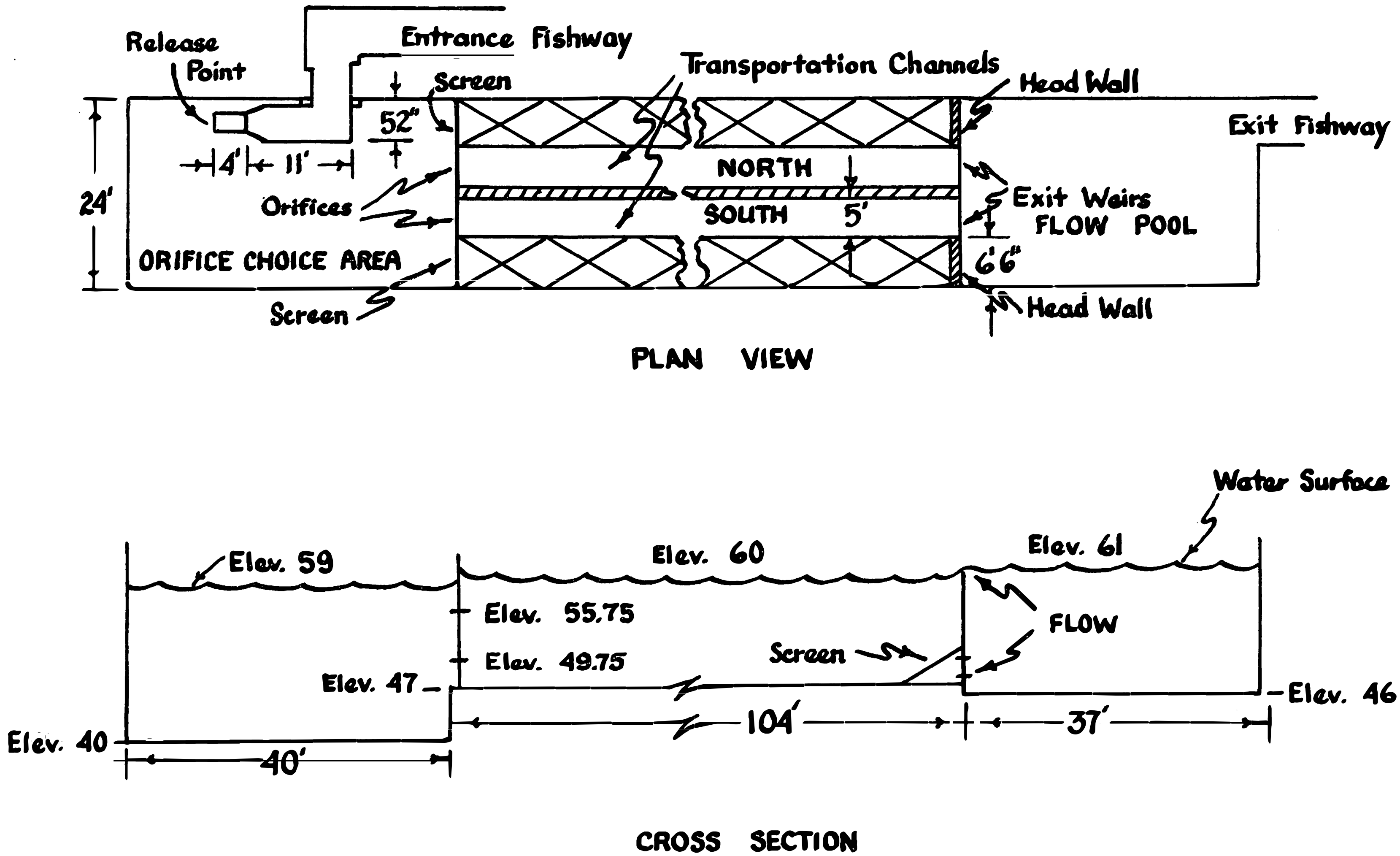


Figure 1.--Plan view of laboratory showing release point, orifice location, and exit point where choice was recorded. Longitudinal cross section shows water elevations.

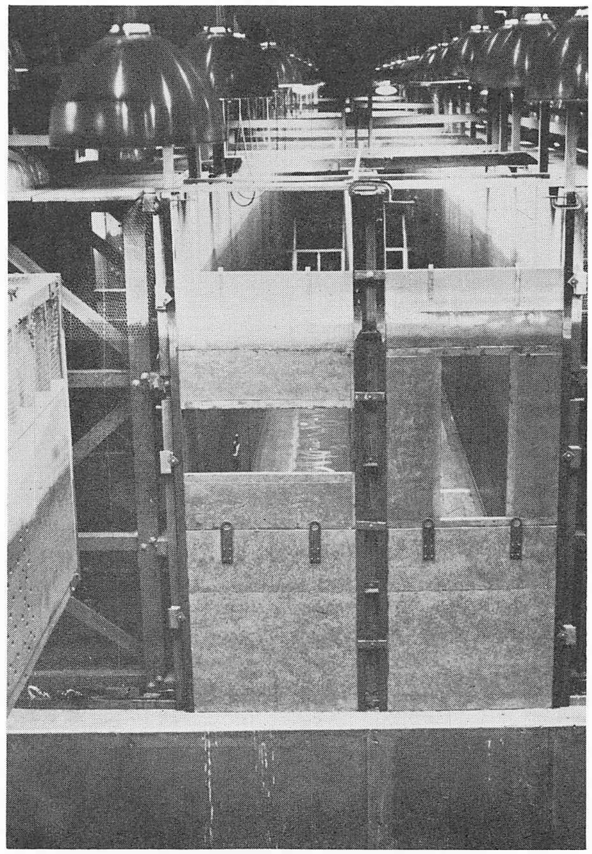


Figure 2.--Test area unwatered to show horizontal (left) and vertical (right) orifice choice condition at the shallow setting (centerline of orifice 3 feet below water surface).

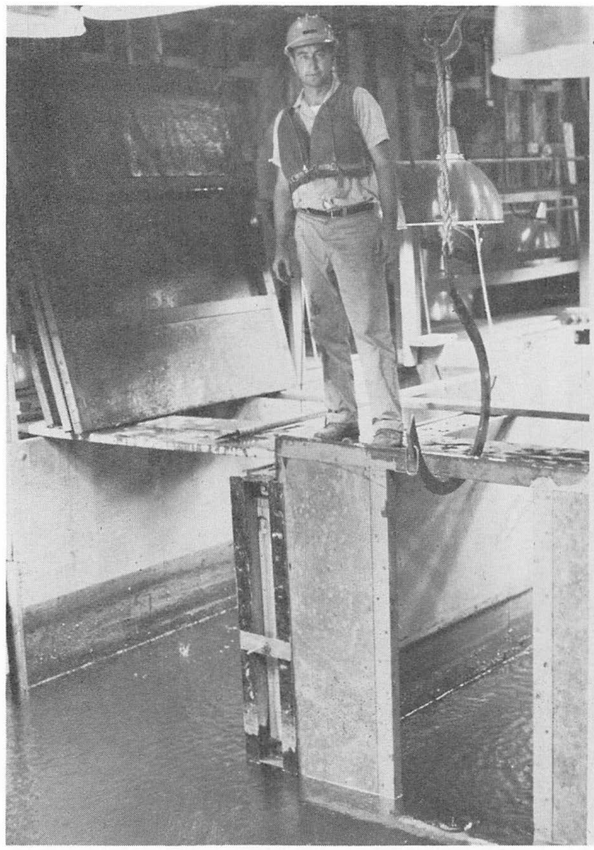


Figure 3.--Removing orifice panel from guide slots to change position of orifice.

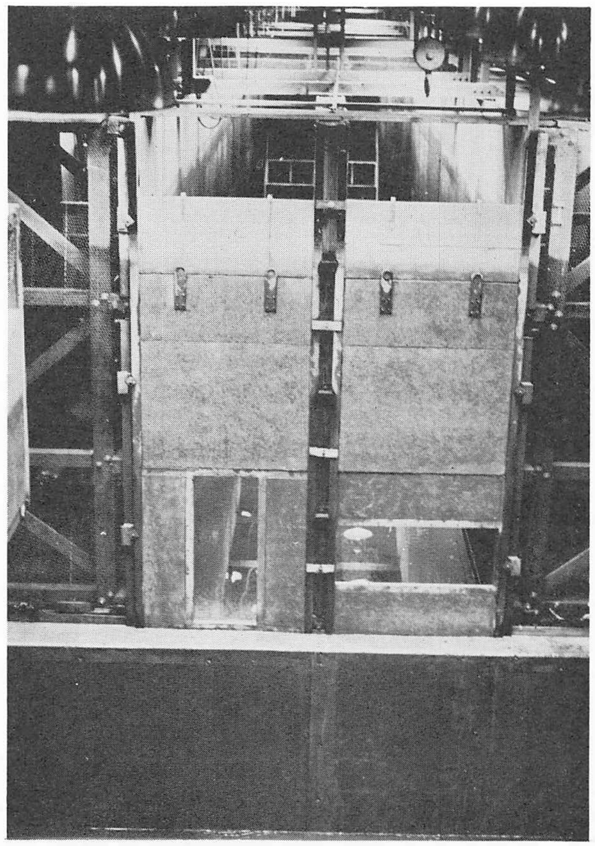


Figure 4.--Vertical and horizontal orifice choice condition at deep setting (centerline of orifice 9 feet below water surface).

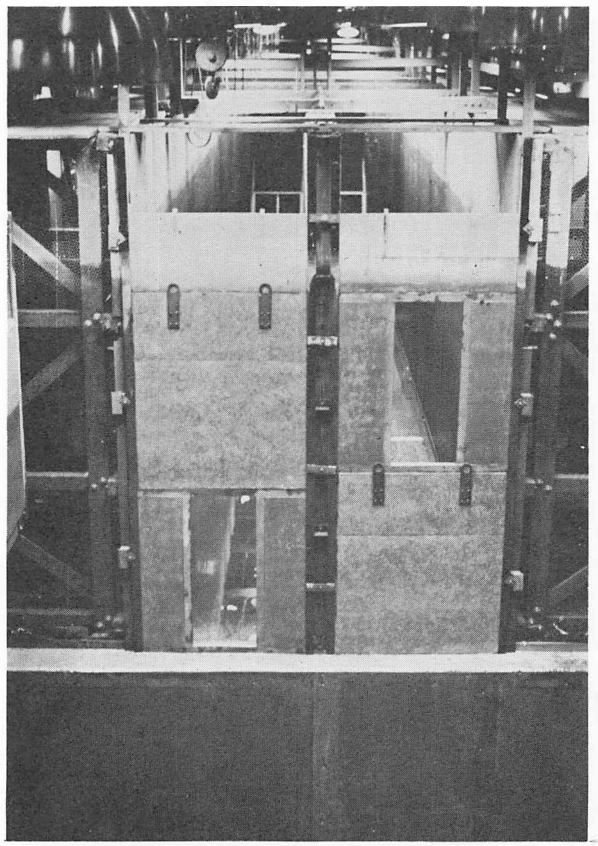


Figure 5.--Test condition for comparing responses of salmon to vertical orifices at deep (left) and shallow (right) positions.

installed at the base of the weir to augment the transportation channel flow. A screen on the downstream side of this orifice prevented test fish from escaping unobserved through this opening.

Shallow orifice flows caused a turbulence on the surface of the orifice choice pool (Fig. 6A). When both orifices were deep this surface turbulence was greatly reduced (Fig. 6B).

Test Procedure

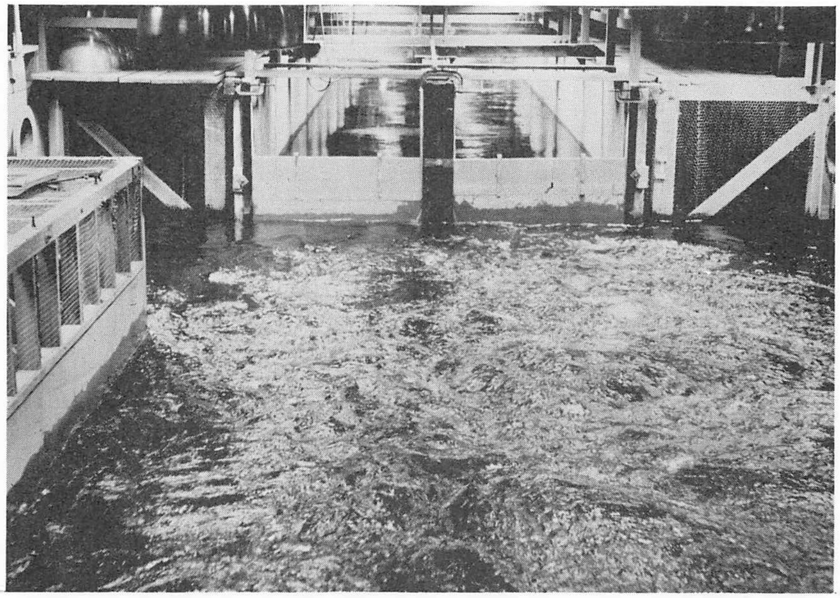
Test fish entered the laboratory from the entrance fishway and were introduced into the orifice choice area through the release compartment where the size and species of each fish was determined by an observer. Fish were permitted to enter the choice area at will during each test period thus allowing more than one fish in the choice area at the same time.

After selecting one of the orifices, test fish proceeded upstream through the transportation channel and crossed the exit weir. The response to the orifice condition was simply recorded on the basis of numbers of fish observed leaving the respective channels (Fig. 7).

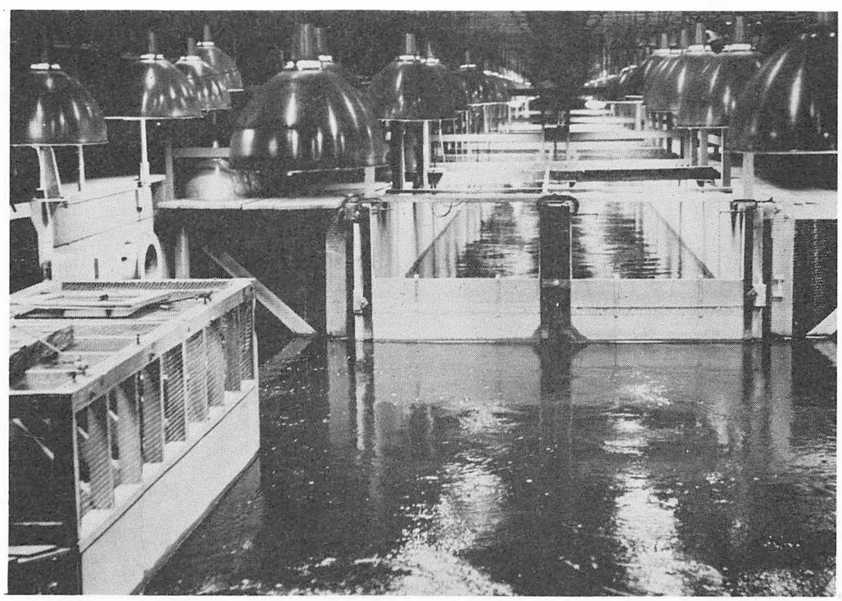
Experimental Design

The experiment was divided into the following four choice conditions to examine the response of salmonids to orifice position and depth: (1) Between a horizontal and a vertical orifice, both 9 feet below the water surface; (2) between a horizontal and a vertical orifice, both 3 feet below the surface; (3) between two horizontal orifices, one 3 feet and one 9 feet below the surface; and (4) between two vertical orifices, one 3 feet and one 9 feet below the surface. Test conditions 1 and 2 constituted one block, and test conditions 3 and 4 constituted another block. Test conditions were randomized within blocks and blocks were run alternately for three or four replicates.

An adequate preference measurement depended upon salmonids choosing between two orifices. Fish that made a center frontal approach to the test panel were in a position to choose between orifices. Fish that made a lateral approach were in a position to choose between orifices only if they rejected the orifice to which they were first exposed. Rather than attempt to direct all fish to a center frontal approach, orifices were changed from one channel to the other halfway through each test period. Each test period lasted 2 days because it was impractical for both biological and mechanical reasons to modify a test condition at intervals shorter than 1 day. By this manipulation, a given lateral approach, say from the right, would have led fish to an initial exposure at one of the two orifices being compared on 1 day, and the other of the same two orifices on the succeeding day. Orifices were assigned to channels randomly on the first day of each 2-day period.



(A)



(B)

Figure 6.--Orifice choice area (foreground) during shallow (A) and deep (B) orifice discharges.

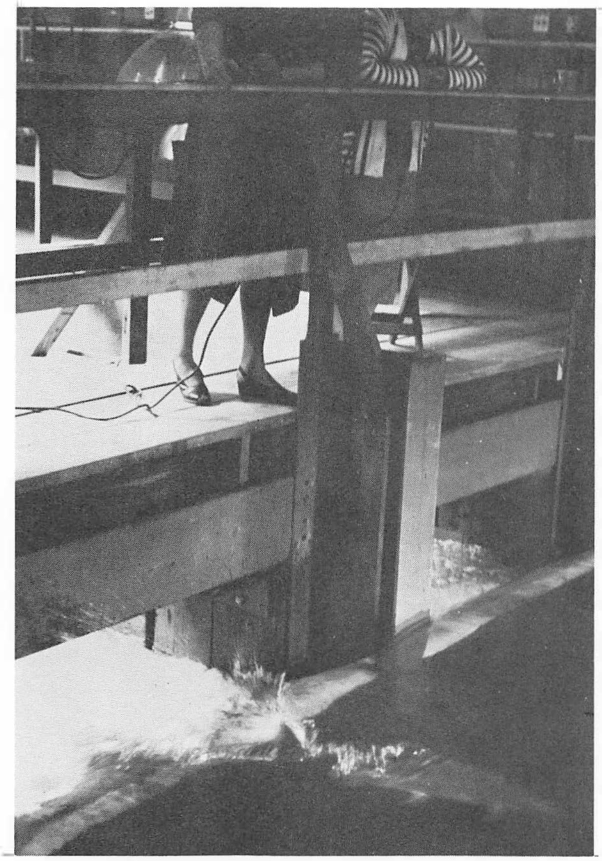


Figure 7.--Recording passage of fish at upstream end of transportation channels. Tallies of the number of salmonids leaving each channel provided a record of the responses of these fish to the prevailing orifice condition at the downstream end of the respective channels.

This design requires the assumption that approach patterns remain similar between days for a 2-day test period. In other words, if majority of fish approach the test panel from the right side on one day, a similar majority will be assumed to do the same thing on the succeeding day. This assumption was accepted and basic preference measurements were computed as follows:

1. The proportion of fish entering each orifice was calculated by day and coverted to percentage.

2. The two percentages obtained from one orifice during each 2-day test period (one from the north channel and one from the south channel) were averaged to yield the basic preference measurement.

Evaluation of orifice preference was made for each test condition separately. Average percentages for the two orifices being compared during the 2-day test period totaled 100 percent. Preference for a specific orifice, therefore, would be shown by an average percentage greater than 50 percent. Only average percentages from one of two orifices being compared were used in the preference evaluation. Since average percentages were replicated for each test condition, t-tests were used to examine departure of their means from 50 percent. Arcisin transformations (Senedecor, 1957) of the average percentages were used to compute t-values.

RESULTS

Deep Horizontal Orifice vs. Deep Vertical Orifice

Significantly more than 50 percent of both 807 chinook salmon and 2, 737 steelhead trout chose the vertical orifice (Table 1). The proportion of 202 coho salmon that chose the vertical orifice was not significantly different than 50 percent.

Shallow Horizontal Orifice vs. Shallow Vertical Orifice

None of the three mean percentages tested were significantly different than 50 percent (Table 2). During the second replicate both 692 chinook salmon and 2, 065 steelhead trout reversed the inclination demonstrated in other replicates, and showed a preference for the horizontal orifice. This reversal contributes appreciably to the nonsignificance noted for them. Only two replicates totaling 201 coho salmon cannot be expected to detect small departures from 50 percent for that species.

Shallow Horizontal Orifice vs. Deep Horizontal Orifice

Significantly more than 50 percent of both 720 chinook salmon and 2, 131 steelhead trout chose the shallow horizontal orifice (Table 3). The two replicates totaling 136 coho salmon failed to show significant departures from 50 percent for that species.

Shallow Vertical Orifice vs. Deep Vertical Orifice

None of the three mean average percentages tested showed a significant departure from 50 percent (Table 4). Although the trend for 1, 171 chinook salmon was toward the shallow orifice in all replicates, the magnitude of the trend differed widely between replicates. The majority of a total of 2, 589 steelhead trout represented by the first two replicates tended toward the 3-foot depth. However, steelhead trout in the third replicate were similarly distributed between the two depths. In both replicates a trend toward the 9-foot depth was demonstrated among a total of 248 coho salmon.

Channel Preference

It was pointed out earlier that the experiment was designed to insure valid results even if test fish showed a preference for either the north or south channel. As it turned out, there was a preference for the south channel. In all replicates for all species except the second one for steelhead trout, the proportion of

Table 1.--Average percentages[1] of salmonids entering both orifices in test of deep horizontal orifice vs. deep vertical orifice.

Replicate number	Chinook salmon		Steelhead trout		Coho salmon	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
	Percent	Percent	Percent	Percent	Percent	Percent
1	32.65	67.35	43.00	57.00	32.15	67.85
2	26.30	73.70	29.45	70.55	48.35	51.65
3	31.25	68.75	35.95	64.05	45.90	54.10
4	32.00	68.00	41.10	58.90		
Mean	30.6	69.4*	37.4	62.6*	42.1	57.9[NS]
n	807		2,737		202	

[1]Direct observations made during a basic time unit of 2 seqential days were combined to form a preference measurement called "average percentage" (see text for details).

*Denotes a mean average percentage that was found to be significantly (95% level) greater than 50%.

[NS]Denotes a mean average percentage that was found to be not significantly (95% level) different than 50%.

Note: Only the means designated * or NS were tested (see text for details).

Table 2. --Average percentages[1] of salmonids entering both orifices in test of shallow horizontal orifice vs. shallow vertical orifice.

Replicate number	Chinook salmon		Steelhead trout		Coho salmon	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
	Percent	Percent	Percent	Percent	Percent	Percent
1	21.20	78.80	48.50	51.50	44.00	56.00
2	52.20	47.80	58.00	42.00	47.50	52.50
3	25.00	75.00	40.75	59.25		
4	32.45	67.55	38.35	61.65		
Mean	32.7	67.3[NS]	46.4	53.6[NS]	45.8	54.2[NS]
n	692		2,065		201	

[1] See Table 1.

[NS] See Table 1.

Table 3. --Average percentages[1] of salmonids entering both orifices in test of shallow horizontal orifice vs. deep horizontal orifice.

Replicate number	Chinook salmon		Steelhead trout		Coho salmon	
	Shallow	Deep	Shallow	Deep	Shallow	Deep
	Percent	Percent	Percent	Percent	Percent	Percent
1	78.75	21.25	69.20	30.80	63.90	36.10
2	84.20	15.80	66.60	33.40	59.80	40.20
3	72.70	27.30	73.25	26.75		
Mean	78.6*	21.4	69.7*	30.3	61.8[NS]	38.2
n	720		2,131		136	

[1]See Table 1.

*See Table 1.

[NS]See Table 1.

Table 4. --Average percentages[1] of salmonids entering both orifices in test of shallow vertical orifice vs. deep vertical orifice.

Replicate number	Chinook salmon		Steelhead trout		Coho salmon	
	Shallow	Deep	Shallow	Deep	Shallow	Deep
	Percent	Percent	Percent	Percent	Percent	Percent
1	63.00	37.00	55.90	44.10	46.55	53.45
2	59.25	40.75	55.70	44.30	37.50	62.50
3	52.45	47.55	49.20	50.80		
Mean	58.2[NS]	41.8	53.6[NS]	46.4	42.0[NS]	58.0
n	1,171		2,589		248	

[1]See Table 1.

[NS]See Table 1.

salmonids choosing any given orifice was greater when that orifice was in the south channel than when it was in the north channel. The means of the percentage difference between the south and north channels (Table 5) were found by t-tests to be significantly greater than zero for each species.

Table 5. --Percentage difference obtained by subtracting the percentage of salmonids that chose the north channel from the percentage of those that chose the south channel.

Test condition	Replicate	Chinook salmon	Steelhead trout	Coho salmon
	Number	Percent	Percent	Percent
	1	59.5	29.8	
	2	9.2	10.5	35.7
1	3	9.1	14.7	3.3
	4	31.0	30.0	57.6
	1	16.4	60.6	
	2	4.4	0.4	
2	3	21.0	30.1	30.8
	4	36.9	25.3	30.8
	1	20.7	11.0	
3	2	2.8	26.8	27.8
	3	25.8	25.3	45.6
	1	12.8	24.6	
4	2	30.5	30.0	18.1
	3	31.1	38.4	46.6
Mean		22.23	24.05	32.92

DISCUSSION

Both the approach to an orifice and the manner in which a salmonid seeks upstream passage when its progress is blocked at a vertical wall have a bearing on the shape and location of orifices in prototype structures. The preferences demonstrated by salmonids in the present study may prove useful in both respects.

It should be pointed out that the behavior of the salmonids in this study may have been modified by their recent experience in fish ladders, their release into the orifice choice pool (Fig. 1), and the dimensions of that pool. In any event, the study was conducted with salmonids that were actively moving upstream and no orifice shape or location was rejected by all members of any of the three species considered on any day.

Some behaviorial characteristics that might be important in the choice of an orifice by a salmonid are: (1) If a satisfactory orifice is presented in the path of a moving fish, it would be expected to accept it. A satisfactory orifice for one fish, obviously, might be unsatisfactory for another, even for fish of the same species. (2) If there is no orifice or there is an unsatisfactory orifice in the line of travel of a moving salmonid, it would be expected either to search for another or stop moving upstream. (3) When faced with seeking upstream passage, salmonids might be expected to follow a series of search procedures that lead from one clearly defined direction to another, etc.

Orifices should be placed to intercept the bulk of migrating fish directly and be accessible during the initial search movements of the remainder.

Chinook salmon and steelhead trout demonstrated a preference for vertical over horizontal orifices and orifices centered 3 feet from the surface over those centered 9 feet from the surface. Percentages of these two species showing significant preferences occurred when orifice orientation was tested at the least acceptable depth (test condition 1), and when the least acceptable orifice orientation was tested at the two depths (test condition 3). When both orifices were placed at a shallow depth (test condition 2) replicates were dissimilar, and when vertical orifices were placed at both depths (test condition 4) the preference for the 3-foot depth was not consistently large.

The findings that a higher proportion of salmonids entered the south channel than the north channel may be interpreted in two ways. Either salmonids that accepted the first orifice contacted approached the orifices in greater numbers from the south or a discernible number of salmonids tended to seek upstream passage to their right. Considerable variation exists between replicates for percentage difference between north and south channels (Table 5). These values are not a measure of the proportion of the total number of fish that approached the orifices from the south.

The method used to analyze the choices made in this study is based on the assumption that the laboratory and experimental techniques might have caused more fish to enter the south channel than the north. It is possible that this assumption is in error. If so, more accurate percentages of fish choosing a given orifice would be obtained if the percentage of fish that went to the south channel regardless of orifice (Table 5) were removed entirely from consideration instead of being distributed equally in the two channels as was actually done (Tables 1-4).

Table 6 shows the percentage of the fish making a choice or making a frontal approach to the test panel that chose a specific orifice. The values shown in Table 5 were subtracted from 100, and the result was divided into the percentage of fish choosing a given orifice when it was in the north channel to obtain the values shown in Table 6.

The conclusions concerning significant preferences drawn from the data in Tables 1 to 4 are unchanged by the treatment in Table 6 except for a significant preference amoung coho salmon for the surface orifice (test condition 3) in the latter.

Results obtained in the laboratory tests apply to a reasonably deep approach area (19 feet) but the depth range of the orifices was limited to 9 feet because of the existing sill of the transportation channel. Deeper submergence of orifices may have produced more clear cut responses, particularly in comparing the response to vertical orifices at shallow versus deep positions.

Application of these results to a prototype condition requires consideration of the effect of competing turbine discharges on the preference of fish for shallow or deep orifices. Since the turbines discharge at depths beneath existing collection channel ports, it is possible that competing attraction flows (i. e., turbine vs. collection channel discharges) might influence the vertical distribution of fish as they approach a powerhouse collection channel and produce results somewhat different than those noted in the laboratory where the effect of the turbine discharge was not a factor.

Table 6. --Percentages of salmonids that chose the vertical orifice at the shallow depth exclusive of values shown in Table 5. Comparable to columns showing * or NS in Tables 1-4.

Test condition	Replicate	Chinook salmon	Steelhead trout	Coho salmon
	Number	Percent	Percent	Percent
	1	92.8	60.0	
	2	76.1	73.0	77.8
1	3	70.6	66.5	51.7
	4	76.1	62.7	59.7
	Mean	78.90*	65.55*	63.07NS
	1	84.4	53.8	
	2	47.7	42.0	
2	3	81.6	63.2	58.7
	4	77.8	65.6	53.6
	Mean	72.88NS	56.15NS	56.15NS
	1	86.3	71.6	
3	2	85.2	72.7	69.3
	3	80.6	81.1	68.0
	Mean	84.03*	75.13*	68.65*
	1	64.9	57.8	
4	2	63.3	58.1	45.8
	3	53.6	48.7	26.6
	Mean	60.60NS	54.87NS	36.20NS

Note: For explanation of * and NS, see Table 1.

SUMMARY AND CONCLUSIONS

Salmonids were presented with a choice of entering one of two orifices. Each orifice measured 2 by 5 feet and was aligned either horizontally or vertically at depths of 3 and 9 feet (measured from the centerline of the orifice to the surface of the introductory area). A 1-foot head was maintained on the orifices. Orifice conditions were changed daily and offered test fish a choice between: (1) Vertical and horizontal orifices set deep; (2) vertical and horizontal orifices set shallow; (3) shallow and deep horizontal orifices; and (4) shallow and deep vertical orifices.

Test results are summarized as follows:

1. A majority of chinook salmon and steelhead trout preferred the vertical orifice to the horizontal orifice at deep and shallow settings. This preference was statistically significant when the orifices were set deep.

2. A majority of chinook salmon and steelhead trout preferred shallow orifices to deep ones. This preference was statistically significant when orifices were horizontal but not when they were vertical.

3. Coho salmon responses to the orifice test conditions were the same as chinook salmon and steelhead trout with one exception--a majority of coho salmon perferred the deep vertical orifice to the shallow one. None of the preferences were statistically significant, however.

In conclusion, the vertical orifice appears preferable to the horizontal orifice where submergence (centerline) is in the range of 3 to 9 feet. The effects of orifice depth on response were more pronounced when orifices were horizontal than when they were vertical.

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 p.

Snedecor, George W.
1957. Statistical methods. Fifth edition. The Iowa State College Press, Ames, Iowa. 534 p.

U. S. Army Corps of Engineers
1960. Annual fish passage report (North Pacific Division) Bonneville, The Dalles, and Mc Nary Dams. Columbia River, Oregon and Washington, 1948 and 1960. Prepared by the U. S. Army Engineer Districts, Portland and Walla Walla, Corps of Engineers, Portland, Oregon. (Each year published separately).

U. S. Army Corps of Engineers
1960. Progress report on Fisheries-Engineering Research Program. North Pacific Division (July).